NUMBER 3 / 2016

# hydrolink

## LATIN AMERICA SPECIAL

**IAHR Latin America Division Congresses**

| | |
|---|---|
| 0 | Santiago de Chile, 1962 |
| I | Porto Alegre, 1964 |
| II | Caracas, 1966 |
| III | Buenos Aires, 1968 |
| IV | Ciudad de Mexico, 1970 |
| V | Lima, 1972 |
| VI | Bogota, 1974 |
| VII | Santiago de Chile, 1976 |
| VIII | Quito, 1978 |
| IX | Merida, 1980 |
| X | Ciudad de Mexico, 1982 |
| XI | Buenos Aires, 1984 |
| XII | Sao Paulo 1986 |
| XIII | La Habana, 1988 |
| XIV | Montevideo, 1990 |
| XV | Cartagena de Indias, 1992 |
| XVI | Santiago de Chile, 1994 |
| XVII | Guayaquil, 1996 |
| XVIII | Oaxaca, 1998 |
| XIX | Cordoba, 2000 |
| XX | La Habana, 2002 |
| XXI | Sao Pedro, 2004 |
| XXII | Ciudad Guayana, 2006 |
| XXIII | Cartagena de Indias, 2008 |
| XXIV | Punta del Este, 2010 |
| XXV | San Jose, 2012 |
| XXVI | Santiago de Chile, 2014 |
| XXVII | Lima, 2016 |

**Abstracts in Spanish**

**Resúmenes en español**

IAHR
AIRH
International Association
for Hydro-Environment
Engineering and Research

*Supported by*
**Spain Water and IWHR, China**

# THE MANY WATER MANAGEMENT CHALLENGES FACING LATIN AMERICA

## EDITORIAL BY ANGELOS FINDIKAKIS & ARTURO MARCANO


*Angelos N. Findikakis*
*Hydrolink Editor*


*Arturo Marcano*
*Guest Editor*

The present issue of Hydrolink focuses on different aspects of water issues and challenges in Latin America through several articles by authors from the region. Its publication coincides with the XXVII Congress of the Latin America Division (LAD) of IAHR. The LAD has a long history of facilitating and promoting the collaboration and sharing of ideas among hydraulic engineers and researchers in the region, as explained in the reflections of two of its members, Alejandro Lopez and Raul Lopardo, on their more than 50 years of participation in the LAD activities.

As pointed out in the article by Henao and Marcano there are plenty of water resources in Latin America, but most of them cannot be used because they are too far from populated areas where water demand is growing. The uneven distribution of water resources, in combination with pollution and hydrologic extremes expected to be amplified due to climate change, create serious challenges for many countries in the region in their effort to satisfy their water needs, protect their people from catastrophic flooding and meet the Sustainable Development Goals (SDGs) adopted by the United Nations in January 2016.

Even though water management issues are becoming more challenging with time due to population and economic growth, by no means are they new. The Pre-Colombian civilizations of Central and South America dealt with some of the same issues, as demonstrated by the examples of the water capture and conveyance systems of the Nazca culture and the Incas discussed in the article by Kuroiwa.

Past poor planning and management of the available water resources create the conditions of a water crisis in some countries, as in Colombia. Pineda and Ordóñez explore several contributing factors to such crises, including the fast pace of large land use changes, the inefficient use of water in agriculture, the construction of poorly conceived storage reservoirs, often filled with sediments within few years, inadequate risk management in areas prone to flooding, the lack of protection of ecologically valuable water bodies and the pollution of many rivers.

Flood protection is a major issue in many parts of Latin America, as in the periphery of many sprawling cities the lack of enforcement of zoning regulations makes it possible for communities to expand in floodplains. This issue is discussed in the article by Lopez and Courtel, who describe the repeated devastating impact of debris mud flows on communities along the central coast of Venezuela. The complex issues involved in flood protection have also been studied in Argentina, leading to the recommendation for integrated flood management, an approach followed in the City of Santa Fe, as explained in an article by Carlos Paoli, which because of space limitations will be published in the next issue of Hydrolink.

In many parts of Latin America limited water availability requires new approaches to meeting the needs of domestic water supply in cities and rural areas, supporting agricultural food production and enabling the continuous operation of mining and industrial facilities. The article by Da Silva Manca, Dalfré Filho and Zuffo discusses the water crisis faced by different cities in Brazil, especially São Paulo, emphasizing demand management and presents the results of a survey of specialists asked to offer their opinion on potential solutions, such as increasing the reuse of treated wastewater and the reduction of water losses in the distribution systems, which in some cities are high. The article by Garcia-Villanueva and Collado examines water use in agriculture in the context of the drive to increase food production to meet the needs of the growing population in Mexico through increases in agricultural yields, cropping intensity and the expansion of arable land. Besides agriculture, which is the largest water user, other important industries in the region depend heavily on the availability of water, such as the mining industry. The article by Adriasola, Terroba, Muñoz and Ruiz explores the opportunities and addresses the challenges of using desalinated seawater to support the operations of the copper mining industry in Chile, which are located in areas where no other water resources are available.

As the public and policy makers are becoming more aware of the potential water-related risks and challenges associated with climate change, the need for the development of adaptation and mitigation measures is increasing. Lasarte, Tomicic and Jensen describe three such examples, the first concerning the vulnerability to flooding of a catchment in Montevideo where the most effective mitigation measure would be to relocate some of the people living in the lower part of it; the second analyzing the impact of the retreating glacier that is a major of water supply of Quito and where adaptation measures should focus on demand management and protection of the high elevation moors and wetlands known as páramos from forestation, grazing and cultivation; and the third focusing on solution scenarios for the flooding problems in Port of Spain, Trinidad and Tobago, caused by inappropriate urban management practices and exacerbated by climate change.

Finally, besides dealing with issues of too much, or too little water, Latin America is exploring ways of using natural water processes for producing clean energy. An example of such efforts is presented in the article by Teixeira, Solari and Alonso, who describe research under way in Uruguay aimed at assessing the potential of marine wave energy production through analytic and numerical studies and laboratory tests of flap-type wave energy converters.

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# MESSAGE FROM THE CHAIR OF THE IAHR LATIN AMERICAN DIVISION


*José Vargas*
*Chair of the IAHR Latin American Division*

Un saludo desde Latinoamérica para todos los colegas del mundo, desde el sur del mundo desde la Universidad de Concepción de Chile.

Nuestra región contiene más del 25% de los recursos hídricos del mundo y tiene menos del 8% de habitantes, con una distribución muy desigual de recursos hídricos teniendo entre las zonas más áridas y más húmedas del planeta, que lo hace un laboratorio natural para lo más variado temas de la ingeniería hidráulica y de recursos hídricos.

Azotada por extensas sequías espacial y temporalmente, como también por intempestivas inundaciones de gran periodo de retorno, nos hace presagiar exhaustivos estudios hidrológicos para enfrentar esos nuevos escenarios, con las medidas de gestión y obras hidráulicas que sean necesarias para satisfacer nuestro desarrollo económico sustentable.

Nuestra IAHR LAD ya con más 50 años de actividad, iniciada el año 1962 con el llamado Congreso 0 en Santiago de Chile, en este año con varias entidades públicas y privadas del Perú organiza el XXVII Congreso Latinoamericano de Hidráulica con su lema “De la sabiduría hidráulica ancestral a la tecnología de punta al servicio del desarrollo sostenible". Evento que permite que la comunidad de ingenieros hidráulicos latinoamericanos comunique sus experiencias y permitan, a través de la transferencia efectiva, esbozar la posible implementación de estudios hidrológicos e hidráulicos y de diversas políticas públicas y de gestión de recursos hídricos, para establecer las infraestructuras hidráulicas necesarias que permitirán satisfacer las demandas de un desarrollo sustentable de nuestra región.

IAHR LAD quiere privilegiar la interacción entre todos los colegas de la región y que este evento resulte en un efecto catalizador para otras actividades en el futuro.

Greetings from Latin America to all my colleagues around the world, from the University of Concepcion in Chile.

Our region contains more than 25% of the world's water resources and has less than 8% of the world’s population, with a very unequal distribution of water resources, having the driest and wettest areas of the planet, which makes it a natural laboratory for the most varied topics of hydraulic engineering and water resources.

Stricken by extensive droughts, in terms of both areal extent and duration, as well as by high return period floods, Latin America calls for comprehensive hydrological studies to address these new scenarios, with the management measures and hydraulic works that are necessary to meet our sustainable economic development.

Our Latin American Division (IAHR LAD) with over 50 years of activity, launched in 1962 with the so-called Congress 0 in Santiago de Chile, this year organizes (along with several public and private entities of Peru) the XXVII Latin American Congress on Hydraulics with its motto "From ancestral hydraulic wisdom to the latest technology for sustainable development ". An event that allows the community of Latin American hydraulic engineers to communicate their experiences and through their interaction, sketch ideas for possible hydrological and hydraulic studies and the implementation of various public policies and water resources management, to establish the necessary water infrastructure that will meet the demands of sustainable development in our region.
IAHR LAD wants to facilitate the interaction among all colleagues in the region and wishes that this event becomes a catalyst for other activities in the future.

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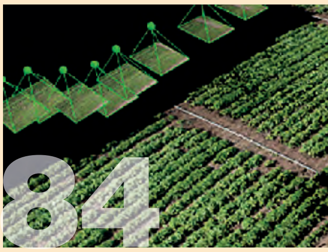
# IN THIS ISSUE

## LATIN AMERICA SPECIAL



## IAHR LATIN AMERICAN DIVISION CELEBRATES A HALF CENTURY

# SOME PERSONAL THOUGHTS AND REFLECTIONS

BY ALEJANDRO LOPEZ

It is a great honor for me to share my thoughts and memories from the Latin American Congresses of Hydraulics, which I have participated in for over 54 years. I was fortunate enough to participate in the organization of the First International Conference of Hydraulics and Fluid Mechanics held in 1962 in Santiago de Chile. The proceedings of this Congress, whose cover is shown in Figure 1, are of particular importance as they refer to the birth of our Latin American Division and the creation of the biennial Congresses that have now been held for more than 50 years.

## Resumen

El primer encuentro de investigadores e ingenieros relacionado con actividades académicas y profesionales latinoamericanos dedicados a la Hidráulica y Mecánica de Fluidos, se celebró en Santiago de Chile en el mes de agosto de 1962. Este encuentro es hoy conocido en la División Latinoamericana de la IAHR como el Congreso O. Esta reunión se comenzó a gestar en 1961, por iniciativa del Profesor Francisco Javier Domínguez, Jefe del Laboratorio de Hidráulica de la Escuela de Ingeniería de la Universidad de Chile. Concurrieron también los Profesores Arthur Ippen, Presidente de IAHR en esa fecha, Vito A. Vanoni, Enzo y Matilde Macagno, quienes dictaron cursos de su especialidad antes del Seminario.

En el seminario hubo representantes de 9 países, y se presentaron trabajos en 3 áreas temáticas.

En paralelo con el Seminario se efectuaron reuniones con el fin de formalizar la creación de la División Latinoamericana de IAHR, fijar la periodicidad de los congresos regionales y designar la sede del siguiente congreso.

On that occasion, I sent my first contribution. It was in Mexico, in 1970, that I presented my work on sediment transport, a theme that has been a milestone in my work as a researcher and an engineer.

Later in 2000, at the Congress celebrated in Cordoba, Argentina, I was given the privilege of becoming the Vice President of our Division and in 2002 at the Congress held in Havana, Cuba, I was elected President of the Regional Division.

From the very beginning I attended most of the IAHR Congresses and thus, I have been able to not only learn from the advances and efforts made in each country in our field of expertise, but also build a strong and deep friendship with several colleagues from our continent and from Spain. Many of these friendships still continue and the friends that are no longer with us have a special place in my memory and heart.

***Raúl Alejandro López Alvarado*** **graduated in Civil Engineering from the Universidad de Chile, and completed his graduate studies at the University of Kyoto. He has been a member of IAHR since 1962, and served as Chair of the IAHR Latin American Division. He organized the IAHR LAD Congresses in 1962, 1976, 1994 and 2014. He had a productive and long academic career at the University of Chile, Pontificia Universidad Católica of Chile and the Universidad de Santiago de Chile, where he conducted research on the many aspects of sediment transport on steep slopes, debris flows, scour and reservoir sedimentation. Presently, he is Director of the Civil Engineering School of the Pontificia Universidad Católica of Valparaíso. He has worked both in the public sector and as a Consultant.**

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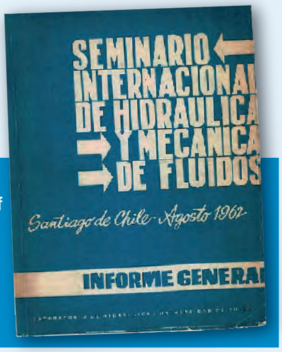
I would like to express here my gratitude to our visionary professors and mentors that have worked so hard to create this Congress and our Division. So that the present generation remember them, here are the names of the outstanding visionaries that created the First Regional Committee:

Francisco Javier Domínguez (Chile), José S. Gandolfo (Argentina), José Leite de Souza (Brazil), Lorenzo Roda (Peru), Daniel Gersie (Venezuela) and Oscar Maggiolo (Uruguay) shown in Figure 2. The sessions held by this Committee were attended by Dr. Arthur T. Ippen, President of IAHR at the time.

I hope to continue to participate in these meetings, as an Honorary Member of the IAHR Latin American Division, to encourage young professors, engineers and students to continue contributing to the development and the success of our Division and its congresses. ■



SEMINARIO INTERNACIONAL DE HIDRAULICA Y MECANICA DE FLUIDOS

Santiago de Chile - Agosto 1962

INFORME GENERAL

Figure 1. Cover of Proceedings of the International Seminar in Hydraulics and Fluid Mechanics, held in Santiago de Chile in 1962

Figure 2. Attendance to the International Seminar on Hydraulics and Fluid Mechanics that marked the creation of the IAHR Latin American Division. At the centre of the front line are Professors Matide Macagno, Francisco Dominguez and Arthur Ippen, President of IAHR

# SOME PERSONAL NOTES ON HALF CENTURY OF IAHR-LAD CONGRESSES

BY RAUL LOPARDO

It is my honor to convey to the new generation of members of IAHR some concepts that I have collected over nearly half a century during which time I have attended the IAHR Regional Latin American Congresses (LAD). My first experience of participation in this event, that has become a classic in our continent, took place when I returned to Argentina after completing my doctorate in France. It was December 1968 and I had four years of experience working as hydraulic engineer. There, I started my first presentation at the III Congress celebrated in the cities of Buenos Aires and La Plata. The photograph shown in Figure 1 was taken in front of the venue of the III Congress of the LAD.

I was fortunate to meet, in that third Congress, personalities such as Arthur Ippen and James Wallace Daily (at that time the President of IAHR), and the outstanding Professors, Francisco Javier Domínguez and Sergio Montes from Chile, José Leite de Souza from Brasil, Enzo Levi from Mexico, Marcelo González from Venezuela, and other prominent researchers from our continent who were welcomed by the Argentineans José Gandolfo, Roberto Cotta and Horacio Caruso.

## Resumen

Desde que en 1968 expuse mi primera contribución en el III Congreso Latinoamericano de Hidráulica en Buenos Aires, al actual XXXII Congreso a desarrollarse en Lima ha transcurrido casi medio siglo. Durante ese lapso el mundo ha tenido severos cambios socioeconómicos y tecnológicos que se han reflejado en nuestros encuentros bianuales. Hemos tenido el desafío de atravesar exitosamente las revoluciones informática, de las comunicaciones y ambiental sin perder la esencia de las ciencias básicas de la ingeniería hidráulica, los conceptos de nuestros maestros, el interés por la experimentación y la vocación de servir a la sociedad. Pero además de lo mucho que he aprendido en todos nuestros congresos y la ilusión de haber aportado algo en sus sesiones técnicas, lo más valioso ha sido el haber conocido y disfrutado de grandes amigos de muy diversos países. Ellos forman parte del más grato recuerdo y seguramente de mi mayor éxito a lo largo de tantos congresos, más allá de la hidráulica experimental, el diseño de aliviaderos, la cavitación por pulsos de presión y la macro turbulencia.

***Raúl Antonio Lopardo*** **graduated in Hydraulic and Civil Engineering at La Plata National University in Argentina and received his Doctorate in 1968 from Toulouse University. Since 1969 he has worked at the National Water Institute (INA) in Argentina, where he has taken different positions: Head of the Research Team, Director of the Hydraulics Laboratory, Scientific Manager and Director. He has participated in hydraulic modeling studies of many large dams, and delivered post-graduate courses in Argentina, Colombia, Paraguay, Brazil, India and Spain. He served as Chair of the IAHR LAD and as member of the IAHR Council; he is a member of the National Academies of Engineering and, Physical and Natural Sciences of Argentina. He has published more than 200 articles on macro turbulent flows, cavitation, local scour and hydraulic modeling**

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Since that meeting, I have never stopped contributing as an author or co-author to every IAHR LAD Congress, including this year's Congress in Lima. This is a record of 48 consecutive years. I feel then indissolubly joined to this event and my career in applied research and technological development can be followed easily by simply following over the years the titles of the topics of my contributions in these Congresses.

Those romantic and rebellious young people of the late sixties had an Herculean task to fulfill our vocation as engineers and teachers in hydraulic engineering over half a century of Latin American Congresses. The largest and most difficult task was to predict the impact of the continuous changes and to adapt ourselves to the increasingly fast and important advances of technology, without losing the essence of the basic hydraulic engineering sciences, the concepts of our teachers, the interest in experimentation and the commitment to serve society.

Figure 1. Attendance to the III IAHR LAD Congress celebrated in the cities Buenos Aires and La Plata, 1968

It was the year 2002, and as a President of the Regional Committee, I gave the inaugural speech of the Congress in La Habana. I felt then that I had fulfilled my dream and that my relationship with the activities of the LAD would finish quickly. Luckily, events did not turn that way, and even at this moment I am still planning some presentations in the near future.

Furthermore, apart from what I learned in all our congresses and the illusion of having contributed during their technical sessions, the most valuable thing was to have known and enjoyed the friendship of Lincoln Alvarado, Alejandro López, Francisco Domínguez, Eduardo Varas, Ramón Fuentes, Arturo Marcano, Julián Aguirre Pe, Luis Teixeira, Rafael Guarga, Nelson Pinto, Marcelo Marques, Jaime Iván Ordóñez, Raquel Duque, Ciro Menéndez, José Antonio Maza Álvarez, Nahún García Villanueva, Arturo Rocha, Julio Kuroiwa, Diosdado Pérez Franco, Cristóbal Mateos, Ramón Gutiérrez and José María Grassa, and many other young and not so young people from Argentina, the rest of Latin America and Spain. They are part of the most pleasant memories and doubtless of my biggest success through many congresses, beyond the experimental hydraulics, spillway design, cavitation by pressure fluctuations and macro turbulent flows. ■

# PLACING LATIN AMERICA'S WATER RESOURCES IN CONTEXT

BY ANGELA HENAO & ARTURO MARCANO

Latin America (LA) is one of nature's most blessed regions of the world! This subcontinent, with an area of around 17,840,000 km$^2$ and more than 400 million of inhabitants, represents 42% of the American continent and 12% of the total earth surface above sea level.

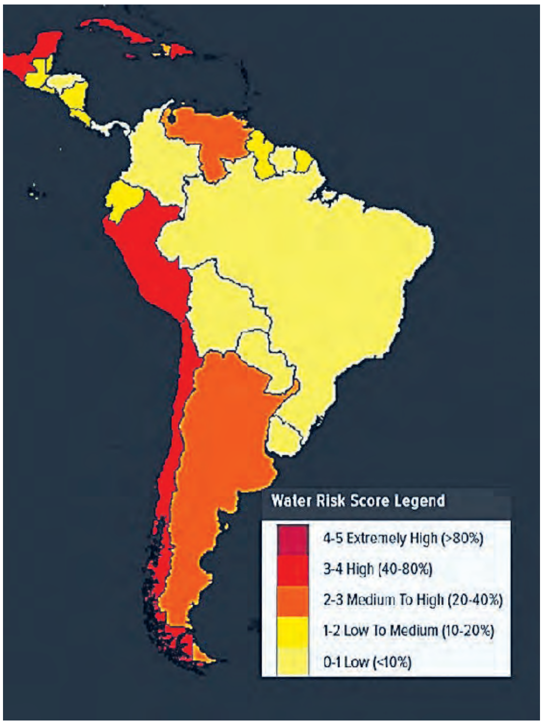
## Resumen

A pesar de las asimetrías existentes en muchas de sus regiones, Latinoamérica ha logrado que las metas del Milenio de disponibilidad de agua potable y servicios de tratamiento, hayan sido cumplidas en buena parte. En general, lo ha hecho mejor que otras regiones en desarrollo. La Gestión Integrada de los Recursos Hidráulicos (GIRH) tiene el potencial de crear resiliencia de los sistemas y por ende mejorar la seguridad hídrica. A partir del 2015 se han planteado los 17 Objetivos del Desarrollo Sostenible, que requieren de una nueva agenda que incluye: eficiencia en el uso del agua, recuperación del agua, reuso de aguas servidas, calidad de agua, sostenibilidad de la infraestructura hidráulica, desastres naturales, tecnología de agua, manejo de los servicios de ecosistemas del agua, empoderamiento del ciudadano, adecuado manejo de los recursos hídricos, y una gobernabilidad por parte del liderazgo de la sociedad; en otras palabras, aplicar la GIRH pero bajo el paraguas del Cambio Climático.

Although its population is just 6% of the world's population, LA is home to almost half of the planet's biodiversity and according to UNDP (2010) it has more than a quarter of its forests, making it the greatest endowed area of natural capital in the world with the potential to become the world leader in environmental services, such as for example, carbon capture and sequestration. This potential can be translated into forest bonds, tradable biodiversity certificates or ecosystem service certificates.

LA is considered the biological region with the most diversity on earth. Six of LA's countries (Brazil, Colombia, Ecuador, México, Venezuela and Peru) hold more than 40% of the world's biodiversity and LA has the second-largest barrier reef ecosystem in the world from Mexico to Honduras.

In the region, water is not a problem. The subcontinent has as much as 28-30% of the world's freshwater resources and 24% of the world's arable land. It contains three of the largest river basins in the world: the Amazon, the Orinoco and Río de La Plata, and the Guarani aquifer, one of the world's largest groundwater bodies, shared by Argentina, Uruguay, Brazil and Paraguay. The Global Water Partnership (GWP) estimates that LA contributes 11% of the value of world food production.



In the zone between the Pacific Ocean and the Andes, there are some of the planet's most humid areas such as Chocó in Colombia, where rainfall can be larger than 9,000 mm per year, but at the same time there are zones like the Atacama desert in Chile, which is so dry that it has not rained there at all for more than 100 years. The average precipitation in LA is in the order of 1,500 mm per year (50% more than the mean world value) but with a highly non-uniform distribution. The same applies to the annual evaporation with an average of 850 mm and extremes between 300 mm to 1,300 mm. Although the average annual availability of water is around 43,800 m$^3$ per person, which is a huge amount, this water lies away from the areas of consumptive demand. In Peru with an average of 62,500 m$^3$/person/year and 22% of the country population living in rural areas, just 79% of the people have access to potable water. On the average, considering urban and rural areas, 21% of Peruvians have no access to water supply services, 37% have no basic sanitation facilities and only 24% of total domestic wastewater is properly treated. There are imbalances in water availability in areas of Argentina, Bolivia, Chile and Venezuela as a consequence of the uneven distribution of resources, population and economic activities. In 2004, almost 13% of LA's population (71.5 million of people) did not have access to safe water supply, of which 63% lived in rural areas (IDB, 2004, Magrin 2007), dependent on rainwater and therefore being vulnerable to droughts. In 2015 the percentage of people without access to safe drinking water supply had been reduced to 5% of the overall population and 16% of the rural population (UNICF/WHO, 2015)

Around 5 million km$^2$ of land are arid or semi-arid, mostly in north and central Mexico, north east of Brazil, and along the Pacific coast from Peru to the northern part of Chile, in the Atacama desert.

As water demand increases with time, so does contamination and conflicts between users. The result is water stress on the freshwater ecosystems.

### The Millenium Development Goals (MDGs)

The Millennium Summit in New York in September 2000 was the largest gathering of world leaders in history. It adopted the UN Millennium Declaration which set in motion a new global partnership to reduce extreme poverty. In 2001 the UN Secretariat published the eight Millennium Development Goals (MDGs). These goals were devised not by governments through an open debate, but by a working committee mostly formed by members of international lending agencies.

The MDGs were a roadmap for how the world development should be by the year 2015. They were not a legally binding instrument or a formal UN resolution, but in practice they acquired a politically and morally compelling character. Eight sets of goals were defined and a series of related indicators were used to measure the progress towards achieving each of the targets. The overall progress in LA was positive, but not for all the goals.

For the environment MDGs achievement in LA, 2012 emissions of greenhouse gases were 7.7 ton/year per capita, larger than the world average of 6.7 tons. On the other hand there was a reduction in the use of substances that cause depletion of the ozone, and the conservation legally protected areas increased from 8.8 in 1990 to 23.4 % in 2014.

The region reached the drinking water goal in 2010 with 95% of the LA people having access to safe drinking water. With respect to improved sanitation facilities, the percentage of people with it went from 67% in 1990 to 83% in 2015 almost reaching the target of halving the percentage of people without it by that year (UNICEF/WHO, 2015). Whilst these achievements are true for the regional average, there is large variation from country to country, in the degree of the achievement of the goals. Still in rural areas the access to safe water can be as low as 48% in Haiti, 69% in Nicaragua, 79% in Peru, or as high as 95% in Paraguay. Trend indicators show a very serious deterioration of the environment and a depreciation of natural capital with deforestation increasing in countries were it seemed to be controlled.

In summary, the countries of LA have done better than other developing regions but they need to do much more, and need to consider some of the emerging problems, such as climate change.

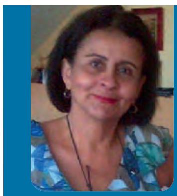
### The Sustainable Development Goals, (SDGs) and The 7th World Water Forum

Year 2015 is over and so are the MDGs. In September 2015 the post-2015 development agenda emerged, including the set of "Sustainable Development Goals (SDG)". 17 goals and 169 objectives were adopted officially by the United Nations in January 2016. The scope of the SDGs is broader aiming at reaching the three dimensions of sustainable development: economic development, social inclusion and protection of the environment. The SDGs include explicitly climate change as an aspect that has affected the development reached until now. SDG 13 addresses this topic directly.

SDGs consider water in a more comprehensive and integrated manner than the MDGs, focusing on taps and toilets including things from drinking water availability and sanitation to quality and broader water-related ecosystem health and their relationship with climate change.

SDGs are more than a checklist, they should generate projects that would help to reach the goals. In the 7th World Water Forum (WWF) that took place in Korea the motto was "FUTURE WATER TOGETHER" making reference to the importance of *"the global community as a whole moving together into a better future of water and green nature"*. The 8th WWF will be in Brazil in Latin America in 2018.

According to the surveys carried out during the Forum the main problems we are facing are climate change, disasters and integrated water resource management.



***Angela Henao*** **is a Hydraulic Engineer with 39 years of experience. She started working with the Environmental Agency of Venezuela and after finishing her PhD in Water Resources went to CIDIAT, an Institute of 4th level at the University of Los Andes where she is in charge of the Master Program in Water Resources Planning. She is a specialist in water resources planning and management, information systems, and water and climate change.**

***Arturo Marcano*****, IAHR Vice President. He worked since 1977 in the construction and operation of the Lower Caroni Hydroelectric Development (17,000 MW) in Venezuela, where he was Head of EDELCA Hydraulic Laboratory and Department. He has worked in Hydro projects in Central America, Africa and Asia. He lectures Hydraulic Engineering and Hydropower in Undergraduate and Graduate Courses at Universidad Católica Andrés Bello and Universidad de Los Andes, in Venezuela.**

### Water and climate change

Climate change impacts everything, water being the primary medium through which climate change influences ecosystems. Climate change affects all countries in the world. Studies indicate that under climate change and for any

of the scenarios that the IPCC formulated, extreme values (droughts and flooding) will be more intense and the assumption of stationarity in climatological records needs to be abandoned. Coastal zone management, water supply, infrastructure, agriculture, estimation of demand, rainfall and rainfall distribution in time, runoff, are all going to be affected. The most affected probably will be those who are most vulnerable.

More than ever, integrated water resource management under present climate variability has to be incorporated into LA country planning. Water resources and how they are managed impacts almost all aspects of society and every sector of the economy. Energy crises in some countries are not a product of climate change, but climate change is making the situation worse. If no measures are undertaken all that has been achieved could be lost.

The United Nations Framework Convention on Climate Change (UNFCCC) is responsible for the Kyoto Protocol, and for the international agreement which commits its parties by setting internationally binding emission of greenhouse gases reduction targets.

At the Paris climate conference (COP21) in December 2015, 195 countries adopted the first-ever universal, legally binding global climate deal, setting a global action plan to limit global warming to below 2°C.

LA must now evaluate the possible impacts, vulnerabilities, and risks associated with climate change and take measures on adaptation and mitigation. The use of integrated water resources management incorporating these aspects has the potential to create resilience and enhance water security.

### Towards a new water agenda for latin america

It is clear that there is a need for a new water agenda for Latin America. An agenda that incorporates water efficiency, resource recovery from water and wastewater systems, water quality, sustainability of water infrastructure, natural disasters, smart technology for water, understanding and managing ecosystem services for water. All of that, and more, must be considered under the umbrella of climate change. This agenda must include getting the public involved in such a way that citizens feel empowered, and become more aware of the need for improved management of water resources, and work to influence their leaders to improve governance. ■

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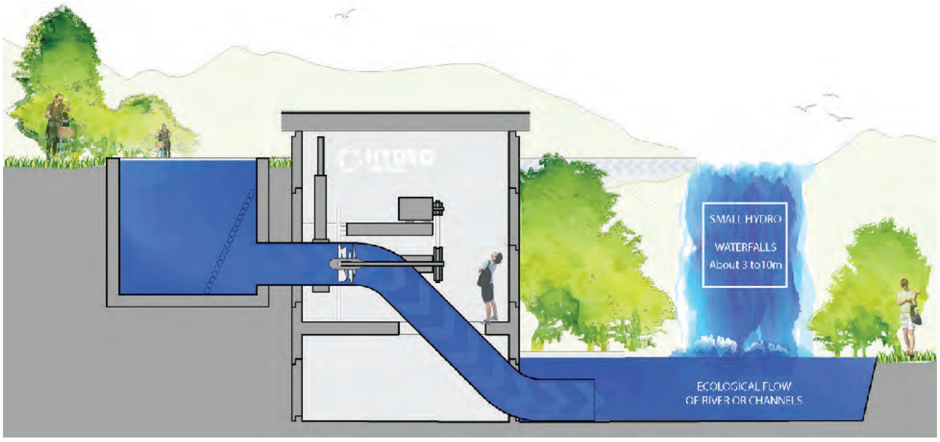

# HISTORIC EXAMPLES OF WATER MANAGEMENT IN PRE-COLUMBIAN ANDEAN SOCIETY

BY JULIO M. KUROIWA

## Resumen

En este artículo se presentan algunos ejemplos del manejo del agua en culturas andinas precolombinas que ocuparon el territorio entre el Sur de Colombia hasta el Norte de Chile y Ecuador y que posteriormente fueron conquistados por el Imperio Inca. Se presentan ejemplos de manejo de agua para fines agrícolas en Caral (3000 A.C), las galerías filtrantes de la Cultura Nazca (200 – 800 D.C.) y las obras hidráulicas en las ciudadelas de Macchu Picchu y Tipón del Imperio Incaico (1450 D.C.). Estas soluciones de ingeniería podrían inspirar soluciones a problemas hídricos en el mundo actual.

Figure 1. Truncated pyramid in Caral, ancient site located 200 km North of Lima. This city was built around 3,000 B.C. and is considered the oldest city in America

Pre-Columbian American societies have been known to have developed capabilities in water management, particularly in those regions where this resource is scarce. This article summarizes some of the evidences of water management and engineering techniques in the Andean cultures that occupied the territory that spans the area from Southern Colombia to Northern Chile and Argentina and that, eventually, were assimilated or conquered by the Inca Empire.

We know that the first American urban center emerged in the Supe River Valley approximately 5000 years ago. This urban center was built by the Caral Civilization and is located 200 km North of Lima, Peru's modern-day capital. This culture was contemporary with the Sumerian Civilization in Mesopotamia, the Harappa Civilization in India, the Chinese Civilization and the Egyptian Civilization in Northern Africa. However, the Caral Civilization developed in complete isolation while there is evidence that Asian and African cultures interacted. During the era of the Caral Civilization irrigation canals and water reservoirs were built and terraces were formed to contain earth. Farm fields were fertilized with seabird manure and fish head waste. The Caral Culture influenced the Andean cultures that emerged in the next millennia. Evidence has been found in artistic manifestations of the design of civil works (Shady-Solís et al., 2006). Figure 1 shows a truncated pyramid built in the ancient city of Caral.

In Pre-Columbian Andean history there have been periods of marked territorial expansion of a particular culture as evidenced in construction and manufacturing techniques, the arts, etc., in the areas of its influence. These periods are called Horizons and where followed by periods

Figure 2. Cobble walls of Nazca canal downstream of filtration galleries. This irrigation structure is still in use

of division called Intermediate periods in which local cultures were formed.

The Nazca Culture flourished between the first and the eight century of our era in the so called Early Intermediate period along the Central Coast of Peru. The Nazca people built systems to divert underground water to channels that, in turn, irrigated fields and supplied water to small cities. Rodríguez-Zubiate (2005) summarized a study conducted by Delgado-Gutarra (2003) in which the latter was his advisee. In this research project the design and construction techniques of the filtration galleries built by the Nazca people were analyzed. Underground water was intercepted before it entered the alluvium substrate of the Aija River, which was dry 10 months a year. Trenches were excavated in the Nazca desert to capture underground water coming from higher areas. The uppermost reach of the trenches was covered and the downstream reach was left open forming filtration galleries whose water was conveyed to irrigation canals and provided supplies to population centers. The cross section was approximately rectangular and its base measured between 0.4 m and 1.8 m. The walls of the filtration galleries were covered by cobbles that both provided stability and were permeable enough to allow underground water to pass through the openings as seen in Figure 2. The gallery “roof” was either made out of stone or the wood of a local tree called Huarango (Prosopis pallida). Maximum depth of the galleries was 6.8 m. Access to the filtration galleries for inspection and maintenance was allowed by short spiral walkways as seen in Figure 3.

Wright and Valencia-Zegarra (2000) and Wright (2006) analyzed two important centers of the Inca Empire (Late Horizon) from the engineering viewpoint: Macchu Picchu and Tipon. Macchu Picchu is a small Inca city, now a World Heritage

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Figure 3. Spiral access hole to filtration galleries in Cantayoc, Nazca. It is located 450 km South of Lima

Figure 4. Rock canal and waterfall in Tipon, a small Inca urban center located 24 km South of Cusco City. Notice that energy losses are induced upstream of the waterfall by creating a sinuous path. Consequently, the jet trajectory stays close to the stone wall

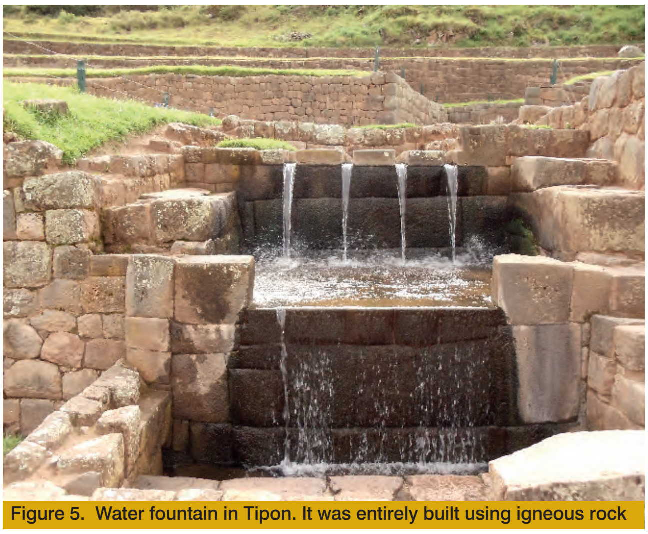

Figure 5. Water fountain in Tipon. It was entirely built using igneous rock

Site, discovered by Hiram Bingham in 1911 (Bingham, 1913) and is located in southeast Peru in the Cusco Region. Water was supplied by a spring located uphill in a mountain right next to this archeological site. Analysis of water samples taken during the research conducted by Wright and Valencia-Zegarra showed that water quality is good even by today's standards. Water was conveyed by a 749 m long canal built with granite rocks. Clay was used to waterproof its base. The main canal supplied water to fountains built in series. The geometry of the fountains allowed the placement of a large water container called "aribalo" used to carry water to the houses. Macchu Picchu also had a very efficient underdrainage system that kept water away from the ground surface even during very intense rainfall events. During excavations conducted at Macchu Picchu's main plaza it was shown that the Inca engineers had provided underdrainage by placing stone chips (in essence, the byproduct of rock carving) under this open area. Terraces, locally called "andenes", provided stability to the mountain by controlling erosion and landslides and to allow cultivation of crops. Retention walls and gravel underdrains were included in the terrace design. Wright and Valencia-Zegarra (2000) indicated that crops partially provided food supply to the city and it is certain that most of the food supply was provided by nearby farms. Figure 4 shows a canal in Tipon. Notice that alignment changes rapidly just upstream of the waterfall to induce head losses and diminish the spread of the jet. Figure 5 shows a water fountain at Tipon.

Andean Pre-Columbian Civilizations ingeniously solved water resources related problems, by adapting engineering techniques to local conditions and, in essence, without negatively affecting the environment. These examples of good planning and engineering may provide hints to solve water-related problems in the present time! ■

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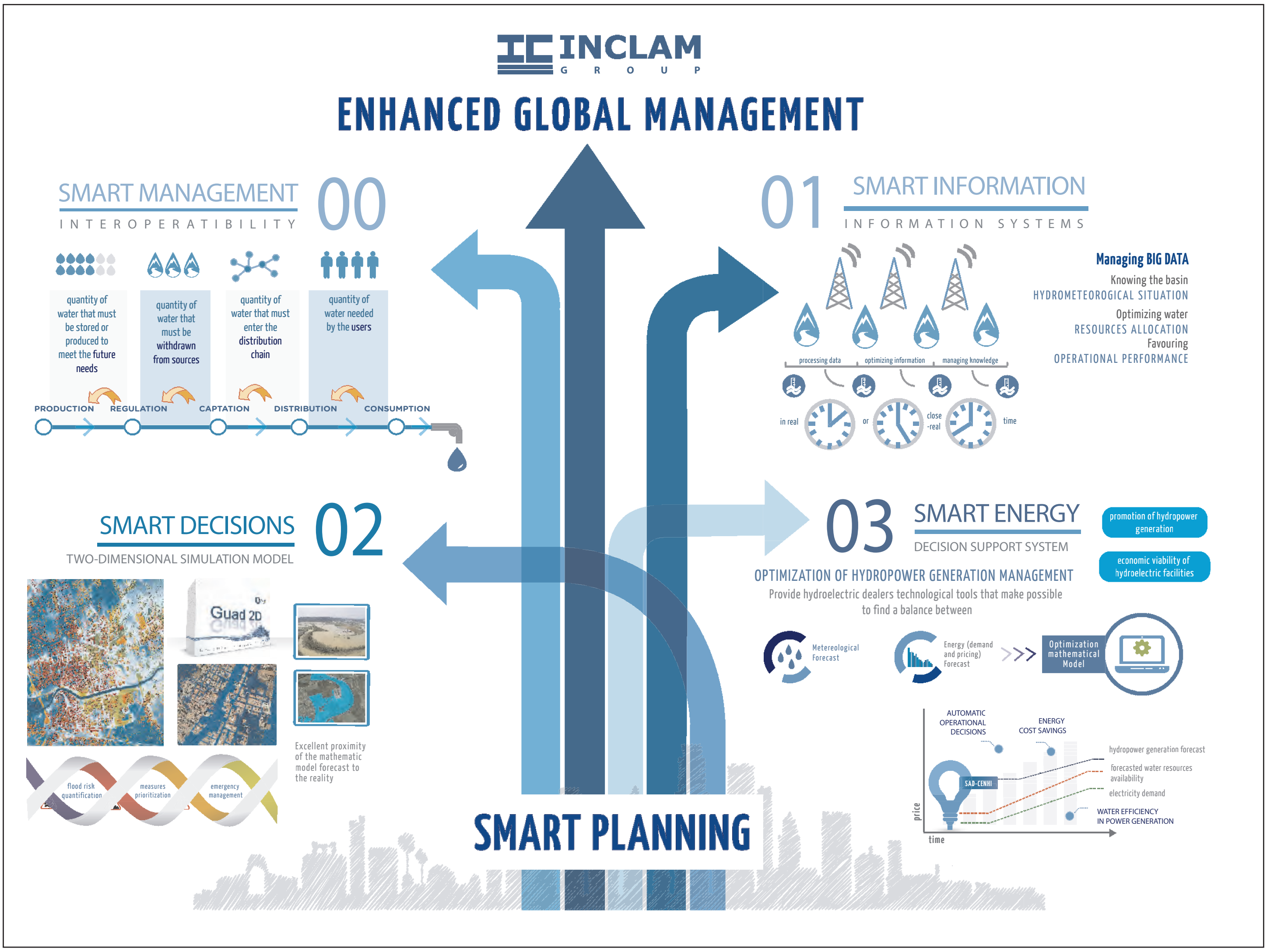


# THE WATER CRISIS IN COLOMBIA

BY MYRIAM VICTORIA NOVOA PINEDA & JAIME IVÁN ORDÓÑEZ ORDÓÑEZ

## Resumen

Muchos países de Latinoamérica sufren actualmente una crisis del agua, por falta de una política integrada de manejo del recurso, dentro de los planes de desarrollo sostenible. Esta crisis se agrava con el cambio climático y las modificaciones antrópicas, anunciando una vulnerabilidad creciente en la disponibilidad de agua. La crisis es patente en muchos problemas ambientales como la pérdida de calidad de las fuentes hídricas, la pérdida de vida útil de los embalses debido a la sedimentación, la degradación de los humedales debido a la desecación, los rellenos, y la contaminación, y las deficiencias en abastecimiento de agua y saneamiento básico, irrigación, y navegación.

Water is the most important resource of humanity: life is not possible without water. When water is scarce, drought torments plants, animals and people equally; in fact, it affects all living organisms. When water is too abundant, disasters due to flooding, landslides and debris flows threaten all living beings in these areas. Even so, water does not seem to be one of the leading elements in national planning in Latin America. Development plans call for the construction of infrastructure, transportation networks, telecommunications, energy generation, mining and oil production, and call for industrialization at the level of more developed countries. These are viewed as the vital elements of development, but they do not place much emphasis on water infrastructure.

Climate change is already recognized as a factor for planning, but relatively little attention is paid to the fact that anthropogenic land changes have a more drastic effect than climate change on the availability of water. The later usually occurs at a faster pace, while climate change occurs over longer time scales. Within a few months of construction, a road, railway, dam or dyke can completely modify the drainage patterns in a given area, causing dramatic changes in the regional availability of water before climate change has any effect on it. A decrease in the availability of potable water and the implementation of basic sanitation to avoid contamination of water sources and the proliferation of water borne diseases, can rapidly affect people's quality of life.

The water crisis and its management and planning are of paramount importance today in the field of water resources in Latin America. This is especially true in Colombia where, despite the relative abundance of water, many problems hamper its conservation and sustainable development. Water resources development must be reoriented on the basis of past lessons, accounting for present challenges and various proposals for their solution, considering the demand and supply of water, and the pressures of climate and anthropogenic land use changes.

### Potable water and basic sanitation

Even though significant progress has been made in the supply and treatment of water for the larger urban centers, many cities still lack truly potable water due to the combination of the high cost of treatment plants and filtration systems, and the lack of protection of most watersheds from human encroachment and pollution. The rural sector is almost completely abandoned, due to the lack of proper strategic planning for water supply and basic sanitation infrastructure in rural areas.

Large infrastructure projects, which appeal to politicians, are often built at great economic cost, utilizing resources needed to formulate effective plans for water development, which could quickly improve people's quality of life. There is a great need for more coordinated efforts in optimizing economic spending on attainable short term goals, to achieve adequate levels of water quality and quantity for all communities and a sensible improvement in the quality of wastewater effluents.

### Land reclamation for agriculture

Management of water for agriculture and husbandry in Colombia has not been successful in the last 50 years, despite large


Figure 1. Intake of the Saldaña River; Tolima Triangle irrigation project, Colombia

Figure 2. Sogamoso river Hydropower project, Magdalena-Cauca basin, Colombia

manpower costs and monetary expenditure. There are few efficiently operated irrigation districts, few storage reservoirs, and a worrisome backwardness in the agricultural sector. The lack of proper research and development efforts in the design of suitable intake structures and distribution systems, control of water losses, channel and intake sedimentation and increasing costs of operation and maintenance reduce the real extent of irrigated lands, and minimize production.

In Colombia, planners spend more time experimenting with complicated administrative schemes for the equitable fund allocation among regions, than in making proper evaluations of water and soil resources, in order to detect real needs and potentialities for agricultural development, in accordance to the availability of markets, the profitability of products, and the required finances; too much emphasis is placed on economic and legal constraints, and not much on technical support for planning.

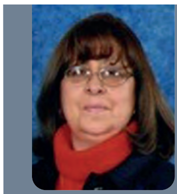
## Risk management for flooding and natural disasters

The serious flooding emergency of the 2010-2011 rainy season, clearly revealed the many deficiencies in risk management for natural phenomena in Colombia, which are also most likely extensive in other countries in Latin America. These deficiencies frequently are due to the lack of knowledge about the functioning of natural systems, (particularly those of tropical and subtropical regions), and the anthropogenic effects caused by infrastructure projects. These projects are usually planned with limited areal scope and no holistic conception on the use of natural resources, introducing vulnerabilities that much exceed those that are purely natural.

## Sediment management in reservoirs

The absence of adequate regulation for the management of sediments in large reservoirs, leads to loss of storage volume and the early end of the useful life of projects for water supply and hydropower generation. These problems must be faced, as it is done in more developed countries, such as the European Union, within a legal framework to allow the evacuation of sediment from the reservoirs, with periodic use of bottom gates, or other available means proven physically and environmentally safe.

Privatization of energy generation systems, as has been going on for example in Colombia, since 1996, debilitates national engineering practice, which created and operated these projects efficiently for years. International owners are mostly interested in short term profits, and not in the long term - costly maintenance of reservoirs, dams and appurtenances - which can lead to the early loss of important infrastructure in which countries spent money, manpower and human lives.



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## The protection of water bodies and wetlands

Wetland degradation is usually brought about by the construction of dykes and landfills that obstruct water flow, affecting the development of aquatic ecosystems. Typical of this degradation is the problem facing the “Ciénaga Grande of Santa Marta”, in Colombia, the largest coastal lagoon in Latin America, with over 500 square kilometers of water surface area and peripheral mangrove wetlands. The lagoon and its surrounding areas are under extreme anthropogenic change stress due to large illegal landfills, and the construction and enlargement of a major roadway along the sand spit that created it.

Loss and degradation of wetlands, by filling, pollution and interference with its water sources, interrupt and diminish their capacity to perform their physical and biological functions: the storage of water and mitigation of floods, the retention of sediments and nutrients, the growth of medicinal plants and organisms, aquifer recharge and subsoil salinity control, absorption of contaminants, and the maintenance of trophic chains essential to sustain the life of all living organisms.

### Inland navigation and its effect on river contamination

Contamination of river waters is one of the major causes of the increased costs in withdrawal, conveyance, distribution, and particularly in water treatment, for multipurpose uses. In Latin America today, most river pollution is caused by untreated discharge of wastewater from agricultural lands and urban concentrations. Industrial pollution is still incipient, although the risk persists from the lack of control of industrial effluents. An additional risk is imposed by the much heralded need for fluvial transportation of industrial goods, as it is promoted now for the Magdalena River of Colombia, 29th in the list of largest alluvial systems of the world. Fluvial navigation of people and normal loads could benefit riverine communities, but only industrial fluvial transportation has the unequivocal support of economic planners, who consider it as the only economically profitable part of inland navigation. The reason claimed is the assumed low cost in transportation of bulk materials.

It is worthwhile to remember that the most contaminated rivers in the world are those in which large industrial navigation systems exist. Most fluvial bulk cargo shipments consist of dangerous materials such as crude oil and its derivatives, unprocessed minerals from mining operations, fertilizers, pesticides, and other chemical materials that contain dangerous substances that could run havoc when directly discharged in water sources by accidental spills. The safety of people and not the costs of transportation should be the deciding factors; when the cost of cleaning of spills is considered, the cost of industrial navigation does not look so profitable.

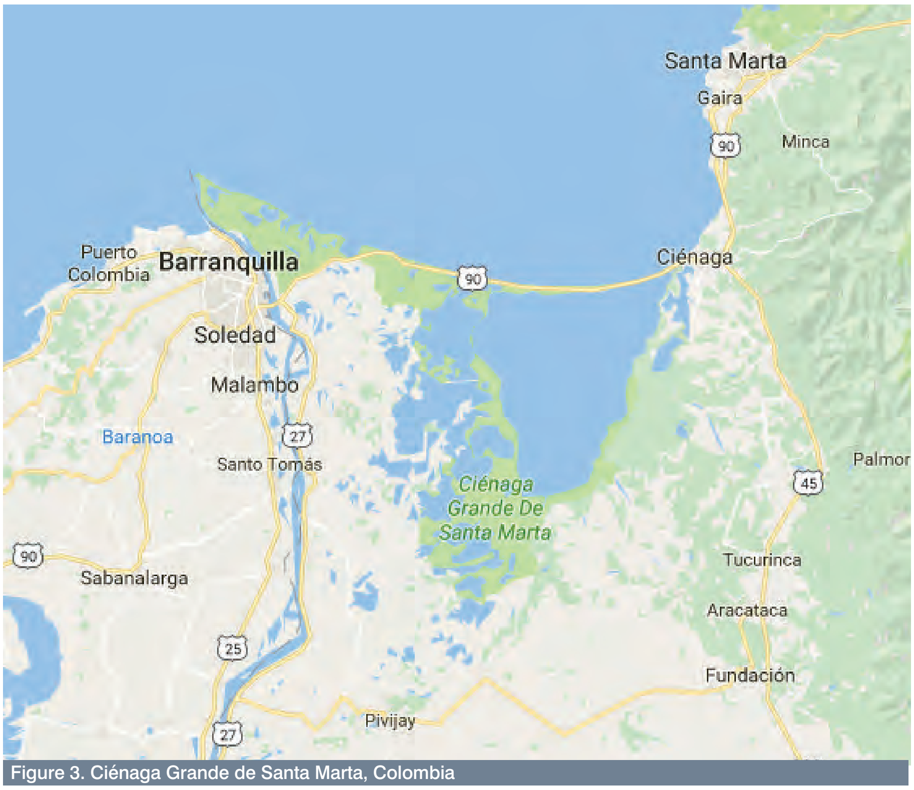

Figure 3. Ciénaga Grande de Santa Marta, Colombia

### Management of water resources

The water crisis is brought about by society's disregard for the need to develop instruments for an integrated policy on water management within the plans for sustainable economic development. This policy should also take into account the present challenges of climate change and anthropogenic land use changes, making the countries more vulnerable to the spatial and temporal variability of water supply.

The lack of adequate criteria for the management of water resources, generates environmental problems, and affects the quality of life. It also leads to the present deficiencies in water supply infrastructure, distribution networks, and potable and wastewater treatment plants in both urban and rural areas, infrastructure for irrigation projects, and the security of fluvial navigation.

Some of the most common environmental problems are the continuous degradation of water quality in rivers and other water bodies, the loss of reservoir life to sedimentation, and the degradation of wetlands by desiccation, landfilling and pollution. Education of water users and increase in public awareness on water management issues is also needed.

Socioeconomic, cultural and environmental sustainability must prevail, over the construction of large infrastructure works in development plans. There is not much worth in having electricity to illuminate the poverty of marginalized urban and rural communities; it does little service to the people on the roadsides, and along railways and rivers, to see luxury vehicles and huge loads of food, fuels, and riches of all sorts, crossing their paths at high speeds towards the well-served tables of the most fortunate, in the large and far away urban centers. Development cannot be achieved by reproducing the infrastructure of the developed nations; it requires well-nourished communities of educated people, confident, and hopeful of a dignified future, with work, robust economic growth, and an environmentally sustainable future. If a long term policy approach to water management with a holistic view of development is not implemented soon, the consequences could be disastrous and changes could become irreversible. ■

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# THE 1999 DEBRIS FLOW DISASTER IN VENEZUELA: WHAT HAS BEEN DONE FOR RISK MITIGATION PURPOSES?

BY JOSE LUIS LOPEZ & FRANCOIS COURTEL

Thousands of landslides were triggered by heavy rainfalls along the northern coastal range of Venezuela in December 1999. These landslides generated debris flows that washed away a number of towns situated on the alluvial fans of the state of Vargas, killing thousands of people and causing the worst natural disaster in Venezuelan history. This paper shall describe and critically review the mitigation measures that have been implemented to reduce the risk of flooding by debris flows in this region.

### Description of the 1999 debris-flow event

The state of Vargas is located at the foot of the Avila Mountain range on the northern coast of Venezuela and borders the Capital District of Caracas to the south. A steady but low intensity rainfall started in the coastal and mountain area at the beginning of December, 1999. It was followed by heavy precipitation from the 14th to 16th December 1999, amounting to 900mm in three days. Almost simultaneously, 24 streams generated debris flows on the morning of December 16. Large quantities of sediment, woody debris and fractured rocks were eroded upstream and transported by the flows down the valleys, causing massive destruction in the urban areas developed on the alluvial fans. The total amount of sediment deposited has been estimated to be in the order of 20 million m$^3$ (Lopez et al., 2003). The deposition of debris flows created a new coastline in the State of Vargas and the amount of land gained from the sea was estimated to be about 150 Ha (Figure 1).

## Resumen

Miles de movimientos en masa se produjeron en la región norte costera de Venezuela debido a las intensas lluvias de diciembre de 1999. Los deslizamientos generaron aludes torrenciales que bajaron de la montaña y destruyeron pueblos y urbanizaciones enteras que se habían desarrollado en los abanicos aluviales del estado Vargas, matando a miles de personas y causando el peor desastre de origen natural en la historia del país. Este artículo se concentra en la descripción y revisión crítica de las medidas de mitigación que han sido implementadas para reducir el riesgo de desastre en esta región.

### An overview of adopted mitigation measures

After the 1999 disaster, an integrated approach for risk mitigation of debris flows was designed, including structural and nonstructural measures, aiming to reduce both hazards and vulnerability. These measures were applied mostly to the intermediate and lower parts of the catchments, since the upper part belongs mainly to the Avila National Park and has little human intervention.

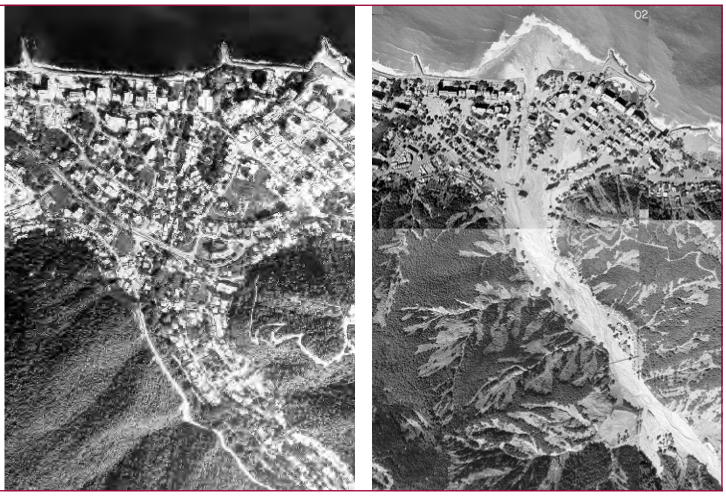
Structural measures consisted mainly of retention dams built in the canyons and channel works carried out in the alluvial fans, tending to limit or suppress the consequences of the debris flow phenomena. Non-structural measures aimed to reduce the vulnerability with land use regulations, warning systems, contingency plans, and by improving education and awareness, and the institutional empowerment. Hazards maps were delineated, using the Flow-2D model, to demarcate areas according to different ranges of flow velocities and depths reached during debris flows events, information required to prepare a land use zonification. The most relevant mitigation measures are briefly discussed herein, analyzing its actual state and assessing their effectiveness to mitigate future events.

### Sediment retention dams

In 2001, government authorities initiated an intensive program to build sediment control dams and channel works in most of the basins, to protect the downstream populated areas. By 2008, 24 streams had been channelized and 63 dams had been built in the canyons of the torrents. Basically, 37 of the structures are closed-type dams and 26 are open-type dams. Closed-type dams are solid dams that completely intercept the stream flow and the sediment material. Open-type dams have openings in the structure, either windows or slits, to intercept only the coarse sediment particles (boulders), allowing the finer sizes to be transported downstream. According to the type of material, 44 of the dams were made of gabions, 14 of concrete, 3 of steel pipe and 2 made of flexible barriers (steel rings). The maximum height of the dams was 11 m, and the minimum height, 3 m.

The dams upstream on the Cerro Grande River were subject to a rapid pace of sedimentation, even the open dams, due to the large sediment yield and woody debris transported by the streams. After the 1999 event, large amount of loose sediment remained in the small channels located upstream and on the slopes of the

Figure 1. Aerial view of the town of Tanaguarena, settled on the canyon and alluvial fan of the Cerro Grande River, showing the situation before and after the 1999 disaster



mountain. Succeeding floods, even with small flows, were able to easily erode and remobilize the sediment particles, transporting them to the downstream reaches, quickly filling the dams. Not only sedimentation was taking place however, as significant bed erosion was observed in some downstream reaches, due to the clear water, or "hungry water" effect as sediment was retained upstream. Figure 2 depicts these two processes in the bed of the Piedra Azul stream. Near dam #2, the photos taken after the construction of dam, and the surveyed bed profiles taken both before and 3 years after construction indicate deposition of sediment upstream and general degradation downstream. A 3 m bed lowering was measured at the foot of the dam. In summary, regarding sedimentation, about 50% of the Vargas dams built between 2001 and 2007, have lost their capacity due to full deposition of sediment. Regarding erosion and abrasion, 4 dams and 3 counter-dams have been destroyed, 2 dams present important damage and 11 present minor damage.

### Land use regulations

The 1999 disaster showed that hundreds of dwellings have been exposed for years to large debris-flow hazards, due to lax land use policies. A previous lower-magnitude event in 1951 affected the same region, but the memory of its impact was not enough of a deterrent factor for the aggressive urbanization at that time. Thus, the disaster zone was defined as an "Environmental Protection and Recovery Area" and hazard maps were delineated in 2002 using modeling techniques (Flow2D) and GIS maps. A Management Plan was developed in 2005 and it was complemented with an Urban Zoning Plan in 2007, which established two regulated zones in the affected areas. In the first zone, a fringe along both margins of the rivers was defined where no permanent occupation was permitted. This fringe was already defined by the Venezuelan Water Law, but it was generally not respected, especially by informal dwellings, neither in the Vargas State nor in the rest of the country, explaining the frequent damages occurring by flooding. In the second zone, almost all kinds of land uses, including residential, were allowed under the condition that all mitigation works (dams and stream channelization) were completed and the buildings were modified to address any residual hazard. Many factors altered this planning. First, the control works did not follow the original program, so in many rivers the existing works differ noticeably from the original design. Second, as described above, their integrity has been degraded with time and their capacity to mitigate the impact of future debris flows has been undermined.

Sixteen years after the disaster the process of occupation and reoccupation of the affected areas is noticeable. This process was initiated by inhabitants who stayed in place after surviving the disaster, then by others who illegally occupied abandoned buildings, or built new illegal structures, several being in the prohibited river fringe. In the last few years, as part of massive housing construction programs, the government itself constructed dozens of apartment blocks in zones under restriction.

### Monitoring and warning systems

A novel experimental monitoring and early warning system program was designed in 2006-2007 to protect the western part of the state (Catia la Mar, 100,000 inhabitants). A network of 19 rainfall and flow stations was implemented in three basins (Tacagua, La Zorra and Mamo). The main components of the Data Interpretation System were a rainfall-runoff hydrologic model, running in real time, and a permanent graphic evaluation of debris-flow hazard that used two rainfall indicators representative of the short-term rainfall (recent hours) and the long-term rainfall (recent days), respectively. Based on past observations, a rainfall threshold line that would cause debris-flow events was established. Due to the small size of the catchments, it was necessary to complete the network data with a rainfall forecast broadcasted by the Venezuelan Weather Service, based on extrapolation of precipitation patterns from the existing regional radar. Unfortunately this is not yet available, and the lack of forecast greatly limited the efficiency of the system. Furthermore, deficient maintenance and vandalism resulted in great deterioration of the rainfall monitoring network, thus the Warning System is not currently operative.

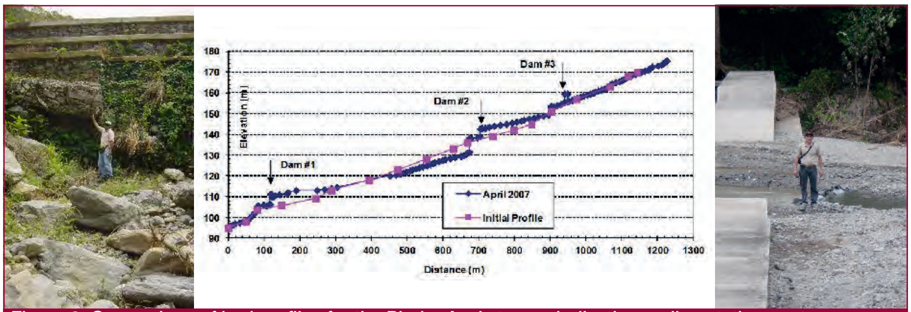


Figure 2. Comparison of bed profiles for the Piedra Azul stream, indicating sedimentation upstream of dam #2 (right picture) and general degradation downstream of the same dam (left picture)

***Jose L. Lopez* is a Professor and former Director of the Institute of Fluid Mechanics, at the Universidad Central de Venezuela. His research interests are in the field of river mechanics and mathematical modeling. He edited a book "Lessons learned from Vargas Disaster" which is considered the most comprehensive treatise about this extraordinary event.**

***Francois Courtel* is an independent consultant and Research Associate at the Institute of Fluid Mechanics, Universidad Central de Venezuela. He has served as a consultant for government agencies in the area of sanitation and solid waste. His current research interest lies in the study of hazards and risk management of floods and debris flows.**

### Conclusions

In spite of the fact that debris-flow mitigation measures implemented in the state of Vargas have reduced the vulnerability of the population, it is clear that more efforts are needed to guarantee an adequate degree of safety in the urban areas. The reoccupation of sectors affected by the 1999 and 2005 floods, the potential effects of global warming and climate change, and the rapid pace that control dams have filled up with sediment, suggest that a new disaster could be triggered in the region. More efforts have to be made to improve land use regulations and enforce the law to prevent reoccupation of areas subjected to high levels of hazard. New hazard maps should be elaborated taking into account the existing control works and their actual conditions. ■

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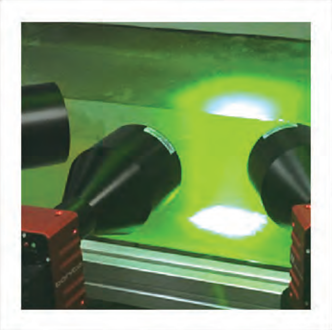


# PRIMARY ACTIONS IN THE FIGHT AGAINST WATER SHORTAGE IN BRAZIL

BY RICARDO DA SILVA MANCA, JOSÉ GILBERTO DALFRÉ FILHO & ANTONIO CARLOS ZUFFO

In Brazil, water shortage is not a problem exclusive to semi-arid and arid regions in the country's northeast. The crisis in the water supply sector in the country's southeast from 2013 to 2015 showed that, if water resources planning is not effective, there will be water shortages to the supply for the needs of the population (see Figure 1).

Figure 1. Cantareira System reservoir before and during the water crisis

Although Brazil is well known for its abundance of water resources, most of the water is found in the North region, where only a small portion of the population resides. In contrast, in the Southeast region, mainly in the São Paulo Metropolitan Region (SPMR), where approximately 20 million inhabitants live, and which accounts for 11 % of Brazil´s GNP, water contamination, the dependence on other river basins and the lack of contingency plans have contributed to an extreme water crisis.

The argument that the water crisis could not have been predicted in advance cannot be substantiated. During 2013, the rainfall index in the region was below average and, during the first quarter of 2014, it was lower than half of the normal. The Brazilian Urban Water Supply Atlas (ANA, 2011) warned that in 2015, considering the water availability, production and distribution and the infrastructure conditions, 55% of Brazilian cities and towns, such as São Paulo, Rio de Janeiro, Salvador, Belo Horizonte, Porto Alegre and Distrito Federal could face water supply deficits.

## Evaluation measures

Using multi-criteria analysis, Manca (2015) evaluated alternatives and opportunities for using water demand management to reduce the stress on the water availability in SPMR, according to the opinions expressed in a survey of specialists (Figure 2).

Based on this survey, "water reuse" (14.2%) was the most important feasible measure that could contribute to an increase in water availability in the region. Redirecting reused water to activities not requiring drinking water quality, such as car fleet washing, green areas watering, washing of sidewalks, patios and squares, would reduce the use of higher quality water. "Apparent and real losses reduction" came in second place with 13.3% according to the specialists interviewed. This result is confirmed by the need to reduce water losses, which range from 30% to 40% in the SPMR distribution system (Toneto Júnior et al, 2013). Considering the two most important measures for water demand management, water reuse and water losses reduction, there are some actions that should be listed, according to the

Resumen

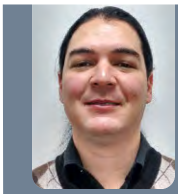
La crisis del sector de abastecimiento de agua en el sureste de Brasil, de 2013 hasta 2015, mostró que si la planificación de los recursos hídricos no se realiza de una manera sistemática y eficaz, no habrá suficiente agua para la población. La sequía prolongada, además de los problemas estructurales, fueron las principales causas de la escasez de agua en la región. La aplicación del análisis multicriterio con expertos del sector mostró las prioridades en esta región. Las pérdidas de agua en el sistema de distribución, alrededor del 40% en la Región Metropolitana de São Paulo deben reducirse. Además, la adopción de medidas para promover la reutilización del agua, disminuirá la necesidad de agua potable para fines diferentes del abastecimiento humano.

specialists. For water reuse, the most relevant factor is the “motivation for the use of reused water” (25.8%), as the water reuse does not rely on the rainfall and can be used for activities that do not require high water quality. In second, the specialists considered “other options in the water demand management” (21.1%) by comparing “water reuse” and “water losses reduction”, indicating that the two measures should be equally implemented. The third factor, “barriers to water reuse” (16.9%), refers to the lack of standardization in the sector. This shows that improving the sector regulation is extremely important. For water losses reduction, the factor with the greatest prevalence is the “barriers to losses reduction” (23.4%), due to the lack of financial support. Consequently, reducing water losses means contributing to the increase of “water availability” (12.0%) and represents one of the main “motivations to reduce water losses” in water shortage periods (11.3%).

## Impacts from the water crisis

The Cantareira System is a system of reservoirs, canals and pumps, with a storage capacity of 990 million of $m^3$ that transfer 33.0 $m^3/s$ of water serving around 8.8 million inhabitants in the SPMR.

In January 2014, the system had in storage only 23 % of its capacity. In May 2014, the system reached the dead storage volume level, requiring the rapid installation of pumps to extract water. Nevertheless, during 2016, the Cantareira System received rainwater above average. On April 6, excluding the dead storage volume, the Cantareira System was at 36,7 % of its capacity (SABESP, 2016).
In this context, the São Paulo state government declared the end of the water crisis in March 2016. However, considering that in 2011 the Cantareira System had around 67 % of its capacity and in 2012 48 %, to declare the end of the water crisis may have been premature. Therefore, this is the moment to prioritize actions of structural nature and to encourage water reuse by implementing standardization and reducing water losses by enlarging the funding, which, at the end, would increase water availability in the SPMR, thus reducing the search for new sources of water. Environmental issues must also be valued, as proper water treatment would bring benefits by reducing the pollution of surface waters and bringing water quality within regulatory standards. ■



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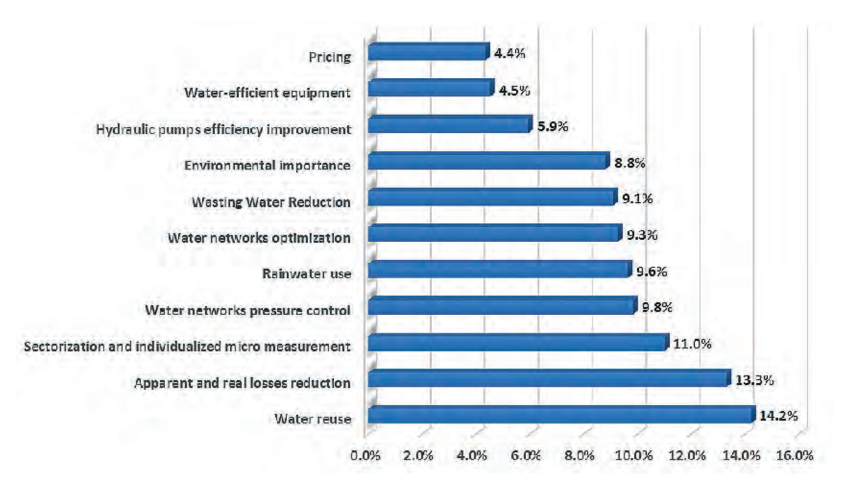

Figure 2. Main measures in water demand management for the SPMR

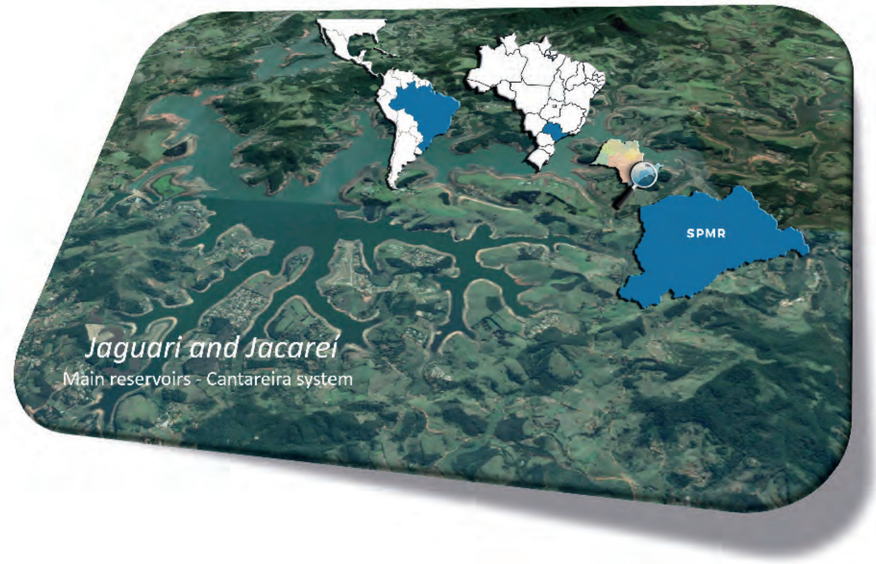

Figure 3. Cantareira System in São Paulo, Brazil

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# USE OF TECHNOLOGY TO MEET MEXICAN FOOD SECURITY FOR 2050 AND BEYOND

BY NAHUN HAMED GARCIA-VILLANUEVA & JAIME COLLADO

## Resumen

Se estima que la población mexicana crecerá 25% en los próximos 35 años, y el promedio de ingesta diaria de calorías se incrementaría de 2 000 a 3 130. La nueva dieta contiene más productos de origen animal, por lo que serán necesarios más cereales. La producción agrícola debe incrementarse en un 70% para el año 2050, haciendo uso del agua, del conocimiento y de la tecnología. La opción es lograr el aumento en los rendimientos agrícolas (52%), en la intensidad de cultivo (18%), y en la expansión de las tierras cultivables (30%), a un costo de 2% del valor de la producción nacional de hidro- agrícola, porcentaje que asciende a unos US$450 millones por año.

The Mexican population is projected to grow by 25% in the next 35 years, and the average daily intake of calories is projected to increase from 2,000 to 3,130 (FAO, 2012). The new diet contains more animal products, so more cereals will be needed for livestock feed. The agricultural production should increase by 70% by 2050, but there is not enough arable land for such an expansion. Fortunately, there is enough water, knowledge and technology, so the best solution is to achieve the required increase in crop production through the increase in agricultural yields (52%), in cropping intensity (18%), and through the expansion of arable land (30%), with a cost of 2% of the national hydro-agricultural production value, which amounts to around US$450 million per year.

## Water for agriculture

The hydro-agricultural sector includes the entire system that grows, processes and distributes food, feed, fiber, ornamental goods, genetic resources, biochemical materials, natural medicines, pharmaceutical products, and biofuels, as well as buffering freshwater runoff from springs and other sources, as an example of the link between water supply for irrigation and environmental services regulation. Consequently, this sector has an impact on the management of natural resources like groundwater and surface water, soil and forest, as well as on wildlife; on social, physical and biological environments, and on public policies and private actions related to the sector. All activities, practices and processes of the public and private sectors involved in agriculture, livestock, forestry and aquaculture are within the hydro-agricultural sector.

## Food security

The amount of water required for food production is not only driven by the people but by eating habits and, therefore, the discussion of water for food should be moved to consumption as well. For example, a survival diet requires 1 $m^3$/person/day while a diet designed primarily with animal products needs about 10 $m^3$/person/day. The most balanced diets range from 2,5 $m^3$/person/day for a minimum intake of animal products in under-served communities to 5 $m^3$/person/day in the more developed regions.

Figure 1. Identified areas to be incorporated to irrigation

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***Jaime Collado*** **is a Civil Engineer with a Ph. D. in Water Resources, 39 years of professional experience and 220 publications. He is a researcher at the Institute of Engineering, the Electric Power Research Institute, and IMTA, where he headed the Water Resources Department. Presently, he is an independent consultant; Vice President of the Mexican Chapter of the ICID; Member of the Editorial Council of the Technology and Water Sciences and Tlaloc-AMH journals and member of the Engineering Graduate College faculty at the National Autonomous University of Mexico.**

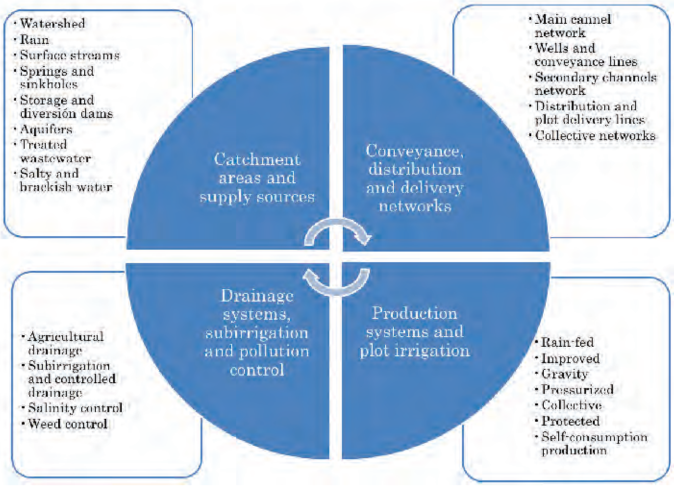


Figure 2. Basic fields of action

## The agricultural output challenge

National data and international trends show water requirements to produce food and clothing in developing countries of 4,5 m3/person/day, and the area needed for its production –under the current productivity schemes– of 0,25 ha/person. The forecast for the Mexican population is 150 million by 2050. At present, irrigators are less than 0,45% of the population, their plots occupy 15% of the total land area, and use 76,7% of the total extracted water.

The current water withdrawal for irrigated agriculture is 65 155 hm$^3$/year out of 84 929 hm$^3$/year of total withdrawals and of 447 260 hm$^3$/year of renewable water resources (NWC, 2015). The current withdrawal for agricultural purposes –with which about half of the food, feed, and fiber is produced– is 1,49 m$^3$/person/day, so it is estimated that at present about 3 m$^3$/person/day is used to produce the consumed food. In 2050 it will be required to extract another 8 144 hm$^3$/year to meet the food requirements.

The actual arable land in Mexico is around 25 Mha instead of the theoretically needed 30 Mha, and it should be expected to rise to 37.5 million hectares by 2050. However, according to the best estimates, the actual arable land could hardly be increased to a maximum of 34,7 Mha. Therefore, to meet the growth in food demand the country should advance in two fronts (FAO, 2011): to increase the productivity per land unit by 80% and to increase the cultivated arable land by 20%.

For these projections to materialize, agricultural production would have to increase by 70% during the period from 2005/2007 to 2050. The projected increase in the Mexican population in this period is expected to be 40%, which means that the production per capita should increase about 22%. Per capita meat consumption would rise from 27 kg per year in 1999-2001 to 44 kg in 2050, which implies that much of the additional production (cereals) will be used as feed for livestock production.

## The technology perspective

Industrial agriculture is characterized by practices that rely on the use of external inputs to the land. Most of conventional agriculture is considered intensive in energy use –it needs 10 calories to produce one calorie of food products– whose high productivity, measured in kg/ha or in kg/m$^3$, is based on the extensive use of chemical fertilizers, herbicides, pesticides, fuel, water and new investments, for example, in improved varieties of seeds and machinery.

About 35% of the agricultural products consumed in Mexico –mainly for cattle feed– come from abroad. However, the sector has met the challenge of ensuring sufficient production for a basic minimum supply as well as for the generation of food, feed, fiber and ornamental crops at acceptable prices, but below the 25% FAO (2012) recommended limit, so it is urgent to increase the domestic production considering the goals set for the year 2050.

Table 1. Example of technology priority actions

| Fields of action-Priority actions |
|---|
| Catchment areas and supply sources |
| • Reduce overexploitation in irrigation districts by improving the efficiency of water conveyance, distribution, and application<br>• Increase arable land by introducing controlled irrigation and drainage systems<br>• Transfer and adapt technology to generate and update inventories of ecosystems and areas in need to rehabilitation<br>• Rehabilitate, modernize, operate and maintain the main hydro-agricultural infrastructure<br>• Integrate micro-watersheds, for hydropower and agricultural production |
| Conveyance, distribution, and delivery networks |
| • Develop, innovate and adapt technology for the acquisition, processing, and transmission of agricultural data in real time<br>• Measure by volume the delivered water to plots to control water rights<br>• Estimate investments leading to tangible benefits (B/C >1)<br>• Support the management, supervision, and decision-making in irrigation zones with drones (see figures 3 and 4) |
| Production systems and plot irrigation |
| • Increase the agricultural production by a combination of irrigation, sub-irrigation, controlled drainage, and plot drainage<br>• Develop technology to establish design criteria for protected and precision agriculture systems<br>• Promote entrepreneurial agriculture by integrating producers in systems of at least 1,000 ha<br>• Combine hydropower energy generated with solar and eolic energy for small-scale agricultural and peri-urban applications |
| Drainage systems, sub-irrigation, and pollution control |
| • Reduce and control the contamination due to agrochemicals<br>• Rehabilitate and increase the agricultural production in saline soils, which is cheaper than opening new irrigation areas<br>• Transform technicized rain-fed zones into irrigation zones<br>• Employ renewable-based systems to rehabilitate saline soils in zones below 5 meters over sea level elevation<br>• Desalinate brackish waters for irrigation<br>• Reuse drained agricultural waters as well as treated wastewaters |

Experiences and the evolution of the Mexican hydro-agricultural sector –which records annualized increments of 0,85% in productivity and 0,6% in arable land– indicates that to meet the hydro-agricultural demand in 2050 a feasible scenario is to incorporate around 1,5 Mha of irrigated agriculture, Figure 1, and 4 Mha of rain-fed agriculture (Garcia-Villanueva and Collado, 2015).

This expansion of arable land should be supplemented with a 35% increase in productivity per unit of physical area, either by an increase in the yield per unit area, by the introduction of double cropping or by using improved seeds, not necessarily transgenic (Wilkinson and Wiedenheft, 2014). This way, similar results to opening 7,5 Mha to the cultivated area will be obtained. In addition, the expansion of arable land must be accompanied by more efficient water use, with the goal of increasing the overall efficiency by not less than 10%; in other words, the product of the efficiencies of conveyance, distribution and application of irrigation water should increase more than 10%.

The main areas of activity that require technological innovations in a hydro-agricultural zone are those depicted in Figure 2.

For each of the four subdivisions in Figure 2 there is a comprehensive set of technology actions that have to be taken, a sample of which are presented in Table 1.

### Financing

To support and strengthen science, technology and innovation in the hydro-agricultural sector, a financing equivalent to 2% of the value of the national hydro-agricultural production is required, which represents an amount around US$450 million per year.

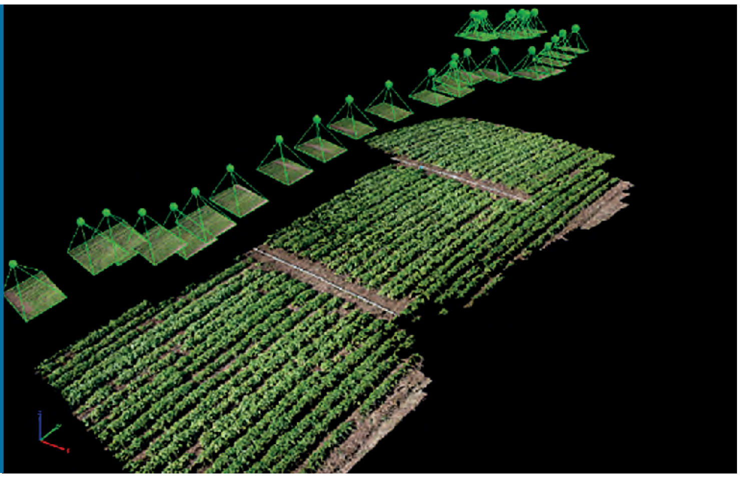
### Indicators

Each technological product contribution must be measured by its impact on a basic set of strategic indicators: Soil, Water, Profit and Food (SWPF), shown in Figure 5, where $N denotes net profit, kgP the total weight in kilograms of hydro-agricultural products, and kgD the total weight in kilograms of demand.

The whole process must be framed and supported with a formal relationship between the scientific community and the producers involved in the hydro-agricultural sector in Mexico.

Figure 3. Ortophoto in 3D of the main channel "Humaya", in ID010, Sinaloa, Mexico

Figure 4. Estimate of bean crop production by drones



### Conclusions

To meet food security for Mexico in 2050, about 70% of the required growth of crop production will come from increases in agricultural yields (52%) and in cropping intensity (18%). The expansion of arable land (30%) will remain an important factor for the growth of agricultural production, although to a lesser extent than in the past.

The technology to increase the hydro-agricultural output per unit of physical area in industrious areas involves: i) new public hybrid crops, ii) higher densities of plant population, iii) application of fertilizers based on soil analysis, iv) well-timed irrigation, and v) establishment of double crops in the same physical area. The most important issues are the accurate analysis of soil for fertilizer application and the timing of irrigation. By increasing plant population density, better use of seeds and the use of bio-fertilizers, farmers can increase, for instance, maize production between 35 and 70 percent (Turrent-Fernandez, et al., 2012). ■

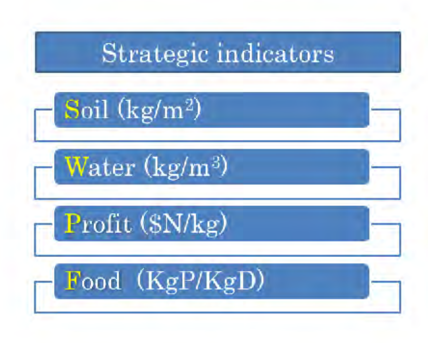


Figure 5. Basic strategic indicators, applicable by crop

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# SEAWATER USAGE IN COPPER MINING: CHALLENGES AND OPPORTUNITIES

BY JOSÉ MANUEL ADRIASOLA, MACARENA TERROBA, RUBÉN MUÑOZ & CARLOS RUIZ

## Resumen

El uso de agua de mar en Chile en la industria minera es cada vez más frecuente por restricciones del uso de aguas continentales. Los costos de inversión y operación que esto significa deben minimizarse mediante diferentes estrategias: en nuevas tecnologías que permitan aumentar la eficiencia de la recuperación de agua y reducir la pérdida de agua en los procesos, aprovechar efluentes tratados de otras industrias y gestionar sinergias entre diferentes usuarios, entre otras. Todo esto sin descuidar la calidad de agua, de modo que los procesos hidro-metalúrgicos involucrados no disminuyan la eficiencia de recuperación de mineral. Esta realidad presenta oportunidades de investigación en los procesos hidro-metalúrgicos y en el proceso erosión-corrosión de materiales metálicos en contacto con agua de mar.

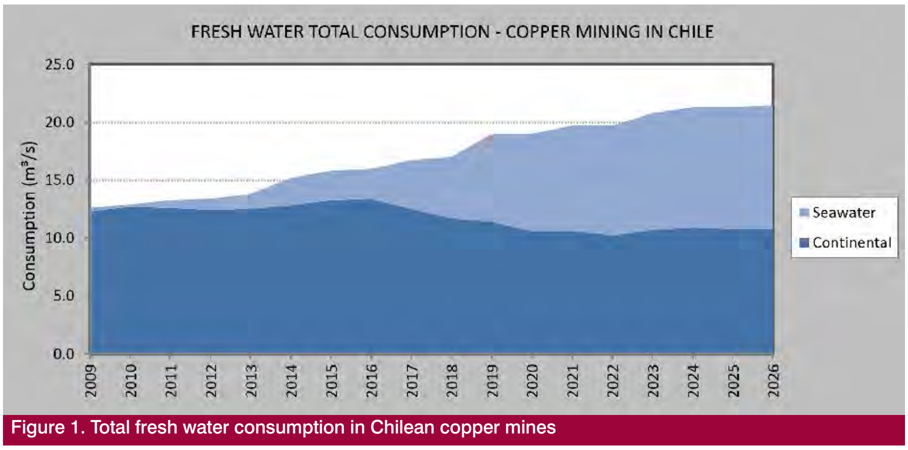

Figure 1. Total fresh water consumption in Chilean copper mines

Copper mining is an essential economic activity in Chile. One of the principal inputs in mining operations is fresh water, which is obtained from sources external to the processing plants to: 1) restore losses that are inevitable in some processes; and 2) supply specific systems that operate using fresh water only. Presently, a significant part of this fresh water is obtained from continental bodies, both surface (rivers and lakes) and underground (aquifers). However, conflicts with other continental water users have intensified and environmental regulations have also changed giving higher priority to human consumption and agricultural use, and at the same time protecting continental water bodies.

While continental water use tends to be increasingly restricted, projections for copper ore processing continue to rise. Thus, fresh water is currently an input that represents a significant risk, in particular for mining facilities located in areas with water shortages. Undoubtedly, the current strategy in these cases is to eliminate continental water resources and replace them with a reliable source without competitors: seawater.

### Quantity and quality of fresh water

Fresh water unit consumption in Chilean copper mining has decreased over time (Cochilco, 2015). This is due to operational improvements that have increased water reutilization efficiency. However, declining grades at several mines in Chile require increasingly higher throughput rates to at least maintain fine copper production. Therefore, total fresh water consumption will inevitably increase.

Figure 1 shows the evolution and projection of total fresh water consumption in Chilean copper processing plants, together with the comparative contributions from continental water and seawater (Cochilco, 2015). The estimate takes into consideration existing operations and future projects.

Current opportunities with respect to the amount of water include:

- Implementation of new technologies for tailings disposal (paste and filtered tailings)
- Surface covering in water reservoirs to minimize evaporation
- Treatment and reuse of various forms of wastewater
- Use of rainwater
- Use of treated effluents from other industries
- Installed means for measuring and managing water consumption in different production areas

With respect to fresh water's physical and chemical qualities, the fundamental concept is to provide the plant with water that does not unacceptably impact process performance. Reported effects of using untreated seawater in copper and molybdenum extraction via flotation include the following:

- Copper recoveries decline 1-2 percent compared to the use of standard industrial water (Castro, 2013)
- Molybdenum recoveries decline 2-30 percent compared to the use of standard industrial water, depending on pH (Castro, 2013)

Recent observations (Veki, 2013) corroborate the upper range of the foregoing projection for molybdenum recovery loss.

As a result, desalinated water use is an option that guarantees that there will be no negative impacts on production. Ideally, desalinated water quality must be adjusted to obtain a quality similar to standard industrial water in order to reduce the treatment plant's capital and operating costs.

From a mechanical and maintenance point of view, untreated seawater usage in concentrators causes high levels of corrosion in equipment and structures compared to standard industrial water utilization; leading to the need for a determined best balance between capital cost for mitigation measures and operating costs for extended and periodic maintenance.

***Carlos Ruiz*** **joined Bechtel in 2005, taking on roles in operations, projects and business development. He served as project manager for the Laguna Seca Debottlenecking brownfield concentrator expansion and led development of all major copper projects in Latin America as operations manager for the BHP Billiton-Bechtel Hub. Carlos was elected a principal vice president in 2012, and in the same year he worked to launch Bechtel's water business line. He is currently general manager of the mining and metals business for the Americas. He previously spent 12 years working in the O&G industry in Chile and the United States.**

***Ruben Muñoz*** **has more than 10 years of experience in the field of hydraulic engineering and water supply in the mining industry. He has participated in the development of over 24 industrial mining projects in Chile and other countries in Latin America. He has experience in both engineering design and preparation of investment budgets for water supply projects. Ruben is currently IDE Technologies' Technical Solutions Director for Latin America.**

***Macarena Terroba*** **joined Bechtel in 2006 and she has 23 years of experience in the field of process engineering and operations in the mining industry. She has worked on more than 30 mining projects related to copper and molybdenum metallurgical processes in her career. Macarena has participated in all engineering phases from conceptual studies to fully detailed design, and has provided technical support to business development activities.**

***José Adriasola*** **has 16 years of experience in hydraulic and hydrologic (H&H) engineering. He joined Bechtel in 2008 and is currently a principal engineer and the H&H lead for the Mining and Metals Global Business Unit. José's expertise includes surface water drainage, hydraulic structures and liquid transport systems. He also taught H&H courses to civil engineering students from 2005 to 2014. José holds a bachelor's degree in civil engineering and a master's degree in hydraulics and hydrology. He is currently one of the Bechtel Distinguished Engineers and Scientists (BDES).**

Regarding water quality, primary challenges and opportunities include:

- Optimizing seawater treatment to obtain a product similar to standard industrial water, without sacrificing efficiency in copper and molybdenum recoveries
- Managing corrosion in both transportation systems and plant infrastructure that come into contact with seawater

### Preparing seawater for use as fresh water

In comparison to other industries, seawater usage in copper mining is relatively new. Its corrosive properties negatively affect elements in carbon steel. When using seawater, multiple measures must be taken to control corrosion in order to achieve the operating and maintenance costs estimated in the design stage.

In many cases, the use of chemical products to prevent corrosion is the best way to counteract this problem. However, these products present limitations when seawater is transported over long distances. During operation of long-distance pipelines, a deterioration in the quality of the water received in the process has been observed, with a greater concentration of corrosion byproducts, such as iron. In addition, there are phenomena such as localized corrosion and microbial corrosion. As a result, the pipelines' interior walls become rougher and this leads to an increase in power consumption in the pumping systems.

Principally, seawater treatment must be capable of removing suspended solids, inactivating bacteria and reducing potential corrosion. Furthermore, it must be considered that the flow velocity is directly proportional to the wear rate due to the erosion-corrosion phenomena (Lienenweber et al., 2016a and 2016b). The treatment recommended by NACE (2012) to reduce the corrosive potential of seawater consists of removing dissolved oxygen and inactivating the bacteria responsible for corrosion. As a result, the corrosion rate could be limited to a maximum of 20 mil per year (1 mil = 0.0254 mm), but this process is extremely expensive.

The seawater reverse osmosis (SWRO) process is a proven technology that recently has managed to reduce desalinated water production costs to less than USD 0.57/m$^3$. The process primarily consists of pre-treatment, reverse osmosis and post-treatment.

Depending on the quality of the seawater at source, pre-treatment consists of some or all of the following processes: coarse screening, chlorination, clarification, coagulation, flocculation and filtration. In the presence of harmful algal bloom (red tide) and severe proliferation of algae, treatment could include a dissolved air flotation (DAF) process. However, the requirement of this process must be analyzed in detail in accordance with the site's conditions and seawater quality records. When seawater quality is under normal conditions, with low suspended solids, proper treatment only requires flocculation, coagulation and filtration with minimal or no chemical products.

The SWRO process receives pre-treated water and delivers it to a group of modules working in parallel. Each module has a high-pressure pump, a circulation pump, a power reclaimer and a reverse osmosis train that has pressurized containers with membranes.

The saline concentrate resulting from the SWRO process has high pressure and salinity. By using an isobaric power recovery system and a circulation pump, the residual pressure can be passed to the osmosis train's supply manifold. Following power recovery, the saline concentrate is returned to the sea, where its high salinity is diluted by means of diffusers.

Finally, the desalinated water is transported to the re-mineralization process, where its quality must be adapted to what is required for the infrastructure coming into contact with the water and the end users.

With respect to seawater treatment systems, opportunities include:

- Minimizing power consumption by utilizing new technologies and production strategies
- Creating synergies with other industrial facilities near the coast
- Developing clean technology solutions that

permit eliminating chemicals in desalination and enable an operation with increased availability

## Intake infrastructure and fresh water transport

Seawater intake infrastructures are expensive. For various reasons, owners prefer to build maritime works that cover long-term requirements. Depending on each site's characteristics, the challenge is to find the lowest total installed cost configuration for intake, transportation to SWRO and discharge of the saline concentrate. In addition to requiring technical experts, this entails the involvement of constructability and cost estimating experts during study stages to ensure that the best alternative is executed.

The same approach is followed for the required infrastructure to transport the desalinated seawater to the point where it is used. Multiple alternative studies must be developed to determine the option with the lowest total installed cost. However, in these cases the owners' preference is to build water transport infrastructure strictly tailored to the immediate needs, leaving out other potential consumers that could benefit in the medium or long term. This is done in order to minimize the capital, operating and maintenance costs. Bruce and Adriasola (2016) describe several technical-economic analyses that should be developed prior to concluding the design stage.

Among the numerous choices that must be made, the decision to use or not use internal coating in the carbon steel pipes is crucial. This is linked to research of the erosion / corrosion process in pressurized piping for seawater. Current state of the art is insufficient to provide conclusive answers regarding the erosion / corrosion process in different carbon steel qualities, transporting different seawater properties and under distinct hydraulic conditions. Therefore, this presents a clear challenge for applied research. Sharing information and experience, and creating opportunities for collaboration between mining companies and the academic world can help advance this research.

Finally, it is imperative to mention the opportunities that exist to reduce capital and operating costs via synergies between users. The potential economies of scale are significant, both for the initial capital investments and for operation costs. The primary challenge is the manner in which this is achieved, i.e., the contracts between involved parties and the legal aspects in general, given that the technical-economic benefits are obvious. ■

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LATIN AMERICA SPECIAL

# CLIMATE CHANGE ADAPTATION TO WATER RELATED CHALLENGES IN LATIN AMERICA –
## COMBINING QUANTITATIVE ASSESSMENTS AND QUALITATIVE RANKING OF ADAPTATION MEASURES

BY ALEJANDRO E. LASARTE, BERISLAV TOMICIC & ROAR A. JENSEN

### Resumen

La adaptación al cambio climático es considerada, por las principales instituciones financieras, por ej, BID, como un desarrollo prioritario para el sector del agua en América Latina. El enfoque que se presenta en el presente artículo consiste en identificar y clasificar las medidas de adaptación y evaluar su eficiencia mediante el uso de modelos numéricos para cuantificar los impactos. Se verificó esta metodología utilizando estudios de casos en América Latina abarcando diferentes tipos de impactos como aumento del nivel del mar, derretimiento de glaciares tropicales, sequías y eventos extremos de tormentas.

Adaptation to climate change is recognized by the main financing institutions, such as the Inter-American Development Bank (IADB), as a development priority in the Latin America (LA) region for the entire water sector. The approach presented in this article addresses, identifies and ranks adaptation measures, and assesses their efficiency by using numerical models to quantify their impacts. This methodology was verified by using case studies in the LA region covering a range of different types of climate change impacts including sea level rise, tropical glaciers retreat, threatened eco-systems (Figure 1), droughts and high intensity storms.

There is a large gap between the global (and more recently regional) assessments of climate change and the need for local approaches at basin scales and exchange of experience with those. This poses a serious challenge to water resources managers who need the appropriate knowledge in order to find practical climate change adaptation solutions.
The overall objective of this article is to present a methodology to generate experience and an approach to formulate general local scale guidelines to be used in climate change adaptation studies in LA.

For each case study, quantitative climate change impact assessments were prepared, and initial adaptation plans were outlined to support the local water resources institutions in their climate change adaptation strategies.

Climate change adaptation case studies are presented for three locations in three Latin American countries:

- Uruguay's capital: Montevideo (focusing on storm water drainage);
- Ecuador's Capital: Quito (focusing on impacts on water supply from glacier retreat and mountain ecosystems changes);
- Trinidad and Tobago (focusing on sea level rise and urban drainage)

The same overall stepwise approach to the assessment has been applied in all case studies. This approach has proven flexible enough to cope with the diverse issues and the different quantity and quality of available data in each case. Large uncertainty, particularly in the projected rainfall changes makes adaptive management necessary, and highlights the importance of building resilience into all project stages i.e. in the initial planning stage, in the feasibility phase and in the final design.

To address inherent uncertainty in climate change assessments, appropriate adaptation measures were identified and evaluated and an initial ranking (or screening) was performed considering their win-win characteristics, the creation of resilience, flexibility given to future system changes, costs and political acceptability. This exercise recognised the possibility that plans and priorities may need to be changed after some years, and that investments made should be sufficiently flexible to cope with such changes. The case studies presented here are rapid assessments conducted with limited man power input. They have relied on readily available data while avoiding time consuming and costly new model developments. Therefore, the applied approach and methodologies could be carried out as part of many practical water resources projects.
In spite of the uncertainties imbedded in the available climate change assessments it was possible, to screen projects or existing schemes for climate change impacts and devise solutions for their alleviation. Furthermore, it was possible to quantify the potential impacts on the water resources and flood frequencies. In some cases, the analyses identified the need for more detailed local climate assessments as one of the most important first steps in the local climate adaptation strategies.
The lessons learned from these practical case studies applications are:

- Climate change impacts on water related issues might in many developing countries be less significant than those originating from the increased anthropogenic pressure on land use and water resources. Nevertheless,

Figure 1. Run-off favorable páramo ecosystem in the High Andes under threat by climate change

climate change is expected to further exacerbate an already challenging situation.

- Local climate change impacts have to be analysed quantitatively in each case. In some cases, the most eye-catching and globally highlighted effects are not always those with the most significant local impacts. An example of this is the analysis of the water supply of Quito where the retreat of the glaciers due to their limited areal coverage, showed to have much less impact on water availability than the surrounding fragile ecosystems that may also be under threat by the changing climate.
- Qualitative assessments that prioritize win-win and no-regrets solutions are useful to guide planning and ranking of adaptation options particularly if the uncertainty associated with climate change assessments is significant
- Options for adapting to climate change are often well-known as traditional solutions to general water scarcity and flood protection problems e.g. traditional structural solutions re-designed to cope with a changed future climate.
- Even small screening studies can reveal important information on the necessity for adaptation and provide guidance to the detailed planning.

## The Case studies

### The Pantanoso Urban River Catchment, Montevideo (Uruguay)

This study included climate change impacts (sea-level rise and extreme rain storms) into an overall analysis of the storm water drainage system and a natural stream in the sub-urban catchment of the Pantanoso River, in the city of Montevideo, the capital of the Oriental Republic of Uruguay. The Pantanoso River is 15 km long, with its catchment (67 km$^2$) located centrally in the Montevideo metropolitan area. In its lower reaches, the river flows through wetland areas before entering the Bay of Montevideo.
The catchment is a transitional area, changing from a densely urbanized part in the East, towards sub-urban relatively scarcely populated in the West. The area is subject to extensive environmental problems and the catchment hosts many irregular settlements, even in areas exposed to floods. The main environmental concerns are the handling and disposal of domestic solid waste and industrial wastes, as well as the pollution of local water resources and streams.

More recently, serious concerns related to climate change have been added to the list of “conventional” challenges in the catchments, and the possible environmental effects of climate change in the medium and long term have come into focus for investigation.
The future operation of the Pantanoso River drainage system has been studied under the impact of relevant projected climate variables (extreme rainfall and tides) and demographic and socio-economic changes in the system (represented conceptually by the catchment runoff coefficient and hydraulic network capacity).

### *Climate change projections*

As the current climate change projections for Uruguay do not include extreme events with 10 to 100 years recurrence intervals, estimates were made, based partly on the extrapolation of the existing knowledge (extreme rainfalls) and on available historical trends (sea levels). The future scenarios, with a time horizon of the year 2100, include the climate change variables at two levels: low climate change and high climate change. The “low climate change” was derived by extrapolations and the “high climate change” by introducing additional uncertainty (extreme rainfalls) by adopting recent, more pessimistic, global forecasts (sea level). For the year 2100, sea level rises of 17 cm and 110 cm have been adopted as low and high estimates, respectively.

For extreme rainfall, increases in peak intensities (and volumes) by the year 2100 by 15% and 21% for 10-year and 100-year rainfall, respectively, have been adopted as “low”, while corresponding changes of 38% and 45% in these rainfall intensities are used as “high” climate change. The future socio-economic development was introduced in the analyses through two variables representing runoff characteristics of the catchment (permeability) and the hydraulic conductivity (blockage) of the channels. These variables were included in two possible future states associated with good and poor management practices, respectively

### Impact assessment

A dynamic mathematical simulation model (MIKE URBAN), which is capable of simulating storm runoff, river and overland flows as well as flooding in the Pantanoso catchment, was used to model the impact of extreme rainfall and tides.

The simulation model was based on available physical data. However some important elements lacked the necessary level of detail and accuracy (terrain topography) or were mostly unavailable (e.g. river cross-sections). The model was not calibrated due to lack of appropriate historical records for operational variables (flows and water levels). Instead, default model parameters were used. All this implies that the model has a demonstration character only. However, despite these deficiencies, the model represents the major characteristics of the system well enough to allow usage of its results for qualitative analysis of the system behaviour under various scenarios.

### *Adaptation measures*

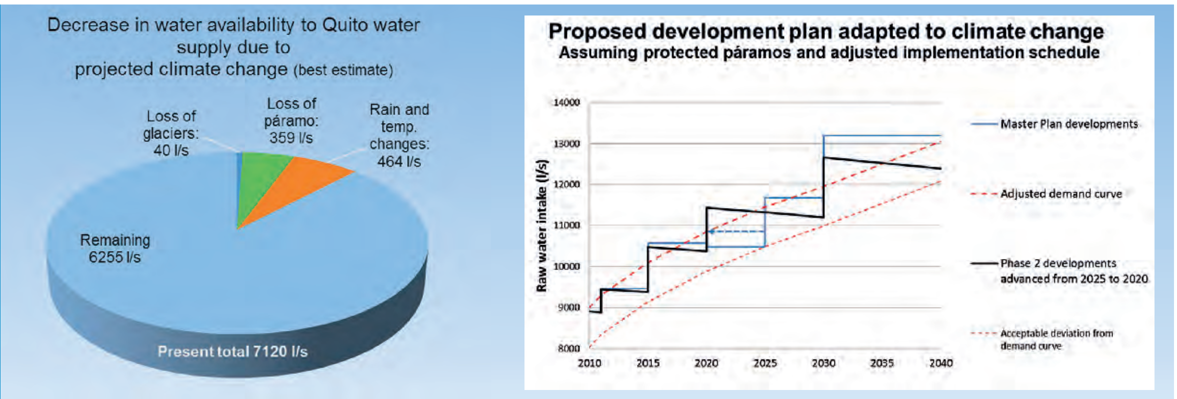
The climate change impacts were superimposed on the demographic and socio-economic development impacts in the catchment. Both climate change and man-made changes increased the flood risks, which in combination with water-borne pollution could significantly increase the vulnerability of the area.

***Alejandro E. Lasarte*** **is Senior Hydraulic Modeler, Engineer and Project Manager at DHI. Mr. Lasarte has more than 30 years of experience on the fields of river hydraulics, flood management, hydrological modelling, water resources modelling, information systems and climate change.**

***Berislav Tomicic*** **is Senior Hydraulic Engineer and Project Manager at DHI, with more than 30 years of experience on modeling of urban hydrology, hydraulics, urban floods and climate change impacts.**

***Roar A. Jensen*** **is Senior Water Resources expert at DHI with more than 30 years of experience from numerous water resources planning, hydrological and hydraulic modelling projects, worldwide.**

Figure 2. Decrease in water availability due to climate change and adaptation of the proposed water supply development plan for Quito



A range of scenarios were developed and analyzed, featuring various combinations of "low" and "high" future changes, in both climate and non-climate variables. These analyses showed that the impact of climate and non-climate changes were of comparable magnitude, but had different impacts in different parts of the catchment.

The lower part of the catchment – Pantanoso Bajo – is subject to a strong tidal influence, which means that its vulnerability is mainly due to sea level rise, i.e. larger extreme tide peaks. The upper and central parts of the catchment are beyond tidal reach, but are sensitive to extreme rainfall increases, as well as to the uncontrolled socio-economic development. In the worst-case future scenario, the flooded area in this part of the catchment could increase more than three-fold compared to the present. The most effective measures to reduce the vulnerability in the Pantanoso Bajo area include re-settlement of people and valuable assets from the flood-prone zones, and physical protection of the most valuable assets. Various general catchment management measures can contribute to the situation improvement here, but not significantly.

## Climate Change Impacts on Glacier Retreat and Mountain Hydrology and Implications for the Water Supply of Quito (Ecuador)

This case study concerned climate change impact on mountain hydrology and glacier retreat and its implications for the water supply to the City of Quito. Quantitative GIS analyses in combination with hydrological modelling and field study results were performed to assess the future impacts on ecosystems and water availability.

The Ecuadorian capital of Quito has a population of 1.6 million and is located almost on the equator at an elevation of 2800 m in the Guayllabamba Valley. Quito's Public Water and Sanitation Company EPMAPS (Empresa Pública Metropolitana de Alcantarillado y Agua Potable de Quito) supplies the city with surface water, captured at high elevations from sparsely populated and almost natural mountain catchments, which is supplied to the city by gravity pipelines.

At present, these catchments are dominated by ecosystems known as páramo (see Figure 1). These high elevation moors and wetlands cover extensive areas above the tree line while the areal extent of the glaciers residing only on the highest elevations is much smaller. From a water harvesting point of view, the páramo constitute an ideal combination of soils with very large water retaining capacity and vegetation with good erosion protection and low evaporative losses. However, field studies have shown the páramo to be a highly fragile ecosystem and both afforestation, cultivation and intensive grazing have been found to lead to the collapse of the sensitive soil matrix, and therefore to a significant reduction in the water retaining capacity. Ecosystems similar to páramo are known to exist in other Andean countries, such as the puna in Peru.

There is a well-founded concern that generally increased temperatures may lead to transformation of larger páramo areas to forest (by the rise of the treeline), or to cultivated fields and grazing areas, all of which will have negative consequences for water harvesting.

The glacier retreat is very well documented in the area and is found to have a negative impact on the yield of the intake catchments.

### *Assessed Impacts*

The impacts of climate change on the resources availability were quantified by combining findings from previous field studies with GIS analyses and hydrological modelling. The analyses focused on three important aspects:

1. Changes in runoff due to changes in the extent or degradation of páramo ecosystems,
2. Changes in runoff due to the retreat of the glaciers in the area and
3. Direct hydrological impacts on the runoff due to projected trends in precipitation and temperature.

The average loss in water availability from all three aspects was assessed at 12% for all of EPMAPS' supply systems (using a central climate projection estimate) of which 1% originates from glacier retreat, 5% from degraded páramo and 6% from changes in rainfall and evaporation. More pessimistic climate estimates resulted in reductions in the present availability of 34 % with almost the same distribution between the three analysed aspects.

### *Adaptation measures*

EPMAPS' existing water supply master plan focuses on how to cope with increasing water demand and how to make the supply more resilient to volcanic activity. The plan aims at reducing demand and losses in the system, but also includes new structural developments to increase the water capture area. The projected decrease in water availability due to climate change will put the water supply under further stress. In addition to measures already included in the water supply master plan, extensive protection of páramo areas from forestation, grazing and cultivation should be introduced to avoid their degradation. Even with such protection measures in place the water availability will gradually decrease due to lower rainfall and to a smaller extent due to glacier retreat, which in turn calls for adjustments in the planned investments, e.g. advancing some of the scheduled developments to keep the supply security at the same level as in the existing master plan as indicated in Figure 2.

### Port of Spain, Trinidad & Tobago

This study focused on investigating and solving the problem of urban flooding in Port of Spain, capital of Trinidad and Tobago, under the impact of relevant climate change variables - sea level rise and extreme rainfall.

In response to repeated serious flooding in downtown Port of Spain, the Government of Trinidad and Tobago initiated an urgent action including a number of individual projects – called "packages", focused on improving the drainage facilities at specific locations in Port of Spain, subject to flooding. Due to the scale of the problem, IADB was asked for financial assistance.

IADB was seeking a more comprehensive and integrated approach, comprising a solid understanding of climate change and environmental impacts, rather than a number of individual, essentially independent local solutions. In addition, the entire catchment of 45 km$^2$, with two rivers and an urban drainage network, were to be included in the analysis. The need for such an integrated approach was highlighted by the initiative to develop public spaces and traffic connections along the urban stretch of the St. Ann's River – the so-called "Linear Park".

Successful realization of the "Linear Park" is highly dependent on full understanding of the St. Ann's River catchment hydrology, its hydraulic capacity and pollution loads.  DHI recommended an integrated catchment management approach, including updating of the catchment hydrology, performing integrated modelling of the drainage system, accounting for climate change and carrying out an environmental impact assessment. The work was divided in some well-defined blocks:

- Flow and Rainfall Measurements Campaign;
- Integrated Hydrological and Modelling Study;
- Supply of the Modelling Platform and Training;
- Climate Change Design Manual;
- Environmental Impact Assessment;
- Re-evaluation of the preliminary design for individual packages

The work performed demonstrated that the flooding problems are the compounded result of various inappropriate urban management practices, with climate change impacts acting as an additional exacerbating factor. It was found that the development of a modelling framework integrating the urban drainage hydraulics with the simulation of the hydrological response of the entire contributing catchment to present and future rainfall events was essential for establishing an understanding of the relative contribution of the various factors to the flooding problems of Port of Spain.

Through the modelling framework, it was possible to demonstrate the influence on the flooding of past urban developments and to compare them to the impacts imposed by the changing climate. The primary cause of flooding problems could be clearly linked to the uncontrolled urbanisation of upstream catchments, while climate change will impose significant additional strain on the drainage infrastructure in the future. The established simulation model was used to analyse a number of solution scenarios, which in turn led to a series of well-founded general and specific recommendations for future adaptation actions. ■

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# STUDIES ON WAVE ENERGY EXPLOITATION IN URUGUAY

BY LUIS TEIXEIRA, SEBASTIÁN SOLARI, RODRIGO ALONSO & SANTIAGO CORREA

## Resumen

En este artículo se presentan los principales resultados obtenidos al estudiar el aprovechamiento de la energía de las olas en Uruguay. A partir de un reanálisis de oleaje calibrado con mediciones locales, se muestra que desde el punto de vista del potencial teórico y sus características principales, el oleaje constituye un recurso plausible de realizar un aporte significativo a la matriz energética del país. A su vez, se presentan los avances alcanzados en el desarrollo de uno de los tipos más comunes de dispositivos de conversión, el cual fue analizado a partir de un modelo analítico y ensayos físicos.

In most countries, marine energy is an alternative energy source that is yet to be exploited, although it has the potential to significantly contribute to the generation of clean and renewable energy [1]. From all the different marine sources, wave energy is the one with the greatest potential [2]. This is particularly true for microtidal regions in temperate zones, such as the Uruguayan coast.

The Institute of Fluid Mechanics and Environmental Engineering (IMFIA), School of Engineering (University of the Republic) has been working on the evaluation of this energy source and its exploitation in Uruguay. The assessment of the resource was performed through a study of the results of a wave numerical model forced by reanalysis wind data. [3].

Moreover, progress was made in the analytical, numerical and physical modeling of a flap-type wave energy converter (WEC) [4]. Certain laboratory facilities were required for this, including a large wave flume equipped with a wave generator that includes dynamic absorption of reflected waves.

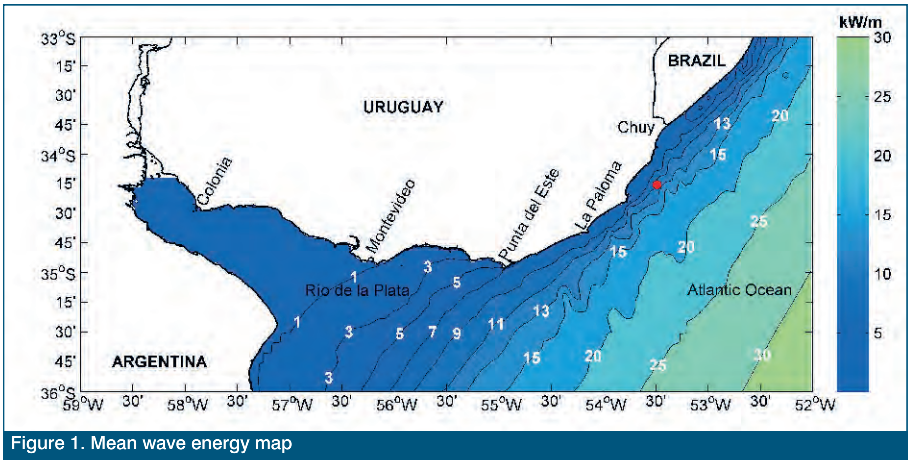

Figure 1. Mean wave energy map

### Assessment of the wave energy resource

An assessment of the theoretical wave potential was conducted from a 31-year wave hindcast performed with the Wavewatch III® third-generation wave model forced by CFSR (Climate Forecast System Reanalysis) winds. The model was calibrated and validated with altimeter data and in situ measurements. The spatial distribution of the resource and its variability at different time scales were analyzed, as well as extreme conditions and the correlation between the variability of the directional wave spectrum and several climate indexes [3].

The mean wave power map is shown in Figure 1. It is observed that the mean wave power in deep water is 30 kW/m. Although the potential diminishes towards the coast, on the Atlantic coast, at a 20 m depth, the theoretical potential doubles the current annual average electricity demand of the country (1050 MW). Meanwhile, the wave power in the Río de la Plata decays from 7 kW/m in the outer zone to 1 kW/m in the intermediate zone and continues decreasing toward the inner zone.

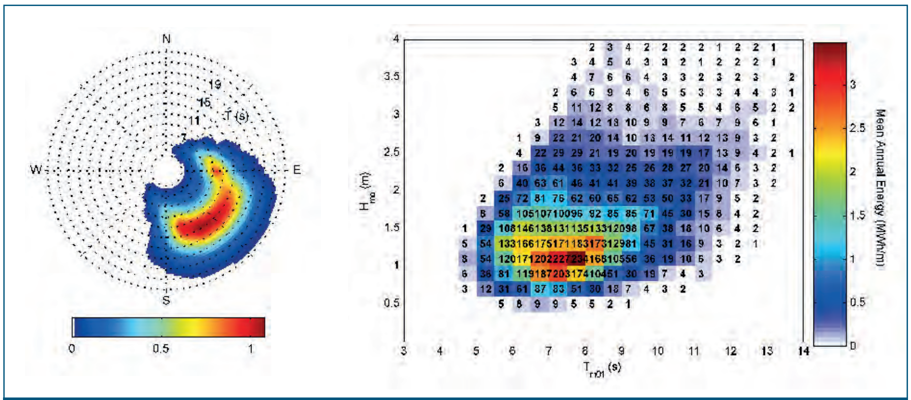

Figure 2. Average wave spectrum (left) and wave energy distribution in terms of significant wave height (Hs) and period Tm01, where the color represents annual wave energy and the numbers represent the occurrence of the sea states in hours per year (right). Both are at the red point on Figure 1

The graphs of Figure 2 provide a better insight into the wave potential at 20 m water depth on the Atlantic Coast between La Paloma and Chuy. The average wave spectrum (left) shows that the energy is spread in the E-S quadrant and concentrated in periods between 9 and 13 s. The graph on the right shows that predominant waves (those with the highest annual frequency) are the largest contributors to wave energy potential, i.e., the most frequent waves are the major contributors to the mean annual energy. This is a positive factor in terms of resource availability because it implies that the wave energy is well distributed in time. These frequent waves on the Atlantic coast

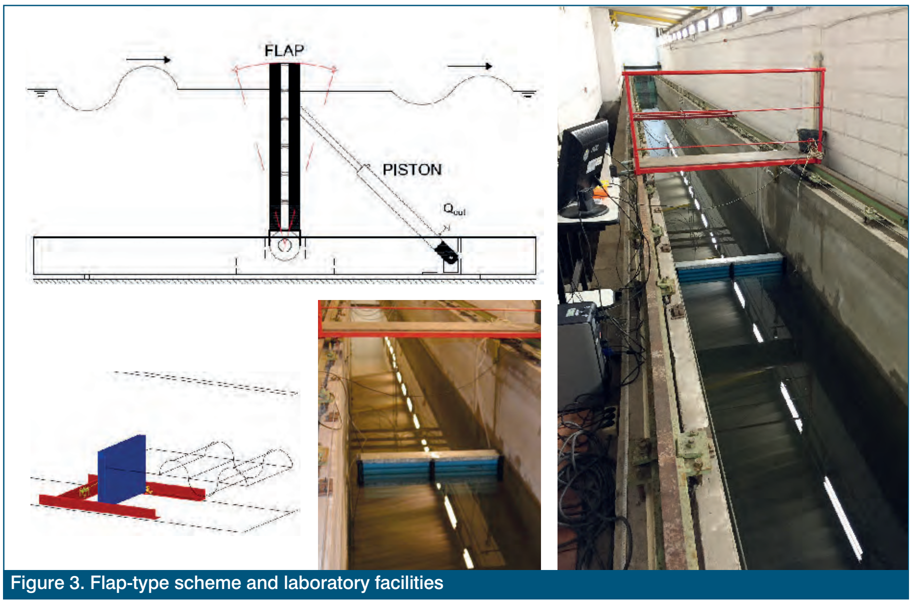

Figure 3. Flap-type scheme and laboratory facilities

have significant wave heights in the range of 0,8 and 1,8 m and periods Tm01 in the range of 6 and 9 s.

Besides the wave power spatial distribution and its relation to the wave climate, the assessment included a temporal variability analysis of different timescales, the relation with climate indexes and considerations of extreme events. The results show low medium- and long-term (monthly, seasonal and annual) variability but not as low variability in the short-term (sea state time scale). Moreover, seasonal variability related to wave direction was detected. In agreement with previous results ([5]), correlations between the monthly wave energy anomaly and Antarctic Oscillation and Southern Oscillation indexes were observed. Finally, related to extreme events, it is observed that high return period significant wave height is not too severe when compared with other areas analyzed by previous authors.

In summary, this assessment has shown that although the wave energy potential in Uruguay is moderate, it is fairly steady throughout the year, and the extreme wave conditions are relatively benign. Therefore, wave energy is an attractive resource for integration into the country energy mix, contributing to its diversification and sustainability.

## Flap-type WEC analysis

A flap-type is one kind of WEC among many other variants developed. Briefly put, it consists on a buoyant flap, ideally oriented perpendicular to the incident waves. The flap spins around a fixed horizontal axis as it is forced by the waves. Commonly, these types of devices are combined either with a piston system, which pumps water to an onshore turbine (e.g. Oyster, [6]), or with a linear generator.
A simplified analytical model of a flap-type wave energy converter was implemented. Based on the results of this analytical model a device that maximizes the energy harnessed working under the typical wave conditions of the Uruguayan Atlantic coast was designed. A physical model of this device was built at a 1:10 scale and tested in the laboratory.

The IMFIA laboratory has a large wave flume that is 70 m long, 1,8 m high and 1,5 m wide, equipped with a piston-type active absorption wave maker, and several capacitance wave gauges along the flume. Pressure inside the piston and at the discharge line were measured allowing for the estimation of the output power, indicating a system efficiency of about 30%. Although preliminary, these results will allow us to advance on the design of this kind of WEC taking into account the particularities of the Uruguayan coast and its wave climate. ■

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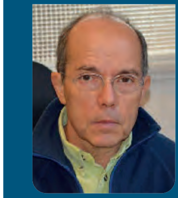

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