Mapping environmental services in Guatemala

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Acronyms and abbreviations

CCAD	Central American Commission for Environment and Development (*Comisión Centroamericana de Ambiente y Desarrollo*)
CDM	Clean Development Mechanism
CIESIN	Center for International Earth Science Information Network
CONAP	National Council on Protected Areas (*Consejo Nacional de Areas Protegidas*)
EMPAGUA	Municipal Water Firm of Guatemala City (*Empresa Municipal de Agua de Guatemala*)
ha	hectares
HEP	Hydroelectric power
INFOM	National Institute for Municipal Development (*Instituto Nacional de Fomento Municipal*)
IUCN	World Conservation Union
MA	Millennium Ecosystem Assessment
MAGA	Ministry of Agriculture, Livestock, and Nutrition (*Ministerío de Agricultura, Ganadería y Alimentación*)
NBSAP	National Biodiversity Strategy and Action Plan
PES	Payment for Environmental Services
PROARCA	Regional Environmental Program for Central America (*Programa Ambiental Regional para Centroamérica*)
qq	*Quintal* (45.45 kilograms or 100 lbs)
s.d.	Standard deviation
TEV	Total Economic Value
UNEP	United Nations Environment Programme
WCMC	World Conservation Monitoring Centre
WDPA	World Database on Protected Areas
WWF	Worldwide Fund for Nature

1. Introduction

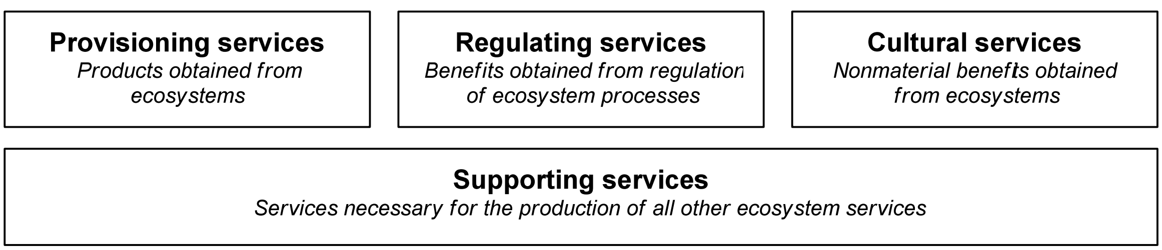
The Millennium Ecosystem Assessment (MA) has highlighted the importance of the services that natural and managed ecosystems provide, and the threats they are experiencing (MA, 2005).

To be able to address the threats, it is important to improve our understanding of ecosystems, the services they provide, and the threats they face. A critical aspect that has often been neglected to date is the spatial aspect of services.

In this paper, we use data from Guatemala to map areas that are important for the provision of indirect ecosystem services—services whose benefits are enjoyed at some distance from the ecosystem that provides them, such as watershed services (enjoyed downstream) or biodiversity conservation (enjoyed globally). These services are usually externalities from the perspective of land users, and so tend to be under-provided. Mapping the areas that supply such services links the supply and demand of ecosystem services in a spatially explicit way, allowing us to identify and prioritize areas of conservation interest.

2. Ecosystem services

The MA classifies the services that ecosystems can provide into four broad categories: provisioning services, regulating services, cultural services, and supporting services (Figure 1) (MA, 2005). This typology separates services along functional lines. These categories illustrate the diverse ways in which ecosystems contribute to human welfare.



Source: Millennium Ecosystem Assessment, 2003.

Figure 1: Typologies of ecosystem services: the Millennium Ecosystem Assessment

We focus here on services whose benefits are enjoyed outside the ecosystems that provide them—what economists call *indirect* benefits (Figure 2). In the MA's classification, these are primarily regulating and supporting services, as well as some cultural services. There are two reasons for doing so.

- First, because of the physical distance between the ecosystems that provide the service and the service users, it is often far from obvious where the services originate. One cannot harvest a crop without knowing where it grows; but it is perfectly possible to enjoy clean water without having the faintest idea of where it came from.
- Second, and again because of the physical distance between the ecosystems that provide the services and the service users, most indirect services are externalities from the perspective of

the ecosystem managers. Ecosystem managers are typically neither compensated for providing the services, nor penalized for not doing so. As a result, they tend to ignore these services in making their management decisions.

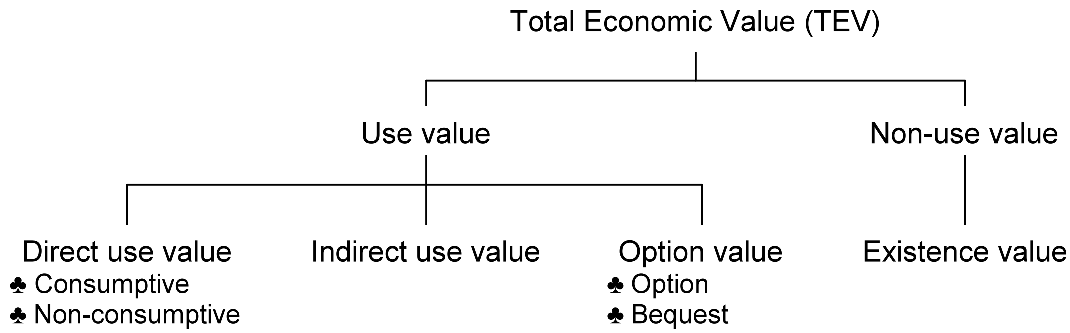


Figure 2: Typologies of ecosystem services: Total Economic Value

In most cases, the main external services of interest are water, biodiversity conservation, and carbon sequestration. Our analysis focuses on water services, for several reasons. First, water is a critical factor in economic growth and human welfare. Insufficient and/or irregular flow and poor quality water constitute major sources of human health and development problems and constraints in many developing countries. Second, biodiversity conservation priorities have been the focus of considerable work in recent years, which has included at least some basic mapping work in most countries, in the context of National Biodiversity Strategy and Action Plan (NBSAP) processes or their equivalent. Carbon sequestration services, on the other hand, are not spatially specific. A molecule of carbon removed from (or prevented from entering) the atmosphere anywhere in the world, by whatever means is equivalent to any other carbon dioxide molecule. The only spatial aspect of this service is the need to document that areas afforested or reforested under the Clean Development Mechanism (CDM) were without tree cover prior to 1990. Third, unlike biodiversity conservation and carbon sequestration, many water uses have tangible (and sometimes rivalrous) use value. Due to the spatial nature of the flow of the service, beneficiaries and their demand are relatively easy to identify and evaluate (Pagiola and Platais, 2007), offering a potential for using market-based mechanisms to equalize the spatially linked service supply and demand.

Payments for Environmental Services. Recognition of the problem posed by the degradation of ecosystem services and of the failure of past approaches to dealing with it has led to efforts to develop systems in which land users are paid for the environmental services they generate, thus aligning their incentives with those of society as a whole (Landell-Mills and Porras, 2002; Pagiola and others, 2002a; Wunder, 2005). The central principles of this Payment for Environmental Services (PES) approach are that those who provide environmental services should be compensated for doing so and that those who receive the services should pay for their provision (Pagiola and Platais, 2007). This approach has the further advantage of providing additional income sources for poor land users, helping to improve their livelihoods. Several countries are already experimenting with such systems, many with World Bank assistance. Implementation of PES mechanisms has been essentially ad hoc until now, focusing on low-hanging fruit. Mapping and estimating the relative values of areas that are important for service provision will allow a more systematic approach to the implementation of PES mechanisms.

3. Methodology

Our analysis is comprised of two components. First, we mapped the areas that provide water services ('water supply areas') by identifying the specific location of the intakes used by major users ('takepoints') to obtain their water and then delineating the portions of the watershed that contribute water to those intakes. Second, we estimated an index of the value of each water supply area using various measures of the magnitude of the service they provide.

We focus on the larger, formal sector water users. There is also a considerable amount of direct use of water by rural households. Transaction costs make it impractical in most cases to base PES mechanisms on such dispersed users.

In mapping the areas that provide water services, we focus on surface water sources, omitting underground tapping and extraction of groundwater sources, as the understanding of belowground waterflows is insufficient to allow recharge areas for specific wells to be identified. Information on groundwater use is also more difficult to obtain.

Identifying water supply areas

Mapping water supply areas begins by identifying the specific location of the water takepoints from which users obtain their water. As water use in Guatemala is highly decentralized, this was generally accomplished by contacting the users directly. Unfortunately, in many cases it proved impossible to obtain more than a general location, so that assumptions had to be made to plot a specific location from the available data. These assumptions are detailed in the discussion of individual water users.

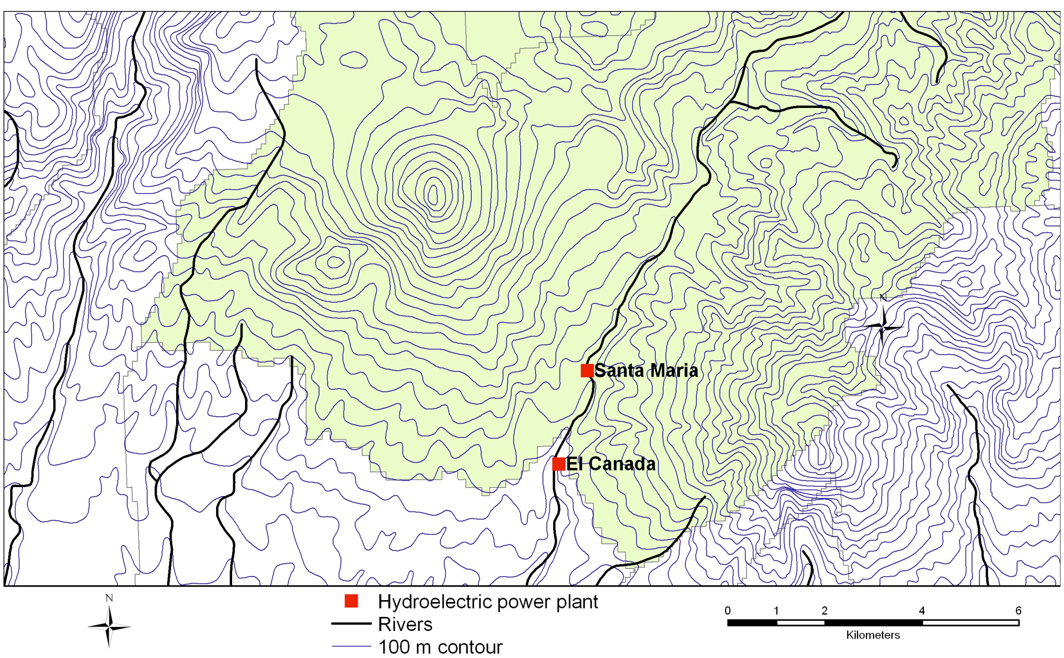


Figure 3: Delineating water supply areas

Once the location of the water takepoints was identified, we delineated the approximate water supply area for each takepoint using the closest 100m contour line up to the limit of the watershed, based on the principle that 'water flows downhill' (Figure 3). In cases where water is extracted from a river whose tributaries stretch over multiple distinct watersheds that are all part of a larger drainage basin, all upstream watersheds in addition to the proportion of the watershed above the intake are included in the water supply area. The approach offers a practical and much less expensive alternative to conducting hydrological survey for a quick assessment of water service supply. It tends to over-estimate the size of the water supply area, by including some lateral areas at altitudes close to that of takepoint from which water would likely drain past the takepoint.

- Where multiple takepoints were used by a given user, we took the lowest takepoint if they were located in the same watershed, or repeated the process for each takepoint if they were located in separate watersheds.
- In some cases, multiple users are located in the same watershed. For example, the Canadá and Santa Maria hydroelectric power (HEP) plants are both located on the Río Samalá, about half a kilometer apart. In this case, we delineated a single water supply area, using the contour line closest to the plant furthest downstream. When the two users are located far apart, however, separate water supply areas are delineated. For example, the Matanzas HEP plant, on the Río Matanzas, has its own water supply area. Río Matanzas ultimately flows into the Río Chixoy, and thence to the Chixoy HEP plant about 40km downstream. In this case, a separate water supply area is delineated for Matanzas, which is fully contained within the boundaries of the Chixoy water supply area.

We use the watershed map of Guatemala developed by Nelson and Chomitz (2002). They generated a 100-meter hydrologically correct elevation surface by interpolating contour lines and spot heights in combination with lakes and river data. This map differs slightly from the watershed map produced by the Ministry of Agriculture, Livestock, and Nutrition (*Ministerío de Agricultura, Ganadería y Alimentación*, MAGA), but the differences are too small to materially affect the results.[1]

The study area is limited to the highland areas of Guatemala, omitting the northern Petén department (Figure 4). Petén accounts for about a third of Guatemala's land area, but only 3 percent of its population and 4 percent of the poor.

[1] We chose to use the Nelson and Chomitz (2002) watershed map so that we could also use their poverty map of Guatemala and undertake analyses of how service supply areas relate to poverty (Pagiola and others, 2007). If we had used the MAGA watershed map, we would not have been able to examine how areas that are important for service provision compare to areas of high poverty.

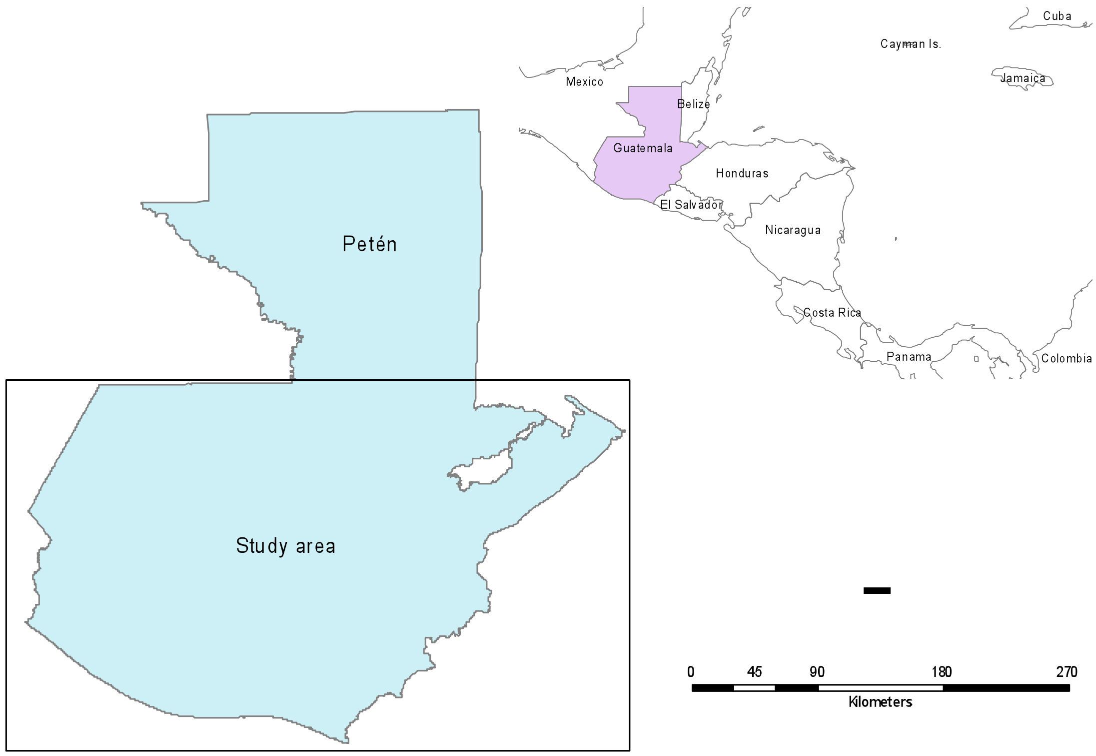


Figure 4: Study area

Estimating the value of water supply areas

All water supply areas are not equally valuable. The value of each water supply area is estimated using information on the nature and magnitude of each individual water use. Data were obtained from governmental and non-governmental sources, as well as collected in the field. The lack of legislation regulating the use of underground sources for industrial and domestic use renders very difficult the collection of information on the subject. It proved particularly difficult to obtain information on water quantities and sources used by private individuals and companies. Part of the work also consisted of organizing existing data on agri-industrial and industrial processing, irrigation, energy generation, and domestic use that weren't in formats compatible for geographic analysis, or that were available in scattered and incompatible forms. When possible, available data was corroborated with information from observations in the field or verified by telephone or in person.

One possible approach to estimate the value of individual water supply areas is to use the actual water use by downstream users. While this approach has its attractions, it also faces significant limitations. First, the amount of water use says little about the value of such use. Some uses are very valuable, such as human consumption, others less so. In many countries, for example, agriculture is by far the largest user of water, but a variety of subsidies and other distortions means that this use is often very inefficient. The marginal value of an additional cubic metre of water may be very high in some uses, and very low in others. Second, although water volume used seems to provide an index which is comparable across users, this is not in fact the case. Consumptive water uses (for example, irrigation or domestic supply) cannot be compared directly to non-consumptive uses (such as HEP generation). Even among consumptive uses, some generate significant return flows (thus reducing their net use) while others do not.

In this study, we used indices that directly reflect the benefits that water provides. Because of the different nature of each water use, each set of users has its own value index. That for HEP plants, for example, is based on the installed generating capacity of each plant, while that for domestic water supply systems is based on the number of households served, while that for irrigation systems is based on the area irrigated. These value indices give a broad sense of the relative importance of each water supply area. Unfortunately, the indices are incommensurate, and so cannot be added together to obtain a single unified index. Ideally, the marginal value of an additional cubic meter of water in each use would be estimated, but estimating these values is far beyond the scope of the present study. Using the prices paid by users for their water would not resolve the problem, as many users pay nothing and others pay administratively determined prices that are un-related to either the cost of provision or the value of use.

The indices are then expressed in per hectare terms by dividing by the size of the corresponding water supply areas.

- Where a given user drew water from several distinct water supply areas, we prorated the total value across each area according to their contribution to total use.
- When multiple users (of a given kind of use) are located in the same watershed, the value index for the water supply area reflects their combined use. Thus the value index for this water supply area of the Canadá and Santa Maria HEP plants on the Río Samalá is based on its contribution to both plants together.
- However, when the users are located far enough apart that separate water supply areas are delineated, the value index for the water supply area that serves both users reflects their combined use, but that for the broader water supply area only reflects the value of the use by the downstream user. Thus in the case of the Matanzas and Chixoy HEP plants on the Río Matanzas, the value index for the Matanzas water supply area reflects the fact that this area also contributes to Chixoy, but the value index for the rest of the Chixoy water supply area is based on its contribution to Chixoy alone.

4. Mapping water service supply areas

Guatemala receives about 111 billion m^3 of water annually, giving an average availability of 8,600 m^3 per person per year (FAO, 2007). The country is divided into three broad hydrological basins (López Choc, 2002; Cobos, 2002). Watersheds that drain to the Pacific Ocean are generally small and have steep slopes. Watersheds that drain towards the Caribbean tend to be larger; they include Guatemala's longest river, the Río Motagua. Watersheds in the northeast of the country drain towards the Río Usumacinta in Mexico, and then on to the Gulf of Mexico. Total water withdrawal were estimated to be about 2 billion m^3 in 2000, or less than 2% of the country's total renewable water resources. Among the major sectors, agriculture accounts for over 80.5 percent of withdrawals, followed by industrial users (13.5 percent) and domestic users (6.5 percent) (FAO, 2007).

Detailed data tables are provided in Appendix 1. Maps for each service are shown in Appendix 2.

Hydroelectric power producers

HEP producers are the easiest water users to map, as their location and installed generating capacity is well-documented, and in most cases can easily be verified from available on-line satellite imagery. Moreover, the number of hydroelectric plants is small (Appendix Table 1). Most HEP plants are operated by the state-owned National Institute for Electrification (*Instituto Nacional de Electrificación*, INDE). There are also several privately-operated HEP plants.

Map 1 shows the location of the 17 HEP plants in Guatemala, and the water supply areas that feed them. The shading reflects the importance of each water supply area, in terms of installed generating capacity per hectare. The mean size of HEP water supply areas is 70,000 ha, but there is considerable variation (s.d.=141,000 ha). The largest water supply area, at over 0.5 million ha, serves the 300MW Chixoy plant. If this area is omitted, the average size of the remaining water supply areas drops to 32,000 ha. Three other water supply areas cluster at about 100,000 ha, with one at just under 40,000 ha and all others smaller than 25,000 ha. The smallest area, at under 4,000 ha, serves the 3.9MW San Isidro plant. Although the largest plant has the largest water supply area, the size of the plant is generally uncorrelated with the size of the water supply area.

The mean value of these water supply areas is 1.04KW/ha, but again there is very high variability (s.d.=1.04KW/ha). It is interesting to note that the highest value water supply area is not the one serving the largest hydroelectric plant (Chixoy). Because of its large size (545,000 ha), the value of this water supply area is only 0.55KW/ha. The water supply areas of medium-sized plants tend to be of much higher value. Thus the highest-value water supply area, at 3.45KW/ha, is the 13,100 ha upper watershed of Río Las Vacas, which provides water to the 44MW Las Vacas plant. In second place is the water supply area for the 90MW Aguacapa and 8.2MW Poza Verde plants, which generates 2.68KW/ha. The smallest water supply area, that of the San Isidro plant, has a value of 1.03KW/ha, very close to the mean. The smallest plant, the 0.7MW Chichaic plant, is associated with the lowest watershed value of 0.04KW/ha, because its 17,300 ha water supply area is larger than that of several other plants.

Domestic water supply systems

There is a large number of domestic water supply systems in Guatemala, with as much as 70 percent of households having access to piped water (World Bank, 2004). Guatemala is the only Central American country that does not have a national public corporation that manages domestic water supply in most urban areas (Walker and Velásquez, 1999). The domestic water supply sector is comprised of three components:

- service to the Guatemala City metropolitan area, provided mainly by the Municipal Water Firm of Guatemala City (*Empresa Municipal de Agua de Guatemala*, EMPAGUA);
- other urban areas, served by municipal governments, either directly or through public corporations; and
- rural areas served by Community Based Organizations (Foster and Araujo, 2004).

This study focuses on urban water supply systems, mainly due to data availability constraints. The coverage of water supply systems in rural areas is in any case much lower. No ministries have explicit oversight authority over the water sector. As a result, information on domestic water supply systems is very hard to obtain. Except for the systems operated by

EMPAGUA, most water supply systems are very poorly documented. To accommodate the uneven quality of available data, we conducted separate analyses for systems run by EMPAGUA and by the municipalities.

We contacted 273 of the 331 municipalities in Guatemala to collect data on their water supply systems. As with other water users, we omitted systems that rely solely on wells. Since information is not available on relative dependence on surface vs. ground sources, our focus on surface sources may lead to overestimation of the values of water supply areas for those systems that rely on both types of sources. We focused on relatively larger systems using a cut-off of 1,000 households served.

Among those contacted, 199 municipal systems rely, either solely or partly, on surface water sources. Of these, 85 (43 percent) had water systems serving more than 1,000 households. In most cases, specific takepoint locations were not available—only the name of the river or stream on which they are located. We assumed that takepoints are located at the closest upstream point of the named river to the urban centers served, thus allowing us to roughly delineate water service supply areas to many municipal systems.[2] Detailed data on names of surface water sources were only available for 42 municipalities; and for another 5 municipalities we assumed they drew water from the only nearby river. Thus, we were able to delineate water supply areas for a total of 47 municipal systems. The municipal water supply systems and their water supply areas are shown in Map 2 and Appendix Table 2.

As can be seen in Map 2, the water supply areas serving domestic water supply systems tend to be small. With an average size of less than 11,000 ha, they are generally much smaller than the water supply areas serving HEP plants, although that is not true in all cases. This is partly due to the concentration of population in Guatemala's highland areas, so that most water supply systems draw water from the upper part of watersheds. As with HEP water supply areas, there is substantial variation in size (s.d.=16,000 ha), with supply areas ranging in size from 600 ha (serving Catarina, San Marcos department) to almost 73,000 ha (serving Almolonga, Quetzaltenango department) (Table 2 below).

The value index in the case of water supply areas that provide water for domestic use is the number of households served. Data on the number of households served by municipal systems in 2001 were obtained from the National Institute for Municipal Development (*Instituto Nacional de Fomento Municipal*, INFOM). On average, water supply areas serve 1.08 households per hectare. The highest-value water supply area serves 35,000 households in Santa Lucia Cotzumalguapa, Escuintla department, or 6.41 households per hectare. In this case, the highest-valued areas tend to be those serving the largest number of households. This correspondence is partly due to the small size of their water supply areas. Indeed, the laregst water supply area (serving 1,800 households in Almolonga) has the lowest value among the 47 systems analyzed, amounting to 0.02 households served per hectare. In contrast, the smallest water supply area (serving 1,200 households in Catarina) has a much higher value at 2.1 households served per hectare, making it the 7th highest-value water supply area.

2 This assumption may have resulted in a slight over-estimation of areas, as some systems are likely to draw their water from points higher up in the watershed (to reduce the chances of contamination, or to take advantage of gravity flows).

The five systems operated by EMPAGUA serve most of the capital, currently serving about 85 percent of Guatemala City's water users (World Bank, 2005). The balance is provided by a private firm, Aguas de Mariscal, which supplies about 10 percent of Guatemala City, and some smaller firms and private wells, which supply the remaining 5 percent (World Bank, 2005; Martínez Tuna, 2002). Unregulated tapping of groundwater sources is also common in the Guatemala City metropolitan area but had to be omitted from the analysis because of data unavailability. EMPAGUA's water supply systems and their corresponding water supply systems are shown in Map 3 and Appendix Table 3.

The EMPAGUA systems are served by water supply areas that are much smaller than those serving municipal systems. The mean size of EMPAGUA's water supply areas is 4,100 ha (s.d.=4,800 ha), only 37 percent of that of other municipal systems. The largest water supply area (13,100 ha) serves both the La Brigada and Lo de Coy systems, while the smallest water (121 ha) serves the El Cambray system (the town's oldest, with one takepoint operating since 1786), generating a value of 2.85 households per hectare.

As with municipal water supply systems, the value index for the EMPAGUA systems is the number of households served. The situation is complicated in this case because multiple water sources supply a single population. Each of EMPAGUA's five systems serves distinct areas of the Metropolitan area, but no data were available on the number of households served by individual systems. To estimate the number of households served by each system, we divided system-specific production volumes by the monthly average consumption level of 20 m^3 per household (Foster and Araujo, 2004).[3] We develop weighting factors based on river capacities to prorate the relative contribution of each takepoint to total production of each system.

Although the water supply areas of the EMPAGUA systems are much smaller than those of municipal systems, their value is much greater. The mean value of EMPAGUA's water supply areas is 11.53 households per hectare (s.d.=13.48). The highest value of 55.37 households per hectare is generated in the watershed of Río Canalitos and Quebrada Agua Tibia that serves the Ilusiones system. The high value is due both to the small size of the water supply area and the relatively higher source river capacity of Río Canalitos. The lowest-value water supply area (0.51 households per hectare) also serves the Ilusiones system, with both relatively low source river capacity and large size of water supply area contributing to the small value.

Irrigation

As of 1997, Guatemala has 130,000 ha of irrigated land (FAO, 2007), approximately 80 percent of which is privately owned (MAGA, 1993). Irrigation systems in Guatemala are classified as private, state, and "minirriego" systems (with irrigated areas between 5 and 50 ha). The largest private irrigation systems are dedicated to export products: sugar cane fields and banana plantations (FAO, 2007). Private systems are subdivided in two categories: (a) large, individual farms owned by a person, family or company, and (b) communal systems, where many small scale farmers organize themselves to manage a water source for production

[3] While imperfect, this approach results in a reasonable estimate of the total number of households served. The population of the Guatemala metro region is 2.5 million (INE, 2006), and the average household size is 4.7 people (Valladares Cerezo, 2003), giving about 530,000 households. About 74 percent of water users in Guatemala City are served by EMPAGUA (Martínez Tuna, 2002), or about 390,000 households, which is very close to the figure we obtain of 360,000 households.

purposes. Irrigation in large private farms is characterized by gravity systems, where water is tapped from rivers, collected in temporary earth dams and channels that are rebuilt and cleaned after each rainy season. Other systems include the use of pumps, drip irrigation, and sprinklers. The use of wells is known but not documented. State irrigation systems are characterized by the use of small, permanent concrete dams and channels, as well as the use of pumps to reach areas above river levels. Gravity systems predominate in this group (MAGA, 1993).

Documentation of water withdrawal and intake location of irrigation systems was even more limited than for domestic water supply systems. As with municipal water systems, most information was obtained by contacting water users directly. Here, too, only approximate information could be obtained, and even that for only a small portion of all irrigation systems. We focused on larger systems, with a minimum of 500 ha under irrigation.

The location of irrigated area was estimated by the approximate location of villages or farms. As in the domestic water supply case, we assume that intakes are located near the irrigated areas. Using available data, we proceeded to delineate the service supply areas unless it was impossible to pinpoint from which river water is withdrawn.

The irrigated areas for which data were available and their water supply areas are shown in Map 4 and in Appendix Table 4. The size of the irrigated area provides the value index for these water supply areas.

The water supply areas serving irrigation systems vary widely in size, ranging from a minimum of 2,900 ha to a maximum of 234,000 ha, with an average area of about 64,000 ha (s.d.=73,000 ha). Again, the most important water supply areas are not necessarily those that serve the largest irrigated areas. In fact, the largest water supply area only generates a value of 0.02 ha of irrigated area per hectare. The second largest water supply area corresponds to the lowest value of 0.01 ha of irrigated area per hectare (tied with another two water supply areas). The highest-value water supply area (0.68 ha of irrigated area per hectare) serves an irrigated area of 8,770 ha in the Coyolate watershed. The mean value of the water supply areas to irrigation systems included is 0.14 ha of irrigated area per upstream hectare.

Other water users

Use of water by industrial users is very poorly documented. Moreover, these users proved very resistant to attempts to gather information. Because of this, we were only able to gather data on a small proportion of all users. Moreover, these other users include a wide variety of uses, making it difficult to generate a single value index.

We obtained information for 1,236 entities that use water to process agricultural products, among which 376 were identified in specific watersheds by location, along with data on production and employment, including 347 coffee mills, 14 sugar mills, 6 rice mills, 6 cardamom mills, and 3 dairy plants. Specific spatial information on the location of water intakes was generally not available for these entities. However, descriptive information of coffee mills and sugar mills indicate that they normally tapped rivers and streams located within the farm property. Based on this, we were able to identify 107 coffee mills and 2 sugar mills that were located along rivers or streams. We based delineation of upstream water supply areas on the assumption that water intakes coincide with mill locations (Appendix Table 5 and Maps 5A and 5B).

We also identified the locations of 19 bottled water and soft and alcoholic drink producers in Guatemala City and the Motagua watershed. However, production data were not available.

Value indices for these industrial users would ideally be based on value of production, but we were unable to obtain such data. Using available data, we calculated the value indices, based either on permanent employment or on seasonal production quantities. A small fraction of industrial users also reported on their hire of seasonal workers, but this is omitted in the value index calculation. In most cases, the job generation capacity of an industrial user is positively correlated with the production quantity according to our sample.

As in the case of other users, the water supply areas serving industrial users vary significantly in size, ranging from a minimum of 345 ha to a maximum of 146,700 ha, with an average area of about 21,000 ha (s.d.=36,000 ha). The mean value in terms of production quantity (quintals) per hectare is 37.6 (s.d.=166.1).[4] The mean value in terms of jobs generated per hectare is 1.07 (s.d.=4.49). Like the other uses, large water supply areas tend to have smaller values. For instance, both the smallest production quantity value (0.1 qq/ha) and the smallest job value (0.0005 jobs/ha) are found in the largest water supply area, whereas the highest-value water supply area in terms of both production quantity (816.8 qq/ha) and jobs generated (21.04 jobs/ha) has the second smallest size of 712 ha.

4. Mapping biodiversity

To complement our map of water services, we also secured information on areas that are important for biodiversity. As a first approximation of the areas that are important for biodiversity conservation, we use the country's protected areas system. There is no obvious value index for land that is of biodiversity importance. Here we use the World Conservation Union (IUCN)'s classification of protected areas as a crude ranking of importance. IUCN has defined a series of six protected area management categories, based on primary management objective. A summary of categories and their definitions is provided below (IUCN, 1994).

Table 1: IUCN protected area categories

Categories	*Definition*
Ia	Strict Nature Reserve: protected area managed mainly for science
Ib	Wilderness Area: protected area managed mainly for wilderness protection
II	National Park: protected area managed mainly for ecosystem protection and recreation
III	Natural Monument: protected area managed mainly for conservation of specific natural features
IV	Habitat/Species Management Area: protected area managed mainly for conservation through management intervention
V	Protected Landscape/Seascape: protected area managed mainly for landscape/seascape conservation and recreation
VI	Managed Resource Protected Area: protected area managed mainly for the sustainable use of natural ecosystems

Source: IUCN, 1994.

4 1 *quintal* (qq) is equivalent to 45.45 kilograms or 100 lbs.

We collected from various sources geospatial data on protected areas and biological corridors. The map is shown in Map 6.

- Established protected areas: As of 2003, there are 120 official protected areas, covering over 3 million ha, or 29 percent of total land area (CONAP, 2003), much higher than the 8.6 percent average in Central America and the Caribbean region, or the 10.8 percent worldwide average (UNEP-WCMC, 2003).[5] Of these, 11 protected areas, covering over 2.5 million ha, are located in the Petén region.
- Areas of special protection (*Area de Protección Especial*): This class of areas refers to areas of high biodiversity that are in the process of being declared protected areas. As of 2007, there are 19 such areas (CONAP, 2007). Note that the list is evolving as existing areas being declared as protected areas and new areas of conservation interest being identified and added.
- Proposed protected areas and biological corridors from the "Central American Vegetation/Land Cover Classification and Conservation Status" dataset. These data were developed by the Regional Environmental Program for Central America (*Programa Ambiental Regional para Centroamérica*, PROARCA), as part of their effort to improve protected area management in the Mesoamerican Biological Corridor (MBC).

We use the 2000 GIS map of Guatemala's protected areas prepared by PROARCA. This map, which contains 94 named established protected areas including 12 areas of special protection, provides a more comprehensive coverage of the country's protected area system than the map currently available from the World Conservation Monitoring Centre's (UNEP-WCMC) World Database on Protected Areas (WDPA).[6] Detailed information on each site is summarized in Appendix Table 6. We extract geospatial data on proposed protected areas and biological corridors from the "Central American Vegetation/Land Cover Classification and Conservation Status" dataset, which is disseminated by the Center for International Earth Science Information Network (CIESIN) at Columbia University.

The protected areas in the study area tend to be more numerous but smaller in size than those in the Petén region. There are 5 category I areas (covering 27,700 ha), 5 category II areas (covering 10,000 ha), 6 category III areas (covering 320,000 ha), 7 category IV areas (covering 24,100 ha), 6 category V areas (covering 4,300 ha), 2 category VI areas (covering 181,400 ha), 25 areas categorized as buffer zone (covering 158,000 ha), and 38 areas without any category information (covering 272,000 ha) (Figure 2). The areas of special protection are not assigned to any category in this dataset.

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5 The number of protected areas is given as 156 in some sources. The discrepancy arises from whether protected area complexes that include a core zone, various multiple use zones, and a buffer zones are counted as a single protected area or several separate ones.

6 There are minor discrepancies between the PROARCA map and the WCMC map in the management categories of different protected areas. For instance, Laguna Lachuá national park is defined as a category I management area in the PROARCA map but a category II area in the WCMC map. We maintain the PROARCA classification, which presumably reflects local knowledge and perception more accurately.

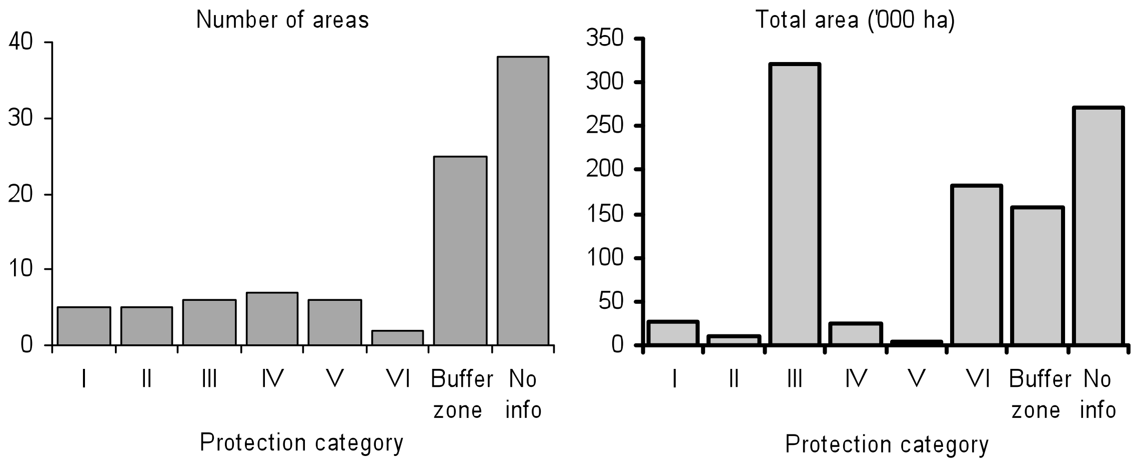

Figure 2: Distribution of protected areas in the study area

The largest protected area in the study area is Sierra de las Minas, covering 240,000 ha including the associated buffer zone. Watersheds in the Sierra de las Minas range serve two HEP plants, dozens of large and medium-size industries, large irrigated areas, and over 200 communities. However, these areas face aquifer depletion, industrial misuse of water supplies, sedimentation, and pollution from agricultural runoff (WWF, 2007).

5. Discussion

Several important results emerge from this mapping work. The first and most important is that water services are very site specific. Some areas provide water to important water users, and some do not. Moreover, the value of water supply areas varies widely from case to case. Figure 3 shows how the value index for different water uses varies with the size of the water supply area. With some exceptions, water supply areas with high value indices tend to be small, whereas large-sized water supply areas are almost unanimously found to be of low value. These counterintuitive findings emphasize the importance of mapping work such as that carried out in this study, which allows water supply areas to be both identified and valued. Without such an analysis, there is a substantial likelihood that conservation efforts may be mis-directed, being used either in areas which do not contribute to water service provision, or to areas that are less important than others.

As already noted, the most important water supply areas for any given use, on a per hectare basis, are not necessarily these associated with the largest service use, with the notable exception of the water supply areas of the EMPAGUA systems. Smaller areas serving more modest users can have higher values per hectare. This is most obvious in the case of HEP plants, in which the value of the water supply area serving Chixoy is much less than that of areas serving smaller HEP plants. Thus prioritization of interventions should not be based solely on the magnitude of downstream water uses, but needs to also consider the size of the water supply area.

In addition, the impact of land management on watershed hydrology and sedimentation are usually observed more clearly in smaller-scale watersheds (Faurès, 2004). Interventions in smaller watersheds will thus tend to be more likely to be based on a strong understanding of how upstream land use affects downstream water users.

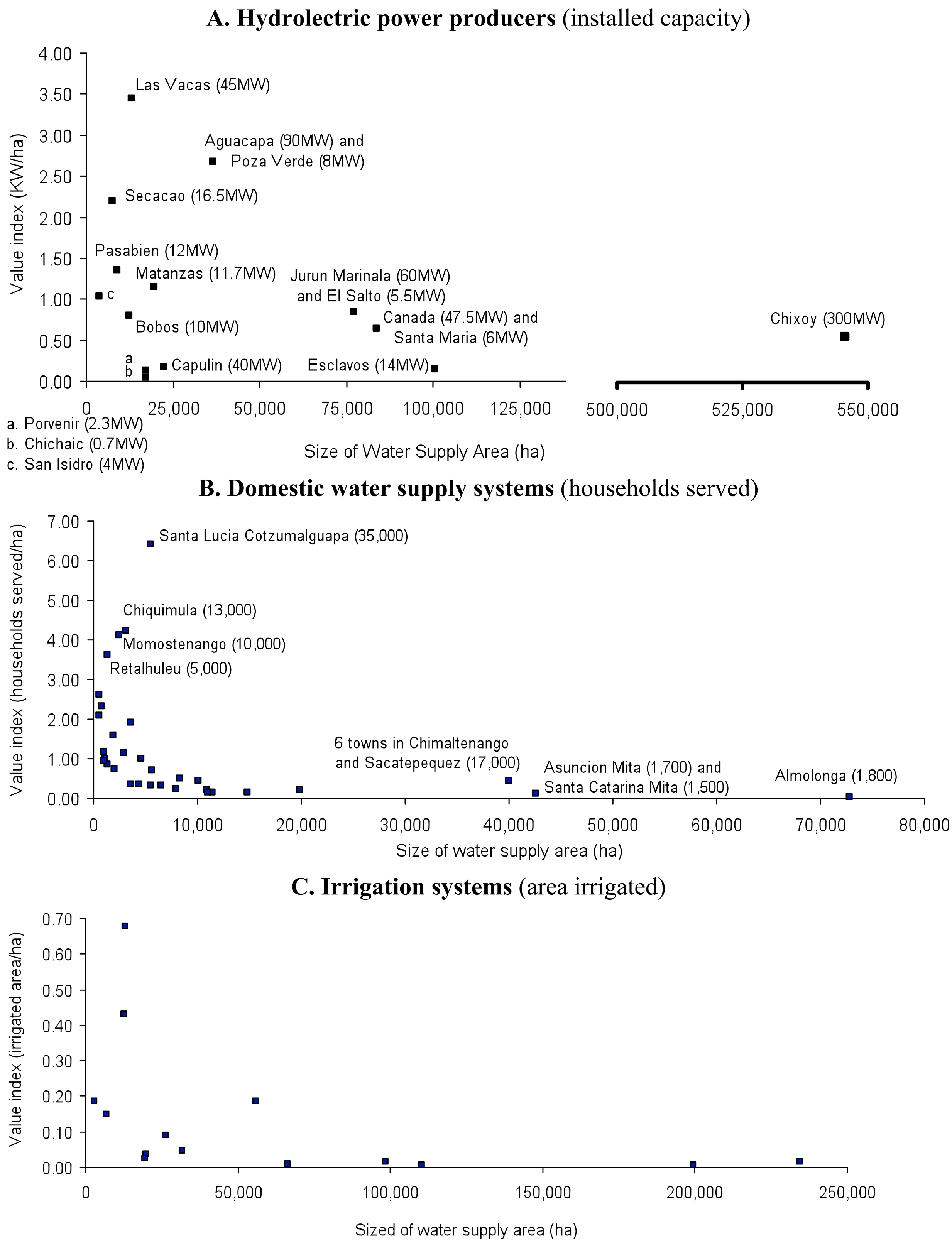

Figure 3: Relationship between size of water supply area and value index

As Table 2 shows, the average size of water supply areas varies by user. On average, HEP plants have the largest water supply areas (70,000 ha), followed by irrigation systems (64,000 ha) and industrial users (21,000 ha). Domestic water supply systems, on the contrary, tend to be fed by much smaller water supply areas (11,000 ha). This is especially true for the EMPAGUA systems, which are supplied by water supply areas of only 4,100 ha. In all cases, however, there is substantial variability.

Table 2: Size of water supply areas

	Mean (ha)	*Standard deviation (ha)*	*Minimum (ha)*	*Maximum (ha)*	*Total area (ha)*	*Number of areas*[a]
HEP producers	70,000	141,000	3,800	545,000	966,000	14
Domestic water supply						
▪ Municipal systems	11,000	16,000	600	72,800	431,000	38[b]
▪ EMPAGUA systems	4,100	4,800	121	13,100	70,500	17
Irrigation systems	64,000	73,000	2,900	234,000	899,000	14
Industrial users	21,000	36,000	345	147,000	525,000	25

Notes: a. Water supply areas that service multiple plants are counted once.
b. Systems are served by multiple water supply areas. Each water supply area is accounted separately.

Comparison of the value of water supply areas across users is not feasible, as different value indices are used to measure the relative importance of supply areas for each group (Table 3). However, we find significantly larger variances in the two value indices for industrial users than for other users.

Table 3: Value of water supply areas

	Units	*Mean*	*Standard deviation*	*Minimum*	*Maximum*	*Total value*	*Number of areas*[a]
HEP producers	KW/ha	1.04	1.04	0.04	3.45	14.62	14
Domestic water supply							
▪ Municipal systems	HH/ha	1.08	1.43	0.02	6.41	41.07	38[b]
▪ EMPAGUA systems	HH/ha	11.53	13.48	0.51	55.37	196.07	17
Irrigation systems	Ha/ha	0.14	0.20	0.01	0.68	1.91	14
Industrial users	qq/ha[c]	37.62	166.07	0.10	816.82	902.85	24
	Jobs/ha[c]	1.07	4.49	0.0	21.04	23.58	22

Notes: a. Water supply areas that service multiple plants are counted once.
b. Systems are served by multiple water supply areas. Each water supply area is accounted separately.
c. Alternative indices of value.

Many water supply areas provide water to more than one kind of user. Map 7 shows the overlaps across water supply areas. The map allows us to identify areas that provide service to multiple user groups. The majority of the overlapped areas supply water to two user groups, with a small number of areas providing water for three kinds of users. The water supply areas of HEP and irrigation systems overlap the most, amounting to 192,000 ha, mostly in the mid-southern region. In the second place are industrial users and irrigation systems, whose water supply areas overlap on 179,000 ha. Moreover, there are 104,000 ha of water supply area that feeds three user groups, industrial users, irrigation systems, and HEP simultaneously, followed by 18,800 ha overlapped by industrial users, irrigation systems, and domestic supply systems. No areas supply to all four user groups. As can be seen, many of the overlaps are concentrated in the mid-southern region of the study area, where all four types of users are present. Since the water supply areas of irrigation systems and industrial users are mostly located in the south, their water supply areas tend to overlap more with other user groups than HEP and domestic supply systems. HEP plants are most likely to have water supply areas that are not shared with any other users.

6. Conclusions

This approach taken in this study focuses on tying together the demand side (water users) and supply side (upstream land management problems) of the water equation, offering a systematic view of the spatial distribution of uses and the sources of their water. The kind of decision tool can help target limited conservation resources to land use management that provides the most benefit.

The results illustrate the high spatial heterogeneity of water services, an important factor to be considered in designing any intervention. Two hydrologically similar watersheds may differ dramatically in their value in terms of the water services they provide, depending on whether or not there are important water users downstream.

As an initial effort to develop a geo-referenced database of water services, the analysis is necessarily crude. This paper illustrates the methodologies for conducting water service mapping and valuing analysis. As discussed in section 3, this study has encountered considerable data limitations, primarily centered on water intake locations and water demand measurement. Except in the case of HEP, the resulting maps thus provide only a partial view of water supply areas in the country. The results could be substantially improved by

- conducting a systematic inventory of water users, which would collect both the location of water takepoints and at least basic information on the nature and extent of their water use[7]; and
- improving procedures to delineate water supply areas, by more carefully tracing flows.

The most important weakness of the current mapping exercise is the inability to include groundwater uses. While data are available on the location of many wells and on the uses that these wells contribute to (with the same quality issues as we have on surface water uses), the lack of information on how groundwater flows currently prevents us from identifying the recharge areas that contribute to specific wells.

Even with these weaknesses, data such as these provide a potentially useful tool to prioritize areas in which interventions might be needed. All watersheds are not equal. Some have many high-value uses downstream, while others have few or none. Even within watersheds that

[7] Such data would also allow additional analyses, such as understanding the pattern of withdrawals in areas where total water supply is insufficient to satisfy the needs of all users.

have high-value uses downstream, there is considerable variability in their relative importance. These mapping data provide at least a first cut at which areas are most important.

Such mapping work is likely to be particularly useful in identifying areas that have potential for development of PES mechanisms. To date, PES implementation has been essentially opportunistics, focusing on a few 'low hanging fruit.' Mapping data such as these open the way for a more systematic assessment of potential.

- They indicate areas of high value to downstream water users, where the potential for a deal may be particularly high.
- When data on other services are also available (such as the biodiversity data shown here), they allow areas that are important for multiple services to be identified. 'Bundling' payments for multiple services may be necessary if the value of a single service is insufficient to justify conservation measures; alternatively, bundling services may result in higher payments to upstream land users.
- They also indicate areas where PES mechanisms may be harder to develop, because of the presence of multiple downstream water users. When multiple users with similar needs draw from the same water supply area, each will have an incentive to attempt to free-ride on the efforts of others; when multiple users with different needs draw from the same water supply areas, their requirements and priorities may be incompatible.
- When spatial data on poverty are also available, they allow an assessment of how PES might affect the poor (Pagiola and others, 2007).

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Appendix 1: Data tables

Appendix Table 1: Hydroelectric power plants and their water supply areas

Plant	*River*	*Generating capacity (MW)*	*Water supply area (ha)*	*Value index (KW/ha)*
Chixoy	Chixoy	300.0	545,000	0.55
Matanzas	Matanzas	11.7	19,700[a]	1.14
Aguacapa	Aguacapa	90.0	36,600[b]	2.68
Poza Verde	Aguacapa	8.2		
Jurun Marinala	Michatoya	60.0	77,100[b]	0.85
El Salto	Michatoya	5.5		
Canadá	Samalá	47.5	83,700[b]	0.64
Santa Maria	Samala	6.0		
Las Vacas	Las Vacas	45.0	13,100	3.45
Secacao	Trece Aguas	16.5	7,500	2.19
Esclavos	Los Esclavos	14.0	110,700	0.14
Pasabien	Pasabien	12.0	8,900	1.35
Bobos	Bobos	10.0	12,400	0.80
Capulín	Osuna	40.0	22,500	0.18
San Isidro	San Isidro	3.9	3,800	1.03
Porvenir	Cabuz Tzoc Chapa	2.3	17,300	0.13
Chichaic	Cahabon	0.7	17,300	0.04

Notes: a. This area is located within the watershed that serves Chixoy; its importance also reflects its contribution to Chixoy.
b. These water supply areas serve several users.

Sources: Location of national hydroelectric power plants: personal communication with Ing. Arturo Ajcajabón of Instituto Nacional de Estadística (INDE) in 2004

Location of private hydroelectric power plants: personal communications in 2004 with Ing. Rodrigo Tormo (Secacao), San Isidro and Matanzas by Ing. Rafael López, and descriptive locations for all other private HEP (Las Vacas, El Capulín, Río Bobos, and El Canadá) by Ing. Alonso, Ing. Renato Patzán, and Ing. Florencio Gramajo

Appendix Table 2: Domestic water supply systems and their water supply areas

Municipality	*Department*	*Households served per system (2001)*	*Total upstream area (ha)*	*Value index (Households served per ha)*
Santa Lucia Cotzumalguapa	Escuintla	35,000	5,459	6.41
Chiquimula	Chiquimula	13,248	3,117	4.25
Momostenango	Totonicapan	10,000	2,436	4.10
Retalhuleu	Retalhuleu	4,787	1,323	3.62
Jutiapa	Jutiapa	4,500	4,552	0.99
Palin	Escuintla	4,152	8,266	0.50
Teculutan	Zacapa	4,100	19,904	0.21
Fray Bartolome de las Casas	Alta Verapaz	4,030	5,671	0.73
Morales	Izabal	3,260	6,197	0.53
Palencia	Guatemala	3,000	1,885	1.59
San Sebastian	Retalhuleu	2,320	10,901	0.21
Gualan	Zacapa	2,150	7,385	0.29
San Antonio Suchitepequez	Suchitepequez	2,060	6,465	0.32
Solola	Solola	2,010	14,879	0.14
Nuevo Progreso	San Marcos	1,849	791	2.34
Jacaltenango	Huehuetenango	1,828	11,412	0.16
Panajachel	Solola	1,813	8,008	0.23
Chichicastenango	Quiche	1,800	5,493	0.33
Almolonga	Quetzaltenango	1,774	72,780	0.02
Río Hondo	Zacapa	1,700	11,066	0.15
Totonicapan	Totonicapan	1,535	2,867	0.56
San Carlos Alzatate	Jalapa	1,515	4,340	0.35
Santa Catarina Pinula	Guatemala	1,510	2,020	0.75
Zaragoza	Chimaltenango	1,495	568	2.63
Cuyotenango	Suchitepequez	1,285	34,753	0.04
Tactic	Alta Verapaz	1,262	3,646	0.35
Catarina	San Marcos	1,200	572	2.10
Río Bravo	Suchitepequez	1,183	20,066	0.06
Soloma	Huehuetenango	1,180	993	1.19
San Juan La Laguna	Solola	1,100	1,308	0.84
Mataquescuintla	Jalapa	1,099	1,113	1.03

Appendix Table 2: Domestic water supply systems and their water supply areas

Municipality	*Department*	*Households served per system (2001)*	*Total upstream area (ha)*	*Value index (Households served per ha)*
Zacapa	Zacapa	1036	3,472	0.30
Cubulco	Baja Verapaz	1,000	1,060	0.94
Asuncion Mita	Jutiapa	3,492	42,566[a]	0.12
Santa Catarina Mita	Jutiapa	1,651		
La Esperanza (2 towns)	Quetzaltenango	2,739	10,064[a]	0.30
Santo Domingo Xenacoj (2 towns)	Sacatepequez	2,000	3,554[a]	1.92
Santiago Sacatepequez	Sacatepequez	4,817		
San Andres Itzapa	Chimaltenango	3,178	39,950[a]	0.43
Parramos	Chimaltenango	1,406		
Jocotenango	Sacatepequez	3,000		
Antigua Guatemala	Sacatepequez	4,407		
San Antonio Aguas Calientes	Sacatepequez	3,125		
Alotenango	Sacatepequez	2,137		

Notes: a. Multiple systems share the same water supply area

Sources: Number of households served provided by Instituto Nacional de Fomento Municipal (INFOM, 2004)
Location of sources based on personal communications from individual systems

Appendix Table 3: EMPAGUA systems

Systems	*Production per day (m^3)*	*Households served per system*	*River/creek where takepoints located*	*Water supply area (ha)*	*Value index (Households served per ha)*
Lo de Coy	140,000	210,000	Río Pansalic	1,324	2.67
			Río Las Flores	843	2.44
			Río Xaya[a]	8,709	9.63[b]
			Río Pixcaya[a]	13,079	13.69[b]
La Brigada	40,000	60,000	Río La Brigada	189	7.80
Santa Luisa	10,000	15,000	Quebrada La Manguita	128	16.03
			Quebrada La Piedrona	888	2.22
			Quebrada San Antonio	455	17.49
			Río Acatan	244	12.29
Ilusiones	25,000	37,500	Río Los Ocotes	7,987	0.51
			Río Teocinte	9,355	0.52
			Río Canalitos and Quebrada Agua Tibia	516	55.37
El Cambray	25,000	37,500	Río Pinula	1,078	27.18
			Riachuelo Panasequeque	3,841	2.04
			Quebrada Agua Bonita	121	2.85

Notes:
a. Shared with La Brigada system.
b. The value reflects households served by both La Brigada and Lo de Coy systems
c. Only surface source water is considered

Source: Description of EMPAGUA systems provided by Leonel Vásquez Maldonado of EMPAGUA (May 2003 and February 2004)

Appendix Table 4: Irrigation systems and their water supply areas

Watershed	*Sub-watershed*	*Irrigated area (ha)*	*Water supply area (ha)*	*Value index (Irrigated area per ha)*
Achiguate	Guacalate	10,390	56,020	0.20[a]
Coyolate	San Cristóbal	8,770	12,947	0.68
Acomé	Catchment area Acomé /Agüero /Cabeza de Toro	5,500	12,786	0.43
Motagua	Catchment area Motagua	5,000	n/a	n/a
Grande de Zacapa	Catchment area Grande de Zacapa	3,613	234,353	0.02
Coyolate	Catchment area Coyolate	2,880	n/a	n/a
Motagua	Catchment area Motagua	2,700	n/a	n/a
Maria Linda	Naranjo	2,400	n/a	n/a
Motagua	Jones/Santiago/Catchment area Motagua	2,348	26,235	0.09
Salinas	Salamá	1,500	31,761	0.05
Coyolate	Catchment area Coyolate	1,500	n/a	n/a
Achiguate	Democracia (Achiguate)	1,490	98,629	0.02
Ostua Guija	Lago Guija 2	1,408	n/a	n/a
Grande de Zacapa	Catchment area Grande de Zacapa	1,274	n/a	n/a
Lago Atitlán	Quiscab	1,046	6,968	0.15
Motagua	Bobos	1,000	n/a	n/a
Los Esclavos	Catchment area Los Esclavos	1,000	199,531	0.01
Achiguate	Achiguate	1,000	n/a	n/a
Motagua	Teculután	769	19,904	0.04
Motagua	Catchment area Motagua	760	n/a	n/a
Nahualate	Catchment area Nahualate	750	110,500	0.01
Nahualate	Catchment area Nahualate	750	n/a	n/a
Nahualate	Ixtacapa	750	n/a	n/a
Ocosito	Sumula	700	n/a	n/a
Suchiate	Catchment area Suchiate	700	n/a	n/a
Paz	Catchment area Paz	650	n/a	n/a
Motagua	Catchment area Motagua	629	n/a	n/a
Maria Linda	Michatoya	600	n/a	n/a

Appendix Table 4: Irrigation systems and their water supply areas

Watershed	*Sub-watershed*	*Irrigated area (ha)*	*Water supply area (ha)*	*Value index (Irrigated area per ha)*
Maria Linda	Catchment area Maria Linda	540	2,884	0.19
Maria Linda	Catchment area Maria Linda	540	66,377	0.01
Achiguate	Catchment area Ceniza	500	19,623	0.04[b]

Notes:

a. This water supply area serves two irrigation systems in sub-watersheds Democracia and Guacalate of watershed Achiguate. The value reflects its contribution to the irrigation system in the Democracia sub-watershed (1,490 ha of irrigation area).

b. This water supply area serves two irrigation systems in the sub-watersheds Democracia and Ceniza. The value reflects its contribution to the irrigation system in the Democracia sub-watershed (1,490 ha of irrigation area).

c. Only surface source water is considered

Sources: MAGA data

Appendix Table 5: Industrial users and the water supply areas

Department	*Municipality*	*Number of mills*	*Total production (quintals)*	*Total permanent jobs*	*Water supply area (ha)*	*Value indices*	
						Production (qq/ha)	*Jobs /ha*
Sugar mills							
Escuintla	Masagua	1	581,284	14,976	712	816.8	21.044
Escuintla	Escuintla	1	1,021	9,420	4,077	0.3	2.310
Coffee mills							
Guatemala	Petapa	1	-	-	21,090	-	-
Escuintla	Palin	1	15,000	300	12,532	1.2	0.024
Sacatepequez	Jocotenango	1	60,000	30	17,818	3.4	0.002
Jalapa	San Luis Jilotepeque	1	13,333	25	10,265	1.3	0.002
Huehuetenango	San Pedro Necta	1	23,111	12	12,101	1.9	0.001
Alta Verapaz	Cahabon	1	3,000	12	3,072	1.0	0.004
Santa Rosa	Nueva Santa Rosa	1	4,000	12	30,253[a]	0.3	0.001
Santa Rosa	Pueblo Nuevo Vinas	1	1,000	8	2,571	0.4	0.003
Santa Rosa	Pueblo Nuevo Vinas	1	5,000	8	3,323	1.5	0.002
Santa Rosa	Santa Maria Ixhuatan	1	500	3	1,309[a]	0.5	0.003
Huehuetenango	Cuilco	2	8,319	-	5,150	1.6	-
Baja Verapaz	Purulha	2	2,400	-	3,447	0.7	-
Santa Rosa	Casillas	2	6,500	20	345	18.9	0.058
Santa Rosa	Cuilapa	2	11,500	19	87,381[a]	0.7	0.002
Huehuetenango	La Democracia and La Libertad	2	11,399	7	8,211	1.4	0.001
Chiquimula	Esquipulas	4	41,000	30	2,513	16.3	0.012
Baja Verapaz	Purulha	5	4,600	225	11,928	0.4	0.019
Santa Rosa	Cuilapa	5	32,000	53	9,150[a]	4.1	0.007
Santa Rosa	Santa Cruz Naranjo	6	14,500	73	146,701	0.1	0.0005
Santa Rosa	Santa Cruz Naranjo	8	14,800	79	10,466[a]	2.1	0.009
Jalapa and El Progreso	Mataquescuintla and San Agustin Acasaguastla	10	83,126	256	5,969	13.9	0.043
Jalapa	Mataquescuintla	20	217,243	479	15,918	13.7	0.030

Appendix Table 5: Industrial users and the water supply areas

Department	*Municipality*	*Number of mills*	*Total production (quintals)*	*Total permanent jobs*	*Water supply area (ha)*	*Value indices*	
						Production (qq/ha)	*Jobs /ha*
Santa Rosa	Pueblo Nuevo Vinas, Cuilapa, Barberena, Chiquimulilla	29	47,055	92	99,091	0.6	0.001

Notes:

a. This water supply area serves multiple industrial users. The values reflect its contribution to all users.

b. Only surface source water is considered

Sources: Personal communication with individual users

Appendix Table 6: Protected areas and formal buffer zones

Protected area	*Category*	*IUCN category*[b]	*Area*[c] *(ha)*	*Year established*[d]
A. Protected areas[a]				
Abaj Takalik	Area of special protection	Not defined	133	
Astillero Municipal de Tecpán	Regional Park	IV	1,601	2000
Atitlán	Multiple Use Area	III	118,992	
Bocas del Polochic	Wildlife Refuge	III	23,419	1996
Cerro San Gil	Protected reserve for spring	Not defined	43,337	1996
Chocón Machacas	Protected Biotope	II	7,859	1989
Cordillera Alux	Protected reserve for spring	Not defined	4,417	
Cumbre Alta	Area of special protection	Not defined	8,295	
El Espino	Private Natural Reserve	V	255	1997
El Higuerito	Private Natural Reserve	V	823	1995
Iximché	Cultural Monument	II	10	
K'antí Shul	Private Natural Reserve	V	1,149	1999
Lago de Güija	Area of special protection	Not defined	1,392	
Laguna Chichoj	Area of special protection	Not defined	50	
Laguna de Ayarza	Area of special protection	Not defined	1,408	
Laguna el Pino	National Park	I	500	1955
Laguna Lachuá	National Park	I	9,776	1975
Laguna Yolnabaj	Area of special protection	Not defined	377	
Los Altos de San Miguel Totonicapán	Regional Park	IV	12,056	1997
Manchón Guamuchal	Private Natural Reserve	V	1,648	1998
Mario Dary	Protected Biotope	II	1,159	1977
Montaña Espíritu Santo	Area of special protection	Not defined	8,261	
Monterrico	Multiple Use Area	III	2,766	1977
Pachuj	Private Natural Reserve	V	414	1996
Parque Regional Municipal de Quetzaltenango	Regional Park	IV	5,658	1998
Punta de Manabique	Wildlife Refuge	III	131,906	
Quiriguá	Cultural Monument	II	33	1979
Río Dulce	National Park	I	13,560	1955
Río Sarstún	Multiple Use Area	III	40,781	
San Rafael Pixcayá	Area of special protection	Not defined	154	
Santa Elena	Private Natural Reserve	V	47	1997
Semuc Champey	Natural Monument	II	964	
Sierra Caral	Area of special protection	Not defined	20,678	
Sierra Chinajá	Area of special protection	Not defined	12,678	
Sierra de las Minas	Biosphere Reserve	VI	147,088	1989
Sierra de los Cuchumatanes	Area of special protection	Not defined	97,619	
Sierra de Santa Cruz	Area of special protection	Not defined	44,818	
Sipacate-Naranjo	National Park	I	1,782	1969
Tewancarnero	Regional Park	IV	499	1996
Visis Cabá	Biosphere Reserve	VI	34,312	1997

Appendix Table 6: Protected areas and formal buffer zones

Protected area	*Category*	*IUCN category*[b]	*Area*[c] *(ha)*	*Year established*[d]
Volcán Acatenango	No-hunting zone	Not defined	3,154	1956
Volcán Agua	No-hunting zone	Not defined	3,748	1956
Volcán Alzatate	No-hunting zone	Not defined	514	1956
Volcán Amayo	No-hunting zone	Not defined	606	1956
Volcán Cerro Redondo	No-hunting zone	Not defined	39	1956
Volcán Chicabal	Regional Park	IV	1,253	1956
Volcán Chingo	No-hunting zone	Not defined	351	1956
Volcán Coxliquel	No-hunting zone	Not defined	746	1956
Volcán Cruz Quemada	No-hunting zone	Not defined	146	1956
Volcán Culma	No-hunting zone	Not defined	17	1956
Volcán El Tobón	No-hunting zone	Not defined	234	1956
Volcán Fuego	No-hunting zone	Not defined	4,526	
Volcán Ixtepeque	No-hunting zone	Not defined	203	1956
Volcán Jumay	No-hunting zone	Not defined	952	1956
Volcán Jumaytepeque	No-hunting zone	Not defined	115	1956
Volcán Lacandón	No-hunting zone	Not defined	1,868	1956
Volcán Las Víboras	No-hunting zone	Not defined	298	1956
Volcán Moyuta	No-hunting zone	Not defined	313	1956
Volcán Pacaya	National Park	I	2,047	1956
Volcán Quetzaltepeque	No-hunting zone	Not defined	318	1956
Volcán San Antonio	No-hunting zone	Not defined	36	1956
Volcán Santo Tomás	No-hunting zone	Not defined	3,150	1900
Volcán Suchitán	Regional Park	IV	2,545	1956
Volcán Tacaná	No-hunting zone	Not defined	950	1956
Volcán Tahual	No-hunting zone	Not defined	437	1956
Volcán Tajumulco	No-hunting zone	Not defined	4,136	1956
Volcán Tecuamburro	No-hunting zone	Not defined	1,523	1900
Volcán y Laguna de Ipala	Multiple Use Area	III	2,291	
Zunil	Regional Park	IV	468	1996
B. Buffer zones				
Sierra de las Minas			94,525	
Volcán Acatenango			4,433	
Volcán Agua			9,725	
Volcán Alzatate			1,731	
Volcán Amayo			2,074	
Volcán Cerro Redondo			335	
Volcán Chingo			825	
Volcán Coxliquel			943	
Volcán Cruz Quemada			731	
Volcán Culma			436	
Volcán El Tobón			907	
Volcán Fuego			9,366	
Volcán Ixtepeque			1,664	

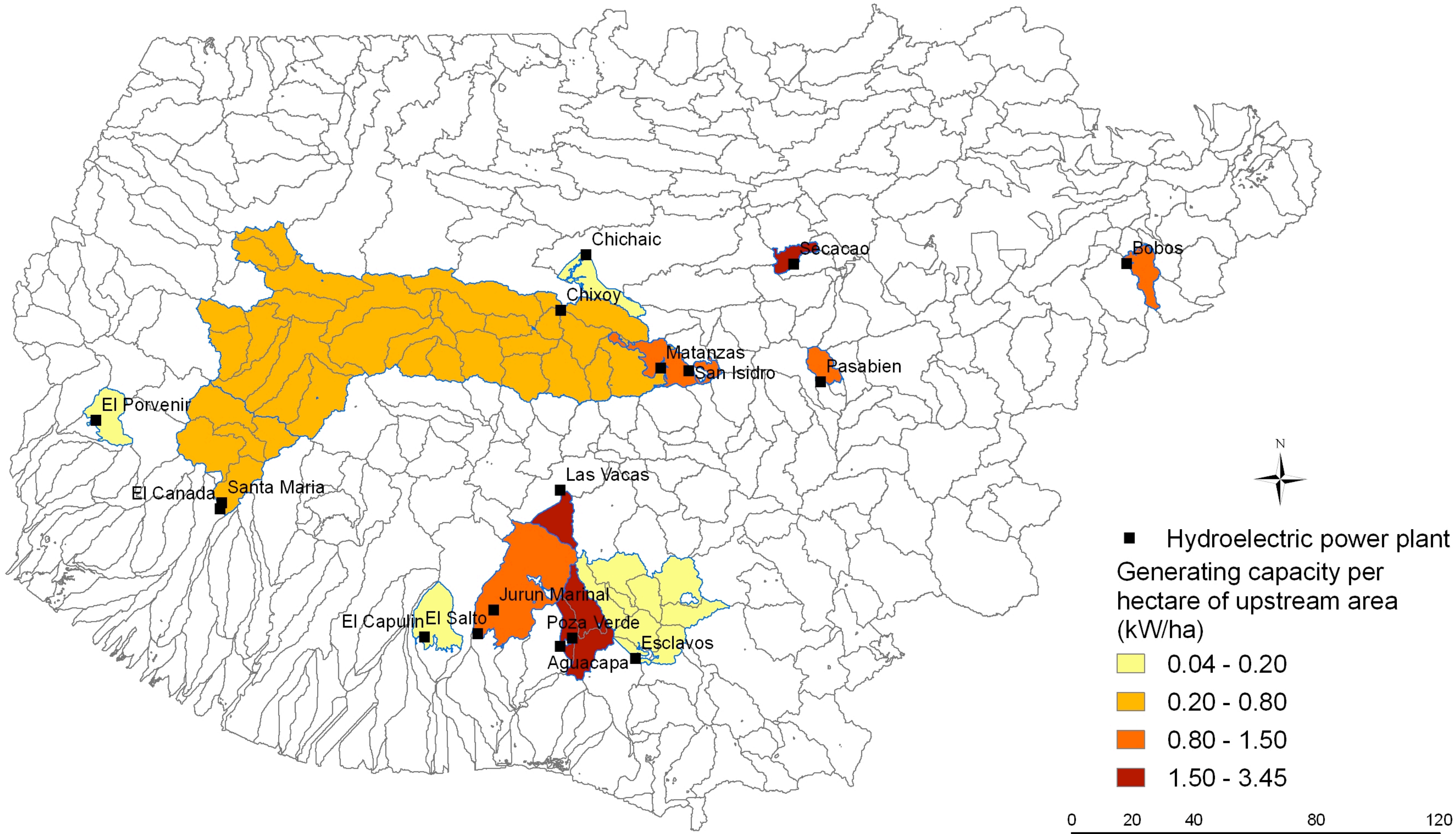
Appendix Table 6: Protected areas and formal buffer zones

Protected area	*Category*	*IUCN category*[b]	*Area*[c] *(ha)*	*Year established*[d]
Volcán Jumay			1,813	
Volcán Jumaytepeque			732	
Volcán Lacandón			2,972	
Volcán Las Víboras			2,150	
Volcán Moyuta			730	
Volcán Quetzaltepeque			781	
Volcán San Antonio			65	
Volcán Santo Tomás			4,771	
Volcán Tacaná			1,998	
Volcán Tahual			2,450	
Volcán Tajumulco			8,693	
Volcán Tecuamburro			3,606	

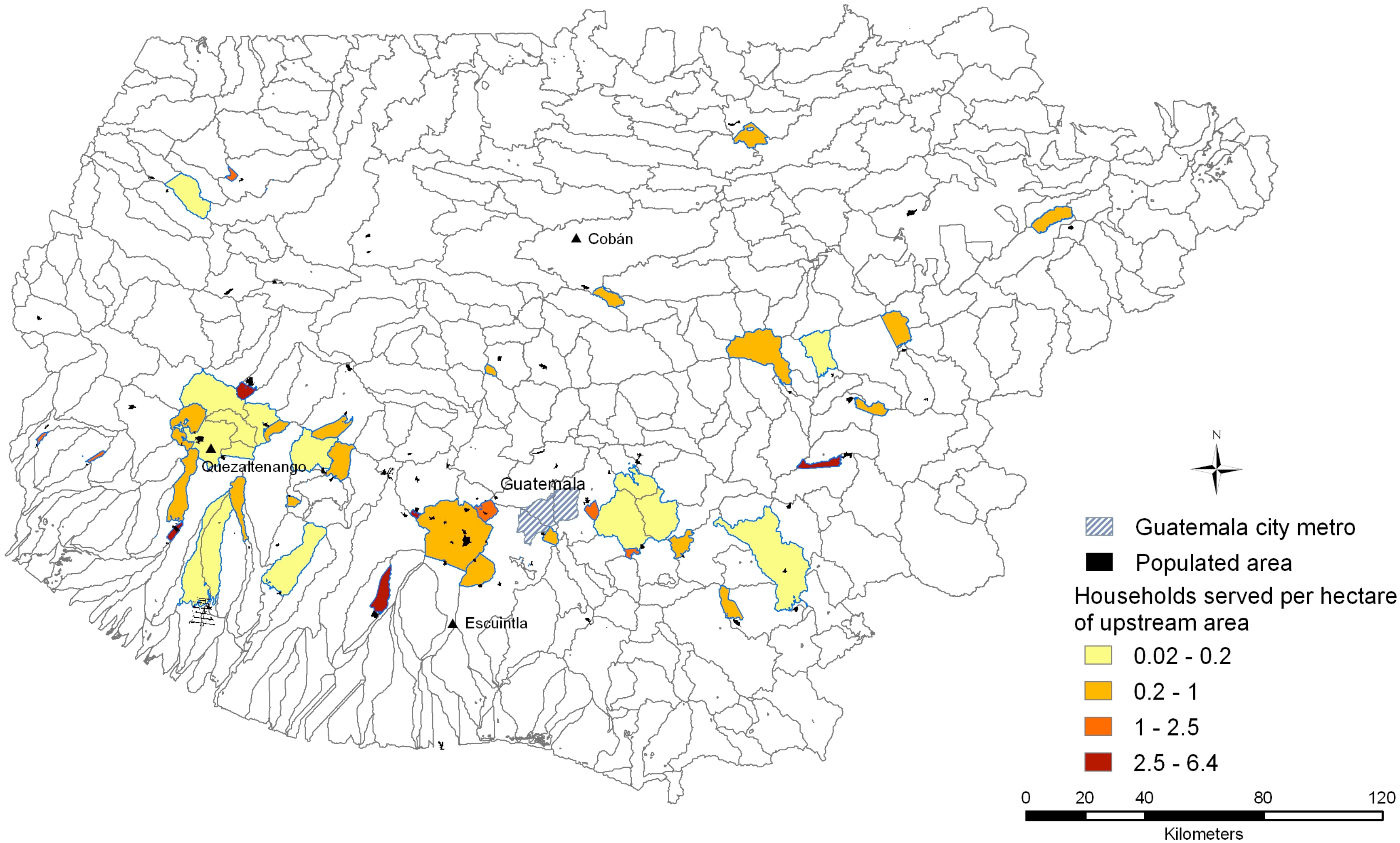
Notes: [a] All 69 protected areas are designated areas.
[b] Information on IUCN management categories from the PROARCA map does not always agree with that from the UNEP-WCMC map. We adopt the PROARCA definitions in this study.
[c] For sites with formal buffer zones, areas of sites reported in sub-table A do not include those of the corresponding buffer zones. The areas of the buffer zones are reported in sub-table B.
[d] Supplementary information obtained from UNEP-WCMC protected areas database.

Sources: 2000 GIS map of Guatemala's protected areas prepared by PROARCA.
UNEP-WCMC protected areas database, whose original source is the GIS dataset from *Mapa Digital de Áreas Protegidas*, CONAP, 1999.

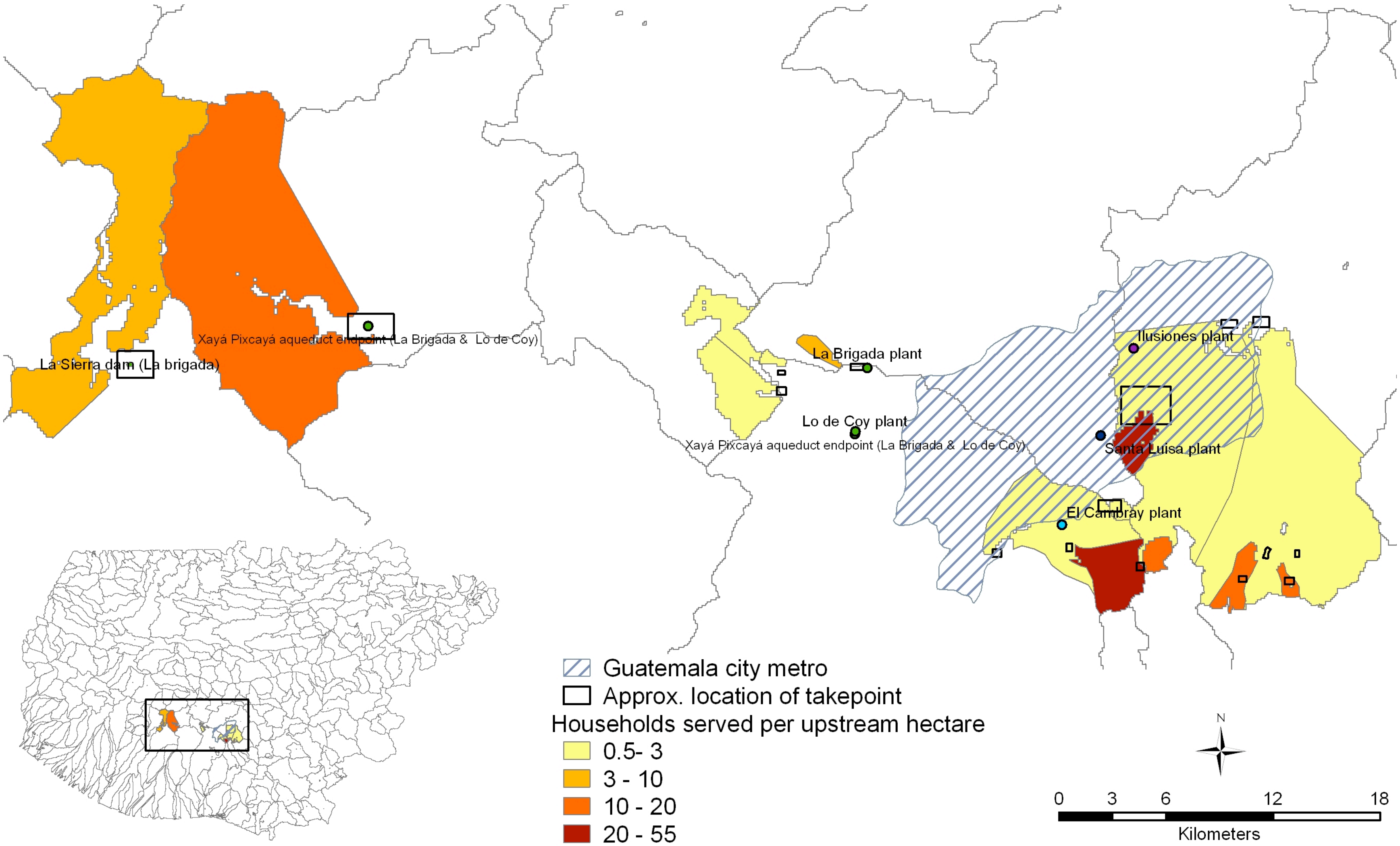
Appendix 2. Maps of service areas



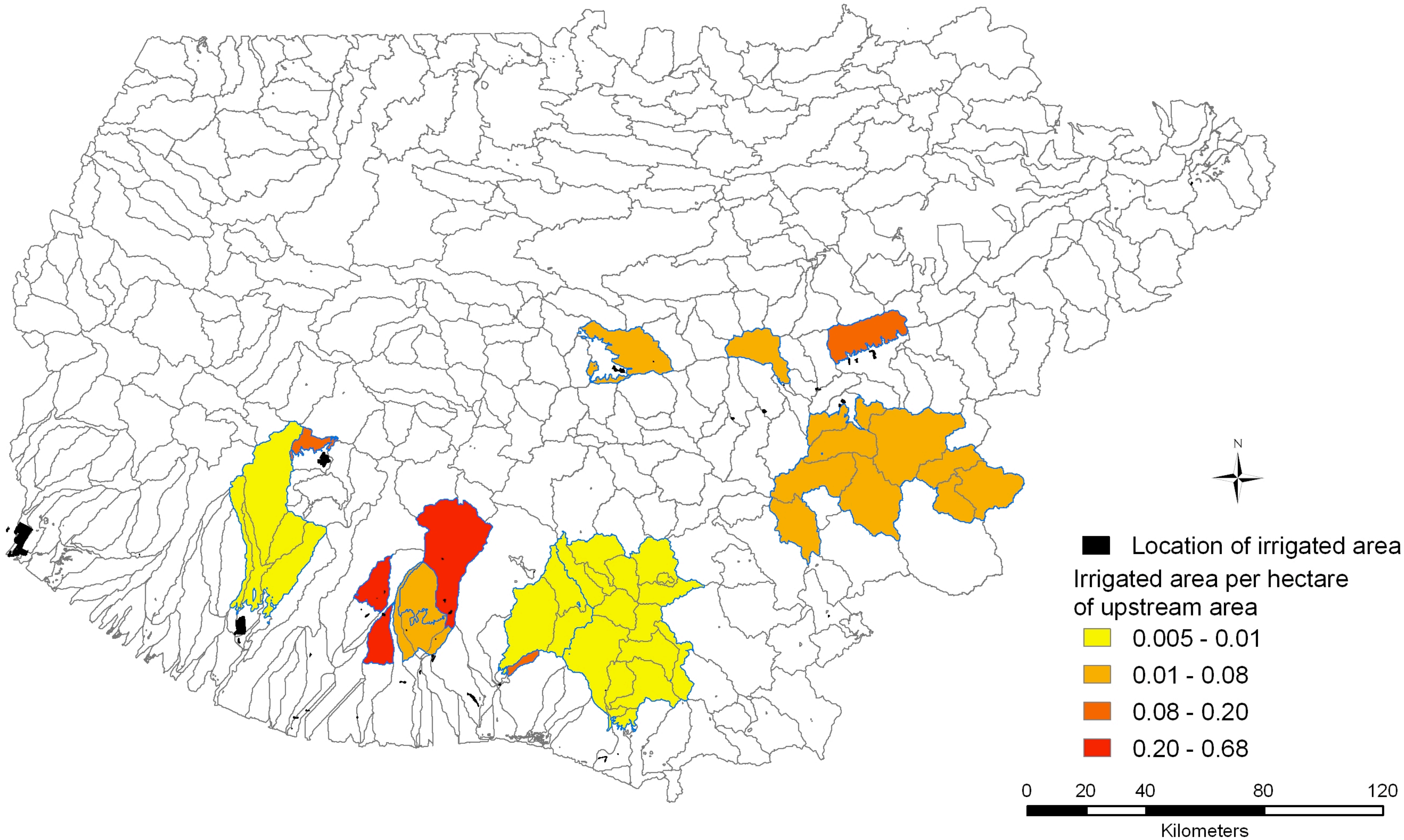
Map 1: Hydroelectric power plants and their water supply areas



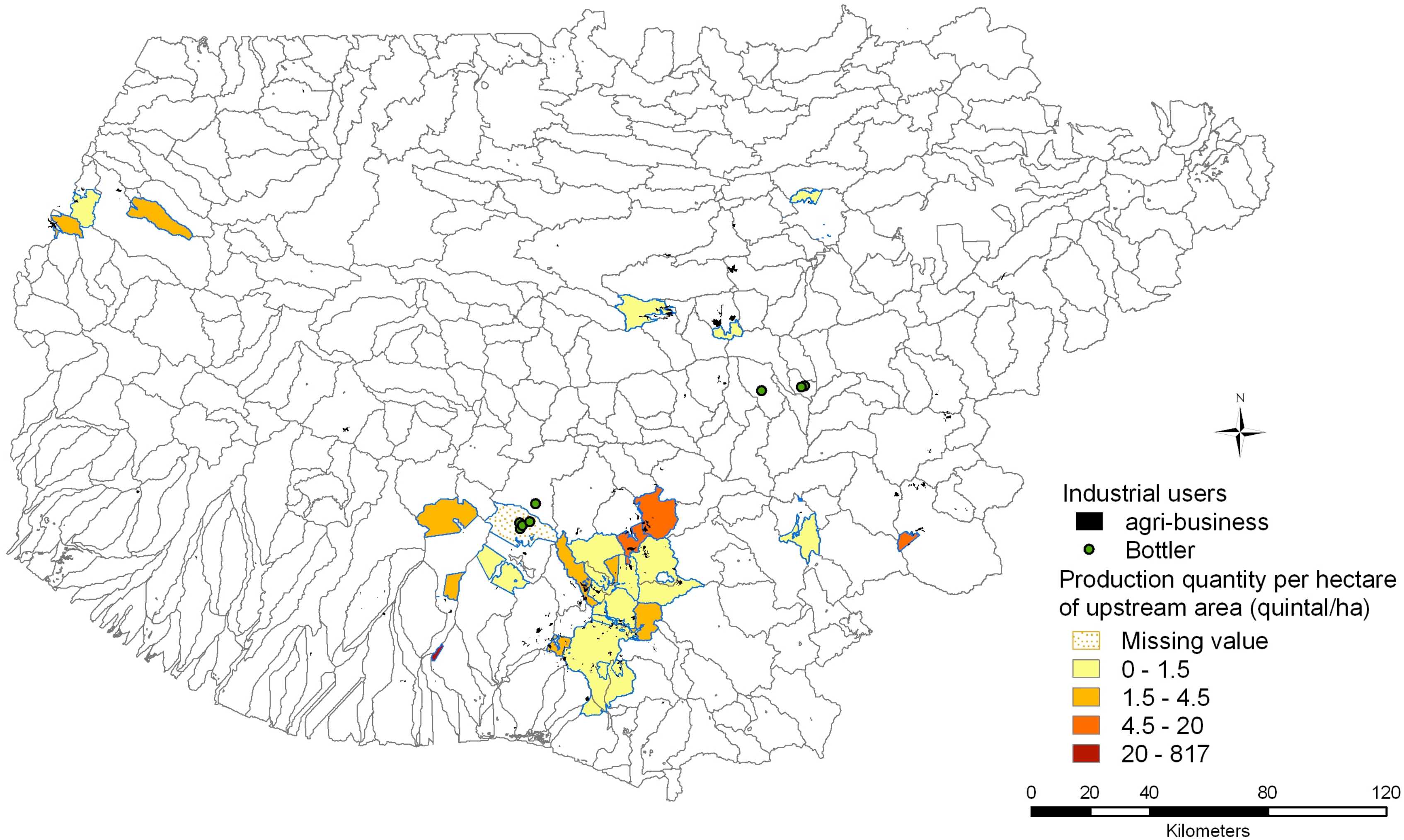
Map 2: Municipal water supply systems and their water supply areas



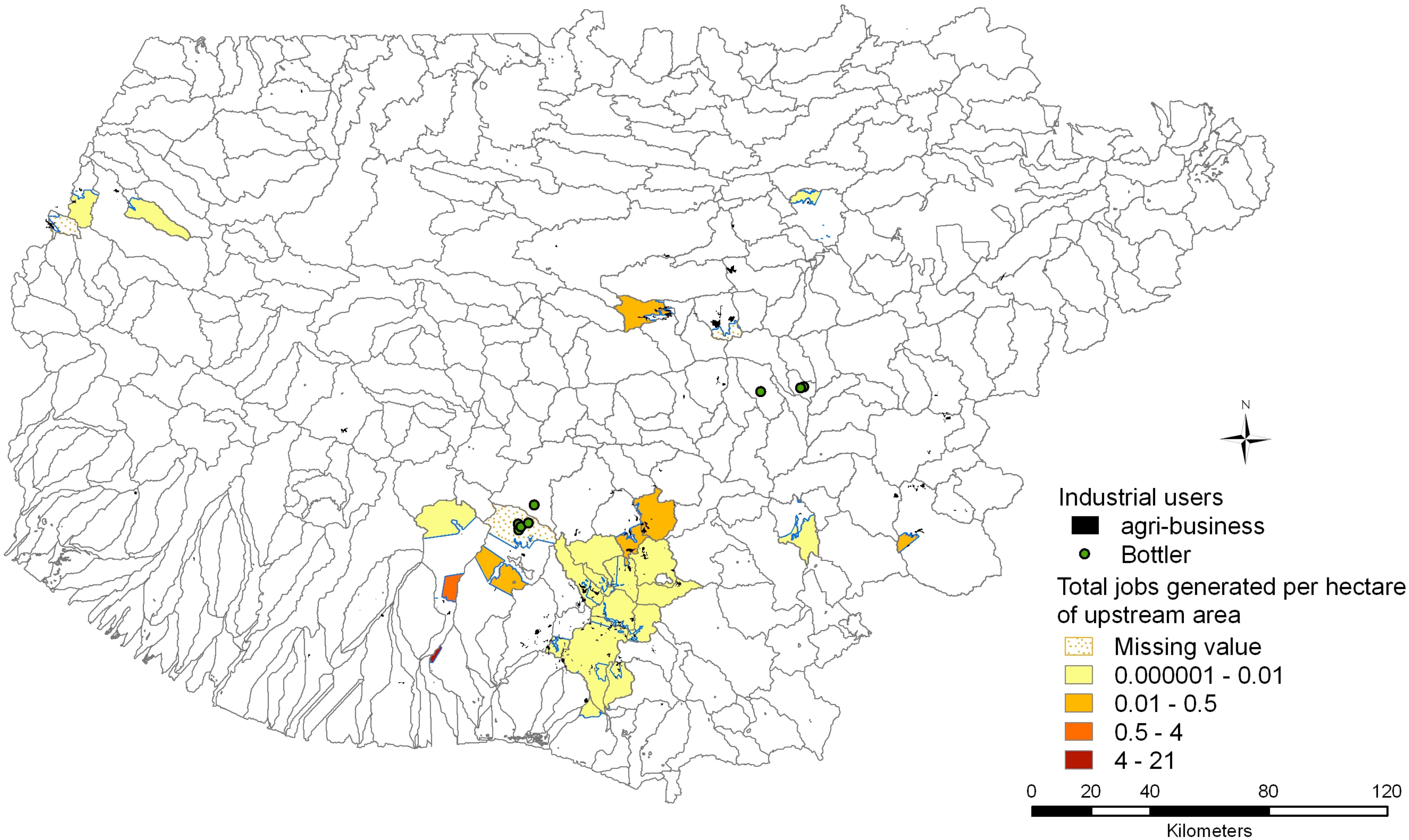
Map 3: Guatemala City water supply systems and their water supply areas



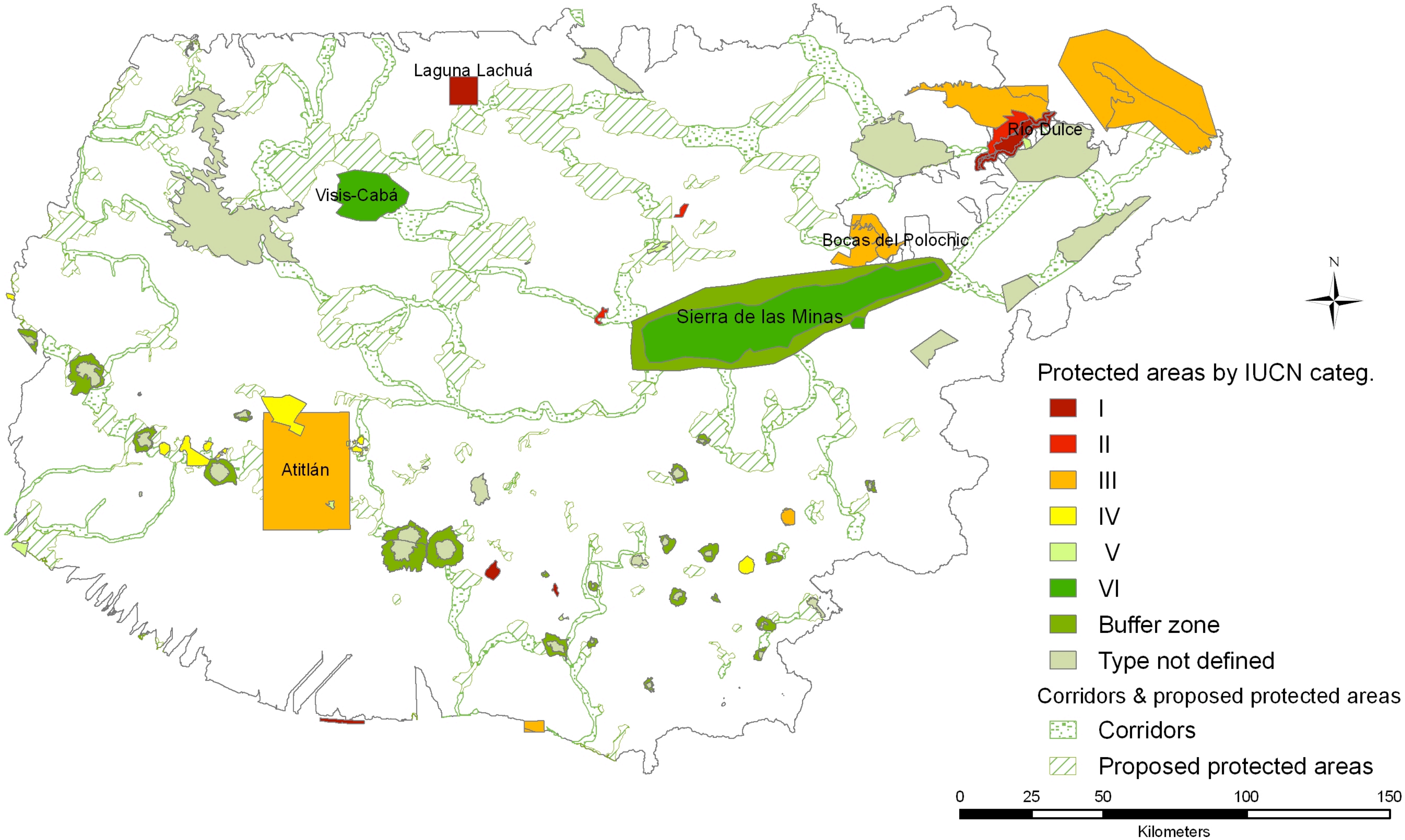
Map 4: Irrigation systems and their water supply areas



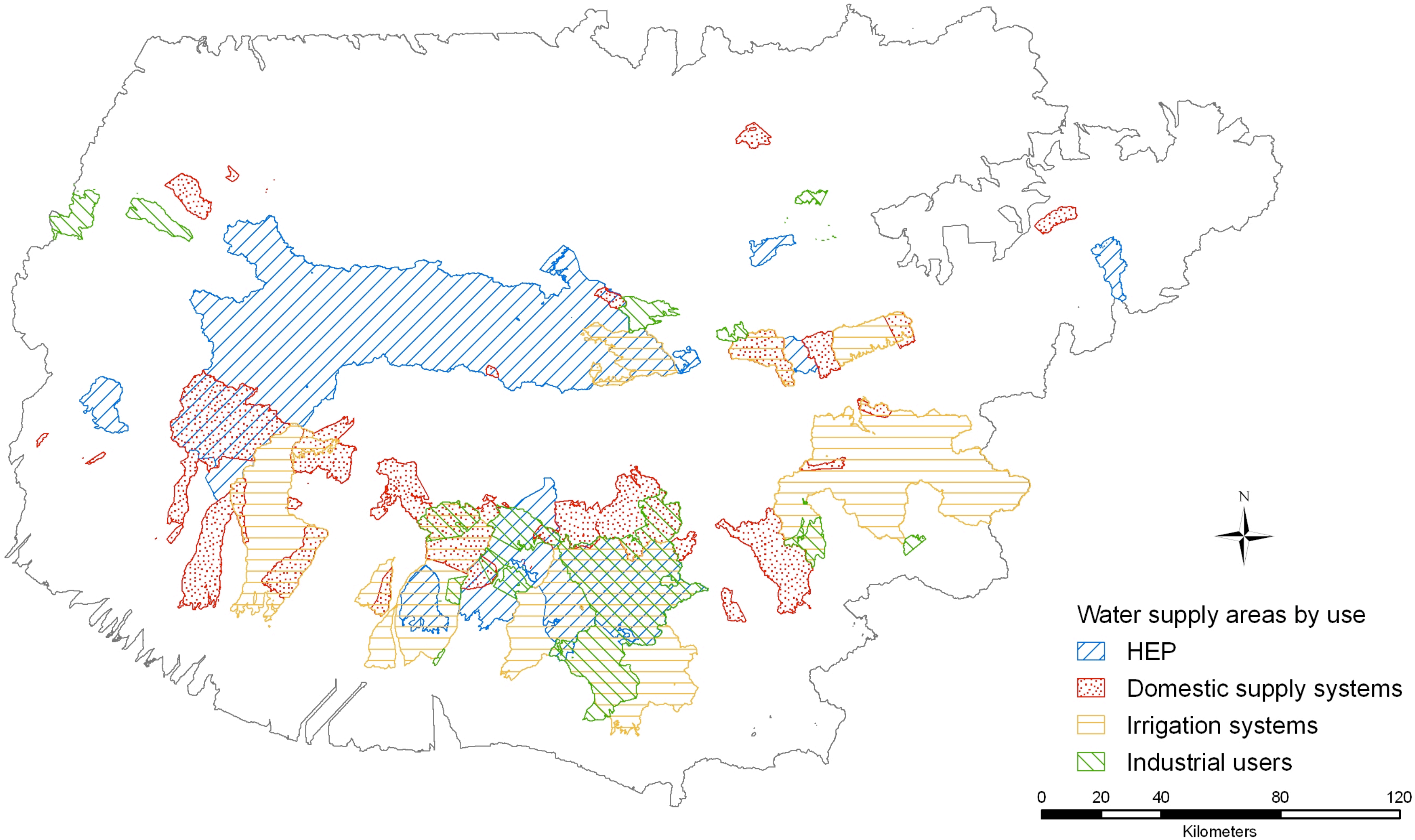
Map 5a: Industrial users and their water supply areas



Map 5b: Industrial users and their water supply areas



Map 6: Protected areas and biological corridors



Map 7: Overlap of water supply areas