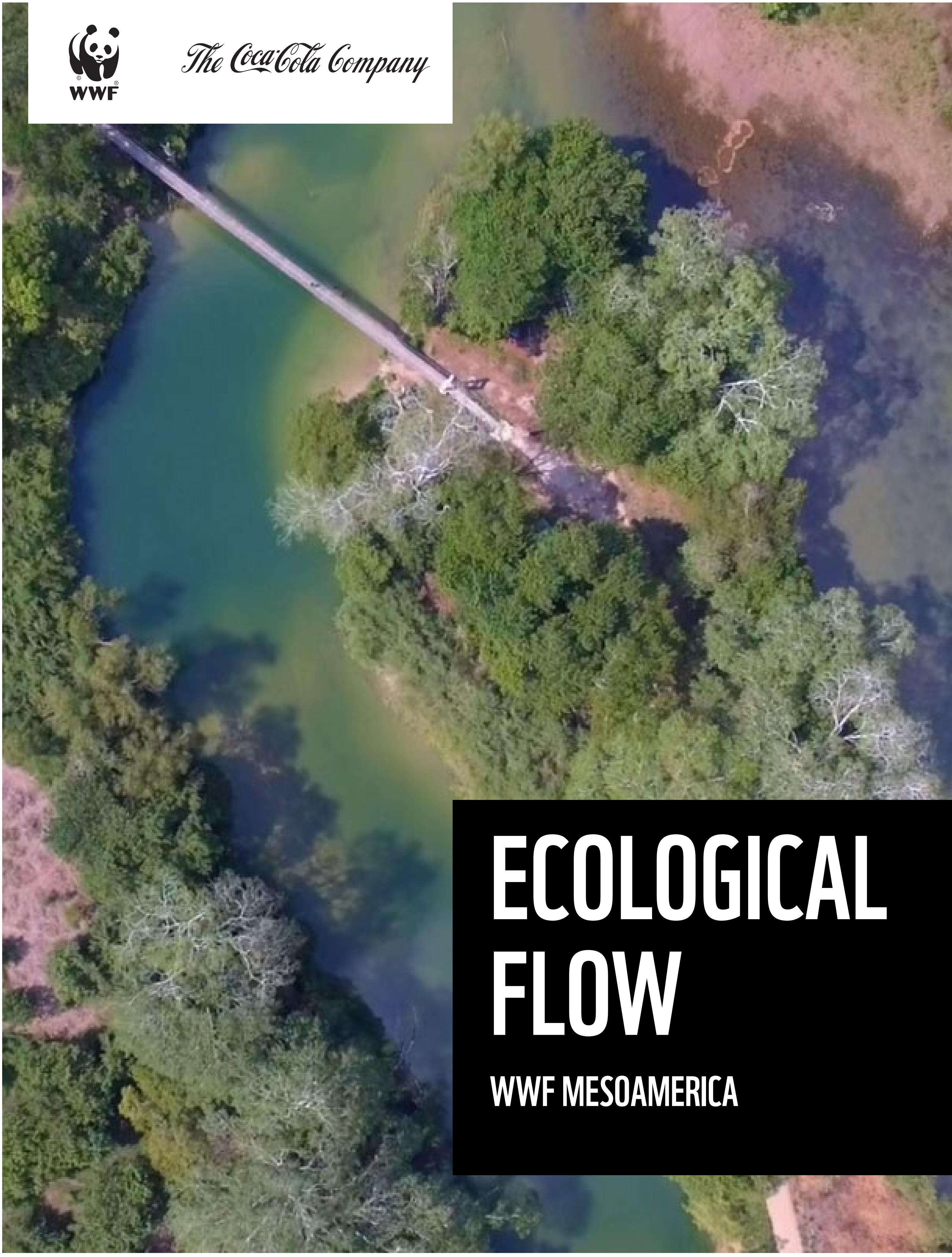
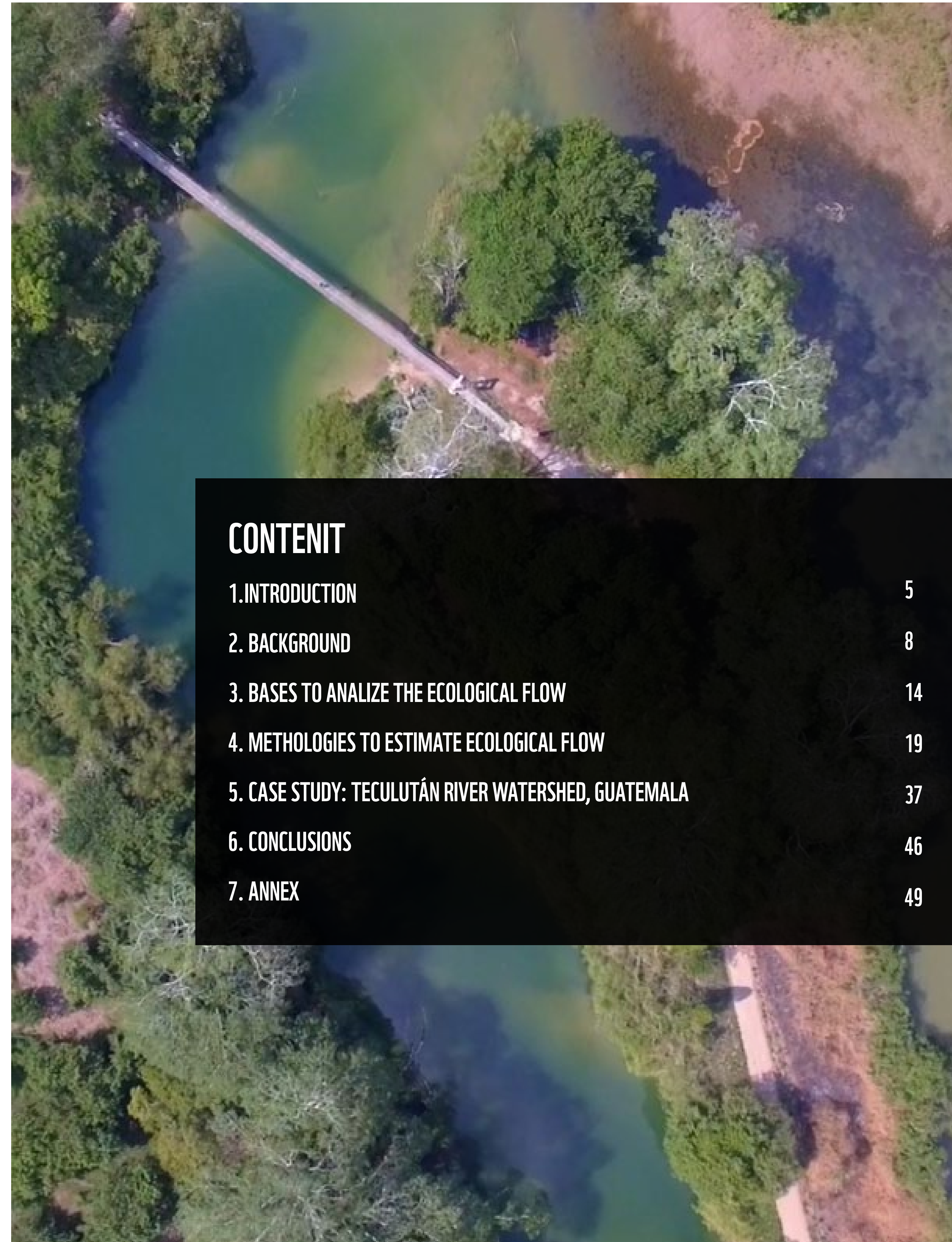
The Coca-Cola Company



ECOLOGICAL FLOW

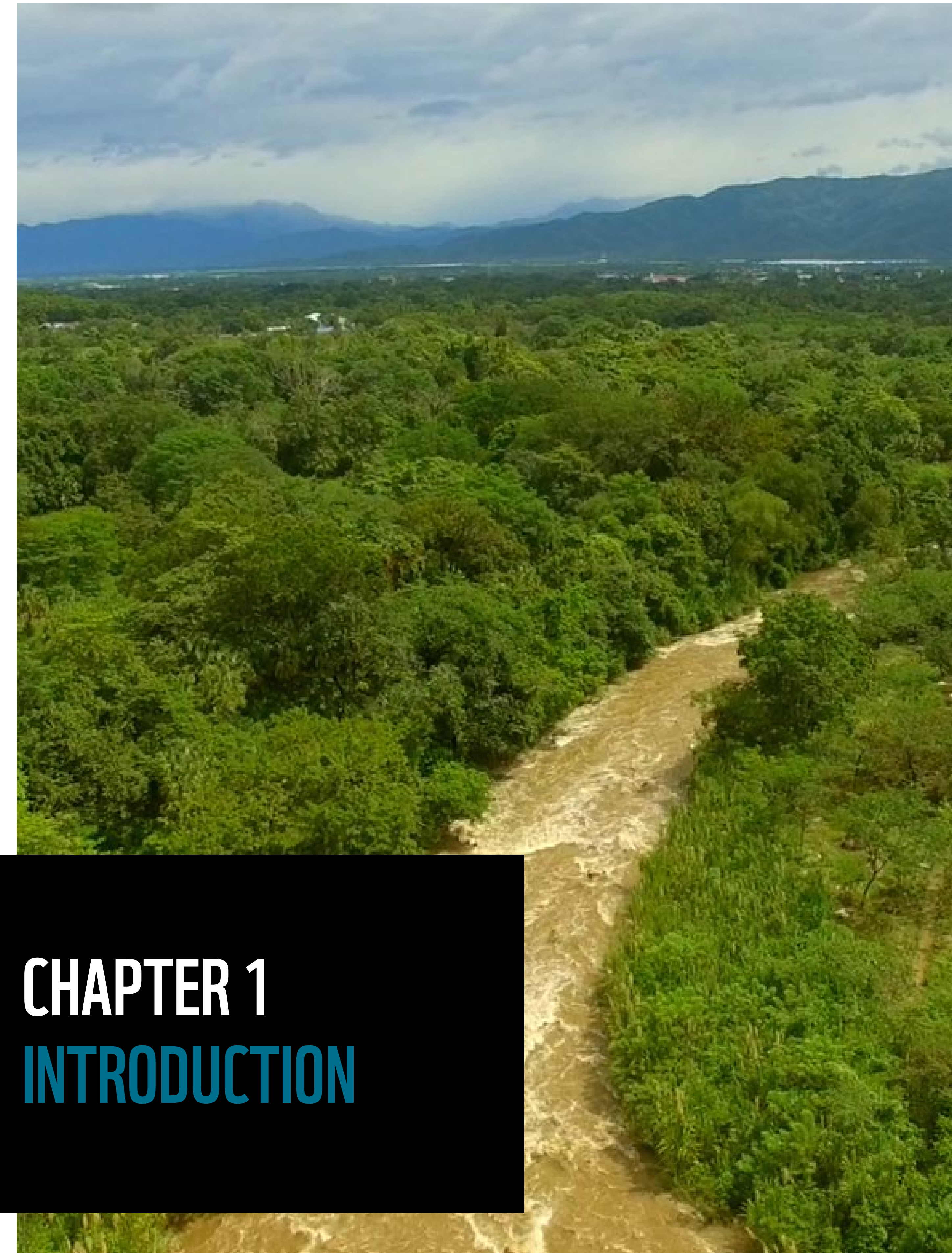
WWF MESOAMERICA



CONTENIT

ECOLOGICAL FLOW

WWF MESOAMERICA

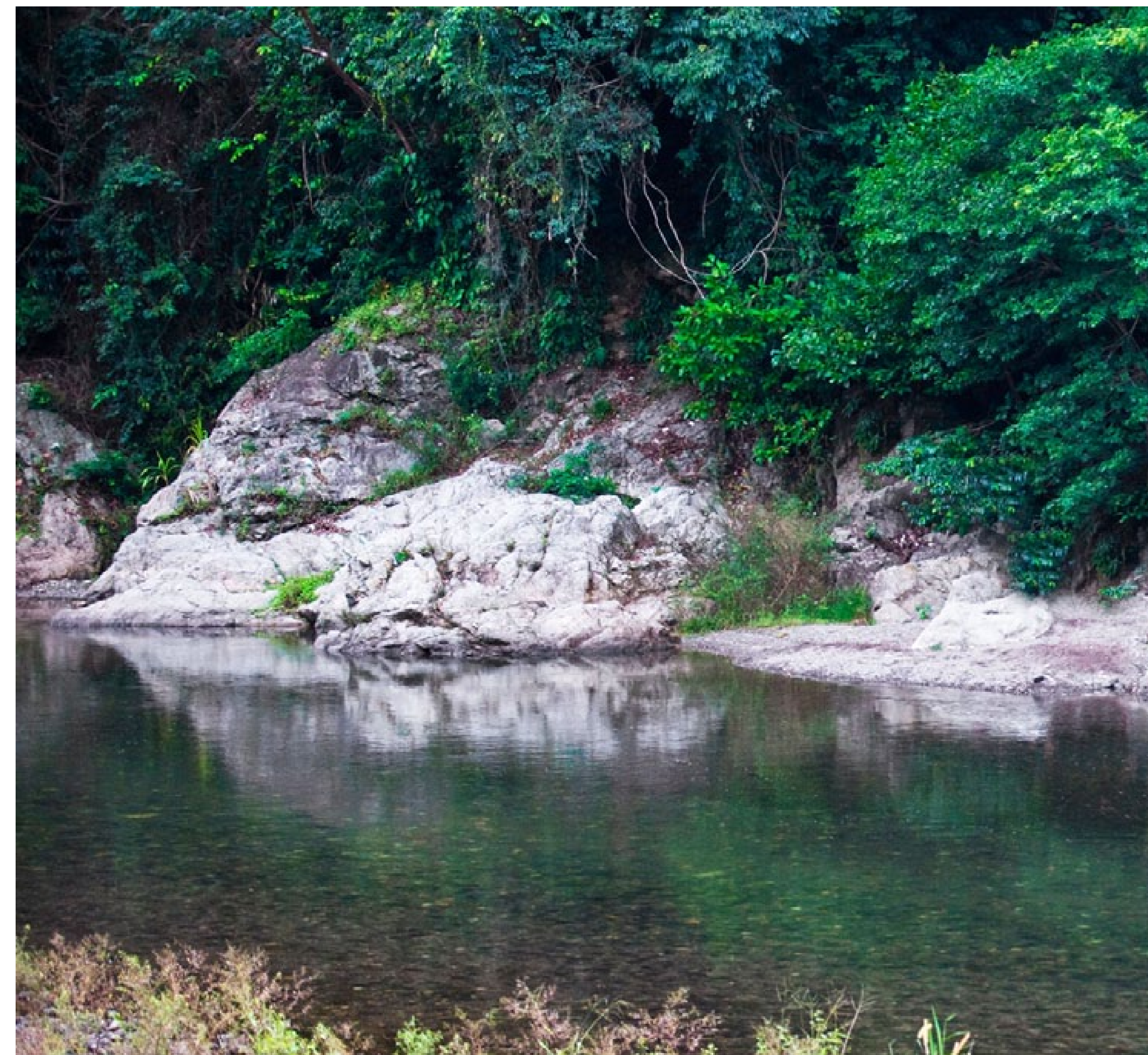


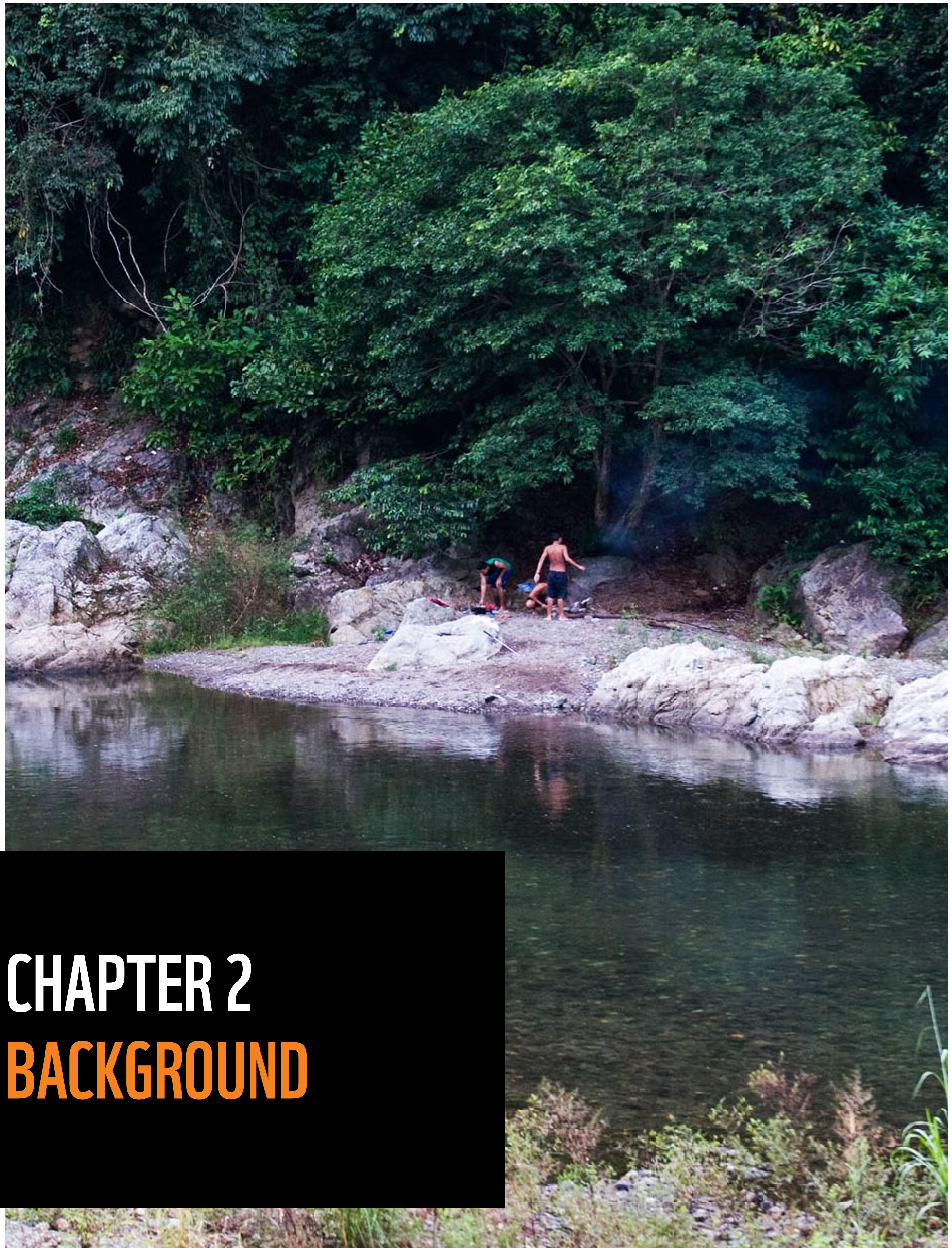
CHAPTER 1
INTRODUCTION

The cycle of water is life and, thus, the river-flow system is the "pulse" nurturing the planet. It sustains the processes, functions, and ecological integrity that lead to providing ecosystem services such as water provisioning, regulating extreme weather events (droughts and floods), some support services, and services associated to cultural features.

The growing demand for water resources has affected the species and ecosystems in the watersheds, which include lakes, ponds, rivers, streams, and creeks, as well as coastal areas. Human water consumption is producing water stress or exerting pressure on water, as a result of its use by various productive sectors, such as agriculture, livestock, and industries, while ignoring the water needed by the environment or ecosystems. The uncontrolled increase of the population, the changes in land use, water-quality degradation, and the impact and vulnerability caused by climate change also deteriorate ecosystems and the quality of life of the inhabitants who depend on ecosystem services. These interventions and the damage accumulated throughout time have led to a decrease in the availability of the resource and the subsequent inability of the water systems to maintain the ecosystem services and the water flows that many people depend on. Thus, a new type of water conflict has arisen between the capability of satisfying short-term economic demands of the resource and the various ecosystem processes and services provided by water. It is imperative to address this emerging conflict because, if these signs of degradation are ignored, ecosystem services will be restricted, and it will be increasingly difficult to sustain the livelihoods that depend on continued water availability.

As a result of the studies addressing the challenge of finding a balance in the use of water for future quality supply for all users, the need to guarantee the ecological flow regime has been posed. The ecological flow is defined as the water regime that is required to maintain ecological processes (reproduction, migration, feeding, succession of species, etc.), connectivity in the whole watershed, and long-term hydrological balance, on which water availability for all depends.





CHAPTER 2 BACKGROUND

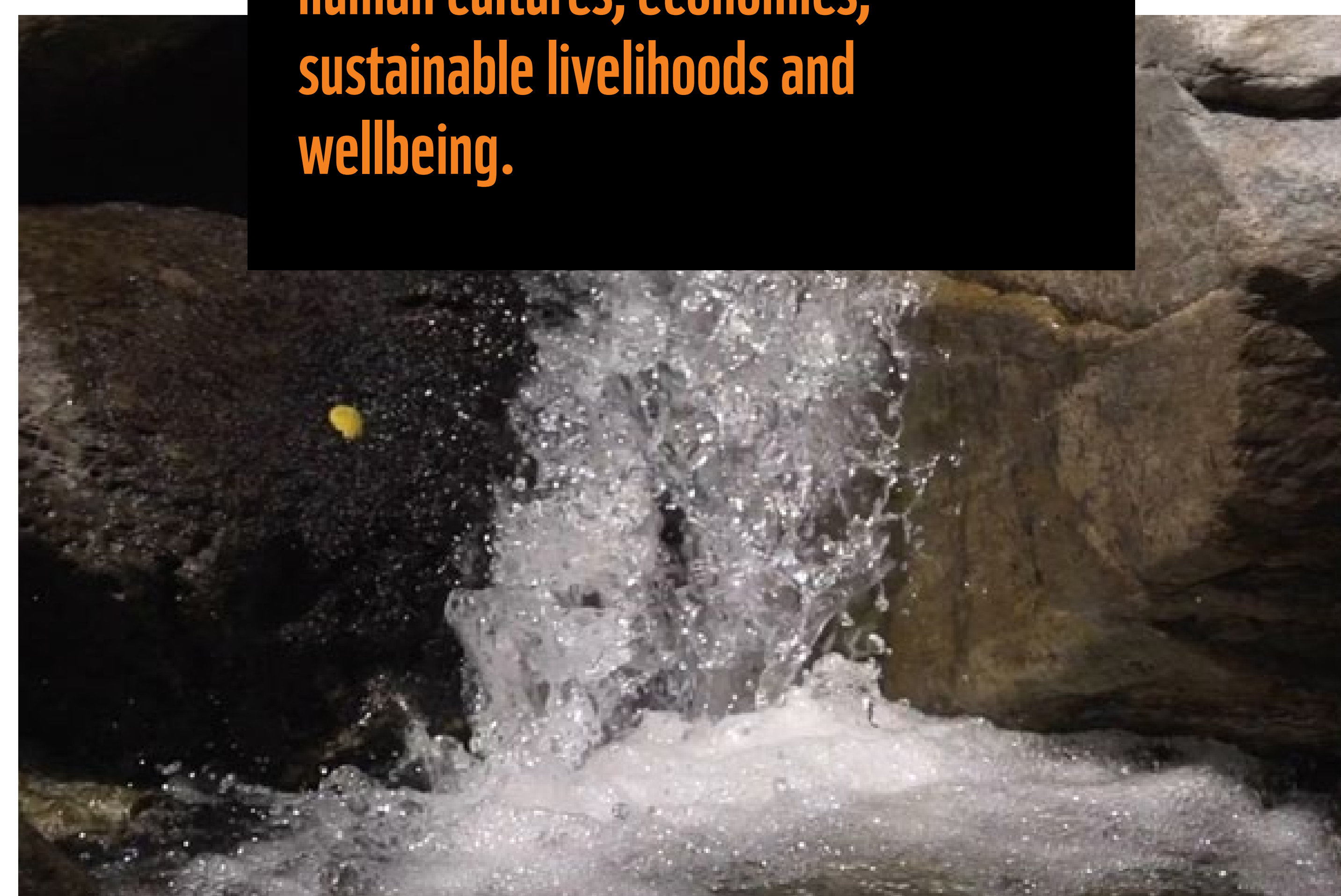
Human activities use water in various ways, and this has had a cost on natural capital, which is evidenced by the loss of more than 80% of freshwater diversity in the last 40 years. Likewise, almost 40% of wetland-dependent species have been lost. We have only been able to conserve one third of the world's large rivers in a proper state of connectivity. These are just some of the causes that have led to a crisis resulting in severe water scarcity. Approximately 2/3 of the human population suffers from severe water stress, for at least a couple of months in the year. It is estimated that there will be a 55% increase in global water demand by 2050, and in addition, climate change will further intensify this pressure.

The concept of ecological flow was conceived in the 1960s and it started to be addressed systematically, above all, with the idea of reserving a certain amount of water for the environment, specifically as protection against flooding, as water supply or as a means to generate hydroelectric power. In the 1970s, this contribution on ecological flows focused on maintaining the minimum flows so that rivers would have water all the time. The concept of ecological flows shifted to a more holistic vision in the 1990s. The concept of minimum flow was left behind and specialists started to analyze components and attributes. Thus the concept of regime with its components and attributes started to be understood from a holistic point of view, which entailed a biotic approach to the system; that is, everything pertaining to living beings and their life processes within this system. The new perspective allowed the concept of sustainable development and the life of human beings and the environment to be closely interrelated. Consequently, sustainable development, in addition to the objective of increasing the quality of life of human beings also considers the capability to support ecosystems.

The various types of research generate information to better understand the hydrological regime from an ecosystem perspective, aimed at restoring and conserving ecological flows. This holistic model integrates specialists from various disciplines working in unison, in accordance with a common conceptual framework. In order to establish objectives, it is necessary to previously define the water needs of the environment, with the purpose of conserving an ample spectrum of species, as well as processes and services. Likewise, the ecological flow must be considered a tool that is part of a series of instruments that will be used to accomplish adequate integrated management of water resources, an effort that should engage other entities.

In 2007, the Brisbane Declaration was agreed on. It defines ecological flow as "the quantity, timing and quality of water flows required to sustain freshwater and estuarine aquatic ecosystems and the human wellbeing that depends on these ecosystems." Ten years later, the scientific community met to review the concept and made some amendments to the concept. The new definition of Ecological Flow issued by the Brisbane Declaration in 2017 is the following:

The quantity, timing, and quality of freshwater flows and levels necessary to sustain aquatic ecosystems which, in turn, support human cultures, economies, sustainable livelihoods and wellbeing.



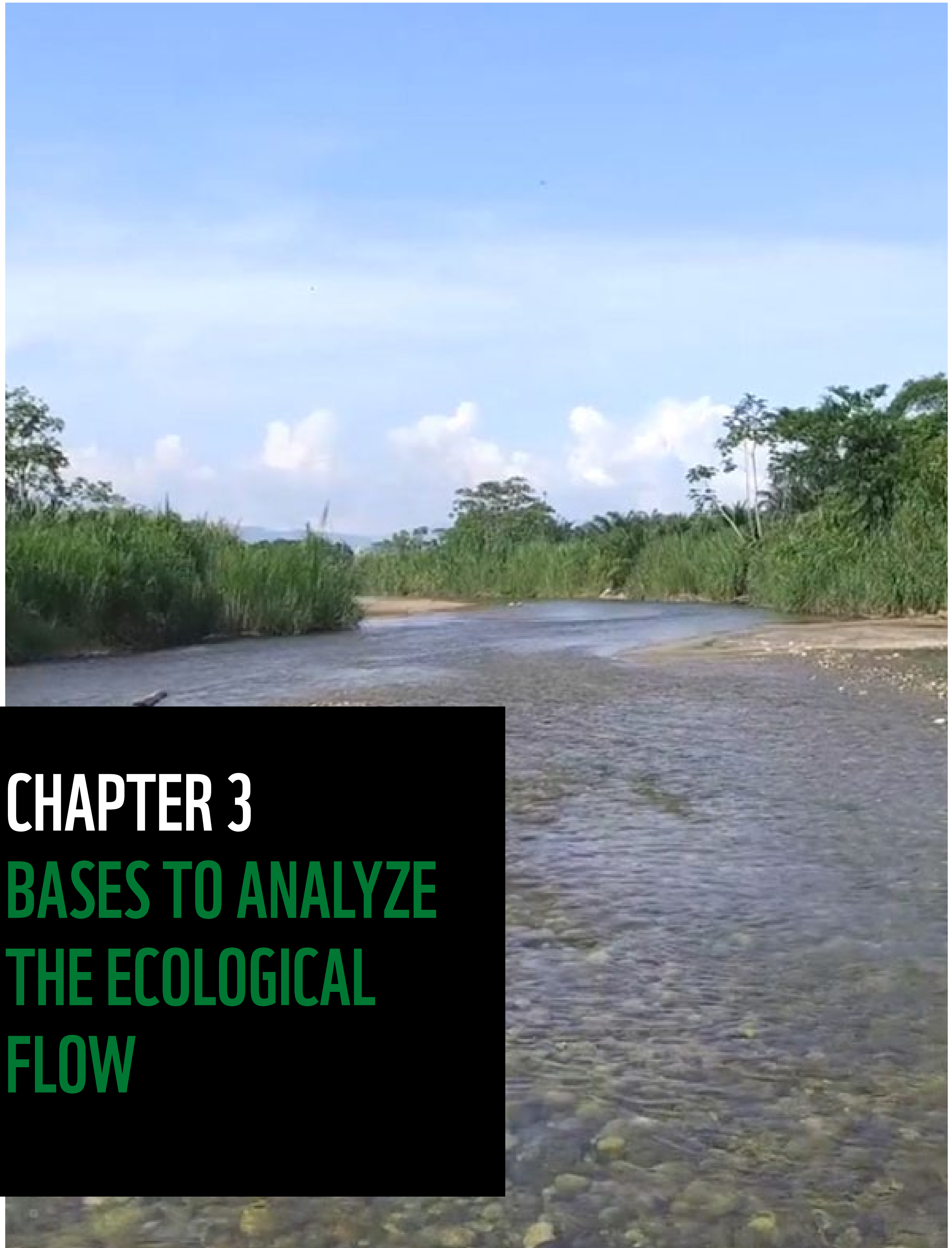
As of the United Nations' Conferences on Water held in Mar del Plata, Argentina and in Dublin, Ireland, in 1992, the concept of integrated management of water resources acknowledges water as an integral part of the ecosystem. This includes surface water and groundwater, water quality, aquatic ecosystems, and land management. This means that, as part of the integrated management of water resources, one must consider its processes and biodiversity in a sustainable manner. Current work is aimed at considering related ecosystems as water-resource users, so that an ecological flow regime for water is guaranteed for watercourses. Thus, it is essential to consider groundwater as an element that plays an important role in the ecological flow, and to link the relationship between runoff and recharge to supply urban areas and to other uses.

For many years now, information about surface water and groundwater has been gathered, to be used as indicators to determine the flow of water bodies in watersheds. A flow can be considered ecological whenever it is able to maintain the functions, composition, and structure of a river ecosystem in a way that is equal or similar to its natural conditions.

"Ecological flow" is a polysemic term (with several meanings), according to the objective for which it is being used. A brief definition of ecological flow shows that it is the flow ensuring supply for all living beings and maintaining a regular flow in time, as near as possible to natural conditions, guaranteeing continued ecosystem sustainability. In terms of management, the ecological flow is an instrument that enables agreement on the integrated and sustainable management of water resources and that establishes the quality, quantity and regime of the water flow required to maintain components, functions, and processes. In addition, it promotes the resilience of aquatic ecosystems that provide goods and services to society. This type of management is the process through which development and coordinated water, land and watershed-related resource management is promoted, with the aim of maximizing economic and social wellbeing equitably, without compromising the sustainability of vital ecosystems. The ecological flow harmonizes economic, social, and environmental water demands and recognizes that goods and services of watersheds depend on physical, biological, and social processes. Consequently, the only way to guarantee the supply of water resources for the future is to conserve the water required by these processes.

Previously, watershed management plans were based on a biological inventory; that is, on the species that the area and its ecosystems contained, and often, the water required by these species and ecosystems to survive was not considered. Water resources in protected areas may become biological corridors, depending on the course of a river, for example. The current principle of ecological flow specifies that, after defining the flow (volume over time) of a river, a portion of this flow can be reserved for environmental uses. Consequently, other users would not have access to this volume that has been set apart for the environment. In order for this process to be efficient, responsibility must be borne by an entity that has the discretion to grant a user the volume of water it requests, which would be provided according to the availability of water in that location, just as Mexico is already doing with its water resources.

In summary, the aim of the ecological flow is to reproduce the natural hydrological regime to a certain point, endeavoring to conserve the seasonal patterns of minimum and maximum flows (dry and rainy seasons), the high-flow regime and the rates of change. These parameters are useful to hydraulic or hydroelectric infrastructure management.

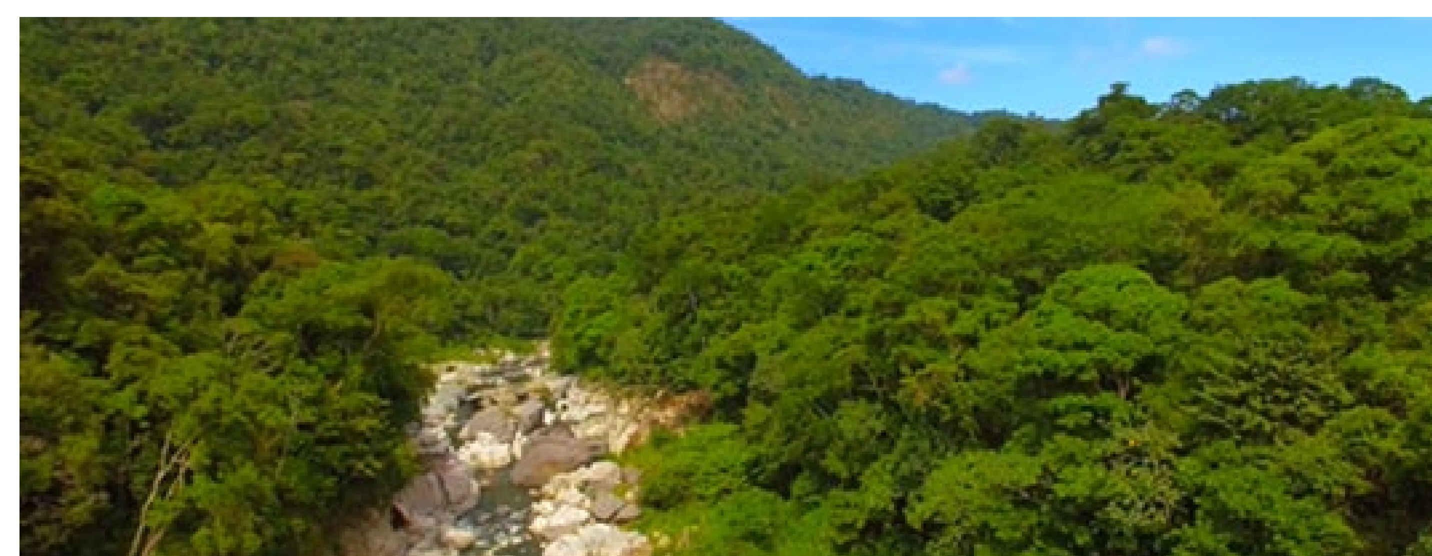


CHAPTER 3
BASES TO ANALYZE THE ECOLOGICAL FLOW

HOW MUCH WATER DOES A RIVER NEEDS?

In recent years, the concepts of socioecological flow or socioenvironmental flow are increasingly being used. Traditionally, the term ecological flow has been used when the aim of the assessment or implementation of some portion of the regime was to conserve ecological processes and, generally, environmental flow has been used when the aim is to conserve a portion of water for ecosystem services. For the system to provide these services, it is necessary that the ecological process is in suitable conditions, since they are closely linked. However, the objective is different in each case, given that the co-existence of social interests and ecosystem services is closer than the one with ecological processes. By definition, water uses imply, to some extent, the impairment of the ecological processes of the ecosystem. Thus, there is an increasing trend to use the terms socioenvironmental flows or socioecological flows, which incorporate social indicators into the ecological assessment of the regime.

The ecological flow entails analyzing the quantity, timing, and quality of fresh-water flows and the regimes that are necessary to sustain aquatic ecosystems which, in turn, support human cultures, economies and sustainable livelihoods and wellbeing. In this definition, aquatic ecosystems refer to rivers, springs, riverbanks, floodplains, wetlands, lakes, and coastal water bodies such as lagoons and estuaries, in addition to ecosystems that depend on groundwater. It also includes the uses at the watershed level.

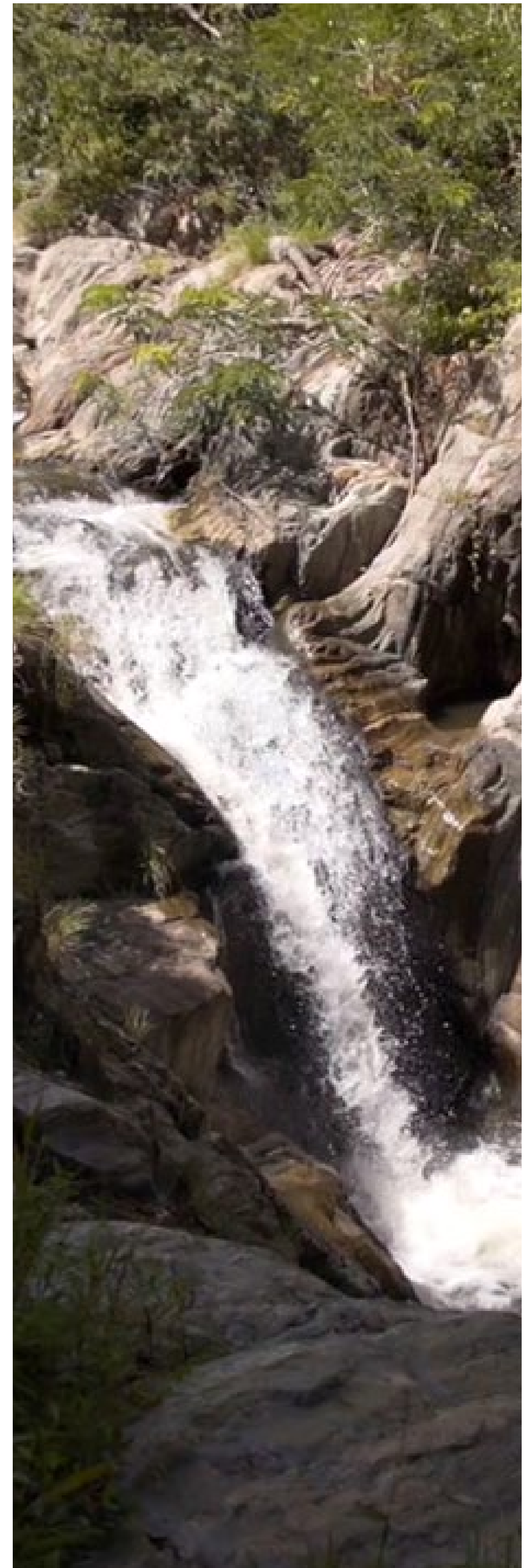


Regime attributes and components sustain ecological integrity. Components include low flows, extremely low flows, high flows, and even small and large floods. These components are analyzed based on their attributes. Attributes refer to the magnitude of those flows, their frequency, duration, timing, and rate of change.

The other major characteristic in the context of assessing ecological flows is flow predictability, which forecasts their behavior during the various annual and seasonal cycles. They are addressed based on the range of variability, whose analyses consider the flows expected in average, wet and dry conditions, by means of a series of statistical techniques. The purpose is to obtain a quantitative assessment of the events happening over time.

Based on this analysis and assessment, it is possible to identify the times of the year in which events occur, with a higher level of precision in regard to flows, and to link them to various ecological functions, such as connectivity, for example. Connectivity may be associated not only to synchronization of biological cycles, but also to sediment transport and the different aspects of primary productivity. These ecological functions are linked to one or more ecosystem services, which may be assessed through various methods of approximation.

Currently, when speaking about ecological flows, one does not speak about minimum flows. One speaks about a portion of the hydrological regime destined to remain in the environment to fulfill ecological functions or to provide environmental services. This implies different orders of magnitude, depending on the particular river. Previously, a value of 10% of the volume was used as the basis to estimate the ecological flow, which resulted from Donald L Tennant's contribution (the Tennant or Montana Method), according to the river management schemes in place in the 1970's specifically in the state of Montana, in the United States. This method contends that serious degradation conditions occurred when flows reached 10% or less. Unfortunately, this has contributed to the dramatic loss of aquatic biodiversity in the last 40 to 50 years. Therefore, this 10% value is definitely no longer applicable. In the context of Latin America, each country progresses at its own pace and generates the information relevant to its territories.



HYDROLOGICAL REGIME

Variations in the flow define the hydrological regime of a river, which may include temporary variations owing to storms. During extreme events, an overflow may occur when water influx is greater than the capacity of the river to drain it, so that it overflows and covers nearby plains. The water flowing underground (base flow) takes much longer to feed the water flow and may take days, weeks, or months for runoff from rainfall to reach it. On the other hand, if there is absolutely no rainfall or the mean rainfall is less than normal during long periods, the river may eventually dry out when the inflow of rainwater accumulated in the soil and subsoil reduces the baseflow to zero. This can have disastrous consequences for the life of the river and its riverbeds and for the people depending on it for their water supply. However, there are other species whose biological processes are governed by these droughts as a natural part of their cycle, as is the case with floods. This must be considered when speaking about the natural hydrological regime that is specific to each ecosystem.

The flow regime, with its attributes and components, is key for the diversity of aquatic ecosystems. It organizes and defines the physical environment, the ecosystem, and the species that live in them. It maintains ecological processes, the connectivity of the whole watershed and the long-term hydrological balance. To the extent that the hydrological regime can be maintained in a pristine or natural-like state, the biological condition of the ecosystem will also be closer to its natural state. Therefore, when there is more water pressure, biological conditions deteriorate. This is known as the gradient of the biological condition.

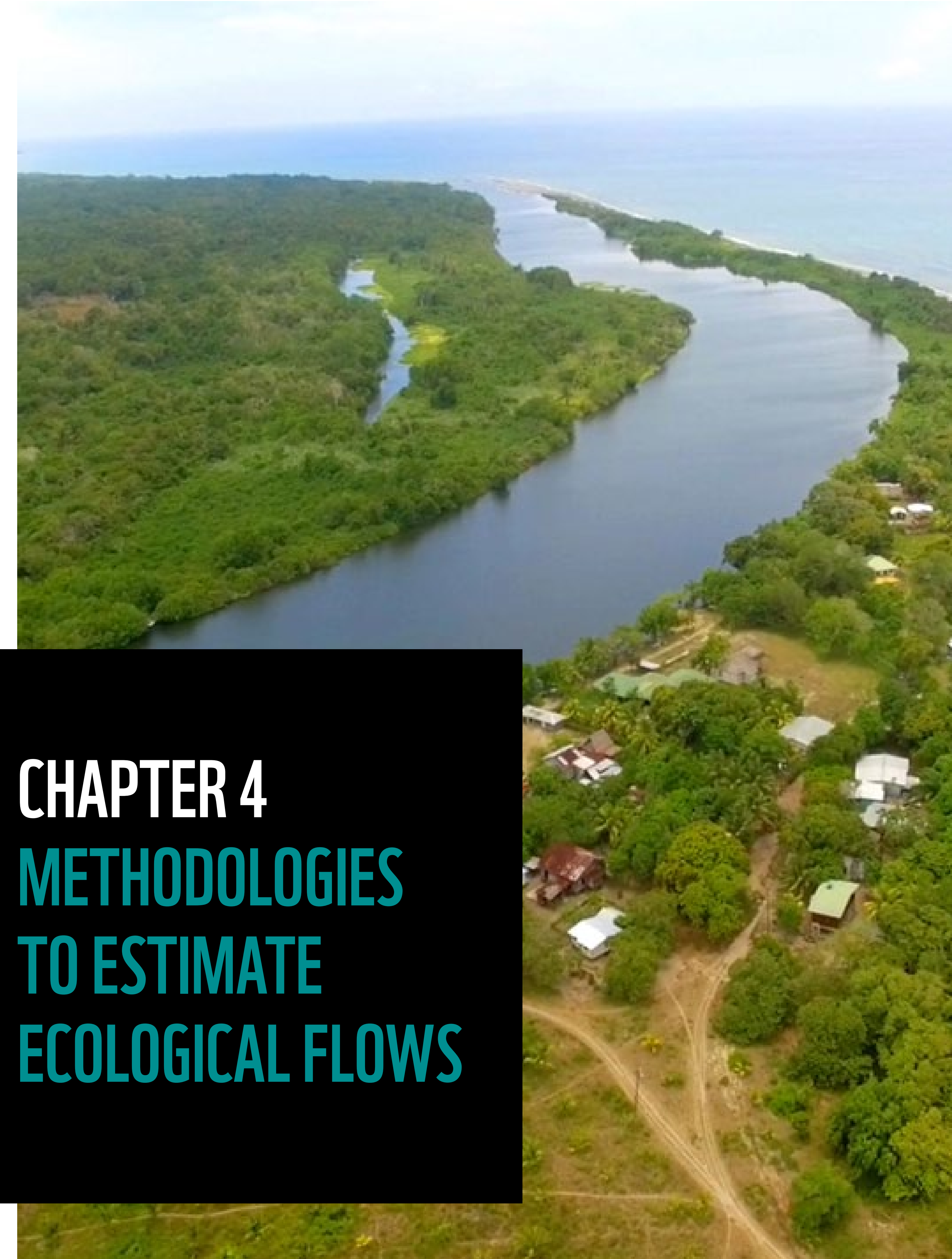
Water pressure is the ratio between the use of water and renewable natural resources. For example, if the renewable resource in a watershed is one million cubic meters and water uses are around 20 million, water stress will be nearly 19 million; that is, 95%. By international standards, 20% means a low to medium level of use. In the context of the Sustainable Development Goals, the way in which States should report their progress in implementing ecological flows is by subtracting ecological flows from the renewable volume of watersheds and aquifers[1].

THE THEORY OF DISTURBANCES

Ecosystems go through random processes that can affect the density of existing species. Flow variability is a characteristic of rivers that is fundamental for them to maintain biodiversity. This variability turns into self-organization processes that correspond to the theory of disturbances. These disturbances alter the physical structure and the composition of biotic (flora and fauna) and abiotic (chemical and physical) elements, to the point that they can change the overall biodiversity within an ecosystem. The main ecological disturbances include fires, floods, storms, earthquakes, and volcanic eruptions, in addition to those caused by human impact and not by natural factors.

This theory is very important in ecological terms and stipulates that the system needs disturbances because, to the extent that they occur, the system will endure natural stress so that only the fittest individuals will adapt and survive. Consequently, only the genes of those surviving and adapting will be transmitted to the next generation. These individuals will adapt and evolve to the new ecological and climatic conditions and will often be better prepared, with increased resiliency. In the hydrological context, hurricanes and droughts are disturbances that place the system under natural stress. In these cases, it is important to note that the stress conditions benefit the whole biotic community and not only one species. This type of elements are the ones that must be underscored in order to achieve intelligent management, above all now that climate change is a reality.

[1] An aquifer refers to groundwater or the water table.



CHAPTER 4
METHODOLOGIES TO ESTIMATE ECOLOGICAL FLOWS

In biological terms, ecological flows are a phenomenon whose unit is difficult to measure. They could be expressed as a volume of water per unit of time, which can be stated in liters per second (L/s), cubic meters per second (m3/s), millions of cubic meters (cubic hectometer) per year (hm3/year), but it can also be expressed as millions of cubic meters (cubic hectometer) per day (hm3/day), per month, per week, etc. They could also be traced by means of this water movement, based on various hydraulic variables that allow a better understanding about what this unit implies.

In is important to recognize that we all depend on water, so that it is essential to be clear about the way in which this resource is being managed. It means not only that a river should maintain a certain flow throughout the year, but also that, in the rainy season, a river should have enough force and expand its flood area, transporting all the needed nutrients and maintaining its use as a waterway. The ecological flow helps to restore natural river functions. Although nature has been considered as a user, the concept should be expanded to consider it as a water supplier. As long as we conserve our watersheds and their ecosystems, the hydrological cycle will be maintained.

NATURAL RIVER PARADIGM

This paradigm explains the processes of the natural hydrological regime (NHR). During the low-water season (from March to April in Guatemala), some species perform their biological processes, such as nesting, growth, and the onset of mating, although they may be different in other species. The various life-cycle aspects of some species are synchronized, such as those of strictly aquatic species like fish and some macro-invertebrates (e.g., insects and mollusks, among others), and also riparian species, such as certain plants and trees. Moderate river overflows (or floods), which sometimes occur from May to October, during the rainy season, fulfill a function for certain species, such as birds. Then, during the high-flow times, from June to September (although this varies depending on extreme events that cause high flows and flooding in different months of the rainy season), this plays an important role in other biological processes of the species living in the watersheds or wetlands.

The paradigm is constituted by five attributes:

• **Magnitude** is how high flow peaks are during the year. These peaks are important because they help to transport sediments naturally, carrying nutrients to portions of the ecosystem when the floodplain expands .

• **Duration** is important because some species require that the area be flooded during a certain amount of time for them to lay their eggs and protect them under water for 15 days or more, for example.

• **Frequency** is important because it establishes how many times these floods or runoffs occur, which are reflected on the flood area or the depth of the river.

• **Timing** defines the times of year when these events occur and the low-water times, which are used for various biological processes.

• **Rates of Change** describe the speed with which these overflows occur. They go hand in hand with flood areas.

These elements have an impact on four characteristics, which are water quality, availability of energy sources, physical habitat, and biotic interactions. All of these constitute ecological integrity. When the regime is altered, these biotic aspects of the system are also altered. What is more, if degraded conditions are permanent, ecological functions, biodiversity and environmental services are lost.

Ecological flow can be measured by means of parameters recorded in meteorological or hydrometric stations. With them, the hydrological regime is estimated, especially the low-water levels. The hydrometric station records the baseflow (groundwater flows), while the meteorological station does not. When no hydrometric station is available, the ecological flow can only be estimated by means of the climatological pattern.

[2] Low water is the minimum flow level reached by rivers in the dry season.

[3] Riparian refers to the vegetation that grows on the riverbanks.

[4] Floodplains are plains adjacent to rivers that flood due to river overflows during the rainy season, when soils are no longer able to infiltrate water.

When holistic methods are applied, there is considerable participation by society and local specialists to sample the area's flora and fauna, which generates increased knowledge. Vegetation is very important because it is one of the indicators of environmental characteristics; above all, because its life phases are adapted to hydrological periods or hydroperiods. The objectives of analyzing the flora in the area could include certain actions: 1) to characterize the structure, composition, and spatial distribution –vertical and temporal– of the river-channel vegetation, including the vegetation in the riparian zone and 2) to link and identify the magnitude, duration, and period of return of high and low flows that aquatic and riparian vegetations need for their functions and services.

In regard to the objectives for analyzing fauna, especially fish, they are aimed at identifying and evaluating the ecologically-important species; identifying the species that are sensitive to flow changes, to adjust the ecological flow proposal; and using fish as organisms that are indicators of the ecosystems' conservation status.

In addition, some of the disciplines constituting the holistic method include hydrology, hydraulics, and geohydrology. Hydraulics is a model for the topographic survey of the river channel, which determines the condition of the channel. Hydrology, on the other hand, is used to establish the flows. These hydrological models predict how this flow would react in a specific terrain in regard to speed, depth of flow (depth from one end of the river to the other), and area. Therefore, it is important to keep in mind that some species depend on these conditions for their biological processes all along the river. If there are variations in these conditions, it is possible that organisms may encounter difficulties in their life cycles.

Geohydrology is the part of hydrology that pertains to water storage, circulation, and distribution in the saturated area of geological formations in the subsoil, considering the physical and chemical properties, their interactions with the physical and biological environment and the impact of human actions. In this context, groundwater samples are taken to understand its dependence on the baseflow, since if the water recharge zone is affected, it will be reflected in the lower portion of the watershed.

Hydraulic models are also useful to determine the specific flows required in an area for certain species to complete their biological processes. For example, for them to mobilize from one place to another for their feeding, reproduction, growth, or nesting. The LiDAR Program is a good tool to develop these models based on the input of data gathered in the field.

Frequently, the floods resulting from rapidly rising rivers are considered damaging to some crops, homes, and infrastructure in communities; but, on the other hand, these floods are of economic value for other agricultural / livestock activities, such as crops and livestock raising, on which many families depend for their livelihoods.

Another benefit of measuring the ecological flow is resolving conflicts among the people who use the water, such as the ones using water for irrigation, and other users, for example, a hydroelectric plant whose installation is being planned for the future. The companies using groundwater flows in addition to surface water are other important users. Likewise, there is another fundamental user: biodiversity, which is an important concern for all of us. Often, biodiversity is not considered a relevant user, but it is the basis of life and the availability of water resources.

The results of ecological flow analyses can be linked to ecological functions, such as the four levels of connectivity, synchronization of biological cycles, sediment transport and the various aspects of primary productivity, among others. Similarly, ecological flows are linked to the environmental services upon which all users depend, such as provisioning (water and food), regulation (floods), support (biodiversity), and cultural relevance (indigenous communities).

The role played by the flow regime or ecological flow implementation impacts the eco-hydrological connectivity, which is composed of four levels: 1) longitudinal, throughout the entire watershed; 2) vertical, the water that infiltrates and recharges the water tables, but it is also the water that evaporates; 3) lateral, the water that runs through the channel and that, during the rainy season, reaches the floodplains in areas where there normally is no water, above all during the low-water season, and 4) these levels are linked with a fourth dimension known as regime. The regime allows the other three levels of connectivity to interact with each other and with the biotic community.

In 2018, as part of the United Nations' Sustainable Development Goals, a series of indicators were launched. One of them refers to water stress (indicator 6.4.2). A guide for this indicator was developed, in order to integrate ecological flows and to have States report the progress achieved in annual implementation of ecological flows.

OBJECTIVES

There are many methodologies to assess ecological flows. However, it is essential to identify the purpose for this measurement and to define what is being sought. Essentially, this determines the path for the assessment of ecological flows. Likewise, it is important to define conservation targets, particularly the species (fauna and flora) and the processes. The studies that are undertaken to determine the ecological flow must span at least one year, so that they include a representation of the entire hydrological regime. It is also important to consider that the characteristics and the needs of each river and each watershed are different. Therefore, the bases for the assessment must consider these factors, since there is no universal formula for every situation. The analysis procedure, that is, the methodological approach, must be based on the natural river paradigm, within the range of flow variability and the components of the ecological flow.

Conversely, as long as the gradient of the biological condition and the impacts or consequences of altering flows are considered, it is possible to perform a systematic, structured, and organized assessment of ecological flows. In these terms, this is a procedure that could be reproduced in any type of flood, both perennial and ephemeral. What changes are the magnitude, frequency, rate and change and predictability components.

The fundamental watershed-management principles are based on identifying the current condition of the river and the specific conservation strategies for that river. To that end, it is important to consider what ecological functions and environmental services are to be obtained from the water resources. Once they have been identified, they can be linked to the various flow components and attributes, in order to design the strategies to protect these regime attributes or components, or to restore them, if that were the case. However, it is also essential to determine the extent to which these flow characteristics want to be protected or restored, considering their conditions, whether they are in a near-natural state or if they are under too much pressure, from the anthropic and hydrological standpoints, in terms of water use.

Regime attributes and components (Table 1) sustain ecological integrity. Components include low, extremely low, and high flows and even small and large floods. These components are analyzed based on their attributes. As a reminder, attributes refer to the magnitude of these flows, their frequency, duration, timing, and rate of change. The other major characteristic within the context of assessing ecological flows is the predictability of flows, in order to forecast their behavior during the different annual and seasonal cycles.

TABLE 1

FLOW COMPONENTS AND THEIR ECOLOGICAL FUNCTIONS

Flow Components	Ecological Functions
Low or Base Flows	**NORMAL LEVEL** • Provide an adequate habitat for aquatic organisms • Maintain adequate levels of water temperatures, dissolved oxygen, and chemical components • Keep water-table levels in floodplains, soil humidity for plants • Provide water for land animals to drink • Keep fish and amphibious animals' eggs suspended • Make it easier for fish to move to feeding and spawning grounds • Maintain hyporheic organisms (those who live in saturated sediments) **DROUGHT LEVEL** • Make it easier to recruit certain plants in floodplains • Purge exotic and invasive species from aquatic and riparian communities • Concentrate prey in limited areas to benefit predators
High Flow Pulses	• Forge the physical character of the river channel, including pools and currents • Determine the size of the river channel substrates (sand, gravel, stones) • Prevent accumulation of riparian vegetation on the channel • Restore normal water-quality conditions after long periods of low flows by washing away waste and contaminants • Aerate eggs in spawning pebbles, prevent sedimentation • Keep adequate salinity conditions in estuaries.
Componentes de caudales	**Funciones Ecológicas**
Floods	• Foster signals for fish to migrate and spawn • Oroginate a new life-cycle phase (e.g., insects) • Allow fish to spawn in floodplains, provide nursing grounds for juveniles • Foster new feeding opportunities for fish and aquatic birds • Recharge the upper level of the water table in floodplains • Maintain diversity in the various types of floodplain forests by means of prolonged flooding (different plant species have different tolerance) • Control plant distribution and abundance in floodplains • Deposit nutrients in floodplains • Maintain species balance in aquatic and riparian communities • Create recruiting sites for colonizing plants • Create physical floodplain habitats • Deposit gravel and stones in spawning grounds • Wash organic materials (food) and woody debris (habitat structures) from the channel • Purge exotic and invasive species from aquatic and riparian communities • Disseminate riparian-plant seeds and fruits • Promote horizontal river channel movement to create new habitats (secondary channels, oxbow lakes) • Make it easier for seedlings to have prolonged access to moist soils

[5] Anthropic: produced or modified by human activities.

Management objectives allow establishing a balance between water use and ecosystem conservation, based on an assessment of ecological importance and the level of water pressure or pressure on the use of resources. The assessment is performed in various layers. The analysis is structured in accordance with the information available and the advances in science in regard to ecological flows, and it is performed based on the habitual flows for various hydrological conditions; that is, for dry, very dry, average, and wet years. This is very important in sites whose regime is extremely variable from the low-water season to the rainy season. The hydrological regime is related to the fluctuation between maximum and minimum (ordinary and extraordinary) flows during a specific period of time; for example, one year.

Ordinary flows. They are the flows occurring in wet, average, dry and very dry conditions. These flows are desirable when there is an extremely variable regime from season to season (low-water / rainy).

Extraordinary flows. These are flows that do not occur all the time, such as peak events or floods, which statistically occur once a year and are known as intra-annual floods. There are also inter-annual floods, which occur over a period of 1.5 years, 5 years, or more. These flows are important because they purge the system of invasive species or clear the channel of plants that cannot adapt to existing conditions.

It is important to emphasize the need to generate information in the field, in each country or region, since every case is unique. This information that is generated is a tool to close the gap between knowledge and public policies, with the aim of addressing the specific hydrological set of problems and the various needs, according to the conditions existing in intermittent and ephemeral rivers as well as in perennial ones. Ephemeral rivers are those that carry water only during very short periods of the year, for example, when tropical storms or hurricanes occur. Thus, in two or three days, there is considerable groundwater recharge; that is, the water table is fed with abundant water. Infrastructure that prevents the outflow or free discharge of flows has a considerable impact on groundwater recharge.

Surface ecological flow is very important from the standpoint of risk management because, to the extent that channels are not obstructed, hydraulic capacity remains intact. This means that, when extreme meteorological events occur, channels can fulfill their role of discharging water quickly. In addition, they fulfill another role, which is to recharge the aquifers that supply water for the various uses.

With regard to the priority of attributes and components, they are equally important. No single one is more important than the others. The difference among them is the biological, ecological, or physical phenomenon that is being assessed. In fact, they are the scientific way of organizing ecological flows in a clear and strategic manner, in order to estimate the metrics and the ecologically relevant indicators for the system, with a holistic approach. For example, if connectivity is being assessed, then magnitude has considerable implications. Thus, the higher the magnitude, the higher the flood levels will rise. If these levels rise higher, there will be increased lateral, vertical, and longitudinal connection. These are three of the four connectivity dimensions.

The above is a good example to understand the fourth connectivity dimension, which refers to regimen or timing. If we increase flows, they will be connected laterally, vertically, and longitudinally, which is normal during the rainy season. However, it is also possible that intermittent rivers run dry during the low-water season. Flows must cease or decrease. Then, this variability in magnitude is the one that

allows the three physical connectivity dimensions to interact. If, on the other hand, macroinvertebrates are being assessed, for example, flow speed may not be relevant. Rather, the speed of the flows affects them because currents sweep them away. What is really important for macroinvertebrates is that soils are flooded so that they can develop their life-cycle processes.

In currents or watersheds that are intermittent or ephemerous, groundwater recharge for water tables is very important for human use. The water that we use in those areas worldwide is mostly groundwater. Thus, in order to analyze recharge, we must first focus on the rainy season, since there will be no recharge in the dry season. If it does not rain and there is no runoff, there will be no groundwater recharge. Furthermore, flows that overflow should also be analyzed, although they depend on the characteristics of the soil and the watershed. In theory, there should be greater recharge to the extent that flows spill over their annual channel. The channel is hydraulically designed to quickly drain the water. Water drains faster at the point where the geographic depression is greater, due to gravity. If one is seeking to manage recharge, then the aim is to retain water as long as possible because, the longer it is retained, the more time there is for water to infiltrate into the soil. Basically, this is one of the functions of floodplains. In this case, analyses should focus on the rainy season and the flood events or pulses and not on low flows.

Each case depends on the phenomenon or ecological process that one wishes to observe. If one wants to analyze, for example, the mobilization of species in search of food, fish could be considered. In this specific case, the longitudinal connectivity should be maintained, so that stretches of the channel do not dry out, depending on the species and their physical needs. Conversely, it is essential to ensure that there is always longitudinal connectivity to make it easier for them to mobilize, with the purpose of their having enough food provisioning or shelter. If it is the rainy season, it would probably be related to reproductive events.

Ultimately, if nothing is known about the system, the most efficient action is to analyze all the components and all the attributes, because we already know that they have a joint function in the system. Consequently, if all of this is included in the desk research , surely its implementation will have a positive effect in the field, with an ecological approach, even if there is no field data, since it is supported by scientific advances and ecological theory.

Another important phenomenon that depends on attributes and components is sediment transport. Even though sediments are sometimes considered a problem when there is an excess of them and they block the channel, it is estimated that a healthy watershed is able to transport the sediments or suspended solids, since it is necessary to transport those nutrients to other reaches of the watersheds. There is also bedload transport, which occur when magnitudes play a more important role than frequency does. Consequently, it is important to know this in order to better understand the role that rivers play and how these attributes and components contribute to the health of the channel.

In summary, after establishing the objective of the study and before selecting the methodological approach, it is advisable to take the following steps before starting to assess ecological flows.

1. Identifying attributes and components

2. Identifying the hydrological conditions of the regime

3. Identifying the ecological functions by component of the hydrological regime (connectivity, synchronization of the life cycles of the various species, sediment transport, re-distribution of the channel beds, water quality, etc.)

4. Identifying ecosystem services and linking them to the attributes and components (water supply for various uses, water-flow regulation, reducing flooding risks, supporting ecosystem-function management, cultural uses for human-recreational purposes).

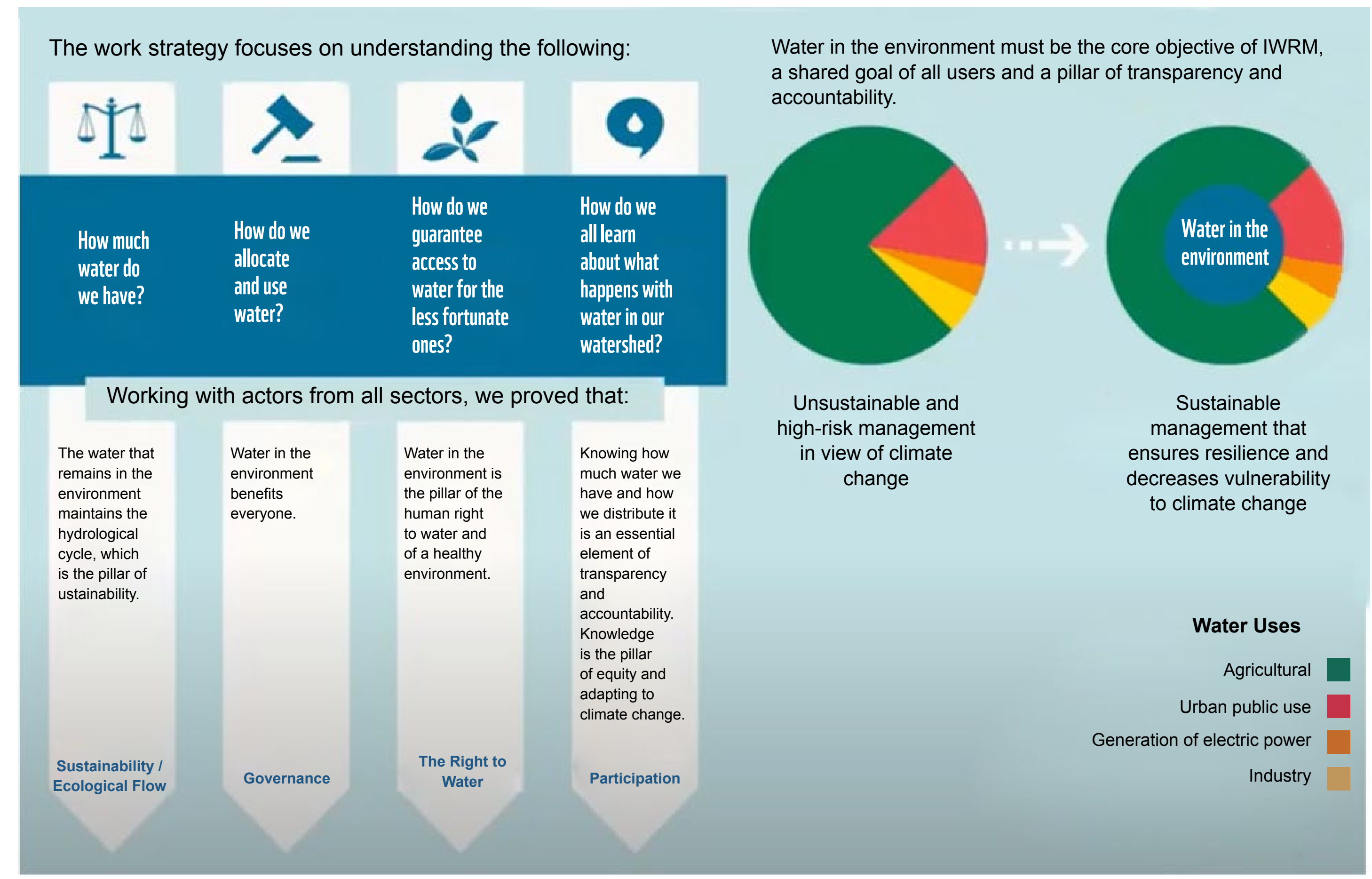
[6] Estudios de gabinete: es una metodología de investigación que recopila información a partir de publicaciones de diversas fuentes.

The principles to perform an assessment of ecological flows is a participative process by various actors. The first step is to determine what kind of river it is and to achieve consensus on the strategy that will be implemented to preserve it. When the conditions of the specific river are clear, it is essential to define if it needs protection or restoration of the natural regime components and attributes and at what level, or from another perspective, the state of the river that is being sought, in addition to establishing whether the focus will be on a stretch of the river or on the entire watershed.

To manage ecological flows based on a holistic approach, a series of actions ensuring the effectiveness of the study efforts, taking into account that stakeholders from various sectors and disciplines will be involved. Bio-physical analyses are obtained from gathering data in the study area. It is suggested that this valuable information be integrated and validated in workshops with experts, with the aim of identifying conservation objectives and estimating the ecological flow. This integration of visions will expedite establishing management objectives and the variables to be analyzed. Once this consensus is reached, a work plan must be developed, and researchers and government officials of relevant entities must be engaged.

It is important for the project to be shared with communities in the area, so as to make it easier to secure the cooperation of all the stakeholders and users, and to help residents understand the purpose of the activities and the importance of the research. Figure 1 shows the process to address the study performed previously to analyzing the ecological-flow data in Mexico.

WORK STRATEGY USED IN MEXICO TO MANAGE ECOLOGICAL FLOWS



HIERARCHAL METHODOLOGICAL APPROACHES: SCOPE, ADVANTAGES AND CONSTRAINTS

There are over 200 methods to perform ecological flow assessments, but the most important factor when considering them is to understand the objectives of each one of these methods because, based on these objectives, one can analyze the assumptions behind each method.

The strategic approach consists of acknowledging that, when engaging in water planning, there are desk-research methods that are currently considered simple and perfectly valid approaches to perform these assessments. This first layer of methods is used for planning purposes. Then, maybe the Tennant method or the methods based on reference values to protect a certain percentage of mean annual runoff or also based on flow-duration curves would be sufficient.

There are other types of methods that require more detailed periodic information that measure whether desired ecological flows are achieved or not. This second layer of methods is also known as hydrological methods or eco-hydrological methods. They consist of an in-depth analysis of the regime and often also of managing existing infrastructure to imitate the ecological-flow regime. They evidently require a greater level of effort, more people involved in the assessment, and greater knowledge.

A third of fourth layer could be applied at those sites where hydrological or eco-hydrological methods are not sufficient to ensure that the regime is being met or where there are very high conservation values in the lower watershed, for example, at a Ramsar site or a protected area. In addition, it is possible that there is also an infrastructure project. In those cases, a more detailed analysis is required. In short, it means that it is necessary to design a field campaign, a monitoring system to be able to go out to the field, gather information, and perform the assessments. This refers to putting forward various work hypotheses and to start testing them based on the indicators and the information gathered in the field, with the purpose of making decisions and finding solutions.

[7] A Ramsar site is a wetland site designated to be of national importance under the Ramsar Convention.

Broadly speaking, there are three major types of hydrological methods. On the one hand, there are those with reference-value cut-offs for water planning, such as the Tennant method and the flow-duration curves, but there are also other hydrological desk-research methods that are very advanced, have a high level of detail, and are generally quite consistent.

The second cut-off is also known as methods that simulate habitats o other hydrobiological methods, such as PHABSIM (Physical Habitat Simulation) or IFIM (Instream Flow Incremental Method), for example. And lastly, the holistic methods such as DRIFT (Downstream Response to Imposed Flow Transformations) and the Building Block Methodology (BBM).

These types of methods are generally very consistent, with this strategic approach to assessments. Hydrological methods are the most cost-efficient ones. Their application is typically a hundred times less expensive than the one for a holistic or systemic method. As these types of methods advance, the need for human and financial resources will increase, and consequently, the uncertainty gap will decrease due to the considerable amount of information that they generate.

In order to exemplify some cases, the method used to report on indicator 6.4.2 of the Sustainable Development Goals is GEFIS (Global Environmental Flow Information System). This is a method based on flow-duration curves. These curves show that, statistically, different flow magnitudes occur or have occurred during certain percentage of the time throughout its history. Thus, flow-duration curves are a very important tools in hydrological terms and they are also extremely important for project design. The flow duration-curve method essentially assumes that if a proportion of this flow-duration curve is kept, these ecological functions and the ecosystem services associated with them will be protected. This proportional protection of the curve depends on the level of conservation desired.

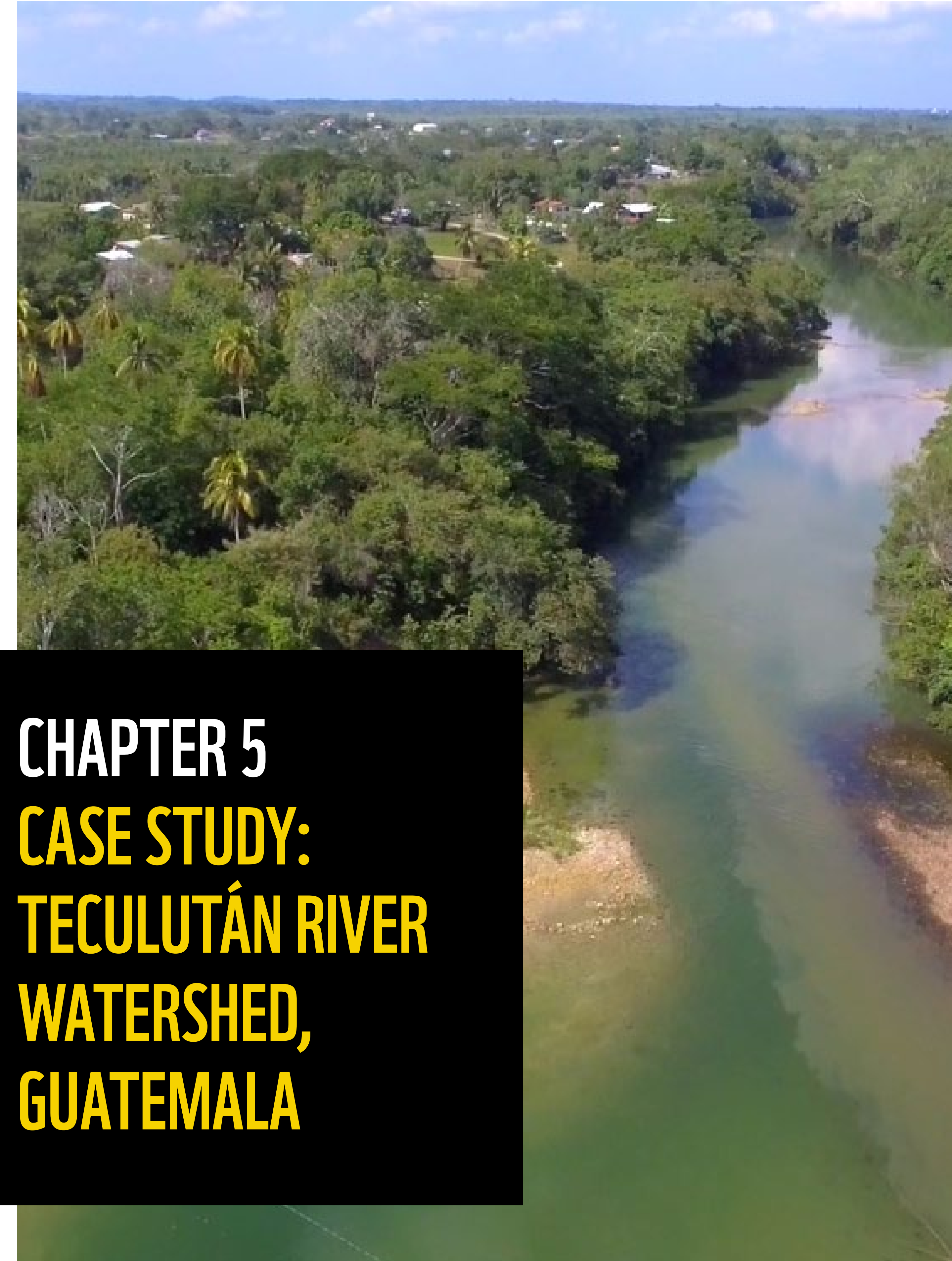
There are other hydrological methods that work with regimes, which accurately determine the various regimes to conserve rivers under different hydrological conditions. Hydrobiological methods are those that model potential useful habitats, that is, water in terms of volume per unit of time (flow), since it carries nutrients as well as water.

Lastly, there are the holistic or ecosystem methods. These are more complex, since contributions are high-level and multi-disciplinary and involve specialists in hydrology, hydraulics, geomorphology, geohydrology, water quality, vegetation, fauna, and social aspects. The information generated by each one of these disciplines is systematized so that flow suitability can be discussed effectively. The order of this panel of experts' discussion topics is very important: 1) Ecological Importance and Sensitivity; 2) Current Ecological State and Desired State; 3) Proposal Development, based on recession curves (concepts and scenarios), to put forward a proposal for dry years, a proposal for average years and a proposal for flood regimes.

In other countries, there is another type of approach, which is using the flow based on ecosystem services and hydrological estimations, measured in percentages of use. By defining these percentages, it is possible to determine how flows behave, from the upper to the lower reaches of the watershed. These are the uses that will allow responding to the need to maintain ecosystem services for each one of the segments.

Cost can be a determining factor to choose the approach to be used. It ranges from USD10,000 or less (in desk-research methods) to up to USD100,000 when creating a panel of experts whose field work must be funded in order to generate the information needed. As reference, the budget that was implemented in the case of Usumacinta, Mexico, was USD150,000, in addition to USD25,000 for a hydraulic study on sediments. A holistic approach was used as methodology.

To reiterate, it is important to understand the objectives of each method that will be used. They are the basis for the approach to yield the results that are sought. Notwithstanding the method that is selected, implementing ecological flows is the first in a series of activities that have been identified to stop and even revert the dramatic curve showing the loss of diversity that depends on the hydrological regimen.



CHAPTER 5
CASE STUDY: TECULUTÁN RIVER WATERSHED, GUATEMALA

Guatemala is a country that depends on water resources. There are 38 watersheds, 314 sub-watersheds, and 2,391 micro-watersheds in the national territory. This water capacity makes water reserves a strategic component of national water security in the short and long terms, since they are based on an allocation (ecological flow) for the system at these critical sites. This allocation ensures ecological services and water sources, and the remainder is subsequently distributed for other uses.

In Guatemala there are:

38
watersheds

314
sub-watersheds

2,391
micro-watersheds

Water reserves are defined as critical sites to gather, regulate, and recharge water, as well as to ensure ecosystem connectivity, which is essential to social, economic, and environmental systems, due to the quantity and quality of water that is incorporated into local and regional hydrological systems (watersheds). This is precisely why water must return to the environment. It underscores this water capacity as a source of supply for priority ecosystems (protected areas and Ramsar sites), populations, and economic activities. It also decreases the risk linked to extreme hydroclimatic phenomena derived from climate change.

The methodology to manage Water Reserves in Guatemala includes the data from the three attributes (water catchment, recharge, and regulation), in addition to two important conservation elements, which are protected areas and Ramsar sites, due to their connectivity, biodiversity and regulation components. All these elements are included in the Map of the Strategic Water Reserves for Guatemala. According to the priorities of this map, the user with the highest priority should be the environment, followed by the population, and lastly, the various sectors. There are some initiatives in Guatemala's southern coast, where rivers are nearing the sea, but it is still not known if that is the amount of water needed by the ecosystem, aquatic or land biodiversity and flora.

CONTEXT

Even though the ecological flow aspect is being addressed, there is no law regulating water, no hydrological planning, no methodology to assess components nor territorial planning as guides to work on projects that use water resources. Thus, the problems are many and affect the social, environmental, productive, and industrial sectors. Most projects use river flows, for example, hydroelectric projects and some agricultural projects; above all, single-crop farming that sometimes use up to 100% of river flows. Hydroelectric plants, on the other hand, return the water that they use to the river. The problem is that they leave a stretch of the river without any water, particularly, the tract between the dam and the powerhouse. In contrast, agricultural projects do not return the water that they use in their productive processes. In the end, though, both uses have an impact on water resources.

In Guatemala, there is no water-administration entity either and there are no data to estimate flows. It is worth noting that the only legal instrument currently in force are the environmental impact studies to influence the adequate use of water resources. However, the Ministry of the Environment and Natural Resources (MARN) does not have any norms or standards requiring users to surrender a percentage of the flow that they use to the environment. Similarly, equity in water management constitutes a crucial lynchpin in developing and implementing public policies that are aimed at promoting equitable distribution of the costs and benefits of water use and the involvement of all the users in managing water resources. Depending on how water is used, it will be necessary to guarantee access to water for today's less fortunate populations and future generations.

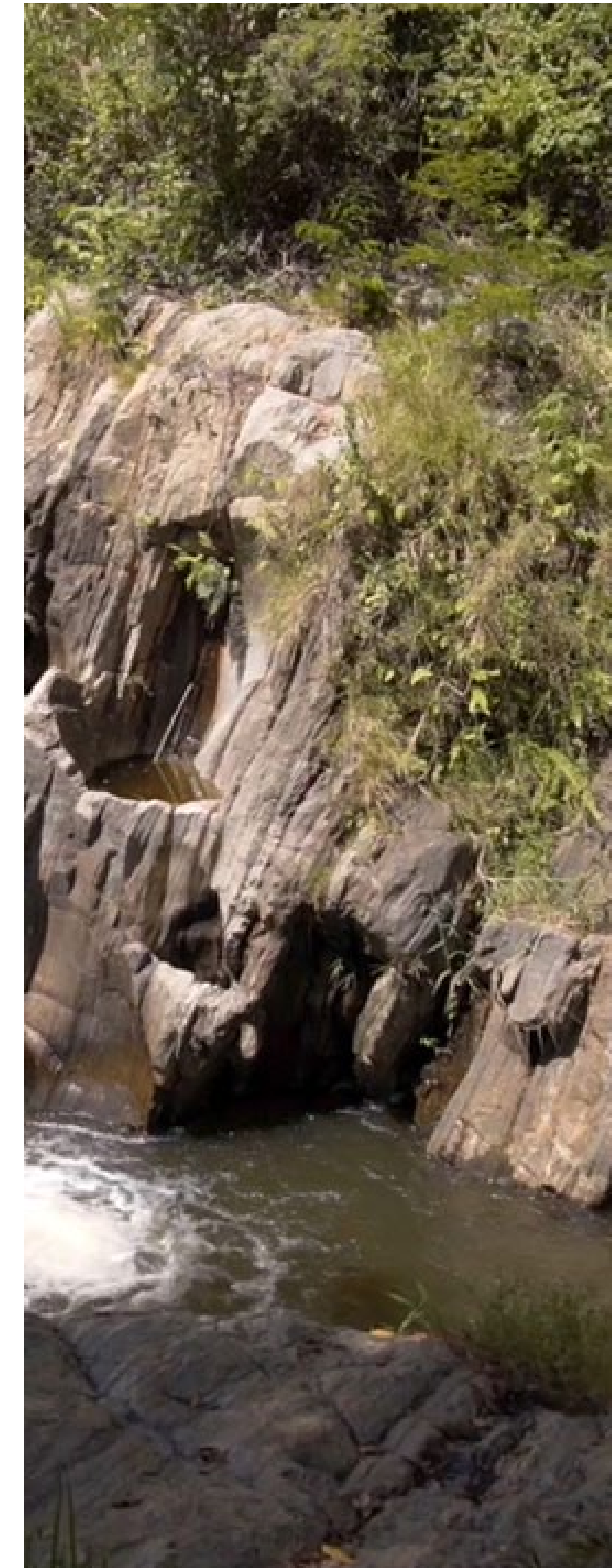
Planning water resources is very important worldwide, and to that end, it is necessary to have relevant information about the territory. There are data from the 1970s, when master plans were developed for irrigation, hydroelectric plants, and other areas in the national territory. The Ministry of the Environment and Natural Resources (MARN) is working on this process with the Internal Water Reserves Committee that was constituted in 2020. Jointly with MARN, training was provided to strengthen capacities at the national level to implement water reserves in the country by means of ecological flows.

In order to make the most of water resources, one should always bear in mind the amount of water in the watershed. With this value, a regimen to distribute water and the way in which the resource will be used can be established. In Guatemala, other countries' ecological-flow parameters or thresholds have been used, even though they have been used incorrectly. An example of this are the environmental impact studies performed for hydroelectric plants. However, there are no technical government criteria to define the amount to be used and the amount that should be allocated to biodiversity and the human population whose livelihoods depend on water resources.

Similarly, there are no norms to define the quality of water resources, although there is a norm for wastewater disposal. However, the norms only establish that the company cannot discharge a certain amount of wastewater, but there are criteria to verify the conditions of the river. In terms of ecological flows, the ecosystem should be the main user of water resources, but this does not happen in Guatemala. Sometimes, the ecosystem is the last one to use water.

TECULUTÁN

The water provided by the Teculután river is the driver of the economy in this region, in addition to having considerable value as a tourist attraction. There are over 25 intakes or surface water catchments used for various purposes, such as human consumption, bottling plants, irrigation, recreation, and tourism.



The water provided by the Teculután river is the driver of the economy in this region, in addition to having considerable value as a tourist attraction. There are over 25 intakes or surface water catchments used for various purposes, such as human consumption, bottling plants, irrigation, recreation, and tourism. This watershed is possibly the one with the most irrigation systems and the one that generates the greatest economic resources, but the volume of water being extracted is considerable. Indeed, the flow of the Teculután river has decreased over time. This is one of the rivers in the southern reach of the Sierra de las Minas that contributes the greatest amount of good-quality water to the Motagua river. The few measurements performed on the Motagua river during the dry season show that from El Rancho and Río Hondo (the driest portion of Sierra de las Minas) its flow doubles because it receives all the water from Sierra de las Minas. However, although the Teculután river provides good-quality water to the Motagua, the problem is that it is full of fecal coliform bacteria.

Another problem affecting this watershed is the impact of forest fires in the upper reach of the watershed. Surely, in the future, these flows will be reduced due to poor rainfall distribution. On the other hand, the watershed depends on cloud forests and thus, its conservation as a protected area is very important. In addition, the flow of the Teculután river is changing due to the surface and groundwater that decreases considerably during the dry season, as a result of climate change.

Currently, there is an environmental instrument for the Teculután river included in a management plan, whose objective is the sustainable management of the sub-watershed, where water resources are the ones that matter the most. This is a methodological model to estimate the ecological flow and it is strategic in nature due to the importance of the Teculután river sub-watershed. The ecological flow instrument determines whether or not the sub-watershed is well managed. It is important to underscore that in this sub-watershed there is an incipient effort at local organization, in which these types of initiatives could be consolidated.

Based on the need for some kind of territorial planning in the Teculután sub-watershed, management plans that prioritized monitoring the Teculután river were developed (work on the Pasabién river was completed one year later). This was done due to the information that was available and the daily flow database (Figure 2). However, the management plan was still lacking quality and quantity measurement indicators. The fact that there was data available for the 1994-2016 period, whose source was the Las Minas hydrometric station, was an advantage when selecting this river as a good place to implement the actions to estimate the ecological flow.

This is the only place where, besides having data, the population shows some willingness to work with local entities. All the activities were integrated into this management plan, and it was considered important to gather the data on the ecological flow. Thus, consideration was given to implementing a pilot project to measure the ecological flow, based on the experience and the methodology that WWF had applied in Mexico. As reference, it is also interesting to note that Mexico has an entity to administrate water resources. This entity has an obligation to provide water to all those who request it. Consequently, WWF Mexico based its efforts on the strategy of requesting the State, through the Secretariat of the Environment and Natural Resources, to represent the environment and to have water allocated to it in order to cover its needs.

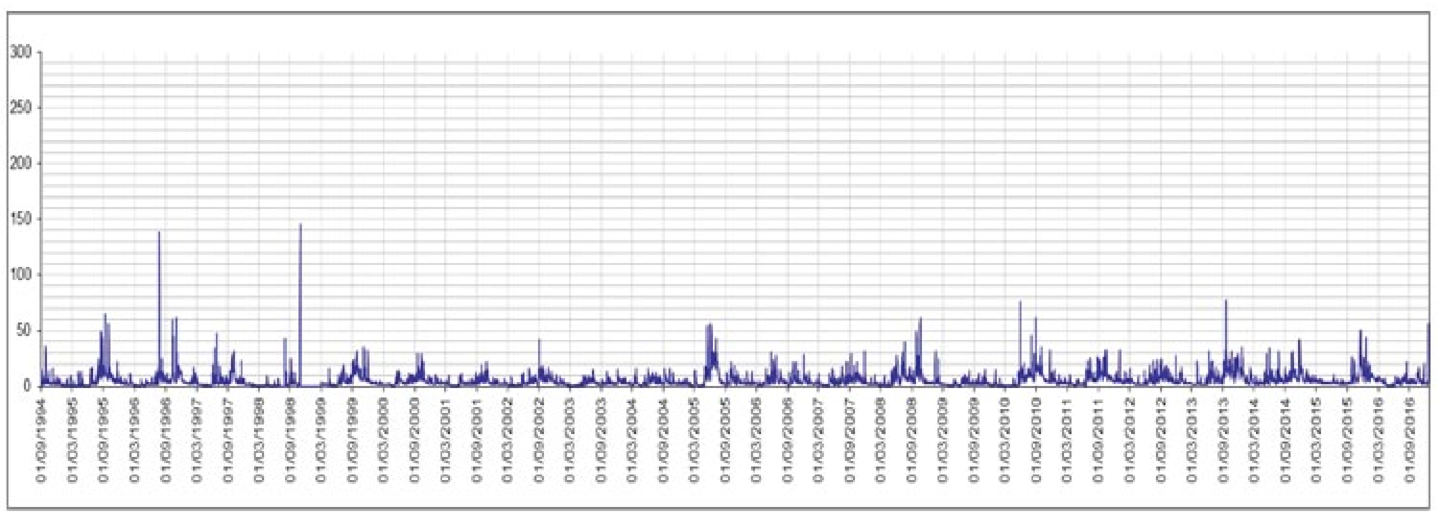
WWF's proposal to estimate ecological flows is valuable because it is a dynamic process, which considers variations throughout time (from January to December); that is, whether it is a wet or a dry year.

This proposal had a technical approach that would become a referent so that MARN would have the best elements to make decisions and to incorporate it into the Guatemalan legislative framework as a norm (water quantity and quality) to be complied with by technicians authorizing environmental impact studies. In addition, it can be useful to resolve local conflicts and can be used by the entities in charge of achieving conservation objectives, whose goal is to defend the interests of maintaining biodiversity.

The results of the hydrological measurements of the Teculután river were obtained based on the records of mean daily flows from the Las Minas hydrometric station –which gauge river runoff– for the 1994 to 1998 and 1999 to 2017 periods (Figure 2). Annexes I and II show the monitoring locations.

FIGURE 2

FLOW RECORDS AT THE LAS MINAS STATION IN THE TECULUTAN RIVER



The total volume of the Ecological Flow established for the Teculután river is shown in Figure 3. These results were obtained in accordance with the environmental-objective matrix for ecological importance and water pressure (Figure 4), which corresponds to the Mexican Norm, Appendix Normative D , which establishes the procedure to determine the ecological flow in hydrological watersheds.

[8] Mexican Norm NMX-AA-159-SCFI-2012- Establishing the ^rpcedire to Deterine the Ecological Flow in Hydrological Watershed. Page 79. https://www.gob.mx/cms/uploads/attachment/file/166834/NMX-AA-159-SCFI-2012.pdf

FIGURE 3

TOTAL VOLUME OF THE ECOLOGICAL FLOW FOR THE TECULUTAN RIVER

hm^3	ENVIRONMENTAL OBJECTIVE			
	A	B	C	D
TOTAL	105.8	81.0	69.9	60.0
% MAR Mean Anual Runoff	55.8	42.8	36.9	31.7
Flows m^3/s	1.872	1.099	0.818	0.603

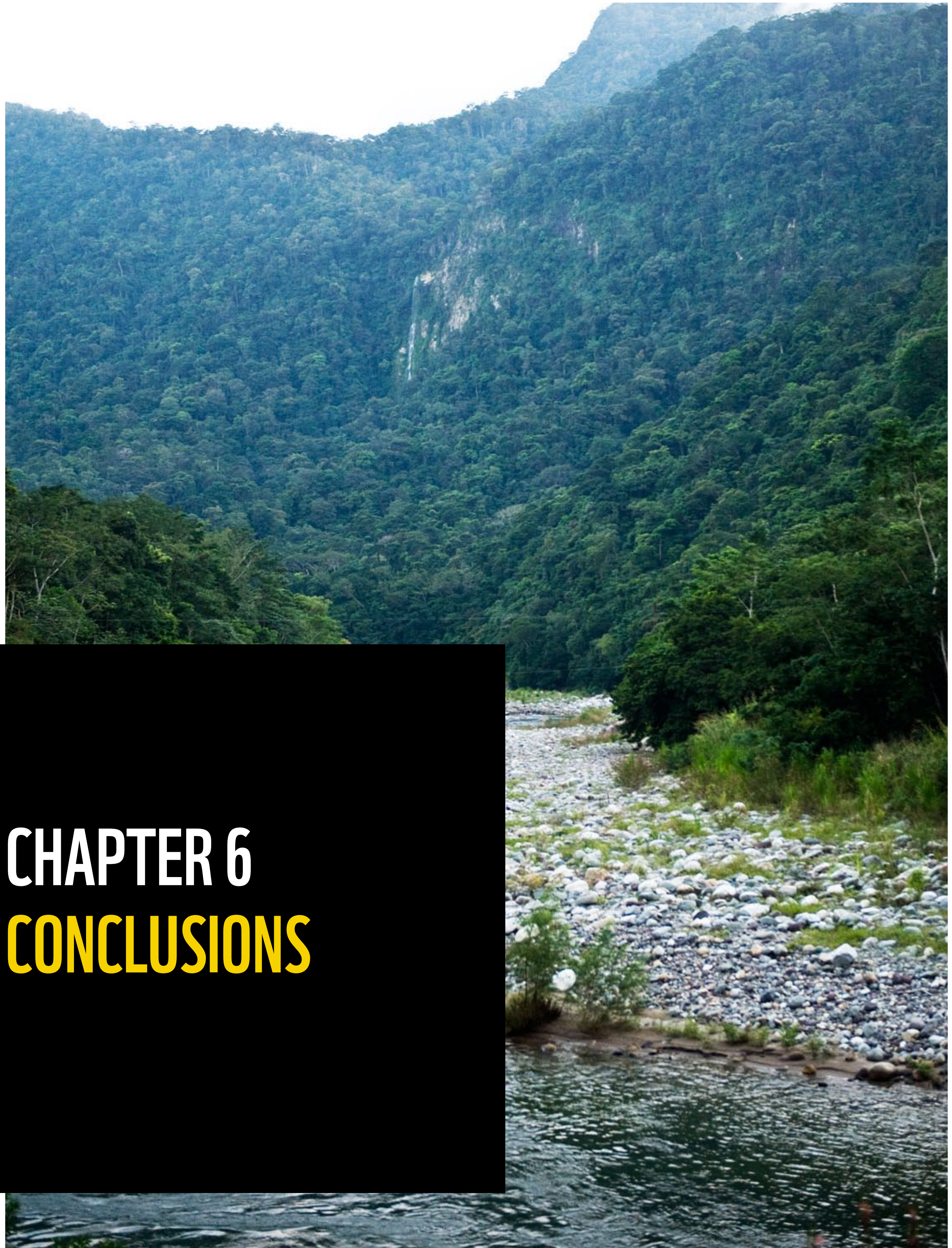
FIGURE 4

WATER PRESSURE ON ECOLOGICAL IMPORTANT AREAS

ECOLOGICAL IMPORTANCE				
VERY HIGH	A	A	B	C
HIGH	A	B	C	D
MEDIUM	B	C	C	D
LOW	B	C	D	D
	LOW	MEDIUM	HIGH	VERY HIGH

PRESSURE FROM USE

The flow of the Teculután river is strategic; thus, addressing the issue is extremely important to consider it as a model that shows that it is possible to undertake adequate management of water resources in Guatemala. For this effort to be successful, Guatemala must initially define what it wants to achieve with it ecological-flow agenda.



CHAPTER 6
CONCLUSIONS

Even though studies on the flows in Guatemala are already being performed, at present there are information gaps. Data have been accumulated based on studies undertaken in the region, so that it has been possible to predict how rivers will behave. Water plans developed to date in Guatemala have been based on available inputs. We must have more information to be able to work on a more accurate planning process.

After determining the ecological flow parameter, it is important to share it, and consequently, to improve the decision-making processes. To this end, it is essential to make this information on watershed water flows known to all stakeholders.

To the extent that we are able to identify the various conditions and to evaluate the path of impact, as well as the climate-change scenarios for the regime, we will be able to design several management strategies, in accordance with specific hydrological conditions. This is known as resilience management or building, and it seeks to ensure that all those depending on the ecosystem can adapt to these impacts.

Perhaps the lack of a law on water in Guatemala could be an opportunity to develop it with an integral approach that contains all the components that are key for its effectivity. In any case, ecological flow experiences should be developed first so as to allow generating this information that can enrich the discussions on this topic by the legislative body. It is possible that this lack of water legislation is an advantage that will allow considering not only water resources, but also the other territorial instruments, such as territorial planning. Integrating additional aspects of the territory will allow generating a norm that is strong enough to address the various topics that need to be regulated.

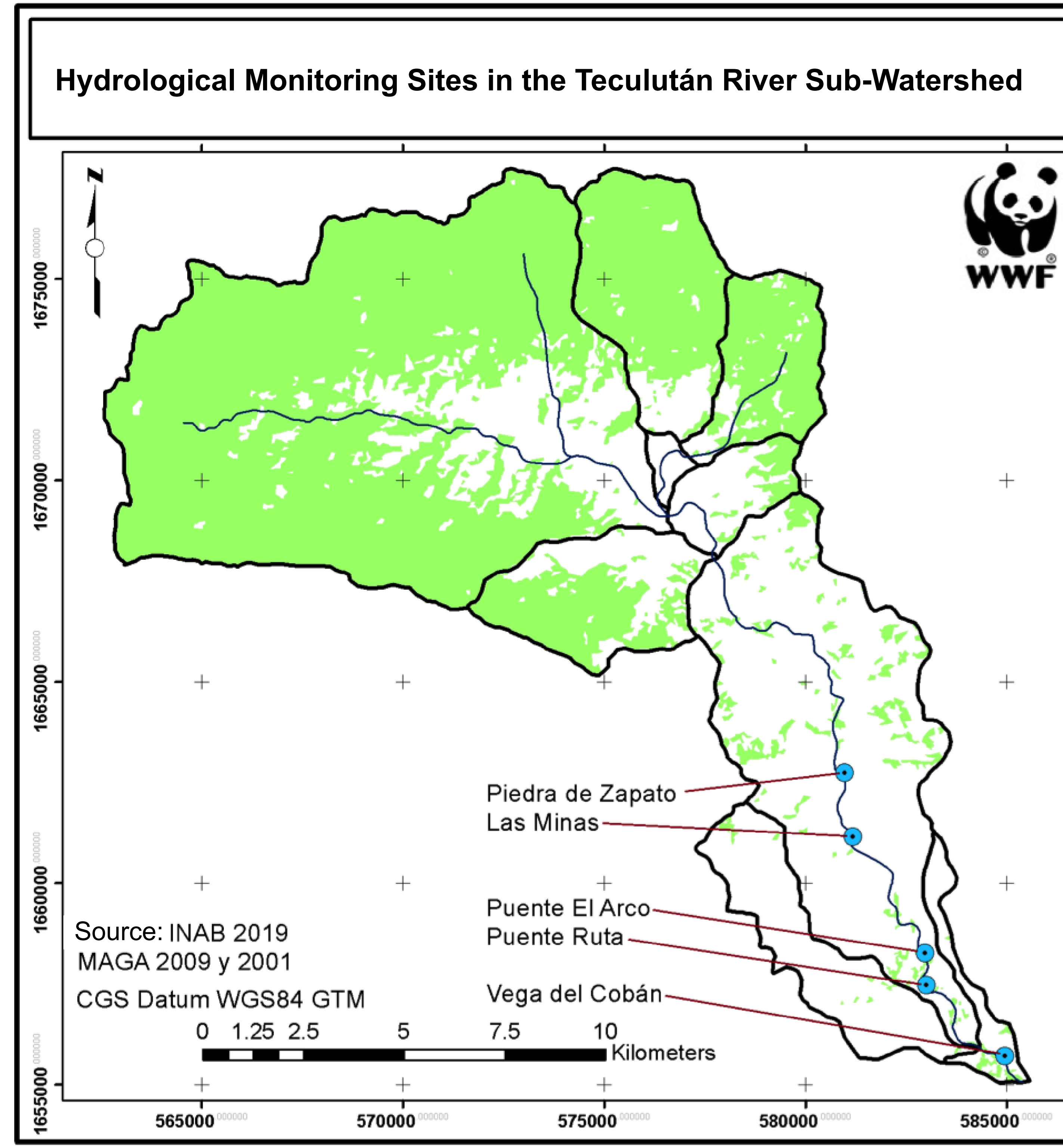
In regard to establishing legislation on water resources, there are three broad spheres. On the one side, there is the evaluation of ecological flows. The assessment of ecological flows is a purely technical-scientific matter, by means of which the various aspects of water regimes are analyzed. There are different strategic approaches to undertake it in a clear, objective, transparent and efficient manner. Once the assessment has been completed, the next step or the second sphere is to share those results with the people living in the watershed for decision-making purposes. In fact, they are the ones that should be aware of the ecological state of the watershed and the pressure it is under. Based on that, they should determine how they want to conserve it and what they want from the watershed in the future. Then, there is the third sphere, which is the implementation phase, in which adaptative management is developed to feed the evaluation, sharing and execution cycles. These three phases constitute a very dynamic and interactive chain among many actors, which include technicians, scientists, politicians, the productive sector, and all those others who incorporate into this process.

It is a fact that the loss of natural flow regimes alters the productivity of those communities that live in the lower reach of the watersheds, since the water-scarcity conflict is becoming increasingly greater. Without ecological flows, communities are at risk of losing their food and environmental security. Integrating ecological flows into watershed development makes it possible to secure the means to achieve consensus in decision making in order to counterbalance infrastructure development (for agriculture and hydroelectric power), livelihoods, and ecosystems.

In general terms, implementation of ecological flows in practices, policies, and legislation allows society to generate knowledge and capacities and to create the institutions that are necessary to implement an integrated water-resource management, in order to be able to adapt to climate change. Most certainly, this requires communication, the participation of actors, awareness raising, adaptative management, and sharing the benefits that flows bring to communities and nature.

ANNEX I

HYDROLOGICAL MONITORING SITES IN THE TECULUTÁN RIVER SUB-WATERSHED



ANNEX II

PHOTOGRAPHS OF THE SUB-WATERSHED STUDY AREAS TO ANALYZE THE ECOLOGICAL FLOW OF THE TECULUTÁN RIVER

Lower reaches of the Teculután River. Óscar Avalos, 2019.

Water conveyance system for human consumption. Óscar Avalos, 2019.

Catchment dams for household consumption. WWF, 2007.

Water conveyance system for human consumption. WWF, 2009.

Conveyance channel for agricultural and livestock use. Óscar Avalos, 2017.

Flow rate and water quality measurements at Las Minas Station.
Óscar Avalos, (left) 2019 y (right) 2009.

Flow Monitoring Point La Piedra en el Zapato, circa 2010.


View of the Teculután river during the dry season, at El Arco bridge.
Óscar Avalos, 2019