

# Assessment of Water Supply as an Ecosystem Service in a Rural-Urban Watershed in Southwestern Mexico City

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**Abstract** Studies from the ecosystem services perspective can provide a useful framework because they allow us to fully examine the benefits that humans obtain from socio-ecological systems. Mexico City, the second largest city in the world, has faced severe problems related to water shortages, which have worsened due to increasing population. Demand for space has forced changes in land cover, including covering areas that are essential for groundwater recharge. The city has 880 km<sup>2</sup> of forest areas that are crucial for the water supply. The Magdalena River Watershed was chosen as a model because it is a well-preserved zone within Mexico City and it provides water for the population. The general aim of this study was to assess the ecosystem service of the water supply in the Magdalena River Watershed by determining its water balance (SWAT model) and the number of beneficiaries of the ecosystem services. The results showed that the watershed provides 18.4 hm<sup>3</sup> of water per year. Baseflow was dominant, with a contribution of 85%, while surface

runoff only accounted for 15%. The zone provides drinking water to 78,476 inhabitants and could supply 153,203 potential beneficiaries. This work provides an example for understanding how ecosystem processes determine the provision of ecosystem services and benefits to the population in a rural–urban watershed in Mexico City.

**Keywords** Ecosystem services · Magdalena River Watershed · SWAT model · Water balance · Mexico City

## Introduction

The severe environmental crisis caused by the transformation of natural ecosystems and the human dependence on the services they provide was recognized a few decades ago (Ehrlich and Ehrlich 1991; Urquidi 1994). The understanding of the processes that drive these changes in ecosystems is limited because scientific disciplines use different concepts and languages to describe and explain the socio-ecological systems. For example, in a protected area, ecologists and sociologists face the problem of deforestation in very different ways; the ecologists would like to combat soil degradation processes and encourage natural regeneration, while the sociologists would like to combat the problems of marginalization and poverty. As Ostrom (2009) advised, if we do not build a common conceptual framework of the social and environmental fields, we will only generate isolated knowledge. Since the beginning of the 21st century, joint efforts have been made among scientists, countries and institutions to apply basic scientific information to understanding the consequences of the use of natural resources for human welfare. Examples of these efforts are the Millennium Ecosystem Assessment (MA) (2005), the Global Land Project (GLP) (2005) and the

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International Geosphere-Biosphere Programme (IGBP) (2006). However, despite all international efforts to assess the Earth's systems as a whole, a number of complications arise when trying to assess a particular ecosystem. Studies from an ecosystem services (ES) perspective can generate a common framework between the social and environmental fields, and this combined/integrated approach may allow us to realize the benefits that humans obtain from socio-ecological systems. ES have been defined many times, and the definition changes depending on the context in which it is employed (Daily and others 1997; Costanza and others 1997; De Groot and others 2002; Kremen 2005; Quétier and others 2007; Boyd and Banzhaf 2007; Dale and Polasky 2007; Stanton and others 2010). We used the definition of Millennium Ecosystem Assessment (2003) as “the benefits that humans obtain from ecosystems” because of its simplicity, broad coverage and suitability for environmental management purposes. This concept adds a new perspective to the problem of natural resource management, in which interconnected ecological processes and the management of nature and its services must be properly integrated. Also, by recognizing that ecosystem processes are services that benefit humans, the task of conserving and managing them properly becomes easier because the benefits that they entail are evident. These benefits include, for example, the water supply, air purification, scenic beauty and soil erosion control (Millennium Ecosystem Assessment 2003).

The links between human welfare and ecosystems for most of the planet's ecosystems are not fully known due to a variety of socio-economic factors and the multiple scales on which environmental information is applied, from global to local. This lack of knowledge results in bad decisions for the management of ecosystem services (Balvanera and Cotler 2007). One of the challenges in developing countries, such as Mexico, is that there is very little information upon which to make management decisions. Researchers often require “further investigation” before giving suggestions, and politicians make decisions without knowing the dynamics of ecosystems and the consequences of the inadequate management of them. Given that environmental problems need immediate solutions, it is necessary to propose guidelines for ecosystem management based on the available scientific information, which can then be used to make informed decisions according to the functioning of the ecosystem.

Many regulating, provisioning, supporting and cultural services are related to water. Some of the services that people benefit from most directly include the provision of drinking water, irrigation water, hydropower, fish, and opportunities for recreation, and flood mitigation (Brauman and others 2007). Among these services, the water supply is likely the most crucial for the maintenance of cities; therefore, understanding ecosystem processes that generate this benefit is critical to creating sustainable programs for megacities.

Mexico City, the second largest in the world (Mazari and others 2001, UNESCO-WWAP 2003, United Nations 2009), has faced severe problems related to water shortages, which have worsened due to increasing population and the pollution of aquifers (Uitto and Biswas 2000). Increasing urbanization has resulted in the creation of the Metropolitan Area of Mexico City, and demand for space for the growing population has forced changes in land cover, including areas that are essential for groundwater recharge (Uitto and Biswas 2000). The total volume of water used by Mexico City is estimated to be 60 m<sup>3</sup>/s, of which approximately 70% is obtained from the Basin of Mexico and 30% from external sources, such as the Lerma and Cutzamala basins, which are more than 100 km away from the city (Jujnovsky and others 2010). Most of the water consumed within Mexico City is obtained from underground sources, and some springs and the Magdalena River are among the few surface water systems that have survived (Ezcurra and others 2006; Sheinbaum 2008). Mexico City still has 880 km<sup>2</sup> of forested area that is classified as a “preservation zone” (Sheinbaum 2008). Because these forests are crucial for the water supply, it is essential to take immediate measures to prevent their urbanization. The development of short-, medium- and long-term programs for ecosystem management, both regionally and locally, is needed to meet the challenge of providing water to the inhabitants of the metropolitan area. Some of the priority sites for the implementation of these programs are the watersheds located in the southwest of the preservation zone. An example is the Magdalena River Watershed (MRW), which was chosen as a model for this study because it is a well-preserved zone in the southwest of Mexico City, provides water for the population and has been studied by the National University of Mexico (UNAM) for nearly a decade (Ávila-Akerberg 2010).

Previous studies have attempted to estimate the volume of water that the Magdalena River Watershed (MRW) provides (González-Martínez TM 2008; Jujnovsky and others 2010). However, due to the lack of environmental information available in the area when these studies were conducted, greater precision is still needed to understand the value of the benefits generated by this ecosystem. It is therefore necessary to obtain a more robust value for the amount of water in the watershed using the preliminary studies as a baseline and to improve the model by incorporating new information with a socio-ecological approach.

Although much has been written on ecosystem services in recent years, there are few studies that show the relationship between ecosystem processes and their direct benefit to the population (Egoha and others 2007). Therefore, the general aim of this study was to assess the ecosystem service of the water supply in the MRW. It was necessary to determine the water balance to understand the ecological processes related

to the hydrological cycle and to calculate the population benefiting from the ecosystem service.

## Methods

### Study Area

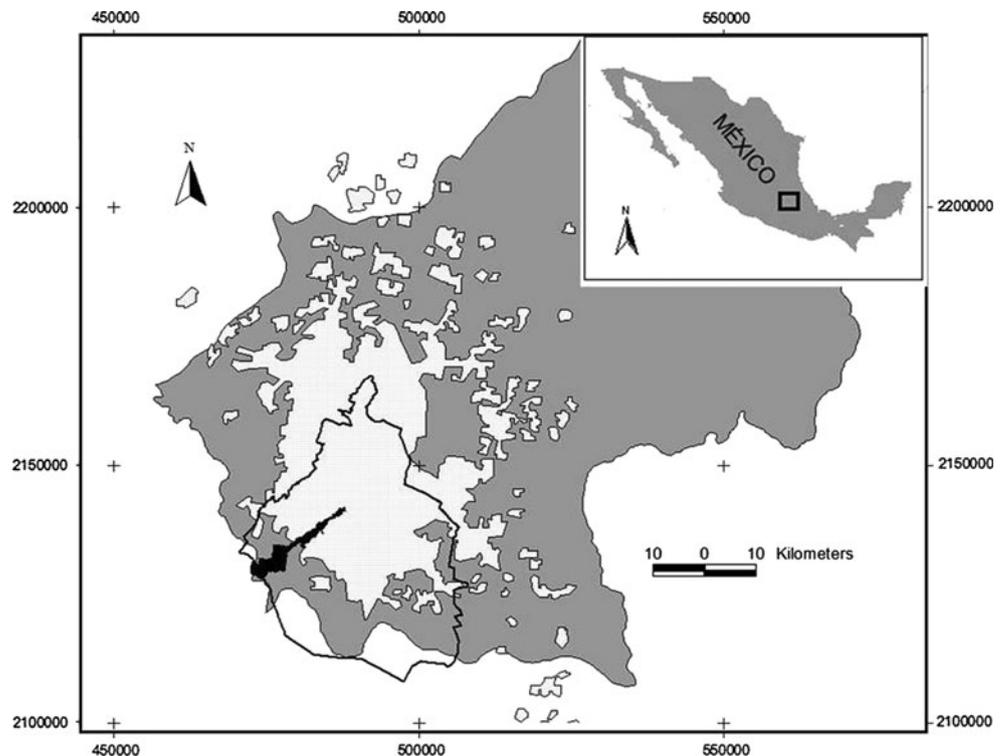
The MRW is home to one of the major rivers in Mexico City and has high biodiversity; it hosts a high percentage of the endemic species to the Basin of Mexico (Jujnovsky 2006; Almeida and others 2007; Ávila-Akerberg and others 2008). It is located at 19° 15' 00" N and 99° 17' 30" W inside the Basin of Mexico (Fig. 1). The entire watershed covers about 33 km<sup>2</sup>, the climate is temperate humid in the lower parts (2400–2800 masl) and semi-cold in the higher parts (2800–3850 masl), the annual precipitation is 900 mm in the lowlands and 1300 mm in the highlands, and the annual temperature ranges are between 9 and 15 °C (García 1988; Dobler 2010). There are three different soil units, Litosol, Feozem, and Andosol. The humic Andosol subunit is the most widely distributed (Álvarez 2000). Given the conserved status of its forests, the MRW is considered to be the most important continuous mass of vegetation and one of the more diverse temperate ecosystems of central Mexico (Facultad de Ciencias-Universidad Nacional Autónoma de México (UNAM) 2008).

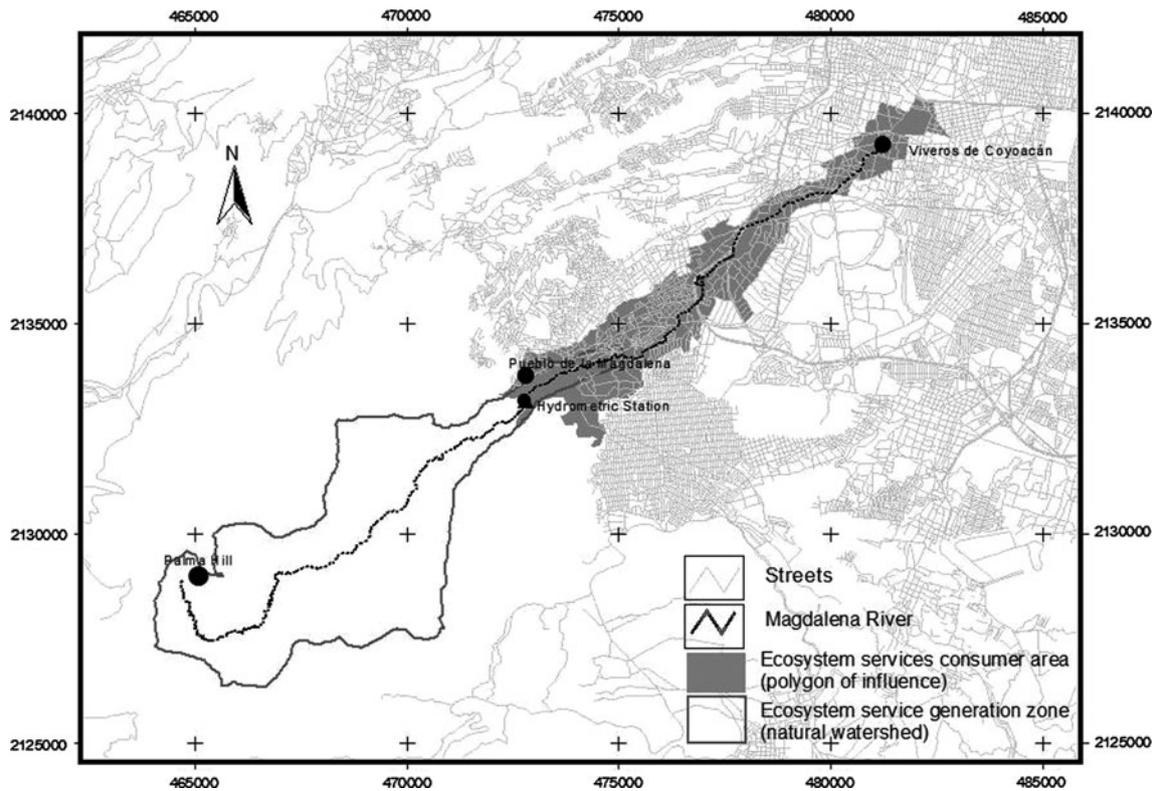
The Magdalena River is the main surface water body in Mexico City; it has good water quality in the higher portion,

which deteriorates as it flows down to the urban area, mainly because it is mixed with sewage water (Jujnovsky and others 2010). The Magdalena River has its headwaters at the base of Palma Hill (3650 masl) and has a total length of approximately 22 km, along which it is fed by various springs. It flows through 12 km of natural area where the predominant vegetation community is *Pinus hartwegii* (pine) and *Abies religiosa* (fir) at higher altitudes and mixed and *Quercus* forest (oak) at lower altitudes. At 2770 masl, a water treatment plant distributes 200 L/s to the Delegación Magdalena Contreras, while two-thirds of the remaining water continues its path into the city, where it is used as sewage and receives inputs from several collectors (Jujnovsky and others 2010). Within the city, the river runs for 10 km until it is piped into the Churubusco River (a larger river which flows out of the Basin of Mexico).

For the purposes of this study, the watershed was divided into two zones to evaluate water provision as an ecosystem service: (1) the source where the service (fresh water) is generated and (2) the location where the water is consumed, this means where potentially beneficiaries are. The ecosystem service generation zone covered an area of 28.8 km<sup>2</sup> and was defined as beginning at the natural watershed and ending at the Magdalena River Hydrometric station, which is the point where the channel measurements reflect the hydrological function of the watershed. Because it is very difficult to follow the natural boundaries of a watershed in urban areas, the ecosystem service consumer area was determined using a polygon of influence. The polygon was proposed in

**Fig. 1** Location of the Magdalena River Watershed (in black), the Basin of Mexico (in dark grey), the metropolitan area of Mexico City (in light grey), Distrito Federal (thin blackline)





**Fig. 2** The Magdalena River Watershed divided into two zones, the zone where the service is generated and the zone where it is consumed

the “Master Plan for Integrated Management and Sustainable Use of the Magdalena River Watershed” by a collaboration agreement between the government of Mexico City and the National University of Mexico (Programa Universitario de Estudios Sobre la Ciudad (PUEC-UNAM) 2008). The delimitation was performed according to the basic geostatistical areas (AGEBs) that cross the river within a radius of 500 m of each side of the channel. The AGEBs are units of information used by the “National Institute of Statistics, Geography and Informatics” (INEGI) to integrate socio-economic data. The polygon extends from the natural area (town of Magdalena) to the “Viveros de Coyoacán”, where the Magdalena River is completely piped (Fig. 2).

#### Water Supply Determination

To determine the water supply, it is necessary to assess the water balance of the Magdalena River. The water balance is defined as  $WB = P - Et - RO - \Delta SM$ , where  $WB$  = water balance,  $P$  = precipitation,  $Et$  = evapotranspiration,  $RO$  = runoff (surface runoff + baseflow + water recharge of the confined aquifer), and  $\Delta SM$  = change in soil moisture (Neitsch and others 2002).

Runoff is an element of the water balance that can be considered to be a water provision ecosystem service because it can be used by people. To assess the runoff

generated by this watershed, hydrologic modeling was conducted using the SWAT model (Soil and Water Assessment Tool), which is the AvSWAT interface 2003 for ArcView 3.2 developed by the US Department of Agriculture (Neitsch and others 2002). It uses water balance as its baseline to determine the input, output and storage of water in the basin. The model works at various scales, including basins and sub-basins which are defined by the hydrological network. Which are them divided into smaller units, using the intersection of two factors that are essential to define the behavior of water in the soil, land cover and soil type, resulting in hydrological response units (HRUs).

The basic steps for using the SWAT model are data entry, calibration of parameters, validation and statistical analysis. The modeling process starts with the collection of data from previous studies (González-Martínez TM 2008; Facultad de Ciencias-Universidad Nacional Autónoma de México (UNAM) 2008; Jujnovsky and others 2010) that can be fed into the model and, in conjunction with parameters derived from field work, used to create a more robust and representative model. The data that were fed the program were the land cover, soil and vegetation type characteristics, hydrologic network type, location of weather stations and weather parameters (Table 1); SWAT requires daily precipitation, maximum/minimum air temperature, solar radiation, wind speed and relative humidity.

**Table 1** Basic information used to run the SWAT model

Information	Source	FORMAT
Digital elevation model	Instituto Nacional de Estadística, Geografía e Informática (INEGI) (2000)	Grid
Land cover Map	Ávila-Akerberg (2005)	Grid
Soil units Map	Registro Agrario Nacional (RAN) (2000) (Only took into account the major soil units)	Grid
Hydrology	Ávila-Akerberg (2002)	Shape
Weather stations	ERIC III (Instituto Mexicano de Tecnología del Agua (IMTA) 2007)	dBase
Zarco	(daily precipitation, maximum/minimum air temperature, solar radiation, wind speed and relative humidity)	
San Francisco		
Río Magdalena		
Monte Alegre		
Desviación Alta al Pedregal		

The SWAT model needs to be calibrated in order to adjust the calculated and observed data. It is necessary to have the actual flow data of the drainage networks in order to compare it with the flows simulated by the SWAT model. We used the Magdalena River hydrometric information for 1999 based on the hydrograph separation filter (Lyne and Hollick 1979) previously made by González-Martínez TM (2008). The model was calibrated adjusting the simulated data to observed. The adjustment was made using the Nash-Sutcliffe index and the coefficient of determination until statistical analysis showed acceptable

values. The parameters modified during calibration can be seen in Appendix 1.

For the validation process the model was run again but using climatological and hydrometric data from 2000.

### Components of the Hydrologic Cycle and Vegetation Relationships

The SWAT model provides information regarding the components of the hydrologic cycle (Table 2), so the variables involved in calculating the water balance were *precipitation, water content in soil, actual evapotranspiration, potential evapotranspiration, surface runoff, baseflow, recharge, and total water yield*. With the information generated from the modeling in the calibration step, we identified the components of the hydrologic cycle for each vegetation type, and therefore their role in ecosystem services generation, i.e., the amount of water produced. With this information, we determined how the hydrological cycle processes were involved in generating the ecosystem service of water supply in the forest.

### Identification of Beneficiaries

The identification of beneficiaries was conducted according to the polygon of influence and to the areas of river water distribution. The real beneficiaries for this study were defined as the current users of the water that is generated in the watershed and potential beneficiaries as people who lived within the polygon of influence but received water from sources other than the Magdalena River.

**Table 2** Description of the components of the hydrologic cycle

Components Of Hydrologic Cycle	Description
Precipitation	Amount of water that falls on a region
Content of soil water	Moisture that remains in the soil at the end of a period of time
Water yield	Total amount of water that contributes to the recharge of the main channel of the river. It is the sum of the surface, lateral subsurface and groundwater flow
Actual evapotranspiration	Loss of surface moisture by evaporation and by transpiration by vegetation that occurs under the current conditions
Potential evapotranspiration	Maximum amount of water that can evaporate from soil completely covered with vegetation under optimal conditions
Surface runoff	Amount of water runoff on the soil surface layer
Baseflow	Amount of water that infiltrates into the ground as subsurface or groundwater flow and contributes to the recharge of the river
Recharge	
Unconfined aquifer recharge	Amount of water that infiltrates into an aquifer that has a limit above the water table. This is also known as a shallow aquifer. It can contribute to both the main river flow and to the recharge of the watershed
Confined aquifer recharge	Amount of water that infiltrates into an aquifer for which the upper and lower limits are found in geological formations with very low hydraulic conductivities and are almost impermeable. The water that enters the aquifer contributes to recharge or runoff outside of the basin

The real beneficiaries were identified according to data from the agency responsible for water management in Mexico City (SACM). This institution uses an information system based on neighborhoods or “Colonias”. However, the agency responsible for generating socioeconomic and population data (INEGI) used “AGEBs” instead. The “Colonias” were used to investigate their sources of water supply and to determine the actual consumption zones of the Magdalena River, and the “AGEBs” were used to determine the population of each neighborhood. Once the beneficiaries were identified, the population number of each colony was estimated. We identified areas that belong to the polygon of influence and those that were outside. We calculated the total population of the polygon and the population that did not belong to but received water from the Magdalena River. Information about the number of inhabitants was obtained from the national population agency (Instituto Nacional de Estadística, Geografía e Informática (INEGI) 2008), and the distribution of water was obtained from the records of the water agency (Dirección General de Construcción y Operación Hidráulica (DGCOH) 2001).

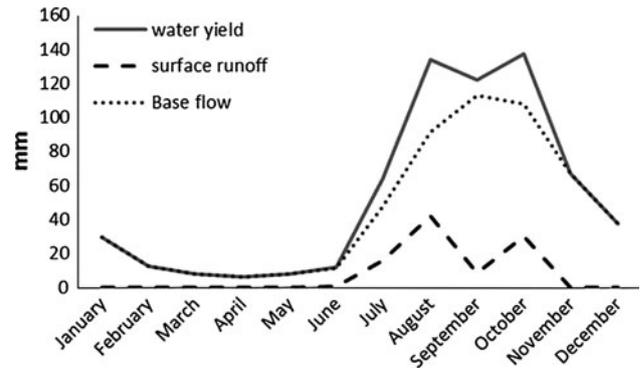
To calculate the actual water availability per capita of the whole polygon (real and potential beneficiaries), the annual baseflow was transformed into daily runoff, differentiating between the rainy season, when rainfall exceeded 60 mm per month (July to November) and the dry season (December to June), divided by the number of people within the polygon of influence. This value was calculated as  $PWA = DBF/N$ , where  $PWA$  = Water availability in liters/person/day, where  $DBF$  = daily amount of water generated by baseflow and  $N$  = total number of inhabitants within the polygon of influence.

## Results

### Water Supply Determination

The calibration model had an acceptable fit between the observed and the simulated annual hydrometric data ( $r^2 = 0.878$ , Nash–Sutcliffe Coefficient = 0.525), which allowed us to analyze the information. The results show that the watershed provides  $18.4 \text{ hm}^3$  of water per year. Baseflow was dominant, with a contribution of 85%, while surface runoff only accounted for 15%. The lateral sub-surface flow contributed 98% of the baseflow, and only 2% drained to the unconfined aquifer as groundwater flow.

The forests in this watershed released 440 mm of water per year into the atmosphere by evapotranspiration, which accounted for 40% of the rainfall. According to the model, only 0.43% of the rain water recharged the confined aquifer, which means that almost all of the flow in the basin returns to the river in a short time.



**Fig. 3** The Magdalena River Watershed annual baseflow, surface runoff and water yield shown in mm

The monthly data showed that baseflow was greater than surface runoff throughout the year (Fig. 3), with the months of July to November having the greatest water yield. It is important to note that from November to February, there is no surface runoff, so the baseflow provides water to the river in the dry season.

### Components of the Hydrologic Cycle and Vegetation Relationships

The SWAT model defined 17 runoff units (or sub-basins) and 13 land cover units. These units included the three types of forests (*Abies religiosa*, *Pinus hartwegii* and *Quercus* and mixed forest) and their associations, including a small portion of the urban area (Fig. 4). The data allowed us to analyze the relationship between vegetation and the components of the hydrological cycle (water yield, surface runoff, baseflow, confined aquifer recharge and evapotranspiration).

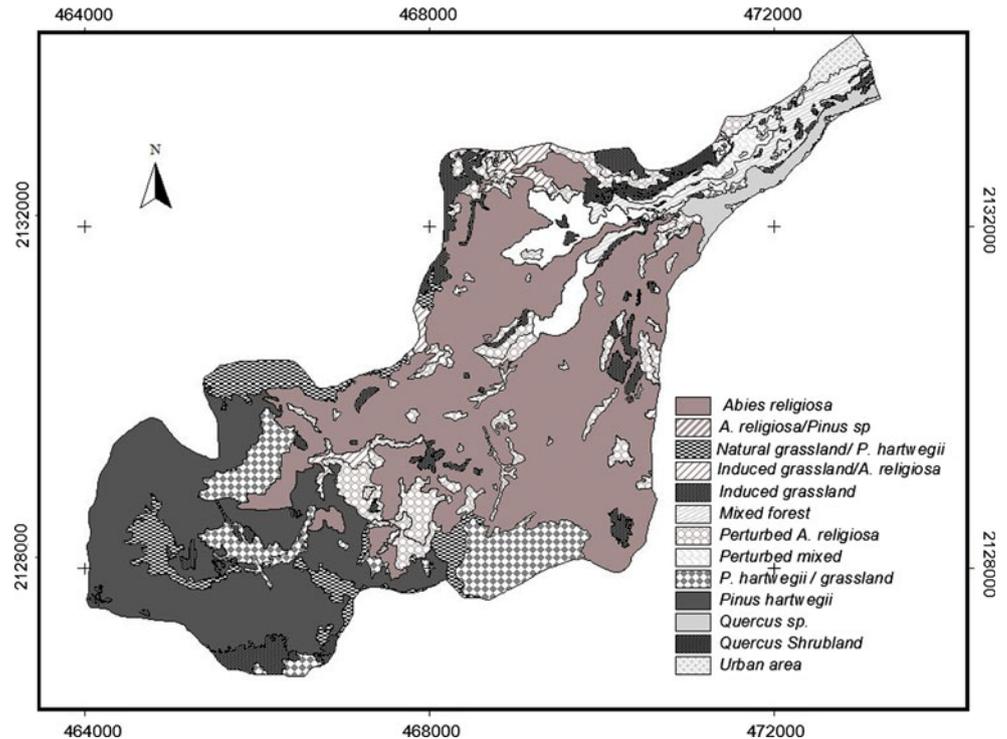
#### Water Yield

The *Pinus hartwegii* forest, in association with natural grasslands, had the greatest potential to generate water yield, with mean values up to 115 mm per year (Fig. 5a), while the urban land cover generated the lowest value. Due to their size, *Abies religiosa* and *Pinus hartwegii* forests generated the largest annual total runoff volume,  $7.4$  and  $4.5 \text{ hm}^3$ , respectively (Fig. 5b).

#### Surface Runoff

The urban land cover had the greatest susceptibility to generate surface runoff with an annual average of 477 mm. Induced grassland areas were also highly prone to form this type of flow and had values between 257–201 mm. Conversely, the oak-scrub vegetation community was characterized by the lowest tendency to generate surface runoff

**Fig. 4** Land cover units in generation zone of Magdalena River Watershed, based on Ávila-Akerberg (2005)



(7 mm) (Fig. 5a). Due to their extension *Abies religiosa* and *Pinus hartwegii* were the main contributors to the total volume of surface runoff. In contrast, *Quercus* sp. produced the lowest volume of surface water runoff, which can be attributed to its flat topography and smaller area compared to *Abies* and *Pinus* forests (Fig. 5b).

#### Baseflow

The areas with the greatest capacity to generate baseflow were in the upper basin and corresponded to *Pinus hartwegii* forest and natural grassland, with average values between 606 and 579 mm per year. The urban area had an average baseflow of 25 mm, which was considerably lower than that of any vegetation unit (Fig. 5a). Taking into account the total volume, the *Abies religiosa* and *Pinus hartwegii* vegetation units contributed the greatest amount of baseflow to the watershed, with annual volumes of 6.5 and 3.8 hm<sup>3</sup>, respectively, while the urban areas provided very small amount of baseflow water (5892 m<sup>3</sup>) (Fig. 5b).

#### Evapotranspiration

The highest evapotranspiration capacity occurred in areas of natural grassland, *Pinus hartwegii* forest and induced grassland, with annual mean values ranging from 431 to 485 mm, while the urban area had the lowest

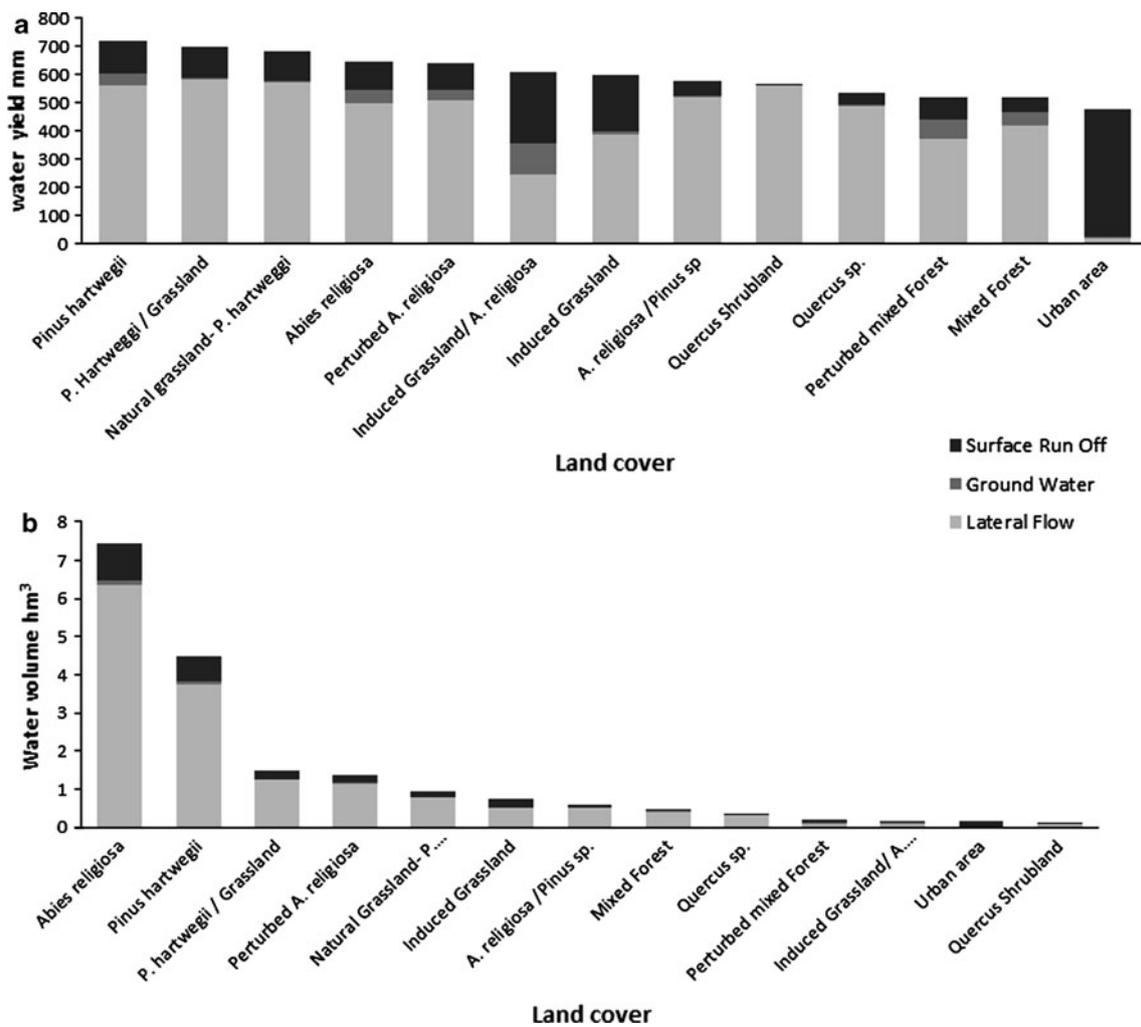
evapotranspiration capacity (348 mm). Due to its area, the *Abies religiosa* forest was the vegetation unit with the highest evapotranspiration value, followed by *Pinus hartwegii* and *P. hartwegii*-grassland. From the 12.7 hm<sup>3</sup> of water lost through evapotranspiration, 42% was lost from the *Abies religiosa* forest, 21% from the *Pinus hartwegii* and 7.8% from the *P. hartwegii*-grassland.

#### Confined Aquifer Recharge

The *Abies religiosa* and *Pinus hartwegii* forests recharged 61% of the water in the confined aquifer. The *Quercus* shrubland contributed the smallest amount for recharge. It should be noted that the induced grassland-*Abies religiosa* forest, perturbed mixed forest and urban areas were identified by the model as areas with a high potential for recharging the confined aquifer. Figure 6 shows schematically the behavior of water in the watershed according to the types of forests and their associations.

#### Identification of Beneficiaries

The ecosystem service consumer area, the polygon of influence, covered 32 AGEs located on either side of the Magdalena River, from the “town of Magdalena” to the “Viveros de Coyoacan”. The total population of the polygon was 107301 inhabitants according to the 2005 census



**Fig. 5** Amount of water generated by vegetation unit according to flow type (surface runoff and baseflow, divided into subsurface and groundwater) shown in mm (a) and in total volume  $hm^3$  (b)

data (Instituto Nacional de Estadística, Geografía e Informática (INEGI) 2008). There were 78476 beneficiaries who receive water from the MRW. Forty-one percent belonged to the polygon of influence, and the rest were residents of highland areas that received pumped water (Fig. 7); therefore, only 32,273 inhabitants from the polygon received water from the Magdalena River, and 59% supplied their water needs from external sources, such as wells and the Lerma-Cutzmala Systems. If we take into account the total population of the polygon of influence and the people who actually received water from the Magdalena River, there were 153,203 potential beneficiaries, which is almost twice as many identified real beneficiaries.

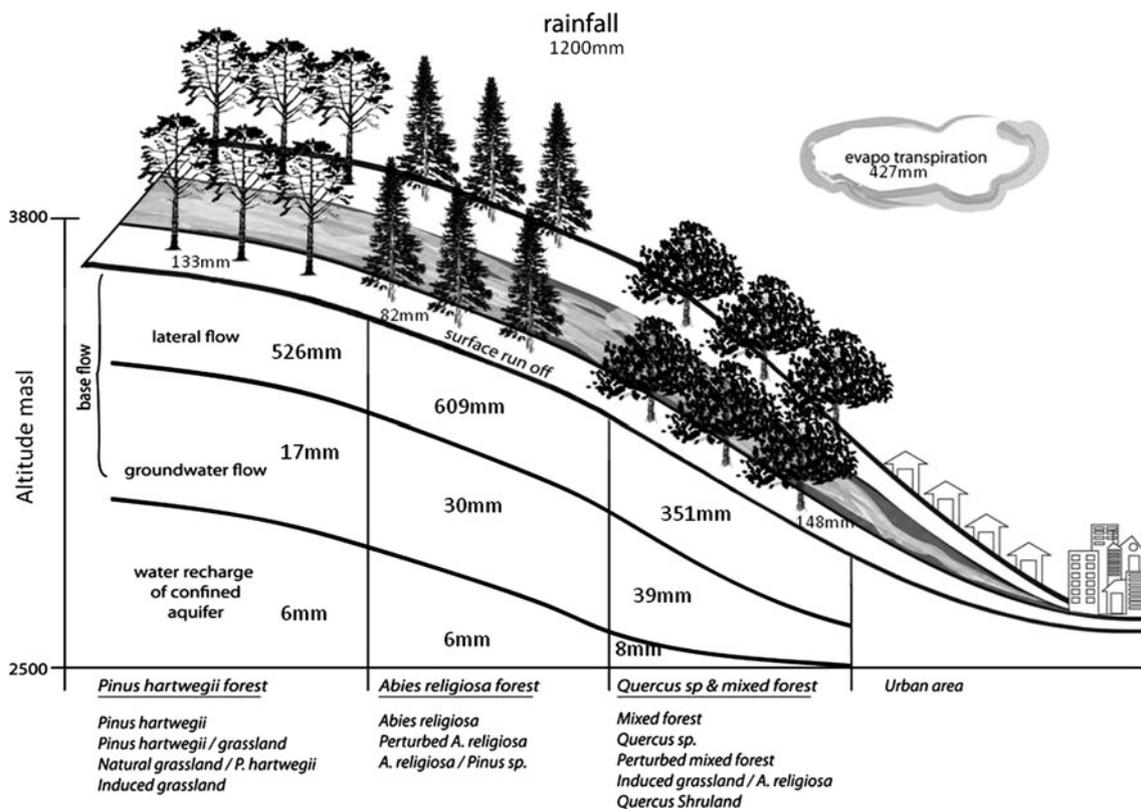
Considering the baseflow only, the MRW generated, on average,  $0.043 \text{ hm}^3$  of water per day. During the rainy season, the basin generated enough water to supply a total of 526 l to each of the 153,203 potential beneficiaries (Table 3).

## Discussion

### Water Provision as an Ecosystem Service

Brauman and others (2007) proposed that one of the main points to be addressed for the development of ecosystem service assessment is to understand its biophysical generation in the ecosystem. Our work provides a fundamental tool for understanding how ecosystem processes, in this case the components of the hydrological cycle, determine the provision of one ecosystem service (water supply) and how this benefits the population. The evaluation of baseflow was critical to assess the ecosystem service of the water supply because it gives both spatial and temporal information on service availability and the actual and potential beneficiaries.

Temperate forests located in header watersheds, such as in the MRW, play an important regulatory function in the ecosystem because they affect the quantity, quality and



**Fig. 6** Schematic representation of water behavior (surface runoff, baseflow, groundwater recharge) in the Magdalena River Watershed according to the types of forests and their associations

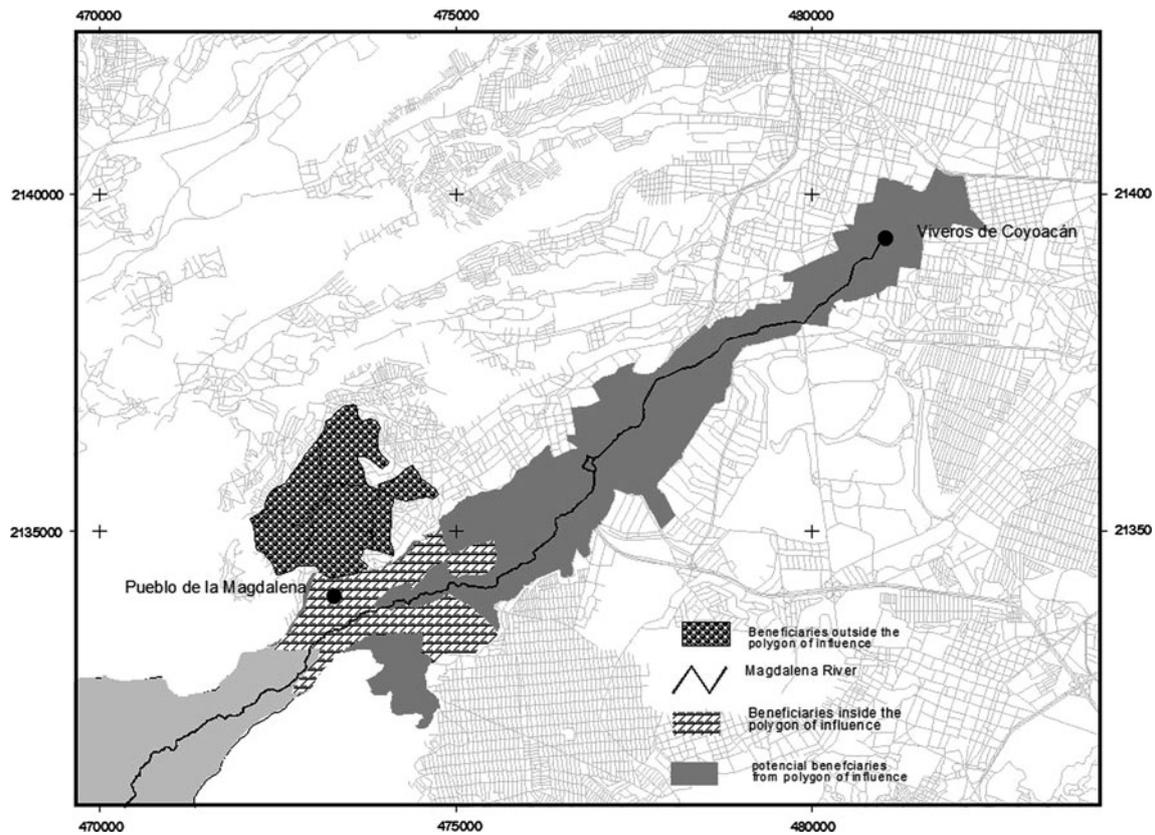
timing of water flow; protect the soil from being eroded; and prevent the degradation of rivers throughout the watershed (Cotler 2004). Data concerning the relationship between vegetation and hydrological behavior are essential for management proposals in specific areas. Sixty-six percent of well-preserved forests remain in the study area (Facultad de Ciencias-Universidad Nacional Autónoma de México (UNAM) 2008), producing only 15% of the water flow in a superficial way, while 85% is produced as baseflow, both in the unsaturated soil zone (lateral subsurface runoff) and in the saturated zone (groundwater).

Each vegetation type has different water requirements according to their physiology and environmental conditions (Matsumoto and others 2008; Brümmer and others 2011). For example, Silberstein and others (2002) reported that evapotranspiration in some *Eucalyptus* forests accounts for 90% of the precipitation; while in the study area where 70% of the forests are coniferous, only 40% of the water is released into the atmosphere.

The pattern in the amount of water flowing on the surface and as baseflow in the Magdalena River Watershed is similar to that reported by Robinson and others (2003) for coniferous forests. The areas with the greatest susceptibility to the generation of surface runoff were urban land cover and induced grasslands, and the zones

that had the greatest ability to generate baseflow were in the upper basin and corresponded to *Pinus hartwegii* forests. It is important to note that the urban land cover had a lower baseflow than any vegetation unit in the study area. This result is consistent with those values reported by Huber and others (1985); Huber and López (1993) and Bent (2001), who showed that logging causes a significant change in the temporal and spatial distribution of reserves of soil water and evapotranspiration from a watershed, proving the importance of forests for the regulation of the amount of subsurface and underground water. Also, as Bruijnzeel (2004) stated, a good vegetation cover is able to prevent surface erosion and, in cases where the coverage is well-developed, can prevent landslides.

Although much has been published about the effect of forests on regulating the amount of water (Andréassian 2004), basic research with an integral approach is still needed to investigate the relationships between ecosystem processes and how they combine to determine the provision of water. As mentioned above, it is important to not make generalizations about the water-vegetation relationship because each vegetation type behaves differently according to its ecophysiology and the characteristics of the study site. Finally, the scale at which the water-



**Fig. 7** The polygon of influence, zone of current Magdalena River water consumption, and zone of potential beneficiaries

**Table 3** Potential water availability in the rainy and dry seasons. Provision water data are shown annually ( $\text{hm}^3$ ), daily ( $\text{hm}^3$ ) and instant ( $\text{l/s}$ )

Baseflow	Annual volume ( $\text{hm}^3$ )	Daily volume ( $\text{hm}^3$ )	Volume of flow ( $\text{l/s}$ )	Potential water availability ( $\text{l/inhabitant/day}$ )
Annual average	15.6	0.043	490	279.4
Rain average (July–November)	12.3	0.080	930	525.9
Dry season average (December–June)	3.3	0.015	180	101.3

vegetation relationship occurs should be taken into account to make more accurate interpretations.

*Water Provision Beneficiaries*

More than half of the population that receives water from the Magdalena River lives outside the watershed, including those beneficiaries living in areas higher than the river who have to have the water pumped to them. It is important to

note that the population is urban, 90% receive less than 5 minimum wages and their main occupation is as laborers or workers (González–Martínez TM 2008).

The data indicate that this watershed could provide water to 153,203 inhabitants. The World Health Organization (WHO/UNICEF Joint Water Supply/Sanitation Monitoring Programme, Water Supply and Sanitation Collaborative Council and UNICEF 2000) recommended that the daily water consumption in cities should be at least 150 l per person. Therefore, in the rainy season, the MRW could supply more than three times the minimum water requirements to the entire population within the influence polygon. However, it would be necessary to develop a resource management strategy for the distinct rainy and dry seasons because the timing of the water supply is a factor that is not taken into account in the water management policies in Mexico City.

It is inconceivable that Mexico City, which is classified as a zone of absolute water scarcity (United Nations Development Programme (UNDP) 2006) with a high degree of pressure on water resources (Secretaría de Medio Ambiente y Recursos Naturales (SEMARNAT) 2009), does not take into account the potential of the Magdalena River to supply a greater population. Although this water

body does not solve the scarcity problem, it could relieve scarcity in the rainy season.

### Model Limitations

This study provides basic information that can be used for a management proposal for an urban river for which there is a lack of information, poor coordination and mismanagement by the authorities. The SWAT is a useful model for analyzing the hydrological behavior of a watershed with the available information. The more field data the model has, the better it will explain reality. Therefore, the modeling conducted for this work is expected to be more robust than that of previous studies (González–Martínez TM 2008; Jujnovsky and others 2010) because the model was fed new information about the vegetation and soil. Despite several years of work in the MRW by different institutions, it is still difficult to obtain information on some parameters, such as meteorological and hydrometric data. Therefore, for future estimates of water supply, it would be essential to have a hydrometric station with updated data for the output of the watershed and meteorological data for the same years. It is also important to conduct a more detailed edaphological study, if possible, for each soil and vegetation unit. It would also be valuable to refine the model to measure the leaf area index and evapotranspiration in the field and to conduct studies on the ecophysiology of plants and the soil water potential.

### Conclusions and Perspectives

In conclusion, baseflow allows the Magdalena River to provide water service year round. The vegetation plays a fundamental role because the areas with the greatest baseflow are those with *Pinus hartwegii* and *Abies religiosa*. Therefore, for the Magdalena River to continue providing water year round, it is imperative that the watershed not lose the tree cover.

This study is presented as an effort to measure one ecosystem service by understanding the processes involved, in this case the hydrological cycle, and to provide benefits to the local people. For a full assessment of the ecosystem with the goal of identifying the ecosystem services that could benefit the community, it is necessary to identify the most important processes that determine the provision of service, the benefits, and measures to ensure that this service can actually impact human welfare.

Although this study focuses on a specific case in southwest Mexico City, appropriate water management is a global priority, but solutions must be local. It is important that the agency responsible for water management in Mexico City (SACM) uses appropriate strategies, taking

into account the ecosystem that generates the water and the timing for which flow occurs. The management agency should also consider the areas that are suitable for receiving the ecosystem service. The inadequate management of a watershed may result in the loss of a valuable service, such as a water supply. Therefore, collaboration with other institutions is important.

It is intended that this project will serve as a tool to use in decision making for proper and informed water management. Moreover, it is possible to extend these results to the forested areas of the “preservation zone”, where the residents of Mexico City could enjoy the ecosystem services in a sustainable way. The sustainability of our natural resources depends on making environmental issues a primary topic on the political agenda, not only in Mexico City but also in the other major cities of the world.

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