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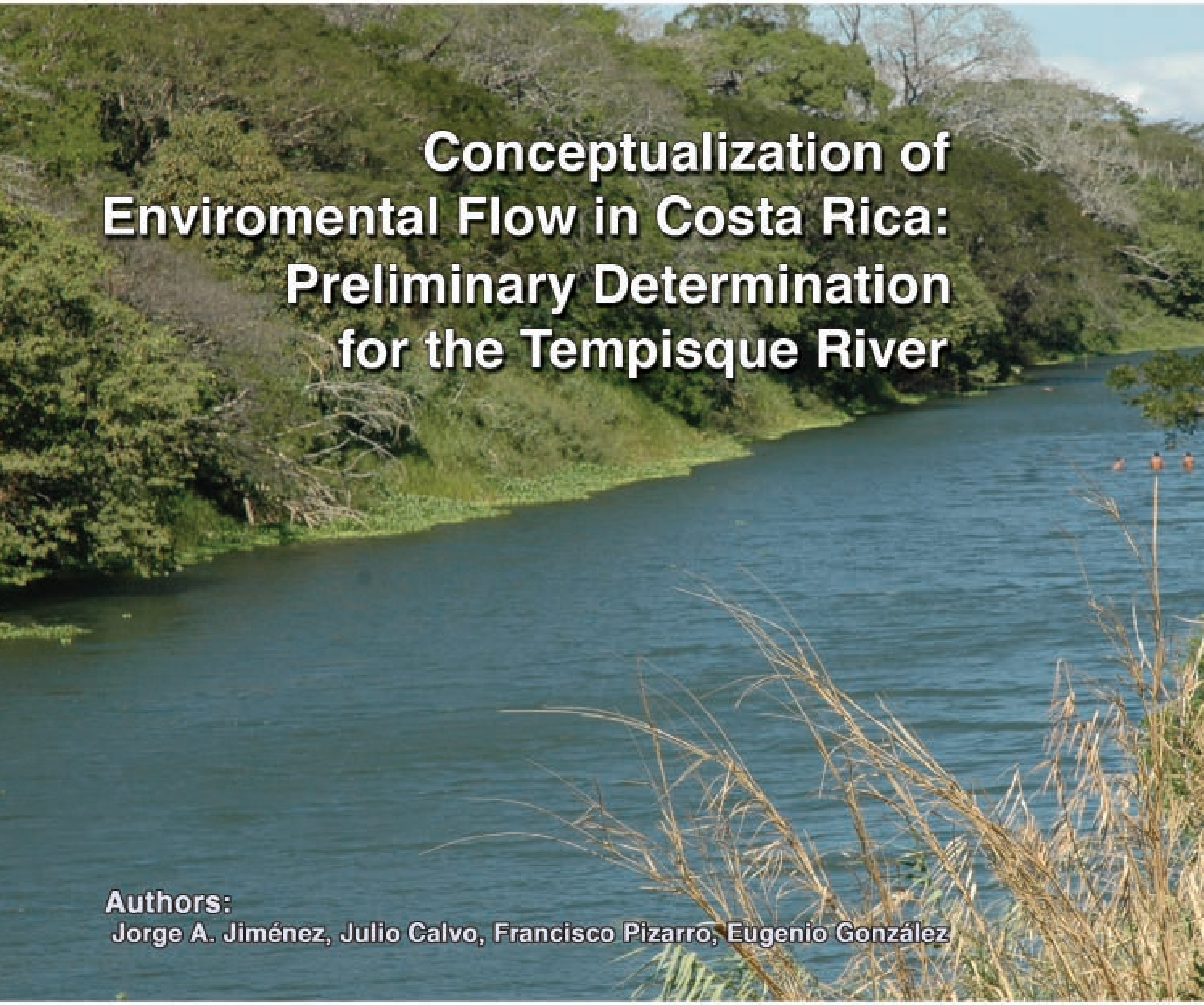

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1. Introduction

Costa Rica receives more than 167 km^3 of rainfall each year, making it a country rich in water resources. Subtracting evapotranspiration, approximately 112.4 km^3 remain for its 34 watersheds.

Most water for human activities comes from superficial water, and is mainly used for hydropower, domestic consumption, irrigation and industrial purposes. On the other hand, nearly all surface runoff has an important degree of contamination. Almost 20% of this derives from urban wastewater (of which only 3% is treated), 40% from solid and industrial waste (with some heavy metal load) and the remaining 40% from the agricultural sector.

The Costa Rican population, with an annual growth rate of around 2.5%, demands an average 28 km^3/day, of which 9.3 km^3 are utilized for human consumption. As the quality and availability of water for consumption and other uses diminish, there is less and less for other users, such as the environment.

How much water should be preserved in order to maintain natural ecosystems depends on many factors. Most definitely, it is a choice made by society, a political decision. Indeed, the essential thrust of the concept of **"environmental flows"** is on consensus-building among the different users as a mechanism to determine how much water should be preserved for natural ecosystems.

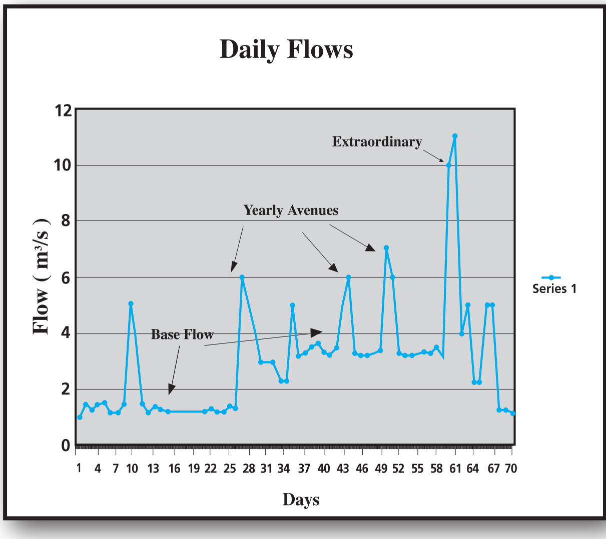
Environmental flow is defined as the quantity of water- expressed in terms of magnitude, duration, seasonality and frequency of flows -and the quality of water- expressed in terms of ranges, frequencies and duration of the concentration of key variables- required to maintain a desired level of health in the ecosystems.

In general, efforts to maintain environmental flow in a basin seek to ensure sufficient quantity of water, distributed according to the natural water regime, with physico-chemical and biological parameters of water quality at appropriate levels. The idea is to preserve the character, extension and condition of aquatic and riparian habitats suitable for sustaining viable biotic populations at a level where they would maintain ecological processes ensuring the goods and services society expects from the ecosystem.

The concept of environmental flow has various key aspects. First is the notion of hydro-period or flow regime. River flows have regimes to which biotic populations have adapted over millions of years. The flow regime is composed of the following elements:

1) Base flow, or the volumes of water present most frequently during the dry season or rainy season

2) Yearly avenues, or relatively brief discharges of large volumes of water. These yearly avenues have a strong influence on periods of reproduction, migration and germination and growth of seedlings in the riparian zone and alluvial plains. Other results are the renewal of water quality and flushing out of the river channel, since yearly avenues tend to restructure sediment beds in the rivers and produce seasonal fluctuations in the habitat of many benthic species.



3) Extraordinary avenues. Because of their volume and force, they sculpt the shape of the river channel and re-distribute heavy materials (rocks and boulders) on the riverbed. These are the avenues that deposit sediments on the flood plain, maintaining soil fertility and recharging moisture in the alluvial plain. These strong floods are also responsible for disseminating seeds and eggs and thus for determining species distribution on the alluvial plains.

Alterations to the streamflow can be either direct or indirect. In Costa Rica, direct alterations are generally caused by the construction of flood control works, diversion of rivers for irrigation purposes or by dams and reservoirs. The most common indirect alterations are due to urbanism, intensive farming, deforestation and discharge of effluents and other wastes.

In the majority of the country's basins, the quantity, quality and patterns of streamflows have been altered. Watersheds have been deforested and change in land use has impacted on the quality of runoff, increasing the amount of sediment in suspension and the concentration of agrochemicals, sewage and other effluents in flows.

Figure 1. Alterations, either indirect from land-use changes (left) or direct, from abstraction (center) or drainage (right), affect the quantity and quality of water in the courses.

An important interbasin water transfer project (the Arenal-Tempisque irrigation project) diverts waters from the Caribbean slope and drains them toward the Tempisque River basin, on the Pacific slope. Diverted flows are discharged according to needs for generating hydropower, with no attempt to follow natural drainage patterns in the Tempisque basin. This unsynchronized discharge alters both volumes and flow regimes, impacting the river ecosystems and associated habitats.

Biophysical changes produced from the flows and subsequently in associated aquatic ecosystems affect people's livelihoods by curtailing anticipated goods from those ecosystems. Examples of such goods are drinking water and fisheries.

Likewise, these changes also restrict services provided by the ecosystems, such as water purification, aquifer recharge, flood mitigation, recreational opportunities, transportation routes and microclimate.

2. How is the Environmental Flow of a Basin Defined or Set?

The process of setting environmental flow in a basin will relate to the degree of "environmental health" we wish to maintain in the basin ecosystems. This is a societal choice and thus depends on political processes in a region. In other words, the concept of environmental flow is not aimed at maintaining pristine ecosystems and accepts that other users require water. A process of consensus building and informed decision making must take place to define the level and quantity of water that will remain available for ecosystems.

Ecological values will not necessarily be the most important for a society, and a balance must be struck between ecological requirements and other types of uses. However, during this process it is important not to eliminate options for future generations by implementing actions that produce irreversible changes.

As a first part of the flows setting process, basic values for decision making should be established. Do we want to maintain some degree of functioning for aquatic ecosystems? What degree? What outcomes are expected? What are the costs and benefits?

Allocating different water uses is a participatory decision (central and local governments, the society of the users and environmentalists.) The main constraint in environmental flow setting in Costa Rica is the scarcity of both technical information and mechanisms for obtaining the genuine participation of all stakeholder sectors.

To obtain effective participation political momentum must be generated, and for this the media is of utmost importance. Decisions about flow assignment should be embedded in guidelines generated by a comprehensive basin-wide management plan that weighs the requirements of the different user sectors.

Reaching a consensual outcome demands multisectoral cooperation, making techniques for conflict resolution very appropriate in these processes. The production of hydrological, chemical, socioeconomic and ecological information about the flow in question is fundamental. At the same time, technical capacity must be built within the state agencies responsible for designing and implementing measures.

One of the critical factors that should be taken into account when determining environmental flow is an understanding that the regime to be generated must match the one species have evolved with and which is coherent with the life cycles of most of the species. It is also vital to understand that the waterway (and associated habitats) is in geomorphologic balance with the existing flow. A reduction in flow is likely to produce more sedimentation, and an increase will cause erosion of the river channel.

Another critical factor to consider is the close relation between water quantity and water quality. Lower streamflow means less dilution of substances dumped in the river, or that water temperature can rise when depth is shallower. The parameters established to define quality of environmental flow should be based on data from non-impacted sites or on international standards.

3. Methodologies for Setting Environmental Flow

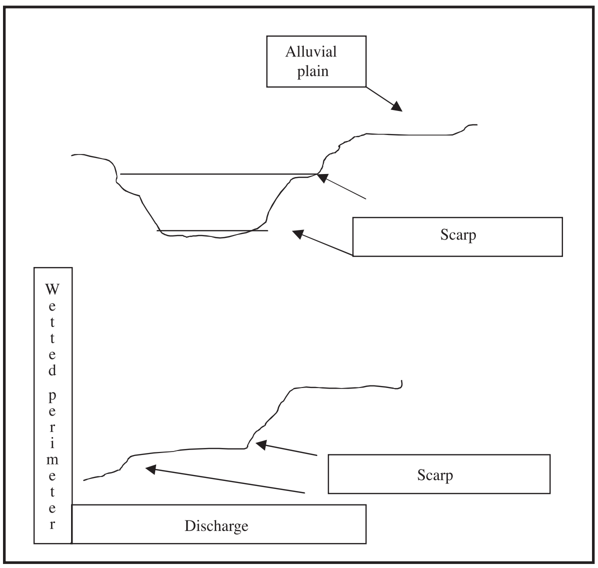
There is a range of methodologies for calculating environmental flow, with different levels of prediction and different information requirements. More than 207 methodologies have been applied in 44 countries around the world. Although classification systems vary, these methodologies can be grouped in two main categories: **rating methodologies and interactive methodologies**.

The first group of methods attempts to determine a specific flow regime in order to accomplish a certain objective, for example, conserving a species of fish or maintaining a specific type of riparian habitat. These methods are generally applied in conditions where the objective is clear and conflict with other types of objectives or interests is unlikely.

In contrast, interactive methodologies try to generate several flow regimes (or scenarios) responding to different interests or desired conditions. These types of methodologies make it possible to explore options and negotiate a flow regime that satisfies (albeit partially) the interests of multiple users. This type of methodology is applied in basins where there are diverse users with a strong interest in the flow regime.

Some of the rating methods used most are the ones called hydrological methods (0.25 method, Hoppe method, NEFM, etc.) These deduce an environmental flow based only on historical hydrological data for a given flow basin. Although results are not very reliable, where there is no information environmental flow can be estimated rapidly.

Other rating methods follow a more hydraulic approach, in which environmental flow is defined by relating a given flow to some hydraulic parameter. One of the most widely used is the wetted perimeter method. This method attempts to relate different levels of flow with submerged habitat available for aquatic populations. For different levels of flow, the area of submerged habitat increases and it can be determined where there are brusque changes of slope, making it possible to set minimum flows for a given area of wetted perimeter.



One of the interactive methods used most is the IFIM (In-stream Flow Incremental Methodology), in which different levels of flow are combined with the qualities or surface area of the habitat of a given species (hydrobiological methods.) The specie's preferred habitat in terms of current velocity, depth or sediment texture is related to different flows in order to present several scenarios for environmental flow setting.

Another method with a more holistic approach is the Building Block Methodology, based on an independent analysis of each one of the components a flow should have in order to maintain ecological aspects (wildlife populations), abiotic aspects (water quality or sediment distribution), etc. Although more comprehensive, application of this method requires a great quantity of information.

Whatever method is used, certain guidelines need to be followed when designing the specifications of a flow. First, specifications should be legally defensible and supported by legislation and regulations currently in force. Second, they should be scientifically defensible, or based on widely accepted scientific concepts and information. Third, they should be administratively feasible, meaning that the agencies responsible for executing the implementation of the environmental flow decided upon have clear guidelines, and their true administrative capacity is taken into account. Fourth, specifications should be rapid to implement and appropriate for country technology and scientific capacity. Fifth, they should involve conservative estimates of the water quality and quantity to be contributed to the ecosystem (safety margin), and finally, specifications should pursue a holistic objective, not just hydrological or chemical.

4. Institutional Framework for Establishing Environmental Flow

The application of environmental flow setting methodologies in Costa Rica is heavily affected by a weak institutional framework in which there are strong conflicts of interest and competencies between the different national and local agencies.

This panorama is complicated by an array of unarticulated legislation and regulations, and a great deal of fragmentation in the functions of the different State sectors.

In almost all of the sectors, institutional mandate is unaligned with a whole-basin context that would permit integrated administration. At the same time, the absence of a superior regulatory body for the coordination and formulation of water management strategies means that the country has no national policy that orders the sectors under an integrated and coordinated vision.

Consensus building to define environmental flows in our basins requires a suitable legal and institutional framework, which makes this a priority area of action. The water resources bill recently introduced in the legislative assembly offers an extraordinary opportunity to influence the generation of this legal framework.

Another area of action requiring urgent attention is to develop and structure processes for defining the environmental flow required in a section of river. These are geared toward obtaining both the effective participation of all sectors affected by the implementation of an environmental flow, and the incorporation of a scientific base to assure the suitability and environmental viability of the flows decided upon.

The dissemination of concepts and methodologies to determine and define environmental flow is another important area of action. An understanding of the concept of environmental flow is the initial foundation for building support to reach this consensus. Information products should be generated and disseminated for different types of audiences.

Since we learn by doing, another desirable action in the near term is to develop a case study using methodological approaches and obtaining determinations about environmental flows. In addition to specific information about flow in an area, this would also generate experience among a multisectoral technical group.

One of the most critical elements in setting environmental flows regimes is the availability of hydrological, chemical and biological information about the waterways. Due to the current lack of much of this information, reliable estimates about the environmental flow of a basin are more difficult to make. Monitoring networks with broad geographical coverage are vitally important.

Finally, it is essential to develop permanent training programs about concepts and methodologies for determining flows. State agencies and technical/scientific institutions need to develop a critical mass of people with a conceptual and methodological grasp of the processes involved.

5. Determination of Environmental Flow for the Tempisque River

Despite the absence of detailed scientific information and a suitable legal framework for the application of environmental flow, it is important to initiate environmental flow setting processes in one of the country's basins.

While only preliminary approximations, given the total absence of information about this theme, these estimates of environmental flow are extremely valuable. They facilitate the development and implementation of estimation techniques and help consolidate multidisciplinary groups working on the same project. For this purpose, environmental flow determination was initiated in the basin of the Tempisque River, in northwestern Costa Rica.

The Tempisque basin spans approximately 543,000 ha, equal to 10% of national territory and 60% of the Guanacaste province. This basin contains an impressive diversity of natural environments and extensive cultivated areas that have created a highly complex mosaic of use (Figure 2.) This region also has a great deal of economic importance due to the productive activities that depend on its water resources. There is no question that tourism, aquaculture and intensive agriculture (sugar cane, rice, melons, etc.) fuel the nation's economy. And while physically outside the basin, the tourism industry in Costa Rica's northern Pacific zone depends on this area for its supply of drinking water and services.

Alongside this development, growing, uncontrolled use of surface and groundwater to sustain productive activities poses a dangerous threat to the region's social, economic and ecological integrity.

5.1 Land Use Trends

Striking changes have taken place in this basin over the last five decades. Around 1955, almost 55% (114,359 ha) of the lower basin of the Tempisque River was pastureland, with no important areas dedicated to farming (Chart 1.) By 2000, agriculture occupied around 25% of the land.

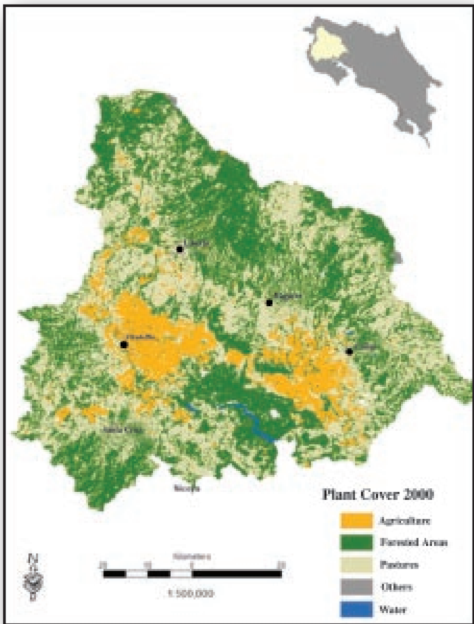


Figure 2. Current Land Use (2000) in the Tempisque River Basin

The rise in agriculture observed over the past 20 years coincides with the implementation in the mid-1980s of the Arenal-Tempisque mega-irrigation project diverting water from the Caribbean slope to the Tempisque basin, making it possible to incorporate around 31,000 ha (mostly flooded rice) into agricultural production within the basin. Practically all of the land used for agricultural purposes (90%), especially cane and rice fields, is concentrated in the lower basin.

Chart 1. Change of Land Use in the Lower Basin of the Tempisque River, 1955-2000

Soil Use	**1956** **Area (ha)**	(%)	**2000** **Area (ha)**	(%)
Mangroves	2928	1.3	1470	0.6
Wetlands	21760	9.4	15690	6.6
Forest	92135	39.8	58559	24.6
Pasture	114359	49.3	100832	42.3
Agriculture	-	-	58780	24.7
-Rice	-	-	19732	8.3
-Sugar cane	-	-	17233	7.2
-Melon	-	-	372	0.2
-Mango	-	-	-	-
-Plowed	-	-	21442	9.0
-Fish farming	-	-	-	-
Urban	565	0.2	1626	0.7
Waters, river, salt marshes	-	-	1321	0.5
Total Area	**231,747**	**100.00**	**238,278**	**100.00**

5.2 Water Use in the Lower Basin of the Tempisque River

Water use and management has been and continues to be one of the most critical issues in the Guanacaste region. This is the only area in the country where marked differences in precipitation over the year result in frequent droughts during the dry season with adverse effects on agriculture, and flooding in the rainy seasons causing damage to crops, infrastructure and human settlements. Overall water demand for human use in the region (4,782,000 m^3/yr) is greater than the surface water available (4,327,000 m^3/yr.)

As a consequence, groundwater is being used to cover this shortage, without a detailed study on use, availability and recharge capacity. More than 1800 wells are located in this region along with another 100 on the periphery, fed from important aquifers located in the basin (Figure 3.)

Because of pressure for this resource and lack of information, government authorities give an excessive amount of surface water concessions. More than 20.5 m^3/sec of water have been granted from this basin, even though the river's maximum flow is rarely over 7 m^3/sec during the dry season. Over 6540 rooms are being built in the coastal zone, and the corresponding demand for water will have to be met with resources from this basin.

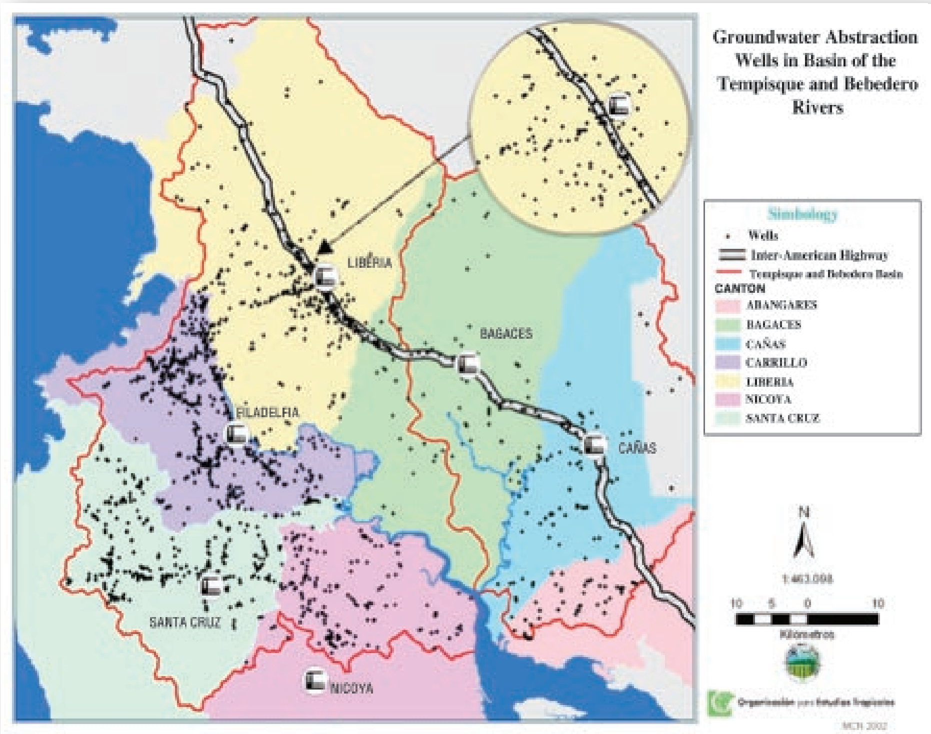


Figure 3. Location of Ground Wells in the Tempisque River Basin

The Tempisque River Basin has been exhibiting unmistakable signs of social conflict and environmental deterioration from the unplanned use of water. Users (agroindustry and more recently the tourism sector) have obtained surface water concessions of more than 20 m^3/sec, even though dry season flows in the mid-basin do not top 8 m^3/sec (MINAE, 2004.)

In the competition for water, current and future access is being curtailed for those with the least economic resources. The first social conflicts have involved community groups upset about the impact on water supply in their areas from concessions for tourism developments in the coastal zone. This conflict led the Central American Water Tribunal to recommend that the Costa Rican Government limit exploitation of aquifers in the basin.

In terms of environment, deterioration of water resources has been dramatic. During the summer months stretches of the Tempisque River waterway practically dry up because of the excessive abstraction of water, resulting in the reduction or elimination of populations of aquatic fauna. Water quality in the basin has been affected by an over-concentration of agrochemicals, particularly inorganic fertilizers. Wetland areas have shrunk more than 60% in the last 30 years due to aggressive drainage and construction of dikes.

Despite these evident signs of social and environmental deterioration, the State has not formulated strategy for managing water resources in the region. The development strategy for the basin remains unchanged from the seventies, when Costa Rica opted to develop irrigation agriculture and the construction of works supporting this activity (reservoirs, irrigation and drainage canals, etc.)

5.3 Calculation of Environmental Flow in the Tempisque

The environmental flow was determined based on hydrological and bathymetric data from a section of the Tempisque River and the habitat and biometric requirements of *Parachromis dovii* (guapote) and *Crocodylus acutus* (crocodile), two characteristic species.

A hydro-biological approach was employed to generate several environmental flow scenarios in the Guardia-La Guinea sub-basin. This sub-basin of approximately 166,000 ha spans part of the middle basin and the entire upper basin of the Tempisque River, equal to 49.5% of the Greater Tempisque River Basin (Figure 4.)

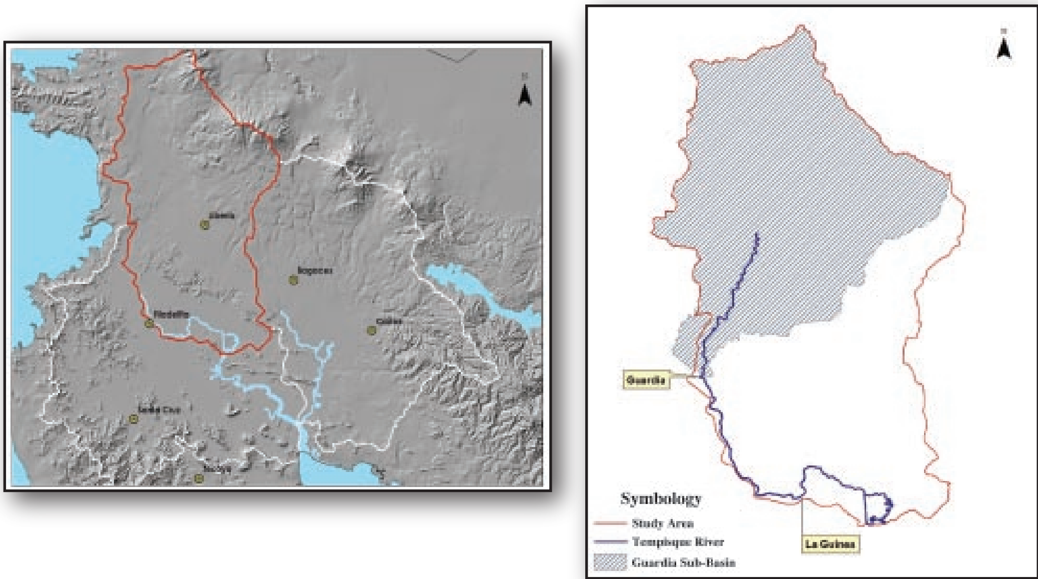


Figure 4. Location of the Guardia Sub-Basin, Subject of Environmental Flow-Setting

The Guardia-Guinea section of the Tempisque River passes over low-sloping plains of alluvial formation where the current consequently loses velocity. It presents an irregular meandric morphology where the channel widens from 20 to 70 meters and the bottom generally consists of sediments with a diameter smaller than gravel (<64mm.)

The proportion of riparian forest to the waterway's width lessens as it reaches the mouth, and the importance of foreign organic material for the ecosystem diminishes from the upper to the lower parts.

In terms of hydrological data, information on flows in the selected area is only available from the Guardia station, south of Liberia. This station provides hydrological information on the upper basin consisting of 95,500 ha, or 57% of the study area, over the two periods of 1951-1969 and 1980-1999. Between 1970 and 1979 the station was moved downstream to the site known as La Guinea, but since the quality of this information was considered doubtful because of the tidal influence, the station was once again moved to its former position in La Guardia.

Alterations of natural habitats in this stretch are mainly the result of channeling to straighten the river (i.e., El Viejo) and of stabilizing banks with longitudinal works to avoid flooding (i.e., the retaining wall in Filadelfia) (Figure 5.)

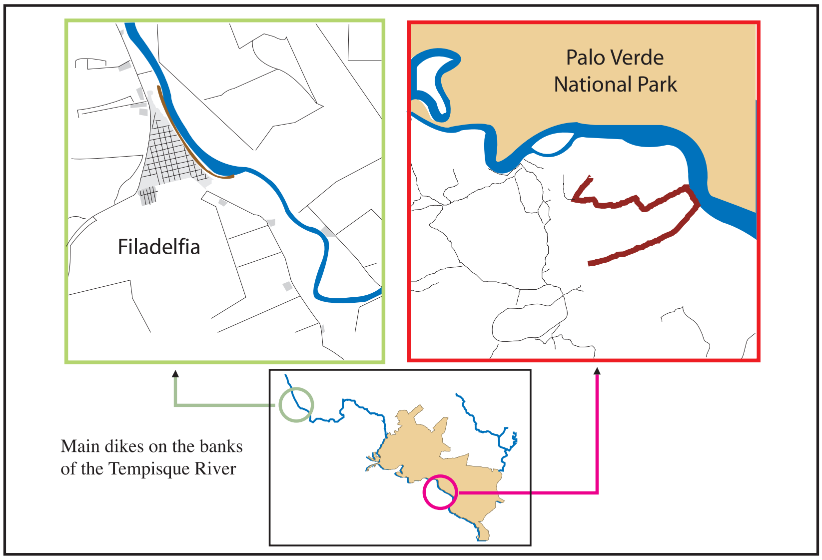


Figure 5. Examples of dikes constructed along the side of the Tempisque River: Filadelfia Dike (left) and the dike at Corral de Piedra (right.)

All of these works are designed to increase the hydraulic capacity of the watercourse, but they have other effects as well: elimination of the dynamic equilibrium of the riverbed; the disappearance of pools, meanders and sandbanks; change in the scarp and depth of the channel; increase in the flow's velocity and reduction in the natural formation of habitat for macroinvertebrates, fishes, amphibians, reptiles and crustaceans, among others.

5.3.1 The Biological Component

Different variables were considered in selecting fauna species to support environmental flow setting.

Selection criteria centered on the availability of information about species in the zone and knowledge of habitat requirements that could be easily related to flow levels. Preference was given to species with large-sized individuals whose passage and distribution are hindered in low depths. Also selected were species dependent on habitat characteristics clearly related to flow.

Although the habitat preferences utilized as criteria in this study are necessarily simple, it is hoped that other studies will generate more detailed information allowing for a better relation between ecological and hydraulic variables.

For this study we selected *Parachromis dovii*, a species of fish ("guapote"), and *Crocodylus acutus,* a reptile (crocodile.)

5.3.1.1 Fishes

As in most of the country's basins, biological information for this waterway is very scarce. The available fish studies on the basin were conducted by Bussing and López in 1977. Twenty-one species of fish were recorded, of which 11 are generally found in water with little current, a condition of the river segment under study. Some of these species are: *Poeciliopsis turrubarensis, Parachromis dovi, Cichlasoma longimanus, Roeboides guatemalensis, Herotilapia multispinosa, Symbranchus marmoratus, Awaous transandeanus, Gobiomorus maculatus, Eleoctris picta,* and *Dormitator latifrom*.

The fish species used, the "Guapote," prefers waters with little current and spawning territories associated with caves in rocks or trunks at depths of about a meter, and especially pools. Due to the size of the guapote, minimum depth for reproduction is around a meter.

Parachromis dovii

5.3.1.2 Crocodiles

Costa Rica's crocodile populations are represented by two species: *Caiman crocodilus fuscus* (Crocodylia: Alligatoridae) and *Crocodylus acutus* (Crocodylia: Crocodylidae); only the second is found in the Tempisque River. Comparative studies in the lower part of the river show a 3.9 increase in population over the last ten years. This is attributed to the concentration of individuals due to loss of wetlands in zones near the river.

The crocodile population is estimated at around 900 individuals in the section running from the mouth of the Tempisque River to 12 kilometers upstream of the mouth of the Bolsón River.

Crocodile populations all along the river have been maintained thanks to the formation of microhabitats key for the species' reproduction, such as sand banks, aquatic and semi-aquatic vegetation, areas of refuge for neonates and minimum depths for reproductive adults.

Crocodylus acutus

Neonates prefer zones near the nesting site, in aquatic areas with little current and protected with vegetation where they can hide from possible predators. When they reach a juvenile state, they move somewhat farther away from the nest but can remain in the vicinity for months and even years. However, when habitat is inadequate neonates may immediately move away to another spot.

Availability of habitat for crocodiles in juvenile, sub-adult and adult stages throughout the river is fundamental for the specie's distribution. The juveniles move up to 13 kilometers from their birthplace. Sub-adults and adults settle into protected sites and deep waters. Because of its size, this species requires at least 1.1 m of depth for its movements.

The territorial preference of reproductive females is strongly influenced by the availability of nesting habitat, and during the reproduction period they exhibit increased activity and movements.

5.3.2 Habitat Requirements Related to Flow

Attempting to relate flow volumes to the habitat requirements of selected species was a fundamental aspect of the process. The reduction of the Tempisque River's flow to levels resulting in shallower caves and refuges, thus impeding the survival of guapote and crocodiles, would have a strong impact on these populations.

Adequate depth and nesting sites are both essential for this species' reproduction. Their requirements call for flows that maintain depths of over 1.1 meters in the study section in order to maintain habitats for reproducers.

Normal natural conditions in the dry season lower the river's flow, causing a concentration of guapote and crocodiles in the areas of greatest depth. This makes them more vulnerable to natural predators and capture by local dwellers. Even greater reduction of flow caused by human use of water thus further increases the concentration of individuals and elevates the risk of depredation.

For adequate reproduction, guapote require zones over 100 cm deep, with rocks, trunks and fallen branches. The environments that satisfy reproduction requirements, created when the river swells, must remain flooded and connected with the river for a period of at least 6 months, when mating takes place.

In the case of crocodiles, the formation of pools is indispensable in order to maintain refuges and copulation sites for adults. Adequate conditions for reproducer crocodiles require depths estimated at over 1.1 meters.

To match the morphometric characteristics of the guapote and crocdile and predator-prey relation, as well as habitat requirements such as refuge and reproduction, the suggested environmental flow would maintain depths of over 60 cm all along the river and at least 1.1m in pools.

5.3.3 Hydrometeorological Information

This study employed the monthly series of daily minimum, average and maximum flows in m3/sec, collected at the Guardia gauging station for the periods of 1951-1969 and 1980-1999. Data collected at La Guinea station from 1970 to 1979 was also used.

The area selected has several meteorological stations with records for different periods and data consistency. Gaps in information at some stations during the selected period were filled in using the normal ratio method. Tests for consistency were made for each station utilizing double mass curve analysis only with annual rainfall data.

The limitation of the rainfall database is that only very few rainfall stations go back to 1951, when flow records first began at the Guardia station. As a result, it was necessary to make an extrapolation of mean annual watershed rainfall to m atch the same time series of flows and thus be able to make a double mass analysis between average annual rainfall and runoff.

One of the rainfall stations in the study area with the longest recording period and best data consistency is the Llano Grande-Liberia Station, with an almost complete series starting in 1953. The average monthly rainfall in the basin for the 1953-2000 period was then estimated by extrapolating from the series of data at the Llano Grande station.

Information was used from 26 cross-sectional topographical profiles of the Tempisque River's main channel between Guardia and the Cutacha, generated by a previous study, to determine the effect of different flows on the hydraulic characteristics of the main channel and habitat of the two aquatic species selected.

Data on water use and concessions within the study area, generated by the Water Department of the Ministry of Environment (MINAE), were also used, including information on the spatial location of each concession, claimed use and the date exploitation began. This database was used to make estimates on the volumes of water abstracted at different points of the Tempisque River.

5.3.4 Impact of Water Resource Use on the Flow Regime of the Tempisque River

Irrigation and other uses in the sub-basin analyzed were minimal during 1951-1969, so the flows regime from that period is closer to natural river flow.

A comparison between the flows in this period and the 1980-1999 period, when water use did indeed increase in the sub-basin, should rule out the influence of climatic variability in the flows regime. Graphic comparisons of rainfall and monthly flow in the basin for both periods and an analysis of moving averages (5 years) of annual precipitation were used for this purpose.

Figure 6 illustrates the behavior of mean annual rainfall in the Tempisque River basin. As it can be noted, there is a great deal of variability given that the average precipitation is 1798 mm with a standard deviation of 546 mm, resulting in a variation coefficient of 30%. The range of annual rains is defined as 3100 to 1100 mm.

In the same graphic, runoff data have been included for the two periods data is available. As can be observed, there is a direct relation between the magnitude of rain and runoff.

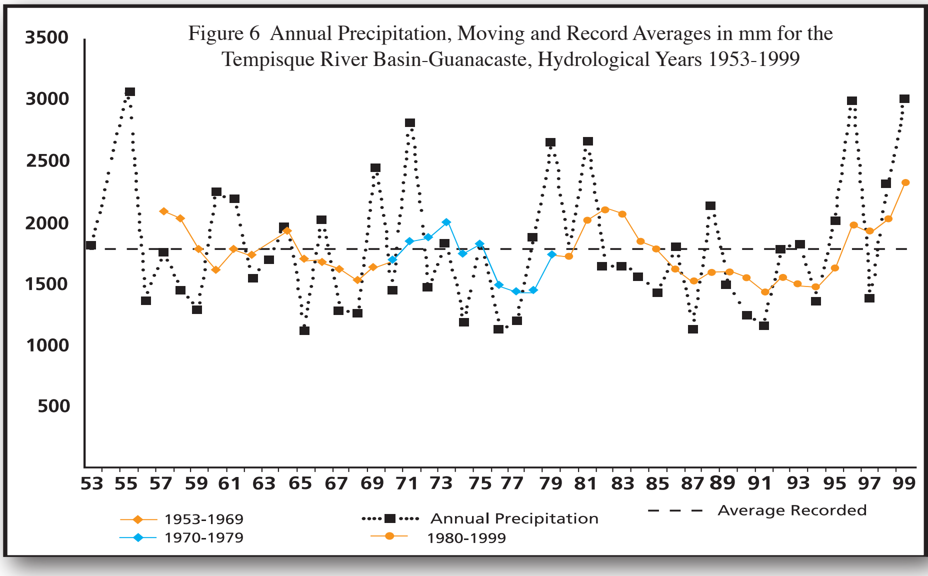


Figure 6. Behavior of average annual rainfall in the Tempisque River Basin as of the Guardia Station

The line of moving averages indicates that there are dry cycles (points below the line for the record average) and wet cycles (points above the line for the record average) As can be observed, dry cycles tend to last longer than wet ones, with the 1986-1996 cycle being the longest recorded. Of the total 43 moving averages obtained from this analysis, only 15 averages were wet, while 24 were dry and 4 were normal (equal to the record average.) There is consequently a trend toward more dry cycles.

Comparing rainfall averages from these two periods (Chart 2), the differences between average annual rainfall are minimal at just 7.7 mm or 0.4% (no statistically significant difference p = 0.05). The same occurs with respect to standard deviation and the coefficient of variation. However, when annual runoff is compared there is a noticeable difference of 91 mm, equivalent to 10% less runoff than in the first period. Standard deviation and coefficient of variation increase considerably. Although the difference between the runoff averages is noticeable, it was not found to be statistically significant, with p = 0.05

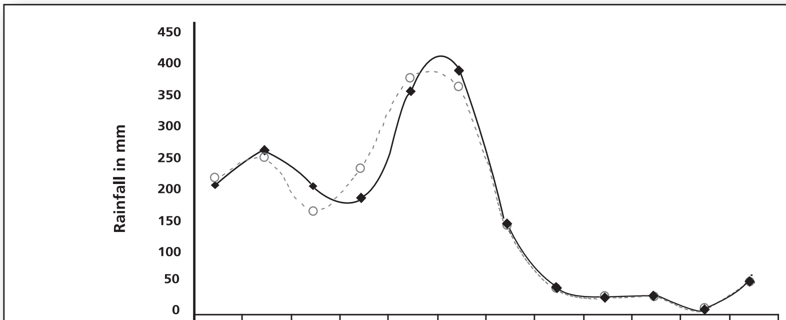
Chart 2. Average Annual Rainfall and Runoff in mm, Tempisque River Basin at Guardia, Liberia

	Annual Rainfall			Annual Runoff		
Period	Av.	S.D.	C.V.%	Av.	S.D.	C.V.%
1953-69	1819.4	539.5	29.7	914.4	373.1	40.8
1980-99	1811.7	557.0	30.7	823.0	412.0	50.1
Difference (mm)	7.7		-1.1	91.4		-9.3
Difference in %	0.4			10.0		

The difference in runoff detected in Chart 2 may be due to the withdrawal of surface water from the Tempisque River for irrigation and other purposes during the dry season. To confirm this hypothesis, it is necessary to compare average monthly rainfall and flows so as to demonstrate that the differences are concentrated in the dry season, which is when more water is used for irrigation. Due to the existing climate variability, a double mass analysis must be made using annual rainfall against annual runoff, which would remove the effect of annual climate variability and leave the explanation for the differences to other causes related more to the use of water and basin management.

5.3.4.1 Monthly Flows Regime and Rainfall Pattern of the Tempisque River at Guardia

Figure 7 presents the rainfall pattern for the same periods of years with information on flows. The dry season is clearly defined as starting in December and ending in April. In the dry period, differences between monthly rainfall averages are minimal and some differences are observed only in July and August, but these are not statistically significant at p= 0.05.



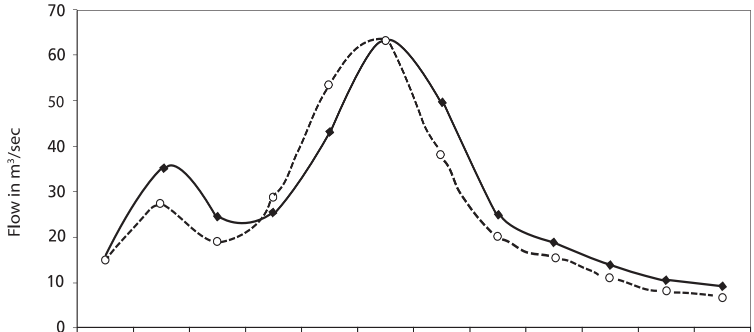
	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr
1953 -69 Period	198,2	253,0	197,1	177,6	345,2	380,3	135,9	35,7	21,1	23,2	2,5	49,5
1980 -99 Period	208,3	242,3	157,6	225,6	368,8	353,5	131,4	37,8	19,6	19,2	8,7	38,9

Figure 7. Average Monthly Rainfall for Two Periods, Tempisque River Basin at Guardia

Observing the minimal differences of these patterns, equally minimal differences are to be expected between the flow regimes during the same periods for those same months.

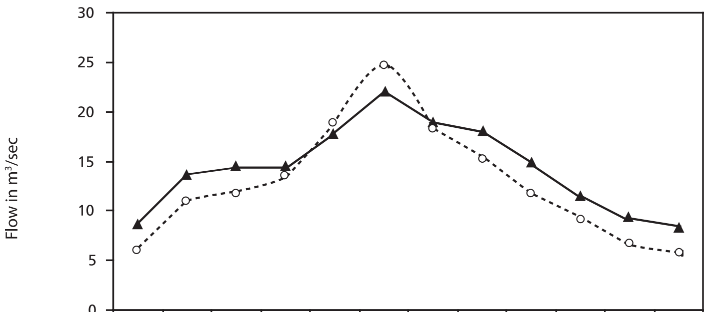
Figure 8 presents the average daily flows per month for the same periods indicated. As can be observed, flows reflect the two peaks of rainfall. During the dry season low-level flow is fed by groundwater stored up in the basin's aquifers during the rainy season. As hypothesized, the flows of the second period are lower in the dry season months from November to April. June and July have less flow than in the first period, but this is a direct response to the lower rainfall during those months in that same period. This also holds for the months of August and September, where the flows of the second period are greater than in the first, similarly reflecting the greater rainfall during those months in the second period.

The differences in flows from January to April are significant, with $p < 0.05$. Flow difference in this period is around 3 m^3/sec, confirming that water is being withdrawn from river flows for human and agricultural uses in the second period. Figure 9 shows the distribution of the monthly average daily minimum flows from the two periods recorded. In this case the pattern peaks at maximum in the month of October, corresponding to the month with the heaviest flow of the year. It is noteworthy in Figure 9 that the second period exhibits monthly average minimums that are lower than in the first period. The differences between the months of January to May are statistically significant at $p < 0.05$. In these months the difference also amounts to approximately 3 m^3/sec.



	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr
1951-69 Period	14.7	35.2	24.2	25.2	42.9	63.1	49.3	24.7	18.5	13.7	10.5	9.0
1980-99 Period	14.8	26.9	19.0	28.2	53.2	63.0	37.8	20.0	15.3	10.7	7.7	6.4

Figure 8. Monthly Average Daily Flow for Two Periods, Guardia Station-Tempisque River



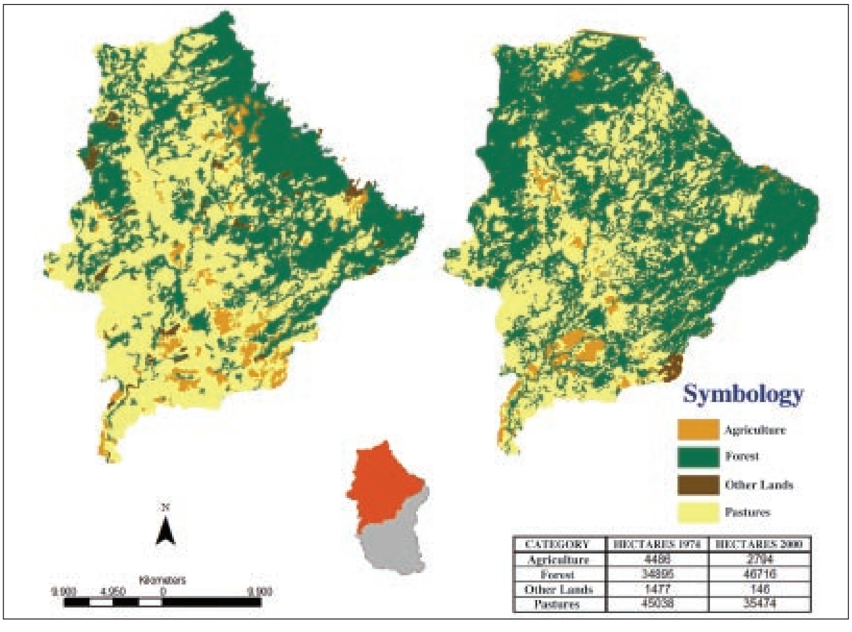
	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr
1951-69 Period	8,3	13,6	14,5	14,4	17,6	21,7	18,9	17,6	14,6	11,3	9,1	8,1
1980-99 Period	5,76	10,70	11,57	13,24	18,55	24,30	18,17	15,14	11,48	8,91	6,43	5,61

Figure 9. Monthly Average Minimum Flow for Two Periods, Guardia Station-Tempisque River

It can be concluded from Figure 8 that the month with the highest average daily flow is October, with 63 m^3/sec for both periods, and the month with the lowest flow is April, at the end of the dry season, with 9 m^3/sec and 6.4 m^3/sec for the first and second period, respectively. The month of April is thus the most critical in defining minimum environmental flows, since this is when the use of water resources has the greatest impact on the ecosystem.

To understand the relation between rainfall and runoff it is necessary to make a double mass curve obtaining the average and accumulated annual rainfall and runoff as of the first year of records for each period. This data is graphed by placing accumulated rainfall on the x axis (independent variable) and accumulated runoff on the y axis (dependent variable.) Since annual runoff is directly related to the average annual rainfall, the relation must remain proportional for all years, resulting in a linear trend of points. If the trend (slope of the curve) of points has deviations, it is because runoff has fallen (i.e., withdrawal of water.)

The drop in runoff between the two periods could also be due to changes in land use (e.g., more forest cover, increasing losses due to more evapotranspiration and diminishing net useful rainfall due to its interception) or changes in the use of river water and groundwater for irrigation and other uses. The first possibility has some weight, since recovery of forest cover has risen significantly throughout the Tempisque basin and Guanacaste province, in general. Figure 10 shows that from 1974 to 2000, there was an almost 34% increase of forest cover in the study area, resulting in greater water losses from interception and evapotranspiration. Nonetheless, the results are contradictory: if greater forest cover were the cause of the differences, flows in the second period should be lower during the rainy season, when the phenomenon of interception and evapotranspiration are more significant. But as Figures 7 and 8 show, these differences relate more to the rainfall pattern. Consequently, while it is possible that processes associated with forest recovery are taking place and affecting the hydrologic regime in the basin, the magnitude of their impact is not clearly reflected in the data. It would seem that water withdrawal better explains the reduction of Tempisque River flows, especially in the dry season.



CATEGORY	HECTARES 1974	HECTARES 2000
Agriculture	4488	2794
Forest	34895	46716
Other Lands	1477	146
Pastures	45038	35474

Figure 10. Changes in Land Use between 1974 and 2000, According to Interpretations of Land Sat Satellite Images (GIS-OTS- Palo Verde Station, 2004)

The double mass curves for the first and second period of data on runoff mark out a linear trend with a high coefficient of correlation. However, the slopes of the two curves are statistically different at $p < 0.05$. The slope for the first period is 0.475, indicating that 47% of the annual rainfall translates into runoff. This relation falls to 43% in the second period, indicating that the relation has been altered due to use of water resources. These changes of slopes reinforce the hypothesis set forth in this study, since the changes of slope in the double mass curves cannot be attributed to climate variability.

Observing Figures 11 and 12 carefully, it will noted that the points of the first period are better aligned than those of the second period, confirming suppositions that before the 1980s irrigation was not a common practice in Guanacaste and its impact was thus minimal. The points in the second figure are not as aligned, indicating that withdrawal of river water did not begin uniformly during the period. As of 1988 there is a notable break in the rainfall-runoff relation, and one can consequently assume that a significant process of water withdrawal began as of this year.

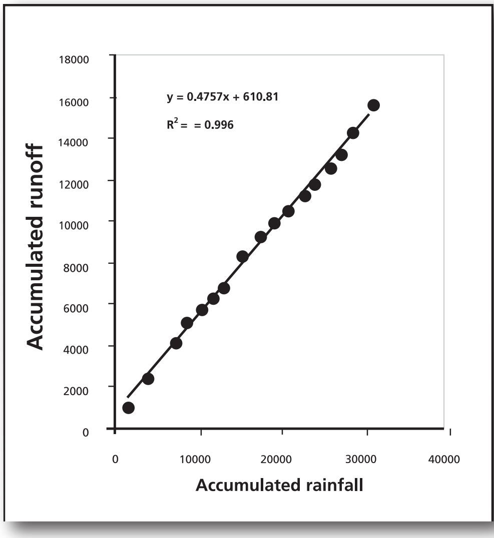


Figure 11. Double mass curve, accumulated average annual runoff vs. rainfall in 1953-69 Guardia Station, Tempisque River

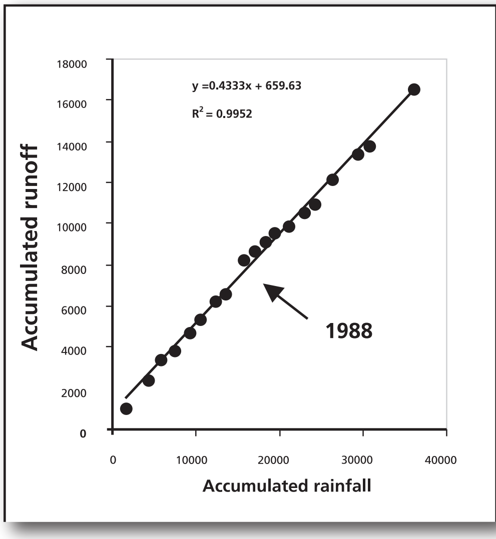


Figure 12. Double mass curve, accumulated average annual runoff vs. rainfall in 1980-99 Guardia Station, Tempisque River

5.3.4.2 Use of Water Resources and Concessions within the Study Area

From 1977 to 2004, 245 water concessions have been granted in the study area, of which 113 (46%) correspond to wells. The total volume of water granted amounts to over 20 m^3/sec, of which 85% is surface water and 15% is groundwater. The largest sector is irrigation, representing 76% of surface water use and 97% of groundwater use. The second most important sector is agroindustry (processing and other types of plants), which consumes 20% of surface water.

In 1986 there was a boost in abstraction of water from the basin, whether with wells or directly as surface water from the waterways (Figures 13 and 14.)

Groundwater concessions are concentrated in the lower-middle part of the study, while surface concessions are located all along the main rivers, especially the Tempisque and Liberia Rivers.

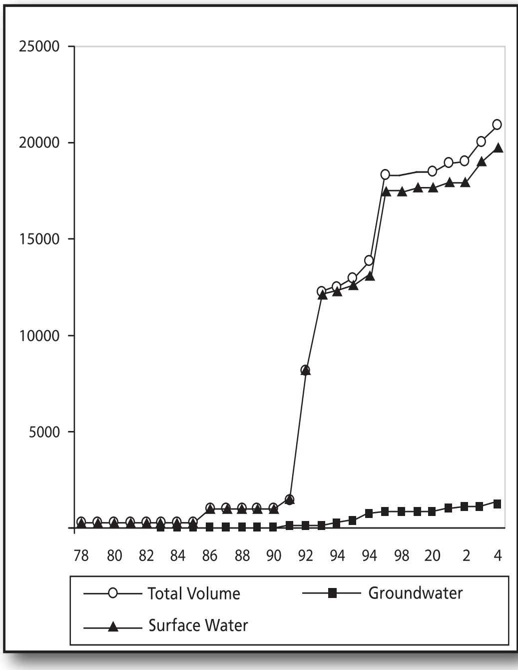


Figure 13. Accumulated volume of water under concession (liters/sec) after 1978.

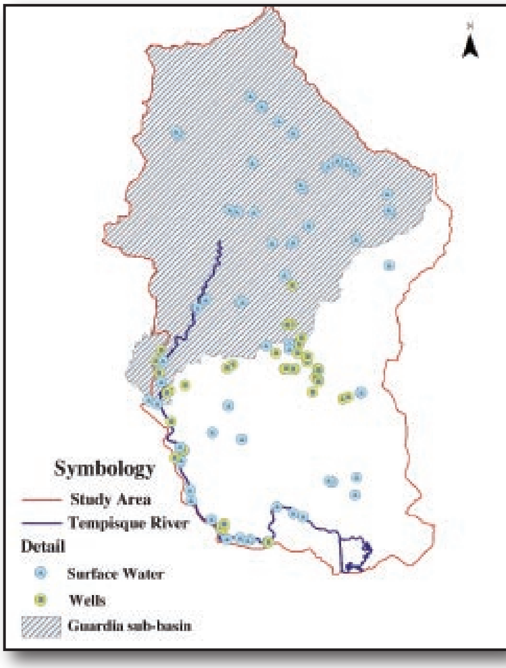


Figure 14. Distribution of concessions in the area and accumulated within the Tempisque River Basin-study area (GIS-OTS-Palo Verde Station) Guanacaste, Costa Rica. 1977-2004 period

The surface water concessions above the Guardia Station abstract a total volume of around 3,114 liters/sec, or just 17% of the total volume given in concession within the study area, showing clearly that the concentration of irrigation and agriculture takes place in the middle and lower part of the study area. After the Guardia Station, the Tempisque River has no direct inputs of surface water from either natural or artificial channels. In this sector not all of the surface waters on the right side can drain into the Tempisque due to the construction of dikes, and the surface waters on the left have been channeled so that they drain out after the Tempisque Canal (in La Cutacha.) As a result, during the dry season, Tempisque River flows from Guardia to La Cutacha (see Figure 4) are basically the same that pass by Guardia. After Guardia 14 concessions of surface water from the Tempisque are reported, reaching a total of 5,773 liters per second. If these concessions function at full throttle during the dry season, for all intents and purposes, what is left at the end of the section studied is less than 10% of the flow available during the month of April (we are referring to the average daily flow for the 1980-99 period of 6.4 m^3/sec.)

The impact of these concessions on the river flow is impressive. In April, the most critical month, average flow falls significantly all along the river when water is used as assigned under concessions (Figure 15.) One of these, located 7 km from Guardia, employs 3000 liters/sec for a sugarcane mill. The same data in percentages (Figure 16) shows that at Guardia some 30% of the natural flow has been assigned. Seven km below Guardia flow amounts to 35% (3.2 m^3/sec) and at the end of the section equals 7% (0.6 m^3/sec) of natural flow.

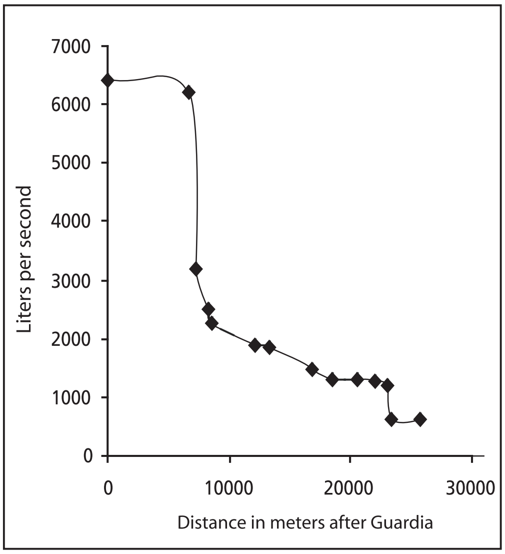


Figure 15. Volume under concessions as of Guardia

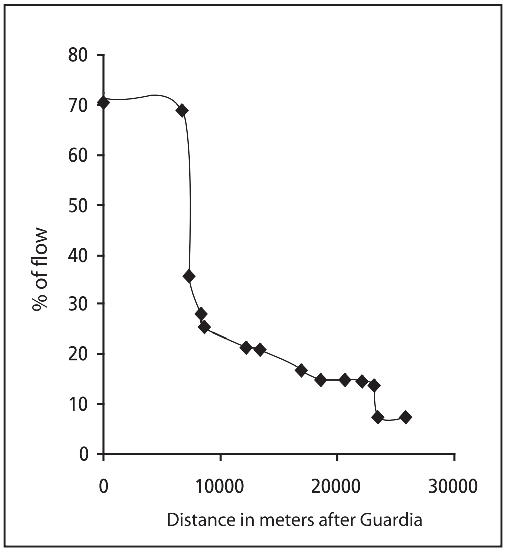


Figure 16. % of the original flow remaining in the month of April (1953-69 period)

At the Jobo pass in April, 2002, the flow of the Tempisque River is significantly below 0.5 m^3/sec (Figure 17.)

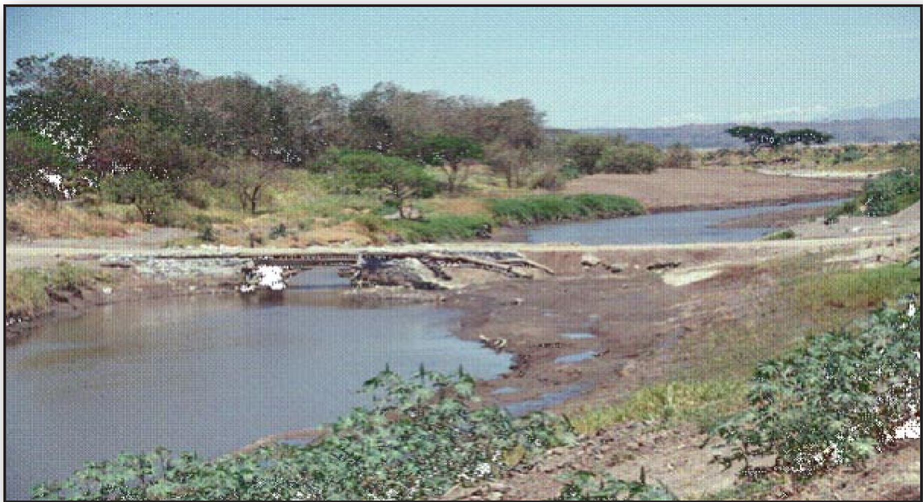


Figure 17. Photo of the Tempisque River, Jobo pass, at the end of April 2002. Existing flow is less than 0.5 m^3 / sec.

It is evident, then, that the concessions existing all along this section are making use of almost the entire volumes allocated, leaving insufficient flow to meet environmental requirements. Like the concessions before Guardia, estimated abstracted volume closely matches the volumes of water under concession.

5.3.5 Determining Environmental Flow

Since the series of data on flow in 1951-69 is the most representative of the Tempisque River's natural flows, this is the base data that will be used for setting environmental flows. Since several concessions are currently in operation and water is being withdrawn directly from the river, this fact needs to be taken into account in order to define environmental flows.

Chart 3 contains a statistical summary of the 1951-69 period and the proposed environmental flows. Ideally, environmental flow should correspond to the daily minimum flow recorded during that period (line 4.) This would be the lowest level of flow recorded historically and thus the minimum threshold supported by species and ecosystems. However, merely considering this possibility signifies extensive conflict with the current socioeconomic situation, given that in the second period the average daily flow has fallen significantly due to the award of concessions; restoring a minimum flow equal to the historical minimum flow means that most of the existing concessions would have to end, which is neither politically or socially feasible.

For demonstration purposes, environmental flow is proposed as 50% of the minimum historical flow in the 1951-1969 record, equal to 50% of the value of line 4, included in line 8 of Chart 3. This would be the minimum low-level flow that should pass through Guardia and continue until reaching the Gulf of Nicoya. The only purpose in using this amount is to generate a scenario in which it is accepted that only 50% of historical flows will be maintained. The impact this would have on the referent species will be simulated later.

As mentioned previously, determining the degree of health we wish to maintain in a river is a societal choice. However, this scenario makes it possible to generate a situation in which users must relinquish a portion of the resource assigned during the dry season and ecosystems must adapt to lower critical thresholds, which will reduce the extent and quality of habitat in drier years.

Chart 3: Summary of Statistical Data on Tempisque River Flows in Guardia, Recommended Environmental Flows and Maximum Flow Available for Concession (m^3/sec.)

Line	Records 1951-69	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr
1	Average	14.7	35.2	24.2	25.2	42.9	63.1	49.3	24.7	18.5	13.7	10.5	8.96
2	Stand. Dev	10.7	25.5	11.3	11.6	29.4	49.8	43.2	7.9	5.1	3.2	2.5	1.8
3	Num.Yrs	18	18	18	19	19	19	19	19	19	19	19	19
4	Min. Value	6 7	9.3	11.6	12.0	15.2	19.8	17.4	14.7	12.8	10.4	7.1	6 4
5	Max. Value	51 8	107.0	55.4	58.0	140.0	208.0	179 8	41.3	28.8	21.0	15.7	12 0
6	Limit Conf.-95%	9 4	22.6	18.6	19.6	28.7	39.2	28.5	20 9	16 1	12.2	9.3	8.1
7	Limit Conf. +95%	20 0	47.9	29.9	30.8	57.1	87.1	70.1	28.5	21.0	15.2	11.6	9.8
	Enviromental Flows	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr
8	Absolute Minimum	3.4	4.6	5.8	6.0	7.6	9.9	8.7	7.4	6.4	5.2	3.6	3.2
9	50 % Normal Reliability	11.3	30.6	18.5	19.2	35.3	53.3	40.6	17.4	12.1	8.5	6.9	5.8
10	Maximum 95 % Reliability	16.6	43.3	24.1	24.8	49.5	77.2	61.4	21.2	14.6	10.0	8.1	6.6
11	Maximum Flow for Consession	6.0	17.9	12.8	13.6	21.1	29.3	19.8	13.6	9.7	7.0	5.7	4.9

5.3.5.1 Monthly Flows Available for Concessions

Once the monthly minimum environmental flow is defined, the flow available for concessions can be established. These flows correspond to the difference between the Absolute Minimum Environmental Flow (line 8) and the lower limit of reliability intervals at 95% (line 7). The average daily flows available for concessions would subsequently be those found in line 11. It should be understood that these are the maximum flows available for concession per month. Since these have been determined by employing the lower limit of 95% reliability intervals, it is assumed that even in the driest years it will be possible to supply both the environmental flow and concessions.

Establishing the maximum volume of water for concessions allows flows to have a monthly and yearly variation. In the rainiest years, habitat will expand proportionally with the increase in flows, providing opportunities for species and ecosystems to recover from the effects of dry years.

Since 3.1 m^3/sec have already been conceded before Guardia and 5.7 m^3/sec have been conceded after Guardia, total concession demand amounts to 8.1 m^3/sec. Figure 18 presents the flows available for concessions per month and current potential demand. As can be noted, in the months of May, February, March and April there are shortages of 2.1, 1.1, 2.4 and 3.2 m^3/sec, respectively. These shortages must be resolved either through renegotiation of current concessions until reaching the maximum flows to be conceded (line 11 Chart 3) or through additional inflows of water directly into the Tempisque River (for example, from the Arenal-Tempisque irrigation system.)

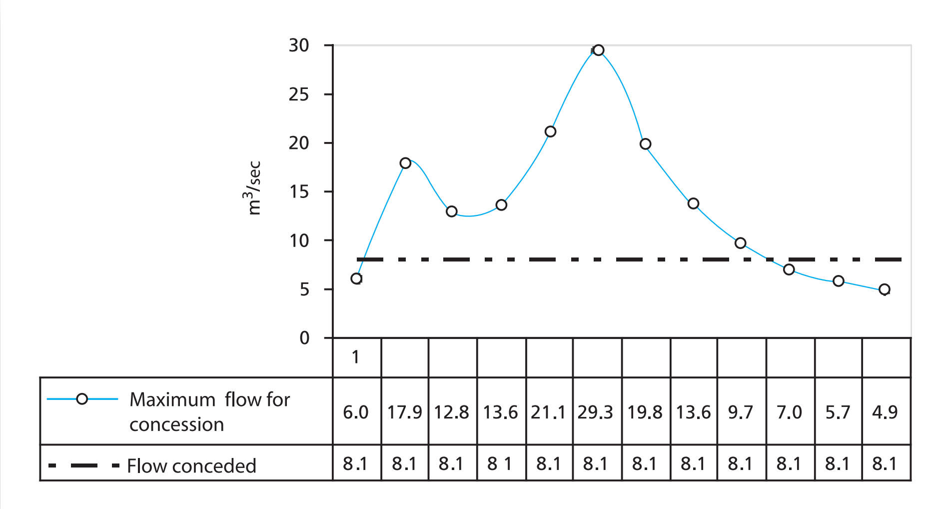
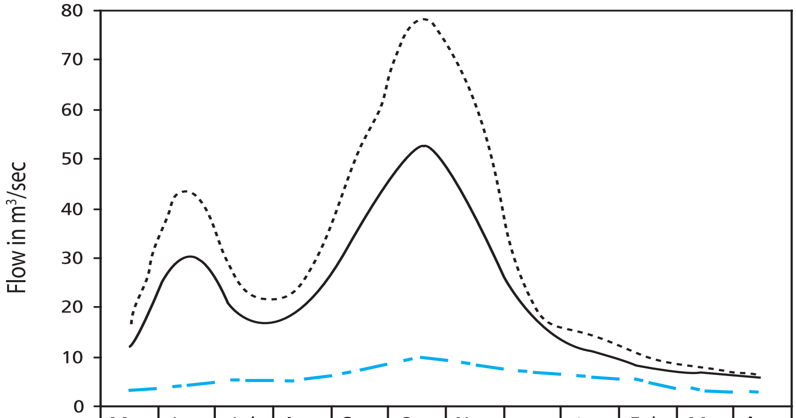


Figure 18. Maximum Flow for Concession in the Tempisque River

5.3.5.2 Normal Environmental Flow and monthly average daily maximum

The normal environmental flow corresponds to the difference between average daily flow (line 1, Chart 3) and the maximum flow for concession (line 11, Chart 3.) The maximum environmental flow thus corresponds to the difference between the maximum flow awarded (Line 11) and the upper limit of the reliability interval of 95% of the averages of daily flows (line 7, Chart 3), which correspond to a flow in very wet years with a 5% probability of occurrence.

Figure 19 represents the monthly distribution of proposed environmental flows for the Tempisque River. As can be observed, these represent a flow regime that simulates natural flows after releasing a maximum flow for other uses. The Minimum Environmental Flows curve corresponds to the lowest-level flows recorded historically, after awarding 50% of the flow for other uses. The Normal Environmental Flows curve has a 50% probability, meaning that it happens 50% of the time and the Maximum Environmental Flows curve has a probability of occurring 5% of the time. In other words, the proposed Minimum and Maximum Environmental Flows curves make up a 95% probability that environmental flows will range between these two extremes, offering different flow regimes for ecosystems and species to adapt, recuperate and maintain a healthy population.



	May	Jun	Jul	Agu	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr
MINIMUMS	3,4	4,6	5,8	6,0	7,6	9,9	8,7	7,4	6,4	5,2	3,6	3,2
MAXIMUMS +95% RELIABILITY	16,6	43,3	24,1	24,8	49,5	77,2	61,4	21,2	14,6	10,0	8,1	6,6
NORMAL or 50% RELIABILITY	11,3	30,6	18,5	19,2	35,3	53,3	40,6	17,4	12,1	8,5	6,9	5,8

Figure 19. Environmental Flows Proposed for the Tempisque River at Guardia

5.3.5.3 Setting Peak Environmental Flows

The environmental flows proposed provide minimum conditions for the persistence of ecosystems and species. However, there are ecological and fluvial geomorphology processes requiring the occurrence of peak flows or extraordinary avenues in order to distribute sediments and organic material, maintain natural dikes and channel form, flush out the channel and deposit new sediments, etc.

In the case of the Tempisque River, during the rainy season there are extreme or peak flows that keep these processes in balance. What is most pertinent about these peak flows is that they are not only important for the river's geomorphology and ecology, but also for maintaining other processes in littoral and marine ecosystems of the Gulf of Nicoya.

Since the current incompatibilities between development and conservation in the Tempisque River basin center more on the use of water resources during the dry season, the need to establish these peak flows seems irrelevant at the moment, given that in the dry season there are no extreme flows. However, it is known that there are intentions of developing projects damming the river and creating a reservoir to supply water for irrigation and tourism development in the Gulf of Papagayo.

Chart 4 provides a summary of eight peak flows and their respective return periods. Without damming, some of these peak flows are maintained so it is not necessary to establish a peak flow sustaining the processes discussed in this section. However, if damming does occur, this would probably affect mainly the lowest peak flows, such as the two-year return period flow, which are precisely the peak flows recommended to be maintained in order to ensure the existence and continuity of the geomorphological and ecological processes.

It is therefore recommended that no type of damming exist anywhere along the Tempisque River to affect the environmental flows defined previously and the occurrence of peak flows with return periods of less than or equal to 2 years.

Chart 4: Estimation of return periods for peak flows in the Tempisque River for 40 years at Guardia Station

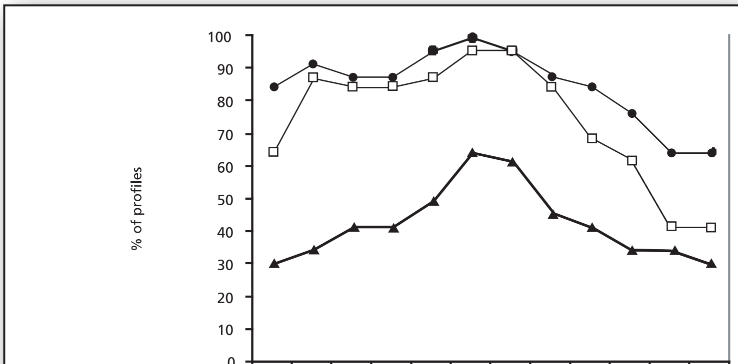
Return Period Years	2	5	10	20	30	50	100	200
Peak Flow in m^3/seg	442	889	1267	1692	1964	2335	2892	3515

5.3.5.4 Effect of the Recommended Environmental Flows on Crocodile and Guapote Habitat

Utilizing 26 topographical profiles located in the study sector and the Hec-Ras Simulation Model, it was possible to simulate depths for each of the 26 profiles according to the flows suggested.

Under both the Natural Flow and Normal Environmental Flow proposed, for all the profiles during all months, minimum depth requirements are satisfied for the crocodile and guapote on the average. For the Minimum Environmental Flow, however, in the months of March, April and May, the depths crocodiles require will not be reached on average, although those required by the guapote are.

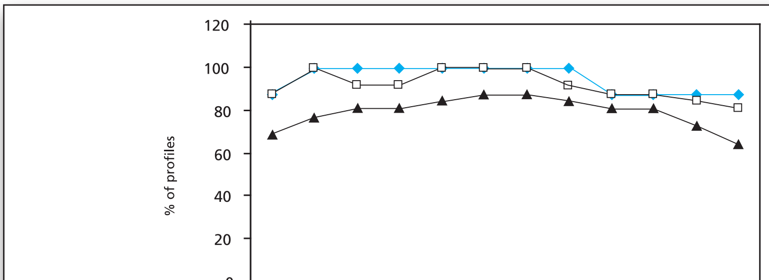
The percentage of profiles that met the recommended depth requirements for the crocodile (Figure 20) range from 65% in April to 100% in October in the case of Natural Flow. With the definition of the Normal Environmental Flow, this range shifts to 42% and 96% for the same months. In the extreme case of Minimal Environmental Flow, the range is 31% and 65% for the same months.



	May	Jun	Jul	Agu	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr
Natural flow	85	92	88	88	96	100	96	88	85	77	65	65
Natural Enviromental flow	65	88	85	85	88	96	96	85	69	62	42	42
Minimum Enviromental flow	31	35	42	42	50	65	62	46	42	35	35	31

Figure 20. Percentage of profiles that met the optimum depth for crocodiles (1.1 m)

The situation for the Guapote is not as serious since the percentages of profiles for the Normal Environmental Flows remain above 80% in all months, with the lowest occurring in April, at 81% (Fig. 21.) Similarly, the situation for the extreme of Minimum Environmental Flow can be considered very favorable since the profiles are above 70% in all months, with the exception of April, at 65%.



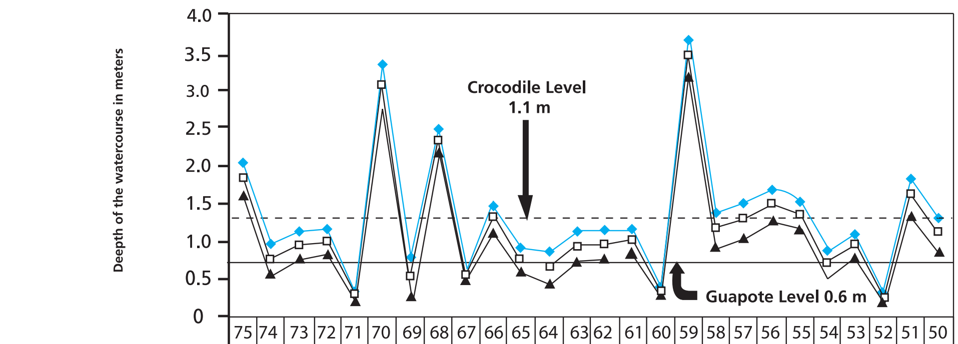
	May	Jun	Jul	Agu	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr
Natural flow	88	100	100	100	100	100	100	100	88	88	88	88
Natural Enviromental flow	88	100	92	92	100	100	100	92	88	88	85	81
Minimum Enviromental flow	69	77	81	81	85	88	88	85	81	81	73	65

Figure 21. Percentage of profiles that satisfy optimal depth for Guapote (0.6 m)

5.3.5.5 Habitat Fragmentation and Critical Sections for the Crocodile and Guapote

Even under natural conditions (natural flow), this section of the river becomes fragmented in April when 38% of the profiles have shallower depths than those recommended for the crocodile. This percentage rises to 58% for Normal Environmental Flows, and reaches almost 70% of the Minimal Environmental Flows (Figure 22.)

As a result, connectivity for adult crocodiles is highly compromised in the dry months under Normal Environmental Flows, and even more so if conditions for Minimal Environmental Flow are taken into consideration. However, in the dry months this species is located in sections of the river with pools and does not move along the waterway since females are protecting their nests and males their territory. Fragmentation thus does not have any great impact. In the case of the Guapote, the problem of connectivity is not so critical.



	75	74	73	72	71	70	69	68	67	66	65	64	63	62	61	60	59	58	57	56	55	54	53	52	51	50
Natural flow	2.0	0.9	1.1	1.1	0.3	3.3	0.7	2.5	0.6	1.4	0.9	0.8	1.1	1.1	1.1	0.3	3.7	1.3	1.5	1.7	1.5	0.8	1.1	0.3	1.8	1.1
Natural Enviromental flow	1.8	0.7	0.9	1.0	0.2	3.0	0.5	2.3	0.5	1.3	0.7	0.6	0.9	0.9	1.0	0.3	3.4	1.1	1.3	1.5	1.3	0.7	0.9	0.2	1.6	1.1
Minimum Enviromental flow	1.6	0.5	0.7	0.8	0.2	2.8	0.2	2.2	0.4	1.1	0.5	0.4	0.7	0.7	0.8	0.2	3.2	0.9	1.0	1.2	1.1	0.5	0.7	0.1	1.3	0.8

Figure 22. Habitat Fragmentation by Depth for the Crocodile and Guapote in Three Flows for April.

For the stretch under study, the lowest depths are in section 52, where depths for Natural Flow, Normal Environmental Flow and Minimum Environmental Flow reach 30 cm, 20 cm and 10 cm, respectively.

The recommended environmental flows in this study correspond to maintaining habitat thresholds for the two fluvial species selected. We assume that with these thresholds other ecosystems and fluvial species are also being protected under the concept of the selected species being umbrella species. The intent of the exercise is to provide a scientific framework of reference to reach agreement on final environmental flows together with social and political actors. However, it must be recognized that the environmental flows of the Tempisque River maintain not only the ecosystems and species of the sector studied, but also more complex littoral and marine ecosystems of the Gulf of Nicoya, which have great ecological and economic importance for Costa Rica.

Consequently, it is imperative to maintain connectivity in the fluvial system of the Tempisque River so that there is a continuum between the Gulf and the upper part of the basin. There are flows of sediments, organic material and nutrients that are vital for maintaining the health of the Gulf of Nicoya. Likewise, the avenues of the Tempisque River must have a great influence on these ecosystems.

6. Conclusion

While recognizing the limitations of the information, this study at least arrives at a proposal so that social actors can initiate dialogue leading to agreement about environmental flows set for the Tempisque River. The study makes the following contributions:

- It characterizes the magnitude of the climatic variable and its effects on the flows regime. This analysis concludes that dry periods are more and more prolonged, but the two periods of data on flows utilized in this study show monthly rainfall averages with insignificant differences. Even so, differences were detected in the patterns of flows, especially in the dry month when flows are lower in the second period (1980-99) than in the first (1951-1969.)

- Employing double mass analysis, it was possible to select the 1951-1969 period as the most representative of the natural flows regime of the Tempisque River. Data from this period provide the foundation for setting environmental flows. Likewise, it was possible to demonstrate the impact of using water for irrigation, with a significant reduction of flows during the dry season months in the second period. On average, flow has diminished more than 3 m3/sec, signifying withdrawal of 33% of the average natural flow. This analysis concludes that the impact of using water for irrigation upstream from Guardia changed rainfall-runoff hydrological relations starting in 1988, which coincides very closely with the increase in water concessions at the end of the eighties.

- Using information available about groundwater concessions, estimates were made of the potential quantity of water being abstracted directly from the watercourse of the Tempisque River. Withdrawal volumes both before and after the Guardia Station bear a close relation to the changes detected when comparing the flows of the two periods.

- A proposal of maximum flow for concession is made taking into account the natural flows regime and the minimum flows recorded historically, which must be established because environmental flows are based on this data. For the most critical month, April, the maximum flow for concession is 4.9 m3/sec. Since concessions all along the river already reach 8.1 m3/sec, either 3.2 m3/sec of the concessions already granted must be renegotiated, or this flow deficit must be put back from some other alternative source.

- The environmental flows proposal presents three curves of flow: Normal Environmental Flow (50% of probabilities), Maximum Environmental Flow (upper limit of the reliability interval of 95%) and Minimum Environmental Flows. Likewise, it is proposed that peak flows with two years of return be maintained within the concept of environmental flows.

- The effect of the proposed environmental flows on the habitat of the two umbrella species (Crocodile and Guapote) was assessed with the HEC-RAS Model, placing special emphasis on changes of depth in 26 topographical profiles along the study section. After this assessment, it was concluded that only the Minimum Environmental Flows present considerable effects on fragmentation and quality of habitat.

- The environmental flows recommended should be maintained from Guardia to the Gulf of Nicoya in order to conserve littoral and marine ecosystems, as well. For this reason, it is argued that no damming of the river should be allowed anywhere along its main channel, to ensure connectivity between the upper basin and the Gulf.

- The recommended depth requirements are for a healthy population of adult crocodiles and guapote. Although the recommended environmental flows do not satisfy 100% of these requirements, they do provide a framework for regulating flows such that during the year and between years there are different regimes that allow a species to adapt, recuperate and prosper. Species will face conditions of stress and fatigue only in the driest years.

- Apart from setting and conserving environmental flows, it is necessary to carry out basin management and restore riparian forest along the main waterways, not just as biological corridors but also as a strategy to provide better conditions for thermal regulation and oxygenation of the water, which will have a positive effect on habitat quality.

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