Insights into Sustainable Management of Water and Wetlands in the Sierra Gorda Biosphere Reserve, Mexico

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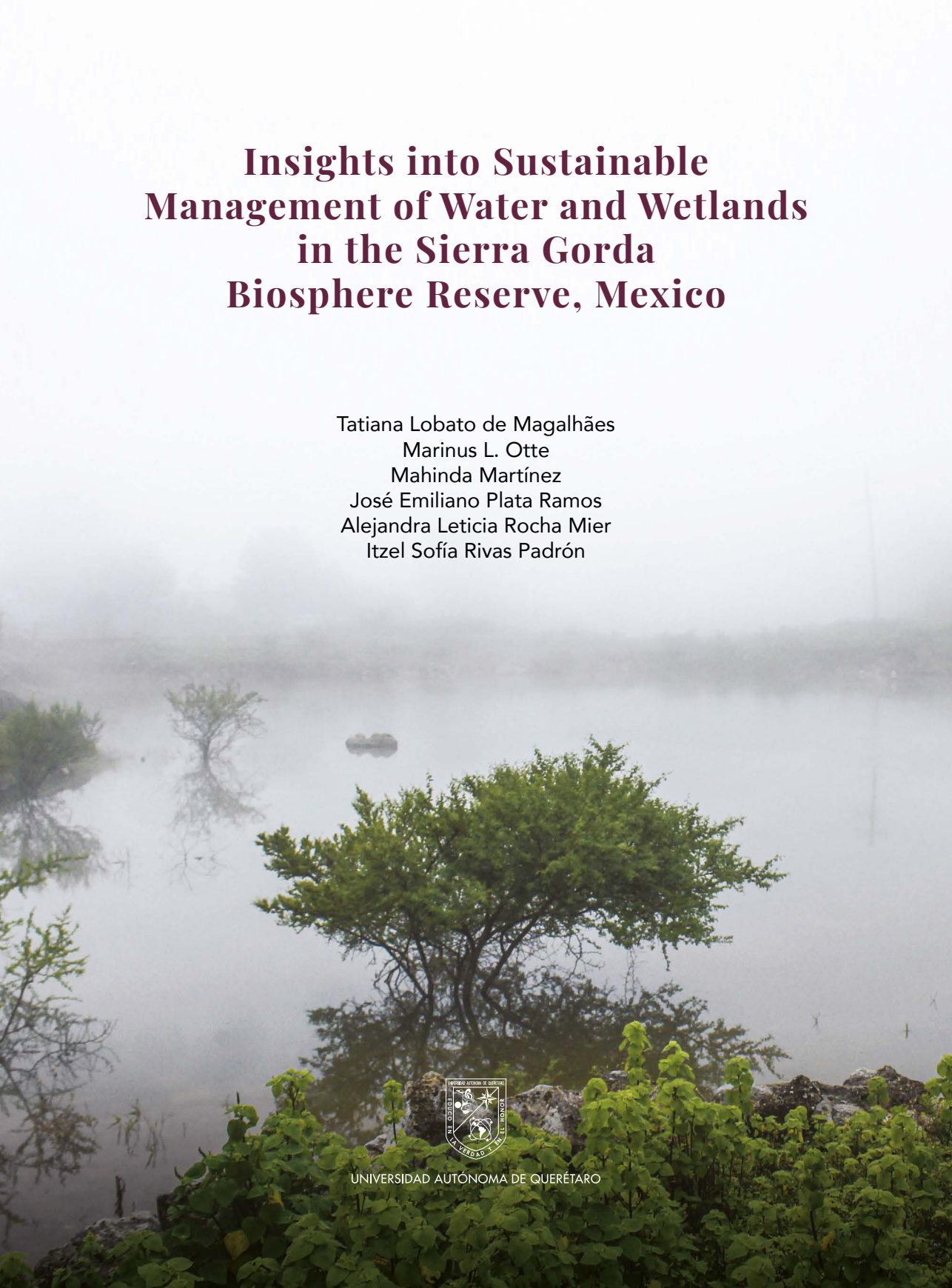

UNIVERSIDAD AUTÓNOMA DE QUERÉTARO


SIERRA GORDA
BIOSPHERE RESERVE
ARROYO
SECO
Santa María River
Conca
560 masl
El Tepozán
1761 masl
Guanajuato
Ayutla River
Jalpan River
Escanela River
PINAL DE
AMOLES
Rancho Nuevo II
2340 masl
Cuatro Palos
2616 masl
PEÑAMILLER
Querétaro
Image from a satellite © 2022 TerraMetrics.
Data of the map © 2022 INEGI.
By Paula A. Montoya Lopera
30 Km


an Luis Potosí
Carrizal de los Durán
810 masl
El Pocito
1145 masl
N
anta María River
JALPAN DE SERRA
Presa de Jalpan
Río Verdito
1188 masl
LANDA DE MATAMOROS
del Maíz
masl
Moctezuma River
Moctezuma River
Hidalgo
LEGEND
Municipality
Visited site
Biosphere Reserve
River

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The Jalpan Dam, Ramsar Site in the state of Querétaro, important for migratory birds and water supply

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A waterfall near El Tepozán,
Arroyo Seco

FOREWORD

The development of sustainable water security strategies to preserve freshwater ecosystem functions and services to reduce water-related risks to humans and conserve biodiversity and abundance of biota is urgent. Nevertheless, wetland losses and degradation rates are alarmingly high, particularly in inland wetlands that face prolonged drought. Through the Fulbright Specialist Project "Water management in a karstic rural impoverished environment, FSP-P006854" we worked in the Sierra Gorda Biosphere Reserve in the state of Querétaro with a multidisciplinary and multi-partner team in collaboration with representatives of the government, rural communities, civil societies and non-governmental organizations, as well as with students, professionals, and scientists from two academic institutions: North Dakota State University in Fargo, North Dakota, USA, and Universidad Autónoma de Querétaro in Querétaro, Mexico.

The project led to the creation of this book with a view to establish a "water dialogue" among people in the region. The findings of this book on management of water and wetlands in the Sierra Gorda Biosphere Reserve are now more important than ever as they demonstrate how conservation, sustainable management, creation, and restoration of wetlands are central to achieving a more prosperous and sustainable future for people and their natural environment.

This publication emphasizes how wetland systems can support sustainable water management and identifies potential practices for its implementation in the Sierra Gorda. It includes a comprehensive description of the methodologies we used in this project. Knowledge about how and where to restore and create wetlands is essential to enhance sustainable management of water and secure ecological services and functions, such as suitable habitat for wildlife, human well-being, and sustainable

socio-economic development. The methodology used in this project could be replicated in other regions with similar characteristics and water-related issues.

Finally, this book was not a once-off exercise, it is intended as the starting point for continued collaboration in wetland research, teaching, and outreach by scientists of Universidad Autónoma de Querétaro and North Dakota State University.

The Mission of Jalpan de Serra

Water from the Sierra Gorda

A view of "El Edén"
Ecotourism Project in Pinal de Amoles

INTRODUCTION

This book is the result of work carried out by a team of students, professionals, and professors from Universidad Autónoma de Querétaro (UAQ) and North Dakota State University (NDSU) as part of the Fulbright Specialist Program. In a period of eight days, we collected first-hand information on the water use and management in several communities in the Sierra Gorda Biosphere Reserve, with Jalpan de Serra as expedition-base.

Surface water and wetlands in this region are scarce and increasingly threatened by land-use transformation, urban and agricultural expansion, and invasive species. Groundwater extraction, pollution, and unsustainable agricultural practices such as flood irrigation are major concerns. Also, the intermittent availability of water and the porous substrates complicate the sustainable management of water. The problem is further exacerbated by the fact that the Sierra Gorda Biosphere Reserve is an economically marginal area from which habitants migrate to other regions inside or outside Mexico.

Since 2012, the Education and Communities Support Coordination of Universidad Autónoma de Querétaro (CEACOM-UAQ) has been working on three strategic lines of development: water scarcity, food sovereignty, and decent housing. Specifically, that department has been working on the installation of rainwater harvesting systems to store water in rural communities in the upper reaches of the Sierra Gorda. Universidad Autónoma de Querétaro already had a long-standing relationship with rural communities in the region, a huge advantage that enabled us to achieve good results within the short period of the field visits. In this project, we worked mostly in the communities of Carrizal de los Durán and El Pocito in Jalpan de Serra, Cuatro Palos and Rancho Nuevo II ("El Edén" Ecotourism Project) in Pinal de Amoles, and El Tepozán in

Arroyo Seco. These communities have about 109 functional rainwater harvesting systems as their principal water source, which were constructed with the intervention of CEACOM-UAQ in collaboration with Cáritas de Querétaro I.A.P., Peace Corps, and the engineer José Castro Orvañanos. In Cuatro Palos and El Tepozán the rainwater harvesting complements the water received by a pipe system implemented by the State Water Commission (CEA). However, these systems are interrupted very frequently due to management issues. In Carrizal de los Durán one of the main sources of water is from natural springs.

We further visited several communities in Landa de Matamoros that face severe wastewater treatment issues and had specific questions about water management, particularly in Río Verdito. We also visited a forest restoration project near Jalpan de Serra in a key location for water collection, led by Patricia Ruiz Corzo (director of the Sierra Gorda Ecological Group) and situated on a private property in Agua del Maíz, Pinal de Amoles.

A Mexican cypress (*Taxodium* spp.),
riparian vegetation at the Santa María River, Arroyo Seco

A waterfall near Pinal de Amoles

BACKGROUND

Sierra Gorda Biosphere Reserve

The Sierra Gorda Biosphere Reserve in Querétaro, Mexico, is situated in a predominantly semiarid environment with karstic geology at elevations from 350 to 3,160 meters a.s.l and precipitation ranging between 350 and 2,000 mm per year. This mountainous region is part of the Sierra Madre Oriental and slopes to the Gulf of Mexico, with a relief of sedimentary origin constituted by marine Mesozoic sequences and volcanosedimentary epimetamorphic deposits that support the marine formations in angular unconformity. It is located in the north of the state and is delimited to the west by the plains of Guanajuato, to the north and northeast by the Huasteca region of San Luis Potosí, to the east by the Sierra de Hidalgo and part of the Mezquital Valley, and finally, to the south by the Semi-desert of Querétaro. The Sierra Gorda Biosphere Reserve, established as a reserve on May 5, 1997, is a protected natural area that houses thousands of species of plants and animals, some of them protected and others in danger of extinction. It is currently administered by the National Commission of Natural Protected Areas (CONANP). The Sierra Gorda Biosphere Reserve has 383,567 hectares, 70% private properties, 27% communal areas ("ejidos"), and 3% federal areas, representing 32% of the state of Querétaro, with at least 100,000 inhabitants, 638 communities, and five municipalities (*i.e.*, Arroyo Seco, Jalpan de Serra, Landa de Matamoros, Peñamiller, and Pinal de Amoles). The main town in the area is Jalpan de Serra (21°13'05.2" N, 99°28'26.6" W, 760 meters a.s.l.).

This region harbors many types of vegetation such as high elevation pine-oak forests, lowland tropical forests, moist montane forests, and is home to a great diversity of cacti. Gallery forests with rivers and streams are sheltered by junipers, willows, and poplars. Cloud forests are perched at higher elevations, like islands in almost perpetual fog.

The upper reaches of the mountains are covered with temperate forests of oaks, firs, pines, cedars, and junipers. The Sierra Gorda Biosphere Reserve is a very species-rich region, home to butterflies (800 species), birds (342), reptiles and amphibians (131), fungi (127), mammals (110), fish (27) and a key population of *Ara militaris*, the military macaw, in Mexico. Hydrologically, the reserve belongs to the Pánuco River region and is part of two main basins: the Moctezuma and the Tamuín. The main rivers of the Sierra Gorda Biosphere Reserve are the Extoraz, the Escanela-Jalpan, and the Santa María. In addition to the environmental diversity, there are also five Franciscan Missions declared a World Heritage Site by UNESCO in 2003.

Communities

We gave workshops in five different communities: Carrizal de los Durán and El Pocito in Jalpan de Serra, Cuatro Palos and Rancho Nuevo II ("El Edén" Ecotourism Project) in Pinal de Amoles, and El Tepozán in Arroyo Seco, all located in the state of Querétaro. The information regarding the communities and municipalities is presented in Table 1.

In the case of Concá, in Arroyo Seco, the activities were conferences aimed at the student population, faculty and representatives of the government. In Jalpan de Serra and Landa de Matamoros, we visited with government representatives wastewater treatment systems and some critical points of rivers and streams contamination.

Arroyo Seco. Concá is a town about 20 km from Arroyo Seco municipality at 508 meters a.s.l., the municipal seat. In Concá, 26 people speak an indigenous language (Pame and Teenek). Also located within this municipality is the community of El Tepozán at 1,820 meters a.s.l. Of the 103 adults in El Tepozán, 24 are older than 60.

Jalpan de Serra. This municipality is located in the north of the state of Querétaro. To the north, it borders with the state of San Luis Potosí,

to the south with the municipalities of Pinal de Amoles, San Joaquín, and with part of the state of Hidalgo. To the east it borders with Landa de Matamoros, which is the municipality with the second-most significant territorial extension within Querétaro. In Jalpan de Serra we worked with two communities: Carrizal de los Durán and El Pocito.

Pinal de Amoles. The community of Cuatro Palos belongs to the municipality of Pinal de Amoles and is located at one of the highest points of the Sierra Gorda Biosphere Reserve. There is a scenic lookout near the summit of the Cerro de la Media Luna at 2,727 meters a.s.l., with a sweeping view of the region's incredible landscapes in every direction. It attracts many tourists, which is the main economic activity for Cuatro Palos. A little down the road from Cuatro Palos is "El Edén", an ecotourism project located in the community of Rancho Nuevo II.

The Jalpan Dam, Ramsar Site, in Jalpan de Serra

Table 1. Statistics on populations and housing of communities and municipalities involved in the project

Community	Total private homes	With dirt floors	With sanitary facilities	Connected to public water supply service	Total population	Adults	Minors	Men	Women
Carrizal de los Durán	21	—	11	0	89	40	49	43	46
Cuatro Palos	32	31	11	3	142	67	75	70	72
El Pocito	29	—	—	—	113	65	48	63	50
Rancho Nuevo II El Edén	15	—	—	—	—	87	—	46	41
El Tepozán	43	34	11	—	201	103	98	101	100
Municipality/Locality	**Total private homes**	**With dirt floors**	**With sanitary facilities**	**Connected to public water supply service**	**Total population**	**Adults**	**Minors**	**Men**	**Women**
Concá, Arroyo Seco	275	—	248	262	1076	631	445	511	565
Jalpan de Serra	—	—	—	—	22,025	—	—	10,489	11,536
Landa de Matamoros	4,332	982	3,537	2,295	18,905	—	—	8,927	9,978

Water infrastructure in the communities

Cuatro Palos and El Tepozán have infrastructure for water supply provided by the State Water Commission (CEA). However, the systems suffer from frequent problems, such as pumps breaking down or burning out, and scarcity of water during droughts is a challenge in both communities. Some decades ago, before the installation of the rain harvesting systems, the people lacked additional provision of water, not even during the rainy season, because they did not have ways to capture and store it. Carrizal de los Durán and El Pocito are two neighboring communities that do not receive the drinking water service of the CEA, but they get their water from springs. There is one in Carrizal de los Durán with water during the whole year, and there is very small one in El Pocito. Therefore, before the installation of the rainwater harvesting systems, the residents of El Pocito had to carry water throughout the year, even during the rainy season, from a nearby spring or well, on foot or with the help of a pack animal. Another means of obtaining water in El Pocito is to bring it in by trucks with a capacity of 1,500 liters. The inhabitants of Carrizal de los Durán installed systems for the distribution of water from a spring. Houses at lower elevation receive water through gravity, but those at higher elevations use alternative strategies to get it from the springs like using pumps or carrying it by hand. In conclusion, these five communities can be characterized as follows:

- All except Cuatro Palos have a pyramid of ages that reflects a decrease in infants and young people, compared to adults. Therefore, the populations are in decline.
- One of the factors benefiting Cuatro Palos is its scenic location and a lookout point that attracts visitors, which in turn bring economic benefits. The development of ecotourism in and around the community will further stimulate sustainable economic stability if managed well.
- Challenging sanitary conditions, such as lack of sewage treatment and clean water supply.
- Use of rainwater harvesting systems: four in Carrizal de los Durán, 29 in Cuatro Palos, 35 in El Pocito, and 41 in El Tepozán.

Why wetlands?

Wetlands are all around us. They are the springs, ponds, lakes, marshes, bogs, and the floodplains along rivers that are home to lush vegetation and many animals. Birds and mammals feed on the plants, the fish in the water, or on the myriad of insects. Wetlands may be mostly grassy or home to majestic trees like the Mexican swamp cypress. They all have in common that they are wet, with usually shallow standing or flowing water. They may be dry for large periods of time, but the plants and animals that are typical of wetlands depend on the water being there during certain periods for their reproduction.

Wetlands are the most important part of the water cycle because they clean the water. They are the Earth's kidneys. Pollutants that are picked up by streams pass through wetlands and are degraded by the bacteria and fungi or may get stuck in the soil, where they may be taken up by plants and put to good use. Wetlands are so good at removing pollutants from water that they are being constructed for that purpose around the world. They are cheaper to build and maintain, and better at removing a wide range of pollutants than mechanical or chemical methods.

In addition to functioning as a home for plants and animals as well as cleaning our water, wetlands provide several other benefits to humans: ecosystem services. They store water during periods of high precipitation and release it during periods of drought. That means wetlands prevent flooding and the destruction of homes and roads, but also make it possible to grow food when the rains do not arrive on time. Wetlands also supply food for people, in the form of fish, birds, frogs, and edible plants like water spinach and rice. They provide building materials, such as wood for construction and reeds for thatching roofs. Around the world, particularly along the coasts, the shores of large lakes, and along large rivers, communities that depend entirely on wetlands for their food, water, and livelihood can be found.

An old church shrouded in fog
in Cuatro Palos, Pinal de Amoles

Yet, there is a global destruction of wetlands. It is estimated that we have lost 80% of all wetlands over the past three centuries, mostly to agriculture and development of cities. This is in part because many wetlands occur along rivers, which is where humans build their communities, but also because their value has not been adequately recognized. As we begin to understand more about how important wetlands are for us, we have started serious efforts to restore those that are damaged and even construct new ones. We must take care of wetlands before they disappear, in order to make our world healthy. Also, we have to educate youth and new generations to actively protect our wetlands for the future.

The Escanela River in Pinal de Amoles

A view from Cuatro Palos, Pinal de Amoles

Doctor Marinus L. Otte
in Agua del Maíz, Pinal de Amoles

PROJECT APPROACH

Enabling capacity-building in water and wetland science and management was a crucial objective of our project, aligning with the Fulbright Program mission, and key for safeguarding water of good quality in a sustainable manner. Last September, 2021, doctor Marinus L. Otte (North Dakota State University, Fulbright Specialist) visited Universidad Autónoma de Querétaro in a four-week consultation about water and wetlands as part of the Fulbright Specialist Project (FSP-P006854) "*Capacitación en gestión del agua y humedales en diferentes sectores sociales: comunidades rurales, gobierno y academia*/Water management in a karstic rural impoverished environment", coordinated by doctor Tatiana Lobato de Magalhães (Universidad Autónoma de Querétaro). This project focused on sustainable water and wetland management and conservation in the state of Querétaro through a three-pronged approach combining 1) aquatic science education, 2) wetland awareness, and 3) engagement of local stakeholders. The Fulbright Specialist's visit was also key to improve the Universidad Autónoma de Querétaro's ongoing efforts in the region relating to water availability and quality.

We organized one-day courses for five communities within the Sierra Gorda Biosphere Reserve in Querétaro, Mexico. As part of these activities, local people and the project team exchanged experiences relating to water and wetlands, focusing on the specific needs of each locality (for example, water pollution and the potential use of constructed wetlands for water treatment, spring management and protection, habitat for wildlife, and education). All courses were open to undergraduate students from various rural campuses of Universidad Autónoma de Querétaro located in the reserve (Concá, Jalpan de Serra, and Pinal de Amoles). Running a wetland education, society engagement, and awareness

The expedition members

project during the pandemic was a challenge in terms of logistics and planning. We held many short-term workshops across the Sierra Gorda Biosphere Reserve, and all activities were in outdoor locations instead of large-scale indoor gatherings, as a health safety measure. Only a few participants were invited for all activities, to ensure groups remained small, while keeping social-distancing and wearing masks. Challenging though this may have been, on the other hand this meant we were able to interact more directly with individuals, which we felt made the experience more productive for all.

Language can be a challenge in international outreach projects, particularly when they involve local people. In this context, we planned courses molded in small parts with continuous translations for answers and questions, introductions, and technical comments. All of our didactic materials were presented in both Spanish and English. This promotes further opportunities to improve bilingual capabilities not only for stakeholders and direct participants, but also for children who will benefit from the bilingual materials we offered to the local schools. Finally, we are publishing this book you are reading in both Spanish and English (digital version).

Eight-day expedition

We carried out an eight-day expedition across the Sierra Gorda Biosphere Reserve (September 18-25, 2021), during which we interacted with at least 300 participants (community, university, civil society, and government). We provided workshops on water and wetlands to five rural communities, visited several natural and artificial wetlands, water reserves, treatment systems, and water collection systems, organized two meetings with local representatives from government, university and civil society, visited two rural campuses of Universidad Autónoma de Querétaro, collected material for diagnostics (surveys), took at least 4,000 photographs, and filmed more than 14 hours of audiovisual material for a documentary, including 38 recorded interviews. In addition, one

A workshop on wetlands
in the middle of the forest in Pinal de Amoles

The expedition members
at the Santa María River, Arroyo Seco

A workshop on wetland construction in slope regions

Doctor Marinus L. Otte during a workshop

undergraduate and two graduate students of Anthropology, Watershed Management, and Biological Sciences programs supported the activities during the expedition, which in turn provided them with opportunities to connect directly with the Fulbright Specialist and Universidad Autónoma de Querétaro faculty members and learn from their experience and expertise. Based on the film recordings, five short videos and a one-hour documentary were produced. The Spanish version of the documentary was premiered in Querétaro on 4 February, 2022. Finally, we promoted an exhibition about the project outcomes in the Ximhai Sciences Museum of Universidad Autónoma de Querétaro, released in August 2022. All project material is available on the website: https://uaqfulbrightspecialist.weebly.com

Short talks, pamphlets, and drawings

The project team promoted the following lectures based on doctor Marinus L. Otte's experience with projects in the Americas, Asia, and Europe, and as editor-in-chief of the scientific journal *Wetlands*.

1) "Sustainable solutions for environmental problems with water-loving plants." For the Botanical Society of Mexico audience (more than 2K views) as part of the monthly webinar program of said society on 25 August, 2021 (https://www.socbot.mx/plantaacutestico-webinar.html).
2) "Wetlands as solutions for environmental problems." For faculty and students of the graduate programs in Biological Sciences and Watershed Management of the Natural Sciences Faculty at Universidad Autónoma de Querétaro (118 participants), on 7 September, 2021.
3) "Students vs Editors — or how to get your paper published." For graduate students of the Natural Sciences Faculty, including the masters program of Watershed Management and Biological Sciences, at Universidad Autónoma de Querétaro (30 participants), on 14 September, 2021.
4) "Wetlands." for undergraduate students of the rural campus of Universidad Autónoma de Querétaro in Concá, Arroyo Seco (30 participants), on 21 September, 2021.

A woman from Cuatro Palos, Pinal de Amoles, with a wetland pamphlet

A woman from El Pocito, Jalpan de Serra, showing her water and wetlands drawing

Due to a lack of infrastructure (for example, electricity, or suitable sites) and the need to be in outside areas due to the COVID-19 pandemic, we created nine bilingual pamphlets in both Spanish and English with several topics on wetlands, as follows:

- What is a wetland?
- Why are wetlands important?
- What do wetland plants look like?
- Wetlands and mosquitoes.
- Threats to wetlands.
- Constructed wetlands.
- How to construct wetlands.
- Holistic management of springs.
- Wetlands for water management in small dwellings.

We shared the pamphlets with the participants during the interactive presentations and donated all pamphlet sets to the communities along with other didactic material (boards and pencils). Finally, we invited participants to make drawings or written messages about the importance of water and wetlands. A total of 29 of them were shared by participants with the common theme that water is life, important for human beings and nature. The workshops enabled participants to express their opinions regarding water, particularly it helped those who were perhaps too shy to speak up during the presentations or could not read or write.

A summary of messages by the participants

- Water is the heart of our planet Earth because it is vital for humanity, vegetation and animals. Without water, there is no life.
- Water is life. For me, it is the most important natural resource because if the water runs out there will no longer be plants or animals or living beings like humans. That is why I believe that if we take care of it and treat it, we can live in a better world. For me, not having water is like not being able to breathe.

- Planet Earth must change its name to Planet Water.
- Water is the life of all living beings. Plants, animals, and humans. For me it is very important to take care of it and think of new generations.
- Water is important to me because both people and animals depend on it. It is also important to know how to take care of it because we are already running out of water on our planet and our future generations will be affected. Take care of water for you and me because water is life.
- The government and other entities should invest in making people aware, as well as support the construction of reservoirs to store rainwater, the development of reforestation projects, and soil conservation programs that prevent soil erosion.

Group activities

We organized two workshops about water and wetland management for government representatives in order to engage stakeholders in the development of water security practices and strategies. The project team shared the experiences and challenges of the Sierra Gorda Biosphere Reserve communities and lessons learned worldwide to inspire decision-makers to include practices that involve artificial wetlands and protect the remaining natural ones in future projects in this region. The first workshop was in the reserve (Campus Jalpan, Universidad Autónoma de Querétaro), and the second in the city of Querétaro (Campus Cerro de Las Campanas, Universidad Autónoma de Querétaro with livestream transmission by Facebook). The workshops consisted of three sections: introductory lecture about wetlands, experiences from the Sierra Gorda, and conclusions. They included several activities to promote exchange of ideas among the participants, for example, creating a water security cognitive map and listing pros and cons of using wetlands to solve environmental issues. Finally, the participants were asked to form pairs to discuss wetland and water opportunities which the institutions they represent could potentially collaborate on in the short, medium, and long term. Many excellent opportunities were identified, particularly regarding education and awareness. We achieved some outstanding results from

the contact with the diverse groups. The most notable one was the identification of the need for an "umbrella association" with stakeholders in water and wetland management in the region. In addition, Guadalupe Sánchez Weimann, director of the Natural Protected Areas National Commission (CONANP), agreed to convene an association of stakeholders in water and wetland management in the region, and to organize a conference in the fall of 2022.

Another disclosure mechanism used in the project was the interview conducted by TV UAQ on September 9, 2021. As a result, a working meeting was held with the State Water Commision team.

Visits to communities, lakes, springs, and treatment systems

The Fulbright Specialist, scientists from Universidad Autónoma de Querétaro, and local representatives visited some of the natural and artificial wetlands in the region to evaluate their condition, as well as to identify species of interest to use in restoration and in artificial wetlands. We also visited wastewater treatment systems and contaminated streams, and engaged local people in activities to learn basic concepts of water management and quality, recognition of aquatic plant species, types and ecology of wetlands, and their role in water security and biodiversity maintenance.

Storytelling

While working with the Sierra Gorda Biosphere Reserve communities, we recorded around 14 hours of audiovisual material on the landscape and life in the Sierra Gorda Biosphere Reserve, and 38 interviews with local people in storytelling style. They shared their stories about water and wetlands in this fragile region and recount changes in water management between their childhood and present, for example, with stories about

disappeared springs. They also talked about new methodologies to get water resources, polluted rivers, and key messages to safeguard water for the future. In collaboration with Universidad Autónoma de Querétaro General Coordination of Social Communication team, five short videos (~10 minutes) were created about the following topics: project introduction, water issues, solutions for sustainable water management, water in the past, and safeguarding water for tomorrow. We also produced a one-hour long documentary titled *Water Talks-Perspectives from Sierra Gorda* (Spanish title: *Percepciones sobre el agua*).

Documentary and short films

- Documentary premiere: https://fb.watch/a_6w-TRmSE/
- *Safeguard water*: https://www.youtube.com/watch?v=m0Vg9lctfiQ
- *Water issues in the Sierra Gorda*: https://www.youtube.com/watch?v=Fig-WRAm3E3U
- *Ways to safeguard water*: https://www.youtube.com/watch?v=2tPxeLQ3ijs
- *Water in the past*: https://www.youtube.com/watch?v=seh8DOgTUkc
- *Safeguard water for tomorrow*: https://www.youtube.com/watch?v=Jdv-7E27EDLs

Surveys

During the Universidad Autónoma de Querétaro and Fulbright Specialist 2021 expedition to the Sierra Gorda, 30 surveys were carried out in the communities by students belonging to the Natural Sciences Faculty. These surveys were answered by 16 men and 14 women, and covered the topics about how to get water, water treatment methods, and challenges in relation to the access to clean water. Most of the interviewees now have a system to collect rainwater at home, but face problems with water distribution and supply. Overall, they enjoyed the courses we provided as part of the project and are interested in learning more

about water and wetland management, including topics such as water quality, wetland biodiversity, spring conservation, and use of aquatic plants. People from the rural communities were very concerned about the forests, biodiversity, and sustainable management of water.

Major issues concerning water identified by the communities

- Hoarding of water.
- Contamination of water bodies.
- Irresponsible water use.
- Need for more cisterns to store rainwater.
- Omissions in the administrative sectors concerning water.
- Effects of climate change, drought and scarcity of rainwater.
- Environmental degradation.
- Economic impacts.
- Lack of water culture.

Hurdles

Perhaps our most important role during the visits was to promote more awareness about sustainable water management and wetland conservation and protection. As in most regions, such efforts are complicated because the majority of wetlands in the region were destroyed or severally altered in the past. Most local participants did not know what the term "wetland" means, nor did they have any memory of what used to be there — the problem of "shifting baselines". Most of the people we encountered in Jalpan, the largest city in the Sierra Gorda and its economic center, did not know that the reservoir near the town, the Jalpan Dam, is also a Ramsar Site (watersheds of international importance and protected for its biological diversity). It is an important stop-over and resting place for migratory birds.

We observed lack of knowledge about the importance of wetlands not only in the rural communities, but also among students of urban areas. That also means there are many opportunities to raise wetland awareness and initiate a dialogue about water and wetland conservation.

A reforestation project, important area for water collection in the watershed, in Agua del Maíz, Pinal de Amoles

The Fulbright Specialist talking with the director of Grupo Ecológico Sierra Gorda I.A.P. during a meeting in a forest restauration project, essential for the enforcement of the water sources in the region

A forest in Agua del Maíz, Pinal de Amoles

A spring in Carrizal de los Durán, Jalpan de Serra

THREATS TO WATER AND WETLANDS

Climate and global change

When we talk about threats to the quantity and quality of water and wetlands in the Sierra Gorda Biosphere Reserve, or anywhere else in the world, we are not referring to natural variation, but to detrimental changes as a result of human activities.

Climate change is arguably the biggest threat to water and wetlands because it encompasses the entire world, across national borders and natural boundaries. Climate change is a variation in global or regional climate patterns, particularly apparent from the mid to late 20th century onwards and attributed mainly to the increased levels of atmospheric carbon dioxide produced by fossil fuels. Climate change is part of global change, which refers to all the transformations occurring to our entire planet, not just to our climate. Although carbon dioxide from fossil fuels is seen to be the main reason for changes in our climate, changes in land use coincide and contribute as well. Humans have modified the world, for example by their agricultural activities, by building cities and roads, hunting animals, and harvesting plants from land and water. Changes to our planet due to the activities of humans are so profound that we now refer to the time we live in today as the Anthropocene. Changes in land use in turn affect the amounts of carbon dioxide that are taken up by plants through photosynthesis, but also how much carbon dioxide and water is released by all organisms through respiration. The effects of global and climate change mean that most of Mexico, including the Sierra Gorda Biosphere Reserve, is forecast to receive less precipitation in the future.

How do climate and global change affect the Sierra Gorda water and wetlands?

Increasing temperatures and droughts. Much of Mexico is expected to see decreases in precipitation, less cloud cover, and higher temperatures. This will mean decreases in water availability and its levels in rivers and lakes, and more frequent and prolonged droughts. Wetlands will shrink or disappear altogether, and intermittent streams will be drier for longer periods. All organisms that depend on water, including humans, will be strongly affected by these changes. Not only will the amount of water on the landscape diminish, but so will water quality. Many water bodies suffer from high levels of plant nutrients, particularly closed-basin ponds and lakes. As those water bodies evaporate, the pollutants stay behind, and their concentrations increase. Water from such ponds and lakes will become unusable for consumption for longer periods than is already the case, and possibly permanently.

Existence, abundance, and distribution of animal and plant species. All life needs water, but some species are more resilient to changes in water availability and quality than others. If the forecast is correct and the Sierra Gorda Biosphere Reserve will receive less precipitation, then this will particularly affect animals and plants that depend on water for their reproduction and food, in other words, animals and plants that live in rivers, streams, lakes, ponds, and wetlands. Fish, frogs, and salamanders will become less common, or go extinct entirely, and therefore so will the animals that feed on them. Wetland plants may have to endure longer drought periods, and this will impact plants that need water throughout the year, such as waterlilies. In Central Mexico, water bodies will disappear, while species of dry scrub and semi-desert will expand southwards. How severe these changes will be is very difficult to predict, but it is certain that they will happen. Because of human activities Earth is changing much faster than at any time in the history of the planet.

Increases in social conflicts over water. Wherever water availability dwindles, conflict arises. This may be on a small scale, for example between

neighboring properties, or over long distances. An example of the latter is described by Marc Reisner in his book *Cadillac Desert: The American West and Its Disappearing Water* from 1986. It is about how the cities in the western USA, such as Los Angeles, Las Vegas, and Denver, obtain water from very far away, even outside their states. These cases indicate that the water that is available in the Sierra Gorda Biosphere Reserve, particularly the springs, cannot be regarded as safe from exploitation by cities that are far away. With the current technologies, it would be no problem for a city like Querétaro to source its water from the Sierra Gorda 185 km away — the city of Los Angeles in California gets its water from, among other places, the Colorado River Aqueduct, 400 km away. It can therefore not be ruled out that entities from outside the Sierra Gorda will look for access to its water, which could cause major upheaval in the region.

Water requirements and pollution

As more people live in an area, the demand for water will be higher, as well as the levels of pollution. In parts of the Sierra Gorda Biosphere Reserve, populations are declining due to the lack of economic opportunities. However, towns in the Sierra Gorda, such as Jalpan de Serra and Landa de Matamoros, have seen a quite significant increase in population. As a result, there were changes in the demand for water and pollution levels got worse. That is nothing special, as it occurs anywhere in the world. However, the demand for water and the potential for pollution are unevenly distributed across the Sierra Gorda. The need for clean water in the cities means that water has to be transported from remote sources, while polluted water in urban settings requires good wastewater treatment before it is discharged back into the rivers. Water pollution is also not restricted to the urban centers. Different types of pollution occur depending on the location. In the cities, run-off from hard surfaces, such as roofs, roads and industrial complexes, and wastewater from households and businesses lead to water pollution with a complex mix of soaps, oils, and many other inorganic and organic substances. In rural areas,

households contribute to pollution as well as agricultural activities, such as nutrient run-off from crop fields, and wastes from cattle operations such as feed lots.

Wetland degradation and destruction

One of the most important characteristics of wetlands is that they are full of water. However, they are not as wet as deep lakes and seas; in other words, they are shallow, transitional between permanently dry and wet, across space or time. Walking from dry land around a wetland to the waterline, the ground becomes wetter. It is therefore no wonder that agriculture in arid regions is often in or very close to wetlands — it is traditionally the only place where crops can be reliably grown. This is why, as mentioned previously, more than 80% of wetlands have been destroyed. In addition, up until some decades ago wetlands have been regarded as bad places, best to be converted to something useful, like crop production.

We now realize that wetlands that are intact provide many ecosystem services that in total are more valuable than crop production. For example, they buffer changes in water availability, storing water when there is too much and recharging the supplies when there is too little. It is therefore better to grow crops near wetlands instead of in them. Still, when crops are grown near wetlands they are under threat of damage and pollution, due to increased erosion and the use of fertilizers and pesticides, which leach into the wetlands. Even when wetlands, lakes, and rivers are not surrounded by agriculture, another threat is deforestation.

Deforestation and its effects on water and wetlands

The forests on the slopes of the Sierra Gorda Biosphere Reserve, as in any mountain range, act like sponges, storing water when the rains

come and releasing it during the dry season. They provide the main storage for water in watersheds that feed into streams, rivers, and lakes downslope.

Around the world, forests have been cut down for the purpose of creating crop fields and grazing meadows, often with disastrous consequences. In many instances, deforestation has led to erosion and loss of soils, and downslope lakes and rivers have been filled in by massive amounts of sediments. Particularly in arid regions, erosion due to deforestation has caused irreparable damage. It is therefore essential that existing forests in the Sierra Gorda are protected and that reforestation is promoted, specially in areas that were previously covered by forests but now experience erosion.

Invasive species

By all measures the most harmful species on Earth is the human, *Homo sapiens*. We have been instrumental in the dispersal of invasive species. Detrimental species may do harm directly, for example, weeds that reduce crop production, or indirectly by impacting negatively on the ecosystems that provide beneficial services to us. They may outcompete species that are more desirable to us or create physical problems, such as obstructions to navigation in waterways.

Invasive species occur in all biological groups. They are generally exotic species that have the ability to displace the native ones. It is never easy to spot alien species and it is even harder to determine when they arrived or how. Often it takes decades to detect them, and by then the invasion is already very problematic. Among such species, the water hyacinth (*Eichhornia crassipes*) has invaded water bodies in tropical and subtropical regions around the world. In the Jalpan de Serra reservoir it causes periodic infestations. The plant is only capable of establishing itself in nutrient-rich waters, so its presence indicates eutrophication. Although it is an excellent plant for improving water quality, particularly if the plants

are harvested to optimize removal of nutrients from the water, it causes serious obstructions and changes in the biotic composition.

Exotic fishes are also found in the state of Querétaro although their presence in the Sierra Gorda Biosphere Reserve has not been confirmed. Among the species occurring in the wider region are *Carassius auratus* (golden carp), *Ctenopharyngodon idella* (grass carp), *Cyprinus carpio communis* (common carp), *Ictalurus punctatus* (channel catfish), *Oncorhynchus mykiss* (rainbow trout), *Lepomis macrochirus* (blue mojarra), *Micropterus salmoides* (largemouth bass), *Oreochromis aureus* (blue tilapia), *Oreochromis mossambicus* (Mozambique tilapia), and *Poeciliopsis gracilis* (guatopote jarocho).

An overflowing geomembrane where it used to be a natural wetland

Crystalline water from the spring
in Concá, Arroyo Seco

OPPORTUNITIES

We identified several opportunities in the Sierra Gorda Biosphere Reserve for water and wetland sustainable management, including watershed management, springs conservation, and restoration of natural and artificial ponds (locally known as "bordos"). Urban towns across this region would benefit greatly from the incorporation of wetlands in wastewater treatment systems (tertiary treatment) in existing and future projects. People in the region are well aware of the importance of natural springs conservation, but knowledge about how to protect and conserve them is lacking. In addition, changes in land use, such as deforestation and road construction, erode the soil, pollute the water, and compromise essential water resources, and they seem hard to avoid.

Watershed management

Watershed management planning identifies activities that affect the health of the watershed. All activities that occur within a watershed will affect natural resources and water quality and supply. Proper watershed management recommendations contribute to reduce and solve negative impacts. This process results in a partnership among all affected parties in the watershed. The key steps of a watershed management plan are as follows:

Step 1
Identify the characteristics of the watershed and inventory its natural resources

- Delineate and map the watershed's boundaries and the smaller drainage basins within the watershed.

The Fulbright Specialist talking about spring conservation with people from Carrizal de los Durán, Jalpan de Serra

- Inventory and map characteristics of the watershed, such as natural and manmade drainage, land use and cover, soil types, erosion areas, water quality, pollution sources, industrial discharges, municipal stormwater systems, failing septic systems, illicit discharges and so forth.
- Collect additional information specific to the watershed, such as obstructions that are not officially mapped, rare o threatened plant species.
- Volunteers to make observations during stream walks.
- Establish a baseline of the overall nature and quality of the watershed.

Step 2
Build local partnerships

- Identify partners, people with an interest in the watershed ("stakeholders"), including residents, landowners, federal, state, and municipal government officials, environmental and civic groups, local business and industry leaders, agricultural users, teachers, and so forth, and include them in an association or partnership for the development of projects.
- Promote awareness regarding the importance of sustainable water management. Once individuals become aware of and interested in their watershed, they often become more involved in decision-making and hands-on protection and restoration efforts.

Step 3
Determine priorities for action

- Establish clear goals, visions, and actions to be taken.
- Determine what the opportunities are to address pressing environmental issues.
- Establish frequent maintenance of municipal stormwater systems, improving or replacing those that are inadequate, and disconnect stormwater systems of sewage systems.
- Identify and eliminate undesirable and unintended connections to municipal stormwater systems.

- Increase inspections and maintenance of existing septic systems and encourage repairs to failing systems.
- Promote septic tank use.
- Encourage vegetated buffers adjacent to waterbodies and wetlands.
- Identify available areas for open space acquisition, greenways planning, and the establishment of vegetated buffers along waterbodies and wetland areas.
- Identify the priorities of restoration of the natural resources and the habitat of the wildlife.
- Identify and evaluate opportunities for non-structural flood protection efforts.
- Improve waste management, pollution prevention, and recycling efforts.
- Build green houses to propagate native aquatic plants.

Step 4
Conduct educational programs

- Promote the formation of citizen review groups and advisory committees.
- Organize outreach projects, such as small workshops for local communities.
- Create citizen committees to monitor the watershed.

Aquatic plants in the spring
of Concá, Arroyo Seco

A spring in Río Verdito,
Landa de Matamoros

Springs conservation

The Sierra Gorda Biosphere Reserve is rich in natural springs, many of which supply water during the entire year, and many people and their livestock depend on these springs for their daily water supply. Climate change is predicted to lead to higher temperatures and less precipitation for much of Mexico. This means that some springs may become intermittent water supplies or dry up completely, while the demands for clean fresh water will increase.

Moreover, the condition of most springs in the region, at least those that can be easily reached, is not good. Many springs serve multiple purposes, such as drinking water for people and animals (Figs. 1, 2 and 3), washing laundry (Fig. 4), and recreation (Fig. 5). Traditionally, these are all normal uses for springs, as is the wastewater discharge to streams (see below on the subject of water pollution). However, although the human population of many communities in the immediate region has been declining, the population of the wider region has been increasing, and mobility of people has dramatically increased over the decades. Increasingly, people visit on day trips, while others may have weekend homes in the area. Urban centers have steadily grown in size. For example, the population of Jalpan de Serra increased from 7,848 in 1975 to 30,457 in 2015. The need of clean freshwater will increase pressure to exploit springs in the mountains. There is therefore an urgent need to develop appropriate management and protection plans for the springs in the Sierra Gorda Biosphere Reserve.

Figure 1. A spring near Concá, Arroyo Seco. This spring is surrounded by a fence and the vegetation around it is regularly cut. It provides drinking water for animals and people

Figure 2. A water trough for livestock sits idle next to the stream that is fed by the spring. Photograph by Cristian Eduardo Rodríguez Jacinto

Figure 3. Water from the spring is retained by a small dam. This makes it possible for the local community to harvest the water for household use, transported to homes by the black tube at the top of the image. Excess water spills over through a larger pipe during periods of high flow, for example, during the wet season which extended into the expedition in September 2021

Figure 4. Washing laundry in water that arises from a spring near the campus of Universidad Autonóma de Querétaro in Concá, Arroyo Seco. Photograph by Marinus L. Otte

Figure 5. A child playing by the water of a spring

There are a number of issues that can be addressed and that should have high priority, in no particular order

Livestock and springs. During the wet season, livestock roam the mountains around the communities as food and water is plentiful during that period. However, during the dry season water sources become scarce, and one place the animals congregate is immediately downstream from springs (Fig. 1). Had there been no fence around the spring, the animals would walk right into it. As is clear from Fig. 2, troughs would have been used for watering animals in the past. This is no longer the case there, perhaps because the animal number per family increased over the years. However, this means that the animals now walk directly into the stream, within a few meters from the source, and not only drink there but also urinate and defecate. Local people told us that this is also the time when children like to play in and near the water, but the pollution is so bad that that is no longer possible. An easy solution is to prevent animals, particularly large livestock, from being in the water. In the case of the spring at Carrizal de los Durán, livestock could easily be barred from the first 200 meters of the spring, away from the local community, so that that part can stay clean and be used by children (and their parents) to play in the water. Another, even better way to keep animals away from the water is by reinstating the use of troughs, which can be gravity-fed with water from the springs, but away from the stream.

Vegetation removal. This practice carried out around the stream seems logical in order to maintain access. However, these springs may also harbor plants and animals that are only found associated with them. It is not known if that is true for the spring in Carrizal de los Durán or other ones in the region because there have been no studies, but the presence of endemic plants and animals in springs is well known. Removing the vegetation will also affect native plants, as well as the animals that depend on them, including amphibians and insects. In addition, the vegetation holds the soil around springs together. Therefore, removing it leads to soil erosion and organic matter into the spring, which negatively impacts water quality. Biodiversity improvement associated with the springs

and water quality, not just for the one at Carrizal de los Durán, but all springs in the Sierra Gorda Biosphere Reserve, should be enough reason to keep the vegetation around the springs as intact as possible.

Washing clothes near the spring. Washing clothes directly in springs leads to water pollution. This practice should therefore be abandoned with urgency. An easy solution is to create a basin situated at a lower elevation and some distance from the spring so that it is filled with water by gravity. Such basins should have two outlets. When the basin is not in use for washing, the water should simply pass through the first outlet and back into the stream. But when the water needs to be used for laundry, the outlet towards the stream should be closed, while the second outlet brings the used water to a small, constructed wetland. That wetland will then clean the water before it can be discharged. This system does mean that all users must know and follow the instructions to open and close outlets as needed.

Recreation in the spring. Near Concá there is an area with multiple springs that are primarily being used for recreation. On our visit in September 2021, it was clearly visible that all were negatively impacted by the recreational activities to some extent, some showing mats of blue-green algae (a pollution signal), erosion and littering. These springs are a good opportunity for the local community. However, if the deterioration is allowed to continue, people will no longer visit the springs, and so revenue will go down. Several opportunities for improvement exist, including limiting access to certain springs, creating nature trails with educational materials to explain the value and vulnerable nature of the springs, and making an open-air exhibit with plants and fish in the abandoned concrete structure that was once used for fish farming.

Natural and artificial ponds

"Bordos" are constructed ponds predominantly used to provide water for livestock. Traditionally, these ponds were small watering holes, dug into the landscape. Some are small (Figs. 6 and 7), others large (Fig. 8),

and some modern systems are lined with geomembrane (Fig. 9). In the Sierra Gorda Biosphere Reserve, they are typically shared among communities and "ejidos". During the rainy season, from June to September, most livestock roam the landscape around the communities, where they find enough food and water. However, during the dry season, from October to May, they descend on these ponds for water. Their presence creates several problems. One is that the excrements enrich the water with macronutrients which reduce water quality; another is that the animals trample the sides of the pond, damaging their structural integrity and increasing sediment loading. In addition, almost every plant that tries to establish itself in the ponds is eaten by cows and horses. In their present state, ponds do not provide much benefit to the communities other than water for livestock. However, if they were converted into healthy wetlands, additional benefits could be created, including monetary ones. Since water is perceived as beautiful, the area would be more attractive to tourists and local people.

Opportunities for improving natural and artificial ponds benefits

Use natural materials. The use of specific local clay instead of geomembrane for lining should be a priority. The area is rich in dense clay, and this could be used to line the ponds. Geomembrane is strong, but it will degrade, particularly where it is exposed to the elements, such as the edges of the ponds (Fig. 9). Another problem with geomembrane lining is that it prevents aquatic vegetation from establishing itself. Vegetation makes the pond more scenic, serves as livestock feed, and stabilizes the embankments with its roots. In addition, geomembrane will degrade and leave future generations to deal with contamination.

Keep livestock out. Prevent livestock from directly entering the ponds. Instead, bring water to drinking basins at a distance from ponds, far enough to prevent run-off of excrement into the water. If the troughs are situated at a lower elevation than the ponds, they can be filled by gravity feed.

Fill the ponds with clean water. Ensure that the water filling ponds does not carry high sediment loads. This means that the water should come from clean streams or via slopes that are vegetated. Water running into the ponds from bare slopes and roads should be prevented. Especially when it comes from roads, the water will carry oil and pollutants that could be bad for human and animal health.

Natural vegetation. Allow natural vegetation to develop and plant desirable plants. Ideally, the vegetation should be native, but non-native species that are not invasive may be considered as well. For example, the giant reed, *Arundo donax*, is present in the region. It is not native, but also not very invasive, and has beneficial uses, such as provision of material for fencing. It is also a species that stabilizes shores and is decorative. For native vegetation to develop, the shores of the ponds should slope down gently into the water so that a shallow fringe of two to three meters can be established, particularly in the large ponds.

Boardwalks. Boardwalks along the ponds, perhaps as part of trails through the region, should be considered. This will enable visitors to get close to the water and enjoy the views, while not impacting on the vegetation and water.

Fish. It may be possible to establish fish populations in the water although that would require ensuring ponds with sufficient depth to sustain the fish populations even during the most extreme droughts. Care should be taken not to introduce non-native species, such as carps, that will eat all the aquatic vegetation. Instead, species that eat insects, including mosquito larvae, should be considered.

El Tepozán, Arroyo Seco

Figure 6. A small pond in El Tepozán, Jalpan de Serra

Figure 7. A recently constructed pond on the steep slopes below Cuatro Palos, Pinal de Amoles

Figure 8. A large pond in El Tepozán, Jalpan de Serra, is regularly excavated to remove access sediments from erosion upslope

Figure 9. A recently constructed pond near Cuatro Palos, Pinal de Amoles, is lined with geomembrane and fills mostly with water coming down the road. It is fenced to keep cattle out to prevent damage to the lining

Constructed wetlands

Wetlands are natural landscape features, but they can be constructed to provide their benefits where we need them. Of course, mimicking natural features through construction is nothing new — we have created gardens, forests, and ponds for thousands of years. However, one application, construction of wetlands for water quality improvement, is more recent. Wetlands are very good at removing all pollutant types, including bacteria and viruses. Wetlands have been constructed in the Sierra Gorda Biosphere Reserve in the form of ponds (Figs. 6-9) and as small-scale systems for treatment of graywater from households (Fig. 10). However, most ponds in their current state only serve to supply drinking water for livestock. They provide little habitat for other organisms, except for small fish, insects, and a few plants. They are not constructed for the purpose of cleaning water, and they are not very attractive.

Most of the graywater treatment systems have fallen into disarray because they were not well maintained. The existing ones provide immediate opportunities for reinstallation, but they could be improved because concrete is not necessary. These systems should be bigger than the one shown in Fig. 10. It is possible to build small wetlands as depressions in flat areas lined with clay, which is readily available locally. Care should be taken to check clay porosity before use, and the clay needs to be compacted in place. It should then be impermeable and resilient enough to perform as well as and as long as concrete.

The substrate for the plants should be porous so that the plants can easily establish themselves. There is no need to have standing water on the surface. Such systems are known as "sub-surface flow wetlands." A diagram of how these can be constructed is shown in Fig. 11. If space is available, larger systems could combine sub-surface flow with surface flow (Fig. 12), as well as floating systems (Fig. 13). These can be constructed in series or within one system. The more diverse a wetland is in terms of vegetation and depth, the better it will be as a wildlife habitat.

Figure 10. A concrete structure behind a house in El Tepozán, Jalpan de Serra, was once used for the treatment of graywater. When asked if it had worked and why it was not being used now, the answer was: "Yes, it worked very well, but we did not maintain it." Photograph by Marinus L. Otte

Figure 11. A schematic drawing for a water flow path of a surface-flow (free water surface) constructed wetland. Design by Saraí Melina Parra Hernández

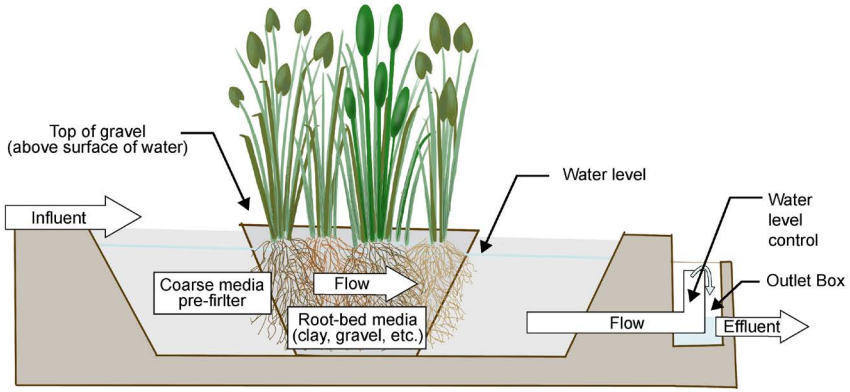


Figure 12. A schematic drawing for a water flow path through a subsurface flow constructed wetland. Design by Saraí Melina Parra Hernández

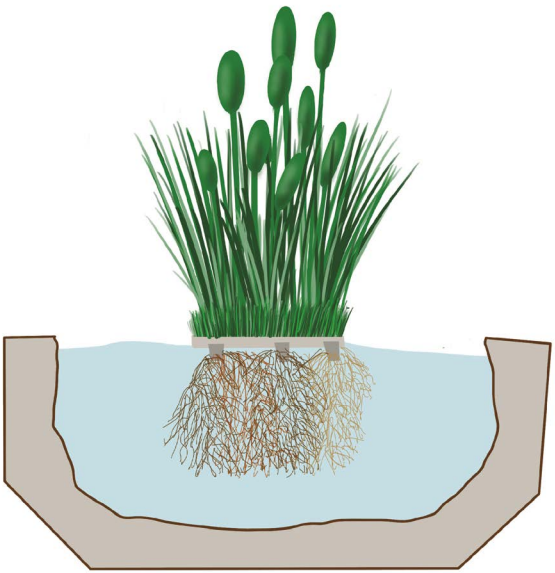


Figure 13. A schematic drawing for a cross-section of floating treatment wetland established in a pond or canal. Plant crowns are supported by solid-core foam or other buoyant matrices facilitating the survival of semi-aquatic and aquatic species. Design by Saraí Melina Parra Hernández

It would further be desirable to have all the graywater from homes collected and treated by constructed wetlands before discharge. This requires reinstallation of waste pipes in many homes. Water supply to the systems will be variable over the year, but as long as the systems do not dry out completely, that should not be a problem — many plants adapted to wetlands can in fact tolerate some periods of drought. Constructed wetlands are much cheaper than conventional chemical and physical treatment systems and easier to maintain. However, they must be cared for some extents, for example, if the plants produce too much dead material. This can smother the plants themselves, particularly in small systems where space is limited.

On a much larger scale, wetlands have been constructed as a final step for 'polishing' or 'tertiary' treatment; for example, after conventional treatment in municipal wastewater treatment facilities. Many such examples exist in Europe, Asia, and North America, but they are not common in Mexico. In the Sierra Gorda Biosphere Reserve, large constructed wetlands for wastewater treatment are not in use, but opportunities certainly abound. The wastewater treatment facility of Jalpan de Serra (Fig. 14) could benefit from a constructed wetland for tertiary treatment before discharge into the river.

Figure 14. The wastewater treatment plant at Jalpan de Serra. It treats water from the city, not just black and graywater from homes, but also runoff from the streets. In addition, clean water from a spring under the city is directed into the wastewater stream. As a result, the system often exceeds its capacity in terms of volumes of water, particularly during the wet season, and then is not capable to clean the water to a desirable quality before discharge into the Rio Jalpan.
Photograph by Cristian Eduardo Rodríguez Jacinto

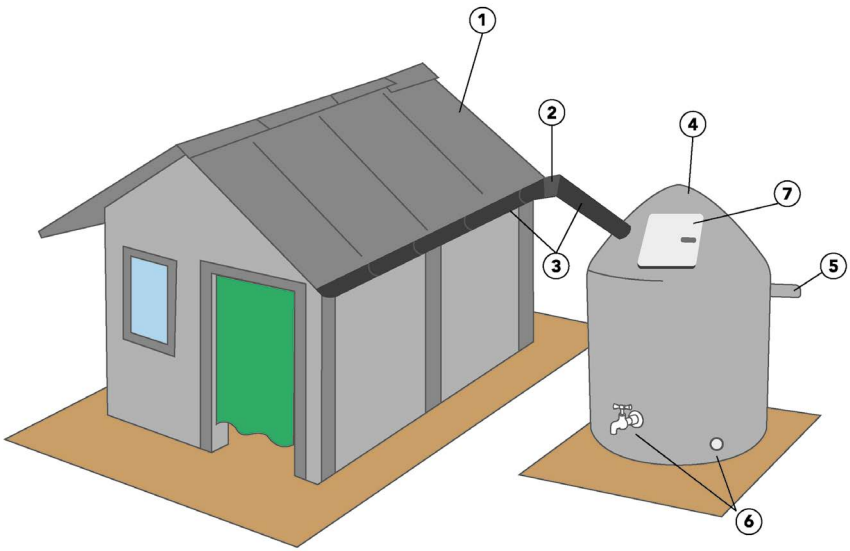
It would be even better if the inflow of water into the treatment facility were limited to black and graywater. Runoff from the streets of the city should be diverted into a separate drainage system, which could then be treated by its own constructed wetland. Such systems are referred to as "stormwater" treatment wetlands. Furthermore, clean water discharge from a spring under the city, as is the case in Jalpan de Serra, should not occur at all. Not only does that increase the volume of water going through the treatment facility, but it also decreases the efficacy of the system because the chemical reactions that favor cleaning the water depend on pollutant concentration — the higher the concentration, the more efficient the reactions.

Examples of plants for constructed wetlands

- *Azolla* (aquatic fern).
- *Cyperus, Eleocharis, Schoenoplectus* (aquatic sedges).
- *Lemna* (duckweed)).
- *Juncus* (rush).
- *Nymphaea* (waterlily).
- *Persicaria, Polygonum* (both known smartweed) and *Rumex* (dock).
- *Potamogeton* (pondweed).

Methods for water collection

In the Sierra Gorda Biosphere Reserve there are many rainwater harvesting systems in rural communities and some urban areas. These systems collect, store, and redistribute rainwater. People use house roofs as the main surface to capture rainwater through gutters that in turn go to tanks (Fig. 15). Given climate change effects, with a warmer and drier climate predicted for the region, rainwater harvesting may become a more important means of obtaining clean water than it has been in the past. The water is stored in iron-cement tanks, which are relatively easy



Operation of the Rainwater Catchment Systems

The components of the Rainwater Catchment Systems are:

1) A roof or surface that captures rainwater.
2) A net to catch leaves.
3) A system of gutters that directs the water towards the storage tank.
4) A tank to store rainwater.
5) A tube in the upper part that lets the water exit in case the cistern fills up.
6) Two valves to remove the water. The first enables the water to be used and it is high enough to fit a bucket beneath. The second allows the cistern to drain when it is washed.
7) A door to enter the cistern.

Figure 15. A schematic drawing for a standard system to collect water via roofs implemented in the Sierra Gorda Biosphere Reserve communities by Universidad Autónoma de Querétaro and collaborators. Design by Jessica Daniela Ramírez Santana

to construct at low cost. They are promoted because they can be easily constructed by people at all levels of society. The low cost means that the technology is available for many households; however, supervision by a master mason during the construction is strongly recommended to ensure that the construction materials are of good quality.

The advantages of domestic rainwater harvesting systems with iron-cement tanks are the reliability of water supply next to the house, and the low cost. The construction technique is simple. Being gravity-fed, the systems do not require energy to operate, and they are easy to maintain. One disadvantage is that how much water can be collected depends on the roof area, in addition to the fact that the initial cost to install the entire system may still be too high to be covered by a single family. However, the cost of rotomolded tanks of the same capacity is much higher. Climate change is predicted to lead to longer drought periods alternated by very intense rains in very short time periods, which will present new, unpredictable challenges in the future. CEACOM-UAQ considers iron-cement tanks to be a socially relevant technology. By collaborating in their construction community members acquire technical and organizational skills and strengthen the social fabric.

Before the installation of rainwater harvesting systems, the communities experienced periods of water scarcity. Water had to be carried from places far from the homes or was brought in by trucks at considerable cost. This meant that it was quite common for households not even to have gardens. However, when rainwater harvesting systems were installed, many households began to grow their own food. There are further opportunities to preserve water and ensure water supply to vegetable gardens by treating wastewater with constructed wetlands. This strategy is part of the CEACOM-UAQ approach to promote food security and independence in the Sierra Gorda Biosphere Reserve communities.

During the dry season, dust, plant material, and other materials that can contaminate the water accumulate on the roofs. It is therefore advisable to clean the roof before the rain starts, and to separate the water

from the first rains into separate receptacles, for example for use in the vegetable gardens. Water collected during subsequent rains will be much cleaner and should be stored for other purposes, such as drinking and cooking. In addition, a series of filters can be installed to clean the water. Although this would be a beneficial improvement, a limitation would be the cost. It is also recommendable to create community monitoring mechanisms to maintain the cisterns and prevent their deterioration. One way to do this would be to organize yearly meetings to discuss issues regarding water quality and supply, identify problems, and agree on measures for repair and improvement.

How can you protect your tank?

A traditional, pre-hispanic green method to protect the exterior walls from the natural elements is by using a mixture of slime from *Opuntia* spp. (nopal, prickly pear cactus) with lime and salt.

Atmospheric humidity condensers or fog catchers. In the upper parts of the Sierra Gorda, fog traps (atmospheric moisture condensers) have been successfully installed as a water harvesting strategy (Fig. 16). The fog catcher is an atmospheric humidity condensation system that uses a fog collecting mesh placed between two posts installed with tensioners and with a gutter at the bottom. The collected water must be directed to a container for storage. This system works when the relative humidity is around 100%. The fog catcher is a low-cost technology, environmentally friendly, durable, easy to install, and low maintenance. A 48 meter square fog catcher costs approximately 400 USD and catches up to 144 liters a day. The quality of the water will depend on the conditions of the contact surface and the air composition.

Figure 16. Collection of water with nets in Cuatro Palos, Pinal de Amoles, 2,600 meters a.s.l. Photograph by María José Pérez Aguas

An iron-cement tank of a rainwater collection system in Cuatro Palos, Pinal de Amoles

Biodiversity

Biodiversity can be defined as the number of species that occupy a place at a given time. Mexico is among the 12 most diverse countries in the world, which combined contain around 70% of the planet's diversity. Mexico has six ecological zones: 1) tropical warm humid, 2) tropical warm sub-humid, 3) temperate humid, 4) temperate sub-humid, 5) arid and semi-arid, and 6) flood zone. Being on the transition between the dry north and the humid south and with elevations ranging between 700 and 3000 meters, Querétaro exemplifies the diversity in landscape and biology of Mexico. Given the karst nature of the Sierra Gorda, springs and rivers are more common, among which are (from north to south) the Concá, Ayutla, Jalpan, Hongos, Tanculín, Extoraz, and Moctezuma rivers. Lentic environments are less common, with the Jalpan Dam being the largest.

The aquatic environments in the Sierra Gorda Biosphere Reserve are strictly freshwater. The degree of deterioration due to human activities varies widely. There are relatively unimpacted areas with clean water and vegetation consisting of native species. However, unfortunately, most of the environments in the Sierra have been impacted quite strongly. For example, by human infrastructure, channel wall erosion, natural vegetation losses, eutrophication, and invasive introduced species.

Several groups of aquatic organisms have not been well studied in the Sierra Gorda. Among these are fungi, mosses, and amphibians. There are at least partial inventories of algae, vascular plants, insects, and fish. Since the area has been under-studied, we can assume that many new discoveries await in the Sierra Gorda. It is important to note that many species occur only at certain times, so continuous surveys are essential in this area.

Algae. Algae are integrally associated with water, floating in the water or attached to rocks and plants. All algae are important primary producers, and some genera (such as *Chroococcus, Merismopedia and Oscillatoria*) are indicators of eutrophication, that is, they grow fast in nutrient-rich

environments. In total, 47 genera and 102 species have been found in the Sierra Gorda.

Vascular plants. These organisms include various life forms and have different degrees of dependence on water. Among them are the trees associated with the rivers (riparian forest), which are ecologically important as they retain banks, avoid landslides, and keep water shaded and cool, so that aquatic weeds cannot choke the water channels. Trees purify the water by taking up nitrogen and phosphorus, provide food, wood, and refuge for fauna. In the Sierra Gorda, 30 tree species from 10 different botanical families have been found, the "amates" (figs and mulberry trees, traditionally used to make bark-based paper) and "matapalos" (strangler figs) being the most diverse with 10 species. The other vascular plants associated with aquatic environments do not form woody structures such as trunks and branches; they are often found along the shores of streams, rivers, and lakes. These include ferns, of which there are three species in the Sierra Gorda Biosphere Reserve, and flowering plants of which 31 species have been found. These plants purify and oxygenate the water, give shelter to fauna, and are the main primary producers of biomass. Unfortunately, this group also includes invasive species that cause very serious problems such as accumulation of excessive plant matter, desiccation and silting of water bodies, and displacement of other species. They can also act as disease vectors.

Insects. Aquatic insects vary in their dependence on water. They can be fully aquatic throughout their life cycle like some beetles, but others only spend part of their life cycle in water, such as dragonflies. Collembola, mayflies, dragonflies, stone flies, bed bugs, neuroptera, beetles, flies, caddis flies, moths, bees, and wasps are found in the Sierra Gorda Biosphere Reserve. Insects are diverse and abundant and can be used as indicators of deterioration and conservation of aquatic environments.

Fish. Fish are the most conspicuous vertebrates in the water and have served as a food source and artifacts since the earliest human cultures. They also serve as environmental indicators for which they have eco-

nomic, sociocultural, and scientific importance. In the Sierra Gorda there are 13 native species, but there are also six exotic species, such as carps, that were introduced on purpose as a food source or accidentally due to the trade in ornamental species.

Aquatic birds. Birds in Mexico may be residential (present throughout the year) or migratory (only present during certain times of the year). Among the latter, waterfowl stand out, of which many migrate from the United States and Canada and stay in or migrate through Mexico during the winter. The Jalpan Dam reservoir was already recognized as an important refuge for aquatic birds for several decades, but since 2016 systematic records have reported the occurrence of 192 bird species, 65 of which are aquatic. This diversity is now being protected by the designation of the site as a Ramsar Site (#1352). Among the aquatic birds, the Mexican duck, cormorants, and cattle egrets stand out.

Flagship species

There are a number of species that make the Sierra Gorda special. Such species may be referred to as "flagship species," which designates animals or plants that attract the attention of the general public because they are beautiful or have specific cultural significance. Highlighting the flagship species in this book allows you to make visible the wealth of biodiversity that exists in the Sierra Gorda, and in that sense the importance of generating adequate strategies for the management and treatment of water, as well as wetlands.

In the Sierra Gorda, flagship species include the military macaw — already protected by state and federal laws, and internationally. It is not a wetland species, but it depends on a biodiverse and species-rich environment. The Mexican duck, the endemic salamanders, and waterlilies could be considered as notable "Sierra Gorda flagship species."

- The Mexican duck (*Anas diazi*) was once considered a sub-species of mallards, but since 2021 is recognized as a separate species. It has its main distribution in Central America and the Caribbean (see https://www.audubon.org/field-guide/bird/mexican-duck). It is found in winter in the Sierra Gorda, especially in reservoirs (Fig. 17).
- The "ajolote serrano" (*Ambystoma velasci*, axolotl in English) is a salamander endemic to Central Mexican highlands, that occurs in the states of Hidalgo, Guanajuato, Puebla, and Querétaro. This species is considered to be an indicator of clean water.
- The "nenúfar" or waterlily (*Nymphaea ampla*) is a perennial plant of still waters found across Central and South America, from Texas to Peru. It occurs in the Sierra Gorda in and around Jalpan de Serra and Arroyo Seco (Fig. 18). This plant has a stem buried in the mud which produces broad leaves that float on the water surface. Large, showy white flowers emerge between the leaves and are pollinated by beetles.

Applications of biodiversity in water and wetlands management

Wetland organisms are very important for satisfying human needs. Among the most obvious are the very presence of clean water, food in the form of fish, crustaceans, insects, aquatic birds (ducks, geese), and aquatic plants such as rice and watercress. Wetland organisms also offer less obvious benefits like water purification and oxygenation, and they have transcendental beauty, like the wooded springs. They also produce construction and craft materials such as wood and tule. Perhaps the saddest thing is that the importance of aquatic biota stands out when it disappears. Then the rivers go out of their channels due to the lack of riparian forest, water fills with green algae because the plants on the shore no longer stop the phosphates, and there are no fisheries because the water is polluted.

In summary, aquatic biota provide essential food, flood control, channel stabilization, and habitat for fishing or hunting waterfowl. Wetlands

without biota lose their "services" provided to humans, such as their ability to clean water and provide food, as well as their cultural, recreational, and aesthetic importance.

Figure 17. Mexican duck (*Anas diazi*). Photograph by Ulises Torres. Source: iNaturalist. https://www.inaturalist.org/photos/61845034?size=original

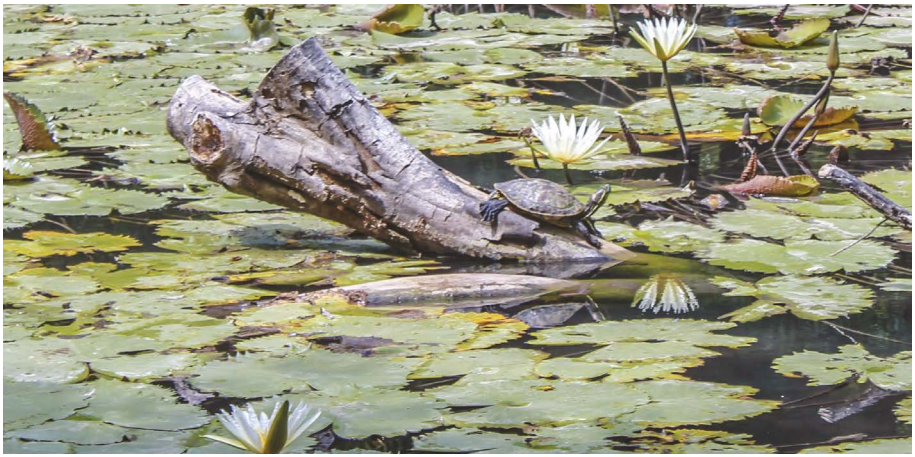


Figure 18. Waterlily (*Nymphaea ampla*) in a spring in Concá, Arroyo Seco

Promoting well-being and creating awareness

It is well-known that spending time outdoors in natural environments is good for physical and mental health. It is also known that people are attracted to water — most people enjoy walking along the shores of rivers and lakes or just sitting down to gaze over the water while enjoying a picnic. Wetlands in particular promote health and well-being for people. In the Sierra Gorda Biosphere Reserve, many opportunities exist to develop ecotourism in a sustainable way; for example, by improving pond water and vegetation. Public education, outreach projects, and development of natural areas can greatly influence successful ecosystems and watershed management.

Ideas for outreach and education

- Organize periodic informational meetings.
- Promote stream walk assessments.

- Organize storm drain stenciling projects.
- Promote watershed clean-up days and riparian planting/habitat restoration days.
- Coordinate activities with school systems within the watershed.
- Install information kiosks and websites.
- Distribute audiovisual presentations.
- Create newsletters and other printed materials.

Citizen Science

Citizen science, also known as volunteer monitoring, is scientific research conducted, in whole or in part, by non-professional (amateur) scientists. Through the public participation in scientific research, we can advance research and increase the public's understanding of science. Citizen science is a wonderful way to help people learn new things about water and wetlands.

Some benefits of citizen science projects

- Involvement with science.
- Participation as an individual, class, group, or community.
- Training on data collection methods.
- Projects that fit interests, skill level, and time availability.
- The satisfaction of directly and indirectly helping wetlands and other habitats, animals, and plants.
- The enjoyment of being a citizen scientist.
- The discovery of science as an adventure!

A classic citizen science research example is the "World Wetlands Survey," led by the Society of Wetland Scientists and collaborators. Around 500 citizens worldwide told scientists about the state of conservation or degradation of wetlands in more than 80 different countries, which re-

sulted in a document about global wetland loss and degradation (outcomes available on https://worldwetland.network/our-work/world-wetlands-survey/).

The following examples of citizen science projects for the Sierra Gorda Biosphere Reserve could all engage government, local communities, and schools.

Project 1
Water flow from natural springs

Citizens measure how much time is needed to fill a container with water from the spring, then calculate the spring flow in volume per time unit, for example, liters per minute.

- Repeat the measurement periodically, for example, every week or month.
- Build graphs and tables with the data. Include information about who measured each time.
- Compare data within and among years.

This information is a powerful tool to help communities understand variation in flow in springs and how external events could be affecting this flow.

Project 2
Biodiversity

Citizens count species in a specific ecosystem.

- Choose a species group, for example, plants, frogs, reptiles, birds, or insects.
- Determine the ecosystem type, for example, lake, spring, river, or artificial pond.

- Decide how many monitoring places and what monitoring unit should be used associated to the mapping of the plan of the watershed management. For example, monitor one or more parts of a pond and register how many plants there are in a one meter squared. Do this one or more times per season or year.
- Create a collection of reference materials (for example, a herbarium or insect collection). Do not worry about the species names. Collect the organisms and show them to a scientist later.

This project is important for understanding local biodiversity and changes over time.

Project 3
Water quality

Citizens monitor water quality in tanks, ponds, reservoirs, or other water bodies.

- Monitor the color of the water (use a color table for reference), presence of water sediment, water pH (with pH tapes), water temperature, and presence of microorganisms. Use low-cost microscopes, for example, foldscope: https://en.wikipedia.org/wiki/Foldscope.
- Draw the microorganism types.
- Repeat periodically, for example, every week or month.
- Build graphs and tables with this data. Include information about who measured each time.
- Compare data within and between years.

This project would assess changes in water quality.

Project 4
Water use at home

Citizens monitor water use in their house.

- Measure the water flow in each faucet and shower by timing the seconds needed to fill a 1 L container with water from the faucet or shower.
- Measure how much time each person in the household spends to take a shower or clean dishes, then multiply the flow by time of use. First calculate the specific water flow of each house. Example to calculate the amount of water used in a 10-minute shower:
  Shower flow: 20 L/minute = 0.33 L/second
  1 shower takes 10 minutes
  1 shower therefore uses 20 X 10 = 200 L
- Build a table with all the information.
- Estimate how much water is used. Take into account the number of people who live in the house, the number of showers per week per person, the duration of the shower (in minutes).

This project would create awareness about water use.

Job opportunities and needs

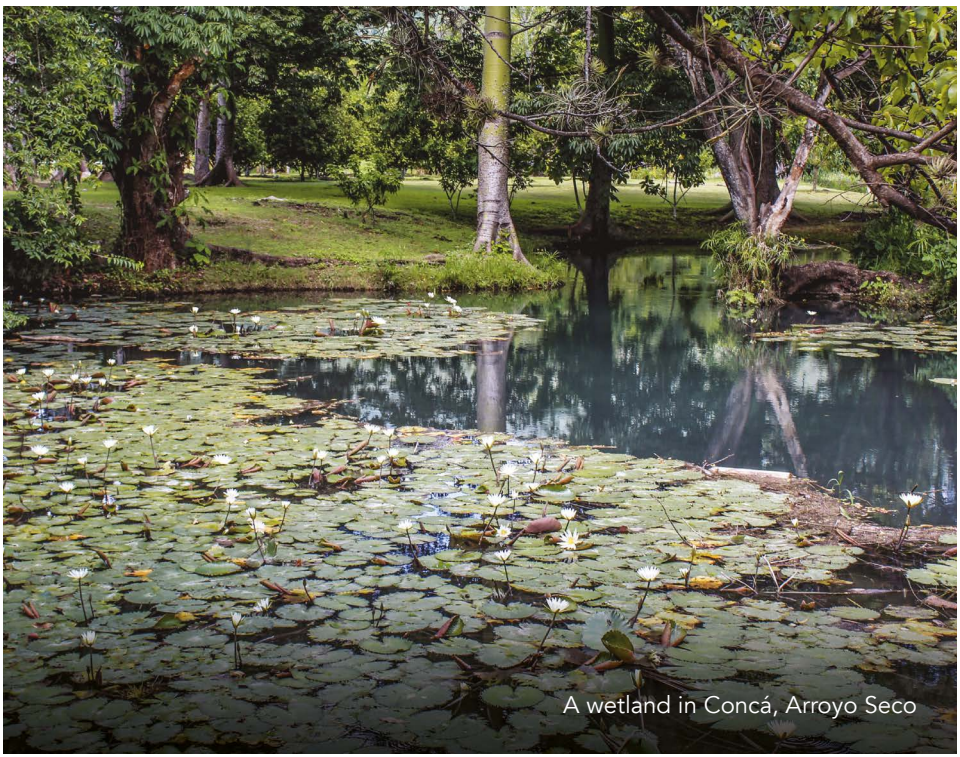
During the Universidad Autónoma de Querétaro-Fulbright Specialist 2021 expedition to the Sierra Gorda Biosphere Reserve, work opportunities were identified within the communities. These include establishing aquatic plants on the embankments, assessment of access sites for cattle to drink water while avoiding pollution and erosion of bank edges. There is also a need for innovative approaches to biofilters that mimic as closely as possible a small wetland to treat graywater so that it can be used to irrigate orchards. Another opportunity is to cultivate wetland plants for food, construction, folk medicine, and ornamental purposes.

The Sierra Gorda Biosphere Reserve is emerging as a tourist destination for those who enjoy nature activities and outdoor spaces. This creates

job options for people in the tourist industry. However, it is also necessary to mitigate the negative impacts of this kind of activities. This region provides many opportunities for raising conservation awareness and for ecotourism.

Possible actions to mitigate threats

First and foremost, it is imperative that all parties with an interest in the quality and availability of sustainable water use in the Sierra Gorda Biosphere Reserve communicate with each other. People must come together or there is no hope of ever improving the situation. With this in mind, we propose the following actions in favor of the water and wetlands in the Sierra Gorda Biosphere Reserve.



A wetland in Concá, Arroyo Seco

A view of the Sierra Gorda
from Cuatro Palos, Pinal de Amoles

Possible actions to mitigate threats

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Big actions

- Create an overarching organization which brings together all stakeholders, such as individuals, interest groups, civil societies, representatives of communities and municipal, state, and federal leaders, including religious and traditional community leaders, to communicate about sustainable ways to protect and manage water and wetlands in the Sierra Gorda Biosphere Reserve.
- Organize a conference with presentations about all issues related to water and wetlands. The main focus of the event should be the development of sustainable management of water and wetlands, with an aim to secure water availability and outstanding quality for the future.
- Restore and create wetlands. Some ideas have been provided in this book.
- Educate people about water use. This is particularly needed in urban areas, where people are used to water simply coming out of a tap and being transported off after use via sewage systems. The public at large must understand that the full cycle of water is crucial to our daily lives, and how humans are an integral part of that. Another aspect of this is teaching people about the cost of products if expressed not in terms of money, but in terms of water (Energy-Water-Food Nexus; see Water Footprint Network).

Small actions

- Further develop methods to collect and store water.
- Further develop and reinstate methods to treat wastewater and continue to maintain them.
- Install dry toilets and septic systems at home.
- Reuse treated water for irrigation of vegetable gardens.
- Be conscious of the amounts of water being used for daily activities, such as cleaning the house and car, irrigation for the garden, personal care, and so forth.
- Recycle, reuse, and reduce.

A willow (*Salix* spp.)
over the Santa María River, Arroyo Seco

A flooded area with macroalgae proliferation and duckweed (*Lemna* spp.) near Jalpan de Serra

A wetland near Landa de Matamoros

The Santa María River in Arroyo Seco

A rural house on the road to El Pocito, Jalpan de Serra

A view of the Sierra Gorda
near El Pocito, Jalpan de Serra

A Mexican cypress (*Taxodium* spp.)
at a stream in Río Verdito, Landa de Matamoros

CONCLUSIONS

This book aims to create a stronger connection regarding water and wetlands between human society and nature in the Sierra Gorda and between the Sierra Gorda and the world. Many other localities, particularly arid high-altitude areas worldwide, face similar water and wetland management issues. How can the experiences from the Sierra Gorda contribute to solve similar dilemmas in different regions?

The most important take-home message from the Universidad Autónoma de Querétaro-Fulbright Specialist 2021 expedition is that all parties involved in the problems with water quality and availability in the Sierra Gorda Biosphere Reserve must find representation in an organization, maybe a forum or committee, to start talking about water issues at all levels. The interrelationship between humans and the environment requires the benefit of scientific knowledge about environmental issues. Some problems are enormous, as the effects of climate change, others are small, such as wastewater treatment from individual households. Minor actions, such as collecting all wastewater in one place, treatment by a small wetland, and subsequent use for vegetable gardens, are easy to do.

Safeguarding water and wetlands for the future is a priority for all of us!

Roads of the Sierra Gorda
on the way to Querétaro

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SUMMARY

The Sierra Gorda Biosphere Reserve Universidad Autónoma de Querétaro-Fulbright expedition carried out by our multidisciplinary team inspired this book. The project highlights Marinus L. Otte, professor at North Dakota State University, Fulbright Specialist, and editor-in-chief of *Wetlands*. The project and the expedition were coordinated by Tatiana Lobato de Magalhães, research professor at the Natural Sciences Faculty of Universidad Autónoma de Querétaro, chapter chair at the Society of Wetland Scientists and associate editor of the international scientific journals *Wetlands* and *Aquatic Botany*. The expedition team also incorporated Alejandra Leticia Rocha Mier, Education and Community Support coordinator, and Cristian Eduardo Rodríguez Jacinto, Social Communication and Media — expedition cameraman and photographer. Three students provided invaluable support: Lizeth Harzbecher, graduate student in Biological Sciences, Miguel Sarmiento, graduate student in Watershed Management, and José Emiliano Plata Ramos, undergraduate student in Anthropology and the main photographer during the expedition. Mahinda Martínez (professor at the Natural Sciences Faculty) and Itzel Sofía Rivas Padrón (Social Intervention coordinator) strongly contributed to the project.

The project "*Capacitación en gestión del agua y humedales en diferentes sectores sociales: comunidades rurales, gobierno y academia*/Water management in a karstic rural impoverished environment, FSP-P006854" consisted of workshops and training courses, recordings of testimonies and audiovisual materials for a documentary on perceptions about water and wetlands during an eight-day expedition. It also led to the production of this book.

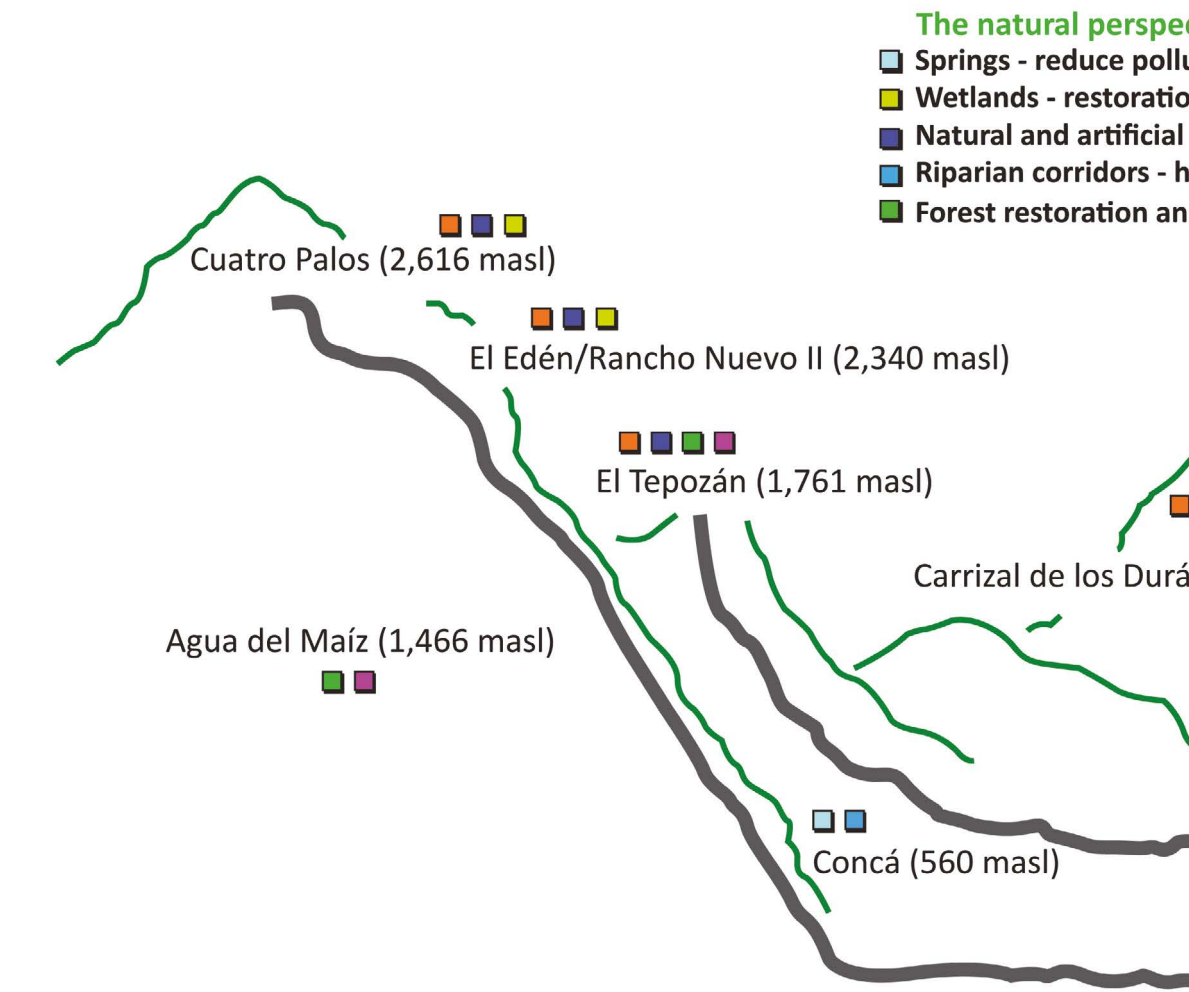
ABOUT THE AUTHORS

DR. TATIANA LOBATO DE MAGALHÃES is a research professor at Universidad Autónoma de Querétaro, Mexico, and has specialized in wetland research and education for more than ten years, with a strong focus on ecology, genetics, and distribution of aquatic plants. Currently, she is International Chapter chair at the Society of Wetland Scientists (SWS), associate editor of the scientific journals *Aquatic Botany* and *Wetlands*, editorial member of the Springer book series Wetlands: Ecology, Conservation, and Management, recognized by the National System of Researchers in Mexico, and certificated as a Professional Wetland Scientist by the SWS. She was awarded the 2021 Academic Merit medal by Universidad Autónoma de Querétaro, the "José Mariano Mociño (1757-1820)" medal by the Mexican Society of Botany, and the 2018 Graduate Research Fellow Wetland Ambassadors by the SWS.

DR. MARINUS L. OTTE is a professor at North Dakota State University, Fargo, United States, and has specialized in wetland research and education for more than thirty years, with a strong focus on pollution and phytoremediation. His work includes research projects and teaching in many countries around the world, including the Netherlands, Ireland, Kyrgyzstan, Northeast China, Taiwan, several states in the USA, and most recently in Mexico. He has been editor-in-chief of the scientific journal *Wetlands* since 2012 and has published almost 100 peer-reviewed articles.

Opportunities for Sustainable Manage

Communities of the Sierra Gord



The human perspective

- Collect rainwater - roofs, nets
- Improve municipal sewage treatment - infrastructure for run-off, users pay
- Social aspects - creating a committee, engaging local people
- Citizen Science Projects - monitoring and education

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da Biosphere Reserve

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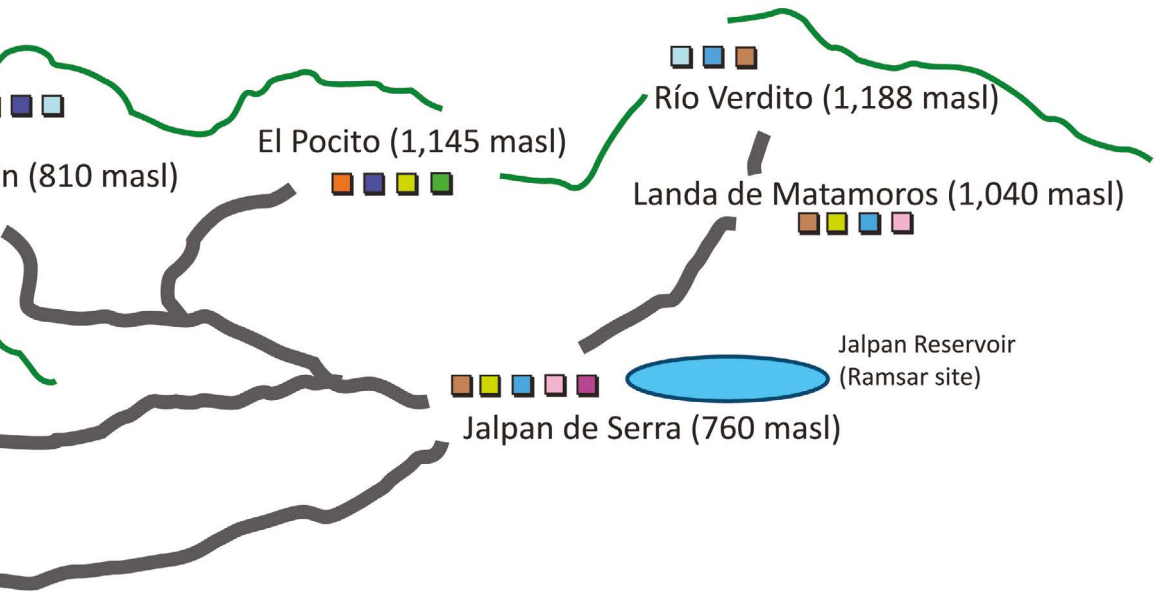

Schematic drawing of opportunities.
Design by Marinus L. Otte and Tatiana Lobato de Magalhães

This edition of *Insights into Sustainable Management of Water and Wetlands in the Sierra Gorda Biosphere Reserve, Mexico*
was designed by Alejandro Zamorano
at Fondo Editorial de la Universidad Autónoma de Querétaro.
Gisella Cordero and the authors were
in charge of the editorial care.
It was published in December, 2022,
in Santiago de Queretaro, Mexico.

This book aims to create a stronger connection regarding water and wetlands between human society and nature in the Sierra Gorda and between the Sierra Gorda and the world. Many other localities, particularly arid high-altitude areas worldwide, face similar water and wetland management issues. How can the experiences from the Sierra Gorda contribute to solve similar dilemmas in different regions?

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