CRHIAM
CENTRO DE RECURSOS HÍDRICOS PARA LA AGRICULTURA Y LA MINERÍA
ANID/FONDAP/15130015

REPORT

WATER RESEARCH CENTER FOR AGRICULTURE AND MINING – CRHIAM

ANID FONDAP CENTER
2013-2023

10 YEARS

CONTRIBUTING TO WATER SECURITY
HIGHLIGHTING PERIOD 2018-2023

CRHIAM

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ANID/FONDAP/15130015

Universidad de Concepción

UNIVERSIDAD DE LA FRONTERA

Universidad del Desarrollo

Agencia Nacional de Investigación y Desarrollo

Ministerio de Ciencia, Tecnología, Conocimiento e Innovación

Gobierno de Chile

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1. MESSAGE FROM THE DIRECTOR:

A retrospective look at CRHIAM

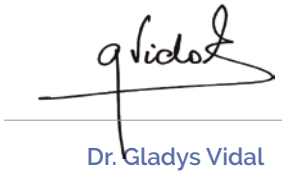
1. MESSAGE FROM THE DIRECTORS:
A retrospective look at CRHIAM

Chile is currently experiencing one of the greatest water crises in its history due to the effects of climate change on the national territory, affecting the population, ecosystems, and economic development. It was in this context that the Center for Water Resources for Agriculture and Mining (CRHIAM) was founded in 2013, within the framework of the fifth competition for the Fund for Financing Research Centers in Priority Areas (FONDAP) of the National Agency for Research and Development (ANID). CRHIAM is led by the Universidad de Concepción, in partnership with the Universidad de La Frontera and the Universidad del Desarrollo.

The mission of CRHIAM is to be a national reference in the generation of advanced scientific and technological knowledge on water resources for agriculture, mining, and communities, with an emphasis on achieving the sustainable development goals. The vision of CRHIAM is to be a world reference in water resources research, considering the principles of water security. The CRHIAM's main objectives are: a) To promote research on water security; b) To train researchers at the undergraduate level and, especially, at the graduate and postdoctoral levels; c) To create links with leading national and international research institutions and with the public and private sectors; and d) To contribute to better water management through the effective communication and dissemination of scientific evidence that contributes to public policies and public knowledge.

CRHIAM's work encompasses five lines of research: RL1: Efficient use of water in agriculture and mining; RL2: New sources of water for agriculture, mining, and communities; RL3: Availability and quality of water for agriculture and mining in times of climate change; RL4: Technology for water treatment and environmental remediation; RL5: Water governance, ecosystem services, and sustainability.

In its 10 years of existence, CRHIAM has become known for generating interdisciplinary scientific evidence and for its regional presence, with researchers from Antofagasta (Region II) to Temuco (Region VII). To date, the Center has published more than 700 WOS papers and at least 120 books and book chapters, trained 131 postdoctoral researchers, and supervised 77 doctoral theses. The impact of its publications has led it to achieve an H index of 43 in its first decade of existence. In addition, the CRHIAM has implemented the Diploma Program on "Water Resources for Sustainable Development," which has already graduated 116 professionals, and the training of approximately 70 community leaders through the course "Water Resources Management and the Urban Water Cycle," held in conjunction with the water company Essbio-Nuevosur in the regions of O'Higgins, Maule, Ñuble, and Biobío. In addition, CRHIAM has contributed to the generation of 14 patents of scientific evidence, generated primarily in the context of mining processes and the health sector. CRHIAM has also published various documents with relevant contributions to decision-making, such as a Communication Series, policy reports, infographics, and the podcast "Water Has Its Science." The material is available to the community through its website, crhiam.cl, and CRHIAM's various social media channels, which are continuously updated.



Dr. Gladys Vidal
Director 2018-2023

Dr. Pedro Toledo
Deputy Director 2018-2023

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2. ABOUT CRHIAM:

The evolution of a water resources research center

2. ABOUT CRHIAM:
The evolution of a water resources research center

2.1 The Foundation of CRHIAM

Under a scenario of global climate change, it is essential that agriculture, mining, and communities develop sustainable practices to manage and use water resources responsibly. This means caring for water in quantity and quality, allowing it to act resiliently in the face of natural environmental changes accelerated by the anthropic action.

Given the importance of proper water resource management, in December 2013 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 October 2018 as an interdisciplinary and collaborative research institution in the areas of agriculture and mining for the for the period between October 2018 to December 2023.

The solutions must range from new technologies to the reformulation of public policies that consider the ecosystem as a key part of achieving sustainability. In this sense, the work carried out by the different lines of research of CRHIAM generates a robust scientific base to support making the best decisions for correct water management.

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, considering the principles of water security.

PROJECT OBJECTIVES OVER TIME: FROM INTERDISCIPLINARY TO TRANSDISCIPLINARY

OBJECTIVES

FIRST EXECUTION PERIOD (From December 2013 to October 2018): INTERDISCIPLINARY

01

To promote research and develop technologies in water resources, optimize their management and consumption, find new resources of water and provide standards to regulate the interaction of different actors.

02

To train researchers at the undergraduate and especially graduate and postdoctoral levels to address the lack of advanced human resources in the country.

03

To create links with other national and international research institutions and the public or private sectors to benefit from common research and technology transfer.

OBJECTIVES

SECOND EXECUTION PERIOD (From October 2018 to December 2023): TRANSDISCIPLINARY

01

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.

02

Form undergraduate and especially graduate and postdoctoral human resources in order to create a critical mass to support the development of abilities in the water resources field.

03

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.

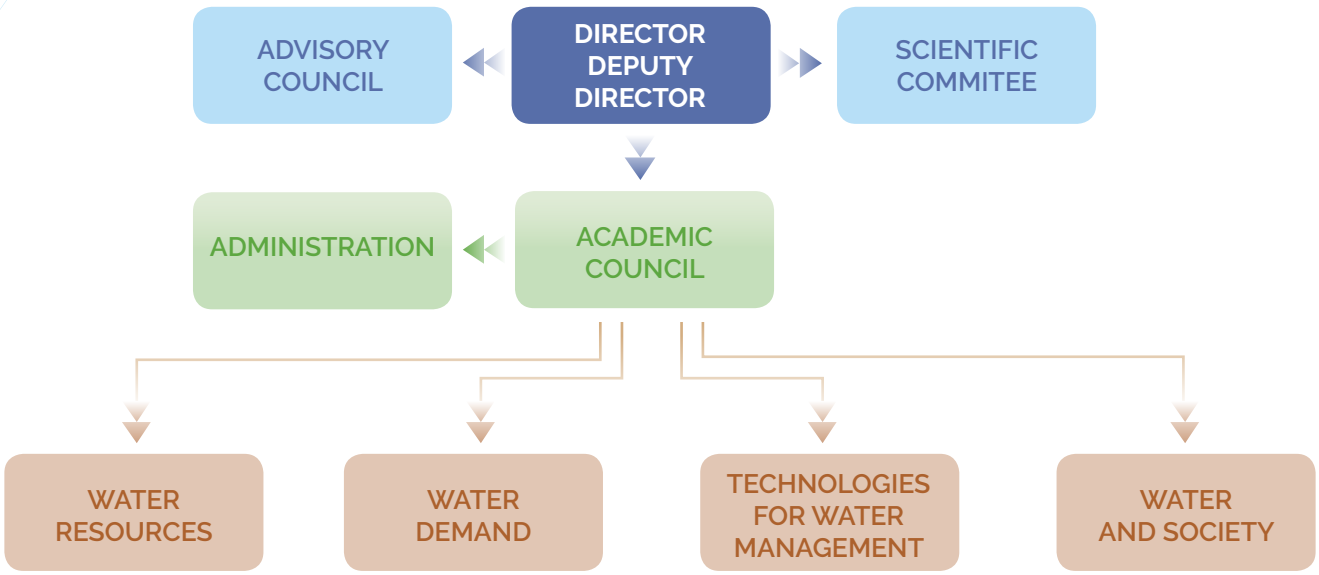
04

Contribute to better water management through communication and dissemination of scientific evidence that contributes to public policies and the knowledge of society.

2.2 CRHIAM organization: The two execution periods (2013-2018 and 2018-2023)

FIRST EXECUTION PERIOD (2013-2018)

ORGANIZATIONAL CHART



FIRST EXECUTION PERIOD (2013-2018): ORGANIZATIONAL CHART DESCRIPTION

CRHIAM is led by its directors and supported by administrative personnel.

Key is the Academic Council, composed of 8 principal researchers leading 4 research clusters: Demand, Technology, Resources and Water and Society, integrated by associate researchers, support staff, postdoctoral fellows and undergraduate and graduate students.

The clusters orient their works in five research lines:

(1) Efficient use of water in agriculture and mining

(2) Seawater as a new source for agriculture, mining and communities

(3) Hydrology, water availability and climate change

(4) Technology for water treatment and environmental remediation

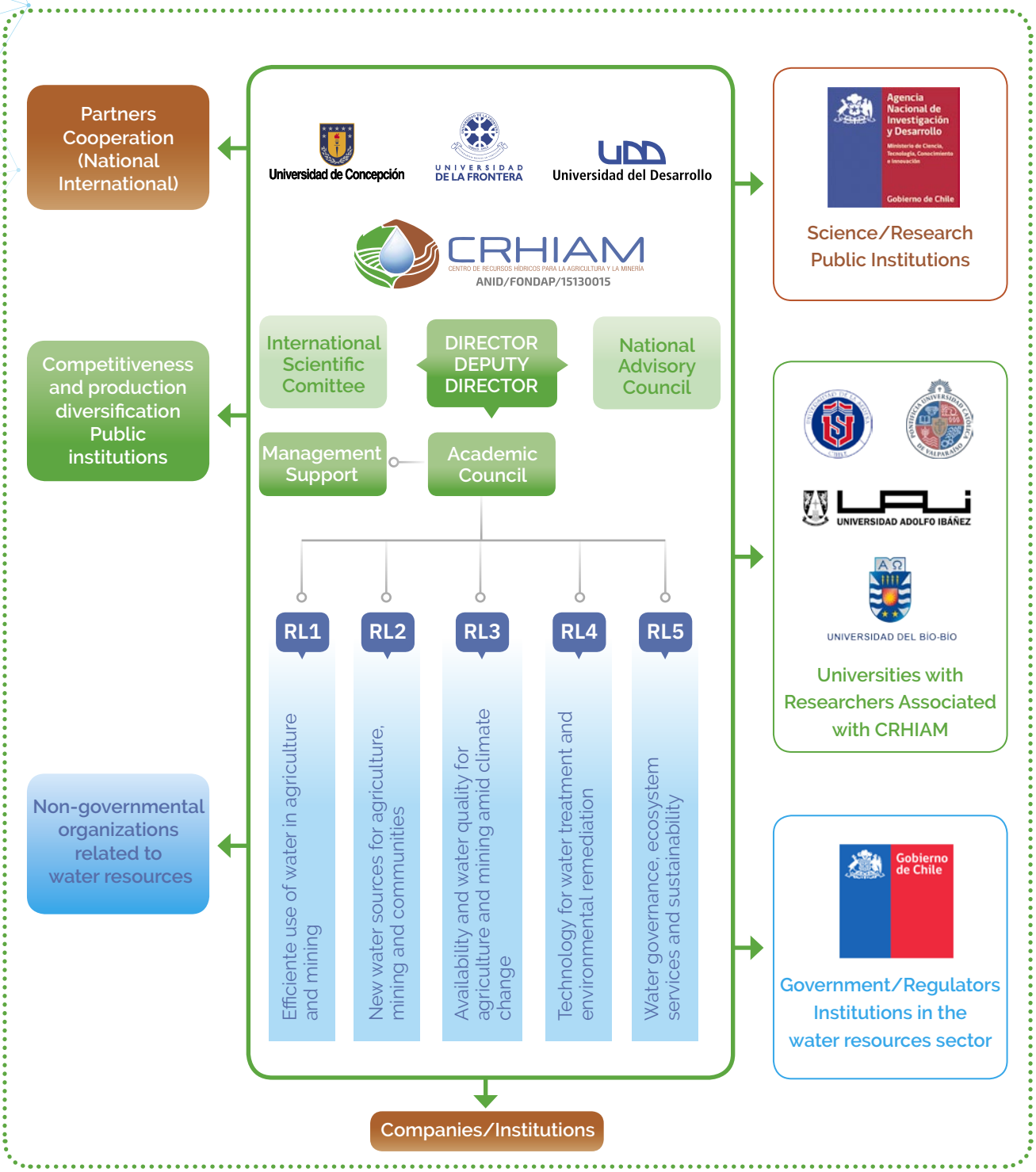
(5) Water governance, ecosystem services and sustainability

The Scientific Committee, composed of academics from foreign universities, ensures that the research carried out is top-tier.

And to guarantee that the work is directly related to issues facing the country, CRHIAM has an Advisory Council, made up of members of institutions linked to water management in agriculture and mining.

SECOND EXECUTION PERIOD (2018-2023)

ORGANIZATIONAL CHART



SECOND EXECUTION PERIOD (2018-2023): ORGANIZATIONAL CHART DESCRIPTION

CRHIAM is led by its directors and supported by administrative personnel.

An academic council of eight principal researchers oversees five Research Lines (RL), Each RL is integrated by two principal researchers, associate researchers, as well as adjunct researchers, support staff, postdoctoral fellows, and undergraduate and graduate students. The name of each RL is detailed below

RL1: Efficient use of water in agriculture and mining.
RL2: New water sources for agriculture, mining, and communities.
RL3: Availability and water quality for agriculture and mining amid climate change.
RL4: Technology for water treatment and environmental remediation.
RL5: Water governance, ecosystem services and sustainability.

CRHIAM seeks to promote interdisciplinary work and dissemination spaces, implement actions with the participation of society and contribute to the development of knowledge to achieve water security for ecosystems, communities and production systems. This objective is pursued through the five lines of research detailed above.

To maintain the highest research standards, CRHIAM has a Scientific Committee of renowned scholars from foreign universities. The center also has an Advisory Council consisting of prominent professionals from institutions involved in water management in agriculture and mining. The council ensures that CRHIAM's work is relevant to the country's critical issues.

2.3 CRHIAM administrative and logistical support team

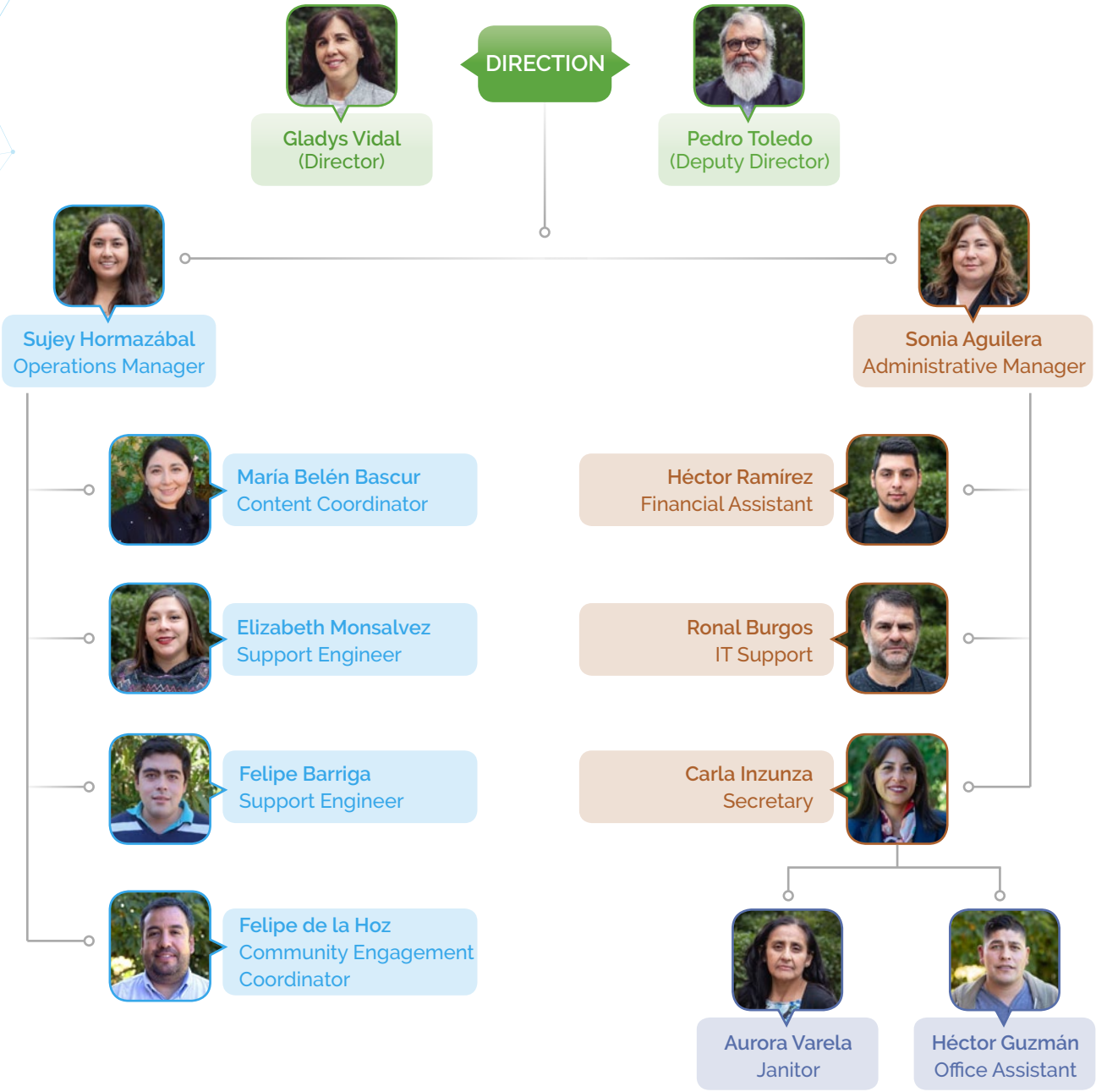


Figure 1. Principal administrative and logistical support team for the period 2018-2023.

CRHIAM TEAM OVER TIME

At CRHIAM we have a staff of researchers whom we call Principal and Associate Researchers. They are responsible for analyzing different topics related to the use and care of water resources for agriculture and mining. They carry out their action both in the field and labs, delivering important publications to the scientific community. All their work is widely supported by the center's collaborators and administrative team.

As of 2018, CRHIAM had 8 principal researchers, 19 associate researchers and 29 people forming part of the administrative and support team (Figure 2).

Figure 2. CRHIAM members during a team meeting in June 2018: Researchers and some members of administrative and support staff.

Below, Figure 3 illustrates the researcher meetings held annually during the second period of the Center's execution (2018-2023). The center annually promotes the meeting of its researchers in person, to strengthen collaborative and interdisciplinary work and thus jointly project the work that contributes to the fulfillment of the center's objectives. However, due to the COVID-19 pandemic, in 2020 and 2021 the meetings were held online, meeting again in person in 2022. The above was not an impediment to continue with the work of excellence of the center despite the health situation experienced in Chile and around the world. In 2023 the center was integrated by 8 principal researchers, 17 associate researchers, 4 adjunct researchers, 11 postdoctoral researchers, collaborators and administrative team.

a

b

c

d

e

Figure 3. Annual meeting of CRHIAM researchers in the second execution period. a) 2019, b) 2020, c) 2021, d) 2022 and e) 2023.

2.4 Scientific Committee

The International Scientific Committee (Figure 4) is responsible for recommending general research guidelines, evaluating the progress of ongoing research at the center and suggesting new lines when necessary. The committee includes members from prestigious international universities: Dr. Jan Hopmans (University of California Davis), Dr. Neil McIntyre (The University of Queensland), Dr. Peter Scales (The University of Melbourne), Dr. Reyes Sierra (The University of Arizona) and Dr. Kelly Munkittrick (University of Calgary). Since the origins of CRHIAM, they played a crucial role in advancing key issues such as interdisciplinary work, establishing a more significant connection with students at the Center, and generating new interdisciplinary products.

a

b

UC DAVIS
UNIVERSITY OF CALIFORNIA

THE UNIVERSITY OF QUEENSLAND
AUSTRALIA

THE UNIVERSITY OF MELBOURNE

THE UNIVERSITY OF ARIZONA

UNIVERSITY OF CALGARY

Figure 4. CRHIAM International Scientific Committee in a meeting with principal researchers of the center. a) First execution period and b) Second execution period.

2.5 National Advisory Council

The National Advisory Council verifies compliance with the general objectives and administrative procedures of the Center. It also links CRHIAM with the external environment and recommends strategies to connect its work with public sector institutions, government representatives, private sector organizations and society in general (Figure 5).

FIRST PERIOD (2013-2018)

SECOND PERIOD (2018-2023)

Figure 5. CRHIAM National Advisory Council in first and second execution period of center.

First execution period (2013-2018)

N°	COUNSELOR'S NAME	POSITION
1	María Eugenia Camelio	FONDAP program Director, National Commission for Scientific and Technological Research, Ministry of Education, Government of Chile
2	Gustavo Tapia	Processes and Technological Innovation Manager, Antofagasta Minerals
3	Patricia Rojas	General Manager, O'Higgins Region Development Corporation
4	Pedro Matthei	President, Chilean association of small and medium-sized hydroelectric plants
5	Álvaro Hernández	Water resources Director, CODELCO
6	Patricio Crespo	President, National Agricultural Society
7	María Loreto Mery	Deputy Executive Secretary, National Irrigation Commission
8	Juan Pablo López	Executive Director, Natural Resources Information Center, Ministry of Agriculture, Government of Chile
9	José Luis Soler	President, Copefrut Directory
10	Guillermo Pickering	Executive President, National Association of Health Services Companies
11	Carlos Estévez	Water General Director, Ministry of Public Works, Government of Chile
12	Alvaro Prieto	Operations Manager, IANSA
13	Alexander Chechilnitzky	President, Association of Sanitary and Environmental Engineering (AIDIS), Chile
14	Ferruccio Medici	Water and Energy Manager, Anglo American

Second execution period (2018-2023)

N°	COUNSELOR'S NAME	POSITION
1	María Eugenia Camelio	Department Head Strategic Targeting Initiatives. National Research and Development Agency (ANID), Ministry of Science, Technology, Knowledge and Innovation, Government of Chile
2	Alexander Chechilnitzky	President, Association of Sanitary and Environmental Engineering (AIDIS), Chile
3	Pedro Carrasco	President, CARSOL FRUIT
4	Álvaro Hernández	Consultant
5	Ramón Cardemil	Agricultural Production Manager, IANSA
6	Rodrigo Ruiz	Manager R&D Projects, Mineral Processing
7	Óscar Castro	Manager Process, FLSmidth
8	Wilson Ureta	Executive Director, National Irrigation Commission
9	Sebastián Jofré	Department Head Aquatic Ecosystems, Division, Natural Resources and Environment, Ministry of Environment, Government of Chile

2.6 CRHIAM researchers

• ACADEMIC COUNCIL: PRINCIPAL RESEARCHERS IN SECOND EXECUTION PERIOD

Dr. GLADYS VIDAL

- **Director since October 2018.**
- **Position:** Principal Researcher from December 2013.
- **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.

Dr. PEDRO TOLEDO

- **Deputy Director between October 2018 and December 2023.**
- **Position:** Principal Researcher from December 2013 to December 2023
- **RL2:** New water sources for agriculture, mining and communities.
- Doctorate in Chemical Engineering, University of Minnesota, USA.
- Chemical Engineering, Universidad de Concepción, Chile.

Dr. JOSÉ LUIS ARUMÍ

- **Position:** Principal Researcher from December 2013.
- **RL5:** Water governance, ecosystem services and sustainability.
- Doctorate in Engineering, University of Nebraska, Lincoln, USA.
- Civil Engineering, Universidad Técnica Federico Santa María, Valparaíso, Chile.

Dr. ROBERTO URRUTIA

- **Position** Principal Researcher from December 2013.
- **RL3:** Water availability and quality for agriculture and mining amid climate change.
- Doctorate in Environmental Sciences, Universidad de Concepción, Chile.
- Biology, Universidad de Concepción, Chile.

Dr. RICARDO BARRA

- **Position:** Principal Researcher from December 2013.
- **RL5:** Water governance, ecosystem services, and sustainability.
- Doctorate in Environmental Sciences, Universidad de Concepción, Chile.
- Biochemistry, Universidad de Concepción, Chile.

Dr. DIEGO RIVERA

- **Position:** Associate Researcher from December 2013 to May 2016 and Principal Researcher from June 2016.
- **RL1:** Efficient use of water in agriculture and mining.
- Doctorate in Agricultural Engineering, Universidad de Concepción, Chile.
- Civil Engineering, Universidad de Concepción, Chile.

Dr. MARÍA CRISTINA DIEZ

- **Position:** Associate Researcher from December 2013 to November 2018 and Principal Researcher from December 2018.
- **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.

Dr. LEOPOLDO GUTIÉRREZ

- **Position:** Associate Researcher from December 2013 to June 2020 and Principal Researcher from June 2020.
- **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.

• ASSOCIATE RESEARCHERS

Dr. FERNANDO CONCHA (RIP)

- **Director between December 2013 and September 2018.**
- **Position:** Principal Researcher from December 2013 to June 2020 and Associate Researcher from June 2020 to July 2022.
- **RL1:** Efficient use of water in agriculture and mining.
- Doctorate in Metallurgical Engineering, University of Minnesota, USA.
- Chemical Engineering, Universidad de Concepción, Chile.

Dr. EDUARDO HOLZAPFEL

- **Deputy Director between December 2013 and September 2018.**
- **Position**: Principal Researcher from December 2013 to November 2018 and Associate Researcher from December 2018.
- **RL1:** Efficient use of water in agriculture and mining.
- Doctorate in Water Resources Engineering, University of California, USA.
- Agricultural Civil Engineering, Universidad de Concepción, Chile.

Dr. AMAYA ÁLVEZ

- **Position:** Associate Researcher from December 2013.
- **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.

Dr. DAVID JEISON

- **Position:** Associate Researcher from December 2013.
- **RL4:** Technology for water treatment and environmental remediation.
- Doctorate in Environmental Sciences, Wageningen University, Netherlands.
- Biochemical Civil Engineering, Pontificia Universidad Católica de Valparaíso, Chile.

Dr. FERNANDO BETANCOURT

- **Position**: Associate Researcher from December 2013.
- **RL1:** Efficient use of water in agriculture and mining.
- Doctorate in Applied Sciences with a Concentration in Mathematical Engineering, Universidad de Concepción, Chile.
- Chemical Civil Engineering, Universidad de Chile, Chile.

Dr. MARIO LILLO

- **Position:** Associate Researcher from December 2013.
- **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 Civil Engineering, Universidad de Concepción, Chile.

Dr. OCTAVIO LAGOS

- **Position:** Associate Researcher from December 2013.
- **RL1:** Efficient use of water in agriculture and mining.
- Doctorate in Engineering, University of Nebraska, Lincoln, USA.
- Master of Agricultural Engineering with a mention in Water Resources, Universidad de Concepción, Chile.
- Agricultural Civil Engineering, Universidad de Concepción, Chile.

Dr. RAIMUND BÜRGER

- **Position:** Associate Researcher from December 2013.
- **RL1:** Efficient use of water in agriculture and mining.
- Dr. rer. nat., Mathematik, Universität Stuttgart, Germany.
- Diplom-Mathematiker, TU Darmstadt, Germany.

Dr. RICARDO FIGUEROA

- **Position:** Associate Researcher from December 2013.
- **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.

Dr. JOSÉ LUIS CAMPOS

- **Position:** Associate Researcher from December 2017.
- **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.

Dr. PABLO CORNEJO RIVAS

- **Position:** Associate Researcher from October 2018.
- **RL4:** Technology for water treatment and environmental remediation.
- Doctorate in Agrarian Biology, University of Granada, Spain.
- Agricultural Engineering, Universidad de La Frontera, Chile.

Dr. OLGA RUBILAR

- **Position:** Associate Researcher from October 2018.
- **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.

Dr. RICARDO OYARZÚN

- **Position:** Associate Researcher from October 2018.
- **RL3:** Water availability and quality for agriculture and mining amid 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.

Dr. ROBERTO PONCE

- **Position:** Associate Researcher from June 2020.
- **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.

Dr. LINA URIBE

- **Position:** Associate Researcher from May 2022.
- **RL1:** Efficient use of water in agriculture and mining.
- Doctorate in Metallurgical Engineering, Universidad de Concepción, Chile.
- Materials Engineer, University of Antioquia, Colombia.

Dr. YANNAY CASAS

- **Position:** Associate Researcher from May 2022.
- **RL4:** Technology for water treatment and environmental remediation.
- Doctorate in Applied Biological Science, Ghent University, Belgium.
- Master in Process Analysis of the Chemical Industry, Universidad Central Marta Abreu de Las Villas, Cuba.
- Chemical Engineer, Marta Abreu de Las Villas Central University, Cuba.

Dr. RICARDO JELDRES

- **Position:** Other Researcher (Adjunct) from May 2020 to December 2022 and Associate Researcher from January 2023.
- **RL2:** New water sources for agriculture, mining and communities.
- Doctorate in Engineering Sciences with a Concentration in Chemical Engineering, Universidad de Concepción, Chile.
- Chemical Civil Engineering, Universidad de Concepción, Chile.

Dr. MARJORIE REYES

- **Position:**Associate Researcher from January 2023.
- **RL1:**Efficient use of water in agriculture and mining.
- Doctorate in Biological Sciences, Universidad de Concepción, Chile.
- Biology, Universidad de Concepción, Chile.

Dr. JORGE ROJAS

- **Position:** Associate Researcher from December 2013 to December 2023.
- **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.

Dr. ALEX GODOY

- **Position:** Associate Researcher from December 2013 to December 2022.
- **RL1:** Efficient use of water in agriculture and mining.
- Doctorate in Engineering Sciences with a mention in Chemical Engineering and Bioprocesses, Pontificia Universidad Católica de Chile, Chile.
- Bioprocess Biology, Pontificia Universidad Católica de Chile, Chile.

Dr. SERGIO ACUÑA

- **Position:** Associate Researcher from December 2013 to December 2020.
- **RL2:** New water sources for agriculture, mining and communities.
- Doctorate in Engineering Science with mention in Chemical Engineering, Universidad de Concepción, Chile.
- Food Engineering, Universidad del Bío-Bío, Chile.

Dr. VERÓNICA DELGADO

- **Position:** Associate Researcher from December 2013 to March 2020.
- **RL5:** Water governance, ecosystem services and sustainability
- Doctorate in Law, Università degli Studi di Roma tor Vergata, Italy.
- Law, Universidad de Concepción, Chile.

Dr. PABLO CORNEJO OLIVARES

- **Position:** Associate Researcher from December 2014 to December 2019.
- **RL4:** Technology for water treatment and environmental remediation.
- Doctorate in Agricultural Biology, Universidad de Granada, Spain.
- Agricultural Engineering, Universidad de la Frontera, Chile.

• ASSOCIATE RESEARCHERS WHO ALSO CONTRIBUTED TO THE CENTER (MAINLY DURING THE FIRST EXECUTION PERIOD: 2013-2018)

Dr. JORGE JARA

- **Position:** Associate Researcher from December 2013 to November 2018.
- **Cluster:** Water Demand.
- Doctorate in Engineering Science, Washington State University, USA.
- Agronomist Engineering, Universidad de Concepción, Chile.

Dr. ALEX SCHWARZ

- **Position:** Principal Researcher from December 2013 to July 2018 and Associate Researcher from August to November 2018.
- **Cluster:** Technology for Water Management.
- Doctorate in Civil and Environmental Engineering, Northewestern University, USA.
- Civil Engineering, Pontificia Universidad Católica de Chile, Chile.

Dr. CHRISTIAN GOÑI

- **Position:** Associate Researcher from December 2013 to June 2017.
- **Cluster:** Water Demand.
- Doctorate in Engineering Sciences, Universidad de Concepción.
- Metallurgic Engineering, Universidad de Concepción.

Dr. RODRIGO BÓRQUEZ

- **Position:** Associate Researcher from December 2014 to November 2018.
- **Cluster:** Technology for Water Management.
- Doctorate in Chemical Engineering, Universität Karlsruhe, Germany.
- Chemical Engineering, Universidad de Concepción, Chile.

Dr. ALEJANDRA STEHR

- **Position:** Associate Researcher from December 2013 to January 2016
- **Cluster:** Water Resources.
- Doctorate in Environmental Sciences, Universidad de Concepción, Chile.
- Civil Engineering, Universidad de Concepción, Chile.

Dr. ALDO MONTECINOS (RIP)

- **Position:** Associate Researcher from December 2013 to January 2016.
- **Cluster:** Water Resources.
- Doctorate in Oceanography, Universidad de Concepción.
- Oceanography, Pontificia Universidad Católica de Valparaíso, Chile.

Dr. JOSÉ VARGAS

- **Position:** Associate Researcher from December 2013 to January 2016.
- **Cluster:** Water Resources.
- Doctorate in Environmental Sciences, Universidad de Concepción, Chile.
- Civil Engineering, Universidad de Concepción, Chile.

Dr. GONZALO MONTALVA

- **Position:** Associate Researcher from December 2013 to January 2016.
- **Cluster:** Technology for Water Management.
- Doctorate in Civil Engineering, Washington State University, USA.
- Civil Engineering, Pontificia Universidad Católica de Chile, Chile.

SERGIO CASTRO

- **Position:** Associate Researcher from December 2013 to November 2016.
- **Cluster:** Water Resources..
- Pharmaceutical Chemistry, Universidad de Chile, Chile.

Dr. DANIEL SBARBARO

- **Position:** Associate Researcher from December 2013 to December 2014.
- **Cluster:** Water Demand.
- Doctorate of Philosophy, Engineering, University of Glasgow, Scotland.
- Electrical Civil Engineering, Universidad de Concepción, Chile.

Dr. ÓSCAR LINK

- **Position:** Associate Researcher from August 2015 to December 2015.
- **Cluster:** Water and Society.
- Doctorate in Engineering, Technische Universität Darmstadt, Germany.
- Civil Engineering, Universidad de Concepción, Chile.

• OTHERS RESEARCHERS: ADJUNCTS

Dr. ROBERTO ROZAS

- **Position:** Adjunct Researcher from June 2020.
- **RL2:** New water sources for agriculture, mining and communities.
- Doktor rer. Nat. Institut für Physikalische Chemie, Universität zu Köln, Germany.
- Master in Chemical Engineering, Universidad de Concepción, Chile.
- Chemical Engineer, Universidad de Concepción, Chile.

Dr. PATRICIO NEUMANN

- **Position:** Adjunct Researcher from June 2020.
- **RL4:** Technology for water treatment and environmental remediation.
- Doctorate in Environmental Sciences, Universidad de Concepción, Chile.
- Environmental Engineer, Universidad de la Frontera, Chile.

Dr. ROBINSON TORRES

- **Position:** Adjunct Researcher from January 2021.
- **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.

Dr. NÉLYDA CAMPOS

- **Position:** Adjunct Researcher from June 2023.
- **RL1:** Efficient use of water in agriculture and mining.
- Doctorate in Business Economics, Universidad del Desarrollo, Chile.
- Doctorate in Philosophy, Macquarie University, Australia.
- Commercial Engineer, Universidad de Concepción, Chile.

CRHIAM
CENTRO DE RECURSOS HÍDRICOS PARA LA AGRICULTURA Y LA MINERÍA
ANID/FONDAP/15130015

10 YEARS

CONTRIBUTING TO WATER SECURITY

HIGHLIGHTING PERIOD 2018-2023

3. ACHIEVEMENTS OF CRHIAM

3. ACHIEVEMENTS OF CRHIAM

3.1 CRHIAM work in numbers: Since the beginning of CRHIAM (December 2013 to December 2023)

Figure 6 shows CRHIAM's performance over ten years. The results of CRHIAM reflect its researchers' hard work and unwavering commitment. During this period, the number of published papers was 30.3% higher than expected, with a total of 719 papers indexed in WoS from December 2013 to December 2023. Additionally, the average impact factor for 2023 was 4.93, which exceeded the expected value of 3.0.

Additionally, 93.2% of the publications were published in high-quality journals (Q1/Q2). The CRHIAM's H-index is 43, indicating a high level of research productivity and impact. Moreover, the number of postdoctoral researchers actively working is 131, which exceeds the expected value of 70. During December 2013 to December 2023, 77 Ph.D. students, 73 master's students, and 393 professionals/undergraduates were graduated under the guidance of CRHIAM researchers.

CRHIAM has expanded its efforts to establish collaborative networks. During the 10 years (December 2013 to December 2023), research centers jointly published 411 international publications (Figure 6), exceeding the expected value of 203. Similarly, the number of visiting researchers amounted to 248, surpassing the expected value of 186. These collaborations involved institutions from Europe and the United States, with a greater emphasis on European connections. The previously mentioned is evident from the substantial number of international trips, totaling 248, including visits by foreign researchers to the Center and trips by CRHIAM researchers to other countries.

INDICATORS FOR THE RESEARCH OF EXCELLENCE

719

NUMBER OF ISI PUBLICATIONS

EXPECTED VALUE: 552

INDICATORS FOR ADVANCED HUMAN CAPITAL TRAINING

131

NUMBER OF POSTDOCTORAL FELLOWS

EXPECTED VALUE: 70

77 NUMBER OF FINISHED PHD THESIS

EXPETED VALUE: 41

393 NUMBER OF FINISHED UNDERGRADUATE THESIS

EXPECTED VALUE: 340

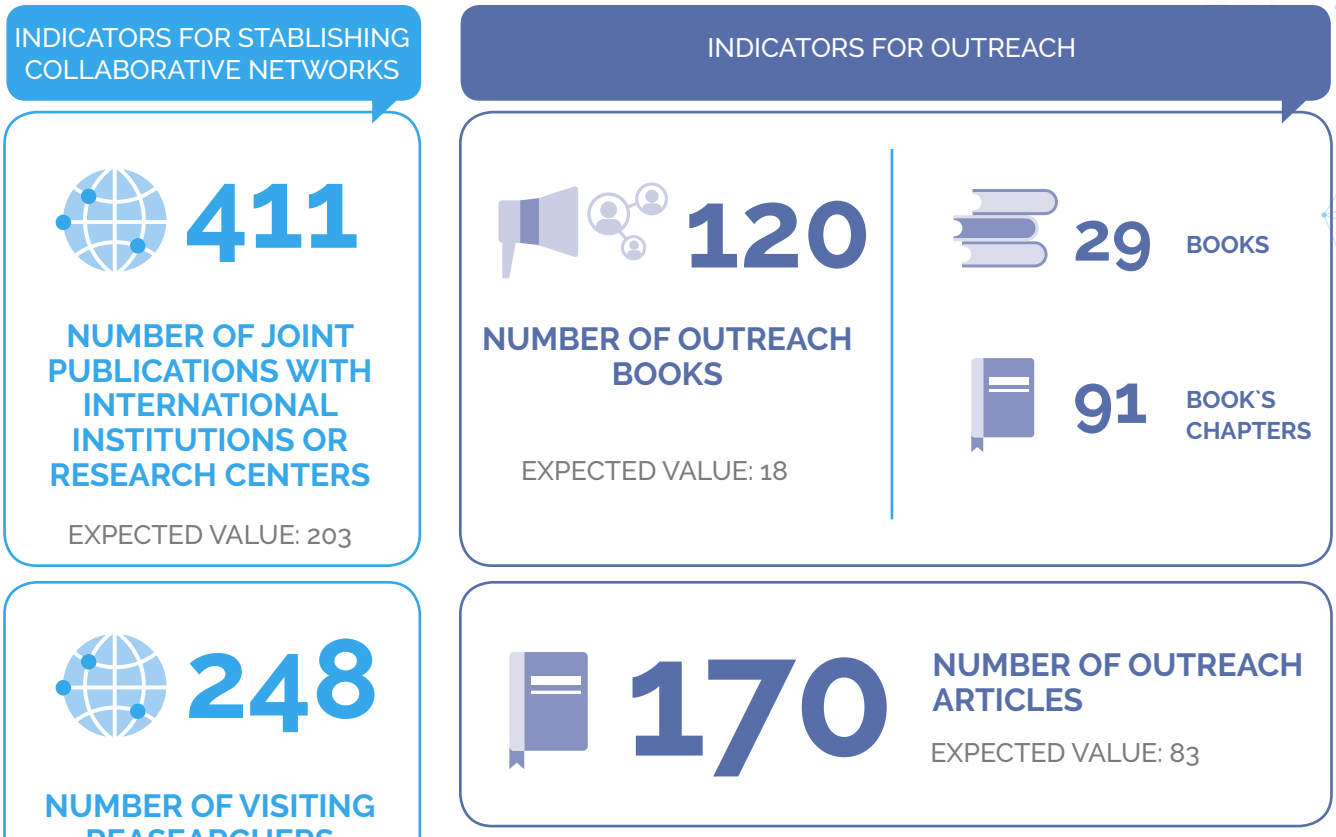


Figure 6. Selected CRHIAM indicators for the ten years of Center`s execution.

At a national level, the Water Research Center for Agriculture and Mining (CRHIAM) collaborates with various sanitary, agricultural, and mining companies. This collaboration includes working on undergraduate and postgraduate theses, professional training, and organizing events such as Water Forums, book launches, and conversations. In the mining sector, CRHIAM collaborates with companies such as Anglo American, the Center of International Excellence Sustainable Minerals Institute (SMI) of The University of Queensland, Codelco, and BHP, among others. For the agricultural sector, CRHIAM works closely with IANSA, fruit companies like Cope Frut and Carsol, and the Consorcio Tecnológico del Agua (CoTH2O), which promotes and catalyzes the development, scaling, and transfer of solutions and technological innovations that contribute to the reduction of gaps in the efficient and integrated management of water resources. Moreover, in the health sector, CRHIAM collaborates with Essbio, Aguas Andinas, Esval, Aqualia, and Wetsus, among others.

Amidst the water crisis faced by the country, water management has emerged as a critical issue. User organizations (OUA) are non-profit entities governed by the Water Code, which aim to distribute water resources to their users and build and maintain infrastructure for this purpose. They play a crucial role in the territory. In this context, CRHIAM has collaborated with surveillance boards of various rivers, such as the Ñuble River, Huasco River, Aconcagua (first section), Longaví River, and Biobío River, through discussion panels and training.

During the first week of October of each year, CRHIAM joins the celebrations of the Science Festival, an activity organized by the Ministry of Science, Technology, Knowledge and Innovation (CTCI). With scientific fairs and talks open to the community, the Center has been part (in different years) of activities organized in Santiago, Concepción, Chillán, and Los Ángeles, reaching hundreds of people at the national level.

From December 2013 to December 2023, CRHIAM published 29 books and 91 book chapters, which is higher than the expected value of 18. Additionally, the number of outreach articles was 170, more than the expected value of 83.

Since its beginning, the Center has recognized the importance of training on water resources to address issues related to efficient water use. To achieve this, the Center has provided training opportunities at various levels, incorporating the concept of "open science." This approach aims to share academic knowledge with the broader community. For instance, CRHIAM has collaborated with the National Agricultural Society (SNA) through its SNA Educa network to offer learning opportunities to agricultural technical schools, such as the Liceo Agrícola El Carmen and the Liceo Agrícola de Chillán. While the training has been primarily theoretical, it has also included practical sessions to allow students to apply what they have learned in the classroom. To illustrate, CRHIAM installed a rainwater harvesting system at the Liceo Agrícola de Chillán, which students used to irrigate native trees and gain practical experience in its operation. Similarly, at the Liceo Agrícola El Carmen, the Center developed an agricultural telemetry training module, which serves as infrastructure to train agricultural professionals, agricultural school students, and local farmers. Moreover, CRHIAM has supported the WorldSkills Chile Olympics, a competition that tests the skills of middle and higher technical education students. It is worth noting that 2023 there will be 800 competitors.

CRHIAM has entered into collaboration agreements with various organizations such as Biblioteca del Congreso Nacional, Fundación Newenko, Regional Directorate of Hydraulic Works (DOH Región del Biobío), the Regional Government of Atacama, University of Atacama, and Asociación Chilena de Desalinización A.G. (ACADES). Its researchers have also been involved in various committees, such as the Commission on Water Resources and Desertification of the Chamber of Deputies (Dr. Amaya Álvez, RL5, and Dr. Verónica Delgado, CRHIAM researcher from RL5, 2013-2020), the Special Committee on Water Resources, Desertification and Drought of the Senate, and Mesa Compromiso Nacional. One of the notable contributions of CRHIAM is the

work carried out by Dr. Amaya Álvez, who was elected as a conventional constituent during the first period of drafting the proposal for a new Constitution for the country. Furthermore, the Center has actively participated in various work tables such as Mesa de Ciencia y Conocimiento vis-à-vis socio-environmental disasters, Mesa de Género de CTCI at the Biobío Region, and is a member of the Green Infrastructure Committee of the Regional Government of Biobío.

From December 2013 to December 2023, CRHIAM published a total of 29 books and 91 book chapters. This includes 60 Communications Series and 19 Policy Briefs, providing scientific evidence to support decision-making. Notably, the Communications Series covers a wide range of topics, including the human right to water, Mining 4.0, and the salinization of agricultural soils. Two special editions were also published: the first includes the main titles published until 2021, while the second presents the environmental quality of drinking water sources from sanitary service companies in Chile from 2013 to 2020. This edition was prepared in collaboration with the Ministry of Environment, reviewed by the Technical Unit of the Division of Inspection of the Superintendence of Sanitary Services (SISS - Santiago), and continues the work of the Department of Aquatic Ecosystems and Division of Natural Resources and Biodiversity.

Finally, it is essential to mention that the researchers at CRHIAM were in charge of developing the "Manual of Good Practices for the Efficient Use of Water in the Agricultural and Mining Industry." This manual resulted from the "Technologies, CRHIAM Methodologies, and Guide for best practices for water sustainability in agricultural and mining industries" project (ANID/FSEQ210002). This project received the first national prize in the "Fondo de Investigación Estratégica en Sequía" call, which was carried out in 2022. Thanks to its work, CRHIAM has contributed significantly to decision-making based on interdisciplinary scientific research and aligned with the Sustainable Development Goals. The organization has responded quickly and effectively to the need for access to quality and fresh water for people and productive sectors, a top priority for the country.

To evaluate the weaknesses and opportunities of the Center, CRHIAM carries out benchmarking of several qualitative and quantitative summarized backgrounds in the period 2018-2020 from the Water Research Center for Agriculture and Mining – University of Concepcion (CRHIAM) in contrast with other six (6) research centers related to water management and security topics. The Centers are Arizona Water Resources Research Center – The University of Arizona (USA), the Center for Watershed Sciences – UC Davis (USA), The Advance Water Management Centre – The University of Queensland (Australia), UNESCO IHE Delft Institute for Water Education (EU), Water Center for Latin America and The Caribbean - Monterrey Institute of Technology and Higher Education (Latin America) and Water Research Center – Tel Aviv University (Asia).

The diagnosis clearly identifies CRHIAM as belonging to the water management category for agriculture and mining. However, it takes work to determine who uses the research information generated by CRHIAM. CRHIAM aims to be a world leader in creating knowledge in water resources, and its strategy reflects this purpose. The

organization's chart shows solid research and management capacities supported by constant international recommendations. CRHIAM has an excellent vision for improving work activities to meet new challenges, with a focus on people and society. Involving a community manager or related professional to approach existing or new stakeholders and build relationships over time is essential. Another interesting aspect is that CRHIAM has enormous potential in both young and senior research experience. The research topics are novel and interesting, generating new models based on sustainability. A wealth of scientific information of high social and economic value needs to be shared with the community through shared value solutions.

The Water Research Center for Agriculture and Mining (CRHIAM) is committed to the 2030 Agenda and has established a strategy that focuses on aligning with the sustainable development goals (SDGs) related to water access and quality for sustainable consumption and production. To evaluate CRHIAM's contribution to the SDGs, specified algorithms were used to search complex databases (e.g., Web of Science or Scopus) and identify relevant research articles for each goal needed. Elsevier 2021 SDG mapping queries and Scopus were used as sources, and around 400 papers were identified as contributing to at least one SDG. Due to the multi and interdisciplinary goals and related research required to develop them, each article may contribute to more than one SDG, so "contributions" may be more significant than unique documents. Data obtained shows that CRHIAM research distributed over 15 SDGS, where Clean water and sanitation (SDG6) is the most researched goal with an output of more than 190 documents, followed by Life below water Land (SDG15, 41 documents), Climate Action (SDG13, 32 contributions) and Good health and well-being (SDG3, 23 contributions).

Finally, despite the social conflict in Chile in 2019 and the global COVID-19 pandemic that lasted for a year, CRHIAM has become stronger each year, finding new ways to work and collaborate that have improved its indicators and met the goals of the original project. In response to the pandemic, CRHIAM developed a new work strategy, which has helped increase its presence on various social networks such as Facebook, Instagram, YouTube, Twitter, LinkedIn and Spotify/Anchor. This has raised the profile of the Center's work on water security nationally and internationally.

3.2 CRHIAM: Joint and interdisciplinary work

Synergies between RL for the generation of scientific evidence

The CRHIAM Communication Series (CS), Policy Briefs and references cited in this section can be seen in Table 3, Table 4 (both in section 7) and Annex (document hosted on the Center`s website: www.crhiam.cl), respectively, of this document.

• RL1 Efficient use of water in agriculture and mining

Researchers at CRHIAM across RL1-RL5 have collaborated on an interdisciplinary project titled "Technologies, CRHIAM Methodologies, and Guide to Best Practices for Water Sustainability in the Mining and Agricultural Industries." The project aims to accelerate the availability of technologies, methodologies, and best-practice protocols in the fields of mining and agriculture, focusing on technical, environmental, legal, and social aspects. The project also seeks to develop a public platform that provides a guide to the best practices for water sustainability in the mining and agricultural industries, incorporating all the knowledge generated at CRHIAM since 2013. The inter/transdisciplinary work with other RLs has three research outputs CS (number: 45, 46, 48, 49, 51, 39, 32, 26, 27, 30, 28, and 27, 23, 29, 37, 38), research projects, and published articles (e.g., Souto *et al.*, 2022; Portuguez-Maurtua *et al.*, 2023; Balocchi *et al.*, 2023; Martínez-Retureta *et al.*, 2022; Balocchi *et al.,* 2022; Yepsen *et al.,* 2022).

The results obtained by RL1 have made a significant scientific impact on the local, national, and international community. The online rheology technology developed as part of CRHIAM's work is a perfect example of this. The rheological behavior of mineral suspensions significantly impacts the entire mineral processing chain, and it primarily defines water consumption. The technology has been patented and licensed to a Chilean company. This sensor has been validated in a mining operation in Chile. So far, five contracts have been signed with major copper mining companies, including CODELCO División Andina, CODELCO División Ministro Hales, División Chuquicamata, BHP Escondida, and Lundin Mining CANDELARIA. These companies consider the use of this technology to be critical in improving productivity and reducing water consumption in concentrators.

Regarding international networking, we collaborated with academics from other countries on four research papers. One of these papers focused on a global assessment of river nitrogen isotope composition. Additionally, we contributed to a circular economy textbook highlighting the connection between water security, sustainable development goals (SDGs), and the circular economy. Finally, Matiatos *et al.,* (2021) joined forces with a vast network of researchers to examine global patterns of nitrate isotope composition in rivers

and adjacent aquifers.
Research outputs are connected to real-world problems, making contributions to policy analysis (Álvez *et al.,* 2019), rural communities and citizen science (Rivas *et al*., 2019), and increasing efficiency on water use (Holzapfel *et al.,* 2020; Kuschel-Otárola *et al.,* 2020; Reyes-Bozo *et al*., 2020). In addition to the CS that are available to the public, the team published books such as furrow irrigation design, management, and operation (Holzapfel, 2023). The results of drought project ANID/FSEQ210002 are essential contributions to the country's public policies, especially the public platform and manual with a guide to best practices for the water sustainability of the mining and agricultural industries, covering technical, environmental, legal, and social dimensions and based on all the knowledge generated at CRHIAM since 2013.

The copper mining industry in Chile faces the major challenge of dealing with significant amounts of waste material generated during operations. This waste, known as tailings, amounts to approximately 1.4 million tons daily. Proper disposal or confinement is necessary to prevent any potential environmental hazards. These tailings contain between 30 and 40% of water, which is lost. Many of these tailings contain large amounts of fines and/or clays. Furthermore, Jeldres *et al.,* (2019) published a review on the effect of clays on the flotation of copper minerals by ultra-flocculation (Del Río *et al.*, 2019; Ruylov *et al*., 2019; Vidal, 2019; Concha *et al.*, 2019).

RL1 has made remarkable progress in enhancing water use efficiency by upgrading irrigation techniques, yield prediction, and data analytics. A significant breakthrough has been the conception and testing of approaches that connect field-scale experiments and monitoring to watershed-level water management. The findings have shown the possibility of increasing yield and water use efficiency through field research and evidence-based decision-making at the catchment scale by combining remote sensing and in situ water availability and demand measurements.

• RL2 New water sources for agriculture, mining and communities

The RL2 conducted research from 2013 to 2023, addressing various aspects aimed at sustainable water use with a significant reduction of the environmental impact. Three main factors influenced this particular line: (1) release of fresh water for households and agriculture, (2) anticipate the policy of "not a single drop of fresh water should go to industrial processes," and (3) evaluate the use of low-quality metallurgical water, seawater, well water and recycle water, to sustain or make viable the mining activity. We at CRHIAM are committed to following the principles of Water Security and One Water in all the activities.

The RL2 objectives are achieved by a combination of experienced and young researchers who are connected with quality centers abroad and highly motivated students who work in a suitable research environment. The aim is to create a productive and effective atmosphere for research.

The work carried out involved a fruitful collaboration between RL2 and researchers from various other lines at CRHIAM, including RL1, RL3, RL4, and RL5. Initially, the collaboration had a multidisciplinary focus, but it evolved to become more interdisciplinary over the years. The project involved the participation of researchers from several Chilean universities, such as U. Antofagasta, U. Bio Bio, U. Arturo Prat, and Pontificia U. Católica de Valparaíso. Additionally, researchers from foreign universities such as Aalto U (Finland), U Politécnica de Cartagena (Spain), Universidad Complutense de Madrid (Spain), Heinrich Heine University (Germany), Veer Surendra Sai University of Technology (India), CSIR-Institute of Minerals and Materials Technology (India), and Academy of Scientific and Innovative Research (India) contributed to the project. The project also involved the participation of research centers such as SCIRO (Australia) and companies such as Codelco and SQM.

We are pleased to report that this RL achieved many disciplinary and interdisciplinary results, including publishing papers in high-impact and Q1-Q2 quartile ISI-Web of Science journals. These papers can be found on the website at www.crhiam.cl. Members of RL2 have been Guess Editors of special issues of MDPI Journals (Jeldres (2023a, b), Toledo (2023a, b), Quezada (2022)).

Several transfers to the copper and lithium industries are related to chemical agents such as foaming agents, collectors, conditioners, pH regulators, depressants, coagulants, and flocculants, all of which have a significant industrial impact in the mining sector. In the agricultural sector, the Drought project (Drought) was successfully concluded (Gutiérrez *et al.,* 2023).

In the field of human capital formation, we cannot go into detail about all the theses written by undergraduates and graduates. In this context, we would like to highlight the contribution of RL2 to the Water Resources Diploma for Sustainable Development (Toledo, 2019-2023). One of the significant impacts of this contribution is the continuous training of hundreds of professionals in water resources. However, the most notable outcome, which was not entirely expected, was the successful communication of scientific evidence to the general public in simple Spanish. This was achieved through various mediums such as articles in magazines and newspapers, books, communication series, seminars, forums, workshops, conferences, press releases, letters to the editor, opinion columns, and compelling presence in schools and the National Congress.

Moreover, ANID and CRHIAM made it possible to contribute significantly to public policy proposals in various areas related to water resources, which can be viewed on the referred website. This achievement was unthinkable without ANID and CRHIAM's support in recent years.

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

RL3 has conducted research to understand how climate variability affects the processes that control water production and water quality along different watersheds in Chile. This research line aims to contribute towards the adaptation of water users to climate change and to support the achievement of SDGs 6, 9, 10, 11, and 15. Specifically, this research group has focused on studying mountain hydrology, groundwater recharge, and water quality of surface bodies.

The RL3 maintains an active scientific interaction and synergies with other CRHIAM research lines. For instance, work has been carried out within the Drought project (ANID Project 478650), which brought together different CRHIAM researchers to speed up the development of methodologies and proper design and management practices that allow for better coping with water scarcity. Within the framework of this project, doctors Urrutia and Arumí are collaborating with Dr. Toledo (RL2) to develop water treatment solutions that make it possible to face the growing problem of salinity that affects agriculture in north-central and south-central Chile. This particular project is an extension of the work previously conducted by the same researchers in the framework of García *et al.,* (2023). Together, we are continuing the development of the FIC-Biobío project, "Use of cellulose effluents for agricultural irrigation," directed by Dr. Urrutia and has the collaboration of Drs. Arumí (RL3; RL5) and Vidal (RL4). Finally, Dr. Oyarzún worked with Drs. Jeison and Campos (RL4) on a project to develop and evaluate bioelectrochemical systems that could reduce nitrate levels in treated groundwater. This project was part of Dr. Eduardo Ortega's postdoctoral research. In addition, Dr. Oyarzún collaborated with Dr. Lillo (RL1) to study and characterize precipitation processes in mountain environments, particularly under the influence of climate change and atmospheric rivers. This work was part of the postdoctoral research of Dr. Lucía Scaff.

• RL4. Technology for water treatment and environmental remediation

The RL4 team has been researching technology related to water treatment and environmental remediation. Recently, they have been studying the effects of discharging treated wastewater on people's health, mainly when used in food production. In this report, we will discuss the work of the RL4 team, their collaborations with other RLs, national and international partnerships, and efforts to develop advanced human capital.

The researchers of RL4 are making efforts to connect the members of the RL4 and generate products with other research lines. Thus, in the last five years, RL4 has collaborated with RL1, RL2, RL3, and RL5 in many CRHIAM CS, such as numbers 5, 6, 7, 10, 17, 18, 19, 22, 28, 30, 44, 51, 63 among other. RL4 has primarily worked with the Superintendency of Sanitary Services (SISS) and the Ministry of Environmental Protection together with RL5 and RL3 to publish the CRHIAM CS (special edition): "Environmental quality of potable water sources

in sanitary service companies in Chile. Period 2014 -2020". This document aims to show the evolution in water quality of Chilean ecosystems that generate drinking water for the population. Besides that, together with RL1 and RL5, RL4 had worked on the Policy Briefs numbers 2, 4, 5, 8, 9, and 10, among others.

Drs. Diez, Vidal, and Cornejo worked on the ANID FSEQ210002 drought proposal project entitled "CRHIAM Technologies, Methodologies, and Guide to Best Practices for the Water Sustainability of the Mining and Agricultural Industries," which ended in June 2023 (this project was led by Dr. L. Gutierrez (RL1) and Dr. J.L. Arumi (RL5)). In this project, RL4 researchers worked on Project 1.5. "Improving the use of water by plants for food production under osmotic stress" and "Characterization, treatment by vertical subsurface wetlands and evaluation of the acceptance of reuse of gray water." As a result of this project, we obtained a granular formulated amendment that can increment crop productivity using half the water requirement and the feasibility of using and reusing gray water for irrigation of non-edible products. Dr. Cornejo, the director, and Rubilar, the principal researcher, have secured funding for the InES19 proposal (MINEDUC-FRO19101). This project aims to consolidate research on climate change and sustainability. This project has provided an excellent opportunity for collaboration with other CRHIAM researchers, resulting in the publication of more than 15 papers.

RL4 researchers have multiple cooperation initiatives with countries such as Greece, Argentina, Costa Rica, Germany, Spain, and Brazil. Specific programs fund these initiatives. RL4 researchers currently maintain international cooperation projects with the University Federal do ABC of Brazil-Chile (ANID/FAPESP 2018/08194-2), Greece-Chile (2019-2022) (ANID/MEC80190057), and Germany (ANID/MEC 80190080). In addition, six Regular and Postdoctoral Fondecyt projects (FONDECYT 1211738, 1181089, and 1191230; FONDECYT Postdoctorado 3200963, 3190922, and 3180279), three doctoral dissertations, and one master's thesis are currently in progress. 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 projects are: "Network for Pesticide Risk Reduction: New Strategies and Opportunities," "Nanotechnology for Agriculture: New Strategies and Opportunities and their Environmental Risk," and "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 researchers are currently working with businesses to expand their technology use. They are collaborating with EAGON-Lautaro company and Universidad de La Frontera in the La Araucanía Region to evaluate a pilot plant for a treatment system that removes and degrades wastewater from the chip spray field of the board plant. This treated water can then be used for recirculation purposes. In addition, in 2020-2022, CORFO (the Chilean Corporation for Production Promotion), under social validation, awarded funds for the project

"Resilience and adaptability to the water crisis: sponge cities and sustainable fields through wastewater-purifying wetlands." The project will be executed between the Valdivia Wetlands Center (CEHUM) (Los Rios Region), CAREP Rural Cooperative, and CRHIAM, which is acting as the technology accreditation center. In this same line, during the last couple of years, work has been done on developing algae-based treatment systems as a solution for sanitation in small communities. A pilot plant was implemented in the Mapocho-Trebal plant (Agua Andina water company, Metropolitan Region) in the framework of CORFO project 18COTE-98077. Finally, in 2022, the ESSBIO S.A. water company (O'Higgins, Maule, Ñuble, and Biobío regions) worked with RL4 to enhance the environmental knowledge of citizen leaders where the company is operating through the course "Water Resources Management and the urban water cycle," which addressed the effects of climate change on drainage basins, the water cycle, and water quantity and quality.

• RL5. Water governance, ecosystem services, and sustainability

In the second execution period (2018-2023), the RL5 focused on research related to water security and translating this research into action along the different watersheds where investigations are taking place by producing articles, books, and outreach material. The main research topics were water regulation, water conflicts, ecosystem services, desalination, and artificial groundwater recharge.

Indicators of the interdisciplinary work

The strategies to face the water crisis that affects the country, both to guarantee human consumption and to supply the productive sectors, require scientific evidence to support decision-making. From this perspective, the "CRHIAM Communication Series" (see in section 7, Table 3) has addressed multiple topics that nourish discussions and debates around water management, with contingent themes, but also thinking about future challenges.

Table 1 shows the collaboration between the RLs of CRHIAM to create 60 CRHIAM Communication Series (see details in Table 3). These documents are the result of interdisciplinary work conducted by CRHIAM researchers. They contain scientific evidence that is easy to understand and contributes to society by bringing together different disciplines related to water resources. RL1 and RL5 are particularly noteworthy as they have the highest number of interdisciplinary series, with 34 and 32 (see titles in Table 3), respectively.

Table 1. Sinergy between research lines (RLs) through CRHIAM Communication Series 2019-2023

RL	RL 1	RL 2	RL 3	RL 4	RL 5
RL 1	34[&] (6[*])	7[#]	3[#]	11[#]	12[#]
RL 2		8[&] (2[*])	0	1[#]	0
RL 3			16[&]	2[#]	12[#]
RL 4				23[&] (7[*])	6[#]
RL 5					32[&] (7[*])

[&] The first number in the matrix diagonal indicates the RL's total Communication Series.
[*] Communication Series with two or more CRHIAM researchers from the same research line as authors.
[#] Number of Communication Series that indicate inter-discipline between researchers from different RL.

In the mining area, the document "Mining, energy and water, current situation" (RL1 and RL5), "Radiography of mining in Chile: present and future" (RL1 and RL5), "Processing of copper minerals and the water resource: concepts, challenges and solutions" (RL1 and RL2), "Mining 4.0" (RL1 and RL2), "Mine tailings and their relationship with the water resource" (RL1 and RL4), and "How waters are formed rich in Lithium in the Salar de Atacama?" (RL1 and RL5), among others.

There are several notable series in agriculture, including "Recycling in Agriculture: Disposal of Biosolids in Soil" (RL4), "Salinization of Agricultural Soils through the Reuse of Treated Wastewater" (RL4), and "Arbuscular Mycorrhizal Fungi: Sustainable Biotechnology for Agriculture." Other important series include "Facing Climate Change" (RL1 and RL4), "Use of Pesticides in Agriculture: Basic Concepts, Risks, and Solutions" (RL4), "Food Security in Agriculture: Challenges for the Reuse of Wastewater within the Framework of the Health Network Human, Animal, and Environmental" (RL1 and RL4), and "Phosphorus as a Nutrient: Global Environmental Perspectives and Its Application in Agriculture" (RL1 and RL4), among others.

Furthermore, several series have been generated over the past few decades with a significant focus on environmental education and water governance in different territories. Some of these series are "Human Right to Water" (RL5), "Water Footprint" (RL4), "Sustainability and Water Security" (RL4 and RL5), "Vulnerability of Basins: Stresses and Challenges" (RL1 and RL5), "Disputes Over Water: Actors and Institutions in the Urban and Rural Context" (RL1 and RL5), and "Groundwater Recharge" (RL3 and RL5), among others.

It has been observed that there is synergy between different lines of investigation. Despite the classification of themes by areas, researchers from all lines of investigation participate, which undoubtedly enriches the

information delivered to society and public as well as private decision-makers.

The CRHIAM Policy Briefs (see details in section 7) began publication in 2022 to provide exclusive content for decision-makers in the public and private sectors. Table 2 shows the different RLs for producing CRHIAM

Table 2. Relationship between research lines (RLs) for the CRHIAM Policy Briefs generation 2022-2023

RL	RL 1	RL 2	RL 3	RL 4	RL 5
RL 1	4[&] (1[*])	2[#]	0	1[#]	1[#]
RL 2		3[&]	0	0	0
RL 3			2[&]	0	2[#]
RL 4				10[&] (2[*])	5[#]
RL 5					10[&] (2[*])

[&] The first number in the matrix diagonal indicates the RL's total Policy Brief.
[*] Policy Briefs with two or more CRHIAM researchers from the same research line as authors.
[#] Number of Policy Briefs that indicate inter-discipline between researchers from different RL.

Policy Briefs.

These documents are a summary of the main conclusions and recommendations from the CRHIAM Communication Series. Some of these documents were created due to the governmental agenda, while others emerged from different research lines. As of 2023, 11 policy briefs have been prepared with authors from different lines and 19 policy briefs have been published in total. The most significant contributions to these documents have come from RL4 and RL5 research lines, with RL5 being the one that accounts for the most interdisciplinary documents (6 in total).

The Center has been working on various research topics related to water problems in Chile. Communication series and policy briefs have been prepared to put the scientific evidence generated at the Center into value. The policy briefs have addressed multidimensional water problems in Chile. Here are some of the policy briefs that were prepared with the participation of more than one research line: "Construction of reservoirs to face water scarcity (RL3 and RL5)", "Water management within the water security framework: a problem of governance" (RL4 and RL5), "Collecting rainwater: encouraging the diversification of the water matrix" (RL4 and RL5), "Recommendations for the sustainable use of water in mining" (RL1 and RL2), "Microorganisms in the water: a pending challenge with the ecosystem" (RL4 and RL5), "Reuse of wastewater in agriculture, an alternative in the search for food security" (RL1 and RL4), "Hydrological modeling to face global changes" (

RL1 and RL5), "Nexus: an integrated approach to sustainable water and energy management" (RL4 and RL5), "Lithium as a key player in the global energy transition framework" (RL1 and RL2), and "Environment healthy, water, current situation and future challenges in Chile" (RL4 and RL5), "The sequence increases the risk of floods" (RL3 and RL5).

The collaboration between different research lines has been key in producing these documents, which offer an updated perspective on water resources and their various applications. The conversation about managing water resources efficiently in the country requires short, medium, and long-term proposals. These proposals are an essential contribution from the academic community towards creating a plan of action to address the water crisis in the face of climate change, taking into account the country's different geographic contexts and environmental needs. These documents will serve as a foundation for planning and implementing effective measures to manage water resources sustainably.

3.3 Promoting the development of human capital in water resources since its creation

The CRHIAM Fondap Center has set four objectives to support the development of capacities in water resources. One of their primary commitments is to train human resources at the undergraduate level and support thesis projects. Moreover, they aim to generate a critical mass by providing graduate and postdoctoral programs. CRHIAM offers graduate programs such as Ph.D. and master's, as well as undergraduate programs. Currently, the project has been running for ten years, and it has become a human capital training center, thanks to the contributions of its principal, associate, and adjunct researchers.

Below is a diagram that indicates the doctoral and master programs (Figure 7 and 8, respectively) that students associated with CRHIAM have taken in the different universities (Universidad de Concepción, Universidad de La Frontera, Universidad del Desarrollo, Universidad de La Serena y Universidad Adolfo Ibáñez) that actively work with the center.

DOCTORAL PROGRAM	UNIVERSITY
• Environmental Sciences with mention in Continental Aquatic Systems • Energy • Metallurgical Engineering • Engineering Sciences with mention in Chemical Engineering • Water Resources and Energy for Agriculture • Applied Sciences with mention in Mathematical Engineering • Analytical Sciences and Technology	Universidad de Concepción
• Natural Resource Sciences • Engineering Sciences with mention in Bioprocesses • Agricultural and Food Sciences Environment	Universidad de la Frontera
• Social Complexity Sciences	Universidad del Desarrollo
• Energy Water and Environment • Biology and Applied Ecology	
• Complex Systems Engineering	Universidad Adolfo Ibáñez

Figure 7. Doctoral programs that students associated with CRHIAM have taken in the different universities that actively work with the Center.

MASTER PROGRAM	UNIVERSITY
• Integrated Management, Environment, Labor Risks and Corporate Social Responsibility • Agricultural Engineering • Politics and Government • Social Research and Development • Science mentions Zoology • Industrial Engineering • Engineering Sciences with mention in Civil Engineering • Environmental Sciences	Universidad de Concepción
• Engineering Sciences	Universidad de la Frontera
• Sustainability Management • Engineering Sciences	Universidad del Desarrollo
• Engineering Sciences in Bioengineering • Engineering Sciences in Energy and Environment	Universidad Adolfo Ibáñez
• Chemical Engineering Sciences	Universidad Técnica Federico Santa María
• Agricultural and Environmental Sciences • Engineering Sciences mention Biochemical Engineering • Agricultural and Environmental Sciences	Pontificia Universidad Católica de Valparaíso
• Engineering Sciences with mention in Mineral Processes	Universidad de Antofagasta

Figure 8. Master programs that students associated with CRHIAM have taken in the different universities that actively work with the Center.

As mentioned earlier, during its first decade of operation from December 2013 to December 2023, the Center collaborated with 1545 undergraduate and graduate students from various schools and programs. Additionally, 131 postdoctoral researchers worked with CRHIAM researchers during the ten years of the Center's execution.

Figure 9 shows data on the students (both undergraduate and graduate) and postdoctoral researchers associated with CRHIAM through its scholarships and researchers. The data is presented cummulatively for each year, making it easy to compare each year of the Center's operation. Over the ten-year period that CRHIAM has been active, 393 professionals have graduated from training programs connected with CRHIAM researchers, including 73 masters and 77 doctoral students.

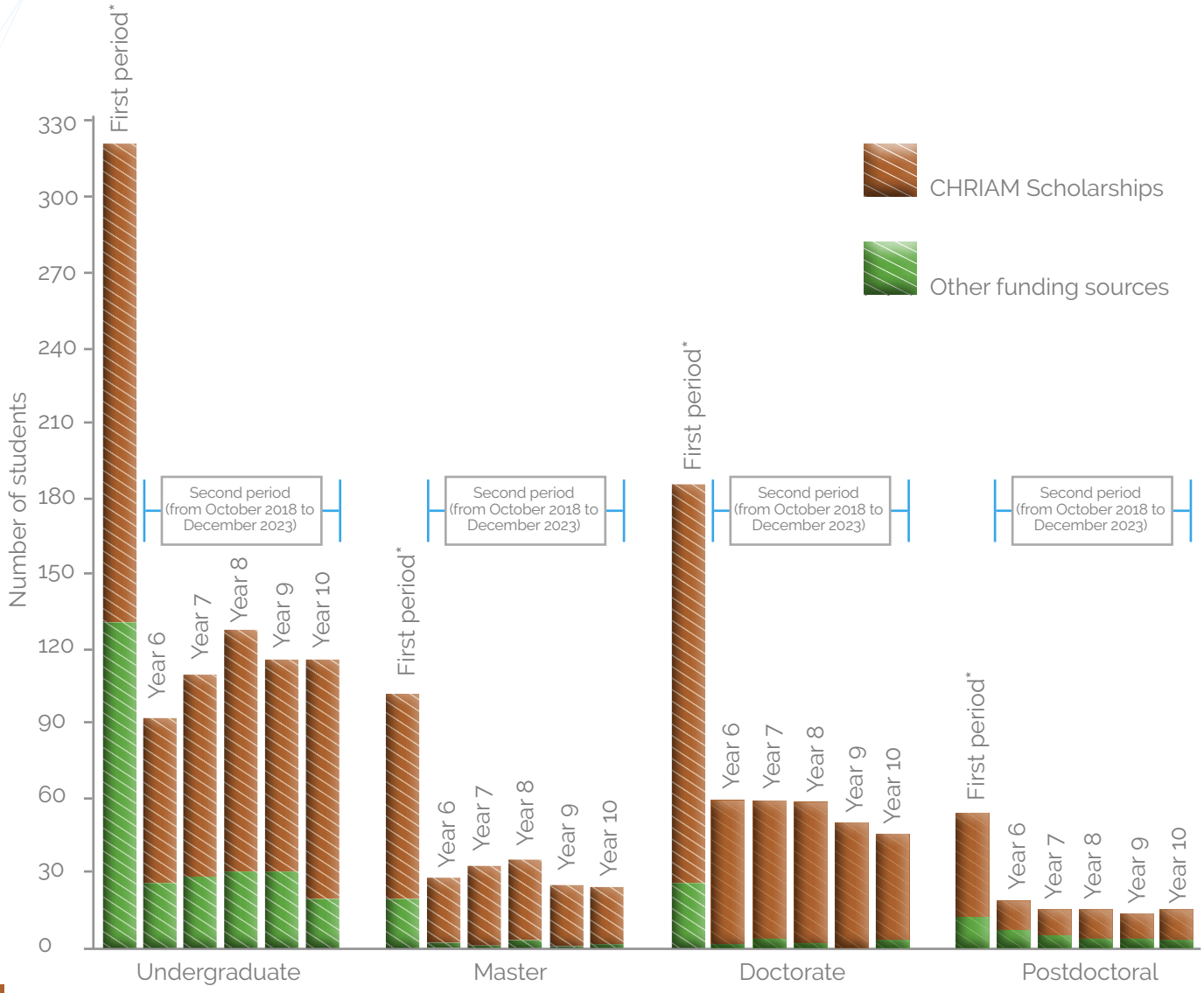


Figure 9. Information on the students (undergraduate and graduate) and postdoctoral researchers of CRHIAM during previous years compared to 2023. * From December 2013 to October 2018.

CRHIAM has supported the training of undergraduate and postgraduate students and postdoctoral researchers. In this regard, undergraduate students, in the period from October 2018 to December 2023 of the execution of the CRHIAM project, trained 222 undergraduate students from the most diverse engineering fields (construction, chemical, metallurgical, bioengineering, agriculture, mineral processes, among others), sociologists, geologists and different degrees (Legal and Social Sciences, Engineering Sciences). The CRHIAM Center has funded 60% of the total number of undergraduate students who graduated. On the other hand, 47 master's students graduated between October 2018 and December 2023, of which around 20% were financed by CRHIAM. Among the students who graduated during this period, five students were co-guided by international researchers from Karlsruhe Institute of Technology | KIT (Karlsruhe, Germany), Leibniz University Hannover (Hannover, Germany), and Universidad de Buenos Aires (Buenos Aires, Argentina).

Additionally, doctoral students graduated October 2018 to December 2023 who worked with CRHIAM researchers were 47, and the Center supported 19.14% of them. Furthermore, 34% of doctorates graduating from the second execution period at CRHIAM had international co-guide professors from Universities such as: Lund University (Lund, Sweden), Radboud University (Nimeg, The Netherlands), Ghent University (Ghent, Belgium), Universidad de Valencia (Valencia, España), Universit'e Versailles Saint-Quentin-en-Yvelines (Versailles, France), Université de Liège (Leija, Belgium), University of the Aegean (Mitilene, Greece), Universidad de Buenos Aires (Buenos Aires, Argentina), Georgia State University (Georgia, USA), Monash University (Melbourne, Australia), Leibniz Universität Hannover (Hannover, Deutschland), Universidad de Sevilla (Sevilla, España), among others.

ANID's main objective is to promote gender parity in the formation of human capital for the country. From this perspective, Figure 10 shows the gender parity of CRHIAM scholarship recipients from October 2018 to December 2023. In this context, 45% of the students with CRHIAM scholarships who carry out postdoctoral training correspond to the female gender, while, at the doctoral level, gender parity was achieved. For master's training, 78% of scholarship recipients are male. Meanwhile, at the undergraduate level, it is observed that CRHIAM has almost achieved gender parity (men: 49%, women: 51%).

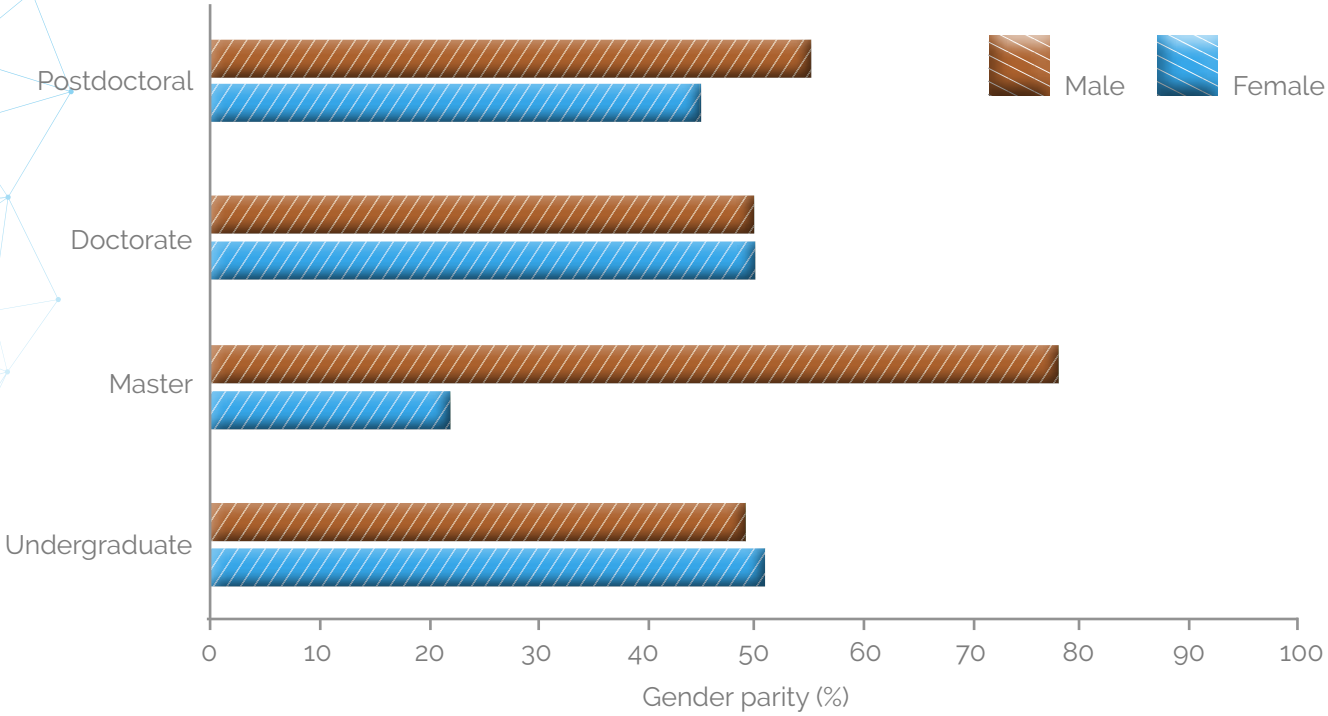


Figure 10. Gender parity for CRHIAM scholarship students at different levels of training, period October 2018 to December 2023.

CRHIAM is working on the formation of its CRHIAM ALUMNI network. The launch of the CRHIAM alumni network will be in 2024. According to the database of CRHIAM graduates at different levels of training, it is possible to say that of the postdoctoral researchers who received CRHIAM scholarships, 75% of them are working as researchers in various universities in the country. Regarding the doctorates who graduated from CRHIAM in 2023, 40% are working in public service institutions. Of the remaining percentage, many of them are still in academia in the field of research. On the other hand, 83% of students who graduated with a master's degree work in the private sector. Finally, for undergraduate students, 38% are in the private sector, 16% are continuing postgraduate studies, 7% are working in the public sector, 20% have not yet graduated (most with scholarships starting in 2023) and 19% are without a permanent job.

Finally, CRHIAM has analyzed which region of Chile the human capital trained in CRHIAM is staying in. Considering the October 2018 to December 2023 period of all the human capital formed, 40% of CRHIAM graduates work in the Biobío region, around 20% in the Ñuble region, and 8% in the La Araucanía region. 6% of CRHIAM graduates work in the Metropolitan region of Santiago, with another 6% in Coquimbo and another 6% in Antofagasta. There are also CRHIAM graduates working in the rest of the regions of Chile, with a percentage less than 5%.

3.4 Water Resources for Sustainable Development Diploma: a CRHIAM program with 5 years of experience (2019-2023)

2023 is the fifth year that the Water Resources for Sustainable Development diploma course has been offered by CRHIAM. It has been delivered as an e-learning course for the past four years. 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 program aims to update professionals in different sectors who need a current, interdisciplinary vision of water resources.

In the class of 2023, there were 25 professionals from different backgrounds: various engineering fields (civil, environmental, agricultural, risk prevention, marine, biotechnology, chemical, and aquaculture), geology, social work, law, chemistry, and biochemistry. In addition, thanks to its online delivery, the new students attended from different cities throughout the country, including Quillota (Valparaíso Region), Temuco, and Punta Arenas (Magallanes y Antártica Chilena Region).

The total number of professionals who have updated their knowledge with CRHIAM in the last five years is 116. Of the total number of professionals (Figure 11a) who have completed the program (2019-2023), 87% of them have training linked to the area of engineering (civil, chemical, environmental, metallurgical, among others) and sciences (geology, agronomy, industrial chemistry, among others). On the other hand, 13% come from the humanities area (lawyers, social workers, journalists, anthropologists, sociologists, among others).

An important aspect to highlight has been the gender parity achieved among the professionals who have completed the diploma (2019-2023), of which 48% have been women and 52% men. The above demonstrates that CRHIAM has managed to form and disseminate scientific evidence associated with water resources in an equitable manner in terms of gender (Figure 11a).

Throughout its development, one of the greatest achievements achieved by the program has been the training of professionals from 14 regions of the country (out of a total of 16). The above reveals the impact of the formation of human capital on water resources throughout the national territory.

It should be noted that only the first version (2019) was taught in person at the headquarters of the University of Concepción, in which 14 professionals from the Biobío Region and 4 from the regions (Metropolitana, O'Higgins and Maule) participated. Although it is observed that from the Biobío Region there have been a total of 39 professionals who have taken the program (2019-2023), 36% of them correspond to those who took the first version (face-to-face format in Concepción, capital of the Biobío Region).

However, due to the COVID-19 pandemic, starting in 2020 the program was taught in E-learning mode, which allowed the participation of professionals from different regions of the country. Of the total number of professionals (116) who have completed the Diploma (2019-2023), 72% have come from regions and only 28% from the Metropolitan Region, which highlights that the training has been decentralized, allowing the development of capacities to regional level (Figure 11b).

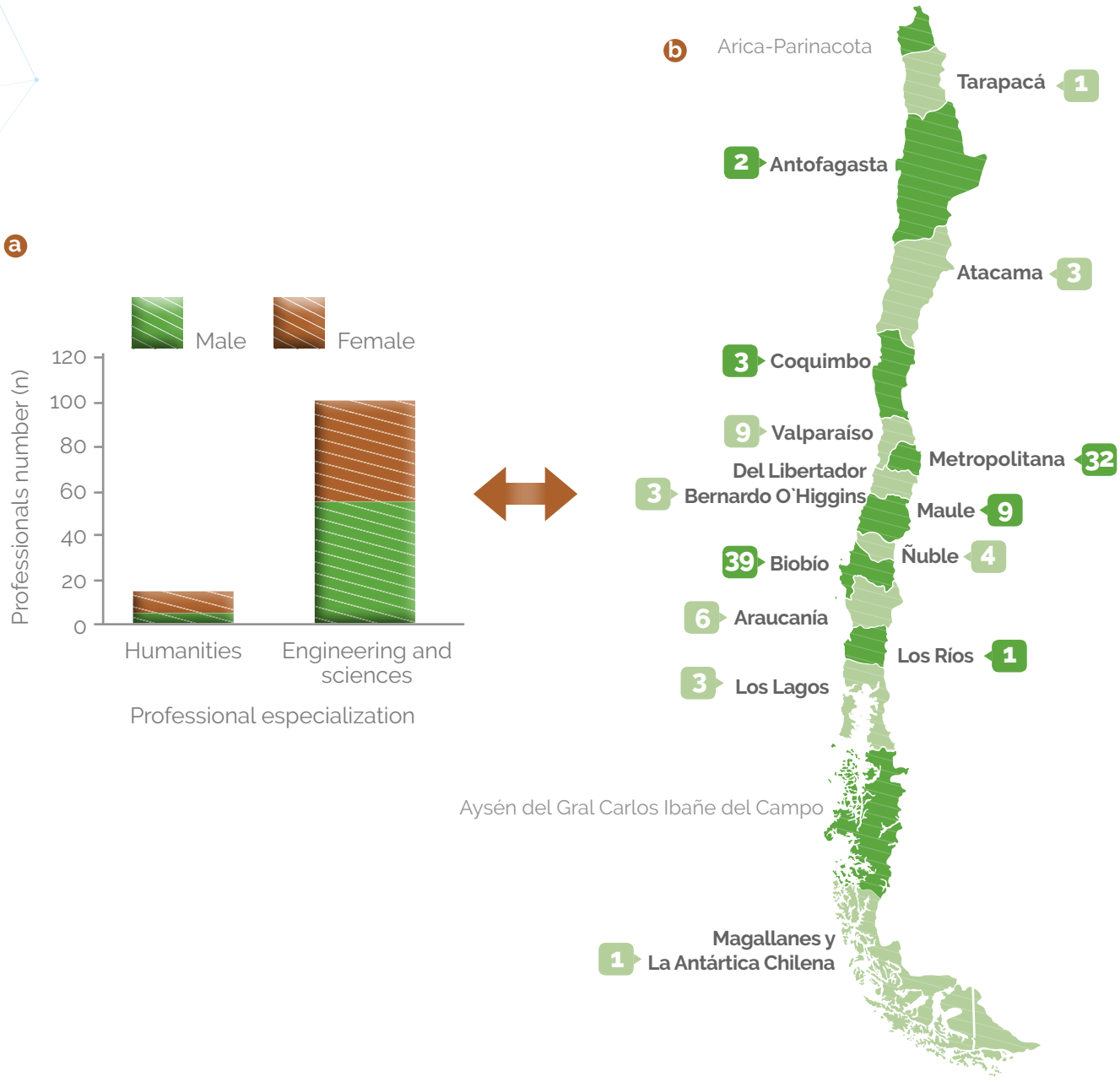


Figure 11. Some details of professionals who have completed the Diploma. a) Distribution of professional area and gender and b) Origin of CRHIAM trained professionals: Diploma in the territory (professionals number).

3.5 Water Resources Management and the Urban Water Cycle course

CRHIAM and Essbio-Nuevosur organized this course under an agreement CRHIAM / Essbio-Nuevosur in four different regions of Chile (O'Higgins, Maule, Ñuble, and Biobío regions). The courses are aimed at citizen leaders (Figure 12) from the regions where Essbio and Nuevosur companies are operating. The objective was to cover essential elements of the effects of climate change on drainage basins, the water cycle, and water quantity and quality. At the same time, concepts of the urban water cycle and infrastructure and its management and the institutional framework were introduced.

Additionally, in the second version, a field visit to the drinking water production and wastewater treatment plants that operate in the different regions was included in the study program. The visit aimed to gain knowledge about the urban water cycle, including extraction, purification, distribution, and wastewater treatment. The courses are taught online in collaboration with the University of Concepcion's Permanent Training program. CRHIAM researchers and professors from the Universidad de Concepción (School of Environmental Sciences and School of Laws) lead the classes, experts on climate change, drainage basins, water technology, and environmental legislation and institutions. One of the main achievements of this course has been to strengthen the link with the territories to raise awareness about the country's water situation. To date, this course has been taught to 80 citizen leaders.

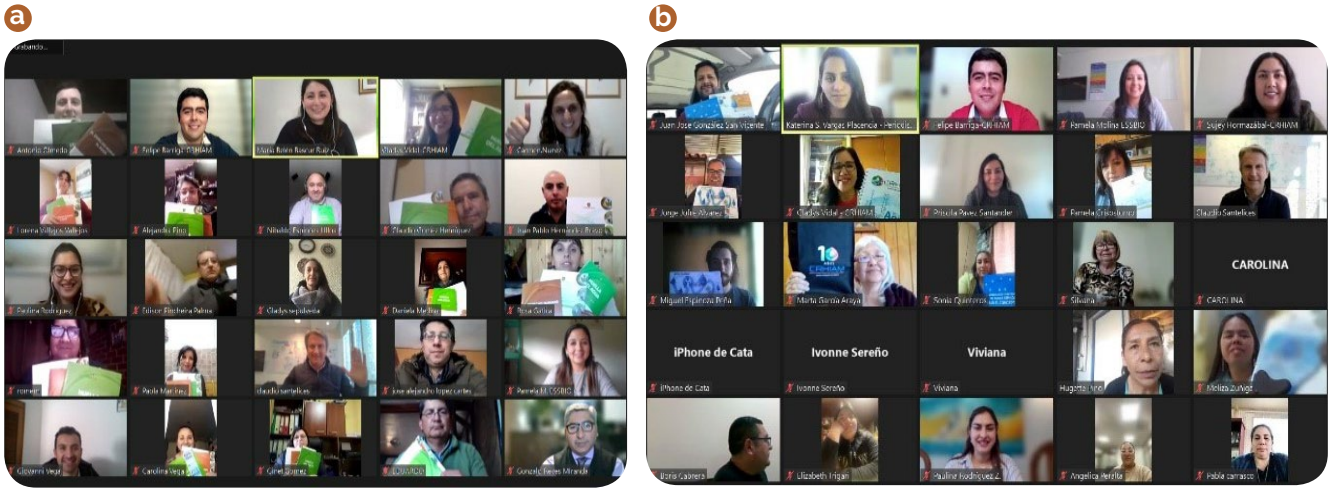


Figure 12. Participants Water Resources Management and the Urban Water Cycle course. a) 2022 version and b) 2023 version.

3.6 Training for people who carry out agricultural activities

The technical high school training activities were carried out by the CRHIAM Community Engagement Coordinator, who is directly connected with the center's administration and the research line on water demand for agriculture (RL1). The goal is to teach students the technical irrigation skills that CRHIAM researchers have developed in the last years of agricultural technical colleges. These professionals from rural areas rapidly apply their knowledge of agricultural irrigation to Chilean farming.

The main indicators of activities carried out in the technical area linked to the person working in agriculture indicate that 2125 people are working as irrigation assistants in a total of more than 100 activities. In the same way, 526 people were served in "field days"; each activity lasted 32 teaching hours, and demonstration training on water techniques was carried out in 18 activities. Some of the activities carried out are shown in the Figure 13.

a

b

c

Figure 13. Agricultural irrigation training activities. a) Training in technical irrigation system (2020), b) training for farmers belonging to the program of the Agricultural Development Institute (INDAP) of the Ministry of Agriculture of Chile (2021) and c) talk to small farmers.

CRHIAM
CENTRO DE RECURSOS HÍDRICOS PARA LA AGRICULTURA Y LA MINERÍA
ANID/FONDAP/15130015

10 YEARS

CONTRIBUTING TO WATER SECURITY

HIGHLIGHTING PERIOD 2018-2023

4. THE WORK OF THE RESEARCH LINES

4. THE WORK OF THE RESEARCH LINES

The topics worked on and to which each of the RLs have contributed are detailed below:

4.1 RL1 Efficient use of water in agriculture and mining

a) Water efficiency in agriculture and mining

Some major contributions to agricultural research include the optimization of applied water and yield estimation in various crops. For instance, Pannunzio *et al.,* (2023) and Lagos *et al.,* (2023) have worked on blueberries, Souto *et al.,* (2022) on hazelnuts, Lecaros-Arellano et al., (2021) on apples, and Valdivia *et al.,* (2021) on quinoa. The AQUASAT platform is an excellent example of how field research, remote sensing, water management, and information technologies can be integrated. It offers actionable recommendations and support for business intelligence. The methods embedded in AQUASAT have been helpful in conducting ex-post assessments as well as within-season irrigation assessments. As a follow-up project, H2Org is a communication technology that enables the development of tools for Water Users Associations (WUAs) to make informed decisions based on reliable, adequate, timely, and updated information from multiple sources. This technology contributes to reducing the existing gap in the demand relationship for irrigation water. H2Org is a decision support system (DSS) for WUA that uses multiple sources of information and allows the management and planning of water distribution for irrigation. Moreover, H2Org is able to estimate the spatiotemporal water demand of crops present in the zone of influence of the WUA, systematic and automatically updated agricultural land use cartography, estimate water availability taking into consideration the high climatic variability, and simulate different scenarios of crop patterns, irrigation systems, and water availability.

b) Catchment-scale water management and water observation

The research goes from upper catchments that feed downstream uses to better estimate water use and water demands from operations to plots and catchments. This approach requires reliable, updated, and relevant data (e.g., plot scale irrigation trial and a pilot-scale flotation column to validate mathematical models) for modeling and assessing different management scenarios. For instance, Rivas *et al.,* (2023) assessed the microbial community and enzyme activity of forest plantations, natural forests, and farmland, showing that land-use change also affected the chemical soil properties of the biogeochemical cycle. Moreover, rooted in AQUASAT, 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, to characterize the water demand of crops (potential and estimated) in a spatially and temporally distributed manner.

c) Data analytics, remote sensing, and in situ measurements

Effective management requires accurate data. However, data is a limited resource, so our team has developed advanced techniques and methods to monitor mining and agricultural operations. We use data-driven, machine learning techniques, and artificial intelligence to enhance various aspects of agriculture, such as outlining agricultural fields (García-Pedrero *et al.,* 2019a), image classification (Seal *et al.*, 2019; García-Pedrero *et al*., 2019b), assessing crop water use (Gavilán *et al.,* 2019), measuring crop evapotranspiration (Souto *et al.*, 2019), identifying areas at risk of flash floods (Portuguez-Maurtua *et al.,*2020), and detecting sorghum heads using unmanned aerial vehicles and test-time-augmentation techniques (Gonzalo-Martin *et al*., 2021).

Moreover, Morales *et al.,* (2023) collated a dataset of 10,000 landslides in the northern Chilean Patagonia, now the largest freely accessible landslide dataset in this region, and then implemented a machine-learning model for semantic segmentation to detect landslides in optical images of the Sentinel-2. Regarding climate change, we have utilized semi-arid dualistic agriculture (Fernández *et al.,* 2019) and precipitation interpolation to enhance the usability of the database (Ossa-Moreno *et al.*, 2019). This database is crucial in modeling complex hydrological systems. Additionally, we have validated a new method to extract water from soil samples for isotopic analysis, which helps us explore the resilience mechanisms of water storage in Andean watersheds. This method can be applied in agricultural systems to study plant water usage (Rivera *et al.,* 2019).

The rheological behavior of mineral suspensions affects the entire mineral processing chain. An online rheometer was designed and implemented with the support of SMI-Ice Chile and CRHIAM. 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. A contract for services is close to being signed with CODELCO DIVISION ANDINA and other divisions of CODELCO. For this company, the technology is critical to improving productivity and reducing. Also, operational control of hydrocyclones is ongoing to optimize the hydrocyclone's operation by correlating the hydrocyclone mechanical vibrations with the flow pattern (roping, spray, semi-roping) in the underflow stream (Daza *et al.,* 2020).

d) Mathematical modeling in mineral processing

The decline of ore grades is directly proportional to the water needed in the mineral processing plants, so 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 hetero coagulation between phyllosilicates and copper/molybdenum sulfides, lowering recoveries and changing pulp rheology (Uribe *et al.,* 2017). Simulation models will be validated

experimentally and be mathematically robust (Bürger *et al.,* 2020a-d). Based on the experience with related models for the continuous sedimentation of solid-liquid suspensions, a spatially one-dimensional model of the hydrodynamics of a flotation column was devised, which is expected to lead to new control systems to reduce water consumption in the flotation columns (Bürger *et al.*, 2018; Bürger *et al.,* 2019; Bürger *et al.*, 2020a,b). The team has made progress in the mathematical modeling of the froth flotation model with drainage that explains how the solid volume fractions in a column of aggregate and tailings evolve over time and space. The ANID granted the Anillo project ACT210030A.

Additionally, a bubble-conditioning reactor is being developed to improve the conditioning of reagents used in copper and molybdenum mineral flotation. Previous results showed that this technology increases the recovery of copper and molybdenum by over 5% and 10%, respectively. It also enhances the quality of the water, which is then reused in the processes that use conventional water and seawater.

e) Mechanical operations in the mining process

In later stages, particle size reduction operations can be improved to reduce water and energy consumption. We have studied the comminution process in several stages during mining: the secondary fragmentation process in the block caving method and fragmentation in the primary and secondary crusher and validated through suitable experiments (Gomez *et al.*, 2021; Moncada *et al.*, 2021; Castro *et al.*, 2022). Regarding Solid-liquid separation and water recovery, the design of ultraflocculator reactors to flocculate fine particles and clays has shown promising results (Betancourt *et al.,* 2020). Additionally, instruments are being developed to determine settling parameters. The effect of air temperature on filtration dewatering performance is also under consideration (Concha *et al.*, 2021). Fragmentation is a crucial aspect of cave mining and crushing, as it involves the dry comminution operations that significantly influence subsequent wet milling, classification, and concentration processes. This is because it determines the particle size distribution of the feed mineral. The Block Caving Comminution Model is designed to replicate the fragmentation mechanics between particles that are underdrawn and vertical loads in a drawing column (as described by Moncada *et al.*, in 2021). In grinding/classification, we explored small hydrocyclones for removing ultra-fine particles from clarified water in mineral processing (Vega *et al.*, in progress). The use of small hydrocyclones (e.g., 10 mm in diameter) for separating particles in the micron range is of growing interest in industry because of the cut sizes these devices can achieve. Also, we addressed the online, operational control of hydro cyclones by correlating mechanical vibrations with the flow pattern (roping, spray, semi-roping) in the underflow stream (Daza *et al.*, 2020). The online operational control of hydrocyclones is expected to help optimize their operation and thereby reduce water consumption in the concentrator plants. The team seeks funding to test this idea in a Chilean concentrator.

f) Seawater to process copper/molybdenum ores by flotation. Seawater to process copper/molybdenum ores by flotation

Seawater has some limitations when used in flotation plants. Firstly, it is a buffer solution that increases lime consumption and operation costs. Secondly, seawater contains various ions, such as Na^+, K^+, Mg_2^+, Ca_2^+, SO_4^{2}, and Cl, which can cause hetero coagulation between phyllosilicates and copper/molybdenum sulfides. This can lead to lower recoveries. (Uribe *et al.*, 2017). Researchers are currently exploring the development of improved reagents for optimizing the flotation process in seawater, with the aim of enhancing its use in mineral processing plants. This topic has been discussed in recent studies by Ramirez *et al.* (2020a, b), Gutierrez *et al.* (2020), Maldonado *et al.,* (2020), and Yepsen and Gutierrez (2020). In 2019, we conducted several studies. Firstly, we investigated the impact of various reagents, including flocculant r, dispersants, and hemicellulose, on the flotation of copper and molybdenite minerals. Secondly, we studied the effect of microbubbles on the flotation of clay minerals. Thirdly, we looked into the floating mechanism of enargite, which can remove the arsenic present in copper concentrate. Finally, we examined the effect of degradation products of anionic-polyacrylamide and their synergy with different metal ions on the flotation of molybdenite and chalcopyrite.

RL1 researchers have increased collaboration with the private sector in the field of scientific interaction and synergies. This collaboration is mainly achieved through the Consorcio Tecnológico del Agua (CoTH2O, https://www.coth2o.cl/), which aims to address agricultural, industrial, and mining water-related challenges and problems by linking the Center's capabilities with the private sector. The main collaboration lines are plot-scale technologies for water efficiency and water resources data management for an integrated cyber-structure. On the other hand, mining has been working in an online rheometer designed and implemented with the support of SMI-ICE Chile and CRHIAM (patent 2017 CL01274-2017). 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 (RL2) is being examined (Ramirez *et al.*, 2020a,b). A patent on this topic was filed at INAPI at the end of 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 fundamental and practical perspectives (Ramirez *et al.,* 2020a, b; Gutierrez *et al.*, 2020; Maldonado *et al.*, 2020; Yepsen and Gutierrez, 2020; patent 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").

4.2 RL2 New water sources for agriculture, mining and communities

a) Quantitative methodology based on molecular modeling tools for the design of flotation, flocculation, and anti-scale reagents to optimize water consumption

Between 2013 and 2018, we developed a quantitative methodology using ab initio calculations and molecular dynamics simulations to design flotation, flocculation, and anti-scale reagents. This methodology aims to optimize water consumption in the mining industry, particularly in regions where water scarcity is a concern. This optimization is vital for the sustainability of the mining industry (Quezada *et al.,* 2017, 2018). The methodology was consolidated between 2019 and 2023. Multiple applications were developed, many using raw or partially desalinated seawater for metallic (copper, molybdenum, pyrite, clays) and non-metallic mining (lithium, clays) (Quezada *et al.,* 2019a-b, 2020a-b, 2021a-d, 2022a-d, 2023a-b; Krishna *et al.,* 2021; Alvarado *et al.,* 2022, 2023, Retamal *et al.*, 2024). Some of the findings are operating in the field, additives for potassium and lithium flotation from brines, and spodumene flotation from rock ore. The methodology and results have been extensively discussed in conferences and workshops.

This report highlights the collaborative work between the RL2 team and other teams, such as RL3, RL4, and RL5 that are closer to agriculture and socio-environmental care. This collaboration aims to use molecular-computational methodology to search for clays that can adsorb phosphorus and nitrogen in large bodies of water. The methodology involves spraying simple clays on the body surface. Clays are preferred because they are non-toxic, and only local soils pose less ecological risk. Moreover, clays are available almost everywhere, making them easy to use. The results show the adsorptive capacity of kaolinite is ca. 25 mmol phosphate per kg of kaolinite, which compares well with the few available experimental results (average of 50 mmol phosphate per kg of kaolinite) and increases with salt concentration (García *et al.*, 2021). An extension to phosphorus control with clays in salty water is well-advanced and interesting in salmon farming (García *et al.,* 2023). García (2024), in her doctoral thesis, is working on the experimental portion. An ambitious plan for 2024 is to migrate from the lab to a pilot plant. The methodology has also elucidated the mechanisms and extension of salt adsorption (NaCl) on kaolinite. We look with great interest at the possibility of filtering the irrigation water of valuable agricultural products in clay filters to control water salinity. We hope a related article will be published in 2024 (Quezada *et al.*, 2024). These new results prompted the development of a low-cost methodology for field application based on a clay filter (Arumí *et al.*, 2023). In a recent investigation, Arumí *et al.,* (2023) studied the water quality in the Maule Region, detecting sodium levels that exceed the maximum allowed in Chilean Standard 1,333, which regulates water quality requirements for irrigation. However, they did not find agricultural problems related to salinity in that Region because traditional sand filters effectively reduce sodium content from 15% to 30%. In the remainder of 2023 and 2024, the reality of salinity in other regions of the country and the possibility of implementing clay filters will be studied.

As water scarcity and stress continue to increase, the need to replace freshwater with water of varying degrees of salinity is becoming more prevalent. Two options to address this issue are desalination or adapting processes to better handle salinity levels. Unfortunately, avoiding fouling is unlikely, so the main priority is to maintain some level of control over the process. 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 the molecular-computational methodology. 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) as sodium polyacrylate salts (PAAS). A fundamental advance in nucleation, crystal growth, and interfacial properties in this period was made based on calculations of molecular dynamics (Rozas *et al.*, 2021, 2023). Research led by RL2 in collaboration.

In addition to the molecular-computational method, there is another method called macroscopic, which uses parameters that have physical meaning. This method involves using improved population balances to quickly analyze the effects of salts in water of low metallurgical quality in different mining processes. Over the last ten years, we have continuously improved this methodology, and in recent years, references from Quezada *et al.*, 2020c-e have been included.

In second execution period, experimental work was also carried out that was valuable in itself but also very useful for calibrating the models used. Here are just a few references: Saldaña *et al.*, 2019; Jeldres *et al.*, 2020; Nieto *et al.*, 2023, 2024; Castellón *et al.,* 2024.

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

The mining industry is facing a complex challenge due to the water crisis. More than simply replacing freshwater with seawater is required. Before that, the industry must optimize its water usage and recycle as much water as possible. This demands an optimization of the operation of the industry concerning water use, particularly in the stages that consume the most water, such as foam flotation. In order to achieve this, the stability of bubbles has been analyzed to discover conditions that will minimize coalescence. By applying this knowledge to flotation, the industry can save water or increase production with the same water consumption. The coalescence of air bubbles in a liquid phase deteriorates the efficiency of several industrial processes, such as froth 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—a gas neck forms between the coalescing bubbles. The resulting bubble's surface area and curvature decrease as the neck expands. Most studies focus on the coalescence of two bubbles

without interactions with many bubbles as in a typical process (see Contreras 2022 for a review). We have created a machine vision system to track individual bubbles in a bubbling solution containing foaming agents, salts, and small particles. The system uses a slow-motion recording system, capturing 480 frames per second. The collected images are analyzed using particle recognition techniques. The algorithms help track bubbles and identify coalescence events, allowing us to monitor bubble positions and velocities and collect data on bubble burst and coalescence frequencies and their area, perimeter, and shape factors. In addition to these properties, the critical information, which is the time that two bubbles remain together before merging, which we call the actual coalescence time, was also determined.

We want to share this information and the machine vision system to benefit flotation processes using fresh, salt, or seawater in mining and other applications. The results of the system's analysis indicate that the dynamic effects and multiple interactions among bubbles in a swarm result in much lower coalescence times compared to static experiments involving just two bubbles. This suggests that flotation conditions should be re-evaluated, primarily if they are based on static times, as non-optimal conditions can limit process efficiency and lead to water misuse.

Impact: The machine vision system developed, and the results obtained should help find the best additives and dosages to get the best product efficiencies with the right amount of water in times of critical shortages. In 2023, the system evolved into an application, CoalesceVision (Intellectual Property Rights in progress) (Solar *et al.,* 2023a), an advanced bubble monitoring and analysis application designed to detect and quantify coalescence events in bubble populations.

Utilizing OpenCV and developed in Python, this tool can detect and track individual bubbles in slow-motion videos. It also includes specially designed algorithms for coalescence analysis, providing an efficient and accurate solution for studying bubble populations. It is worth noting that all these advancements have been made through the efforts of undergraduate students in their theses (Lagos 2023, the effect of salts and mineral particles; Rojas, 2023, the impact of hypersalinity; Salazar 2024, the impact of clays; Godoy 2023, the impact of microplastics; and ongoing Grgurina 2024) (Before Solar, 2021; Ulloa, 2022). The main results and the application have been presented at international conferences (Solar *et al.,* 2023; Lagos *et al.,* 2023). Intellectual Property Rights are in progress (Solar *et al.,* 2024). BHP's Minera La Escondida recently showed interest in extending the application to a different function, automating the common practice of evaluating flotation through the characteristics of the foam, for which we are advancing in an exploratory stage (Echeverría, 2024). Research lines involved in the all execution period of CRHIAM are RL1 and RL2.

c) Dry mining… just a naive dream?

In 2013, we started talking about dry mining with the late Fernando Concha and others; we dared to present a project to CORFO that was flatly rejected. On August 24, 2022, in Santiago de Chile, the initiatives for sustainable mining were defined with the participation of all the actors, including government, mining companies, sanitation companies, universities, and technology centers. One of the initiatives is dry mining. Fortunately, we continue to work on this line, particularly in fluidization in air, on two fronts: experimental and simulation. Initially, we began developing a mathematical method based on Smoothed-Particle Hydrodynamics (SPH). This computational method simulates the mechanics of continuum media, like solid mechanics and fluid flows. It was first developed for astrophysical problems, but we used it to create a simulation. The Finite Particle Method is considered the most advanced form of SPH to date. In 2021, we developed two methods: the Decoupled Finite Particle Method (DFPM) and the Semi-Decoupled Finite Particle Method (SDFPM). Both approximations of FPM, in which the correction matrices are simplified by neglecting non-diagonal terms, effectively decouple corrected value calculations for the field variable and its derivatives along each direction (Achim *et al.*, 2021). This method has the advantage of simplifying the corrections and extending to 3D. It simultaneously avoids the problem of ill-conditioned matrices that can occur in the case of free surfaces (Achim, 2022). More recently, in the experimental part, we have built a fluidization column that separates particles by size. Adjusting conditions, we managed to separate three groups of particles of different sizes (Hermosilla, 2022). Research lines involved RL2.

4.3 RL3. Water availability and quality for agriculture and mining amid Climate Change

a) Mountain hydrology

At the Central Chile headwaters, we have been developing research finding that groundwater storage and release processes play a significant role in base flow generation at the headwaters of rivers that have a small glacial and snowmelt-runoff contribution (Markovich *et al.,* 2019; Parra *et al.*, 2020; Arumi *et al.*, 2021). The lower part of the basins is dominated by the Coastal Mountains' headwater, which possesses a different hydrogeological system from the upper Andean Headwater. Heavily eroded granitic soils are dominant in that area, limiting groundwater recharge and limiting available groundwater in this area (Steward *et al.,* 2016).

Concrete progress has been made in the study of how changes in land use and wildfires affect the water levels in south-central Chile. The study mainly focuses on the impact of these changes on the generation of base and summer flows in forest basins with varying vegetation cover types in the Chilean forest macro-zone, which is situated between the Maule and Los Ríos Regions. In the first approach (Balocchi *et al.,*

2021), the generation of recessive flows was studied in eight small forest basins in central-southern Chile, comparing the effect of different coverage on these flows in a latitudinal gradient, including morphometric variables. In a second approach (Balocchi *et al.*, 2022), the effect of the 2017 mega fire was studied in three micro basins in central Chile through hydrological metrics such as the runoff coefficient and the base flow index, and measurements of the Tritium isotope in the flow.

We work on evaluating the flood risk after climate change in Concepción (Schoener *et al.*, 2022). That article gives the basis of a CRHIAM Policy Brief that alerts how the megadrought hides the risk of flooding (Arumi *et al.*, 2023), published months before the floods that affected Chile in June and August of 2023. On the same topic, Portuguez *et al.,* (2023) published an analysis of flood risk in Peru as part of their doctoral thesis.

Regarding the management uncertainty associated with scarce data, we developed tools using artificial intelligence to study and complete precipitation data series Portuguez-Martua *et al.,* (2022 and 2023). As a result of long-time cooperation with the IAEA, two articles were published in 2020 related to the use of isotopes techniques in mining operations studies (Wolkersdorfer *et al.*, 2020) and on the groundwater impact produced by agriculture (Arumi *et al.,* 2020).

We conducted research on the Laja and Biobío watersheds by analyzing streamflow data and using modeling techniques. This research was carried out by Arumi *et al.* in 2012. We have also worked on hydrological modeling of the Laja River through several theses developed at the Universidad de Concepción and the University of Leibniz Hannover, as outlined in the work done by Muñoz *et al.,* in 2019.

b) Groundwater recharge

At arid zones, we study the contribution of the mountain to groundwater recharge, finding that recharge is mainly produced in wet years, as evapotranspiration demands limited recharge in dry years, and identifying thresholds of annual precipitation that result in adequate recharge (Oyarzún *et al.*, 2017; Sandoval *et al.,* 2018; Oyarzún *et al.*, 2019). Groundwater discharge also controls water chemistry, as shown in the Elqui River, and simple approaches for the estimation of water constituents' behavior in river confluence zones and dispersion and transport through mountain rivers have been assessed (Rossi *et al.*, 2021; Castillo *et al.*, 2021).

Groundwater-dependent ecosystems like wetlands and springs are valued by society (Arumi *et al.,* 2020). However, they are also vulnerable to wrong management practices, soil use change, and climate change (Duhalde *et al.*, 2018). We presented evidence of the vulnerability of mountain groundwater systems to pollution caused by the increase in second homes in tourist areas. (Duhalde *et al.*, 2018; Arumi *et al.,* 2019). In addition, we published results regarding how different ecosystems depend on groundwater using water

balance (Ivelic *et al.,* 2021), environmental tracers' techniques (Arriagada *et al.*, 2019), and remote sensing (Duran-Llancel *et al.,* 2020 and 2021). We study the contribution of irrigation practices and canal seepage to groundwater recharge environmental tracers (Arumí *et al.*, 2020), and we advance the understanding of the contribution of groundwater to river streamflow by the analysis of streamflow recession data (Parra *et al.*, 2019a; Parra *et al.*, 2019b; Paez *et al.,* 2022; Parra *et al.,* 2023).

Artificial groundwater recharge (AGR) has been an issue of public attention in Chile due to the extended drought affecting this country. However, significant advances in AGR implementation in Chile have yet to be made. We have been working with different Water user organizations in Chile: Copiapo, Longavi, Ñuble, Diguillin, Itata, Laja, and Biobío groundwater communities or river boards. Various challenges and progress have been highlighted in relation to the integration of surface and groundwater management (Melo and Arumi, 2021). Based on this, it is possible to identify gaps in the implementation of AGR in Chile, which can be addressed by adopting a multidisciplinary approach encompassing various viewpoints such as hydrogeology, water resources engineering, law, environment, and social aspects. For the successful implementation of Agricultural Groundwater Recharge (AGR) as a watershed management practice in Chile, it is essential to have effective coordination between the Water Users Organizations (WUOs) that manage the surface water required for recharge and the WUOs that manage the recharge volume at the aquifers. However, the lack of such coordination is currently the most significant challenge in implementing AGR in Chile, as noted by Delgado and Arumi in their 2021 study.

c) Lakes: Water quality lakes

The lakes are critical resources for the country's water supply and food security. Therefore, the characteristics of lake ecosystems should be considered essential climatic variables for characterizing the Earth's climate. Lakes are changing rapidly in response to climate change and have been affected by natural and anthropogenic forces in recent decades. The climate amplifies threats to lakes, magnifying the effect of environmental stressors such as eutrophication, transboundary pollution, and the spread of invasive species (Fagel *et al.*, 2022; Montes *et al.,* 2021). In this sense, it is imperative to have instruments that protect these aquatic ecosystems before they begin to be affected by the increase in productive activities (agriculture, tourism, among others) associated with the displacement of agricultural activities towards the lacustrine zone of southern Chile.

Access to information about past environmental and climatic conditions is crucial for making accurate predictions about global changes in the future. However, in Chile, there is a lack of detailed information about past climate beyond what has been recorded through instruments. This is due to the challenges involved in characterizing and quantifying the variability of different climatic components with high resolution. Paleoclimate studies in South America have become highly relevant due to the scarcity of long-

term information available to generate robust climate projections at a regional scale and the importance of forcing (e.g., westerlies) and climatic phenomena (e.g., ENSO, PDO) that can affect even on a global scale. Thus, the information obtained from the lacustrine sedimentary records contributes to understanding these phenomena and characterizing past climatic conditions that, in a long-term context, contribute to the knowledge of current global changes. We have achieved significant results in the reconstruction of high-resolution climatic and environmental changes using lacustrine sediments (Rodriguez *et al.,* 2022; Fagel *et al.,* 2021; Molenaar *et al.,* 2021; Fagel *et al.*, 2023).

Eutrophication represents the natural aging process of lakes because of the gradual accumulation of nutrients, an increase in biological productivity, and the gradual deposition of sediments from their drainage basin. Under natural conditions, the eutrophication process is slow, and rates of change commonly occur on a timescale of millennia. However, due to anthropic causes related to land use change, the increase in erosion and the discharge of domestic sewage, among others, is accelerated on a temporary scale of decades or less (Aguilera *et al.*, 2023).

In Chile, between the Araucanía and Los Lagos regions, there is an essential district of lake ecosystems known as the Nord-Patagonic or Araucanos lakes. This group of lakes is located between 39° S and 41°S of latitude in the Andean and pre-Andean zones, at altitudes from 115 to 580 meters above sea level. These lakes are characterized by glacial origin, deep, very transparent, and ultra-oligotrophic. The ultra-oligotrophic condition of these lakes lies mainly in low rates of primary productivity, which are determined by the low inputs of inorganic nutrients (mainly nitrogen and phosphorus) that come from external natural sources. In order to maintain the trophic condition and preserve the ecosystem services provided by the Nord-Patagonian lakes, different projects are being carried out for the elaboration of Secondary Environmental Quality Standards (NSCA).

We improve the determination of water quality parameters of lakes based on the processing of satellite images as support for the spatial and temporal evaluation and monitoring of ecosystems (Aranda et al., 2021), and we get some initial results that focus on developing models to detect and quantify algal blooms in Araucanian lakes. (Rodriguez *et al.,* 2021; Rodriguez *et al.*, 2022; Barraza *et al.*, 2022; Rodriguez *et al.,* 2023a; Rodriguez *et al.,* 2023b).

Efforts are being made to reuse industrial cellulose effluents for agricultural irrigation. Wheat crops have been irrigated with treated cellulose effluent this year, and the impact of prolonged irrigation on soil, water, and plants is being assessed for a period of four months. The results of this study are expected to be available by the end of the year. In addition, two undergraduate theses and one master's thesis are being developed on this topic.

4.4 RL4. Technology for water treatment and environmental remediation

The main forces driving this line of research to connect "water and environment" and technology are: a) Circular economy from recovery to reuse, b) Technologies: wastewater treatment by conventional and non-conventional technologies and advanced membrane process for water treatment/reclamation, c) the impact of reuse of water in people health, d) Nanotechnology for recovery of water for mining and agriculture and other applications, e) Sustainable management of the rhizosphere for soil-water remediation and f) Pesticides in the environment and mitigation technology.

a) Circular economy: from recovery to reuse

Within the circular economy framework, RL4 is working on optimizing the recovery of organic matter from wastewater to recover biogas and improve the energy balance of wastewater treatment plants (WWTPs), thereby converting them into power-generating plants (Barboza, 2022). The recovery of resources from wastewater is a crucial aspect during its treatment; however, the use of the sludge generated as bio-fertilizer is often limited by the presence of pathogens (Vidal *et al.,* 2022a). Thus, two economic methods have been studied to remove pathogens present in sludge. These methods are based on the application of free ammonium (NH_3) and nitrous acid (HNO_2) that could be generated in the WWTP sludge line itself (Morhell, 2023; Martínez, 2023). WWTP energy efficiency is another crucial aspect of wastewater treatment due to its impact on operating costs and the associated greenhouse gas emissions. Applying partial nitrification and anammox processes to remove nitrogen in the WWTP mainstream would increase energy efficiency compared to conventional nitrification and denitrification processes (Pedrouso *et al.,* 2023). In addition, Da Silva *et al.,* (2022) developed a model to predict methane production from any waste. Meanwhile, wastewater reuse is an essential strategy for confronting water scarcity. However, removing organic micropollutants remains a significant challenge for reuse technologies. Identifying and optimizing the operational conditions necessary to provide efficient, safe, and consistent removal, both in terms of the presence of the contaminants mentioned above and challenges such as antibiotic-resistant microorganisms, is emphasized (Riquelme *et al.,* 2022). Moreover, this practice may contribute to disseminating antibiotic resistance genes to the environment, a matter of global concern. Leiva *et al.,* (2022) studied the reuse of treated wastewater in agriculture from the perspective of the risks associated with ARG dissemination. To evaluate the impact of the circular economy on ecosystems considering their life cycle, we have worked hard using the life cycle assessment tool and its application for the sustainable management of water resources (Vidal *et al.,* 2022).

b) Technologies

Wastewater treatment by conventional and non-conventional technologies and advanced membrane processes for water treatment/reclamation. Conventional wastewater treatment for the minimization of sludge production during wastewater treatment is essential because sludge management is one of the most critical issues in WWTP operation, accounting for 25% to 65% of overall operating costs. In Chile, as in many Latin American countries, about 80% of cities are smaller than 24,000 population equivalents, and consequently, the number of WWTPs without anaerobic sludge digesters is significant. Therefore, other in situ sludge reduction technologies that could be applied in small WWTPs are gaining attention. Ozonation technology that reduces sludge production is considered during the design of small WWTPs, which would significantly decrease overall wastewater treatment costs (Crutchik *et al.,* 2022). Meanwhile, the fluidized bed reactor has the highest treatment capacity for nitrogen removal. This conventional technology is the key that, in the future, will allow groundwater treatment systems to be implemented at full scale to remove nitrate from Chilean groundwater (Franchi *et al.,* 2022).

Non-conventional technologies: Non-conventional technologies: Green technologies or nature-based solutions (NbS) for wastewater treatment in rural communities. Four non-conventional technologies can be used for rural wastewater treatment:

- Constructed wetlands with different cultures can help remove organic matter and partial nutrients. The behavior of phosphorus uptake was higher for a polyculture planted with ornamentals (Carrillo *et al.,* 2022). A lifecycle analysis tool compared a polyculture system planted with ornamental species (*C. papyrus* and *Z. aethiopica*) with monoculture systems planted with different species (*P. australis, S. californicus* and *C. papyrus*). To the best of the knowledge, there have been no environmental studies of constructed wetlands planted with polycultures of this combination of species and their seasonality. The environmental impact index, based on eutrophication reduction (kgP removed), and net environmental benefit indicators were also calculated. There was an environmental benefit for freshwater eutrophication and a negative benefit for global warming. The environmental impact index indicator was inversely proportional to phosphorus elimination, with the CW polyculture reaching the highest values of 3399 kgCO2eq/kgP removed in the warm season (Carrillo *et al.*, 2023). Besides that, the evaluation of organic compounds and antibiotic-resistance bacteria behavior in treated greywater by a constructed wetland and the antibiotic resistance gene behavior in constructed wetlands treating sewage were made (Monsalves *et al.*, 2022 and 2023).

- Algal-bacterial consortia is an alternative solution for treating wastewater in rural areas. This method is effective in providing sanitation for small communities. The process involves achieving high removal rates of ammoniacal nitrogen and organic matter without the need for external aeration, with a hydraulic

retention time of 34 days. Additionally, the algal biomass produced during the process can be used for nutrient recovery, among other benefits. This technology can also be coupled with advanced membrane processes for water treatment and reclamation. Over the last few years, research has been conducted on developing forward osmosis as an alternative for high-quality water reclamation from wastewater of different origins. During the reported period, a study was published on the membrane concentration of sewage as a tool for resource recovery and sanitation improvement (Ortega-Bravo *et al.*, 2022).

- Vermifilters are a technology commonly installed in rural areas to treat domestic wastewater. A study compared the performance of a full-scale verifier for sewage treatment in removing organic matter, nutrients, and antibiotic-resistant bacteria to conventional technology regarding organic matter and nutrients. However, it was found that a disinfection technology was necessary to achieve optimal results (Gutierrez *et al.,* 2023a and 2023b). Seasonality is an influential variable for organic matter and nutrient removal. In addition, the molecular weight distribution shows that the verifier does not generate a considerable change in the distribution of organic matter (COD and Total Organic Carbon (TOC)) and NH_4^+-N. All this work is being carried out under a work agreement with the municipality of Florida in the Biobío Region.

- Advanced membrane process for water treatment/reclamation. Over the last few years, research has been conducted on developing forward osmosis as an alternative for high-quality water reclamation from wastewater of different origins. During the reported period, a study was published on the membrane concentration of sewage as a tool for resource recovery and sanitation improvement (Ortega-Bravo *et al.*, 2022).

c) The impact of reuse of wastewater treated in the ecosystem and public health

The microbiology of treated wastewater was also studied. Specifically, microorganisms that cause intestinal disease in effluents from rural sewage treatment plants were studied by Pilar Suazo in her PhD dissertation (Suazo *et al.,* 2023 and 2024). In this context, The UV disinfection system is a cost-effective and easy-to-maintain solution for decentralized areas. However, it is crucial to remove suspended solids from the influent before it enters the UV reactor. This is necessary due to the problems that can occur with UV disinfection when there are high levels of suspended solids, such as reduced transmittance. Zeta potential provides information on the particles' surface charge distribution at the solid/water interface. Aggregation will likely occur at 0 - 5 mV values because of a low energy barrier, affecting the final disinfection. The particular interest of this study is the emphasis on the reactivation of microorganisms (Gonzalez *et al.*, 2023). Finally, Matus *et al.,* (2023) demonstrate a perfect update and compilation regarding "water, ecosystems, and public health" in Chile.

d) Nanotechnology is used to recover water for mining, agriculture, and other applications

The investigation group has developed biogenic synthesis and production of metallic nanoparticles, and the results obtained from the research have shown the great potential of these biogenic nanoparticles, which were synthesized through biological processes that do not generate contaminants in the environment (FONDECYT 1191089). Therefore, the production and application of biogenic nanoparticles contribute to developing new technologies to increase the country's productivity. Nanoparticles have been used in different areas of research, such as their use in agriculture (ANID-FAPESP 2018/08194-2, Parada *et al*., 2022; Doctoral Thesis of D. Martínez; FONDECYT Postdoctorado 3200963, FONDECYT Postdoctorado 3180279), water treatments (Hermosilla *et al*., 2022; Doctoral Thesis of W. Herrera), medicine (Cisternas *et al.,* 2022; Hermosilla *et al.,* 2022; Doctoral Thesis of C. Cisternas), enhancing biological processes (Hoffmann *et al.*, 2022; Doctoral Thesis of N. Hoffmann), and obtaining value-added products (Fondecyt de Postdoctorado 3190922; Doctoral Thesis of J. Vera).

e) Sustainable management of rhizosphere for soil-water remediation

The research within RL4 has allowed us to obtain several soil microorganisms with potential for use as inoculants under drought conditions. These organisms have been isolated from diverse elevation belts in the Tarapacá Region, the central zone (Valparaíso Region), La Araucanía Region, and Antartica (projects FONDECYT Regular 1210964, InES19-FRO19001, INACH RT_16-20), and have allowed accounting with a battery of strains that are also being used within the activities corresponding to CRHIAM and ANID FSEQ210002. On the other hand, a pilot system has been established for the reuse of salinized water by plants inoculated with mycorrhizal fungi in NFT hydroponic systems (FONDECYT Postdoctorate 3210588) and to corroborate the effect of positive stress at low saline concentrations in lettuce plants (Santander *et al.,* 2022). These investigations have allowed the completion of the doctoral thesis of R. Pérez (Pérez *et al.,* 2021) and the incorporation of two new doctoral students (U. Pérez and F González) into the line research. The results have demonstrated the ability of AM fungi to modify the metabolic profiles of colonized plants (Nahuelcura *et al.*, 2021; Tereucán *et al.,* 2022; Alarcón *et al.,* 2022; Fritz *et al.*, 2022), the use of microalgae extracts (*Nostoc sp.*) as biostimulants of lettuce plants (Silambarasan *et al.,* 2021), the degradation of organic contaminants by bacterial isolates (Silambarasan *et al*., 2022a), the increase in aluminum tolerance by actinobacteria (Silambarasan *et al.*, 2022b), the optimization of cadmium phytoextraction processes with inoculation of sorghum plants with actinobacteria (Silambarasan *et al.*, 2022c), and even international cooperation developing a review theme on the role of beneficial microorganisms in coffee cultivation (Urgiles *et al.,* 2021).

f) Pesticides in the environment and mitigation technology

Research in biopurification technology has made it possible to mitigate the effect of point-source pesticide contamination. Pesticide-tolerant microorganisms (bacteria and fungi) have been isolated, selected, and identified for their use in the degradation of high concentrations of pesticides (Briceño et al., 2020, undergraduate thesis of Sebastian Rojas). The work provides the basis for implementing a continuous treatment system using free and immobilized bacterial consortium for wastewater containing pesticides mixture (FONDECYT 1161481 and 1211738, Doctoral Thesis of Marcela Levio, Levio *et al.,* 2021a,b,c; Levio *et al.,* 2023). In addition, microorganisms capable of producing biosurfactants that increase the solubility of hydrophobic pesticides for their better degradation in biological beds have been isolated, selected, and identified (FONDECYT 1211728, Lamilla *et al.,* 2021, FONDECYT postdoc 3190918, undergraduate thesis of Cesar Llafquen, Diez *et al.,* 2022, doctoral thesis of Barbara Leiva).

We have identified and characterized the lipopeptide surfactin from Bacillus amyloliquefaciens and demonstrated their capacity for pesticide solubilization (Schalchli *et al.,* 2023). Similarly, we have optimized the production of a rhamnolipid from a Pseudomonas marginalis with the potential for oil removal application (Doctoral thesis of Barbara Leiva, Leiva *et al.,* to be published).

4.5 RL5. Water governance, ecosystem services, and sustainability

In the all execution period of CRHIAM, the RL5 focused on research related to water security and translating this research into action along the different watersheds where investigations are taking place by producing articles, books, and outreach material. The main research topics were water regulation, water conflicts, ecosystem services, desalination, and artificial groundwater recharge.

a) Water regulation

Numerous events took place during the intense lustrum of water regulation in Chile. It all started with the social riots of October 2019, which triggered a four-year discussion about the Chilean constitution, with a significant focus on water management. In the same period, several crucial laws were implemented, such as the new Water Code and the Climate Change Law, both introduced in 2022. Therefore, crucial achievements were several articles and books that contributed to that discussion: Barra *et al.,* (2021) discussed how to improve the regulatory model to promote sustainability and control pollution.

An analysis of different governance approaches under the good enough water governance and meta-governance mode approach was published by Julio *et al.,* (2021, 2022). This analysis involved hierarchical, market, and network governance models. The study concludes that combining the three governance

models, encompassing the OECD water governance dimensions is the best approach to achieving water security and ecosystem service conservation.

We conducted a comparative analysis of water resources management in different countries, as described by Tinoco *et al.,* (2022). Their analysis focused on Mexico, Chile, and Brazil and examined the implementation of Integrated Water Resources Management about Sustainable Development Goal 6.5.1. The study also examined how well these countries aligned with the OECD principles on water governance. These three countries show a low performance on gender, finance, and information for decision-making. At the local scale, several studies were conducted by Quevedo *et al.,* (2022), analyzing water governance analysis based on the wetlands in the metropolitan Concepcion.

The issue of water is recognized as a human right, and the priority given to providing human access to water has been incorporated in the 2022 amendments to the Water Code (Torres and Marin, 2023). These amendments are significant in rural areas that have been affected by forest fires in the Austral summer of 2023. Forest plantations, homogeneous landscapes, and the ongoing drought further aggravate this issue. These two factors are interrelated and require more scientific research to understand the best measures to adapt to these drastic environmental changes in recent years. Environmental protection was another focus of the Chilean water reform, and we contributed with different contributions, such as the analysis of spring protection, where we analyzed four proposed ways of improvement: communal regulatory plans, regional land planning plans, construction permit control, and subdivision permits. (Arumi *et al.,* 2019) In addition, we contributed to promoting the principle "who conserves, charges," and legally consecrates instruments for environmental conservation (Delgado and Arumi, 2021).

b) Water conflicts

The relationships between forestry extractivism and water/cultural sustainability are problematic, particularly in the growing socioenvironmental and territorial conflicts associated with forestry plantations and pulp mills. Along with the megadrought, pines and eucalyptus directly impact the Agua Potable Rural (APR) systems (Rural Drinking Water Systems) because their groundwater sources are desiccated by the extensive geographical areas covered by forestry production. This mainly affects the rural population, particularly peasants and the Mapuche people. The large-scale extraction of water through pines and eucalyptus (Torres *et al.,* 2023) aims to produce timber and feed the cellulose plants in several regions of Chile.

Businesses worldwide are still determining the effects of climate change, which has been causing significant and disruptive changes in the socio-ecological systems in which firms and organizations operate. To address this, Roberto Ponce and his team of researchers conducted a comprehensive evaluation of the intersection

of climate change and organizational literature since the late 20th century, as outlined in the study by Díaz *et al.* (2022). An overview of the results indicated that this field is highly concentrated. For instance, most of the productivity has been concentrated in the last five years, with two regions, Europe and the USA, accounting for more than 65% of the total published papers. The high concentration uncovered here could be explained by climate change being a relatively new field of study within the business, economics, and management categories. At the same time, this feature could provide fertile ground for new research opportunities.

c) Ecosystem services

We advance on assessing the status and trends of biodiversity and ecosystem services, using the different basins as study areas. At the Biobío River basin (one of the largest Mediterranean rivers in South America), we identify the direct drivers of change that alter the functions and capacity to provide ES in the future. A total of 116 indicators were used, identifying 16 services with a high level of impairment. The results indicate that land use change and overexploitation of raw materials are the most critical drivers of change in the transformation of aquatic ecosystems in this territory. This assessment and trends of aquatic ecosystems and the analysis of environmental conflicts related to competing uses allow decision-makers to prioritize specific management processes at the river basin scale and highlight the importance of ecosystem and biodiversity conservation for human well-being (Díaz *et al.,* 2018). In specific studies on pollution and biodiversity protection, the presence of microplastics was analyzed in this same basin, as it is considered one of the most severe environmental pollutants worldwide, potentially affecting biological diversity, ecosystem functioning, and human health. It was found to be present throughout the basin, being significantly higher in the lower part of the basin and related to the size of the human population (Correa-Araneda *et al.,* 2022).

In a recent study, Boyero *et al.,* (2021) discovered a strong correlation between detritivore diversity and plant litter decomposition in streams at a global scale. This study set the basis to demonstrate the importance of riparian plant diversity for leaf litter decomposition in stream ecosystems. Stream ecosystem functioning could be particularly vulnerable to forestry practices (Boyero *et al.*, 2021b).

Other impacts of climate change and human interventions are the possible functional changes from perennial to intermittent rivers, which could impact aquatic biodiversity and human well-being. The 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).

In 2023, a book titled "Water Ecosystems and Public Health" by Matus et al. was published. The book covers various topics related to Chile's water quality, reuse, and emerging water quality issues. It provides specific examples from Chile gathered over ten years of CRHIAM research. The book is interdisciplinary, making it a valuable resource for anyone interested in water ecosystems and public health. The connections between water, human health, and ecosystem health must be better addressed in Chile. This book is a significant step forward in addressing many issues, including improving the regulations to tackle new water problems in Chile. This is a crucial contribution towards raising awareness about the impacts of human activities, such as agriculture and mining, on water quality. The book also highlights opportunities to improve water quality while adapting to the triple environmental crisis.

d) Desalination

At the crossroads: ¿Can desalination be a suitable public policy solution to address water scarcity in Chile's mining zones? One approach to alleviating scarcity is incorporating new water sources into supply systems, including desalinated seawater for industrial and municipal use. In Chile, large volumes of water are used in water-scarce regions where mining occurs, alongside agriculture and small communities. This situation has driven a debate around policies to increase the use of seawater to satisfy the water demand of the mining industry. The appraisal suggests that clear regulations from economic, social, and environmental analysis must be generated to provide legal certainty and reduce risks. Alternative or complementary water supply options should be allowed where mining operations can demonstrate negligible hydrological and social impacts or innovative solutions such as stakeholder water rights swaps and water efficiency technologies. We provide insight that will help drive a better policy-making process to tackle water scarcity in Chile and similar areas of the world.

In the field of Desalination, a paper published by Garcia-Bartolomei et al. (2022) discussed the issue of desalination plant localization along the Chilean coast in the north of the country, concluding that there are not many spaces suitable for developing desalination plants and that several considerations must be taken in to account to decide where to set up a new desalination development, despite the long coast surface area. This study concludes that less than 4% of the coastal surface area in the north and center north of the country may be suitable for setting up desalination plants considering a series of criteria such as distance to potential users, highways, and protected areas.

Research was conducted on creating an integrated model for supplying rural drinking water in coastal areas by using nanofiltration to desalinate seawater. The project examined the use of three pilot desalination plants in the communes of Hualpén and Tirúa (Biobío region) and Quemchi (Los Lagos region). Through participatory methodologies, social surveys, and indigenous consultation in the case of Tirúa's case, a community desalination plant in each commune will be installed, whose main objective is to provide drinking

water to people who live without water. With this, it is expected to continuously supply the communities to achieve the international human right to water and water justice standards.

e) Artificial groundwater recharge

The pressure associated with the drought and the uncertainty caused by climate change has increased the dependency on the intensive use of groundwater. However, the increase in groundwater exploitation in parallel with the decrease in rainfall generates a drastic depletion of groundwater levels, triggering conflicts such as the case of Copiapó and Petorca. Therefore, we seek to advance in groundwater management considering the technical and legal aspects, which are poorly developed in Chile.

Regarding the artificial groundwater recharge, we are collaborating with the Diguillín River Board to supervise a 12-year 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 a water users' organization that can manage the recharge led us to publish two contributions regarding the gaps in the implementation of AGR in Chile (Melo and Arumi, 2021; Delgado and Arumi, 2021). We conclude that Chilean legislation of the year 2006 focused on private use of their water rights to perform artificial groundwater recharge to generate a benefit to the private ones. However, successful international and national experiences suggest that territorial organizations, such as river boards, make groundwater recharge to generate public solutions, mainly to reduce local conflicts. We collaborated with various government bodies to encourage groundwater management through Water Users Organizations (WOUs), which are critical stakeholders in addressing territorial groundwater access. The efforts resulted in modifying Water Law 2022, which incorporated the recommendations. On the other hand, groundwater quality protection is not considered in the Law (Delgado *et al*., 2017; Delgado and Arumi, 2021), and there are many cases where human activities could put in risk drinking water sources because of the lack of adequate regulation (Arumí *et al.,* 2019), an actual Law project is discussed at Chilean parliament based on the recommendations.

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5 WoS PUBLICATIONS INDICATORS:

Product of research work over CRHIAM's execution 10 years

5. WoS PUBLICATIONS INDICATORS: Product of research work over CRHIAM's execution 10 years

A fundamental part of the work carried out by CRHIAM researchers are publications in scientific journals. The publications aim to inform the scientific community, researchers, students, professionals and citizens concerned about the use of water resources in Chile and the world; thanks to the research work carried out at the national level and collaborations with international researchers. Below is the list of publications generated by CRHIAM researchers and their collaboration networks (students, researchers: postdoctoral, national and international) between December 2013 to December 2023.

Summary of WoS Publications in numbers: Scope of 10-years of work

Throughout CRHIAM's 10-year history, its main objective has been to promote cutting-edge research with a global impact that positions it as a center of excellence in water resources. This has been demonstrated through the 719 WoS publications, generated by principal, associates and others (adjuncts) researchers. Throughout the Center´s history, they have managed to consolidate their research work, showing notable growth, equivalent to 45% more WoS publications in the second period compared to the first, see Figure 14. The excellence of their research work is also demonstrated by analyzing the number of WoS publications in the top 10% of impact for the Center's main disciplines, which allows us to know how many of the publications have been in category Q1 and Q2 journals. During the first period of CRHIAM, out of a total of 256 WoS publications, 91% were in the top 10% (categories Q1 and Q2), while of the total of 463 WoS publications during the second period, 95% of them were published in Q1 and Q2 journals. Figure 14 also shows the growth in the average impact of WoS publications in which CRHIAM researchers participated, reaching an average over the 10 years of operation equal to 3.36. Comparing both periods of the Center, it is observed that the average impact of WoS publications in the second period (4.18) exceeded that of the first (2.54) by 39%, demonstrating the consolidation of excellent research work over time. The last two years (years 9 and 10) in no way show a decline in the quality of CRHIAM research; the lower number of publications compared to, for example, year 8 is due to a preference for greater impact, the highest in the entire life of CRHIAM.

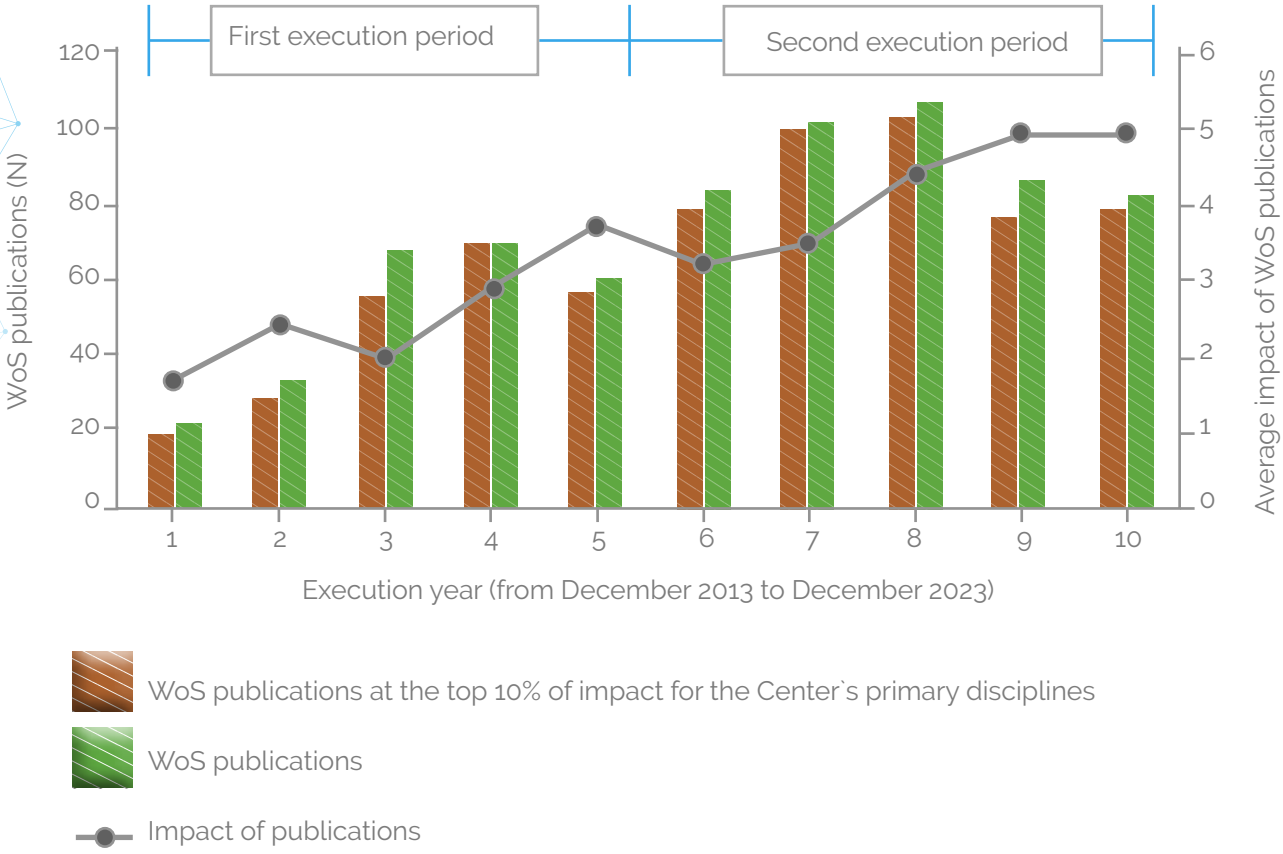

Figure 14. CRHIAM's WoS publications in categories Q1 and Q2 (top 10% of impact), total per year and their average impact during the Center's 10-year execution (from December 2013 to December 2023).

The impact of CRHIAM's research is also reflected in the number of citations to its WoS publications. Comparing this indicator between years 5 and 10, the Center´s annual average number of citations has tripled, reaching a value equivalent to 13.1 by the end of the Center's tenth year of execution (December 2023).

A notable aspect of CRHIAM research is the collaborative work among its members, whether within the same line of research or across multiple areas, with the goal of generating interdisciplinary scientific evidence, integrating different areas of knowledge, and addressing problems comprehensively. Figure 15 shows the number of indexed publications produced by more than one member of the Center. During the first period of operation, 47 publications were published by CRHIAM members, equivalent to 18% of the total publications for the aforementioned period (from December 2013 to October 2018). This percentage increased in the second period (from October 2018 to December 2023); of the total publications in this period (N=463), 24% were produced

through the combined efforts of Center researchers. In summary, of the total of 719 publications generated by CRHIAM researchers during its 10 years of operation, 22% were co-authored by Center researchers. The total number of WoS publications (from December 2013 to December 2023) among CRHIAM members exceeds by eight articles the expected cumulative value (N=149) for the Center's 10 years of operation. The curve in Figure 15 shows the consistent work of CRHIAM researchers to promote associated and interdisciplinary water-related research. Figure 15 shows that the work of CRHIAM researchers within CRHIAM is growing steadily, which is remarkable given their diverse backgrounds. The figure shows that collaboration within CRHIAM is a generality rather than an exception.

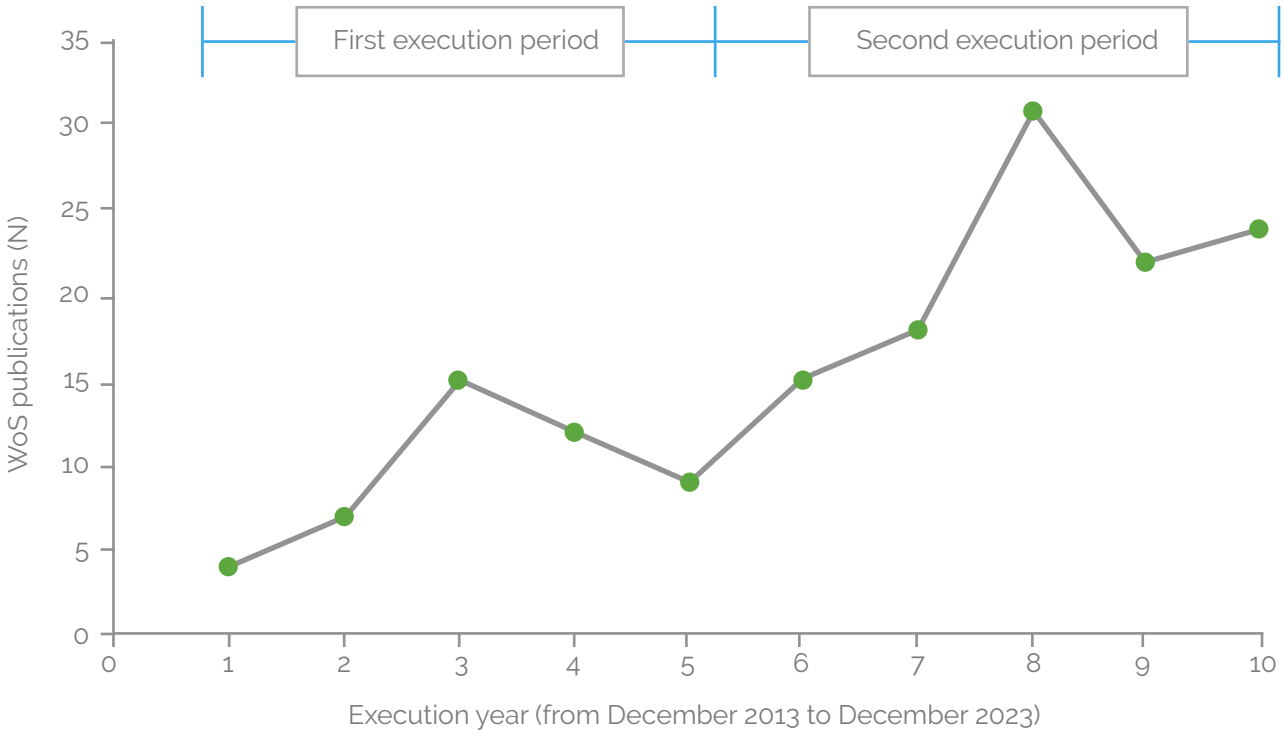

Figure 15. CRHIAM's WoS publications generated among Center members during the 10-year period (from December 2013 to December 2023).

Furthermore, CRHIAM has consistently worked to promote its research work and enhance it through the development of collaborative networks with both international and national research centers. In this regard, the work of all the Center's researchers is noteworthy, as over the course of its 10 years of operation, 411 WoS publications have been published with researchers from international institutions, representing 57% of the total publications during the Center's ten year of operation (from December 2013 to December 2023). Of the total of 411 publications, 44% correspond to the first CRHIAM period and 56% to the second period, reaffirming the commitment of the Center researchers to excellent, collaborative, and interdisciplinary research at the highest standards (see Figure 16). In the last two years, researchers traveled much less, concentrating on preparing the CRHIAM continuity project, which led to a decrease in WoS publications with international researchers.

Figure 16. CRHIAM's WoS joint publications with international institutions and/or research centers (from December 2013 to December 2023).

On the other hand, WoS publications by CRHIAM researchers in collaboration with national institutions or research centers amounted to 205 during the Center's 10 years of operation (from December 2013 to December 2023). Of these, 13% correspond to the Center's first period (from December 2013 to October 2018) and 87% to the second (from October 2018 to December 2023) (see Figure 17). The total number of 205 WoS publications with national institutions or research centers represents 29% of the total publications produced during the Center's 10 years of operation. Of the total of 205 publications, 16% correspond to the first CRHIAM period and 84% to the second period, which highlights the importance for CRHIAM of maximizing effective contact with Chilean institutions that focus on improving water use and finding new water sources.

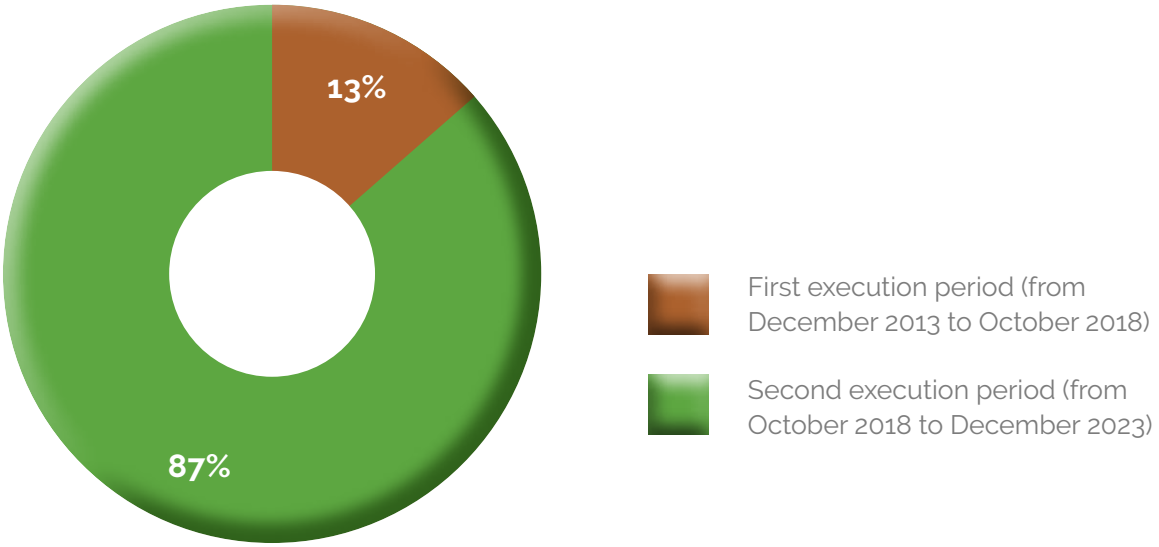

Figure 17. CRHIAM's WoS joint publications with national institutions or research centers (from December 2013 to December 2023).

You can see the list of WoS Publications (10 years) written by CRHIAM researchers in the document:

Annex to the CRHIAM 10 year Report: WoS Publications (from Year 1 to Year 10)

This document is available on the Center's website:

https://www.crhiam.cl/wp-content/uploads/2025/05/Annex_10-years-report.pdf

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6. NETWORKS: A KEY CRHIAM OBJECTIVE

6. NETWORKS: A key objective for CRHIAM

Promoting the international and national collaboration

6.1 International collaboration

The main objective of the Center is to establish a solid national and international network of partnerships. This can be achieved by building bilateral partnerships between individual researchers, which can then be transformed into a more institutional framework. The CRHIAM Center aims to create a network based on its interdisciplinary strengths, which can be helpful in achieving sustainability in various sectors such as industry, government, and civil society. The impact of CRHIAM at the national level is defined as contributing to the excellence of science to achieve water security in different sectors. Furthermore, the Center provides a platform for collaboration between science providers and users to generate innovative and disruptive ideas by combining science, financing, and coworking. Chile faced a severe social, economic, and political crisis during the latter part of 2019, which posed a significant challenge. Moreover, the COVID-19 pandemic has disrupted national and international work. Despite these difficulties, CRHIAM has learned to adapt to this new scenario.

In 2020, international relationships were negatively affected by the pandemic. Traveling and attending international meetings and workshops in person became impossible, which also hindered the research stages of CRHIAM researchers abroad. Despite these challenges, more than 100 research papers were released by the Centre in 2020, and interestingly, a significant proportion of them were co-authored by international researchers.

After the lockdown, we quickly shifted to an online system to maintain our relationships with our international colleagues. Since then, we have adapted to attending and organizing international conferences, webinars, and congresses using the online system. For instance, we attended the Water in Mining Congress in October 2020 (held in Santiago, Chile, from the 14th to the 16th). We organized Brazil's WIPIS 2020 meeting (Interdisciplinary Workshop of Sustainability Indicators). This new approach has helped us to adapt to the new scenario and continue building international relationships.

The challenge to keep international work while the pandemic develops is to make the use of digital transformation tools as a keystone for overcoming this situation. The adaptation process was accelerated by the demand to implement effective communication and work tools through online systems.

The "International CRHIAM webinars" (see in https://www.youtube.com/@crhiam) were also another innovation during the pandemic years; starting in September 2020, we invited our colleagues from the International Scientific Committee to give a live webinar with an average attendance (over 50). In addition, CRHIAM researchers organized at least 11 international events during the first year of the pandemic, 7 of them after declaring the pandemic. Despite the pandemic, the Center showed a great compromise to keep developing international activities alive.

The pandemic challenges highlighted CRHIAM's resilience and researchers' ability to tackle global issues. Maintaining these relationships is crucial going forward.

The national and international actions were not stopped because of established international cooperation initiatives. This fact demonstrated an authentic "culture" for this cooperation at CRHIAM. The pandemic did not impede the further development of new international relationships.

In 2021, CRHIAM continued to promote bidirectional international cooperation even during the pandemic. They achieved this by delivering various training courses. These included: a) teaching water irrigation techniques to teachers at the Bolivian Technological Institute, b) providing technical irrigation courses to students of technical colleges through a joint program between CRHIAM and WorldSkills Chile (https://www.wschile.cl/), and c) organizing a pre-conference course on "Management and technology for water for human use, in agriculture and mining under drought and climate change." This course was part of the Water Congress and was co-organized by CRHIAM and GECAMIN (https://gecamin.com/).

Returning to more typical years, in 2022, the Center offered various webinars and participated in events outside the country, both in person and online. CRHIAM researchers made the following presentations abroad: "Groundwater and the mega-drought in Chile. Gaps for future management in times of change" to students of the Water Management and Sciences degree program at the Autonomous University of Baja California Sur in Mexico (conducted online); the conference presentation "Considerations for the management of treated wastewater for drinking water and agriculture reuse" (conducted online); "Moving from intention to action: Insights on firms' active pro-environmental behavior" (held in Lisbon, Portugal); the seminar presentation "Consolidation of the data processing group for water resources" (held in Madrid, Spain and organized by CRHIAM); the keynote speech "Imaginaries of water in Chile: between the market, the common good, the worldviews of native peoples and the role of universities in search of peace" (given

in Mexico City, Mexico, and organized by CRHIAM); and the launch of the book "Transformations Global Socioecological. Post-pandemic society, climate change, nature, and democracy (held in Mexico City, Mexico, and organized by CRHIAM).

Throughout CRHIAM's history, its researchers have made efforts to generate scientific evidence with international partners. Only in 2022 and of a total of 87 WoS publications, more than 50% (N=46) of them were prepared from joint and direct work with a researcher from a foreign institution. Figure 18 shows that there was direct collaboration by authors from 21 different countries and that they collaborated a total of 72 times, understanding that an author can collaborate on several different publications. This highlights the significant global partnerships established by the Center during its ten-year tenure. Among our top cooperation partners are Spain, Brazil, Australia, Canada, Mexico, Sweden, and Belgium. The above demonstrates the association with international peers, which enhances the level of international cooperation created by CRHIAM researchers.

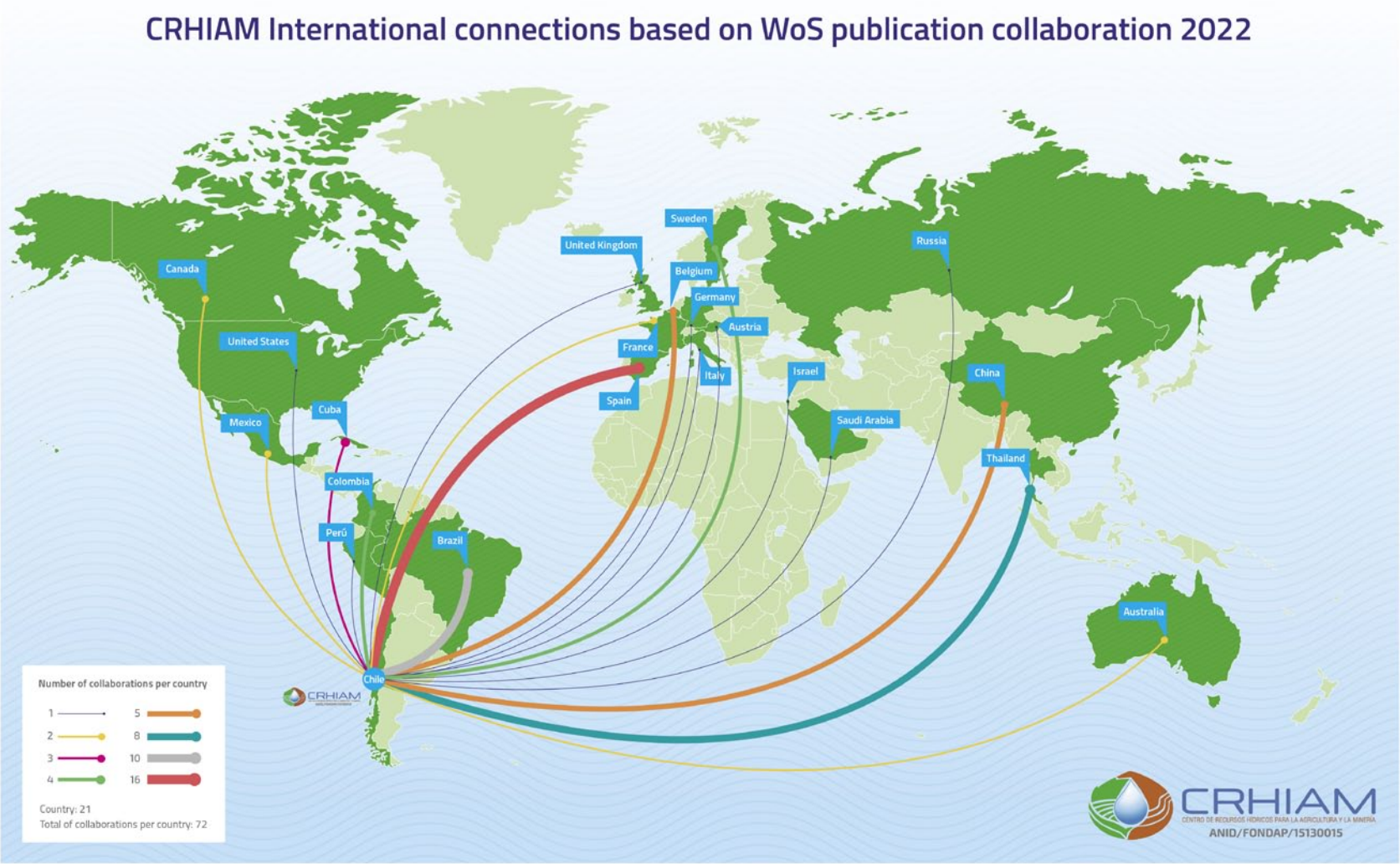

Figure 18. CRHIAM international connections based on 2022 WoS publications collaboration.

In addition, two books co-authored with international researchers were published in 2022, one in life cycle assessment and the other in global socioecological transformations, highlighting the international reputation of CRHIAM researchers in interdisciplinary fields.

In 2023, we returned to in-person activities, keeping an active international agenda that allowed us to return to classical bilateral cooperation with international visitors and develop international workshops, congresses, and courses in the CRHIAM network.

The broad international recognition of CRHIAM is reflected in more than hundred instances of mobility with international partners during these five years, both for stays and to deliver talks in all areas of the Center's research, from materials properties to conferences on global constitutionalism and global commons.
To summarize, the international networks played a crucial role in maintaining the Center's activities during the pandemic. By leveraging technology, the Center could continue conducting research and disseminating information almost as frequently as before. This demonstrated the Center's commitment to this work, a critical factor in ensuring its long-term sustainability.

6.2 National collaboration

At the national level, collaboration with sanitary, agricultural, and mining companies stands out through work on undergraduate and postgraduate theses, professional training, and dissemination instances organized by the Center (Water Forums, book launches, and conversations, among others). In the mining area, the link with Anglo American, the Center of International Excellence Sustainable Minerals Institute (SMI) of The University of Queensland, Codelco, and BHP, among others, stands out. For the agricultural sector, CRHIAM has worked closely with IANSA, fruit companies such as Cope Frut, Carsol, and the Consorcio Tecnológico del Agua (CoTH2O), which promotes and catalyzes the development, scaling, and transfer of solutions and technological innovations that contribute to the reduction of gaps in the efficient and integrated management of water resources. Therefore, in the health sector, CRHIAM has linked up with Essbio, Aguas Andinas, Esval, Aqualia, and Wetsus, among others.

In light of the ongoing water crisis across the country, proper water management has emerged as one of the significant challenges. User organizations (OUA) are non-profit entities governed by the Water Code, which aim to distribute water resources to their users and construct and maintain infrastructure for that purpose. They play a vital role in the region. In this context, CRHIAM has collaborated with the surveillance boards of several rivers, such as the Ñuble River, Huasco River, Aconcagua (first section), Longaví River, and Biobío River, among others, through work tables and training sessions.

Every year, during the first week of October, CRHIAM participates in the Science Festival organized by the Ministry of Science, Technology, Science and Innovation (CTCI). The Center participates in scientific fairs and talks openly to the community. Over the years, the Center has been involved in activities organized in Santiago, Concepción, Chillán, and Los Ángeles, reaching out to hundreds of people nationwide.

On the other hand, the indicators for "dialogue, outreach, and technology transfer" show that, during 2013-2023, CRHIAM published 29 books (see Figure 30) and 91 book chapters (expected value 18). Besides that, the number of outreach articles is 170 (expected value 83).

CRHIAM recognizes the importance of training people in water resources to address issues related to efficient water use. Therefore, from its inception, the Center has provided training opportunities at different levels to promote "open science," which involves sharing academic knowledge with the broader community. For instance, CRHIAM has collaborated with agricultural technical schools affiliated with the National Agricultural Society (SNA) at the school level through its SNA Educa network. Two such schools, the "Liceo Agrícola El Carmen" and the "Liceo Agrícola de Chillán," have participated in training programs with theoretical and practical components. These programs help students apply what they have learned in the classroom to real-life situations.

An excellent illustration of this is implementing a rainwater harvesting system at the "Liceo Agrícola de Chillán." The system enables students to learn about its operation and use it for irrigating native trees. A similar infrastructure was developed at the "Liceo Agrícola El Carmen" to provide agricultural telemetry training to the area's professionals, students, and farmers. It also supports the Center for the Realization of the WorldSkills Chile Olympics, a competition that tests students' middle and higher technical education skills. It is worth noting that 2023 there will be only 800 competitors.

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7. OUTREACH PRODUCTS:

CRHIAM's reach at the local and national level

7. OUTREACH PRODUCTS: CRHIAM's reach at the local and national level

During the second period, CRHIAM followed a communication and outreach strategy aimed at contributing to better water management. The objective was to disseminate scientific evidence that could support public policies related to water security. To achieve this goal, the Center initiated various products and activities. Some of the notable ones include:

7.1 CRHIAM Communication Series

The CRHIAM website publishes interdisciplinary documents aimed at informing public and private decision-makers, as well as the general community. These documents provide the latest studies, knowledge, and experiences to contribute to the water security of ecosystems, communities, and productive sectors. By the end of 2023, the website has 60 documents that cover a wide range of topics, including water footprint, water use in mining, water governance, and food security, among others. Table 3 details the titles of the Communication Series that the different researchers and students of the center have published between 2020-2023. Below the table you will find a link and a QR code, where you can directly access the center's website where all CRHIAM Communication Series are available (free to download).

Table 3. CRHIAM Communication Series published by the Center between 2020-2023 period

Nº	COMMUNICATION SERIE TITLE	AUTHORS
	PUBLICATION YEAR: 2020	
1	On the need to consider Groundwater Protection Areas for Drinking Water collections.	Verónica Delgado, Óscar Reicher and José Luis Arumí
2	Support for decision-making in public policies using paleolimnological tools: evaluating the impact of anthropogenic pollution on lake systems.	Denisse Álvarez, Pablo Pedreros, Verónica Delgado and Roberto Urrutia
3	The human right to water.	Amaya Alvez and Rodrigo Castillo
4	Mining, energy and water, current situation.	Fernando Concha, Amaya Alvez and Marcelo Vergara
5	Water footprint.	Yenifer González, Yannay Casas and Gladys Vidal
6	Recycling in agriculture: disposal of biosolids to the soil.	Gabriela Fernández, Marco Sandoval and Gladys Vidal
7	Salinization of agricultural soils due to the reuse of treated wastewater.	Rodrigo Sepúlveda, Ana María Leiva, Pablo Cornejo and Gladys Vidal
8	Mathematical modeling of unit operations in mining and wastewater treatment plants. A contribution to the efficient use of water and the recovery of water resources.	Fernando Betancourt, Raimund Bürger and Yolanda Vásquez
9	Hydrogeology of fractured rock media.	Daniela Castillo, Ricardo Oyarzún and José Luis Arumí
10	Water quality in ecosystems, nutrients, abatement technologies and emissions regulatory framework.	José Luis Campos, Roberto Urrutia, Gladys Vidal and Viviana Almanza
11	Chilean mining radigraphy: present and future.	Leopoldo Gutiérrez, Ricardo Barra, José Luis Arumí, Úrsula Kelm, Óscar Jerez and Enrique Sáez
12	Economic evaluation of a water highway project.	Roberto Ponce, Diego Rivera and Alex Godoy-Faúndez

Table 3 (cont.). CRHIAM Communication Series published by the Center between 2020-2023 period

Nº	COMMUNICATION SERIE TITLE	AUTHORS
13	Reservoirs and their sustainable management under the scenario of water scarcity.	José Luis Arumí, Verónica Delgado, Alejandra Stehr,
14	Environmental aspects and challenges of urban wastewater treatment and reuse.	Patricio Neumann, Cristian Riquelme, Amaya Alvez and Rodrigo Castillo
15	Governance and management of water in the framework of water security.	Natalia Julio, Ricardo Figueroa and Roberto Ponce
16	Use of invasive species in freshwater: A potential circular economy strategy.	Fabián Figueroa, Pablo Pedreros, Gastón Bravo, Ricardo Barra and Roberto Urrutia
17	Sustainability and water security.	Ricardo Figueroa, María Elisa Díaz, Natalia Julio and Gladys Vidal
18	Arbuscular mycorrhizal fungi: sustainable biotechnology for agriculture in the face of climate change.	Christian Santander, Pablo Cornejo, Gladys Vidal and Eduardo Holzapfel
19	Use of pesticides in current agriculture.	Boris Parra, Ricardo Barra, María Cristina Diez and Gladys Vidal
20	Beyond fishing. An analysis of the ecosystem services provided by freshwater fish in Chilean aquatic ecosystems.	Gustavo Díaz, Ricardo Figueroa, Ricardo Barra and Roberto Urrutia
21	Precipitation biotechnologies for metal recovery in copper mining waters.	Carla Duarte, David Jeison, Leopoldo Gutiérrez and Andrés Ramírez
22	The microbiology of wastewater and the importance of its treatment, under the concept of “One Health”.	Gloria Gómez, María José Ortega, Ricardo Figueroa, Yenifer González and Gladys Vidal
23	Mineral processing and water resources: Concepts, challenges and solutions.	Rodrigo Yepsen, Leopoldo Gutiérrez and Pedro Toledo
24	Artificial groundwater recharge.	Emmanuel Garrido, José Luis Arumi, Mauricio Aguayo and Roberto Urrutia

Table 3 (cont.). CRHIAM Communication Series published by the Center between 2020-2023 period

Nº	COMMUNICATION SERIE TITLE	AUTHORS
25	Biomarkers of water quality, current chilean situation and future projections.	Ma. Fernanda Saavedra, Denisse Álvarez, Ricardo Barra and Roberto Urrutia
26	The scarcity of water in the interior dryland: from disaster to evolution.	Barbara Muñoz, José Luis Arumí, Hamil Uribe,
27	Comparative analysis of water governance in South America.	Cindy Yurani Correa Villa, Rodrigo Antonio Romero Jara, Alejandra Salazar Cañas, Rodrigo Castillo, Mario Lillo, Octavio Lagos and Gladys Vidal
28	Food security in agriculture: challenges for wastewater reuse within the framework of the human, animal and environmental health nexus	Monserrat Sabag, Ana María Leiva, Gloria Gómez, Diego Rivera and Gladys Vidal
29	Salt or not salt? That is the question in processes with salt water.	Pedro Toledo, Roberto Rozas, Gonzalo Quezada, Jorge Saavedra and Leopoldo Gutiérrez
30	Phosphorus as a nutrient: global, environmental perspectives and its application in agriculture.	Valentina Carrillo, Gloria Gómez, Bárbara Fuentes, Octavio Lagos and Gladys Vidal
31	Underwater mining and its potential environmental impact.	Dennis Vega, Leopoldo Gutiérrez, Roberto Urrutia and Dennis Álvarez
32	Disputes over water: Actors and institutions in the urban and rural context.	Rodrigo Castillo, María Belén Bascur, Kimberly Iglesias, Diego Rivera, Amaya Álvez and Robinson Torres.
33	Mining 4.0.	Fernando Concha, Marcelo Vergara and Pedro Toledo
34	Water quality and its use in mining.	Andrés Ramírez, Leopoldo Gutiérrez and José Arumí

Table 3 (cont.). CRHIAM Communication Series published by the Center between 2020-2023 period

Nº	COMMUNICATION SERIE TITLE	AUTHORS
35	Use of isotopic tools for hydrological-environmental studies with emphasis on mining activities.	Pía Urrea, Ricardo Oyarzún, José Luis Arumí and Leopoldo Gutiérrez
36	Use of seawater in mining: advances in the thickening of tailings rich in clays.	Francisco Pulgar, Ricardo Jeldres, Fernando Concha and Pedro Toledo
37	Quality of recirculated water in mining operations. Improvement through chemically functionalized glass microspheres	Kevin Pérez, Ricardo Jeldres, Leopoldo Gutiérrez and Pedro Toledo.
38	Run Lithium because Sodium gets you	Pedro Toledo, Roberto Rozas, Rodrigo Yepsen and Leopoldo Gutiérrez
39	Vulnerability of coastal basins: forcing and challenges	Loretto Arriagada, Diego Rivera, Roberto Ponce and Juan Munizaga
40	Mathematical modeling of biological systems: microalgae and bacteria for wastewater treatment	François Crouchett, Jineth Arango, Raimund Bürger and David Jeison
41	Lithium Strategic resource? To know and tell	Pedro Toledo, Omar Alvarado, Roberto Rozas, Gonzalo Quezada and Leopoldo Gutiérrez.
42	Sustainability of wastewater treatment systems. A look from life cycle analysis	Yannay Casas, Yenifer González, Gloria Gómez, Eduardo Holzapfel, Nicolás Arroyo and Gladys Vidal.
43	Hydrological modeling to address global changes	Rebeca Martínez, Norberto Abreu, Luis Octavio Lagos and Ricardo Barra
44	Comparative study of the regulation of rainwater harvesting	Rodrigo Castillo, Felipe Barriga, Leonardo Fernández, Gloria Gómez, María José Ortega, Amaya Álvez and Gladys Vidal.

Table 3 (cont.). CRHIAM Communication Series published by the Center between 2020-2023 period

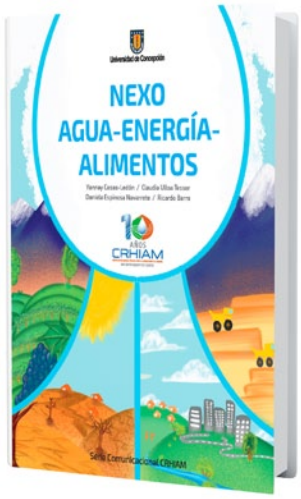
Nº	COMMUNICATION SERIE TITLE	AUTHORS
PUBLICATION YEAR: 2023		
45	Atmospheric rivers and their impact on hydrology	Lucia Scaff, Mario Lillo, Ricardo Oyarzún and Angélica Jara
46	Mine tailings and their relationship with water resources	Lina Marcela Uribe Vélez, Yannay Casas, Leopoldo Gutiérrez, Marcia Vásquez and Antonio Muñoz
47	Bubbles, more than a child's game	Jorge Saavedra, Pedro Toledo, Paola Bustos, Gonzalo Quezada, Gladys Vidal and Sandra Orvalho
48	What is eco-efficiency and how can we measure it?	Josefa León, Fernanda Mardones, Leopoldo Gutiérrez and Patricio Neumann
49	Innovate in the use of water resources in the mining industry	Andrés Ramírez, Leopoldo Gutiérrez, Fernando Betancourt, Ramón Díaz-Noriega and Juan Giraldo
50	Fundamentals of aquatic remote sensing in inland waters	Lien Rodríguez, Roberto Urrutia, Daniela Rivera, José Luis Arumí and Iongel Durán
51	The light-dark of gray water to be considered as a new source of water	Valentina Carrillo, Yenifer González, Gloria Gómez, Verónica Droppelmann, Eduardo Holzapfel, Leopoldo Gutiérrez and Gladys Vidal
52	Water – Energy – Food Nexus	Yannay Casas, Claudia Ulloa, Daniela Espinosa and Ricardo Barra
53	How are the Lithium-rich waters formed in the Salar de Atacama?	Fernanda Álvarez, Camila Poblete, Daniel Matte Estrada, Dilan Campos, Daniele Tardani, Leopoldo Gutiérrez and José Luis Arumí

Table 3 (cont.). CRHIAM Communication Series published by the Center between 2020-2023 period

Nº	COMMUNICATION SERIE TITLE	AUTHORS
54	Volcanism, groundwater and ecosystem services in the Aguas Calientes Valley	Rayén Rivera, José Luis Arumí, Ricardo Oyarzún, Mario Lillo, Ricardo Figueroa and Javier Mariángel
55	Reactive sedimentation models for activated sludge processes in wastewater treatment	Raimund Bürger, Julio Careaga, Stefan Diehl, David Jeison and Romel Pineda
56	Roles and perspectives of the actors for the construction of a Government-Society-Science trilogue: Rapel and Biobío Basins	Natalia Julio, Ricardo Figueroa, Octavio Lagos and Cristian Henríquez
57	Glaciers and ecosystem services: much more than ice	Alexis Segovia, María José Herrera, Alfonso Fernández, Mario Lillo, Marcelo Somos, Diego Rivera and Roberto Ponce
58	Groundwater recharge	Rayen Rivera, José Luis Arumí, Ricardo Oyarzún and Víctor Parra
59	Groundwater contamination by nitrates and removal alternatives	Eduardo Ortega Martínez, Ricardo Oyarzún, José Luis Campos, David Jeison Nuñez and Javiera Toledo Alarcón
60	Groundwater-dependent ecosystems in semiarid environments	Iongel Durán Llacer, Lien Rodríguez López, José Luis Arumí, Rebeca Martínez Retureta and Roberto Urrutia

CRHIAM Communication Series: Special Editions

PUBLICATION YEAR	TITLE	AUTHORS
2021	Constituent Process Edition	Centro de Recursos Hídricos para la Agricultura y la Minería
2022	Environmental quality of drinking water sources of health services companies in Chile. Period 2014-2020	Centro de Recursos Hídricos para la Agricultura y la Minería



https://www.crhiam.cl/publicaciones/series-comunicacionales/

7.2 CRHIAM Policy Briefs

Additionally, the website publishes short documents called Policy Briefs that are 3 to 6 pages long. These briefs aim to disseminate scientific evidence that contributes to public policies by providing relevant and timely information. The topics covered in these briefs include the impact of drought, the reuse of wastewater in agriculture, and lithium as a critical player in the global energy transition, among others (Table 4). These documents were created in 2022, and by the end of 2023, 19 of them were already published on the website of the CRHIAM Center.

Table 4. CRHIAM Policy Briefs published by the Center between 2022-2023 period

Nº	POLICY BRIEF TITLE	AUTHORS
PUBLICATION YEAR: 2022		
1	Construction of reservoirs to address water scarcity	José Luis Arumí and Roberto Urrutia
2	Use of the water footprint for more sustainable management of water resources	Patricio Neumann and Gladys Vidal
3	The transition towards healthy eating depends on the differential increase in the food basket in the family budget in the different quintiles	Stephanie Rivero Zambrano, Alex Godoy Faúndez and Diego Rivera Salazar
4	Water management in the framework of water security: a governance problem	Ricardo Figueroa, Gladys Vidal and Roberto Ponce
5	Rainwater harvesting: encouraging diversification of the water matrix	Rodrigo Castillo, Felipe Barriga, Gloria Gómez, Ma. José Ortega, Amaya Alvez and Gladys Vidal
6	Recommendations for the sustainable use of water in mining	Pedro G. Toledo and Leopoldo Gutiérrez
PUBLICATION YEAR: 2023		
7	Towards an interconnected water system in Chile	Pedro G. Toledo
8	Microorganisms in water: a pending challenge with the ecosystem	Gladys Vidal and Ricardo Figueroa
9	More sustainable management of sanitary sludge requires considering local conditions and implementing better management practices	Patricio Neumann and Gladys Vidal

Table 4 (cont.). CRHIAM Policy Briefs published by the Center between 2022-2023 period

Nº	POLICY BRIEF TITLE	AUTHORS
10	Reuse of wastewater in agriculture, an alternative in the search for food security	Gladys Vidal and Diego Rivera
11	Drought increases flood risk	José Luis Arumí, Enrique Muñoz, Octavio Rojas, Ricardo Figueroa, Mark Stone and Gerhard Schoener
12	Hydrological modeling to face global changes	Luis Octavio Lagos and Ricardo Barra
13	Nexo: an integrated view for the sustainable management of water and energy	Yannay Casas, Claudia Ulloa and Ricardo Barra
14	Lithium as a key player in the framework of the global energy transition	Pedro G. Toledo and Fernanda Álvarez
15	Recommendations to avoid pesticide contamination and protect water resources	M. Cristina Diez, Heidi Schalchli and Marcela Levío-Raimán
16	The chiaroscuro of gray waters. A new water source?	Gladys Vidal and Valentina Carrillo
17	Common Goods, Ancestral Knowledge and Biocultural Diversity in times of crisis: water scarcity, pandemic and climate change	Jorge Rojas Hernández, Patricio Silva Ávila and Ricardo Barra Ríos
18	Healthy environment, water, current situation and future challenges in Chile	Gladys Vidal and Ricardo Barra
19	Groundwater Sustainability: Implications for Water Security	Rayén Rivera and José Luis Arumí

https://www.crhiam.cl/publicaciones/policy-briefs/

7.3 Other products and media appearances

In addition to that, the Center has produced other media products, such as the podcast "El agua tiene su ciencia", which has five seasons and over 60 episodes by 2023 (Table 5 and Table 6).

Table 5. CRHIAM Podcast episods published by the Center in Spotify between 2020-2021 period

NUMBER	CHAPTER TITLE	EXPERT AUTHOR
SEASON 1 - PUBLICATION YEAR: 2020		
1	Groundwater	Dr. José Luis Arumí
2	The importance of water for human consumption	Cristián Vergara
3	Ecosystem protection water suppliers	Amerindia Jaramillo
4	Water and epidemics	Dr. Gladys Vidal
5	Water security	Dr. Ricardo Barra
6	National Science Day	Dr. Paulina Assmann
7	Science from regions	Dra. Andrea Rodríguez
8	How do we teach science?	Dr. Juan Carlos Gacitúa
9	Human right to water	Dr. Amaya Alvez
10	Water and mining	Dr. Leopoldo Gutiérrez
11	National water table	Andrés Esparza
12	Agriculture and water 4.0	Dr. Diego Rivera
13	Sustainable agriculture	Dr. Octavio Lagos
14	Irrigation in Chile	Federico Errázuriz
15	Water governance	Dr (c) Natalia Julio
16	Hidroinngenia Foundation	Gabriela Chávez
17	Mining tailings	Dr. Andrés Ramírez

Table 5 (cont.). CRHIAM Podcast episods published by the Center in Spotify between 2020-2021 period

NUMBER	CHAPTER TITLE	EXPERT AUTHOR
SEASON 2 - PUBLICATION YEAR: 2021		
1	Watershed management	Dr. Ricardo Figueroa
2	Water and environment	Dr. Óscar Parra
3	Water footprint	Dr. Vanessa Novoa
4	Regional Sciences	Dr. Gunhild Hansen-Rojas
5	Newenko Foundation	Evelyn Vicioso
6	Science and high schools TP	Dr. Felipe de la Hoz
7	Sanitary and environment	Alexander Chechilnitzky
8	Green mining	Dr. Marcela Angulo
9	Climate change	Dr. Alex Godoy
10	Glaciers	Dr. Roberto Urrutia
11	Sustainable cultural self-management	Dr. (c) Karien García
12	Water and economy	Dr. Roberto Ponce
13	Culture and dissemination scientific	Dr. Inés Figueroa
14	Desalination in mining	Mariana Concha
15	Water Code	Rodrigo Castillo
16	Soils	Dr. Pablo Cornejo

Starting in 2022, the chapters of the podcast were narrated by the CRHIAM communications team, addressing the summary of the main news about water, agriculture and mining (Season 3), research topics and work of CRHIAM (Season 4), water stories written by the community (Summer Edition) and Sustainable Development Goals (Season 5). The titles of episods are in Table 6.

Table 6. CRHIAM Podcast episods published by the Center in Spotify between 2022-2023 period

NUMBER	CHAPTER TITLE
SEASON 3 - PUBLICATION YEAR: 2022 (I SEMESTER)	
1	Will we have rationing water?
2	Desalination and drinking water
3	Water as a natural common good in the erasure of the new Constitution
4	National Water Agency
5	They launch a platform to review effects of climate change in Antarctica
6	Paraguay as an example in water distribution
7	Constitutional Convention approves transitional rule on water
8	Rain is welcomed with joy in the Coquimbo Region
9	Rains give a slight respite to the drought
SEASON 4 - PUBLICATION YEAR: 2022 (II SEMESTER)	
1	What is CRHIAM?
2	Let's talk about water security
3	X-ray of Chilean mining
4	Sustainable agriculture
5	Climate change and research
6	What is One Health?
SUMMER EDITION - PUBLICATION YEAR: 2023 – WATER STORIES	
1	Leidenfrost effect
2	Raen
3	Mrs. Water and her family

Table 6 (cont.). CRHIAM Podcast episods published by the Center in Spotify between 2022-2023 period.

NUMBER	CHAPTER TITLE
SEASON 5 - PUBLICATION YEAR: 2023	
1	Let's talk about World Water Day
2	SDG 1, all together for the elimination of poverty
3	SDG 2, how to get to zero hunger?
4	SDG 3, health and well-being for all
5	SDG 4, quality education and environment for the future
6	SDG 5, gender equality for all areas
7	SDG 6, clean water for all
8	SDG 7, more sustainable energy
9	SDG 8, decent work for all
10	SDG 9, industry, innovation and infrastructure
11	SDG 10, reduce inequality in and between countries
12	SDG 11, cities and communities sustainable
13	SDG 12, consumption and production sustainable
14	SDG 13, climate action
15	SDG 14, life underwater
16	SDG 15, let's take care of ecosystems terrestrial
17	SDG 16, peace, justice and inclusion
18	SDG 17, alliances to achieve the goals

SDG: Sustainable Development Goals.

https://open.spotify.com/show/0Iw6TzD4dEGMQEofaAJA5l

The Center has also made over 800 press appearances, including creating reports for the TV program "Explorers: From the Atom to the Cosmos", which is broadcast by Channel 24 Hours of Televisión Nacional de Chile (TVN), below are all episodes of the program where CRHIAM has participated (Figure 19).

Topics:

1. Technologies for the efficient use of water in agriculture
2. Transforming seawater into drinking water
3. Rural wastewater treatment using wetlands

Topics:

1. Climate change and water security
2. The water we drink
3. Groundwater recharge, life reserves

Topics:

1. Mining industry 4.0 and technology transfer
2. Agriculture industry 4.0 and integrated water resources management
3. Training the key to future water security

Topics:

1. Basin and water quality
2. Ecosystem services and socioeconomic development
3. Human right to water and sanitation

Topics:

1. Monitoring of North Patagonian lakes
2. The use of microorganisms to confront climate change
3. Water footprint and green mining

Topics:

1. Chile and its windows to be the protagonist of the lithium boom
2. Rainwater harvesting systems
3. Commitment to the SDGs and the commitment to One health

Figure 19. CRHIAM in "Explorers: From the Atom to the Cosmos" TV program.

Since 2021, the Center has also created several educational infographics on topics such as water security, groundwater, and mining in Chile for the general public.

Table 7. CRHIAM Infographics published by the Center between 2020-2023 period

NUMBER	INFOGRAPHIC TITLES
PUBLICATION YEAR: 2020	
1	12 facts about the COVID-19 virus in water
2	The importance of cleanliness domestic to stop the COVID-19
3	Wash your hands with soap regularly is an effective way to prevent the spread through of surfaces
PUBLICATION YEAR: 2022	
1	What is an aquifer?
2	What types of aquifers do we know?
3	What are the ecosystems water dependent underground?
4	What is water security?
5	What is water governance?
6	What is the water cycle like?
7	Minerals in Chile
8	Mineral flotation
9	Use of water in mining
10	Types of irrigation
11	CRHIAM research lines
12	What is CRHIAM?
PUBLICATION YEAR: 2023	
1	Food safety
2	Accelerating change
3	What is SDG 6?
4	Water and sanitation in Chile
5	SDG 1: End poverty
6	SDG 2: Zero hunger
7	SDG 3: Health and well-being

Table 7 (cont.). CRHIAM Infographics published by the Center between 2020-2023 period

NUMBER	INFOGRAPHIC TITLES
8	SDG 4: Quality education
9	SDG 5: Gender equality
10	SDG 6: Clean water and sanitation
11	SDG 7: Affordable energy and pollutant
12	SDG 8: Decent work and economic growth
13	SDG 9: Industry, innovation and infrastructure
14	SDG 10: Reduction of inequalities
15	SDG 11: Cities and communities sustainable
16	SDG 12: Production and consumption responsible
17	SDG 13: Climate action
18	SDG 14: Life below water
19	SDG 15: Life of ecosystems terrestrial
20	SDG 16: Peace, justice and institutions solid
21	SDG 17: Partnerships to achieve the goals

https://www.crhiam.cl/publicaciones/infografias/

7.4 Water Forums and CRHIAM Talk Cycles

The Water Forums are seminars held within the framework of World Water Day and focus on the annual theme proposed by the UN (Table 8). These forums invite relevant actors from the public and private sectors to discuss the different challenges related to water resources. The forums are open to the public, and every year, they attract more than a hundred participants.

Table 8. CRHIAM Water Forums executed by the Center between 2020-2023 period

YEAR	WATER FORUM TITLES
2020	Water and climate change
2021	What does water mean to you?
2022	Underground Waters: making the invisible visible
2023	Accelerating the change

On the other hand, "The CRHIAM Talk Cycles" is an annual initiative that takes place during the first week of each month from April to December. During this event, researchers from CRHIAM present their research topics (Table 9). However, in 2023, the event expanded to include directors and researchers from other centers belonging to the Fondap program. This is to showcase the significance of water resources in other research áreas.

Table 9. CRHIAM Talk Cycles executed by the Center between 2020-2023 period

NUMBER	TALK TITLE	EXPERT EXHIBITOR
EXECUTION YEAR: 2020		
1	Human right to drinking water and sanitation in the new Constitution	Dr. Amaya Álvez, CRHIAM associate researcher
2	Hydrological Isotopes and Applications Environmental	Dr. Ricardo Oyarzún, CRHIAM associate researcher
3	The decentralized treatment of wastewater using microalgae	Dr. David Jeison, CRHIAM associate researcher
4	Importance of water in mineral processing copper-molybdenum in mining in Chile	Dr. Leopoldo Gutiérrez, CRHIAM associate researcher
5	Arbuscular Mycorrhizae: allies silent for water safety	Dr. Pablo Cornejo, CRHIAM associate researcher

Table 9 (cont.).CRHIAM Talk Cycles executed by the Center between 2020-2023 period

NUMBER	TALK TITLE	EXPERT EXHIBITOR
6	Tailings management in seawater	Dr. Ricardo Jeldres, CRHIAM adjunct researcher
7	Water Management in Industry 4.0	Dr. Mario Lillo, CRHIAM associate researcher
8	Biogenic metal nanoparticles	Dr. Olga Rubilar, CRHIAM associate researcher
9	How we influence beings humans in natural cycles of the Earth?	Dr. José Luis Campos, CRHIAM associate researcher
EXECUTION YEAR: 2021		
1	Government or Governance: Towards where are we going?	Dr (c). Natalia Julio, PhD. student in Environmental Sciences UdeC
2	Circular Economy in the Water Cycle	Dr. Patricio Neumann, CRHIAM adjunct researcher
3	Wastewater treatment complex: applications in agriculture and industry	Dr (c). Marcela Levío, PhD student in Natural Resources UFRO
4	Phosphorus in wastewater: principles and technologies of recovery	Dr (c). Valentina Carrillo, PhD. Student in Environmental Sciences UdeC
5	Agriculture is moving to south?	Dr. Diego Rivera, CRHIAM principal researcher
6	Water economy	Dr. Roberto Ponce, CRHIAM associate researcher
7	Climate change and water, energy and food security	Dr. Alex Godoy, CRHIAM associate researcher
8	Water, communities and extractivism	Dr. Robinson Torres, CRHIAM adjunct researcher
9	A sustainable alternative to reduce excess nutrients	Dr. (c) Karien García, PhD. Student in Environmental Sciences UdeC

Table 9 (cont.).CRHIAM Talk Cycles executed by the Center between 2020-2023 period

NUMBER	TALK TITLE	EXPERT EXHIBITOR
EXECUTION YEAR: 2022		
1	Regulation and management of waters in the constituent process	Rodrigo Castillo, CRHIAM support lawyer
2	Local governance experiences of the water	Dr. Marcela Salgado, CRHIAM collaborator
3	Fossil pigments and conditions environmental conditions in Lake Laja in the Chilean Andes	Dr. Lien Rodríguez, CRHIAM collaborator
4	Experiments, artificial vision and simulation in flotation minerals with sea water	Dr. Jorge Saavedra, CRHIAM collaborator
5	Lake sediments and their use as change archives past climatic and environmental	Dr. Denisse Álvarez, CRHIAM collaborator
6	Thermal regime and ecosystems freshwater: knowledge and vulnerability to global warming	Dr. Pablo Pedreros, CRHIAM collaborator
7	Importance of life cycle thinking in decision making	Dr. Yannay Casas, CRHIAM associate researcher
8	Biogenic metal nanoparticles	Dr. Andrés Ramírez, CRHIAM collaborator
9	Tailings and its relationship with water resource	Dr. Lina Uribe, CRHIAM associate researcher

Table 9 (cont.).CRHIAM Talk Cycles executed by the Center between 2020-2023 period

NUMBER	TALK TITLE	EXPERT EXHIBITOR
EXECUTION YEAR: 2023		
1	Water and public health	**Exposes:** Dr. Sergio Lavandero, ACCDiS Fondap Center Director **Moderates:** Dr. Gladys Vidal, CRHIAM Fondap Center Director
2	Water: an element of conflict	**Exposes:** Dr. Antoine Maillet, COES Fondap Center Principal Researcher **Moderates:** Dr. Ricardo Barra, CRHIAM Fondap Center Principal Researcher
3	Our Changing Climate: Observations, Projections and Uncertainties	**Exposes:** Dr. René Garreaud, CR2 Fondap Center Director **Moderates:** Dr. José Luis Arumí, CRHIAM Fondap Center Principal Researcher
4	Climate Change in Systems High Latitudes: Chronicle of a disaster announced	**Exposes:** Dr. Humberto González, IDEAL Fondap Center Director **Moderates:** Dr. Roberto Urrutia, CRHIAM Fondap Center Principal Researcher
5	Connections between Water and Energy	**Exposes:** Dr. Claudia Rahmann, SERC Fondap Center Director **Moderates:**: Dr. Pedro Toledo, CRHIAM Fondap Center Deputy Director

https://www.youtube.com/channel/UCcxFk4uFkxFdvUxdVUKgdBg

Over the past ten years, the CRHIAM Center has focused on educating people about the responsible and conscious use of water resources. This education has been directed towards both productive sectors like agriculture and mining, as well as communities. In the last five years, the Center has collaborated with scientific-humanist schools, technical high schools, and agricultural companies to create different educational initiatives.

7.5 Activities with schools and society in general

To promote scientific and technological education across the region, CRHIAM has been actively involved in the Science Festival organized by the Ministry of Science, Technology, Knowledge, and Innovation, which is primarily carried out by the Regional Associative Programs (PAR Explora) in every region of the country.

This initiative takes place during the first week of October, which is when Science Day is celebrated in Chile. The Center has participated in numerous science fairs organized by PAR Explora Biobío (2019-2023), PAR Explora Ñuble (2019-2022), RM Sur Oriente (2022) and PAR Explora RM Norte (2022) over the years. The Center has prepared various outreach materials, such as infographics, books, communication series, policy briefs, educational games, and experiments, to educate schoolchildren and the community about the importance of water for ecosystems and our planet. During science fairs, members of CRHIAM have given talks on topics such as the water cycle, water footprint, water security, and constructed wetlands, among others (Figure 20). It is essential to note that in 2023, the Science Festival held over 200 free activities throughout the country.

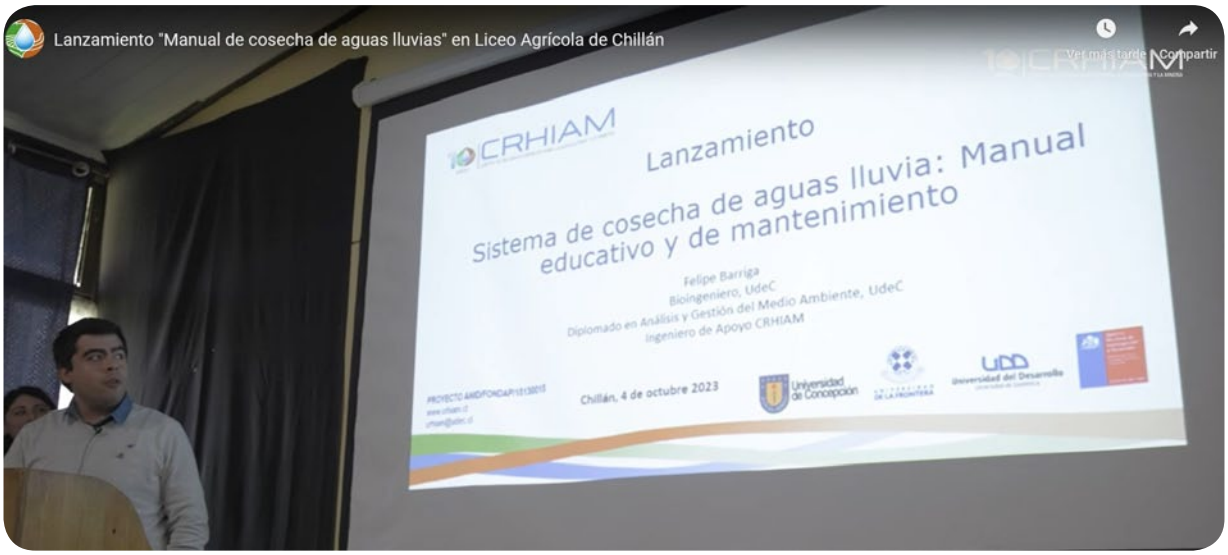
Figure 20. Science Festival developed in the Concepción (year 2022) and Los Angeles cities (year 2023).

Additionally, CRHIAM has hosted online talks and activities for the community during the Science Festival week. In this regard, it is worth mentioning that the "Rainwater Harvesting Manual" was launched in collaboration with the company Cosecha Agua (Figure 21). The presentation of the manual took place at the "Water Forum" activity, which is held annually to celebrate World Water Day, and in which representatives from the public, academic, business and community sectors interested in adopting practices participated. sustainable water management.

Figure 21. Rainwater Harvesting Manual presentation in Universidad de Concepción.

This manual explains how to use rainwater harvesting technology, its installation considerations, and maintenance. The launch event took place in October 2023 at the Liceo Agrícola de Chillán (Figure 22a), which is an educational institution belonging to the network of high schools of the National Society of Agriculture (SNA Educa). CRHIAM, the organization behind the launch, had installed a rainwater collection system in this school (Figure 22b) to help students learn about this technology. It is important to note that the launch event and all the talks organized by CRHIAM as part of the Science Festival can be found on the Center's YouTube Channel.

a



b

Figure 22. Raiwater Harvesting technology. a) Launch of manual and b) Inauguration of rainwater collection system in Liceo Agrícola de Chillán.

The CRHIAM Center has collaborated with the Centro Interactivo de Ciencias, Artes y Tecnologías (CICAT) on multiple occasions (Figure 23). CICAT is an essential entity in the Biobío Region that belongs to the Universidad de Concepción. In 2020, we organized the summer school "Escuela Aguacero: ¡Por un verano hidrolúdico!" together with CICAT, targeting children aged 6 to 11 years old. We also launched the "Terrícolas en Acción" initiative, which aimed to support teachers in rural areas without internet connectivity during the pandemic when schools were closed. In 2021, we partnered with CICAT to develop the "Ecobrigadas" card game. This game was designed to engage students and help connect rural areas without internet connectivity. It also aimed to contribute to the training of teachers in rural schools in the Biobío Region. The initiative distributed 8,000 games to 7,000 families from at least eight schools in the region. Notably, Essbio, a close collaborator of CRHIAM, also participated in this project. In 2022, as part of the ANID Ring project "Cold-Blooded: Drivers of Climate Change Refugia for Glaciers and Streamflow Responses," researchers from CRHIAM actively participated. During the project, elementary students from Los Arrayanes and El Claro schools in Pucón learned about glacier-related concepts through a series of five workshops developed by CICAT. These workshops were part of an earth science educational initiative called "La cuerda del glaciar: experiencias interactivas." In addition, by the end of 2023, CICAT prepared an educational exhibition on the Sustainable Development Goals with the scientific advice and support of CRHIAM. The exhibition was designed primarily for school children.

Figure 23. Collaboration from CRHIAM to CICAT. a) Summer School logo, b) "Terrícolas en acción" educational sheets, c) Ecobrigadas card game and d) Workshop glacier-related concepts in schools.

For the past five years, CRHIAM has participated in WorldSkills Chile (Figure 24), an organization that promotes practical and innovative experiences for students in technical educational institutions. This partnership aims to improve training standards and norms. Specifically, CRHIAM supports the "Technified Irrigation" competition, in which students are evaluated on their competencies in filters, valves, irrigation quality, and drip irrigation systems. Dr. Felipe de la Hoz, in charge of CRHIAM's outreach, designs the module tests and coordinates the support of institutions and companies for the competition. Additionally, CRHIAM conducts courses prior to the olympiad for experts and competitors from the Irrigation Laboratory of the Liceo Agrícola El Carmen de San Fernando, an educational institution with which CRHIAM has conducted multiple trainings. It is noteworthy that in 2023, there were more than 600 competitors at the national level, which highlights the significance of training and promoting professional technicians in agriculture for the sustainable development of the country.

Figure 24. Differents WorldSkill versions in which CRHIAM has participated. a) 2020 version call, b) some competitors of 2021 version, c) 2022 version competition module and d) training and competitors of the 2023 version.

In order to strengthen ties with educational institutions and contribute to the education of schoolchildren in environmental matters, specifically water resources, CRHIAM has participated multiple times in the "Llico Science Fair" (Figure 25). This event is held annually at the Liceo Filidor Gaete in the municipality of Llico, and the Center has participated in scientific stands, workshops, and lectures for hundreds of schoolchildren from the Province of Arauco. The fair provides an opportunity for the students to learn about various topics related to sustainable development and ecosystem care. It is important to note that this event is organized by the ANID INCAR Center (Interdisciplinary Center for Aquaculture Research), the Arauco Municipal Education Administration Department, and the Municipality of Arauco. In summary, CRHIAM has attended scientific events organized at Filidor Gaete High School since 2016.

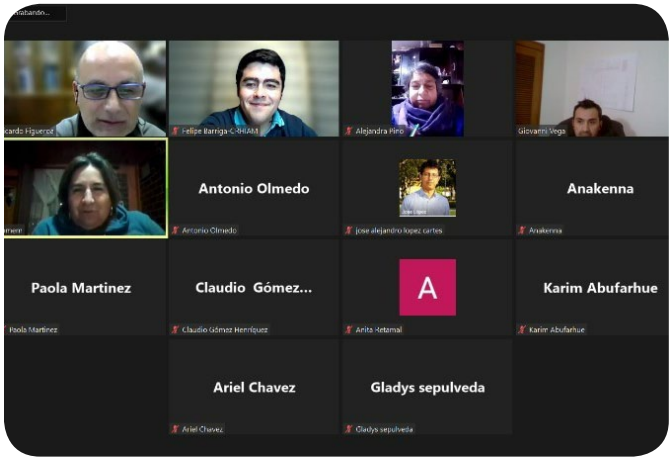
Figure 25. Differents Llico Science Fair versions in which CRHIAM has participated. a) Year 2016, b) year 2019, c) year 2022 and d) 2023.

CRHIAM also carries out various lectures and workshops in educational institutions throughout the year to engage with primary, secondary, scientific-humanistic, and technical high schools.

7.6 Knowledge transfer to the external sector (companies and institutions)

CRHIAM has conducted numerous training sessions to educate different stakeholders who use water for productive purposes about scientific and technological advancements that can help them use water resources more efficiently. Below is a list of the leading training sessions conducted in the last five years. To raise awareness about the importance of the water cycle and its management in the country, CRHIAM collaborated with water companies Essbio and Nuevosur to create a course called "Management of Water Resources and the Urban Water Cycle" (Figure 26). This course was aimed at NGO leaders and environmental activists from the O'Higgins to Biobío region, and 69 people have already graduated from it. The initiative aims to promote the efficient use of water, especially in areas affected by water scarcity. It emphasizes the need for collaboration among all actors involved in the territory to achieve water security and balance public and private interests.

a



b

Figure 26. Management of Water Resources and the Urban Water Cycle course. a) Watershed management class, 2022 year version and b) site visit drinking water production plant (La Mochita, Concepción) in 2023 year.

The Center has provided training in the field of irrigation to over 80 farmers, agronomists, and agricultural technicians connected to the Instituto de Desarrollo Agropecuario (INDAP) through its Local Development Program (Prodesal) from the towns of Teno, Placilla, Nancagua, and San Fernando. They were taught about the operation, maintenance, and evaluation of irrigation systems through "field days" organized by the Center's area of linkage with the environment (Figure 27).

Figure 27. Field day organized in Liceo Agrícola El Carmen to teach about advantages and disadvantages of irrigation, its methods and objectives, and the components of micro irrigation systems. Year 2020, with 35 participants.

In 2021, the Center conducted virtual training sessions for administrators, managers, and professionals from the Directorate of Hydraulic Works (DOH) of the O'Higgins Region. Later that year, within the framework of the FIC project "RPA Information Management in the O'Higgins Region", the Center conducted a workshop on the www.nuestrossr.cl platform. The aim was to improve the organization and standardization of administrative, financial, and technical information in rural sanitation systems (RSS) in the O'Higgins Region.

In 2022, CRHIAM and SNA Educa jointly conducted six presentations under the "Cycle of conferences for small farmers: Technified irrigation and how to face the current water reality." These presentations were held in the districts of Ovalle, San Felipe, Talagante, Molina, Duao, and Yerbas Buenas. The primary objective of these activities was to educate farmers and technical advisors about making more accurate and timely decisions to deal with water availability conditions for agricultural development. In addition, the National Irrigation Commission (CNR) designed the initiative "Training Program for Professionals in the Central Zone in Water

Resource Management" to train and enhance the irrigation management skills of professionals involved in this area. This program included a technical seminar in the community of Olmué, in which CRHIAM participated.

Furthermore, as part of its activities, CRHIAM participated in the "Resilience and Adaptability to the Water Crisis" project with Universidad Austral Centro de Humedales Río Cruces (CEHUM), Los Ríos Region (southern Chile), and the Cooperativa Agropecuaria de Aprendizaje Turístico en Restauración Ecológica y Permacultura Limitada (CAREP). Within this project, a course on "Wastewater: its Pollutants, Environmental Effects, and Regulations" was offered to improve graywater management. Additionally, CRHIAM created an animation called "Wastewater and Graywater" to spread awareness about graywater waste in rural areas. This animation has already received more than 2,500 views on CRHIAM's YouTube channel. Finally, CRHIAM conducted training abroad in Bolivia through the "Telemetry in Agriculture" Seminar for professionals of the Education for Development Foundation (FAUTAPO) in 2021. This led to a technical visit by CRHIAM the following year to the Technical School of Irrigation at the José Martí Institute in the Department of Chuquisaca to verify its technical conditions.

7.7 Communication of the center's work to society: CRHIAM social networks

For CRHIAM, the dissemination of scientific knowledge generated by its researchers has been a fundamental pillar of its work. This commitment is reflected in its fourth strategic objective: "To contribute to better water management through the communication and dissemination of scientific evidence that supports public policies and enhances societal knowledge."

To achieve this objective, the Center focuses its efforts on three main areas:

1. Production of scientific outreach materials, including infographics, communication series, policy briefs, and publications such as books.
2. Organization of community-oriented events, such as talks, book launches, summer schools, and international seminars, aimed at strengthening the exchange of knowledge between academics and society.
3. Active presence on social media and digital platforms, including Instagram, Facebook, Spotify, YouTube, LinkedIn, and X (formerly known as Twitter), where the Center shares engaging content and promotes its activities.

However, it must be considered that the different social networks and digital platforms were created throughout the execution of the Center with the objective of strengthening the communication strategy, with a view to reaching both national and international society. The timeline shown below (Figure 28) details the creation dates of each of the social networks and digital platforms that CRHIAM currently actively uses to communicate its work.

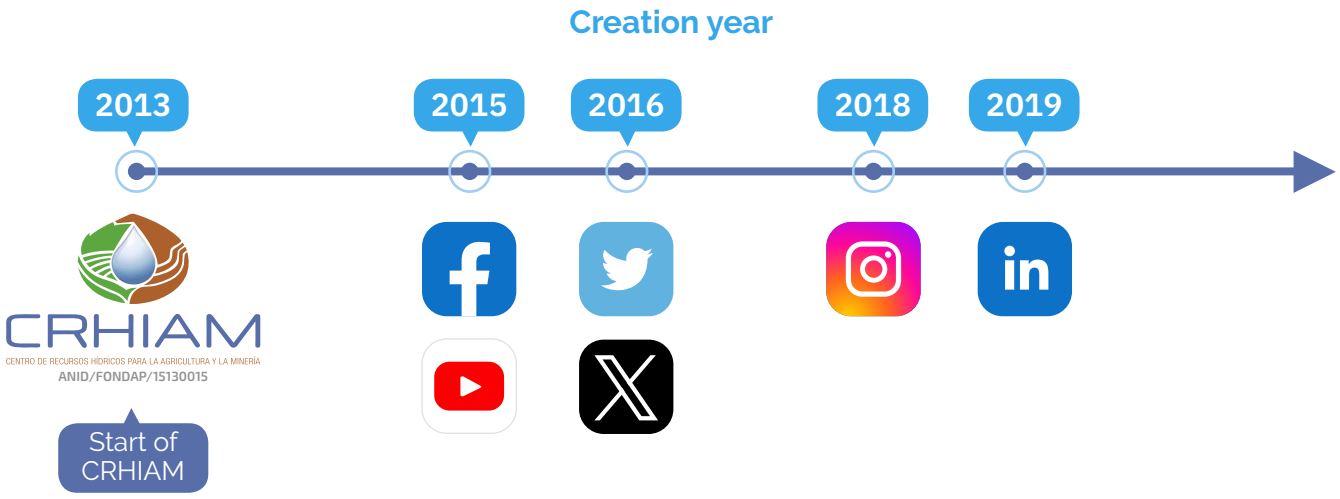
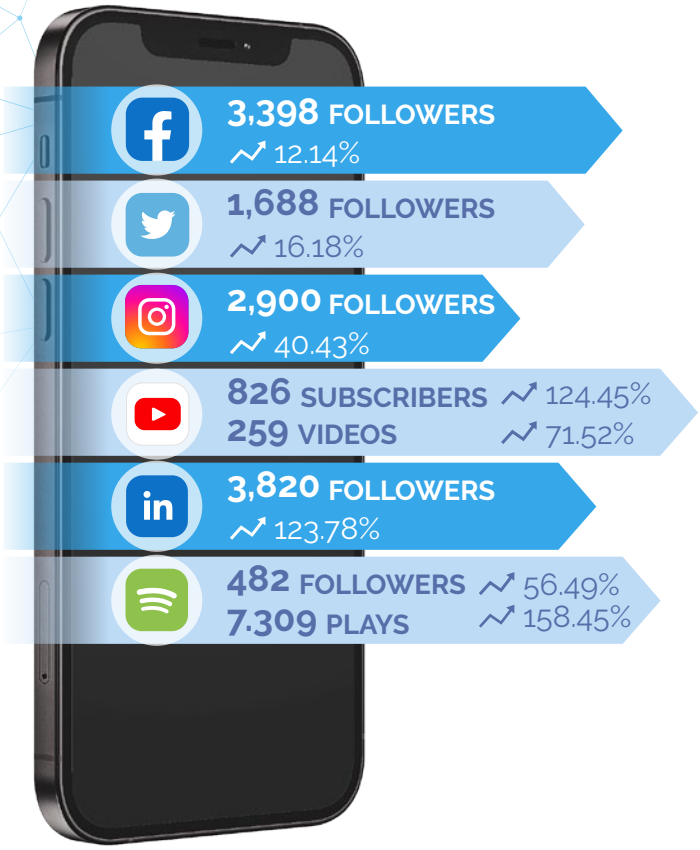


Figure 28. Creation year of CRHIAM's social networks and digital platforms.

Figure 29 illustrates the impact of these initiatives, showcasing both the number of outreach products developed by CRHIAM and the exponential growth of its social media presence between 2021 and 2023. This progress not only demonstrates the Center's commitment to scientific communication but also highlights its ability to adapt to the needs of an increasingly connected and digital society.



*Growth compared to data from 2021

Figure 29. CRHIAM scientific communication achievements. a) Production of scientific outreach materials and organization of community-oriented events and b) CRHIAM social media reach.

*Data from 2013 to 2023

CRHIAM
CENTRO DE RECURSOS HÍDRICOS PARA LA AGRICULTURA Y LA MINERÍA
ANID/FONDAP/15130015

10 YEARS
CONTRIBUTING TO WATER SECURITY
HIGHLIGHTING PERIOD 2018-2023

8. CONTRIBUTION TO PUBLIC POLICIES:
A transversal work line

8. CONTRIBUTION TO PUBLIC POLICIES: A transversal work line

CRHIAM: A center that generates scientific evidence to contribute to the decision making

Over the past decade, CRHIAM has developed various documents and processes to combine the different scientific disciplines within the organization. The aim is to provide high-quality scientific evidence on water resources to contribute to public policies and decision-making. This has been particularly evident during the second phase of the Center's implementation.

The Center has a close relationship with public sector actors at both national and local levels. It has collaborated with the Ministry of the Environment (MMA) on several occasions. Notably, it participated in a webinar on the draft revision of Supreme Decree No. 90. This decree deals with the Citizen Consultation Process, which aims to prevent pollution of marine and continental surface waters by controlling pollutants associated with liquid waste. The decree seeks to regulate the discharge of these pollutants into receiving bodies. In this same line, the Center also contributed to the review of the progress of Supreme Decree 46, "Standard for the Emission of Liquid Waste to Groundwater," which seeks to prevent groundwater contamination by controlling the disposal of liquid waste that infiltrates through the subsoil to the aquifer. One notable contribution made by CRHIAM is towards the preparation of Secondary Environmental Quality Standards for the North-Patagonian Lakes located in Southern Chile. The MMA commissioned this research to compile, systematize, and analyze available information for the preparation of secondary environmental quality standards. The objective of this research was to understand the threats to the preservation of these lakes, including their water quality, sediments, and biota. It was also aimed at identifying possible impacts on aquatic ecosystems, as well as the ecosystem functions and services associated with them. The research will serve as input to support the process of drafting the standards.

A significant achievement was the creation of the "Environmental quality of drinking water sources of sanitary service companies in Chile period 2014 - 2020" Communicational Series Special Edition. This study is an interdisciplinary collaboration aimed at evaluating the quality of water. The research aims to provide data on the quality and availability of water catchment sources, with a focus on protecting aquatic ecosystems, especially in the context of water scarcity. The Department of Aquatic Ecosystems, Division of Natural Resources and Biodiversity of the MMA contributed to this study, and the Technical Unit of the Control Division of the Superintendence of Sanitary Services (SISS - Santiago) reviewed it.

CRHIAM has formed multiple collaboration agreements with various public and private institutions, as well as NGOs. One such significant agreement is with the Library of the National Congress. This collaboration aims to promote, disseminate, study, and exchange experiences and knowledge related to water resources, specifically in the fields of agriculture, mining, and communities. This initiative also seeks to bridge the gap between scientific research and decision-makers in both the Chamber of Deputies and the Senate. In addition, it also signed a collaboration agreement with the Regional Directorate of Hydraulic Works (DOH Biobío Region) to carry out a survey of information on all the wastewater treatment plants of the rural sanitation service of the Biobío Region. During the second execution period, an important agreement was signed between the Universidad de Concepción, the Regional Government of Atacama, and the Universidad de Atacama. CRHIAM also supports this agreement. The main objective of this partnership is to promote the exchange of knowledge in science and technology, collaboration in medical specialties, and joint work on sustainable economic development, clean mining processes, regional studies, aquaculture and coastal development, territorial planning, social development, and responsible water governance.

In addition, CRHIAM has a collaboration agreement with the Newenko Foundation to strengthen collaboration spaces, particularly in the promotion and dissemination of research and initiatives related to water management. In 2023, the Center signed an alliance with the Chilean Association of Desalination (ACADES) to promote the development and use of desalination technologies in Chile. As part of this agreement, CRHIAM will participate in the first International Congress, "New Water Sources for Chile," organized by ACADES in March 2024.

In 2022, a project called "Technologies, CRHIAM Methodologies, and Best Practices Guide for Water Sustainability in the Agricultural and Mining Industries" - ANID/FSEQ210002 - won first place in the national call for proposals for the Strategic Research Fund for Drought. As a result of this project, the "Manual of Good Practices for the Efficient Use of Water in the Agricultural and Mining Industry" was created. This manual is a significant contribution to public policies and decision-making regarding water sustainability in these industries.

In recent times, CRHIAM has been focusing on strengthening its collaboration with the Seremi of Science, Technology, Knowledge, and Innovation (Seremi CTCI) at the local level. In 2020, amidst the COVID-19 pandemic, the organization worked together with the CTCI Seremi to produce three educational infographics and a virtual conversation. These initiatives aimed to dispel misinformation about the virus and educate people about the precautionary measures they should take to avoid contracting it. Additionally, in the same year, CRHIAM participated in the Central-South Macro Zone meeting to develop the first National Policy on Science, Technology, Knowledge, and Innovation (CTCI). In 2022, the organization played a role in establishing the CTCI Gender Roundtable in the Biobío Region. CRHIAM also collaborated with the CTCI Seremi to manage a photography contest called "Water through the lens," which brought together over 100 people from across the country and resulted in the publication of a book with the same name. Finally, we would like to emphasize

the recognition we gave to young researchers in the field of climate change. This initiative was carried out in collaboration with the Seremi of CTCI, and it highlighted the work of young women who are dedicated to research in the areas of climate change, water resources, and sustainability in the regions of O'Higgins, Maule, Ñuble, and Biobío. This call is part of the National Gender Policy of the Ministry of Science, Technology, Knowledge, and Innovation. It aims to promote female participation in this area and encourage young girls and adolescents to consider a career in this field.

CRHIAM was also part of the "Mesa compromiso país", which addresses the problem of access to rural drinking water and essential sanitation services. The Ministry of Public Works led this discussion panel. The Center has contributed to a report titled "Desalination: Opportunities and Challenges to Address Water Insecurity in Chile." This report presents a series of relevant recommendations for the development of the desalination process and its different uses. The report was led by the Ministry of CTCI through the Scientific Committee on Climate Change and was commissioned by the Ministry of the Environment. This is an unprecedented effort in the history of desalination in Chile.

Additionally, CRHIAM was a member of the Green Infrastructure Committee, which the Regional Governor of Biobío presented. The purpose of this committee was to identify strategic investments in response to road and digital connection needs, considering the current climate emergency. The committee worked throughout 2021 to generate the background information that served as input, among others, for the Regional Development Strategy and the Metropolitan Regulatory Plan of Greater Concepción, presented in 2022.

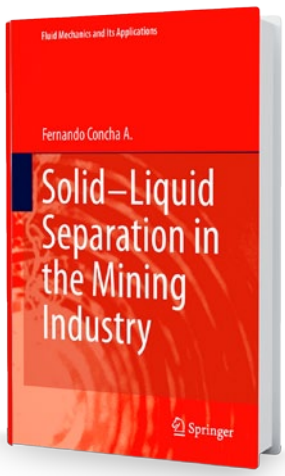
CRHIAM has participated in a significant public event called the Panel on Science and Knowledge in the Face of Socio-environmental Disasters. This event was convened by the Ministry of Science, Technology, Knowledge, and Innovation after the wildfires that occurred in the country during January and February 2023. CRHIAM is one of the more than 15 research centers and universities that are part of this initiative. The main goal of this initiative is to create recovery plans for this kind of disaster. Due to the aftermath of the water crisis and climate change, it is becoming increasingly necessary to find new water sources to guarantee water security for human consumption, ecosystems, and productive activities. One possible solution to address the water crisis is the use of rainwater harvesting systems (SCALL). However, in Chile, these systems still need to be regulated. To tackle this issue, CRHIAM has worked to establish a baseline for these systems. The Center has developed various materials such as the Communication Series titled "Comparative Study of

Rainwater Harvesting Regulation," the policy brief "Rainwater Harvesting: Encouraging Diversification of the Water Matrix," and the educational manual "Rainwater Harvesting." Furthermore, CRHIAM organized the "First International Seminar on Rainwater Harvesting and Management: The new water matrix," which was attended by representatives from the Universidade Federal de Pernambuco of Brazil, the Associação Brasileira de Captação e Manejo de Água de Chuva, the Agência Nacional de Águas of Brazil and the Brazilian startup Pluvi.

Throughout its decade-long existence, CRHIAM has published a total of 29 books (Figure 30) and 91 book chapters. One of the standout publications from its second period of operation is the text titled "The Chilean Model of Groundwater Regulation: Critiques from Environmental Law and Environmental Sciences." This publication highlights how groundwater has been intensively used in many areas of the country in recent years, which has resulted in severe conflicts with local communities and environmental damage. In order to avoid these conflicts, the publication identifies the main gaps in information and research and questions the current regulation of waters, including the Political Constitution and Water Code, as well as Law No. 21,064, which has been in force since January 27th, 2018. Another notable publication is "Commons and Biocultural Diversity in Times of Crisis." The book "Water scarcity, pandemics, and climate change" is a collaborative effort that aims to study and re-approach traditional knowledge and practices related to water management in Chile, Latin America, and the world. The book focuses on revaluing and re-signifying these practices in the context of global crises, including the COVID-19 pandemic and the Anthropocene Era. Another text, "Water Security. Water rights, scarcity, impacts, and citizen perceptions in times of climate change", brings together studies conducted by CRHIAM to understand the complex issues surrounding water from an interdisciplinary perspective. The text includes topics such as the right of indigenous peoples to access water, the hierarchy of water rights, innovation and efficiency technologies, and citizen perceptions of water resources in the context of the changing climate. The third text, "Nature-based solutions for the decontamination of point and diffuse discharges," provides examples of nature-based solutions that are being researched and applied in Latin America. It also includes some emerging research on "blue sky" solutions that seek to mitigate the impact of human activity on the planet. Finally, the book "Water, Ecosystems and Public Health" talks about how the triple environmental crisis, including the climate crisis, loss of biodiversity, pollution, and environmental degradation, is putting enormous pressure on Chile, resulting in water scarcity and flooding. Additionally, two noteworthy books are "Manual Irrigation and Drainage in Fruit Trees," jointly prepared with the Fundación para la Innovación Agraria (FIA) of the Ministry of Agriculture, and "Water Management Technology for Sustainable Intensive Agriculture".

Las Aguas Servidas y su depuración en zonas rurales: Situación actual y desafíos

Editors: Gladys Vidal and Francisca Araya



Solid-liquid separation in the mining industry

Author and Editor: Fernando Concha

Tecnologías de tratamiento mediante lodos activados. Observación microscópica de organismos indicadores

Editors: Gladys Vidal and Soledad Chamorro

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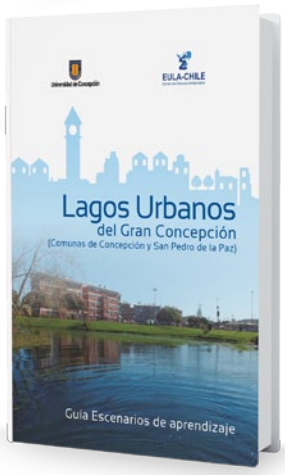
Editors: Gladys Vidal and Sujey Hormazábal

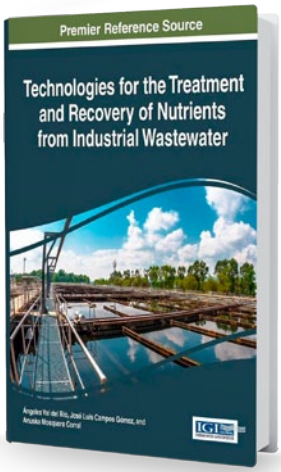


Lagos Urbanos del Gran Concepción: guía de aprendizaje

Editor: Oscar Parra

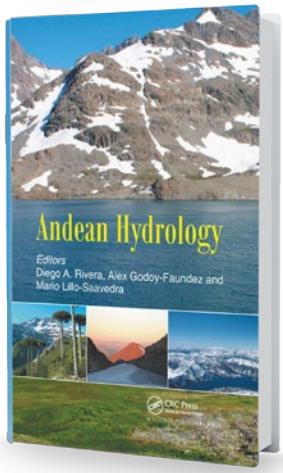
Guía para el estudio de cianobacterias en sistemas lacustres del Gran Concepción: Aspectos taxonómicos, ecológicos, toxicológicos y de control-vigilancia

Editor: Oscar Parra



Technologies for the Treatment and Recovery of Nutrients from Industrial Wastewater

Editors: Ángeles Val del Rio, José Luis Campos and Anuska Mosquera



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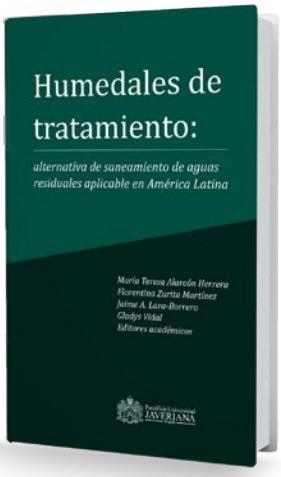

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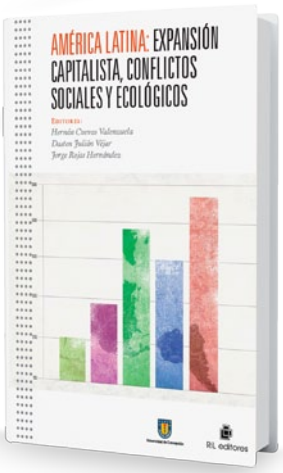

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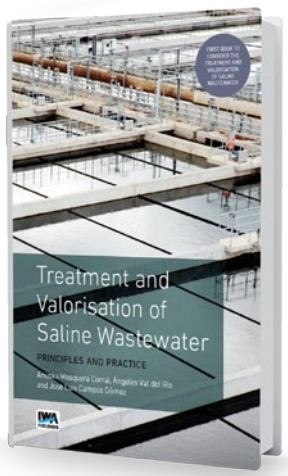
Editors: Gladys Vidal, Gloria Gómez and M. Cristina Diez



Treatment and Valorisation of Saline Wastewater: Principles and Practice

Authors and Editors: Anuska Mosquera Corral, Ángeles Val del Río and José Luis Campos Gómez

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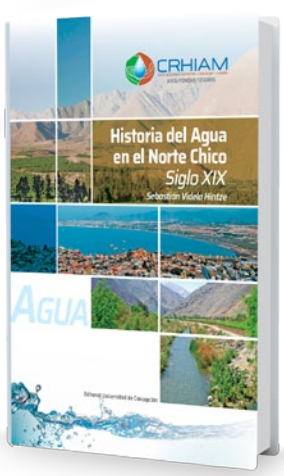
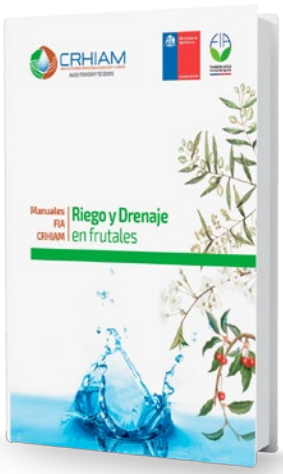
Editors: Verónica Delgado and José Luis Arumí



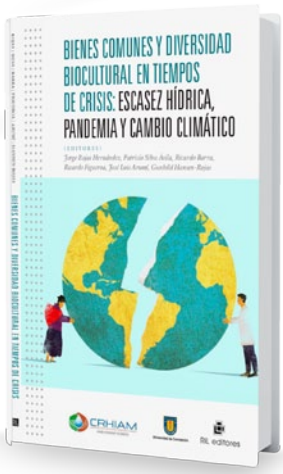
Historia del agua en el Norte Chico. Siglo XIX

Author: Sebastián Videla Hintze
Editor: Gladys VIdal



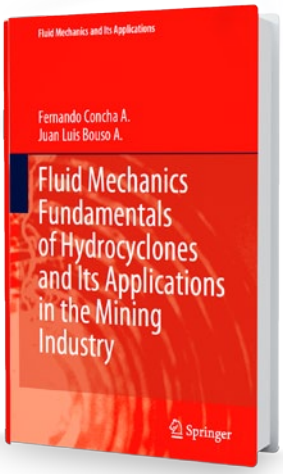
Manual Riego y Drenaje en frutales

Authors and Editors: Eduardo Holzapfel, Ximena Orrego, Jorge Jara, Luis Salgado and Camilo Souto



Bienes comunes y diversidad biocultural en tiempos de crisis. Escasez hídrica, pandemia y cambio climático

Editors: Jorge Rojas Hernández, Patricio Silva Ávila, Ricardo Barra, Ricardo Figueroa, José Luis Arumí and Gunhild Hansen-Rojas



Fluid Mechanics Fundamentals of Hydrocyclones and Its Applications in the Mining Industry

Authors and Editors: Fernando Concha and Juan Luis Bouso

Análisis de ciclo de vida: Fundamentos y aplicaciones para la gestión sustentable de los recursos hídricos

Editors: Gladys Vidal, Patricio Neumann and Almudena Hospido

Evaluación del metabolismo microbiano para el monitoreo y la optimización de sistemas biológicos de tratamiento de efluentes industriales y aguas servidas

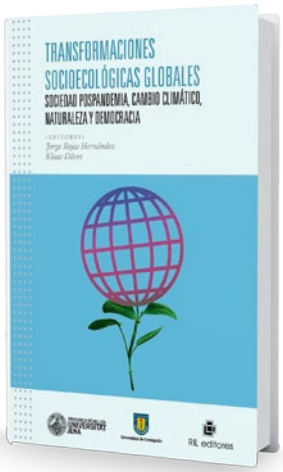
Authors and Editors: María José Ortega, José Luis Campos and Gladys Vidal

En búsqueda del agua ancestral en el norte semiárido y árido de Chile

Author: Sebastián Videla Hintze
Editor: Gladys Vidal

Relatos del agua

Editor: CRHIAM



Transformaciones socioecológicas globales. Sociedad pospandemia, cambio climático, naturaleza y democracia

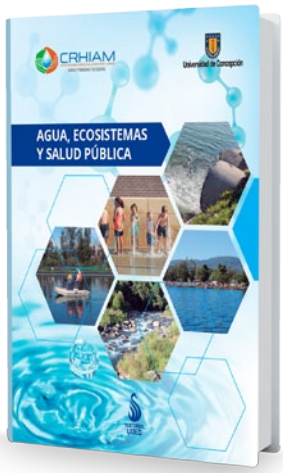
Editors: Jorge Rojas Hernández and Klaus Dörre

Manual Cosecha de Aguas Lluvia

Authors: CRHIAM and Cosecha Agua
Editors: Katerina Vargas, Belén Bascur and Sujey Hormazábal

El Agua a través del lente

Editor: CRHIAM



Agua, ecosistemas y salud pública

Editors: Patricia Matus, Ricardo Barra, Gloria Gómez and Gladys Vidal

Figure 30. Books published by CRHIAM (2013-2023)

All the published books can be found in CRHIAM website

www.crhiam.cl/publicaciones/libros/

In 2023, the government of Chile introduced the National Lithium Strategy. In accordance with the government's request to investigate and produce scientific evidence in this field, CRHIAM organized an online seminar titled "Towards the sustainability of the lithium industry from water resources: A view from the communities, extraction technologies, and the Economy." This event brought together more than a hundred participants. Additionally, CRHIAM has released the policy brief "Lithium as a key player in the global energy transition" and the communication series "How are lithium-rich waters formed in the Salar de Atacama", which underscore the potential and significance of lithium for the national industry and global decarbonization.

It is essential to recognize the work undertaken by CRHIAM towards the creation of a new constitution for the country. The Center supported the Constituent Convention in its efforts to draft the first proposal for a new constitution. However, the proposal was ultimately rejected through a national vote. The Center participated in the Popular Initiatives of Norm, which the Constitutional Convention put forward. They proposed "Governance and management of water in the framework of Water Security" (No. 47,538) to initiate further discussions on the governance of water resources, taking into account communities, ecosystems, and socioeconomic development.

Furthermore, in 2021, CRHIAM organized a series of discussions on science and public policies, specifically on water in the new constitution. The event was attended by former Constituent Assembly members, including Dr. Amaya Álvez, who is also an associate researcher of CRHIAM. Other participants include Dr. Andrés Cruz, Dr. Tammy Pustilnick, and Loreto Vidal, representatives of District 20. Additionally, the Communication Series "Constituent Process Edition" was launched, which addressed topics 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".

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9. REFERENCES BY RESEARCH LINE

9. References by Research Line (RL)

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- Salazar, I. 2024. Comparative analysis of the coalescence in suspensions with particles: Dynamic system of bubbles and static system of pairs of bubbles. Chemical Civil Engineer Thesis, Universidad del Bío Bío (In course). Advisors: Dr. Jorge Saavedra and Dr. Pedro Toledo.

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- Ulloa, Y. 2022. Study of the behavior of bubbles in MIBC and NaCl aqueous solutions through image analysis of a thin-walled column dynamic bubbling system. Chemical Civil Engineer Thesis, Universidad del Bío Bío (Finished). 58 pp. Advisors: Dr. Jorge Saavedra and Dr. Pedro Toledo.

Projects

- ANID/FSEQ/210002 (2021-2022). Drought (In course). Responsible Researchers: Dr. Leopoldo Gutiérrez, Dr. José Luis Arumí, Dr. Pedro Toledo, Dr. Gladys Vidal and Dr. María Cristina Diez.

RL3. Water availability and quality for agriculture and mining amid Climate Change

Publications

- Aguilera, A., Almanza, V., Haakonsson, S., Palacio, H., Beitez-Rodas, G.A., Barros, M.U.G., Capelo-Neto, J., Urrutia, R., Aubriot, L. and Bonilla, S. 2023. Cyanobacterial bloom monitoring and assessment in Latin America. *Harmful Algae*, 125: 102429. **https://doi.org/10.1016/j.hal.2023.102429**

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Book

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RL4. Technology for water treatment and environmental remediation

Publications

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- Carrillo, V., Gómez, G. and Vidal, G. 2022. Phosphorus uptake by macrophyte plants in monocultures and polycultures in constructed wetlands for wastewater treatment. *Ecological Engineering*, 182: 106690. **https://doi.org/10.1016/j.ecoleng.2022.106690**

- Carrillo, V., Casas-Ledón, Y., Neumann, P. and Vidal, G. 2023. Environmental performance of constructed wetland planted with monocultures and polycultures for wastewater treatment. *Ecological Engineering*, 193: 107015. **https://doi.org/10.1016/j.ecoleng.2023.107015**

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- ANID-FOVI22000. International nanotechnology network to deal with the current and future water crisis in the agriculture (INNWA) (2022-2023). Director: Gonzalo Tortella. Co-Director: Dr. Olga Rubilar.

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

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