



AMAZON WATERS

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10

Research Projects

on the World's Largest River Basin





AMAZON WATERS:

10 Research Projects on the
World's Largest River Basin

1st Edition
Edited by OTCA
Brasilia, 2018

The Special Edition of the Amazon Waters Newsletter is a contribution to the knowledge of the Amazon basin from the Amazon Cooperation Treaty Organization through the ACTO / UN Environment / GEF Amazon Project: Water Resources and Climate Change, on the occasion of the 8th World Water Forum, Brasilia, 2018.



Amazon Cooperation Treaty Organization, Permanent Secretariat (ACTO/PS- Brasilia)

Secretary General:
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Coordinator of Climate Change and Sustainable Development:
Roberto Sánchez Saravia (a.i.)

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Address:

OTCA/ACTO: SHIS QI 05, Conjunto 16, Casa 21, Lago Sul, CEP 71615-160 Brasília D.F. Brasil Tel. +55613248-4119 <http://www.otca.info/>

United Nations Environment Programme, Washington D.C.

Task Manager:
Isabelle Van der Beck

GEF Amazon Project - Water Resources and Climate Change (ACTO, Brasilia)

Regional Coordinator:
María Apostolova

Scientific Adviser:
Norbert Fenzl

Communications, Writing and Editorial Production:
María Eugenia Corvalán

Financial and Administrative Officer:
Nilson Nogueira

Administrative Assistant:
Marli Coriolano

English Language version edited by Leslie Carmichael

For further information see:
<http://gefamazonas.otca.info>

Consultants and contracted entities, coordinators of the research carried out under the direction of the GEF Amazon Project:

- » **Centro Internacional para la Investigación del Fenómeno de El Niño (CIIFEN), Dr. Fanny Friend, area:** Creation of the Hydroclimatic Vulnerability Atlas of the Amazon Basin.
- » **Servicios Hidrogeológicos Integrales (SHI), Engineer María Victoria Vélez, area:** Aquifer Systems of Leticia and Leticia-Tabatinga comparative study.
- » **Dr. Naziano Filizola, area:** Geochemical Characterization of the Sedimentation in the Madeira and Solimões Rivers.
- » **Engineer Jorge Benites, area:** Transboundary Diagnostic Analysis (TDA).
- » **Dr. Patrícia Chaves de Oliveira, area:** Floodable Forests in Brazil and Peru.
- » **Dr. Nirvia Rávena, area:** Risk Management and Governance in the Purus River Basin.
- » **Dr. Elsa Mendoza, area:** MAP Region.
- » **Dr. Maamar El Robrini, area:** Rise in Sea Level in the Amazon Delta.
- » **Dr. Yerko Montero, area:** Institutional Cooperation in the Amazon Basin.
- » **Dr. Solange Teles, area:** Legal Framework.
- » **Dr. Cleber Alho, area:** Aquatic Ecosystems.
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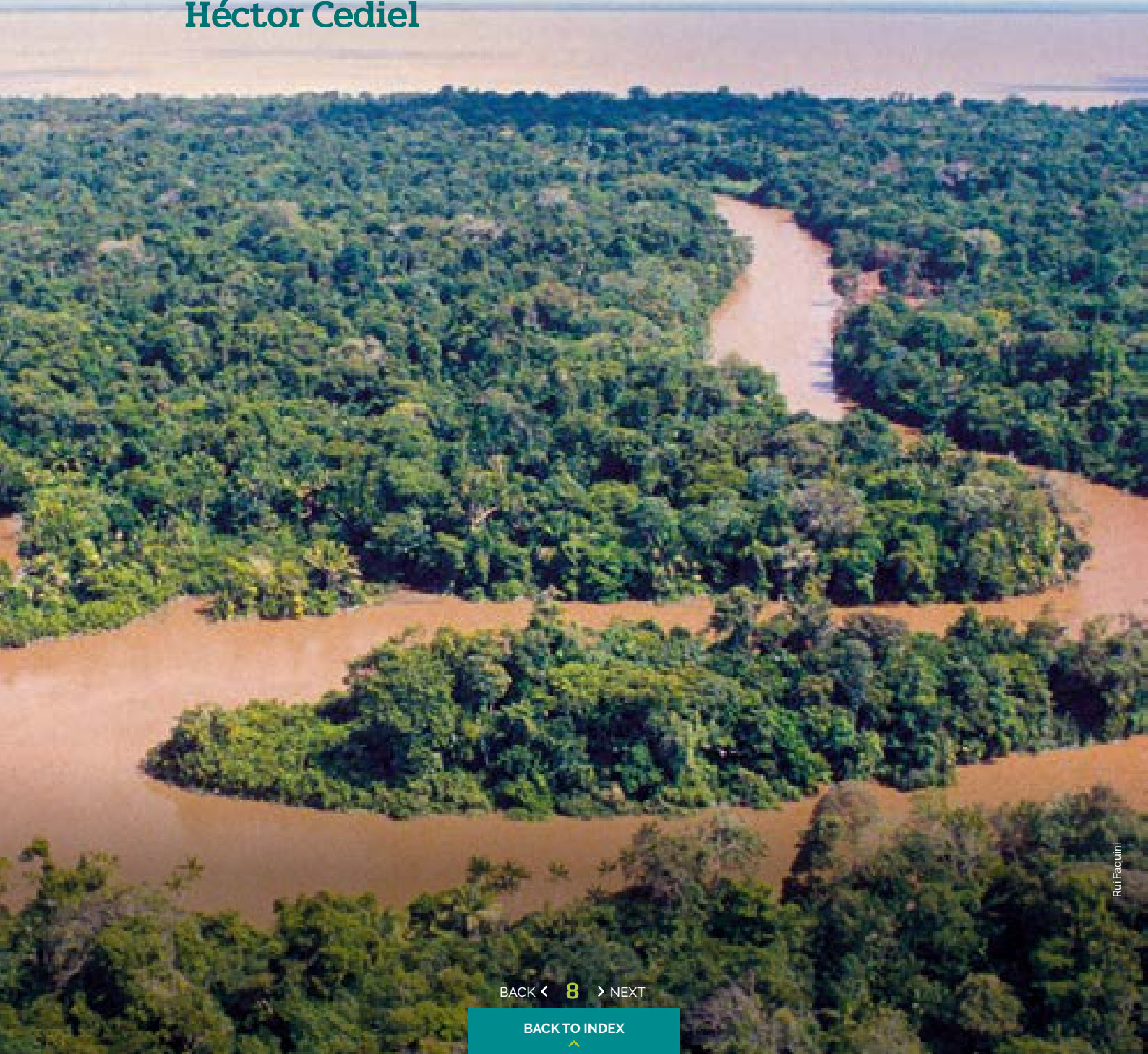
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“...Oh Amazon River!

Beloved river! Anaconda river
tree river ocean river sea river
sky Amazon River!”

Héctor Cediel



Presentation

It is my pleasure to present to the public, which is increasingly interested in discovering new ways of thinking about rivers, the academic scientific community, and the public and private entities in the fields of water and the environment, the results of the research carried out by the Amazon Cooperation Treaty Organization (ACTO) through the GEF Amazon Project - Water Resources and Climate Change.

This new technical and scientific knowledge about aspects of the vast Amazon Basin over four years (2012-2016) is a great advance for our region, as well as a starting point to move forward with the Strategic Action Program. The eight ACTO member countries have given their technical validation to the SAP in order to address the critical problems of the basin in the short and medium term.

This research reflects the governments' joint and permanent work on the project, aimed at proposing tangible solutions for the problems that affect the basin.

Each research project worked with specific population groups in different parts of the basin. The projects received funding and contributions from the governments, ACTO, Global Environment Facility (GEF) and UN Environment Programme (UN Environment). Political resolve by the countries, recognizing the role of transboundary water resources in ecosystems and society, and how they are essential for all facets of human activity, has been particularly important.

This research provides concrete solutions for critical and priority problems in the basin, which have been

identified and evaluated by this regional intergovernmental initiative.

Just having produced the first Hydroclimatic Vulnerability Atlas of the Amazon Basin enables us to visualize the enormous complexity of the challenges facing the countries and agencies responsible for water in the region. The atlas is also a roadmap for identifying new opportunities for our basin, and demonstrates the need to work permanently on the integrated management of the most precious resources of our region.

The research also reveals the state of the groundwaters shared by Leticia (Colombia) and Tabatinga (Brazil) and what could be achieved if these were used more rationally; the sediment load along a stretch of the river and, of course, innovative solutions to deal with extreme hydroclimatic events; new ways to manage water resources; instruments that may be implemented and shared among the countries to adopt measures to deal with climate change, and finally the work that must be done to address the rising sea level in the Amazon Delta.

Here we present some of the most significant achievements, framed within the Sustainable Development Goals of the 2030 Agenda, particularly Goal 6: **Ensure access to water and sanitation for all**. This SDG entails at least seven specific objectives for 2030, in which everyone must do their part: governments, private sector, people like you, dear reader, and we as an institution.

We emphasize the following objectives as achievable between now and 2030: *Achieve universal and equi-*

table access to safe and affordable drinking water for all. In particular, one objective to which ACTO is completely committed, which is to implement integrated water resources management at all levels, including through transboundary cooperation as appropriate.

This project also reveals the progress on how the Paris Agreement, signed in December 2016, has been applied in the Amazon Basin, in that one of its goals is to “strengthen global response to the threat of climate change, in the context of sustainable development and efforts to eradicate poverty.” This agreement is part of the United Nations Framework Convention on Climate Change.

The research shows the importance of increasing our countries’ institutional capacity to comprehensively and sustainably manage transboundary water resources and thereby improve socioeconomic development in the region.

The GEF Amazon Project also uses the GEF scientific dissemination guidelines to strengthen the capacity for knowledge management and thereby promote learning from large-scale experiences and methodologies on integrated management of transboundary water resources.

To this end, on its website and in the *Amazon Waters* newsletter, ACTO has been publishing reports on the progress of the research in order to encourage public awareness of the importance of learning how to protect and use the transboundary water resources of the largest river basin on the planet.

For the ACTO member countries, it is a special pleasure to have participated in such a close and coordinated way in each of the research and pilot projects, and I am very pleased to present this special publication, *Amazon Waters*, a compilation of the technical and scientific work carried out in benefit of the basin.

María Jacqueline Mendoza Ortega

Secretary General
Amazon Cooperation
Treaty Organization (ACTO)







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GEF Amazon Project – Water Resources and Climate Change

The ACTO/UN Environment/GEF Project - Integrated and Sustainable Management of Transboundary Water Resources of the Amazon River Basin, Considering Climate Variability and Change - is a successful regional initiative that involved the eight member countries of the Amazon Cooperation Treaty Organization (ACTO): Bolivia, Brazil, Colombia, Ecuador, Guyana, Peru, Suriname and Venezuela.

Objective of the Project:

To strengthen the institutional framework for planning and execution of joint strategic activities for the protection and sustainable management of the water resources of the Amazon Basin in response to the climate change that the region is experiencing.



Components of the GEF Amazon Project

The project was carried out under three thematic components:

► COMPONENT I. Understanding Amazonian Society

With the aim of constructing a shared vision about the future to guide the development of operational strategies in response to the main problems and needs of Amazonian society, the GEF Amazon Project carried out wide-ranging qualitative and quantitative opinion research, working with its associates in the region. The legal and institutional frameworks of the countries were studied, identifying needs to be addressed with strengthening and cooperation.

► COMPONENT II. Understanding the Natural Resources

Diverse research was carried out in situ that provided innovative technical and scientific results, leading to the formulation of the regional Transboundary Diagnostic Analysis (TDA) of the Amazon Basin and the Hydroclimatic Vulnerability Atlas, which is presented in this book.

► COMPONENT III. Strategic Action Program (SAP)

This is the project's most important product because it entails a jointly developed action strategy for the countries to implement measures to counter unsustainable practices in water resources management and adaptation to climate change, by means of pilot projects, using the principles of integrated water resources management (IWRM) to satisfy the demands of Amazonian society in a context of sustainability of the ecosystems.

By means of a wide-ranging regional participative process, the project was able to document the needs and perceptions of Amazonian society to propose strategic response mechanisms. To this end, the **Transboundary Diagnostic Analysis (TDA)** was applied in each country. The TDA is a technical and scientific analysis that identifies, quantifies and establishes priorities for problems associated with water that are of a transboundary nature. At the same time, it compiles and interprets scientific information about the environmental impacts and socioeconomic consequences of each problem. Finally, it analyzes the immediate, underlying and fundamental causes of

the problems, to identify specific practices, sources, locations and human activities that harm or threaten water resources and the environment.

In this manner, **the priority transboundary problems**, which substantiate the **Strategic Action Program (SAP)** were consolidated at the regional level. The SAP is a consensual guiding instrument for actions by the countries of the basin and for regional cooperation, which establishes strategies and priorities for action at the regional level while aiming at the development of policies and regulations in a context of strengthening institutions and capacities.



The Strategic Action Program (SAP), the most important achievement of the GEF Amazon Project - Water Resources and Climate Change

The **Strategic Action Program (SAP)** for integrated and sustainable management of the water resources of the Amazon Basin, considering climate variability and change, was based on new technical and scientific knowledge obtained from research, response measures demonstrated in the pilot projects that were undertaken, and on the results of a wide-ranging regional consultation process. The program entails dealing with priority transboundary problems and their root causes regionally. The SAP is also aimed at strengthening institutions and the implementation of policies and investments for the basin.

Rui Faquini

The SAP's Three Strategic Lines of Response

1. Strengthening integrated water resources management (IWRM) to increase the capacities of national institutions and ACTO, and to achieve IWRM at the regional level.
2. Adaptation to climate variability and change, monitoring and forecasting hydro-meteorological phenomena, creating adaptation measures for the communities.
3. Knowledge management, including the integrated information system (IIS), strengthening scientific knowledge and regional cultural activities.

With the project results, the eight ACTO countries granted technical validation to the SAP in January 2016.

Main Project Results for Amazonian Society

In each **component of the project** (Component I. Understanding Amazonian Society; Component II. Understanding the Natural Resources, and Component III. Strategic Action Program) **specific activities** were executed.

These activities included seven pilot projects in critical locations of the basin, three scientific research projects, as well as the creation of the integrated information system, the first Hydroclimatic Vulnerability Atlas of the Amazon Basin, and the implementation of national pilot projects in five countries. These endeavors made possible the formulation of the Strategic Action Program (SAP), which was the main objective of the project.

Three results emerged that are essential for fostering sustainable integrated water resources management (IWRM) in the region:

- ▶ **A shared vision of the Amazon Basin**, to understand the common problems and define future development plans for the region, considering IWRM in the Amazon Basin.
- ▶ **The Transboundary Diagnostic Analysis (TDA)**, based on the nine priority transboundary problems associated with water resources and climate vulnerability in the basin.
- ▶ **The Strategic Action Program (SAP)** agreed by the ACTO member countries.



Additionally, through its participative process and the implementation of the pilot projects, studies, training sessions and workshops with more than 1,170 participants, the project has provided scientific data for decision-makers in areas such as aquatic ecosystems, sediment loading and groundwater. In doing so, it has strengthened regional dialogue and institutional capacity for integrated management of water resources in the Amazon, positioning the main transboundary issues on the regional technical cooperation agenda.

The main events held included 11 national workshops, eight regional workshops and seven meetings of the project steering committee.

The project also identified areas that are vulnerable and at risk because of climate change, consolidating the first Hydroclimatic Vulnerability Atlas of the Amazon Basin, strengthening local governments' capacity for adaptation and response to deal with extreme events, by means of: i) implementation of risk governance models, ii) a tri-national early warning system in border areas, iii) policies for relocation of vulnerable populations, and iv) revenue-generating alternatives in flood areas, benefiting a total of 475,000 people.

Additionally, the project developed an integrated information system (IIS) on the transboundary water

resources of the Amazon Basin, to facilitate sharing information about integrated water resources management (IWRM).

One noteworthy innovation was that the project encouraged coordination in the use of surface and groundwaters in the urban centers of Leticia (Colombia) and Tabatinga (Brazil), twin cities that share the same aquifer, which is a subsystem of the great Amazon River Basin.

This project has opened up horizons for future cooperation for knowledge, protection and sustainable management of what is considered the largest aquifer system on the planet, a priceless treasure and a strategic water reserve.

Another outstanding innovative element of the project was how the issue of climate change was contemplated in conjunction with integrated water resources management in the Amazon Basin.

Project Funding

Total amount of the project: USD 52.2 million, with contributions from the Global Environmental Facility (GEF) of USD 7 million, and contributions by the countries and other donors in the amount of USD 45.2 million.



The GEF Amazon Project - Water Resources and Climate Change addressed the following 2030 Sustainable Development Agenda Goals



The Project and the 2030 Agenda for Sustainable Development Goals (SDG)

With support from a wide variety of actors, which represented unprecedented participation by civil society at the worldwide level, and following eight years of negotiations, in September 2015, the member states of the United Nations reached consensus on the document entitled: "Transforming Our World: Agenda 2030, for Sustainable Development" and the 17 sustainable development goals (SDG) along with their respective 169 targets to eradicate poverty, combat inequality, promote prosperity and protect the environment, to achieve by 2030.

These sustainable development goals include new lines of action such as climate change and environmental challenges, on which the GEF Amazon Project has been working intensively.

Starting in 2016, the SDG replaced the Millennium Development Goals (MDG), to guide the work of the United Nations in areas such as the eradication of poverty, sustainable use, and innovation, among others.

It was thus determined that "The 2030 Agenda places people at its core and aims to achieve a rights-based sustainable development under a renewed global partnership, in which all countries participate at an equal footing. Poverty eradication and address-

ing inequalities are central in the new Agenda, and are key priorities for Latin America and the Caribbean," as stated by the Economic Commission for Latin America and the Caribbean, ECLAC.

Specific Achievements of the Project in Relation to the Sustainable Development Goals

In relation to **SDG 1: No Poverty** and **SDG 2: Zero Hunger**

- » Implementation of agro-technological systems for vegetable production by fishing communities located on flood plains.
- » Empowerment of local communities in conditions of poverty, and the creation of economic alternatives through the implementation of measures for adaptation to climate change. **(SDG 13).**



Sérgio Amarel, OTCA

In relation to **SDG 6: Clean Water and Sanitation**

- » Application of integrated water resources management for the water resources of the Amazon Basin, involving: optimization of water use, transboundary considerations, measures for adaptation to climate change, formulation of policies and strengthening of legal and institutional frameworks, along with the necessary funding for the agreed-upon strategic actions. **(SDG 3).**
- » Incorporation of the groundwater component in integrated water resources management in the Amazon Basin.
- » Development of a program for the use and protection of groundwater.
- » Protection, management and monitoring of aquifers.
- » Implementation of a regional water quality monitoring system.
- » Conservation of headwaters, grasslands and wetland ecosystems.
- » Reduction of the vulnerability of bioaquatic ecosystems.
- » Monitoring of erosion, sediment transport and sedimentation.



- » Response to the impacts of land occupation and the dynamics of land use.
- » Development and consolidation of a regional information platform for IWRM.
- » Increased scientific knowledge about Amazonian water resources.
- » Development of rainwater collection systems for isolated communities.
- » Support to strengthen the IWRM institutional and management frameworks.

In relation to **SDG 13: Climate Action**

- » Development of a hydro-meteorological monitoring network in the Amazon Basin.
- » Development of forecasting and warning systems for droughts and floods.
- » Implementation of a climate risk management system for local governments.
- » Development of the integrated monitoring system for climate change vulnerability and adaptation.
- » Incorporation of issues addressing climate variability and change in the management practices and policies for the basin, to reduce the vulnerability of the populations and ecosystems, to extreme climate events.



Projecto GEF Amazonas

- » Development and implementation of measures for adaptation in relation to glacier loss, from the Andes to the Amazon. **(SDG 6).**
- » Promotion of cultural, educational and artistic activities about water resources and climate change. **(SDG 4).**

In relation to **SDG 14: Life Below Water** and **SDG 15: Life on Land**

- » Protection of river and coastal bioaquatic ecosystems.
- » Protection of coastal zones affected by rising sea level.



Rui Faquini



“No man ever steps in the same river twice, for it’s not the same river and he’s not the same man.”

Heráclito de Efeso

Study N°. 1

► Mapping Areas at Risk for Climate Change:

Creating the First Hydroclimatic Vulnerability Atlas of the Amazon Basin

Areas: Geography/Geospatial Technology /Climatology



In order to visualize the vulnerability of the populations and ecosystems to extreme hydroclimatic events (droughts and floods), the Amazon Cooperation Treaty Organization (ACTO) has developed the first Hydroclimatic Vulnerability Atlas of the Amazon Basin, through the ACTO/ UN Environment/ GEF Amazon Project - Water Resources and Climate Change. The Centro Internacional para la Investigación del Fenómeno del Niño (CIIFEN) (International Center for Research into El Niño), based in Ecuador, was selected to produce the atlas.

The atlas reveals the enormous complexity of the challenges facing the countries and agencies in charge of water in the region. It is a roadmap for identifying opportunities and challenges in the basin, and shows the need for permanent work on the inventory of risks and opportunities for the integrated and sustainable management of the basin.

Objectives of the Atlas:

To systematize existing information provided by the ACTO member countries, in order to create new knowledge and provide information to strengthen integrated planning and management of water resources by the institutions of the region.

The area of study is the Amazonian part of the territories of the eight ACTO countries, the tropical biome, the Guiana and Brazilian Shields (massifs or very old geological formations) and the Amazonian plains. The Amazon Basin covers an area of 6,118,000 km². Its altitude ranges from 6,643 MAMSL in the Andes to 0 MAMSL at the mouth of the Amazon River on the Atlantic Ocean.



Producing the Hydroclimatic Vulnerability Atlas of the Amazon Basin

The atlas was produced in four phases:

1

Description: environmental, biogeophysical socioeconomic and infrastructure characterization of the Amazon Basin.

3

Assessment of vulnerability to extreme hydroclimatic phenomena: susceptibility and adaptive capacity; calculation and analysis of vulnerability.

2

Analysis of hydroclimatic threats.

4

Creation of the Hydroclimatic Vulnerability Atlas of the Amazon Basin, at a scale of 1:1,000,000.

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Work Methodology

Step 1

Definition of the spatial analysis unit.

Step 2

Collection of information and creation of the geodatabase, to unify the units of measure and projection of each file.

Step 3

A methodology was designed for analysis of the climatological component and identification of hydroclimatic threats, taking into account the following variables: 1. Annual precipitation. 2. Mean annual temperature. 3. Real evapotranspiration. 4. Water balance. 5. Standardized precipitation index. The corresponding map for each variable was created. For example, extreme hydroclimatic events were represented using the Extreme Precipitation Standardized Index, after which those events were zoned to create the threat maps for droughts and floods.

Step 4

A methodology was created to determine vulnerability, which entailed the following studies: 1. Representation of the different degrees of susceptibility, adaptive capacity and vulnerability. 2. Calculation of hydroclimatic vulnerability due to socioeconomic factors. 3. Methodological calculation of hydroclimatic vulnerability due to biophysical factors. This vulnerability refers to the susceptibility of elements in the environment in relation to the threat from extreme hydroclimatic events, and their capacity to recover from impacts (adaptive capacity). To make the atlas, a formula of calculating vulnerability to floods and droughts was established. Indicators that represent the level of sensitivity of natural factors in relation to floods and droughts, were also established, given that in the biophysical surroundings where those indicators are found, mechanisms for adaptation and recovery have been developed. Examples of these indicators include: susceptibility due to density for rivers, according to their water characteristics in relation to floods, and susceptibility to flooding due to sloping terrain, among others.

Step 5 Vulnerability of the Amazon Basin to extreme hydroclimatic events. After the hydroclimatic threats were identified, the vulnerability of the systems at risk was evaluated: the socioeconomic system (population, livelihood and infrastructure) and the biophysical system (natural environment).

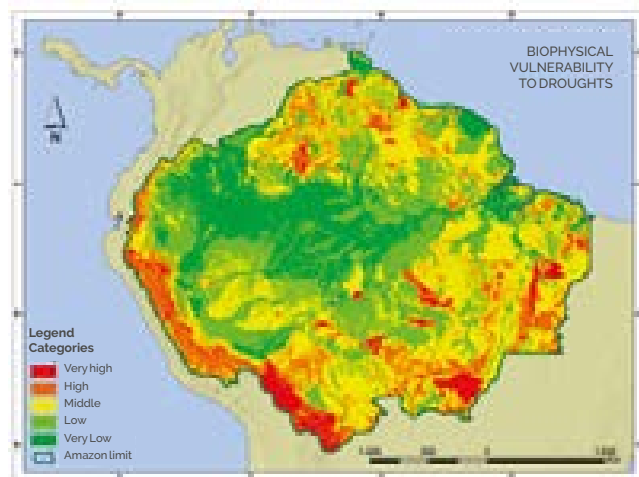
Step 6 To determine susceptibility and capacity for adaptation, the following factors were taken into account: 1. Socioeconomic component: socioeconomic susceptibility and capacity for socioeconomic adaptation. 2. Biophysical component: biophysical susceptibility. The socioeconomic data were taken from the most recent census in each country. Regarding biophysical susceptibility, the following elements were calculated: a) Slope of the terrain, based on the Shuttle Radar Topography Mission digital terrain elevation model. b) Texture of the soil. c) Water density, which took into account the first order rivers or those with the greatest flow, and the second order ones, to evaluate them according to their level of water contribution. d) Vegetation (class, type and sensitivity to droughts and flooding).

Step 7 Determining vulnerability. 1. Determination of vulnerability to flooding: socioeconomic vulnerability and biophysical vulnerability. 2. Determination of vulnerability to droughts: socioeconomic vulnerability and biophysical vulnerability. Formulas defined for each vulnerability factor were applied to the indicators for susceptibility and adaptive capacity, to calculate socioeconomic and biophysical vulnerability.

Step 8 Creation of maps for the atlas. A large volume of information was obtained, along with files from different databases, and detailed classification was done for each document. In this way, 16 tables, 29 figures and 51 maps were created to represent the data.

Result of the Experience: 51 Specialized Maps of the Amazon Basin

Based on the bio-geophysical, socioeconomic, infrastructure and environmental descriptions of the Amazon Basin, which are reflected in the 51 specialized maps, an analysis was done of hydroclimatic threats and vulnerability to those threats. This new information also made it possible to develop a set of guidelines for the Strategic Action Program (SAP).



Biophysical Vulnerability to Droughts

Prepared by CIIFEN for the GEF Amazon
Project- Water Resources and Climate Change

Summary of the main elements obtained from the bio-geophysical, socioeconomic, infrastructure and environmental characterization of the Amazon Basin

Bio-geophysical Description. The Amazon region contains biomes that are very important at the global level (forests, jungles and tropical plains with a high degree of biodiversity), with one of the largest water networks in the world, and it serves as a converter for large amounts of carbon dioxide, which is fundamental for life on the planet.

Relief. The region has two plates: the Guiana Shield (altitude: 2,800 m) and the Brazilian Shield (1,200 m) dating back to the Precambrian geological era, the Earth's oldest period.

Soil. In the Amazon there are approximately 20 kinds of soils, with a predominance of ferrosols (characteristic of plains, hills and flatlands) which make up 51% of the landscape, and Acrisols (acidic soils of cleared forests with low organic content) that account for around 16%. The agricultural quality of the land is fair to poor because it consists of shallow acidic soils.

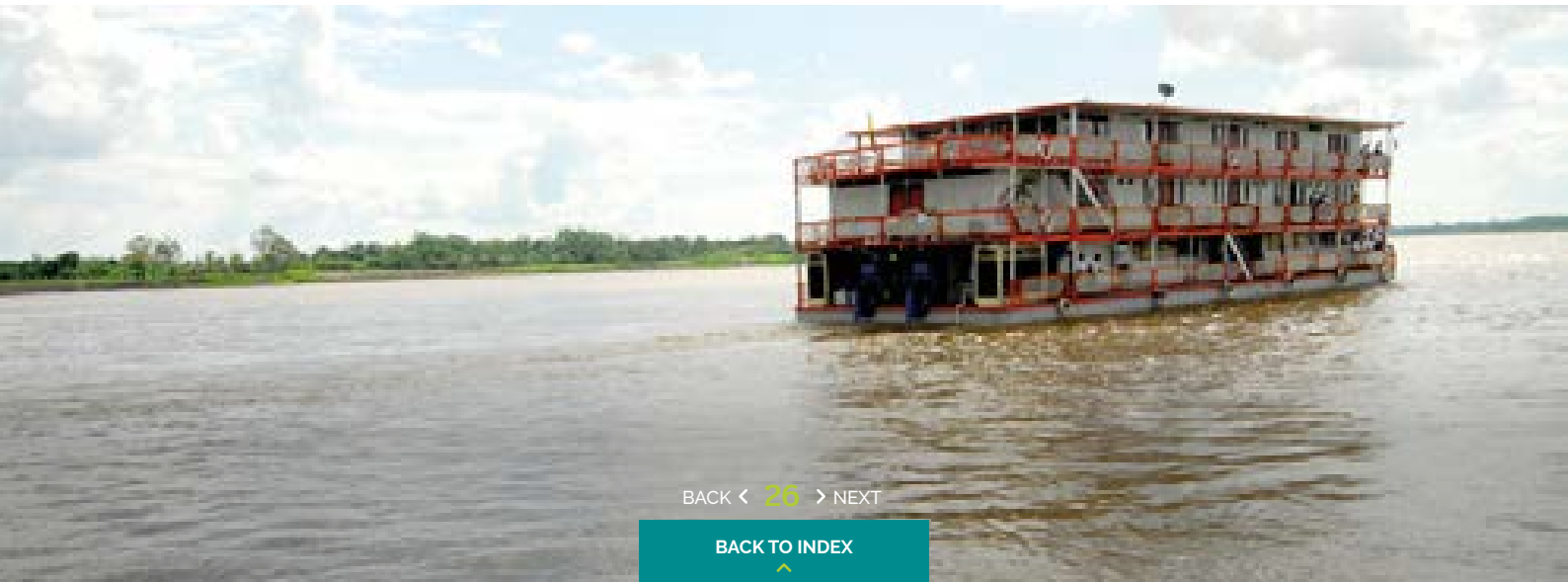
Climate. The region has different types of climates, Andean at the higher altitudes and mainly tropical in the rest of the area, which in turn is classified as equatorial tropical, tropical monsoon and tropical grassland.

Air Temperature. From the center to the mouth of the Amazon, the average temperature is 26 to 28°C. In the mountains, it may be as low as 2°C at the higher altitudes. There are areas with temperatures greater than 28°C in northern Bolivia, the Peruvian Amazon and on the border with Brazil.

Precipitation. This varies greatly by area. Amounts exceeding 3,000 mm/year have been recorded in the northwest, the east, at the river's mouth on the Atlantic Ocean and throughout the foothills of the Andes in the Amazonian regions of Colombia, Ecuador, Peru, Bolivia and Venezuela. There is less precipitation in the southern part of the region and at higher elevations in the Andes.

Evapotranspiration. This refers to the transpiration of vegetation, which is expressed in millimeters per unit of time, and is a key component of the water cycle. Higher figures were recorded in the northwest and at the mouth of the river on the Atlantic. Lower figures were found in the west, at mid-range and higher elevations in the Andes, and in parts of the Venezuelan Amazon.

Water Balance. Areas with greater water availability were found in the northwest, in a strip of the Peruvian Amazon and in the Amazon River Delta. A deficit was observed in the southern and eastern zones, and at the western edges of the high mountains of the eastern cordillera of the Andes. The climate is mainly tropical, and is classified as tropical equatorial, tropical monsoon and tropical grassland.





Climate Variability in the Amazon Basin. Climate patterns in the Amazon are subject to oscillations of periods ranging from an inter-month timescale to interannual and multidecadal, influenced by the oscillatory processes of the Pacific, the meridional atmospheric pressure gradient between the tropics and the subtropics of South America, and the meridional temperature gradient of the surface of the tropical Atlantic Ocean.

Climate Change in the Amazon Basin. The CIFEN showed changes in the climate of the basin, which are influencing the long-term dynamics of the biome. Signs of temperature increase have been identified, in both highs and lows, revealing that the number of days with temperatures above 25°C has been increasing at a rate of as much as six days per decade. A trend toward increased precipitation was also found. Climate change scenarios were generated for the Amazon, based on four models from the CMIP5 (Coupled Model Intercomparison Project Phase 5), developed by the World Climate Research Program (WCRP). The climate changes expected in the basin, based on forecasts of different scenarios for the 21st century, would not have much impact on the location and frequency of hydro-meteorological and extreme hydroclimatic phenomena. Droughts might become more frequent and there could be a slight increase in flooding. But more studies are needed for greater certainty.

Vegetation, Ecosystems and Biomes of the Amazon. Given its huge size and biodiversity, the Amazon tropical forest is important for its capacity to absorb

large quantities of carbon dioxide from the atmosphere and convert it into oxygen, an ecological service for the entire planet. Tropical forest covers approximately 67% of the area and tropical savanna covers around 13%. The tropical forest biome represents 50% of the planet's existing biodiversity.

Hydrographic Network. The Amazon River starts in the Peruvian Andes in the Apacheta ravine, next to Nevado Mismi mountain, at 5,597 MAMSL. Glacial runoff flows toward the Apurimac, a tributary of the Ucayali, which finally joins the Marañón to form the main channel of the Amazon. After the Apurimac and Ucayali merge into one, the river leaves the Andes behind and enters a gently undulating alluvial floodplain. The five rivers whose confluence form the Amazon are the Apurimac, Huallaga, Mantaro, Marañón and Urubamba-Vilcanota. The river we know as the Amazon runs from the meeting of the Marañón and Ucayali Rivers in Nauta (Iquitos), to the river mouth on the Atlantic. In Brazil, the Amazon River is called Solimões from Tabatinga to the meeting with the Negro River in Manaus. With an approximate flow of 220,000 m³/second, the Amazon is the most abundant and longest river of the planet. The Amazon Basin has a total of 285 level 3 hydrographic units (according to the Pfafstetter classification), with the Solimões segment being the longest.

Social and Economic Components. The Amazon is home to populations adapted to its environment. There is a vast diversity of cultures, as well as dialects and ancestral customs. The total population is more than 44 million. The cities with populations greater

than 1.5 million inhabitants are found in Brazil and Bolivia. Around 420 indigenous peoples inhabit the Amazon and they speak 86 different languages and 650 dialects.

Economic Activities. These consist mostly of the extraction of natural resources, minerals, forestry, agriculture and livestock. Around 6 million people fish and hunt.

Agriculture and Livestock. Approximately 22% of the surface of the Amazon is used for agricultural plantations and livestock, which leads to deforestation and changes in land use. Road development has fostered agriculture, mainly for the production of biofuels. Particularly noteworthy are the farming practices of the indigenous peoples, who have identified more than 2,000 medicinal and food species, as well as sources of oils, fats, waxes, varnishes, essences, rubber, condiments and nearly 400 species of timber-yielding trees.

Trade. This is the second most common economic occupation.

Description of Infrastructure

Health Infrastructure. Despite limitations in access to information, it was possible to identify the total number of health establishments in the region. The corresponding map shows the number and distribution of existing establishments in each administrative region. Having up-to-date information on the location of health facilities in this large region will improve access to information for health professionals and help decision-makers in the field of healthcare to expand services and improve coverage, considering climate vulnerability variables.

Education Infrastructure. The map shows the distribution of the existing education establishments (schools and universities) in each administrative region. The areas with the most education infrastructure are found in Peru and Colombia, with less presence from the center to the Amazon Delta. The southern region has the smallest number of educational institutions.

Transport Infrastructure. Transport in the region is done on the river network, roads, and by air. There are 168,191 km of primary roads and 326,849 km of secondary roads (trails, paved paths, streets). Rivers are the main means of transport in the region. Through the Initiative for Regional Infrastructure Integration of South America (IIRSA) and the South American Infrastructure and Planning Council (COSIPLAN) of the Union of South American Nations (UNASUR), projects are being executed such as the Manta-Manaus Multimodal Highway, which is to run from Manta on Ecuador's Pacific coast, through the mountains, to the port of Manaus in the Amazon, to Belem on the Atlantic coast.

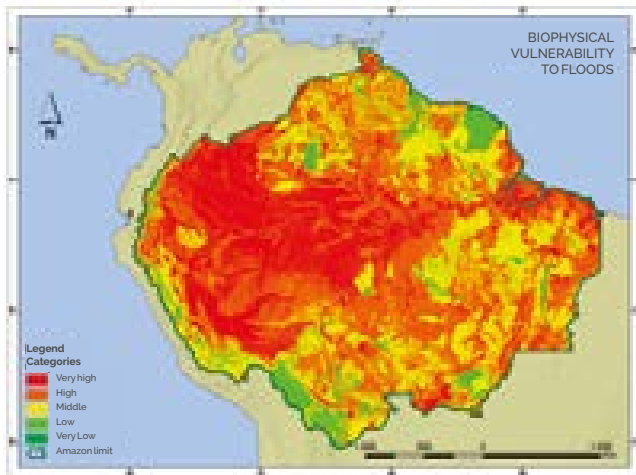
Electrical Infrastructure. Power generation in the Amazon is mostly hydroelectric. There are large and small hydroelectric power plants, which as a whole account for 60% of total electricity generation. Other types of energy are: thermoelectric, thermonuclear, wind and solar.

Environmental Component. Protected Areas. In the Amazon there are designated areas for conservation and protection, called protected areas. These represent 23% of the entire Amazonian territory, approximately 1,897,946 km², not counting indigenous lands. Approximately 33.17% of the protected areas belong to national and regional parks; 20% are natural forests and fewer than 10% are other kinds of protected areas.

Learning from Experience: A Method for Analysis of Hydroclimatic Threats

Once the multi-faceted description of the Amazon was ready (bio-geophysical, socioeconomic, infrastructure and environmental), the analysis of hydroclimatic threats was done.

The conditions under which a system or part of a system is exposed to the impact of an extreme hydroclimatic phenomenon, are considered threats, which are evaluated in terms of probability of losses or damages. Long-lasting droughts and floods in flat areas constitute threats because of the extent of the areas they affect and the magnitude of their impact.



Biophysical Vulnerability to Floods

Prepared by CIIFEN for the GEF Amazon Project - Water Resources and Climate Change

To do an analysis of recurrent disasters in the Amazon, the 2013 DesInventar regional disaster databases (<http://www.desinventar.org>) produced by Corporación OSSO-UNISDR (United Nations Office for Disaster Risk Reduction) were used, along with the EM-DAT database by the OFDA (Office of U.S. Foreign Disaster Assistance) and CRED (Centre for Research on the Epidemiology of Disasters), and the S2ID Integrated Disaster Information System of Brazil.

Floods are the most common kind of disasters, accounting for 50% of the total number of incidents. Droughts, and the associated disaster of forest fires, account for 9% and 4% of incidents, respectively. Having identified the most recurrent disasters, the most affected socioeconomic aspects were explored. In the case of floods, the most affected sectors were crops, forests, roads, and education and health infrastructure. In terms of droughts, the greatest impact occurs in the livestock sector, accounting for 53%, and the human population, representing 38%. In this manner, maps on the impacts of droughts and floods were created, and examining a 35-year period, using the standardized precipitation index.

The systems or elements of the biophysical and socioeconomic environment that are susceptible, and for which those disasters are a threat, were then identified.

After analyzing the hydroclimatic threats, an evaluation was done of the vulnerability of the susceptible systems. In this study, analysis of vulnerability and adaptive capacity was done separately for each kind of disaster, looking at two components: socioeconomic and biophysical. It was found that the education infrastructure in large sectors of the Amazon has very little capacity for adaptation.

Similarly, the maps show the degree of biophysical susceptibility to droughts and floods in terms of impact on vegetation. By combining adaptive capacity and socioeconomic susceptibility, socioeconomic vulnerability was obtained which, combined with biophysical vulnerability, provides a comprehensive picture of vulnerability to droughts and flooding, which gave rise to a map of integrated vulnerability.

Basic Action: Improve Knowledge about Threats and Risks due to Droughts and Floods

Given that droughts and floods have affected the population, agricultural systems and infrastructure of the Amazon Basin on a recurrent basis, creation of this first atlas provided substantial information for the countries to use, and as a key input for joint regional planning of integrated and sustainable water resources management through the Strategic Action Program (SAP).

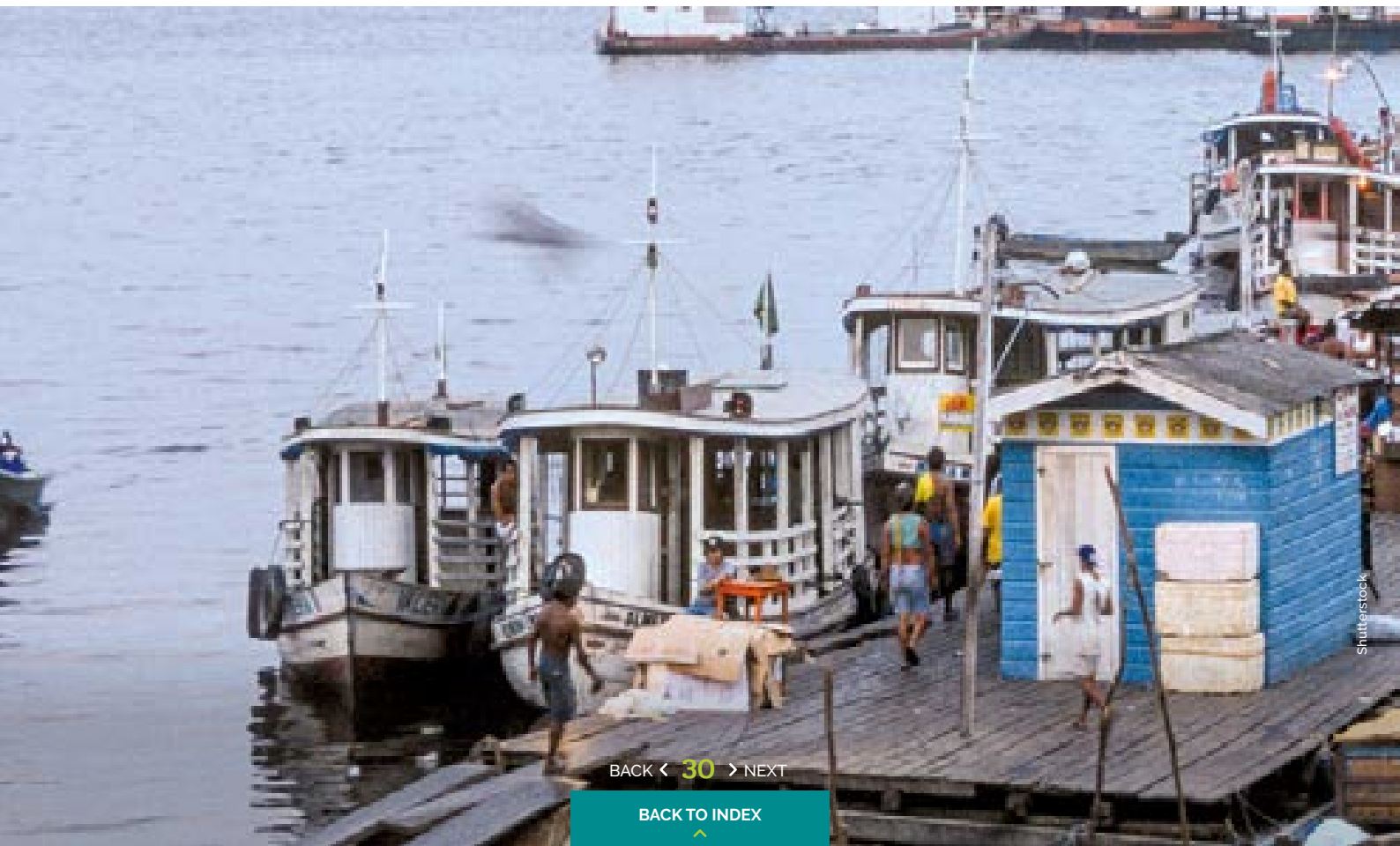
The first strategic action that is needed is to: **improve knowledge about the threats and risks due to droughts and floods**, in order to make it possible to:

- a. Incorporate new knowledge into climate forecasting models that will serve as early warning systems for sector, territorial and regional planning.
- b. Create more detailed threat maps about floods and droughts.
- c. Strengthen the resilience of the communities that face those threats.
- d. Publicize knowledge about droughts and floods.
- e. Learn about experiences of other regions and cultures in terms of how they handle droughts and floods.

Additionally, **a set of five actions aimed at disaster risk reduction due to floods and droughts was presented:**

1. Limit land occupation by the population and reduce the exposure of different elements of the socioeconomic system in zones where droughts and floods are frequent.
2. Plan in accordance with flood and drought cycles.
3. Establish climate forecasting systems to provide early warning.
4. Provide training in the use of climate forecasting information.
5. Implement policies to reduce risk in regions of high and very high vulnerability.

Strategic actions were also proposed for managing flood and drought situations, which require: designing, formalizing, sharing and trying out territorial (municipal) and sectoral contingency plans in response to droughts and flooding. A recommendation was also made to encourage people to buy agricultural, residential and infrastructure insurance policies against natural disasters.



Multiple Uses of the Atlas

The first Hydroclimatic Vulnerability Atlas specifically about the Amazon Basin has provided substantial information to support the project's Strategic Action Program (SAP). Because of its characteristics, this atlas will serve as a fundamental tool for the study of water basins in other regions that are interested in the subject of transboundary waters.

The atlas has multiple practical applications for use with the different target groups addressed by the project, and for dealing with diverse sectors, particularly environmental institutions and decision-makers on the subject of water resources.

The experience gained in the production of the atlas will open new doors for sharing the technical and

scientific knowledge that has resulted from the GEF Amazon Project, and it represents transcendent scientific progress for the region.

At the regional level, the atlas has provided substantial technical and scientific information for better understanding, planning and integrated management of the Amazon Basin by the eight ACTO member countries.


Furthermore, the production of the atlas on the Amazon Basin has raised new questions: How do other regions and cultures deal with the two extreme situations of climate variability (floods and drought)? How does the creation of a Hydroclimatic Vulnerability Atlas shed light on the complexity of a region in terms of extreme events, and also enable comparison of the same phenomena from one region to another?



References/Bibliography for Study N° . 1



- » The seven-page bibliography may be consulted in the Technical Report (Phase II) of the Hydroclimatic Vulnerability Atlas of the Amazon Basin, on the project's website.



“Deep rivers move in
silence; shallow brooks
are noisy”

Hindu proverb

Study N°. 2

► Groundwater for Urban Supply:

Evaluation of the Aquifer Systems of the Leticia-Colombia region

Area: Hydrogeology



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One of the most important results of the GEF Amazon Project was to incorporate the concept of groundwater in the integrated management of water resources of the Amazon Basin.

Thus the sub-project entitled "Joint Use of Surface and Groundwater in the Tri-border Region (Colombia, Brazil and Peru)" was carried out, which entailed three specific and interrelated studies:

1. "Evaluation of the Aquifer Systems of the Leticia-Colombia Region," done by Servicios Hidrogeológicos Integrales (SHI S.A.S.), a consulting firm, which is discussed in this chapter.
2. "Joint Hydrogeological Characterization of the Tabatinga-Leticia Transboundary Aquifer System,"

3. "Evaluation of the Aquifers of the Sedimentary Basins of the Amazon Hydrogeological Province in Brazil (scale 1:1,000,000) and the Pilot Cities (scale 1:50,000)." Volume IX: Pilot City: Tabatinga, Amazonas. This study was done by Brazil's National Water Agency (ANA).

Analyzing Interaction Between Surface and Groundwaters, and Possible Impact of Climate Change

The tri-border zone at Leticia (Colombia), Tabatinga (Brazil) and Santa Rosa River Island (Peru), is characterized by an abundance of water resources, in the air, on the surface and underground. However, problems have existed because of poor management of the water supply for public use, particularly in Leticia, Colombia, where water for human consumption comes from rainwater, surface and groundwater, in which the latter serves as the main source of supply.

This tri-border zone was a key area in the GEF Amazon project, which aimed to improve technical and scientific knowledge about this zone, and so the study "Evaluation of the Aquifer Systems of the Leticia-Colombia Region" was undertaken.

The objective of this study was to describe and evaluate the aquifer systems around Leticia, considering the interaction between surface and groundwater, and how the possible impacts of climate variability and climate change could affect that resource.

Methodology

Step 1 **Secondary information was gathered from the following entities, which were fundamental in carrying out this activity: ACTO, CORPOAMAZONÍA,** the Instituto de Hidrología, Meteorología y Estudios Ambientales (IDEAM) (Institute of Hydrology, Meteorology and Environmental Studies), Universidad Nacional de Colombia (UNAL), Servicio Geológico Colombiano (SGC) (Colombian Geological Service), Ministry of the Environment and Sustainable Development, and the Instituto Geográfico Agustín Codazzi (IGAC).

Step 2 **Three field visits were done in the region of Leticia.** The first was to identify and gather secondary information, the second was an inventory of groundwater locations and the identification of potential sources of pollution, and the third was for physicochemical sampling of the groundwater and water level monitoring, thereby obtaining substantial primary information on certain parameters of the aquifer systems of the region.

Step 3 **Three meetings were held with organizations from the zone:** one meeting with CORPOAMAZONÍA and two meetings to present the project to the community in Leticia, showing the progress and results achieved.

Step 4 **Using the primary and secondary information, a description was made of the aquifer systems of the region, identifying:** the geological and geomorphological conditions of the zone; regional hydrology and climatology; hydrogeological formations present; hydraulic conditions of the formations, particularly the alluvial aquifer of Leticia; uses of groundwater; conditions of operation and consumption from the wells; threat of pollution of underground water; vulnerability of the aquifer; and quality of the surface and groundwater for human consumption.

Step 5 **The current condition of the mechanisms to supply drinking water in the Leticia region were evaluated.**

Step 6 **The demand for water in Leticia for the year 2040 was projected, and scenarios for climate variability and climate change were examined to determine the vulnerability of water resources in relation to such events.**

The above steps made it possible to do a general diagnosis of the problems and define strategies and measures for adaptation to them.



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The area of study was the municipality of Leticia, in southern Colombia, which is the capital of the Department of Amazonas. It covers 5,968 km² and is located on the left bank of the Amazon River, at the border between Colombia, Peru and Brazil. Leticia is at an altitude of 96 MAMSL, has an average annual temperature of 25.8°C and a humid tropical climate most of the year, with flat topography and average rainfall between 2,500 and 3,400 mm/year, according to data supplied by the Corporation for Sustainable Development of the Southern Amazon (Corporación para el Desarrollo Sostenible del Sur de la Amazonía - CORPOAMAZONÍA).

Main Characteristics of the Leticia Region Aquifer Systems

The description of the Leticia region aquifer systems took into account the examination and analysis of a group of variables, the results of which are presented below:

1. Geological aspects. "The southern Colombian Amazon region is geologically characterized by different types of igneous (volcanic), metamorphic (deriving from other) and sedimentary rock that ranges in age from the Precambrian (the Earth's oldest geological era) to the present," according to CORPOAMAZONÍA. The Pebas Formation (middle to late Miocene) also defined as the Lower Tertiary Amazon Geological Formation, and the Calderón Sandstone are the oldest rock outcroppings in the zone of study. Recent and current sediments have been deposited on those rocks, the product of the dynamics of

the Amazon River, namely: the Leticia alluvial terrace, old and recent riverbank deposits, and sand bar deposits, according to data from the Servicio Geológico Colombiano (previously known as INGEOMINAS).

2. Hydrology and climate. The zone is located in the Amazon River Basin, on an alluvial plain on the left bank of that river. The main bodies of water around the municipality and that define the drainage network are: the Amazon River, the Tacana River; the Yahuaraca, Simón Bolívar, Porvenir, San Antonio and Pichuna streams; and the lakes and wetlands of Yahuaraca. The climate is influenced by the intertropical convergence zone (ITCZ), the continental equatorial air mass (masa ecuatorial continental - MEC), and local valley-mountain winds. The annual cycle of average water levels on the Amazon River in Leticia shows a maximum variation of 8.66 m. In this zone, there are high levels of precipitation, with average rainfall of 3,264 mm/year. A comparison of seasonal rainfall and water level on the Amazon River (Leticia station) indicates that the two variables do not coincide completely, and that there is a nearly two-month lag between the measured extremes for both variables, because the water level of the Amazon River in Leticia is influenced by precipitation in the Andean zone of Ecuador and Peru.

3. Hydrogeology. The Leticia region aquifer systems are part of the Amazon aquifer system, whose area is approximately 3,950,000 km².

In terms of the Amazon subbasin in Colombia, the aquifer systems are part of the Vaupés-Amazonas hydrogeological province. In the zone of study, Garcia (2008) used vertical electrical soundings to identify three hydrogeological units. The first was identified as a multilayer free aquifer, adjacent to Leticia; the second an aquifuge (subterranean geological formation, characterized by its impermeability, and therefore unable to absorb or transmit water) that corresponds to the Pebas Formation; the third unit is an aquifuge and corresponds to the basement layer, according to the electrical soundings. The hydrogeological unit of interest for our study, and which contains the groundwater deposits in the Leticia region, is known as the Leticia alluvial aquifer, which has particular hydraulic characteristics. The groundwater in the Leticia region has wide-ranging uses and is defined by the quantity of existing groundwater points. In the inventory done for this study, 226 water access points were recorded which, when added to the inventories done by Garcia (2008) and CORPOAMAZONÍA, results in a total of 1,055 groundwater points.

4. Physicochemical parameters of the groundwater analyzed:

pH, dissolved oxygen, redox potential (related to pH and oxygen content), electrical conductivity and temperature.

5. Static level of the water, determined by using an electrical probe.

During the fieldwork, it was found that the depth of the water level varies as much as 7 m between the dry and rainy seasons.

6. Underground water flow.

The fieldwork showed that the flow generally tends to be north-south and east-west, with considerable influence from the Amazon River. There is a close relationship between the Amazon River and the Leticia alluvial aquifer, in that the river's water helps recharge the aquifer. Evidence of the interaction between the aquifer and the river was recorded in this project.

7. Use of groundwater.

Due to the condition of the aqueduct in Leticia, many people prefer to use

groundwater, with rainwater as their second option, rather than water from the municipal aqueduct. This was the case in both the urban and rural areas. The predominant use is for households.

8. Threats due to pollution.

Through this project, several potential sources of pollution for underground and surface water were identified, which include: 1. The open pit garbage dump at Km 4 of the Leticia-Tarapacá Road. 2. The landfill at Km 17 of that same road. 3. The cemetery in the urban center. 4. Two gas stations in the urban center. 5. The fuel storage system at the Alfredo Vásquez Cobo Airport. 6. The abattoir in the urban center, and 7. Polluted streams, such as the San Antonio and Simón Bolívar.

9. Sanitary conditions at the water catchments.

When unfavorable, these threaten to contaminate groundwater. Here are some of the 11 risk factors that were identified: Almost all of the households discharge their wastewater into septic tanks because they lack sewer systems. Most of the septic tanks (98%) are located at a distance greater than 30 m, however there is a considerable density of such tanks in the zone. It was found that 56% of the tanks have neither an adequate cover nor sanitary catchment seals. It was observed that 15% of the tanks are surrounded by stagnant pools of water.

10. Alluvial aquifer's vulnerability to pollution.

To evaluate this, the GOD method developed by Foster (1987) was employed, which applies three criteria to evaluate vulnerability: depth of the water table in free aquifers, type of aquifer, and the lithological characteristics (composition of the rocks) of the vadose zone (space between the water table and the surface). These measurements are used to determine the pollution vulnerability index, which goes from 0 to 1, with 1 being the highest level of pollution vulnerability. In the study zone, vulnerability was found to be moderate.

11. Quality of surface and groundwater.

Colombia's legislation was consulted, which defines the criteria for water use. The quality of the water for

human consumption was evaluated, based on secondary and primary information, analyzing and processing the data from physicochemical and microbiological monitoring done at different surface streams. A water quality index of the surface water was analyzed, and a water quality zoning map was made. It was found that surface water quality is variable, and water quality is better farther from Leticia's urban center. The most alarming conditions were found in the urban streams, which receive solid waste and wastewater discharges. The quality of groundwater was evaluated based on secondary and current information, and through physicochemical and microbiological monitoring. The preliminary diagnosis was done based on monitoring by CORPOAMAZONÍA in 2009, when 75 water points were evaluated, and a groundwater water quality index was defined. During this project the diagnosis was updated. A sampling network of 20 points was defined, and the physicochemical and microbiological parameters for groundwater were evaluated. In general, the quality of the groundwater is good in comparison with surface water, and it is better for human consumption and other uses.

12. Supply of drinking water and projected water demand in 2040.

Potable water is supplied to Leticia by the municipal aqueduct, underground wells, rainwater and private potable water distribution points. According to the National Institute of Health (Instituto Nacional de Salud) in a survey done in 2012, Leticia's aqueduct does not fully satisfy human consumption water needs and reaches less than 50% of the population that requires water. Many users (61%) therefore opt to use groundwater or rainwater. In these cases, the water receives no treatment and is consumed in the same condition as it is collected. Only 21% of the water consumed is treated with chlorine and only 3% is treated fully. With the information on groundwater consumption recorded by the project and the estimated number of users of the consolidated inventory, the current demand for groundwater was defined, which corresponds to 0.517 Mm³/year and to satisfy a total of 26,875 inhabitants, equivalent to 65% of the total population of Leticia. Demand for groundwater is less

than the estimated maximum demand, calculated at 1,224 Mm³/year. This indicates that there is no excessive water exploitation.

To consider future groundwater scenarios in the region, total water demand and groundwater demand were projected until 2040, applying three methods required for the calculation, and taking into account historical water consumption. Thus, for 2040, groundwater demand ranges between 236,711 and 3,604,929 m³/year. Taking into account trends, and best and worst case scenarios, the project estimates that demand in 2040 will be 750,236 m³/year.

13. Vulnerability to climate variability and change.

The hydro-meteorological variables studied in the project, which could impact the Leticia alluvial aquifer were: level and flow of the Amazon River, precipitation in Leticia and the subbasins of Ecuador and Peru, and regional temperature. Relationships were examined between local climatology and macroclimatic variability indexes, and it was found that the level of the Amazon River is influenced by conditions in both the Pacific and Atlantic Oceans. A trend was also observed in terms of more extreme events impacting the flow and level of the Amazon River.

To estimate future scenarios of climate change and variability, the project used 15 atmosphere-ocean coupling global climate models that were prepared for the Intergovernmental Panel on Climate Change, mentioned in the fourth evaluation report, as well as three regional climate models. In general, the models indicated increases in precipitation, an increase in extreme events--both droughts and floods-- associated with an increase in the temperature of both oceans.

New Strategies and Measures Based on the Principles of Integrated Water Resources Management

With the results obtained from the project, strategies and measures for adaptation have been proposed to address the problems that were identified, using the principles of integrated and sustainable water



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resources management in the Leticia region, and to take measures for the joint use of surface, groundwater and rainwater.

In discussion with the social actors, the project identified the importance of making the wells deeper as the most effective measure to deal with the expected variations in the aquifer level during times of intense droughts, such as those that occurred in 2005 and 2010.

The project also noted that based on the diagnosis of the current potable water supply, it is recommendable that the community share and administer deep wells jointly, to better manage the resource, toward the best future scenario for water supply, which would also entail controlling potential sources of pollution.

The community also discussed the need to optimize and improve the operations, distribution and management of the municipal aqueduct in order to be able to use surface water adequately. Recommendations were also made to look at using rainwater as an alternative, given the amount of precipitation in the region.

To implement the proposed solutions, the project recommended carrying out more detailed hydrogeological studies, which would include a network for exploration and monitoring of groundwaters.

It was also deemed necessary to continue to study climate forecasting models in the region, to develop climate change projections, to be used in conjunction with studies on the effects of deforestation and changes in land use in the basin.

Replication in Colombia

The results of the study "Evaluation of the Aquifer Systems of the Leticia-Colombia Region" will be used in the master plan for Leticia's aqueduct and sewer system. The results will also serve as inputs to continue studying this aquifer that is shared with Tabatinga.

Colombia and Brazil should pursue a joint study to define the geometric and hydraulic conditions of this transboundary aquifer complex. Furthermore, the hydrogeological characterization of the Leticia aquifer could be replicated in other subbasins of the Amazon.

The results of this study constitute a framework for planning water resources in the Amazon, and a technical and academic reference document for other regions interested in studying their own aquifers and developing future projections.

The technical and scientific knowledge that was obtained will facilitate the exchange of experiences in the region and assist in the acquisition of new knowledge, along with the search for new climate forecast-

ing models to better understand climate variability and change.

The experience with the community in Colombia also revealed the need to create environmental education programs about aquifers for schools and universities, to increase awareness and publicize the principles of integrated and sustainable water resources management applied to groundwaters.




References/Bibliography for Study N°. 2

- » See the complete bibliography on pages 69 to 75 of the study "Caracterización Hidrogeológica conjunta del Sistema Acuífero Transfronterizo Tabatinga-Leticia," ("Joint Hydrogeological Characterization of the Tabatinga-Leticia Transboundary Aquifer System") created by SHI S.A.S for the GEF-Amazon project, on the project's website.



GEF-Amazon project

Measures to achieve better water resources management were discussed with local stakeholders in Leticia.

A photograph of a sunset over a wide river. The sun is a large, bright yellow circle in the upper left, casting a golden glow across the sky and water. Several boats, including a large sailing vessel with multiple masts and a smaller motorboat, are silhouetted against the water. The background shows a dark, silhouetted shoreline with trees and buildings.

“The old river in its broad reach rested unruffled at the decline of day, after ages of good service done to the race that peopled its banks, spread out in the tranquil dignity of a waterway leading to the uttermost ends of the earth.”

Joseph Conrad

Study N^o. 3

► Twin Cities that Share the Same Aquifer:

Joint Hydrological Characterization of the Tabatinga–Leticia Transboundary Aquifer System

Area: Hydrogeology



The aquifer systems of Leticia (Colombia) and Tabatinga (Brazil) make up a single transboundary aquifer, which in turn represents a subsystem of the great hydrogeological basin of the Amazon aquifer system, as it has been dubbed initially.

A hydrogeological characterization of this aquifer was done jointly, through a combined analysis of the results obtained from two hydrogeological studies: the aquifer of the Leticia region and that of the city of Tabatinga.

Using these studies, qualitative comparisons were done and similarities and differences were examined to determine the hydrogeological characteristics of this transboundary aquifer. It should be pointed out that there are differences between the two studies in

time frames and area of study (particularly due to the differences in the working scales used and the times when the monitoring and tests were done) and in the exploration methodologies, which make it difficult to compare the results quantitatively and conclusively.

Area of Study. Urban and suburban area of Leticia and urban area of Tabatinga.

Characteristics of the Two Hydrogeological Studies

This joint characterization of the aquifer system was done qualitatively and descriptively, rather than cartographically and quantitatively.

Both studies offer a description, at different scales, of the abiotic elements (hydrology, atmosphere,



Rui Faquim

geology and hydrogeology) of the areas of study, which reveal the homogeneity of both zones in these aspects, in which the hydrogeological component is

essential for determining the possibility of joint use of surface and groundwaters to supply the populations of both cities.

General Characteristics of the Two Hydrogeological Studies in Leticia and Tabatinga

Component/element	Evaluation of the Aquifer Systems of the Leticia-Colombia Region (SHI S.A.S 2015)	Evaluation of the sedimentary basin aquifers of the Amazon Hydrogeological Province of Brazil (scale 1:1,000,000) and Pilot Cities (scale 1:50,000) (ANA, 2015).
Zone of interest	Leticia (urban, suburban and expansion areas)	Tabatinga (urban area)
Scale	1:25,000	1:100,000
Timeframe	The study was done between January and August of 2015. This included the technical study of the rainy season from April to May of 2015.	The study was done in April and October of 2012, which corresponds to a rainy period and a dry one, respectively.
Coordinate System	WGS84 geographical coordinates	UTM and WGS84 coordinates

Description of the Abiotic Elements of the Zone

The following is a comparative description of the abiotic elements of the zone.

» **Geology.** The local and regional geography of the two zones has significant similarities: both cities are located on the Leticia alluvial terrace, a favorable

hydrogeological environment for the occurrence of groundwater, and there are no geological borders that confine the aquifer systems of either city.

» **Hydrogeology.** The Leticia-Tabatinga aquifer subsystem is part of the Amazon aquifer system. Hydrogeological units were defined both in Leticia and Tabatinga. It is important to mention the difference in terms of the methodology

applied to define these units, their thickness and geometric configuration, due to the scales used (differences in the thickness of the aquifer

were found). In Leticia, García R. and CORPOAM-AZONÍA defined the units based on seven electric soundings done in the area of study.

Description of the Hydrogeological Units Defined in the Leticia and Tabatinga Studies

Zone	Unit	Description	Thickness	Classification
LETICIA	Hydrogeological unit I	Formed by the muddy and sandy alluvial deposits of the Leticia terrace and the sandstones of Calderón, constituting a multilayered free aquifer. It extends throughout the area of study. This unit is shallow and its water levels are superficial. Used as a groundwater source by the population of Leticia (García Romo, 2008).	Variable thickness, which is greatest in the area adjacent to the urban center of Leticia, at 70 m, which decreases toward the north with a depth between 50 and 15 m.	Aquifer
	Hydrogeological unit II	Corresponds to the Pebas/Solimões Formation, which acts like an aquifuge consisting of claystone (García Romo, 2008) that underlays hydrological unit I.	Unknown	Between aquifuge and aquiclude
	Hydrogeological unit III	Corresponds to the base or craton (Araracuara and Precambrian formations of the Guiana Shield), which may act like an aquifuge, according to the electrostratigraphic data. Its secondary porosity is low because it is in a tectonically stable environment. (García Romo, 2008)	Unknown	Aquifuge

In Tabatinga, the hydrogeological units were defined by examining three wells that had been drilled for oil exploration, whose depths are greater than 1 km; none of the wells is located directly under the area of study.

Zone	Unit	Description	Thickness	Classification
Tabatinga	Alluvial aquifer	Alluvial deposits that occupy extensive areas along the banks of the Solimões/ Amazon River, consisting of clays with depths of 3 to 8 m, followed by fine to medium coarse sand with thicknesses between 12 and 17 m, which underlie the Solimões Formation.	Between 12 and 17 m	Aquifer
	Içá free aquifer	Completely sandy formation, with good flow characteristics, present in the Benjamin Constant stratigraphic well, but which is not found in Tabatinga.	20 m	Aquifer that is not present in Tabatinga
	Solimões aquitard	The Solimões Formation has some interspersed sediments that permit water flow and whose thicknesses vary between 8 and 12 m. Present in an interspersed manner in the total thickness of the formation	113 m in total	Between an aquitard and an aquiclude
	Javari confined aquifer	Confined between the low permeability sediments of the Solimões Formation in the upper part and the crystalline base in the lower part. Found at a depth greater than 200 m in Benjamin Constant	381 to 500 m	Confined aquifer



Hydrological unit I that is identified in Leticia, and the one that is described in Tabatinga as an alluvial aquifer, are the same one with the same compositional formation characteristics, and are the units used by the human settlements in the two regions. For these reasons, the hydrogeological study focused on the characterization of that hydrogeological unit.

Extension and Thickness of the Leticia-Tabatinga Transboundary Alluvial Aquifer

The aquifer in Leticia extends throughout the zone of study and has thicknesses ranging from 15 to 50 m. In the zone closest to the Amazon River, the thickness of the unit reaches as much as 70 m.

In Tabatinga, a very homogenous distribution of the aquifer was found, with thicknesses varying between 12 and 17 m. When comparing the geometric configurations of the aquifer in the two zones of study, significant differences were found in the thickness of the formation, due to the methodologies used to define the geometry of the alluvial aquifer (geolectric exploration methods in Leticia and stratigraphy of the oil wells in Tabatinga).

Components of the Leticia-Tabatinga Alluvial Aquifer

The following components were taken into account for the characterization:

1. **Hydraulic parameters**, which included the expected range of variation and the results of the constant-rate pumping tests in both zones, to observe the river-aquifer interaction.
2. **Piezometry of the alluvial** aquifer (height reached by the water during sounding). Levels were measured during the fieldwork in Leticia (160 wells measured) and Tabatinga (15 wells). Although the areas of study were different in size, and the number of wells where the levels were measured were different, the trend in the depth of the static level was very similar: less than 6 m at levels near the surface.

These measurements also made it possible to observe that the direction of groundwater flow during the rainy season is very similar in Tabatinga and Leticia, which is in an E-W direction, toward the flow of the Amazon River. The flow direction indicates a direct relationship between the alluvial aquifer and the Amazon River, with excess water at ground level discharging into the watercourse, at the surface. Static level variation at different times in both cities correlates with the water table of the transboundary alluvial aquifer.

The study concluded that the most superficial levels of the aquifer have a direct relationship with precipitation, but the water mass contained in the aquifer is associated with the dynamics of the Amazon River to which it is connected.

3. Recharge mechanisms and volume of water in the alluvial aquifer.

This transboundary aquifer is fed by two recharge mechanisms:

- a. **Recharge by base flow**, which comes from contributions by two base flows of the Amazon River and depends on the dynamics of the Amazon River Basin. Given the large volume of water in the base flow, those quantities could be considered "permanent" groundwater reserves.
- b. **Recharge by precipitation**: Stems from variations in the surface water table of the alluvial aquifer that feed its own surface levels. This recharge is very variable over time. The surplus amounts that raise the water table flow to the Amazon River, and in Leticia these are also directed toward other surface water flows. This aquifer-river interaction is also taking place in Tabatinga.

Main Results

1. **Storage volume of the alluvial aquifer**: Garcia defined a total volume of 54.7 hm³ for the Leticia region in 2008. ANA-Brasil, using data from 2015, defined a total volume of water storage of 17.6 hm³ for the Tabatinga region. This gives a grand total of 72.3 hm³ shared between the two zones.

and the study explains that this amount may actually be greater.

2. Inventory of water points: 1,176 duly referenced groundwater points were found on the Leticia-Tabatinga transboundary alluvial aquifer (with information about their characteristics), which were recorded in the databases of the studies made by SHI S.A.S. 2015 and ANA, 2015. However, it is estimated that there are really more than 3,000 water points that draw on the alluvial aquifer. Those water points are mostly found in the urban centers of both cities.

3. Uses of underground water: In both cities, the groundwater catchments are wells, whose most common diameter is 4 inches, with a mean depth of 18 meters. Most of the wells have been drilled by hand. Their characteristics are the same because the same drilling companies work in both cities. Most of the water points are in operation and the groundwater extracted is mostly for household use.



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4. Hydrogeochemistry and quality of the water. An analysis was done of the physicochemical properties and water quality in the zone of Leticia and Tabatinga. This work was done by three entities: CORPOAMAZONÍA, ANA-Brasil and SHI S.A.S, which did the surface and groundwater quality study.

Electrical Conductivity. This measures the capacity of the water to transport electrical charges, carried on dissolved ions in the water. Dissolved ions in the groundwater are the product of interaction with the underground medium, so that the longer the water remains in place underground, the greater the quantity of ions dissolved into the water, thereby increasing its electrical conductivity. The electrical conductivity figures obtained in each of the studies (for Leticia and Tabatinga) show the same concentration, correspond to the same aquifer and clearly indicate that there is a connection. It was proposed that the groundwater is directly connected with the rainwater; when the two mix, the water has less conductivity than during the dry seasons.

Quality of the groundwater. This is defined by its physicochemical and biological composition. In Colombia, permissible limits of those parameters for different uses are regulated by two decrees and by the Technical Regulations for Potable Water and Basic Sanitation (RAS 2000).

a. Potential of hydrogen (pH). The pH values recorded in Leticia show a tendency toward acidity, with an average of 4.66. The same holds true in Tabatinga, with some variations.

b. Electrical conductivity and total dissolved solids. With respect to this point, the groundwater of the Leticia-Tabatinga transboundary aquifer is of good quality for human consumption.

c. Turbidity and color. The color values are below the limit of detection for the method of analysis used, except for one point in Leticia that did not meet the regulations. In Tabatinga, the turbidity of the water is acceptable.

d. Nitrates and Nitrites. In terms of nitrates, all of the groundwater points show characteristics of quality that make the water fit for human consumption. The nitrites are within the limits established by law. The same situation applies to Tabatinga.

e. Alkalinity and hardness. The groundwaters of Leticia and Tabatinga have low concentrations of alkalinity and are soft, and all of the points that were sampled complied with Colombian regulations.

f. Larger ions: sulfates, chloride, calcium and magnesium. Sulfates are not present in high concentrations in the zone of study. Concentrations of chloride, calcium and magnesium ions are very low, which means that the quality of the groundwater is acceptable in terms of these parameters.

g. Total and fecal coliforms. In Leticia, the figures obtained for coliforms exceeded the amounts indicated as acceptable in the regulations, which means that water for human consumption must be specifically treated to remove this type of microorganisms. In the case of fecal coliforms, the amounts found were within the limits established by the regulations at certain sampling points. On the Tabatinga side, disinfection and filtering is also recommended before using groundwater as potable water.

From the Experience: New Measures for Sharing by Both Cities

1. Regarding potable water in the Leticia-Tabatinga region. The population of Leticia gets its potable water from the municipal aqueduct, (which has technical deficiencies and insufficient coverage), groundwater, rainwater and water obtained from private distribution points. Based on secondary information, it was confirmed that the supply of potable water in Tabatinga is similar to that of Leticia. However, in 2014, a new potable water treatment system went into operation in Tabatinga, which will improve the condition of water for human consumption. The study recommended doing a joint analysis of potable water supply in order to come up with a diagnosis, and design joint border planning and cooperation strategies for Leticia and Tabatinga, which are considered twin cities.

2. Vulnerability and threats from pollution of the alluvial aquifer. In both studies, it was found that the aquifer shows moderate vulnerability to pollution (because of the silts and clays in the superficial layers of the zone and because of the surface water table, among other reasons).

The unified vulnerability map of the aquifer identified potential sources of pollution in Leticia, which could contaminate the entire aquifer, with the risk classified as high. The flow direction indicates that the pollution would reach as far as the San Antonio Stream (border with Tabatinga), and therefore this zone is defined as being at high potential risk for groundwater pollution. In Tabatinga no potential sources of pollution were identified, although there is a large network of septic tanks; 75% of the inhabitants use these and 15% of the population dispose of their waste in the open, which poses a high degree of risk for pollution of the aquifer.

3. Adaptation measures for joint use of groundwater and surface water in the transboundary region. Given that there are 3,000 water supply wells in this region, there is a high risk of pollution due to human factors. This is also the case for the San Antonio and Porvenir Streams, as well as discharges into the Amazon River. Taking into account that the close connection between the aquifer and the river has been validated by the two studies, strategies for future use and planning of the resource must be created jointly, for surface water, groundwater and rainwater.

3.1. Detailed hydrogeological study. It is essential to do a more detailed and integrated study on Leticia-Tabatinga to jointly plan the groundwater resources, because there are gaps in the existing studies, such as the geometry of the aquifer. It was therefore recommended that geographical tests be done, such as electrical tomographies, throughout the area of study. It was also recommended that the Tabatinga region be expanded to include rural zones and urban expansion zones, to obtain a better characterization of the aquifer over a larger area.

3.2. Mitigation of the risk of pollution of water resources.

In Tabatinga, potential sources of pollution need to be identified, characterized and mapped. In both cities an inventory of the septic tanks should be done. There is also a need to create a joint sewer system.

3.3. Study of climate variability and change.

Progress must be made in modeling at the regional level, which can be helpful for climate change projections.

3.4. Joint use of surface and groundwater shared between Leticia and Tabatinga.

The study stresses the importance of how the new water supply system in Tabatinga (city in constant growth) improved the surface water used; however a latent risk exists of social conflict because of pollution, thus the recommendation to evaluate alternatives for a joint aqueduct and sewer system for Leticia and Tabatinga, based on the evidence of the aquifer-river relationship.

3.5. Environmental education and border co-operation policies.

The strategies proposed for Leticia include educational campaigns, as part of border cooperation policy, to create awareness in the community. This also applies to Tabatinga, as proposed in the ANA study. Measures, such as strategies for education and communication are fundamental for both cities so that the populations on both sides can jointly work toward the same end: to protect and conserve the water resources of the basin.

Transboundary Cooperation for Joint Planning of Water Resources

Replication can be done from one city to another, in various areas. From Leticia to Tabatinga and vice versa. In the study on Leticia, it was recommended that the depth of the wells be increased in order to deal with expected variations in water table level during severe drought events, even when those wells are shared by the communities; this could also be done in Tabatinga.

It is also important for Tabatinga to do an inventory of groundwater points for inclusion on the map of the area of study, and to develop a characterization of those catchments. A new potable water treatment system was installed in Tabatinga in 2014, to improve living conditions for the population. In the same sense, Leticia needs to improve its infrastructure.

It is essential for both cities to be able to share the same aqueduct and sewer system in order to optimize sustainable use of surface and groundwater, and it is of fundamental importance that they make use of rainwater, given the significant amount of precipitation in the region.

A proposal was also made to establish a research and monitoring network for Leticia that would also include Tabatinga, with the recommendation that its planning, execution and operations be done jointly by the corresponding national environmental entities.

Both cities have serious deficiencies in their sewer systems, reason for the recommendation of joint planning and transboundary cooperation to create a shared sewer system. This is a priority due to the problem of solid and liquid waste discharge, a situation that could lead to conflicts in the zone, because it has been shown that both the surface and underground water systems in Leticia and Tabatinga are connected, meaning that pollution from one side can affect the other.

Both cities also need to work on a joint study on climate change projections, supplemented with studies to evaluate the effects of deforestation and changes in land use in the basin.

Uniting efforts in both cities for environmental education and communication strategies will make it possible to increase knowledge about the basin and undertake joint work, given that not only do they share a border, territory, traditions and culture, but also the lives of their people depend on the same surface and groundwaters of the Amazon Basin.



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Participative Water Resources Management

As part of the study "Evaluation of the Aquifer Systems of the Leticia-Colombia Region," three meetings were held with the community to address the subject of the aquifer, implementing the principle of participative water resources management.

At the same time, the ANA-Brasil study places emphasis on creating an educational strategy for primary and secondary school students and teachers, making educational materials about the aquifer available to them in Spanish and Portuguese.

Similarly, ANA-Brasil has proposed the creation of a joint communications strategy that would provide training to journalists to enable them to report information about the aquifer in different social media. This task is still pending and needs the support of all stakeholders.

Getting communities such as Leticia and Tabatinga to organize and unite around the aquifer system that they share will make it possible to strengthen institutional capacities in both cities.



Education and communication for the protection of the Tabatinga-Leticia aquifer system requires support and knowledge from the universities and research institutes that operate in the zone. With that goal in mind, ANA has proposed the creation of a civic fund for the aquifer.



References/Bibliography for Study N°. 3

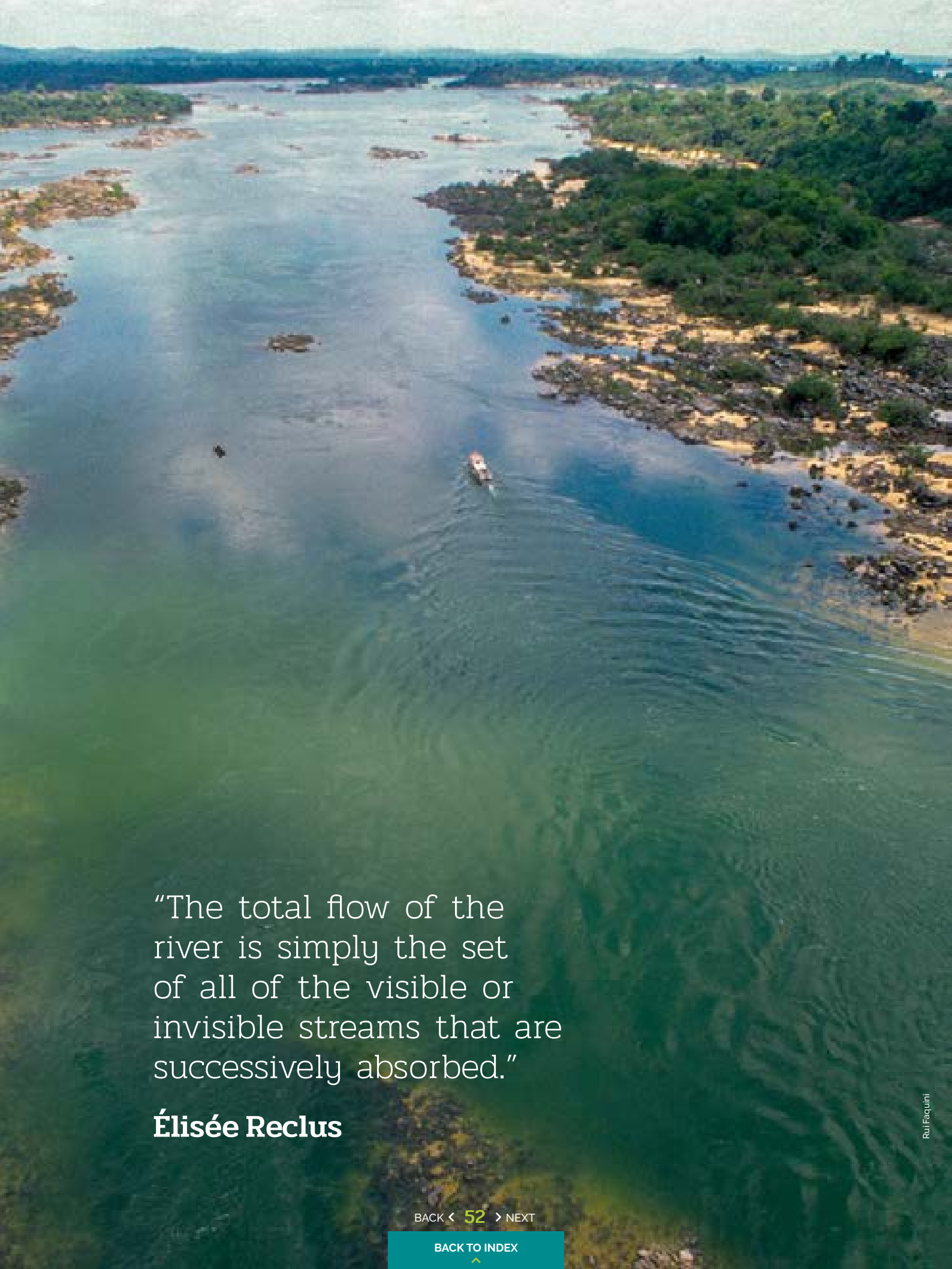
» See the complete bibliography on pages 69 to 75 of the study "Joint Hydrogeological Characterization of the Tabatinga-Leticia Transboundary Aquifer System" ("Caracterización Hidrogeológica conjunta del Sistema Acuífero Transfronterizo Tabatinga-Leticia"), produced by SHI S.A.S. for the GEF-Amazon project.

JOSEPH CONRAD :

<http://biblioteca.unedteruel.org/propuestacineyreligion.html>







“The total flow of the river is simply the set of all of the visible or invisible streams that are successively absorbed.”

Élisée Reclus



Study N°. 4

► Transboundary Cooperation for Sustainable Water Management:

Evaluation of the Aquifers of the Sedimentary Basins of the Amazon Hydrogeological Province (AHP) in Brazil (scale 1:1,000,000) and Pilot Cities (scale 1:50,000):
Volume IX: Pilot City: Tabatinga, Amazonas

Area: Hydrogeology



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The Experience. Pilot City: Tabatinga, Amazonas

“**W**hite mud found in the river beds” is what Tabatinga means in the Tupi language, which we might consider as a “hydrogeological” explanation of one of the characteristics of the aquifer of this city, which was founded by the Jesuits in the 17th century.

Tabatinga is connected to Leticia (Colombia) by the Avenida de la Amistad, which makes the two cities into one. That is why they are called twin cities, although they are practically indivisible if we consider the aquifer below that joins them together. In other words, rather than twins, they are actually conjoined twins, given that the aquifer systems of Leticia and Tabatinga make up a single transboundary aquifer,

which in turn represents a subsystem of the great hydrogeological basin of the Amazon aquifer system.

This is the basis for the interest of the GEF Amazon Project in studying that transboundary aquifer, and of ANA-Brasil, which has had a national groundwater agenda since 2007. This interest gave rise to the study “**Evaluation of the Aquifer Systems of the Leticia-Colombia Region.**” For the same reason, the Brazilian Government produced the study “**Evaluation of the Aquifers of the Sedimentary Basins of the Amazon Hydrogeological Province (AHP) in Brazil (scale 1:1,000,000) and Pilot Cities (scale 1:50,000),**” which consists of 11 volumes on water balance, geology, hydrogeology and numerical flow models and

hydrogeochemistry in the AHP, along with research about the pilot cities of Macapá, Porto Velho, Rio Branco, Santarém and Tabatinga (Volume IX).

The "Proposal for a Project for Environmental Protection and Sustainable Management of Groundwaters in the Amazon Region, to be undertaken by Brazil and Neighboring Countries" is contained in Volume X, which was released in December 2015. Volume XI is about the databank.

At the same time, through the GEF Amazon Project, the comparative study "**Joint Hydrogeological Characterization of the Tabatinga-Leticia Transboundary Aquifer System**" was carried out.

The study that we discuss below refers to Volume IX: "**Pilot City: Tabatinga.**" The objective was to produce a characterization of the physiographic, geological, hydrogeological and hydrogeochemical aspects of this city, to develop a quantitative and qualitative evaluation of the groundwater resources as an input for deci-

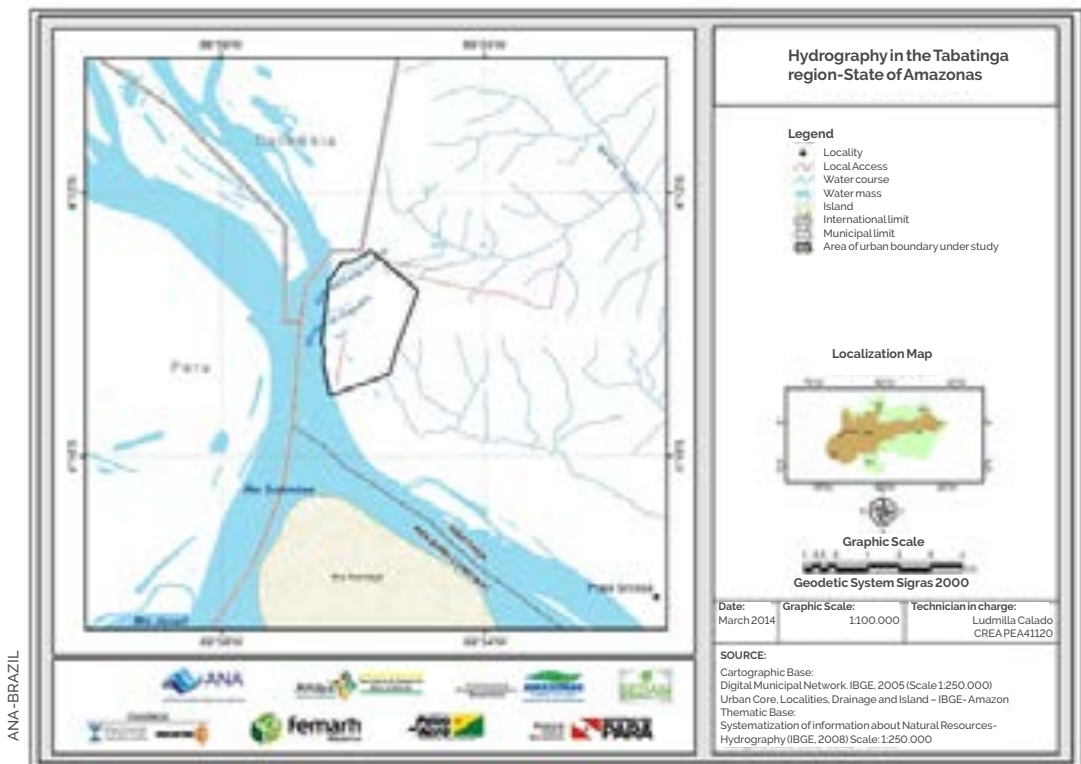
sion-making about the exploitation and preservation of those resources. The study, done by TECHNE Engenheiros Consultores in association with Projotec, was contracted and supervised by the National Water Agency of Brazil (Agencia Nacional de Aguas, ANA-Brasil).

Tabatinga is located in the upper Solimões microregion, on the left bank of the Solimões River,¹ in the Brazil-Colombia-Peru tri-border area. It has an area of 3,224.88 km², and is located in western Amazonas State, at a distance of 1,100 km by air from Manaus.

The population of the municipality of Tabatinga is 52,272 inhabitants, of whom 36,355 (69.5%) live in the urban area and 15,917 (30.5%) live in the rural area. The population consists of Brazilians, Colombians, Peruvians and indigenous people. In addition to Portuguese, Amazonian Spanish is spoken, which is influenced by indigenous languages.

1. In Brazil, the upper section of the Amazon River, from Tabatinga to Manaus, is known by the name Solimões, which is used in this study.

Hydrography in the Tabatinga region-State of Amazonas



Methodology

The study was carried out in three stages:

1. First of all, the existing bibliographic materials were consulted and analyzed.
2. An inventory was done of 15 wells, with qualitative and quantitative testing of water samples and measurement of water levels, all of which was done during two field visits. The first, in April 2012, was during the rainy season, in which measurements were taken of water levels and water samples were collected for physicochemical and microbiological analysis. In the second visit, in October 2012, during the dry season, in addition to the previous analyses, heavy metals analysis was done at five wells, isotopic analysis at six wells, oxygen analysis at 18 and carbon-14 analysis at one well. Pumping tests were also done at two wells, the first at a depth of 32 m and the second at 24 m.
3. The results of the water analyses were interpreted, using the existing data and the data collected during the field visits, as well as the quantitative and qualitative evaluation of the Tabatinga alluvial aquifer.

Results of the Characterization of the Tabatinga Alluvial Aquifer

The characterization of the Tabatinga alluvial aquifer consisted of an examination of the following aspects, which resulted in 101 tables and 92 figures, which may be consulted in the study:

1. **Physiography. Climate Elements and Factors.** Temperature, wind, relative humidity, sunlight and rain are the main factors that condition climate in the region. According to the World Meteorological Organization (WMO), climate characterization must be based on climatological normals over a period of 30 years. For Tabatinga, climatological normals from 1961 to 1990 were used, with data from the National Institute of Meteorology of Brazil (Instituto Nacional de Meteorologia del Brasil - INMET).

Climate. It is tropical and rainy, with a mean temperature above 18°C during the coldest month. There is a short dry season. During the winter months, the region is affected by a cold front caused by a polar air mass that aggressively flows into the Amazon plain in the southern hemisphere.

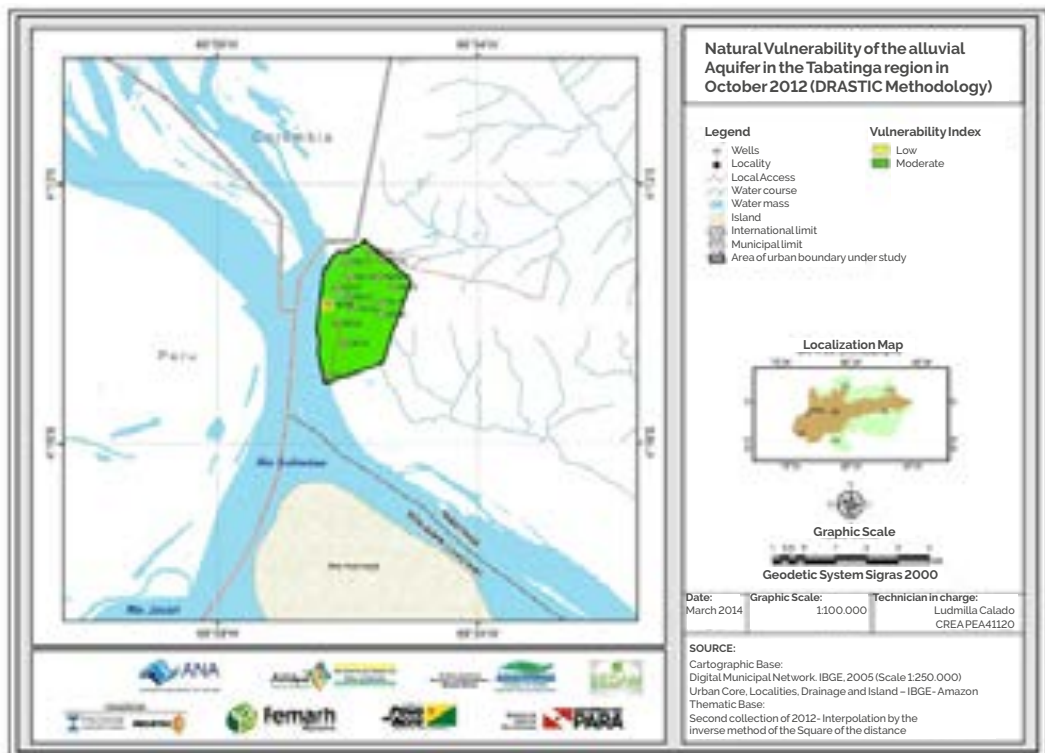
Temperature. Monthly mean temperatures range between 25.1°C and 25.9°C. Maximum normal temperatures in 1961-1990 were between 30.1°C and 31.4°C, with a mean of 30.6°C. However, over the last 30 years, maximum monthly temperatures ranged from 21.7°C to 31.4°C, with an annual mean of 29.1°C. This indicates a local reduction of 1.5°C, contrary to what the global warming hypothesis suggests, which is very significant for the GEF Amazon Project that also studied climate change in the basin.

Wind. The INMET 82410 meteorological station in Benjamin Constant, near Tabatinga, did not record the normal predominant direction of the wind during the 1961-1990 period. In general, the wind behavior studied indicated that winds were calmer than during the previous 30 years, with a mean intensity of 0.8 m/s. The predominant direction is NNE.

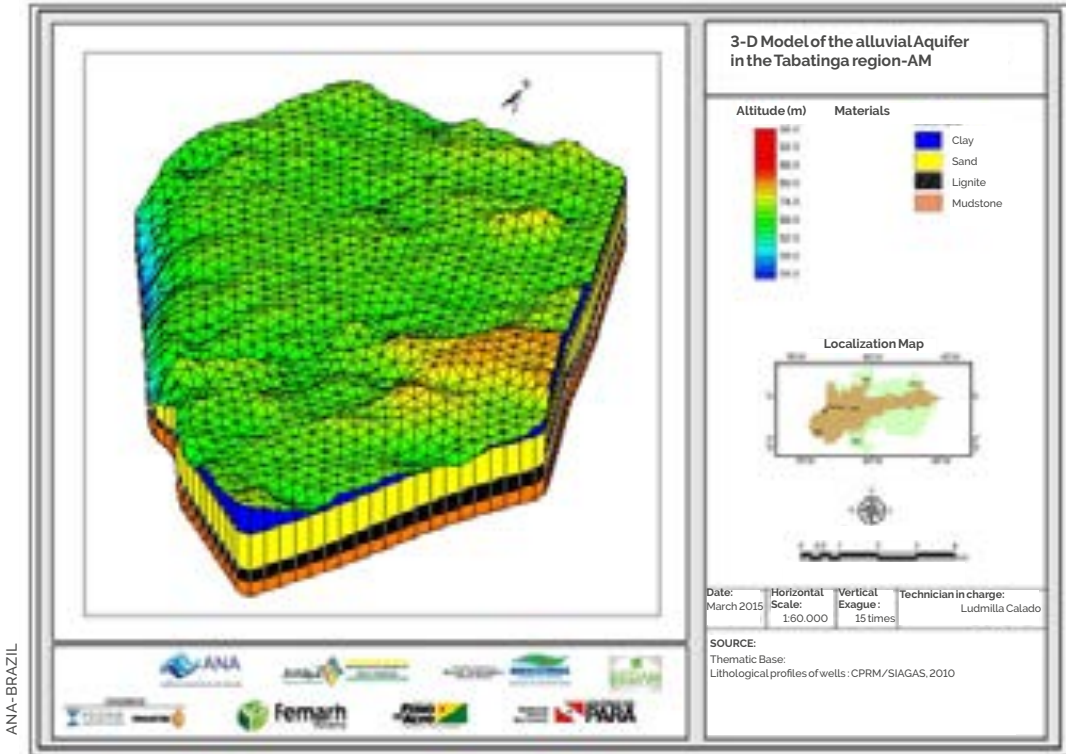
Relative humidity. According to the 1961-1990 normals for relative humidity, this varies from 80.5% in September, which is the driest month, to 83.4% in May, at the end of the rainiest period. The monthly distribution pattern of relative humidity was consistent during that period, and is very similar to what was observed in 1981-2010.

Sunlight. Monthly mean hours of sunlight, according to the 1961-1990 normals, ranged from 98 hours in February to 156.8 hours in August, with a monthly mean of 147.2 hours. The monthly distribution pattern was consistent during that period as well as during the more recent one of 1981-2010. In relation to the normals, there was a reduction of 1.63% in mean annual sunlight in the period from 1981 to 1990.

Natural Vulnerability of the alluvial Aquifer in the Tabatinga region in October 2012 (DRASTIC Methodology)



3-D Model of the alluvial Aquifer in the Tabatinga region-AM



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Precipitation. The data obtained show that, in relation to the normals from 1961-1990, rainfall patterns observed at the Benjamin Constant station during the last 30 years showed a significant reduction (11%) in mean annual precipitation, which might be a reflection of human influence.

Number of rainy days. The annual mean number of rainy days is 168, of which 92 (55%) take place during the rainy half of the year and 76 (45%) occur during the drier half, according to the 1961-1990 climatological norms recorded at the meteorological station. During the 1981-2010 period, although it rained 11% less than in 1961-1990, the average number of rainy days was 22% greater, reaching 205, with 112 days (55%) during the rainy half of the year and 93 days (45%) during the drier half.

Evapotranspiration. INMET water balance data has only been recorded for 1981-2010, and

indicate annual mean potential evapotranspiration of 1,676.7 mm (4.6 mm/day) and annual mean actual evapotranspiration of 1,637.2 mm (4.5 mm/day).

Relief. The relief is characterized by two geomorphological units: The Amazon plain and the Solimões depression. The former consists of very broad floodplains and fluvial terraces that are tens of kilometers wide. In Tabatinga, this surface is found at elevations between 70 and 95 MAMSL. The Solimões depression coincides with the zone of outcropping of the Solimões depression at elevations between 95 and 110 MAMSL, with a drainage network and a meandering route.

Hydrography. Tabatinga is located on the left bank of the Solimões River, which meets the Negro River in Manaus. The Tabatinga landscape has three hydrographic subbasins defined by

the 11 km of brooks or streams of the Tacana, and which have their source in the area known as the Colombian trapezoid, and flow into the Amazon-Solimões. The course of the stream winds considerably and transports sediments during the torrential rainy season. It runs through neighborhoods in Leticia and Tabatinga. The Engenho stream, with a length of 0.73 km, is located on the left bank of the Solimões, in the Don Pedro neighborhood. The San Antonio stream serves as the border between Brazil and Colombia. Tabatinga is on the left bank of the stream and Leticia is on the right. It is 1.08 km long and spans both cities. Its water quality is poor due to pollution, which affects its fish.

Soils. The characterization of the soils in the Tabatinga region is based on the soil classification system of the Brazilian Agricultural Research Corporation (Embrapa). The following types of soils were found: red-yellow aluminum clayey (PVAa) over a surface of 103 km². Its texture varies from sandy to clayey. Eutrophic haptic Ta (GXve) which occupies 36 km², in other words, a soil determined by deep water, which originates in a (eutrophic) brown zone composed of mineral material. And eutrophic neossolo fluvial Ta (RYve), which covers 3.16 km² and consists of underdeveloped minerals, found on the banks of the rivers.

Vegetation. The municipality of Tabatinga is part of the Amazon forest biome. The natural vegetation of the region, according to Veloso et al. (1991), consists of:

- a. Open alluvial rainforest with palms,** meaning that it is established along the water courses, occupying permanently flooded zones or plains where there are swampy forests with numerous large palms. This vegetation area measures approximately 35.12 km².
- b. Dense alluvial rainforest with emerging canopy.** These are riverside forests of rapid growth, found along the water courses. Due to timber use, their physiognomy has become more open. Uniform forests with emerging

canopies are identified by their upper layers of tree branches, which are gigantic and create umbrella-shaped canopies.

- c. Dense lowland rainforest with emerging canopy.** An area measuring around 4.29 km², it is not relevant to the area of study. Urbanization covers about 3.35 km². The urban expansion of Tabatinga and the neighboring municipalities has been causing significant deforestation of the primary vegetation, due to the timber industry and brick manufacturing. Increasingly, primary vegetation has changed to secondary trees such as bananas, ingazeira crops, etc., exposing these soils to erosion processes that worsen rapidly due to the intense rains in the region.

Influence of regional chemical weathering on the groundwater quality in Amazon Hydrogeological Province. When it rains on the surface of the terrain, the rainwater comes into contact with rocks, soils, urban areas, animals and plants. This gives rise to chemical reactions, through a process called chemical weathering, which affects the water. Consequently, in Tabatinga, the groundwater has low levels of calcium, magnesium, potassium, sodium and electrical conductivity, among other elements, and also has high levels of iron, seen in 40% of the samples from the first field visit and 20% of those from the second.

- 2. Geology.** The Solimões Formation underlies the region, extending to Colombia and Peru. The first explorations to tap into the groundwater in Tabatinga began in 1976, with the soundings for the upper Solimões coal project, during which five wells were built with a maximum depth of 22.6 m and a maximum output of 4.2 m³ (Maia et al. 1997). Tubular wells were also built in 2001 in indigenous areas on the outskirts of Tabatinga, with a mean depth of 8 m. In Tabatinga, groundwater is found at variable depths ranging from 1.5 to 15 m, with an average of 7 m. That is why tubular wells with a maximum depth of 25 m were built using the waterjet method, with manual rotary sounding, which is recommended for sedimentary terrains.



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Structure and tectonics. Tectonics is the geological discipline that studies geological structures produced by the formations of the Earth's crust. The regional tectonics of the Solimões Basin south of Tabatinga have a structure in which the delimitations in the subsurface or sub-soil coincide with the stratigraphic sequences of the Ordovician period (approx. 485 million years ago) to the Mesozoic (245 million), among other aspects. The two early wells drilled by Petrobras in the Tabatinga region can be seen on the Geological Map of the Geological Service of Brazil (CPRM). The first well is called Benjamin Constant, the second Rio Curuçá; there is a third well, outside of that map, which is called Rio Javari.

Regional lithostratigraphy of Tabatinga.

The three above-mentioned wells were used for this study, which revealed the following stratigraphy: a) Benjamin Constant Formation. b) Undifferentiated Palaeozoic. c) Javari Formation d) Solimões Formation e) Içá Formation.

Local lithostratigraphy. According to the Geological Map, the outcroppings of the geological units are the Solimões Formation (whose peak, in the urban part of Tabatinga, is at a depth of 19 to 24 m) and the Holocene alluvial deposits

(from the present epoch), which occur on the surface of the floodplain of the Solimões River and occupy a broad area along both riverbanks.

3. Hydrogeology and Hydrodynamics:

From the hydrogeological point of view, four lithostratigraphic units may be found in the Tabatinga area, consisting of the alluvial deposits and the Içá, Solimões and Javari Formations. The alluvial deposits occupy significant areas all along the banks of the Solimões River, and in Tabatinga they constitute clayey layers on the upper part, with a thickness of 3 to 8 m, followed by a fine to medium area with a variable thickness of 12 to 17 m in the Solimões Formation. The sandy layer is defined as the hydrogeological flow unit (HFU), which in this study is referred to as the alluvial aquifer. The Içá Formation is completely sandy and by itself constitutes an HFU represented by the Içá Free Aquifer, present in the wells of the Curuçá River. It is therefore not located in the city of Tabatinga. The Solimões Formation may or may not contain HFUs, so it is regarded as the Solimões aquitard (a formation that contains water and transmits it very slowly) or as the Solimões aquiclude (a low permeability geological formation that contains water and does not transmit it). In the Benjamin Constant well there

is a classic aquiclude, and there are aquitards in the wells of the Curuçã and Javari Rivers. In the Curuçã River well, the Solimões aquitard has two HFUs. There are 19 HFUs in the Javari River well.

Javari confined aquifer. Has a variable thickness ranging from 381 m at Benjamin Constant to 500 m on the border with Peru; it is confined by the low permeability sediments of the Solimões aquitard and it rests on a crystalline base. The aquifer is still unexplored because no well in the region has reached it. It can only be reached by deep drilling. All indications suggest that it is also present in the Tabatinga area.

Alluvial aquifer. The aquifer used in Tabatinga corresponds to the first sandy layer (HFU1) of the "alluvial package." The mean depth of the static level, measured during the first field visit in April 2012, was 4.72 m, and in October 2012 it was 6.33 m. On average, the water level is above the upper part of the sand layer, whose mean depth is 6.0 m. This aquifer may therefore be considered to be a free aquifer. A lithostratigraphic model was made to determine the dimensions and limits of the aquifer. Its hydraulic properties were also studied, using pumping tests. Additionally, the recharge and discharge of the groundwater of the Tabatinga alluvial aquifer were analyzed during the field visit to the network of monitoring wells located in the area of study. The reserve values for Tabatinga are: regulating reserve (RR): 0.060 m³/s. Potential exploitable reserve (PER): 0.024 m³/s. Permanent reserve (PR): 17.6 million m³. The data obtained led to the conclusion that most of the wells examined in Tabatinga (93.3%) have depths of as much as 30 m. The base of the aquifer ranged between 19 and 21 m. The wells deeper than 21 m go beyond the aquifer layer and penetrate the low permeability sediments in the Solimões Formation. The static layers do not exceed 15 m in depth in any of the wells. According to the study, the predominant flows are in the range of 1.5 to 2.5 m³/hour, although these are not sustainable flows. The flows calculated in an equilibrium regime would be 14 m³/day or 0.58 m³/hour. According to the

analysis, conditions would probably be unsuitable for use by a public water supply company. However, for domestic supply, with use of just a few hours per day, the Tabatinga alluvial aquifer is viable, so long as the corresponding entities monitor well construction and water quality.

4. Hydrogeochemistry To evaluate the quality of the groundwater of the alluvial aquifer of the city of Tabatinga, the two field visits were done to take samples. Both used duly tested methodologies. A sample gathering protocol guide was also used. The AHP project's technical accompaniment and oversight committee and the consulting company that was contracted, selected some wells on the Tabatinga alluvial aquifer for quantitative and qualitative analysis. Seven conditions had to be met to be chosen, which included the requirement that they be producing wells, having the owner's consent, and that they get their water from a single aquifer, among others. Procedures for collecting the physicochemical and bacteriological samples were also established, to test for the following parameters: color, electrical conductivity, hardness, turbidity, total dissolved solids, pH, alkalinity, carbonate and bicarbonate, anions, nitrogen metals, coliforms and carbon 14. The results of the physicochemical analysis were evaluated using the ionic balance calculation, including the ionic causes. The Langelier index was used to verify the degree of saturation of calcium carbonate in water. A total of 136 correlations were seen between the hydrogeochemical variables during the rainy and dry periods, measuring each physicochemical and bacteriological element. Correlations between various chemical elements and electrical conductivity were also observed, which indicated the influence of chemical weathering, given the low presence of ions, acid pH and low levels of iron and manganese that are diluted by the intense rains in the zone. Groundwater pollution was also detected, stemming from anthropogenic actions, mainly the dumping of waste water. In the area of study, a lack of sewers and sanitary protection in the installation of the wells was also found.

Heavy metals, BTEX and phenols. The water samples to test for heavy metals, BTEX and phenols in the alluvial aquifer were collected during the second field visit. The metals that were analyzed were: arsenic, barium, cadmium, lead, copper, chromium, mercury, nickel and zinc. Analysis of the heavy metals, BTEX (acronym for the chemical compounds benzene, toluene, ethylbenzene and xylene, all of which are pollutants) and also phenols, included determining whether the well is located near potential sources of pollution, such as manufacturing, gas stations or commercial establishments, among others. Because those parameters pose risks to human health, Brazilian Health Ministry Ordinance N°. 2914/2011 and National Environmental Council (CONAMA) Resolution N°. 396/2008 have established maximum limits for drinking water. In this case, there was no pollution by heavy metals, BTEX or phenols.

Dating. The analyses of oxygen 18 and deuterium led to the conclusion that the alluvial aquifer is recharged by rainwater. Tritium dating indicated that the waters of the alluvial aquifer are a mixture of older water and recent recharge. Radiometric dating using carbon 14 revealed the presence of new water.

Geostatistical modeling. The bases were created to generate a geostatistical model using the hydrogeochemical data (with the physicochemical parameters analyzed).

Biological parameters. To evaluate contamination from human and animal waste, the bacteriological quality of the water was tested by measuring bacteria from the coliform group, mainly total coliforms and *E. coli* (*Escherichia coli*) or thermotolerant coliforms, which are considered indicators of fecal water pollution that is harmful to human health. Ordinance N°. 2914/2011 determines that for water to be considered fit for human consumption, there must be a total absence of coliforms in 100 ml of water. During the rainy period of April 2012, wa-

ter samples from the Tabatinga alluvial aquifer showed the presence of total coliforms in 27% of the wells (4 out of 15), whereas during the dry season in October 2012, they were found in 40% (6 out of 15). In accordance with the ordinance's regulations, during the first field visit, samples from 73% (11 out of 15 wells) and 60% (9 out of 15 wells) during the second field visit, were found to be fit for human consumption. Risks to health exist because the population in the area of study uses water from the wells for all of their needs, mainly household ones. It must be taken into account that the area of study is an urbanized zone with inadequate sewers, which poses a direct risk to the potability of the groundwater due to filtration from septic tanks near water wells and seepage from the sewer network, according to Zoby (2008). This situation applies to both urban and rural wells. Also, some wells are poorly located, they lack maintenance, they are unclean and their water is not treated prior to being consumed. According to Silva and Araújo (2003), household and industrial sewage that winds up in wells and septic tanks, poor handling of urban and industrial solid wastes, and the existence of gas stations, represent sources of pollution for groundwater due to bacteria, pathogenic viruses, and organic and inorganic substances. These pollutants can affect the population through waterborne diseases such as amoebiasis, gastroenteritis, typhoid fever, infectious hepatitis and cholera, among others.

Classification of the groundwaters of the alluvial aquifer according to chemical composition. Based on the data gathered from the 15 wells studied during the two field visits (in the rainy and dry periods), the hydrogeochemical study of the waters of the Tabatinga alluvial aquifer showed, in general, low concentrations of chemicals due to the rainy climate of the Amazon tropical rainforest, and that when extreme values appear, these are due to anthropogenic factors. The geostatistical model of 20 physicochemical parameters analyzed in the groundwaters of the aquifer made it possible to verify

the influence of the seasonal periods on the parameters, and risk levels, without statistical bias.

Natural vulnerability of the alluvial aquifer. In this context, vulnerability is the sensitivity of the quality of groundwater to an imposed pollutant load, determined by the intrinsic characteristics of the aquifer and its encasement. While evaluating the vulnerability of an aquifer is complex, it mainly depends on the functioning of the geological and hydrogeological conditions of the aquifer itself, the topography and the type of soil. There are various methods to evaluate the vulnerability of aquifers. Some were conceived to determine the vulnerability of an aquifer to any pollutant, in other words, general vulnerability. Other methods make it possible to evaluate an aquifer according to specific pollutants such as industrial waste or urban solid waste, etc. Two methods were used in this study, DRASTIC and GOD. The DRASTIC method, which was developed by Aller et al. (1985) for the United States Environmental Protection Agency (EPA),

was used for qualitative evaluation and regional mapping, among other things, and takes into account the variables taken from the acronym DRASTIC: **D**epth to water, **R**echarge, **A**quifer media/lithology of the aquifer, **S**oil media, **T**opography, **I**mpact of vadose zone media/lithology of the unsaturated zone, and hydraulic **C**onductivity. In the case of the GOD method, the three letters represent the values and their relationships: **G**=the alluvial aquifer is a free type and its value is $G=1$. The **O** is equal to the lithology of the aquifer, represented by the loamy alluviums with a value of $O=0.5$. The **D** indicates the depth of the water level of the alluvial aquifer, measured during the field visits, with a value of $D=0.8$. Results: According to the DRASTIC method, during the rainy period, the vulnerability index for this aquifer is moderate at 100% of the wells. During the dry period, the aquifer shows low to moderate vulnerability. According to the GOD method, for both periods, the vulnerability indexes obtained were at 0.4 to 0.45, which indicate medium vulnerability for the aquifer.



Learning from Tabatinga's Experience

The study carried out in Tabatinga coincides in different aspects with the evaluation of the Leticia aquifer system, particularly given that both cities need to use scientific tools to work with the aquifer that unites them, and develop a common aqueduct and sewer system, among many other things, thus strengthening transboundary cooperation.

While the study on Tabatinga determined that the aquifer's vulnerability is moderate, the researchers stressed that the risk of contamination in Tabatinga is actually high, due to various factors that include the lack of a sewer system in the urbanized zone and a lack of planning in terms of the occupation and use of land, which contribute to an increase in the pollutant load.

The study also noted the importance of adopting measures for the preservation and conservation of this water source that is of primary importance for the region's growing population. Relationships between government agencies also need to be strengthened so that the Brazil, Colombia and Peru tri-border region can increase technical and scientific knowledge about the aquifer and to make the systematic management of transboundary water resources possible.

Replication: Toward the Sustainable Protection of Groundwater in the Amazon Basin

This experience, which involved a detailed characterization of the Tabatinga alluvial aquifer, also resulted in creation of the proposal entitled "Project for Environmental Protection and Sustainable Management of Groundwater in the Amazon Region to be Developed by Brazil and the Neighboring Countries" ("Proyecto para la Protección Ambiental y Gestión sustentable de las Aguas Subterráneas en la región Amazónica a ser desarrollada por Brasil y los países vecinos"), which also corresponds to the regional priorities identified in the Strategic Action Program (SAP) of the ACTO/ UN Environment/ GEF Amazon Project - Water Resources and Climate Change.

This project, which is based on scientific studies and technical meetings on the subject of groundwater, hosted by the GEF Amazon Project and ANA-Brasil, aims to create a specific Strategic Action Program (SAP) for the groundwaters of the Amazon aquifer system in the Amazon hydrogeological province.

The project would make use of how the ACTO countries worked together on the GEF Amazon Project in order to continue working together on the issue of groundwater. There is a need to strengthen this area in order to create regional, national and local capacity in a systematic, integrated and sustainable management, and for the planning and preservation of groundwater resources.

This study is one of the three scientific pillars of a project proposal that comes at a time that is key for the Amazon Basin because of deforestation, changes in land use and, particularly, a lack of technical knowledge about the condition of the transboundary groundwaters. Putting the issue of groundwater on the public agendas of the countries that share the aquifer would not only benefit the people of the region, but would also have effects at the global level.

Importance of Disseminating Knowledge about the Amazon Aquifer System

Knowledge about the Amazon aquifer system is recent and could even be viewed as groundbreaking. It is not known outside of academic and scientific circles, and it has not reached local, regional and national governments or the media, much less the communities that need to be informed about the groundwater that they use.

One of the discoveries made during this research was that the temperature has dropped by 1.5°C in the region, which is contrary to the global warming hypothesis, and should be taken into account by the academic scientific community and the institutes of the region that research the Amazon Basin, as well as the cooperation agencies taking part in the GEF Amazon Project.

Disseminating the experiences in the traditional media, sharing the new knowledge through new media platforms, and developing environmental education programs for all levels on the subject of groundwater, will make it possible to increase environmental awareness to preserve the groundwater of the Amazon for coming generations.



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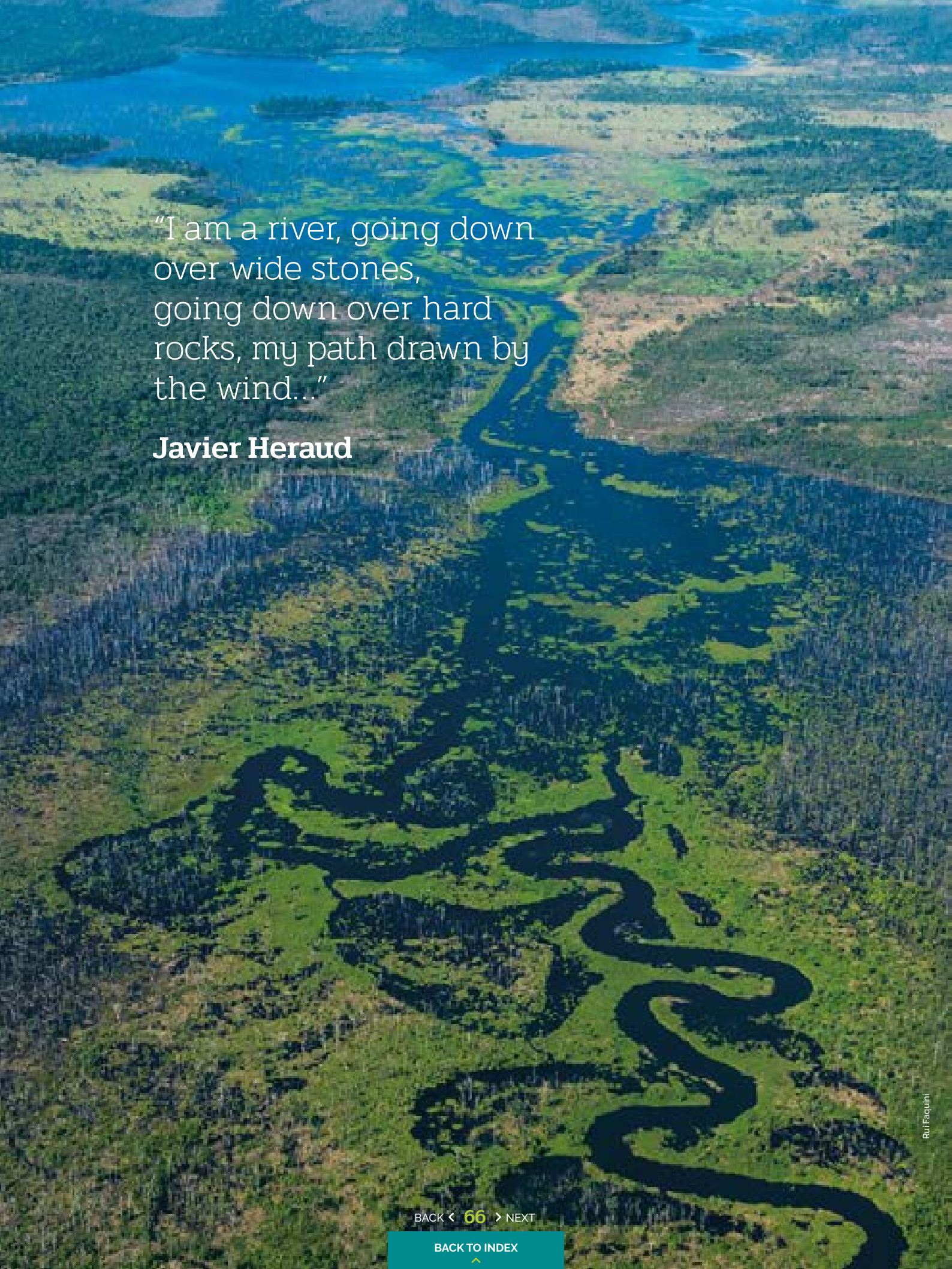
» See Volume IX of the study.

Poet and geographer: Elisée Reclus at:
[www.plataformadeartecontemporaneo/
pac/moreno-y-grau-en-isabel-hurley.com](http://www.plataformadeartecontemporaneo/pac/moreno-y-grau-en-isabel-hurley.com)



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An aerial photograph of a river meandering through a vast, green landscape. The river is dark and winds through lighter green fields and forests. In the background, there are blue bodies of water and more greenery under a clear sky.

"I am a river, going down
over wide stones,
going down over hard
rocks, my path drawn by
the wind..."

Javier Heraud

Study N^o. 5

► What Do the Waters Carry to the Stream Bed?

Geochemical Characterization of the Sediment Load of the Madeira and Solimões Rivers

Area: Hydrogeochemistry



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Introduction

Entering on the Solimões

When the first Portuguese chroniclers traveled on the river in the 16th century, they saw the Yurimáguá people, who inhabited its banks and used poison on the tips of their arrows. The Portuguese thought that the poison was *Solimum*, a Latin word. The word evolved over time, and today the river that they named after entering Tabatinga (Brazil) is known as the Solimões². The name is also said to derive from the word that the travelers used to refer to the native peoples, Sorimões and Sorimão.

As the splendid light brown waters of the Solimões make their triumphal entry into Manaus, they meet with another large tributary, the Negro River, of dark, almost black, water.

However, their waters do not join but instead run side-by-side for 6 km, each in its place, almost without contact, without mixing. This is known as the meeting of the waters, a phenomenon that is famous worldwide, a natural event caused by differences in temperature, velocity and density of the rivers. To this point, the river is called the Solimões in Brazil.

Then, when the two rivers at last join together, a new creature is born, which becomes the famous Amazon River, a source of food, trade, navigation and tourism.

² In Brazil, the upper section of the Amazon River, from Tabatinga to Manaus, is known by the name Solimões, which is used in this study.



An Adolescent and Temperamental River

Did you know that the Madeira is one of rivers with the greatest discharge in the world and the most important southern tributary of the Amazon River?

It is the only one on the right bank that contributes water to the Amazon from the Andes, where it originates, as it flows swiftly toward the Atlantic. It is made up of three Andean rivers, the famous Beni and Mamoré Rivers in Bolivia and the Madre de Dios River in Peru, entering Brazil from the south in Rondonia State and flowing to Amazonas State.

Since 1637 it has been known as the Madeira River (which means wood in English), because when the river rises, it tears whole trees from its banks, which then float in its waters. Despite its fierceness, the indigenous people called it the Cuyari, which means love in Quechua, so there must be a special reason for that.

As the Madeira is an Andean River, its waters rise considerably due to intense rainfall, and it can experience unexpected tidal surges because of increases in the volume and flow of water, and then suddenly return to its previous levels. That is why the inhabitants say that it is very "temperamental," because sometimes it is peaceful but suddenly it goes out of control. It is referred to as a river-in-training, an adolescent, in other words. It does not have a defined

river stream, so every year it applies all of its energies to seeking a new path, bringing with it the banks and vegetation, and swallowing up enormous amounts of earth.

In addition to behaving like an unruly teenager, it transports a large amount of sediments: clay, sand, minerals and rocks, which is why its waters are denser than those of most rivers. This is the subject of the research presented below.

Identifying the Sources of Sediments, Suspended and on the Beds of the Madeira and Solimões Rivers

One of the activities carried out by the GEF Amazon Project was a geochemical characterization and identification of the main anthropogenic sources of suspended sediments and those on the stream bed of the Madeira River, one of the main tributaries of the Amazon, and the stream bed of the Solimões/Amazon River.

The source of the Madeira River is where the Beni and Mamoré Rivers meet in Bolivia. It is 4,207 km long and its basin has an area of 1,420,000 km². It flows through Brazil, Bolivia and Peru. Its flow is twice that of the Mississippi or the Ganges. The Solimões/Amazon begins in Peru. In Brazil, the section between Tabatinga and Manaus is called the Solimões. It is 1,700 km long and its basin has an area of 2,221,990 km².

The results of this research made it possible to define actions for mitigation, to reduce the process of anthropogenic erosion and sedimentation, as well as to formulate strategic actions for the Strategic Action Program (SAP).

Water and sediment samples were taken during the rainy season (from October to April 2012-2013) and the dry season (May to September 2013). The 16 sampling sites were selected based on information about the regional geology of the Madeira and Solimões Rivers, as follows: on the Madeira River: Abuna, Porto Velho, Humaitá, Manicoré, Fazenda Vista, Alegre/Borba. On the Amazon River: Jatuarana, Itacoatiana, Parintins, Óbidos, Santarem (Prainha) and Tabatinga. On the Solimões River: San Antonio do Içá, Fonte Boa, Tefé, Itapéua and Manacapuru.

Sampling was done during two visits, covering 4,000 km of the two main rivers of the Amazon Basin, for the collection and analysis of sediments and water. Samples were taken of water, sediments in suspension and sediments deposited on the stream beds, during the dry and rainy seasons.

Before beginning to collect the samples, and in accordance with the procedures for gathering hydrometric data recommended by the National Water Agency, ANA-Brazil and the World Meteorological

Organization, it was necessary to measure the width, depth and river current velocity. To do so, an acoustic Doppler current profiler (ADCP) was used, provided by the Amazon Potamology Laboratory of the Geography Department at the Universidad Federal del Amazonas (LAPA/DGEOG/UFAM) and the Institute for Development Research (IRD, France).

The methodology for the sampling and physicochemical analysis of the water and sediments followed the *Standard Methods for the Examination of Water and Wastewater* by the American Public Health Association (APHA, 2005). The samples were preserved in accordance with the standard methods for analysis of sediments for delivery to the laboratory. Laboratory analysis of the samples included (i) sedimentological analysis, (ii) geochemical analysis of the sediments, and (iii) analysis of the water.

Results of the Study on the Madeira and Solimões Rivers

A total of 3,600 physicochemical analyses were done using 57 samples of water and sediments from the Madeira and Solimões Rivers. The data thus obtained will be used to create a database, using HYDRACCESS software (available free of charge at www.ore-hybam.org) and Livre Quantum GIS software, which uses satellite images to create maps



Rui Faquini

with the data from the period in which the samples were collected.

The data on the concentration of physicochemical elements in the water and sediments in suspension were used to calculate the flows during the period studied. The results make it possible to create maps about the dynamics of the sediments during the period studied, and also of chemical elements found in the waters of the rivers that were analyzed.

The analytical results on the Madeira and Solimões Rivers indicate a significant increase in the sediment load over the past decade. The measurements are important to estimate the flows of transported elements (sediments, particulate material, dissolved material, etc.). Having completed the processing and analysis of the samples, the results were used to create a database for the Observation Service on Geodynamical, Hydrological and Biogeochemical Control (SO HYBAM).

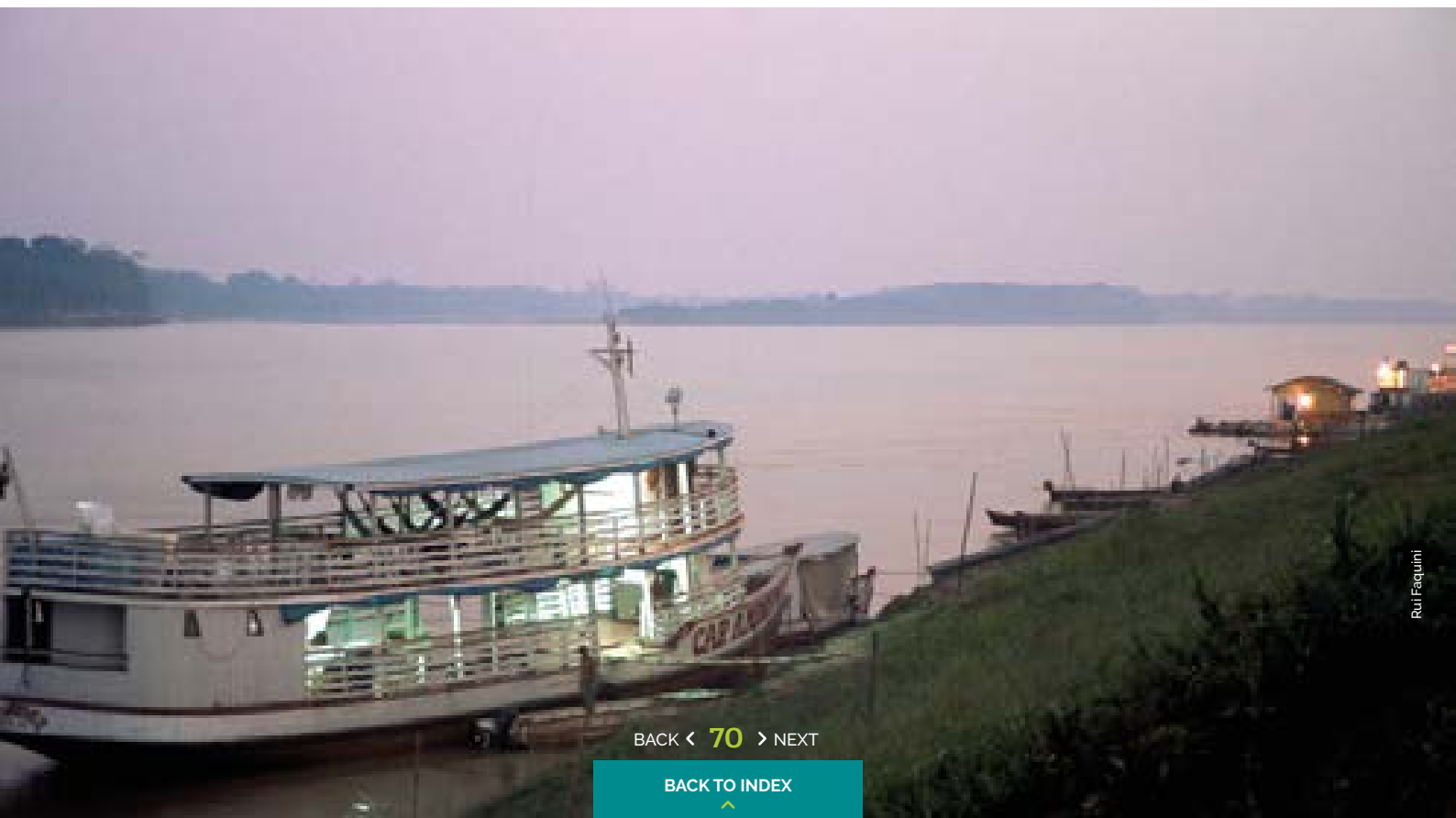
It should be mentioned that a significant collection of data and photographs about the region under study was obtained, which serves to document the entire

research process, and may be used to publish future scientific articles on the subject, which are essential for understanding the Amazon Basin.

Learning from the Experience

The activities undertaken during the two field visits to the two large river systems consisted of, on the one hand, taking water discharge measurements using the acoustic Doppler current profiler (ADCP) and, on the other, gathering water and sediment samples from the surface and the depths, along with the stream beds, tests that were performed at two different times during the hydrological cycle, first in February and March of 2013 and subsequently in October to November. The sites were chosen due to the presence of hydroelectric stations in the vicinity, operated by the National Water Agency (ANA-Brasil).

An agreement was reached with partners at universities and research institutes associated with the Observation Service on Geodynamical, Hydrological and Biogeochemical Control (SO HYBAM) for the acquisition of a dataset on the locations under study, in order to give the project a consistent database.



Sequence of the Research

Step 1

Some 16 sample collection points were identified, 11 of which were studied during the February-March 2013 visit, and eight in October-November 2013. A total of 57 water samples were thus collected in order to test for suspended matter and pollutants, and another 57 sediment samples were taken from the stream beds to test for pollutants. Certain locations were visited during both periods.

Step 2

Testing equipment used in the field. The ADCP emits audio signals at a known frequency through four transducers, which also receive the return signal (echo), after being partially reflected by particles suspended in the water, which travel at the same velocity as the current. Thus, by associating the velocity of the particles suspended in the water, the team also determined its depth, and the course traveled by the boat on which it was installed, and calculated in real-time the discharge of the watercourse, using the basic elements measured: width, depth and velocity of the section, in various measurement profiles throughout the transversal section of the river channel. The ADCP collects several different kinds of data. The main results involved determining: a) temporal evolution of river flows, b) velocities and possible alterations in the morphology of the river channels, and c) the profile of the acoustic signal returned from the suspended particles (correlated with the cloud of sediments suspended in the water), among other aspects.

Step 3

The water samples were always taken near the surface, directly in the watercourse or from a boat, using an 8-liter sampler consisting of a horizontal PVC cylinder aimed in accordance with the current, through a hydrodynamic assembly on the inverted Van Dorn-type sampler. This sampler is equipped with an element that is deployed when the sampler reaches the desired position on the river section, closing the two ends of the PVC cylinder, which had been kept open using a metallic clasp connected to the metallic bindings. The samples were kept at 4°C. Parameters such as pH, temperature, dissolved oxygen and electrical conductivity were analyzed using portable equipment that took measurements in the field, using sensors immersed right into the bodies of water.

Step 4

Collecting the sediments. A cylindrical collection system weighing more than 3 kg (Van Veen-type model) was used, which can be held in a fixed position using a line and was let down from the boat. The equipment was lowered to the bottom of the channel and then raised by the operator with the collected material. At each collection site, three samples were taken. During transport, the samples were refrigerated at 4°C and then frozen until the beginning of the testing.

Replication in Other Subbasins on the Amazon River

Having the support of universities and centers that facilitated the use of specialized equipment was decisive in this research. The procedures entailed gathering specific samples of sediments for laboratory analysis, also taking into account the long distance between the place where the samples were taken and the laboratory.

This, along with the entire research process, methodology and technology employed to create the geochemical characterization of the sediment load of the rivers studied, could be replicated in other subbasins of the Amazon River.

This study created new knowledge in this field, and the universities involved may follow-up on this study and report on the progress achieved.

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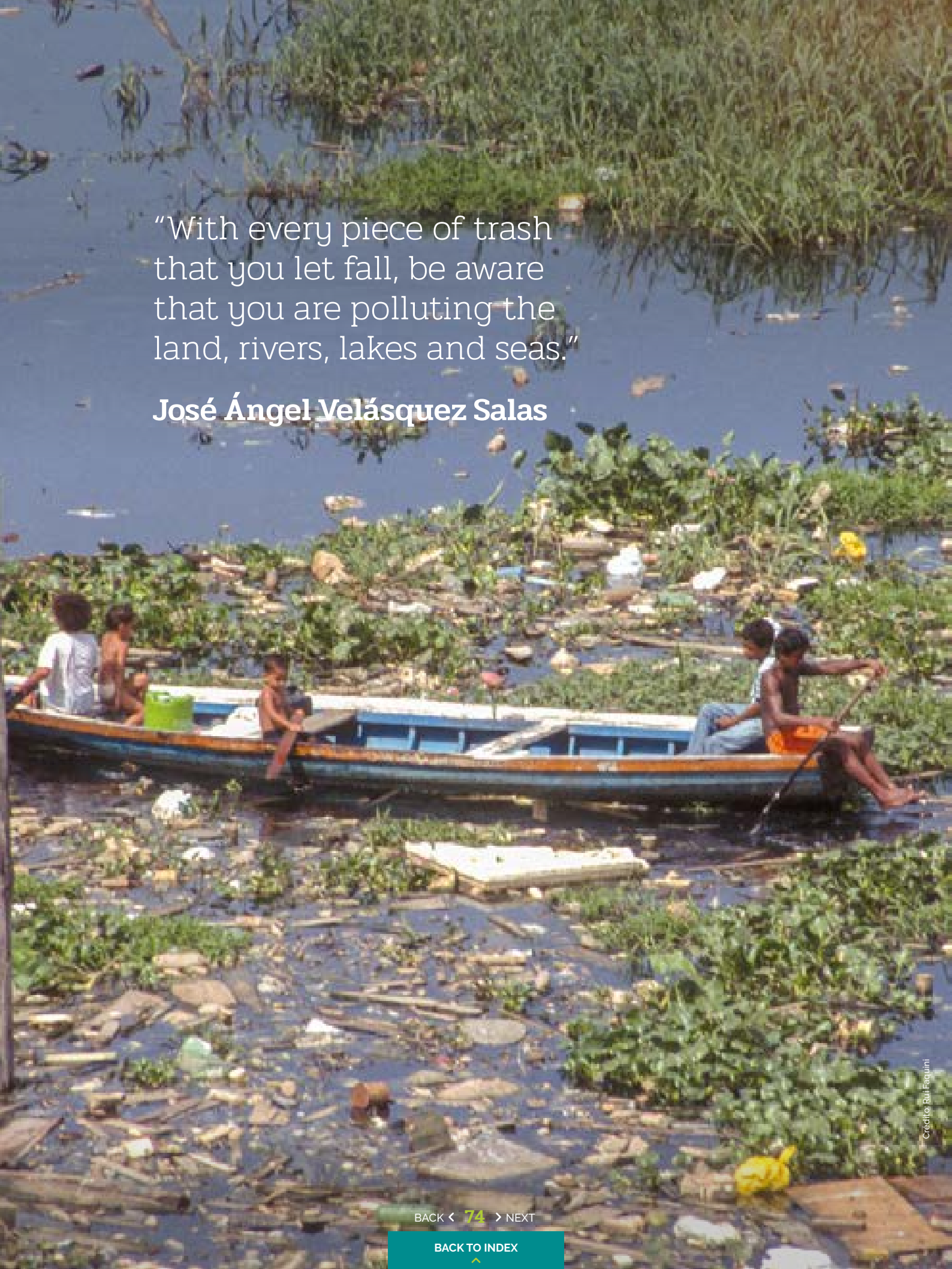
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A photograph of a polluted river. The water is dark and filled with green aquatic plants and various pieces of trash, including plastic bottles and bags. In the foreground, a long wooden boat with a blue interior is filled with several people, including children. One person is using a long pole to navigate the boat through the dense vegetation. The background shows more of the polluted water and a line of trees on the bank.

“With every piece of trash
that you let fall, be aware
that you are polluting the
land, rivers, lakes and seas.”

José Ángel Velásquez Salas

Study N°. 6

► Collective Identification of Problems:

The Regional Transboundary Diagnostic Analysis (TDA)

Area: Integrated Management of Transboundary Water Resources



11 National Workshops in the 8 ACTO Member Countries made it possible to formulate the Transboundary Diagnostic Analysis of the Amazon Basin

The Experience

The Amazon Basin faces many challenges to achieve the integrated management of transboundary water resources (IWRM) in the context of socioeconomic development and the anthropogenic and climate impacts that affect it. The basin constitutes a single hydrological system that crosses the national borders of eight countries (Bolivia, Brazil, Colombia, Ecuador, Guyana, Peru, Suriname and Venezuela), which requires a regional IWRM framework to address the needs of the Amazonian people.

The countries have united under the leadership and guidelines of ACTO, through the GEF Amazon Project, to address the numerous challenges facing the world's largest hydrographic basin and develop technical and

scientific knowledge that will give rise to a new relationship with the river and its diverse ecosystems, while not losing sight of the main objective of this regional initiative, which is to develop a Strategic Action Program (SAP) for IWRM in the Amazon Basin and create a climate conducive to its future implementation.

In this sense, it should be mentioned that this is the first time in the history of the Amazon River hydrographic basin, that the eight ACTO member countries have agreed to pursue firsthand collective research, involving national and local authorities along with civil society and the communities, to objectively identify the critical transboundary problems of the basin, and particularly to determine the current situation of the water resources.

Eleven national workshops for Transboundary Diagnostic Analysis (TDA) were held in Bolivia, Brazil, Colombia, Ecuador, Guyana, Peru, Suriname and Venezuela; in Bolivia, Ecuador and Guyana, two national workshops were held in two different regions.

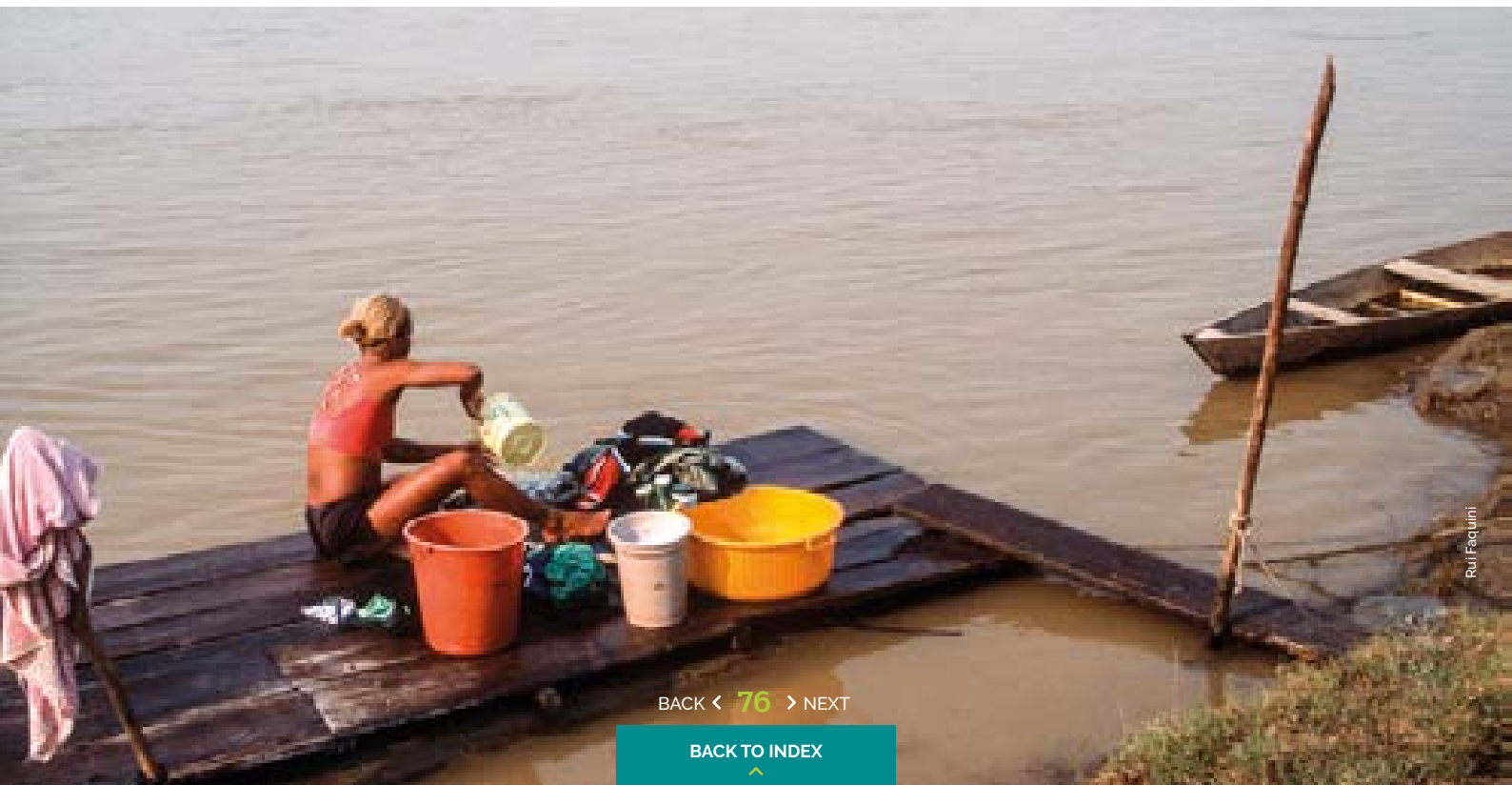
The workshops were decisive because they made participative technical analysis of the water resources of the Amazon Basin possible through the application of the Transboundary Diagnostic Analysis (TDA). The TDA is a working methodology that made it possible to determine objective facts about the situation of the water resources of the Amazon Basin, observing the importance of the sources, the root causes or primary causes and the socioeconomic and environmental effects of transboundary water problems.

The national TDAs were thus formulated, which facilitated the preparation of the regional Transboundary Diagnostic Analysis, which compiled nine priority transboundary problems, their environmental and socioeconomic impacts, their causes, and strategies for adaptation and mitigation.

The regional TDA of the Amazon Basin was based on the national workshops, with the participation of about 500 representatives of institutions from ACTO member countries, and with contributions in the form of scientific and demonstration activities by the GEF Amazon Project.

The regional TDA document is organized in four parts:

- 1** Priority Regional Transboundary Problems of the Amazon Basin.
- 2** Impacts and Causal Chain of Priority Regional Transboundary Problems.
- 3** Strategic Lines for Regional Response.
- 4** Recommendations and Conclusions.



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Importance of Integrated Management of Transboundary Water Resources in the Amazon Basin

The regional TDA made it possible not only to understand and visualize the seriousness and impact of the common problems facing the Amazon countries, but also facilitated the preparation of joint strategies to address these technically and scientifically, given that these are transboundary waters that are shared through a single and unique hydrological system, which in turn gives rise to a diversity of aquatic and terrestrial ecosystems along with very specific and distinct socioeconomic living conditions.

Main Achievements

1. Identification of Nine Priority Transboundary Problems of Water Resources of the Amazon Basin.

A detailed analysis was done of the 50 priority transboundary problems identified in the national TDA processes. Based on that analysis, the specialists identified nine priority regional transboundary problems (PRTP). To establish an order of priority for these problems, an analysis was done of the frequency that the 50 problems identified in the national TDA processes were mentioned.

Similarly, causal chain analysis was applied to the transboundary problem, and strategies were established for each of the problems. This is a significant advance in the creation of new knowledge about the Amazon Basin, which is essential for the decision-makers and social actors that took part in the process of developing this valuable information.

Identification and prioritization of Critical Transboundary Problems

A transboundary problem is an environmental problem that is transboundary in scale, in other words, an environmental problem that originates in, or is contributed to, by one country and affects (or impacts) another. A problem is also considered transboundary when it affects various countries at the same time.

Credit: GEF Amazon Project

Priority Regional Transboundary Problems of the Amazon Basin

- 1 Water pollution.
- 2 Deforestation.
- 3 Loss of biodiversity.
- 4 Extreme hydrological events.
- 5 Erosion, sediment transport and sedimentation
- 6 Changes in land use.
- 7 Loss of glaciers.
- 8 Large infrastructure projects.
- 9 Limited Integrated Water Resources Management

Credit: GEF Amazon Project

Thus, the regional Transboundary Diagnostic Analysis (TDA) of the Amazon Basin identified, established priorities, and defined the causal chain for nine transboundary problems associated with water, which are:

1. Water pollution.
2. Deforestation.
3. Loss of biodiversity.
4. Extreme hydrological events.
5. Erosion, sediment transport and sedimentation.
6. Changes in land use.
7. Loss of glaciers.
8. Large infrastructure projects.
9. Limited Integrated Water Resources Management.

2. Suggested Recommendations Arising from the TDA Processes for the Formulation of the Strategic Action Program (SAP)

Strategic lines of action to deal with the priority transboundary problems at the regional level were consolidated into the following recommendations.

In addition to the technical and scientific considerations, the regional TDA served as a valuable mechanism for consultation, which has facilitated strengthening relations among the countries regarding water resources. This, in turn, has increased trust between governments to project a common future for the region and define priorities for the basin, which has made it possible for the regional Amazon cooperation process to move ahead on the implementation of the Strategic Action Program (SAP).

Strategic lines of response identified and systematized in the regional TDA

Strengthening capacities of the key actors of the basin

- » Strengthen water resources management institutions in the countries.
- » Create technical, financial and institutional capacities to mitigate water pollution.
- » Strengthen the capacities of local actors and their participation in water resources management.
- » Promote a system for participative monitoring and regional oversight of water resources.

Funding for water resources management

- » Create a fund to finance water resources management in transboundary basins.

Legal framework for water resources management

- » Establish guidelines at the regional level and harmonize criteria at the national level for integrated water resources management in transboundary basins.

Adaptation to extreme hydroclimatic events

- » Promote monitoring of extreme hydrological events.
- » Encourage the expansion of hydrometeorological network systems.
- » Promote the implementation of early warning systems and risk and disaster management plans.

Managing information and knowledge about water resources

- » Create a Regional Water Observatory, consisting of public and private entities and civil society to promote research, flow of information and generation of knowledge for water resources management in transboundary basins.
- » Promote applied scientific investigation and knowledge for IWRM in transboundary basins.
- » Establish an integrated water resources information system, with early warning systems in transboundary basins.

Education and culture

- » Promote water culture and environmental education, giving value to traditional and local knowledge for water resources management in transboundary basins.

Public policies

- » Establish regional public policy guidelines to foster IWRM at the country and basin level in the Amazon.
- » Promote public policies on water pollution, land-use planning, land use, forest management, water ecosystems management, rational production practices, economic analysis and development of economic instruments for water resources, in accordance with the laws and regulations of each country.

Adaptation and evaluation of impacts

- » Promote instruments and measures for adaptation to climate change in water resources management of transboundary basins.
- » Promote instruments for the economic evaluation of the environmental impacts of large infrastructure projects in transboundary basins, in accordance with each country's policy standards.

Communication, promotion and dissemination

- » Publicize public water resources policies and strategies in transboundary basins.
- » Promote and publicize technical and scientific cooperation in the field of water resources of the Amazon Basin through multilateral agreements among Amazon countries.

Cooperation Among Countries To Evaluate Transboundary Water Resources Problems

The Transboundary Diagnostic Analysis (TDA) is a working methodology that enabled the countries taking part in the GEF Amazon Project to identify and evaluate problems, not only involving water resources (quantity and quality) and the natural environment, but also economic factors that have immediate or future, direct or indirect impact on water resources, such as land use, demographics, etc.

In all of the countries, the stakeholders participated actively in the application of the methodology, which resulted in a fruitful process of interaction, consultation and a search for solutions, which was reflected in the strategies that were found.

National TDA Workshops

National TDA processes were held in the eight ACTO member countries: Bolivia, Brazil, Colombia, Guyana, Ecuador, Peru, Suriname and Venezuela. National consultants were hired to facilitate the workshops at which the interested parties participated. The workshops were held in different cities.

A regional consultant oversaw all of the national workshops, and coordinated and guided the application of the methodology. The ACTO and the project's coordinators were also present as observers.

The national workshops were run by national associates in each country. In Bolivia, Ecuador and Guyana, two national workshops were held in different places.



Application of the Causal Chain Methodology

Step 1

The available information was shared, taking into account the existing projects in each country, priorities on water use identified by the countries that share the basin, the existence of protected areas associated with international waters, possible effects of climate change, extreme hydrological events (drought and floods) and ongoing research projects about common problems.

Step 2

The application of the TDA methodology at the national workshops facilitated the identification and quantification of the problems in each country. Priorities were established concerning problems associated with transboundary water resources.

Step 3

At the national workshops, a detailed participative analysis was done of the immediate and fundamental causes of each problem. This served as an input to enable each country to recognize their problems and address the root causes, meaning the diverse social, institutional, economic, technological and political factors that determine the problems affecting water resources. In all of the countries, much was learned about the subject and how to apply the methodology with the intersectoral approach of causal chain analysis, which makes it possible to show the cause and effect relations for each main problem.

Step 3: Example of application of the methodology: Participatory identification of the Causes and Actions proposed for Problem N°. 1.



WATER POLLUTION IN THE AMAZON BASIN MAINLY COMES FROM:

- »
- » **Primary direct causes (technical):**
Use of mercury in mining
- » **Indirect secondary cause (economic):** High gold prices in the international market
- » **Tertiary indirect cause (institutional):** Scarce control over the use of mercury in artisanal/illegal mining
- » **Roots causes (sociopolitical):**
Poverty of the communities and local populations.



PROPOSED ACTIONS

- a. Promote studies and research into the impact of contamination from mercury and other heavy metals in areas of greater risk.
- b. Promote policies and strategies for protection and oversight of water sources.

Water pollution in the Amazon Basin mainly comes from:

- » Illegal/informal mining.
- » Hydrocarbon extraction.
- » Residential, commercial and industrial wastewater.
- » River transport.

The TDA was then applied in depth to each of the previously mentioned four aspects of the problem, beginning with illegal/informal mining.

The participants looked at four different types of causes, in the following order: primary direct causes (technical), indirect secondary causes (economic), tertiary indirect causes (institutional) and root causes (sociopolitical) to analyze the problem of water pollution from illegal/informal mining.

Once the causes had been fully identified, the participants at the workshops set out to find response actions, drawing on their different knowledge and expertise, which enriched the solutions offered.

Continuing with the example, we will mention just one of the elements found (of the multiple variables suggested) for each cause and some of the final actions that were proposed during the debates at the workshops.

During each workshop, all of the causes and actions were systematized for each of the different aspects of problem N° 1: water pollution (Illegal/informal mining. Hydrocarbon extraction. Domestic, commercial and industrial wastewater. River transport). The rest of the transboundary problems identified were then analyzed in detail.

This information was converted into graphics for greater understanding of the findings, which were subsequently presented, debated and consolidated in the regional workshop.

Step 4

During the analysis, the countries also assessed the situation of governance, in terms of the management of water resources. This involved reviewing institutional capacities along with certain legal and political aspects, which was very useful for underlining the importance of applying the principles of sustainable development in the region with a long-term perspective.

Step 5

With the inputs obtained at each national TDA workshop, each country produced a report on the workshop and a national TDA document, contributing substantial information to draft the regional TDA in which the nine priority transboundary problems at the regional level were consolidated.

Step 6

Once the information had been obtained from the countries, the national consultants met to do their analysis and were able to define causal chain strategies for each problem.

Replication in the Eight ACTO Member Countries

The TDA process at the national and regional levels in the Amazon Basin produced a theoretical and methodological justification, documented by each country, to identify the priority transboundary water problems.

The application of the methodology created a dynamic of high participation by the stakeholders, significantly enriching the conversation and knowledge about the problems.

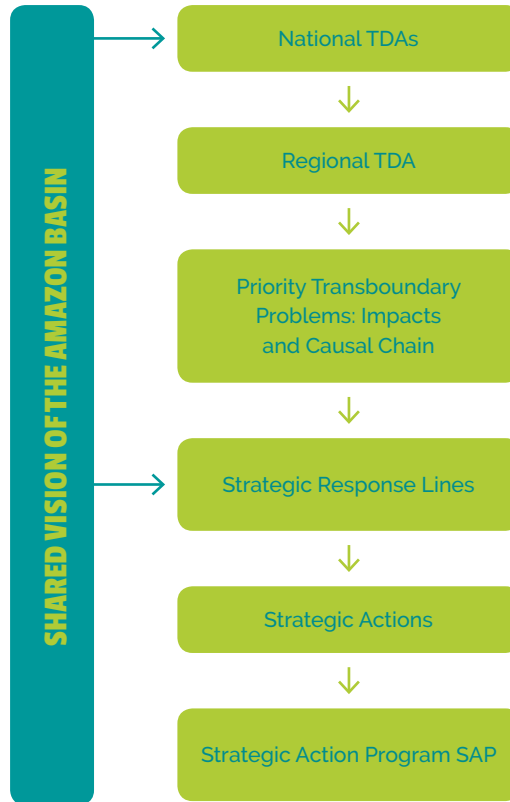
The methodology's efficacy made it possible to carry out 11 national workshops in eight countries in one year, which provided the necessary inputs for the joint formulation of the Strategic Action Program (SAP), a key intergovernmental tool for sustainable development in the basin. The entire process is replicable in other regions, applying the same methodology.

Broad Social Participation: Essential for the TDA

The TDA process, on the one hand, gathered substantial information from the grassroots, in other words, the knowledge and experience available about how integrated water resources management (IWRM) is being applied and, on the other hand, it facilitated participation by the main national actors, such as public and private institutions associated with water resources management.

This methodology could thus be very useful to analyze the complex problems in other water basins. The following is the sequence of the logical process that was used in the Amazon Basin:

The TDA methodology developed by the GEF may be easily understood and applied at workshops with social actors with different academic levels from all walks of life. The methodology enables the participants to focus directly on the problems and their causes, which avoids rhetoric, thus making the participative involvement by the attendees more effective.



One of the most significant achievements of the workshops was the high level of integration, which was very beneficial for the regional process because it facilitated commitment and willingness by the participants to implement the Strategic Action Program (SAP).

This sense of commitment and awareness of priority transboundary problems has facilitated the coordinated search for funding to successfully carry out the Strategic Action Program (SAP).

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Introductory phrase at:
www.concienciaeco.com

...“ The animals run. They run.
They run when I flood their
fields, when I sow their slopes
with tiny pebbles, when I flood
their homes and their meadows,
when I flood their doors and
their hearts, their bodies and
their hearts” ...

Javier Heraud



Study N°. 7

► Elevated Gardens and Fish Tanks:

Innovative Solutions for Sustainable Management of Transboundary Floodable Forests in the Amazon Basin

Area: Integrated Management of Transboundary Water Resources



GEF Amazon Project

Transboundary floodplain forests are plains that are periodically flooded by the Amazon River in Peru and Brazil

The transboundary floodable forests are the plains in Peru and Brazil that are periodically flooded by the Amazon River. They represent one of the most sensitive and threatened ecosystems in the Amazon.

The communities of Tapar Grande, Urucurituba and Igarap do Costa in the jurisdiction of the municipality of Santarm, Par State, Brazil were involved in this pilot project, along with the communities of San Jacinto and San Regis, located in the Pacaya Samiria National Reserve, in Nauta Province, Loreto Department, Peru, the latter being one of the largest floodable areas in Loreto.

Historically, these populations have been able to sustain themselves through fishing and subsistence

farming. Thus, the importance of this project, which started by taking into account the knowledge of the ethnic groups and the way the inhabitants of those areas deal with floods. In recent decades, each flood season, the rising waters have produced emergency situations, different from previous years, affecting the inhabitants' homes and livelihoods.

The purpose of this pilot project was to guarantee the economic livelihood of the communities during the periods in which the water level of the river rises, by implementing innovative agro-technologies involving gardens built on elevated structures for cultivation during times of extreme flooding, as well as innovative fish farming systems using tank networks for production.



Preparatory Stage of the Pilot Project

Step 1

Sociocultural and ethno-botanical diagnoses were done, as well as others on fishing resources in the zones selected, to work with the fishermen and riverside farmers. To do so, a field visit was done during the flood period to choose a suitable site for elevated garden structures.

Step 2

Rapprochement was done with the communities, through surveys and consultations, to motivate people and create a conducive social climate for the project.

Step 3

An architect was hired to build the structure, along with a technical team of three Peruvian consultants and three Brazilians to accompany the communities during implementation of the production systems.

Step 4

Ecosystem resilience tests were done, and structures for the elevated gardens were built.

Step 5

Workshops were held with the communities on semi-hydroponic vegetable production, fish production, promoting family agribusinesses.

Step 6

Use of fishing resources in floodable forest ecosystems was boosted through the introduction of fish farming, increasing the families' use of fish production technology by means of tank networks.

Step 7

Conditions were created to enable communities in floodable forests to be economically active in the local market during the Amazon River's flood periods.

Five Significant Results of the Experiences in Brazil and Peru

The multidisciplinary systemic diagnosis produced the following results:



Credit: GEF Amazon Project

The GEF Amazon Project realized a Botanical Atlas of flora located in the area of flooded forests

- » Creation of a botanical atlas on 52 species native to the floodable Amazonian forests, based on the traditional knowledge of the communities.
- » Implementation of elevated semi-hydroponic gardens in the communities of Tapará Grande and Urucurituba, Brazil. The use of technology in fruit and vegetable production was increased, and farming families received technological training, making it possible for them to grow products for the local markets.
- » Three fish farms with 10 tank networks were set up to increase fish production in floodable forest conditions and generate income for the communities. In Igarapé do Costa, 5,000 fish spawn were provided, in Tapará Grande 2,500 and in San Jacinto, 4,500 spawn of the *Colossoma macropomum* or tambaqui species (an Amazon freshwater fish). Expected yield: 12 tons after eight months of cultivation.
- » Conditions were created in which it will be possible to reduce anthropogenic pressure on fish reserves, thanks to fish farming.



ACTO



GEF Amazon Project

Tanks networks for the cultivation of fish in flooded forests

- » The production of handicrafts made from plant fibers and wood was encouraged, using the technology and by starting a seed bank for the plant species used in Peruvian crafts, to reduce anthropogenic impact on these materials.

New Green Economy Opportunities in the Amazon

This pilot project showed that in the floodable forest zone, it is possible to grow during the flood season, making productive use of the richness of the biodiversity of the ecosystem through innovative agro-tech-



Rui Faquini

nologies. These technologies contribute to the social inclusion of the riverside communities, allowing them to generate income in underserved markets, even during extreme climatic events. The elevated hydroponic gardens and the fish tank networks reduced anthropogenic impact in the area, and could be replicated in other parts of the Amazon Basin.

By observing the geography of the lakes in the ecosystems of the floodable Peruvian Amazonian forests, it was possible to decide the location of the fish tank networks to generate income for artisanal fishermen. In this way, traditional knowledge about artisanal fishing was combined with concentrated fish cultivation as a sustainable development strategy.

This experience showed that new conditions can be created to develop green economy in the Amazon, and thereby reduce poverty in the communities.

Innovative Solutions for Survival: Converting Floodable Areas Into Productive Spaces.

Working with the communities to convert floodable areas into spaces that remain productive during periods of flooding can be replicated in other parts of the

Amazon and other basins that are experiencing the impacts of climate change. The methodology used also made it possible to observe the richness of these ecosystems, and create a unique ethnobotanical atlas based on the communities' traditional knowledge.

The use of technology in producing handicrafts was also encouraged. The diversity of the actions in this pilot project not only showed that they could be replicated, but also that significant changes in living conditions can be achieved, even during flood periods.

New Uses for Floodable Forests

This community of 22,044 inhabitants was able to introduce innovative changes to crop production, fishing and handicrafts during the flood period on the Amazonian plains, using traditional knowledge and technology with the implementation of the elevated structures, 10 m X 10 m, for semi-hydroponic growing. This made a difference because the communities were able to sustain their families by gaining resiliency to conditions of climate change. They learned novel ways to use the floodable forest and created new opportunities during adverse situations, while increasing knowledge about sustainable resource management.



Rui Faquini



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“Before, there was only forest and river, indian, moon and shining sun, but in the vastness of the waters of the Purus, alone, gently, undaunted, proudly, triumphantly, sailed the ship of the proud navigator, valiant Manuel Urbano, eager for a new world to discover..”

Rogério Cavalcante



Study N^o. 8

► Risk Governance Operative Model:

Adaptation to Climate Change and Risk Management in the Purus River Subbasin

Areas: Water Governance/Risk Management/Integrated Management of Transboundary Water Resources



Floods contaminate water wells generating multiple diseases

Climate change is one of the greatest socio-economic and scientific challenges currently facing the Amazon Basin. According to the Intergovernmental Panel on Climate Change (IPCC), climate change is defined as a “change in the state of the climate that can be identified (e.g., by using statistical tests) by changes in the mean and/or the variability of its properties and that persists for an extended period, typically decades or longer. Climate change may be due to natural internal processes or external forcings such as modulations of the solar cycles, volcanic eruptions and persistent anthropogenic changes in the composition of the atmosphere or in land use.” These changes are linked to variations in temperature, precipitation and fog, among other climatic variables.

Climate variations can affect the volume of the rivers, causing floods and droughts, extreme opposed phenomena, causing harm to local populations.

The Amazon region, which includes the Purus River subbasin, is one of the areas with the greatest diversity and availability of natural resources in the world. However, the quality of those resources is threatened, along with the region and its population, by the impacts of climate variability and change.

The beautiful Purus is a secondary river with its source in Peru, and has clear white waters that are rich in Andean sediments. Its path meanders in numerous places, which is one of its defining characteristics. In the midst of exuberant nature, it enters Acre State at Santa Rosa do Purus, passes the municipality of Manoel Urbano and continues to Amazonas State, until emptying from the right bank of the main river, the Amazon, upstream from Manaus. It has a length of 2,960 km, and is only navigable for about five months of the year, because it can rise by more than 15 m, leaving in its path large flooded plains, and forming numerous lakes with its overflowing waters.



City of Beruri on the banks of the Purus River

It is home to a great diversity of species, including dolphins, which are illegally hunted for their meat. Because it is a very productive zone and given the intense commercial activity on the river until Manaus, there is great pressure on the Purus from fishing, hunting, logging and agriculture.

The Purus River has its own basin which, because it has few inhabitants, is called a subbasin, as opposed to a basin, which has a larger population.

The Purus River subbasin is located in Acre and Amazonas States in Brazil, and its western part reaches Peru and Bolivia.

The pilot project concentrated its activities on the areas with the largest number of inhabitants, Beruri, Tapaua, Canutama, Labrea, Boca do Acre and Pauini in Amazonas State; and Santa Rosa de Purus, Sena Madureira and Manoel Urbano in Acre State, Brazil, places with different and specific conditions.

Climate change demands that governments at all levels, local, regional and national, adopt policies that include measures to deal with this, given the great impact that it has on people's daily lives. In that sense, the transboundary dimension involves the institutional capacity of the municipalities of this subbasin to deal with extreme hydroclimatic events (floods and droughts).

The objective of this pilot project was to evaluate the impacts of climate change on risk management and

transboundary water resources management in the Purus River subbasin, and provide the basis to formulate a set of strategies to foster sustainable use of the natural resources of the subbasin, in response to adverse climate conditions.

To this end, the risk governance operative model was developed, using data from the Purus River subbasin, to make it possible to predict the degree of risk associated with climate change in Amazon scenarios, such as forecasting increases in the height of the river and threats of droughts or flooding in the municipalities, information that is fundamental for decision-makers in the countries of the basin. The model, called MOGAM-R, provides input for the creation of adaptation and response strategies for extreme climate events.

In this region, floods pollute water wells, spreading waterborne diseases (diarrhea, cholera and leptospirosis, among others). Flooding also causes septic tanks tend to overflow, does damage to homes and infrastructure, and affects and causes losses in agricultural production. Additionally, large boats come to catch fish, leaving the local population, which depends on fishing, deprived of that resource.

In contrast, during dry periods, river transport is reduced and food and fuel cannot make it to their destinations, and the prices of these products rise, forcing communities to move.

Creation of the MOGAM-R Model

Phase 1 The first phase entailed the description of the Purus River subbasin and characterized the inhabitants' way of life from an anthropological point of view. It described land use and the use of water resources from an Amazon-specific perspective, variables which were used in the model.

Phase 2 Addressed the institutional characteristics used in the model. The nature of the institutions present in the municipalities of the subbasin, their capacities, and national protection and civil defense policy were analyzed from an intersectoral perspective.

Phase 3 The climate component was incorporated into the MOGAM-R. Climate models were created, along with the corresponding climatology and hydrology analyses, with 10-year forecasts for the basin, demonstrating the degree of accuracy of the regional climate model, a process in which specialized meteorologists and hydrologists took part.

Phase 4 The theoretical-methodological premises for definition and integration of the components of the MOGAM-R were presented.

Phase 5 The tool known as fuzzy logic was employed to combine all of the components of the operational model. This tool uses intermediate values to enlarge and improve the assessments, which recognized the municipalities' capacity to generate public policy. User-friendly interaction processes were also described and their components visualized.

Phase 6 Ways to use and apply the model were presented as one of the strategies in the Strategic Action Program (SAP).

10-year Predictive Capacity

The risk governance operative model was created to determine climate impact in terms of three components: first, a climatic and hydrological model that uses more than 1,000 mathematical equations to describe the phenomena; second, by evaluating the communities' capacity for adaptation and, third, by analyzing the institutional capacity in place. In this way, three specific databases were built. Using the model to cross the scales on climate and hydrology factors produced 10-year predictive capacity.

One benefit of the model is that it shows the entire area of this transboundary subbasin, so that it can be observed in its full extent and complexity.

By using the risk governance operative model, decision-makers and the stakeholders of the subbasin can adopt strategies for adaptation and implement actions before an extreme climate event happens. The unique characteristic of this model is that it has been developed from a regional perspective and may be used by transboundary institutions.

To this end, 367 interviews were done with stakeholders during two field visits to the Purus River subbasin, from Peru to Beruri in Amazonas State, which made it possible to understand the risks perceived by the inhabitants and the decision-makers who implement policies associated with risk. During these visits, the people's way of life was observed, along with strategies that they have used in previous extreme hydroclimatic events.



GEF Amazon Project

The sub-basin of the Purus River covers the states of Acre and Amazonas in Brazil, reaching Peru and Bolivia

Two workshops were also held, Manaus (May 2014) and Rio Branco (August 2014), to validate the risk governance operative model, which was created to help develop measures for adaptation to climate change in cases of extreme climatic events and to help prepare the 43 communities participating in the project, which represent 295,000 inhabitants of the Purus subbasin.

Interdependence of the Ecological and Institutional Systems

Each of the experts from the fields of meteorology, computational intelligence, hydrology, anthropology, communications, and political science in the interdisciplinary working group contributed, according to their experience and knowledge, in order to produce the risk governance operative model, which is based on the principle that interdependence is the main characteristic of the ecological (human and physical) and institutional systems, according to the methodology applied, which is known as cross-scale interplay.

In this way, the experts applied different methodologies to assess the impact of climate change in the subbasin. A climatic and hydrological model was

produced, to understand the natural phenomena that affect the subbasin; an evaluation of the capacity of the communities for adaptation to the new reality of climate change, and also an analysis of local institutional capacity.

Understanding the institutional capacity to protect the communities was very significant in this assessment, along with examining the type of climatological phenomena that occur in the zone from a scientific viewpoint. For this reason, the municipalities were examined rigorously to enable local governments to consider the costs of the actions required to mitigate the critical problems stemming from climate change in the region, and to propose new institutional arrangements to deal with them. Thus, it was fundamental to include institutional capacity as a variable in the risk governance operative model.

The anthropologists also worked to come to a better understanding of the traditional people of the subbasin. These communities have been strongly affected by climate change, because new river cycles are occurring rapidly and repeatedly, and people have not had the time, information or means to assimilate this new reality.

Another outstanding event that provided lessons for the working team happened when the risk governance operative model was presented to the inhabitants of three municipalities in Acre State: Sena Madureira, Manoel Urbano and Santa Rosa do Purus. The inhabitants of these municipalities contributed their experiences for inclusion in the model.

Replication of the Risk Governance Operative Model

The creation of a specific risk governance operative model for the Purus subbasin, based on information

obtained in the field on meteorological, hydrological and socioeconomic variables, as well as local infrastructure and institutional capacity, showed that the instrument could be replicated in other subbasins of the Amazon River.

Inclusion of the institutional capacity variable enables the municipalities affected to understand the need to develop public policies for the coordinated management of extreme climatic events.

Adoption of the model will enable the countries to take preventive measures to deal with climate change.



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Climate Change's Transformation of the Amazon Region

The GEF Amazon Project carried out research into specific conditions on the Purus River subbasin, identifying the risks from floods and droughts which have transformed the dynamics of this region, making the people and their ecosystems vulnerable.

These findings are essential for the Amazonian countries, and it is relevant to stress the knowledge and ef-

forts by the communities to adapt to climate change. Having 10-year predictive capacity, the risk governance operative model created for the Purus River subbasin will give local governments access to a broad range of information to develop public policies for the short, medium and long terms, and increase their capacity for adaptation to climate change.

The methodology used to create the model is also a useful resource for governments, research institutes and universities, and could be replicated in other regions.



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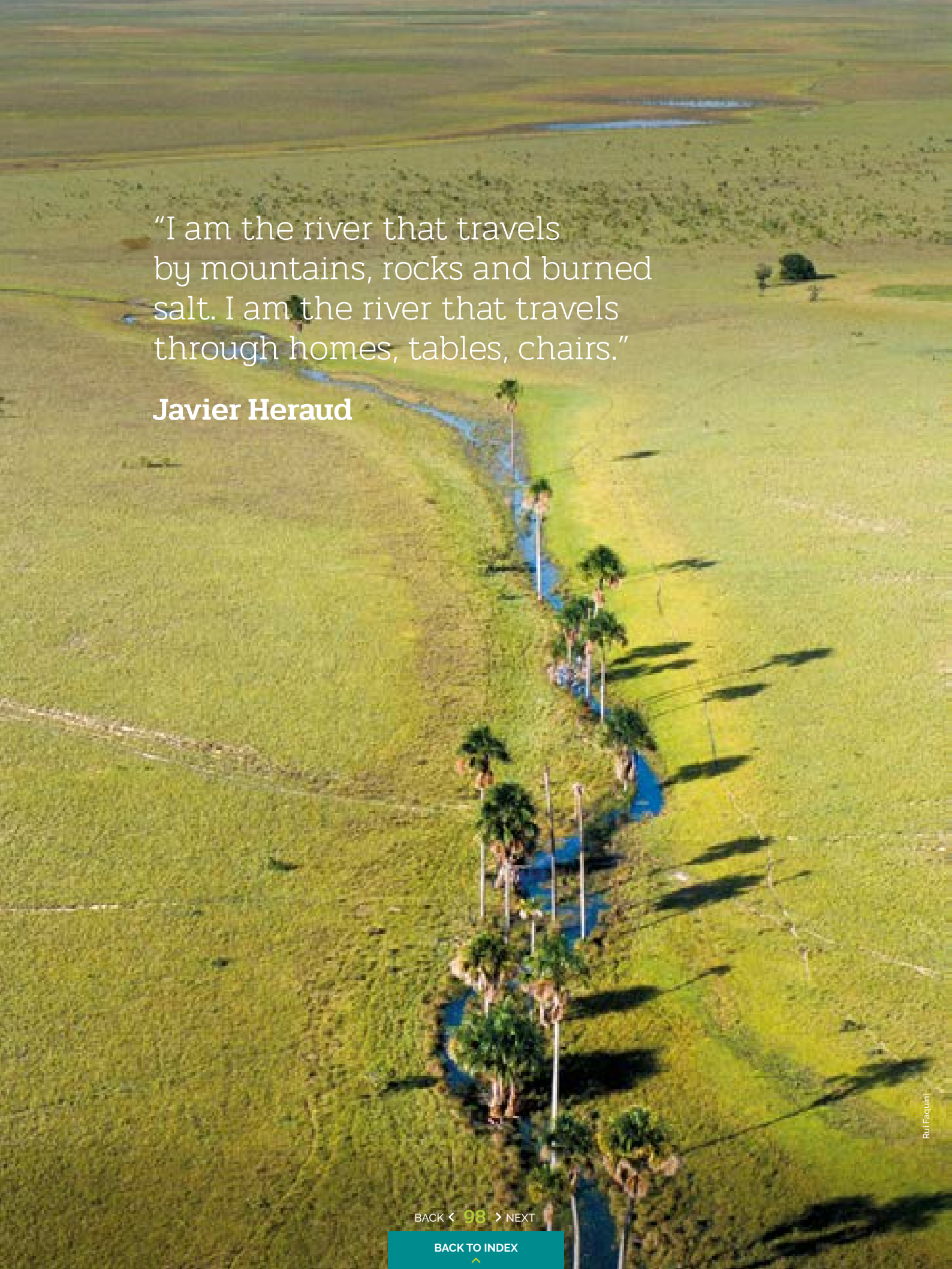
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Ruil Fagumi

An aerial photograph showing a narrow river winding through a vast, flat, green landscape. A line of tall palm trees runs parallel to the river, casting long shadows. The terrain is mostly flat with some sparse vegetation and a few small structures in the distance.

“I am the river that travels
by mountains, rocks and burned
salt. I am the river that travels
through homes, tables, chairs.”

Javier Heraud

Study N°. 9

► Communities in Action To Deal with Climate Change:

Adaptation to Climate Change
in the MAP Transboundary Region

Area: Integrated Management of Transboundary Water Resources



GEF Amazon Project- Audiovisual

The MAP region has more than 900,000 inhabitants who are affected annually by floods

The Acre River is the backbone of the MAP trilateral region (Madre de Dios, Peru, Acre, Brazil and Pando, Bolivia). The Acre is an Amazonian River, which has its source in Peru and along its course serves as the border, first with Brazil and then with Bolivia. It has a length of 1,190 km and empties into the Purus River, in Amazonas State, Brazil. Its basin, which is shared by the three countries, covers about 35,967 km².

Because its waters run through the Peruvian region of Madre de Dios, the Bolivian Department of Pando and the Brazilian States of Acre and Amazonas, different government agencies, social organizations, universities, and the private sector in these three countries have agreed to study this trilateral territory, defined as the MAP region. A very wide-ranging initiative has been organized around specific topics, each of which is called a mini-MAP. One such topic is

the basin mini-MAP, which deals with the hydrological and climatic problems of the Acre River Basin.

More than 900,000 people live in this region, of whom 120,000 are in Madre de Dios, 700,000 in Acre and 90,000 in Pando. The tropical rainforest ecosystem is used for diverse economic activities, such as timber extraction, chestnuts, precious metals, oil, rice and corn crops, cattle ranching and fishing.

Extreme climate events are becoming increasingly frequent in this region. There are periods of heavy rains that cause huge floods, as well as prolonged droughts. In 2010 there was a flood that led to loss of life and homes in both Cobija (Pando) and Assis (Acre). There are also long periods of drought, and because fire is used to burn wood, there have been huge forest fires. In 2005 alone, 400,000 hectares burned, which happened again in 2010.

The basin mini-MAP and the civil defense mini-MAP were incorporated into the GEF Amazon Project to make a diagnosis, better understand the Acre River

Basin and implement an early warning system, which is currently shared by the three countries, not just to warn of fires and floods, but also for other events.

Collaborative Working Relations in the MAP Region

In order to analyze the vulnerability of the MAP region, diverse meetings and activities were held, with active participation by more than 40 governmental representatives and more than 20 civil society institutions from this region. The participants contributed their experience and knowledge to define specific lines of work for adaptation to risk in response to climate change.

The following steps were taken, which were very innovative for the participants, and also facilitated closer ties among the institutions and working groups from the countries. This made it possible to keep to the schedule that the social actors themselves had proposed.

Step 1

Social mobilization and coordination in the MAP transboundary region, meetings with local governments and activists to present this initiative and publicize the GEF Amazon Project. This facilitated participation by diverse governmental bodies and actors of the region. Courses were organized on geographic information systems (GIS), with the aim of updating the databanks in the countries to better monitor deforestation and heat sources, and flooding of the Acre River (March 2013).

Step 2

Subject-specialist meetings were held with local researchers, which resulted in the establishment of a trilateral team of specialists to put climate change adaptation measures into practice in the MAP, considering the specificities of each country. This team helped to improve the work plan for the activity, including the working methodology and schedule of activities (March 2013).

Step 3

Structuring of the geographic information system (GIS). This tool facilitated understanding of the geographic area of the transboundary MAP region and also housed the data. It must be emphasized that this was the first time a trilateral databank was created, designed by technicians from the three countries and with specialists from universities, who shared the same methodology and structure. A total of 19 topics were addressed, using information essential to understanding land use in the basin and its vulnerability to climate change, among other aspects, and enabling regional coordination in response to critical events. (April to October 2013).

Step 4

Analysis of the vulnerability and ecological risk of the transboundary region of the Acre River. The ecological risk index (ERI) was used, which considers three factors: 1. severity, 2. frequency and 3. sensitivity. The data and analysis were presented at the First International Meeting of the Warning System in the Acre River Basin. (November-December 2013)



Rui Faquini

Step 5

Validation of the information produced in the GIS. A field visit was done along the Acre River, with representatives of the three countries to verify the data produced by the GIS team. Information was also gathered about risks through field visits and interviews with local authorities and communities as part of a 185-km journey along the river. (November to December 2013).

Step 6

Establishment of a warning system for critical events. It must be emphasized that the three countries all decided to use the TerraMA2 platform for monitoring, analysis and alert systems, which is available free of charge from the Instituto Nacional de Pesquisas Espaciais de Brasil (INPE), which operates in Acre. (November 2014)

Step 7

Implementation of an emergency radio communications system. (November 2014).

MAP Trinational Early Warning System

The pilot project provided the basis for formulating and implementing strategies for adaptation to climate variability, with representatives of the governments of the three countries and the local communities. The trinational team of 15 specialists provided technical validation of the vulnerability and risk maps during the expedition to the Acre River.

The expedition also mapped activities with potential impact in polluted areas and fragile sites, which showed the high degree of vulnerability of the Acre River Basin and the need to structure adaptation strategies.

In the context of the project, the First International Meeting of the Early Warning System of the Acre River Basin was held (December 2013), at which the trinational maps were presented. How local responsibility would be shared in the early warning system for the MAP region was decided. It was also agreed to use the TerraMA2 platform for the early warning system.

Finally, a trinational early warning system was created and implemented in Pando Department, Bolivia, with the Departmental Emergency Operations Center of Pando (COED-PANDO); Madre de Dios Department, Peru, with the National Water Authority (ANA), Puerto Maldonado, and in Acre State, with the Secretary of State for the Environment of Acre, Brazil (SEMA). The equipment was provided and the corresponding

personnel from the relevant local institutions were trained in the operation of the TerraMA² platform.

Additionally, to support the warning system, a new radio communications system was installed. Joint work by the national, regional and local governments shows the importance of the trinational warning system in this region, and the need to extend the system to neighboring departments or states and other Amazonian areas.

It is also noteworthy that the early warning system was used successfully in the context of the historic flood of February 2015 that raised the level of the Acre River to more than 18 meters, thus benefiting more than 80,000 people in the MAP region.

Learning from the Experience: Integrated Trinational Management of the Hydrological Cycle

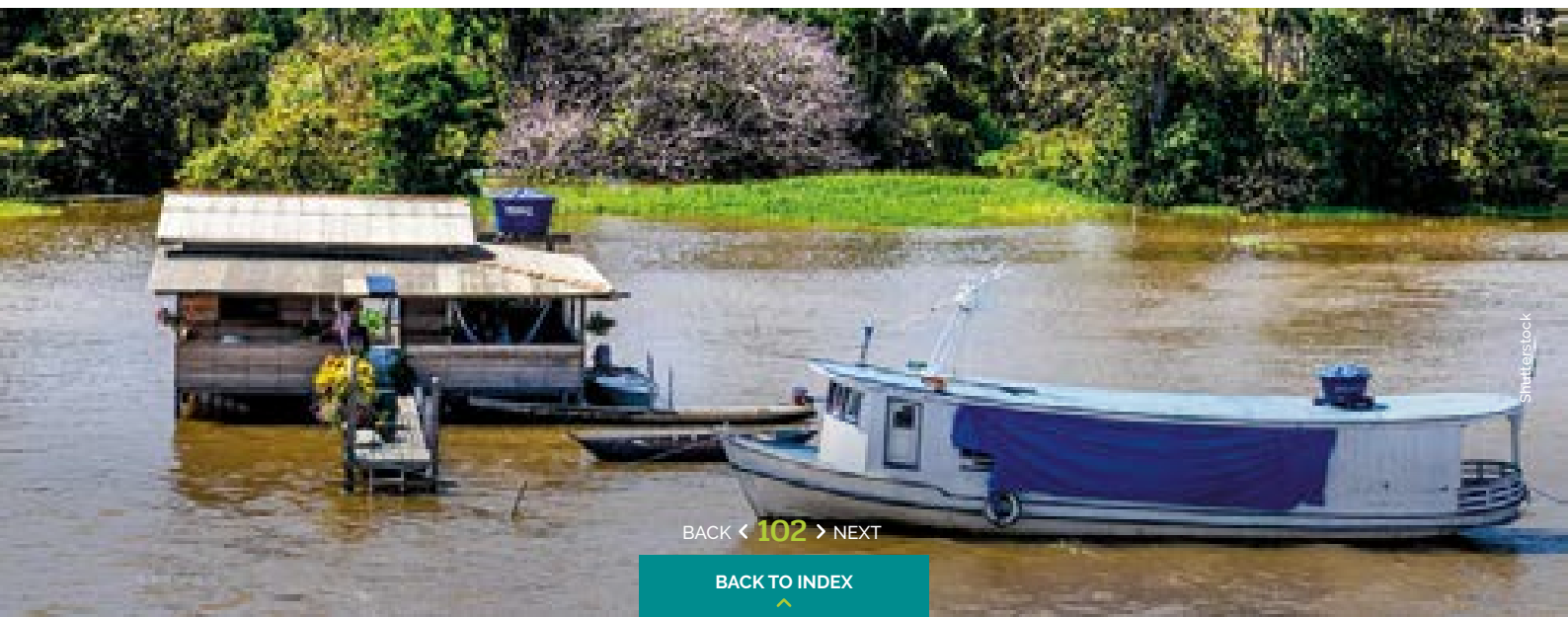
In the Amazonian region, the Acre River's transboundary hydrographic basin is at risk.

Considering that the waters of the Acre River are shared by three countries, dealing with the hydrological cycle requires integrated trinational management, in other words, a joint effort by the three countries for the sustainable development of this region in order to minimize the negative social, economic and environmental impacts of extreme events.

In recent decades, the local environment has faced extreme climate events such as floods and droughts, and has felt the impact of intense anthropogenic pressure (burnings, forest fires, deforestation and agriculture), which have affected the Acre River's aquatic ecosystems, vegetation, soil, and atmosphere and thus the health and economy of its communities.

In this context, the GEF Amazon Project carried out this pilot project with participation by government authorities and local communities from the three countries to address the vulnerability of water resources and help the local population in the face of climate change. The aim was to contribute to the formulation of policies for social and environmental adaptation to the new reality in this complex transboundary region of the Amazon. The project has facilitated increased integration in the region and strengthened cooperation between the three countries.

Of the lessons learned, it is noteworthy that the activity was supported by a social movement and with the involvement of local actors who were already present in the region, by means of the MAP initiative. In this sense, the project strengthened the initiative and enabled participation by the governments of the three countries, without whose support no progress could have been made in the implementation of the early warning system.



Technology to deal with Climate Change which can be replicated throughout the Basin

This experience also showed the project's importance in using technology to address climate change problems, to mitigate the impacts of the extreme events that have happened and those which could occur.

The work methodology that involved mechanisms for participative action, along with the instruments and warning systems that were provided, could be replicated throughout the Amazon Basin. That is because, in addition to the expected results, relations between the three countries were strengthened, enabling them to jointly address the problems, thus generating an environment of integration that has increased the capacity and potential of the region to deal with extreme climate events.

In fact, the system is already being replicated in Peru. The National Water Authority of Peru has reported the installation of systems for warning and hydrological monitoring at the national level, using the TerraMA² platform developed in the framework of the cooperation processes promoted by the ACTO/UN Environment/GEF Amazon Project.

Significance of a Successful Regional Cooperation Experience

The collection of information in the three countries in a very short period of time, to build a trinational georeferenced database and perform the analysis of climate change in the MAP region, demonstrated the scope and importance of the GEF Amazon Project in sharing technologies, methodologies and working instruments.

The fact that three countries were involved in a diagnosis of critical hydrological vulnerability zones, which subsequently led to the creation of a matrix on the vulnerability of water resources to climate change in the MAP region, is very valuable.

Not only did the project facilitate a forum to produce new knowledge in a region that has been severely affected by extreme climate events, to study and analyze these, but the MAP region also took the necessary measures to adapt to the new climate change reality, implementing the early warning system, among other things, and thus increasing the level of awareness about the need to protect water resources in the communities.

In this successful trinational border cooperation experience, experts from the three countries' communities learned from each other, with the project as the facilitator, to promote actions aimed at shared and integrated management of the water resources of the Acre River transboundary subbasin.



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“Like a ship anchored in
the waters of the river-sea,
Like a stone giant where
the waves break,
Like a raised trunk
The dream of the giant
pharaoh Gran Pará,
Reveals to the traveler
The Island of Marajo”

Virgílio Vitelli

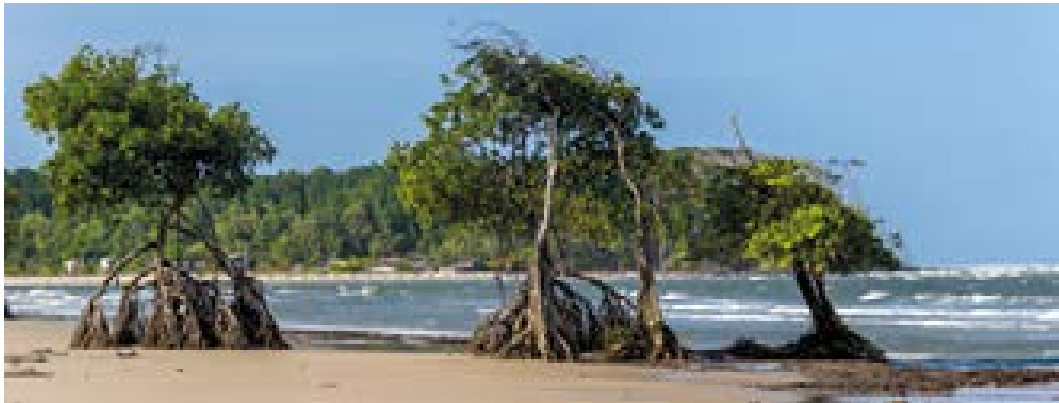


Study N^o. 10

► The Islanders Take on a New Challenge:

Adapting to Rising Sea Level in the Amazon River Delta

Area: Geology, Oceanography, Climate Change



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Marajo Island in the Amazon delta near the port of Belém, (Pará) Brazil.

Portuguese navigator Duarte Pacheco Pereira explored Marajo Island in 1498, prior to the discovery of Brazil. Located 90 km north of Belém, capital of Pará State (Brazil), it is made up of almost 3000 islands and islets, making Marajo the world's largest fluvial-oceanic archipelago and therefore an area of great environmental importance.

Marajo in the Tupi language means defense of the entry into a city. It was densely populated by indigenous peoples who had an organized network for trading primary materials and manufactured goods, which caught the attention of the Dutch, British and French merchants who arrived in search of spices and trading goods. Given its easy access to the Amazon region, there was much interest in controlling this area. In the late 16th century, the Portuguese expelled the other Europeans. The Portuguese secured their

dominion over the region with the founding of the city of Belém in 1616.

This led to the decline of the 29 indigenous peoples who inhabited the island. By the 18th century, the Portuguese had taken members of those communities to other regions as slaves, but the indigenous communities nonetheless left a deep cultural footprint on the island, which now has a population of 250,000. It is said that there are more domesticated water buffalo, which are raised for transport, milk and meat, than there are people.

Massive Loss of land in the World's Biggest Estuary Island

Because of massive land loss on the island and socioeconomic problems stemming from rising sea level, the GEF Amazon Project carried out the study



Coastal erosion in the investigated municipalities

entitled "Adapting to rising sea level in the Amazon River Delta." This included a geological, oceanographic, hydroclimatic and socioenvironmental study of Marajo Island, which made it possible to understand the dynamics of the Atlantic Ocean at the mouth of the Amazon River and propose measures for adaptation to rising sea level. The results of this research were used as an input in the Strategic Action Program (SAP).

Marajo Island (0°-2°S / 48°-51°W) is near the Equator and the mouth of the Amazon River. It is the world's largest estuary island, surrounded by freshwater and seawater. It is bathed by the Amazon to the northwest, the Estrechos and Breves Rivers to the south, and the Atlantic Ocean to the southeast. Its area measures 50,000 km², making it larger than Belgium and the Netherlands. Its ecosystem is made up of an estuary, which serves as a link between the continental and oceanic ecosystems in the delta region. It is important as a home to aquatic fauna. The island's conditions are conducive to the transference of nutrients to the Atlantic Ocean and the recovery of marine fish species. Its economic activities are based on agriculture, water buffalo ranching, tourism and fishing. Marajo Island is divided into 16 municipalities. Given its geographical position, it is considered an entry into the Amazonian region.

The Marajo Archipelago is an estuary complex made up of islands in the Gulf of Marajoara, in which Marajo Island is the biggest. The study by the GEF Amazon Project evaluated the consequences of rising sea

level, which rose between 10 and 25 cm in the 20th century, and could possibly accelerate during the 21st century because of climate change.

Erosion and the transport and distribution of sediments along the coast have caused serious environmental and socioeconomic damages, and proposals are needed for adaptation to deal with the impacts, which have been occurring over the past 15 years.

The study made it possible to assess the consequences of the rising sea level, along with other processes such as the increase in the level of the Amazon River, as well as extreme meteorological events stemming from global climate change and affecting the eastern and northern shores of Marajo Island. In Brazil, a diagnosis of erosion in coastal areas, including the municipalities of Soure and Salvaterra, showed that 60% of this area has been affected by erosion.

That is why this geological, oceanographic, hydroclimatic, and socioenvironmental research project on Marajo Island selected, as the study areas, the municipalities of Afuá and Chaves in the northern part of the island, and the municipalities of Soure and Salvaterra in the eastern part. A study was also done of erosion and changes in the coastline, and the ties between the mangroves and the sandy beach at Soure. Finally, a study was done of the dynamics of the northern coast of Marajo Island, along with the behavior of the tides and an analysis of the estuary, which facilitated the identification of changes in the dynamics at the edge of Amazon estuaries.

In the study area, nearly all of the municipal structures and the people are located in the lower-lying areas (coastal plains). Many of the island's environments are characterized as low elevation coastal zones, which are defined as areas adjacent to the coastline with altitudes of less than 10 m.

This fact is very important in order to understand the potential risk of flooding. The GEF Amazon Project has therefore consolidated specific proposals to support the local governments in their adaptation to rising sea level and coastal erosion.

Results and Lessons from the Marajo Island Experience

The results of the research showed the need to review the historical evolution of the Amazon Delta region. An analysis of changes over time was done of the island's northern and eastern coasts. This was a "type of spatial analysis done by comparing coverage seen on satellite images or maps of the same

area, from different dates, which makes it possible to evaluate the position of the coastline over time, which this project reviewed for the last 15 years," oceanographer Maamar el Robrini, who coordinated this review, explained.

The analysis showed that the coastline shifted toward the interior of the island. Potential threats to local communities from increased sea level were also identified.

Threats Due to Rising Sea Level

The following threats due to rising sea level in the Amazon River Delta were identified:



1. Socioeconomic impact. This refers to loss of homes, destruction of urban and rural infrastructure, increased risk from flooding, problems for the management of potable water, human migration, intrusion of seawater, costs of coastal protection, flooding of archaeological sites, and the loss of agricultural lands and fishing zones due to the alteration of oceanic conditions.



2. Coastal erosion. Almost all of the municipalities studied in this research are located in lower-lying areas adjacent to the coastline, with altitudes of less than 10 m. The risk of flooding is particularly high on the northern and eastern coasts of the island, where the coastline has suffered substantial changes caused by spring tides, increased water levels of the Amazon and Pará Rivers, and rising sea level. These phenomena cause intense coastal erosion and migration of the estuary beaches toward the mangroves, which are disappearing.

Scenarios for Adapting to Rising Sea Level in the Amazon Delta

The GEF Amazon Project consolidated specific proposals to support local governments in adapting to rising sea level and coastal erosion. Educational materials are being produced for the population and a strategy was formulated for relocation of the local population affected by loss of land.

Storms in the Amazon River Delta: An Effect of Climate Change

The inhabitants of Marajo Island are well aware of what happens when the sea level rises, a situation that historically they have dealt with very well. This was very useful for the scientific researchers of the GEF Amazon Project, who set out to understand the behaviors of the sea and the Amazon and Pará Rivers.



Sea level rise causes socioeconomic problems on the Island of Marajo, at the mouth of the Amazon River

The project held a meeting to converse with the fishermen, inhabitants, authorities, teachers and students in the parish of Soure, and to gather information about the coastal dynamics of the eastern shore, between Joanes and the fishermen's beach of Soure.

The project team defined both areas as vulnerable, with a population that is impacted by the effects of rising sea level on Marajo Island. The strategy for relocation of the local population affected by loss of land, entails a broad consultation process with the authorities and the community.

A working team was created, with participation by the Marine and Coastal Studies Group (GEMC), which is part of the Directorate of Research Groups of the National Scientific and Technological Development Council (CNPQ) of the Universidad Federal de Pará (UFPA).

The oceanographer at the head of the GEMC team was given the task of studying and analyzing the tide, while also reviewing the meteorological and geographic data on the island. The meteorologist examined the ongoing changes in rainfall periods, noting that there are now storms in the Amazon that did not occur in the past, and which stem from the phenomenon of global climate change. These storms cause higher tides, meaning that the water rises higher onto the land, contributing to erosion in the coastal zones of the island that were studied.

Similarly, it was necessary to produce different maps of the island to understand the data that were measured, focusing on the dynamics of the coastlines

and comparing current and past data to determine whether the coastline is retracting or advancing. The maps also show meteorological information, such as extreme climate events, in this case storms and winds of increasing velocity and intensity.

As part of the study, an examination was done of the situation of the coastal zones of the countries that border on the waters of the south Atlantic.

Climate Change Impacts the Estuary

The experience gained in this study could be replicated in other estuary and low-lying coastal zones at risk for erosion due to rising sea level worldwide. It would also be useful for basins affected by rising river levels, as in this case.

According to the results of the research, the delta regions are vulnerable ecosystems that cannot be reconstructed by people, because they are the result of a process of sediment accumulation that evolved over thousands of years.

Estuary environments have peculiar dynamics due to the interaction between hydrological processes (water and solid discharge), oceanographic processes (waves, oceanic and coastal currents), atmospheric processes (wind and extreme events, precipitation, pressure) and astronomical processes (tides), and sometimes anthropogenic processes (human actions), which have been determining factors in the evolution of the estuary zones of Marajo Island.

Those are the processes responsible for the mechanisms of erosion, and transport and distribution of sediments along the coast, causing a transformation in the coastline of Marajo Island, which may be seen in other estuary zones of the world.

The phenomenon of coastline retraction is frequently associated with a rise in sea level, which, in turn, is linked to global climate change.

Another aspect that must be taken into account is the increase in the frequency and intensity of storms and their impact on coastal infrastructure, mean-

ing that extreme climate events that affect estuary zones should be addressed and researched. In the northern region of Brazil, meteorologists have described severe storms and also recorded the effects of extratropical cyclones.

In addition to the specificities of estuary zones as ecosystems affected by climate change, coastal erosion in these areas constitutes a problem that has been observed in various parts of the world and is currently considered a global phenomenon. This study has provided numerous lessons because of all the types of variables analyzed.

From a legal point of view, it is also noteworthy that the Marajo Island estuary zone has been classified as an environmental protection area since 1989, under the Brazilian Constitution. It thus receives special treatment for the conservation of its biodiversity and ecosystem, aiming to facilitate sustainable development for its people.

Calculating the Island's Environmental Vulnerability Index

In this study, analysis was done of the consequences stemming from the rise in sea level (Atlantic Ocean) along with the rise in the levels of the Amazon and Pará Rivers in an estuary zone, which is due to diverse factors, including extreme climate events. This study can be compared with similar ones done in other parts of the world, particularly because coastal erosion, which is one of the consequences, is a global phenomenon and leads to the relocation of populations due to loss of land.

A statistical analysis was also done of the island's vulnerability. The environmental vulnerability index (EVI) was calculated at the different study areas. It was estimated that 14.6% of the territory is highly vulnerable, which leads to migration by the inhabitants.

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ACTO/UNEP/GEF Amazon Project Focal Points



Bolivia:

Ministry of Foreign Affairs, Deputy Minister, Ambassador Juan Carlos Alurralde.

Ministry of Foreign Affairs, Limits, Borders and International Transboundary Waters, Director General, Juan Carlos Seguroola Tapia.

Ministry of Foreign Affairs, Borders and International Transboundary Waters Unit, Director, Mayra Briseida Montero Castillo.

Ministry of the Environment and Water (MMAYA), Director General, Oscar Céspedes Montaña.



Brazil:

National Water Agency, Superintendence for Implementation of Programs and Projects-SIP, Superintendent, Ricardo Medeiros de Andrade.

National Water Agency, Superintendence for Implementation of Programs and Projects-SIP, Deputy Superintendent, Tiberio Magalhães Pinheiro.

National Water Agency, Superintendence for Implementation of Programs and Projects-SIP, Water Resources Specialist, Diana Leite Cavalcanti.

National Water Agency, Superintendence for Implementation of Programs and Projects-SIP, Groundwater Coordination Office -COSUB, Water Resources Specialist, Fabricio Bueno da Fonseca Cardoso.

Special recognition to Mr. Humberto Cardoso Gonçalves, co-manager of this regional initiative, current Superintendent at the Superintendence for Support and Implementation of the National Water Resources Management System -SAS/ SINGREH, National Water Agency.



Colombia:

Ministry of the Environment and Sustainable Development, Directorate of Integrated Water Resources Management, Technical Director, Luz Hicela Mosquera.

Ministry of the Environment and Sustainable Development, Directorate of Integrated Water Resources Management, Specialist Professional in Water Resources, Martha Cristina Barragán Acosta.

Ministry of the Environment and Sustainable Development, Office of International Affairs, Advisor for Borders and Subregional Bodies, Mauricio Molano Cruz.



Ecuador:

Secretariat of Water (SENAGUA), Social Sub-secretariat and for Coordination of Water Resources, Undersecretary, Mariana Yumbay Yallico.

Directorate of Territorial and Intersectoral Coordination, Mayra Jacqueline Garzón Ante.

Secretariat of Water of Ecuador, National Assistant, Maria Belén Benitez.



Guyana:

Ministry of Public Works and Department of Communication: Works Service Group, Senior Engineer, Jermaine Braithwaite.

Water Incorporated of Guyana, Division Manager (Operations - DIV2), Marlon Daniels.



Peru:

National Water Authority, Head, Eng. Abelardo De la Torre Villanueva.

National Water Authority, Secretary General, Atty. Yury Pinto Ortiz.

National Water Authority, Subdirector of the International Cooperation Unit, Deputy Director, Guillermo José Carlos Avanzini Pinto.

National Water Authority, Directorate of Water Resources Conservation and Planning, Responsible for the Transboundary Basins Management Area, Adolfo Polidoro Toledo Parreño.

National Water Authority, Directorate of Water Resources Conservation and Planning, Specialist in Water Resources Management, Directorate of Water Resources Conservation and Planning, Hanny Maria Quispe.



Suriname:

Ministry of Foreign Relations, ACTO Focal Point, Marlina Wellis.

Ministry of Natural Resources.



Venezuela:

People's Power Ministry of Foreign Relations, ACTO Desk, Office of Multilateral and Integration Affairs, Mariana Milagros Orta Osorio.

People's Power Ministry for Ecosocialism and Water, General Directorate of Basins, Director General of Basins, Adrián Alberto León Cedeno.

THE AMAZON'S WATERS, safe waters for future generations...

The Amazon Cooperation Treaty Organization, through the ACTO/UN Environment/GEF Project- Integrated and Sustainable Management of the Transboundary Water Resources of the Amazon River Basin Considering Climate Variability and Change, seeks to contribute to the integrated and sustainable management of the planet's largest basin by means of the creation and dissemination of new technical and scientific knowledge, based on the 10 studies presented in this volume, on specific topics such as geology, hydrology, hydrogeology, hydrogeochemistry, oceanography, anthropology and meteorology, among others, in order to achieve an Integrated and Sustainable Management of the largest basin on the planet.

This compilation is meant for the general public, which is increasingly interested in discovering new ways of thinking about rivers, university students and faculty, and officials at public and private entities who are looking for innovative solutions to address the critical problems that affect river basins, with the goal of ensuring that water resources remain healthy and sustainable for future generations.

The studies were done with participative social input, in consultation with the eight Amazon countries, gathering knowledge and practices, and incorporating these into the various methodologies, under the guidance of the project's team of specialized experts from different Latin American countries.

...Positioning TRANSBOUNDARY WATERS on the ACTO Regional Cooperation Agenda