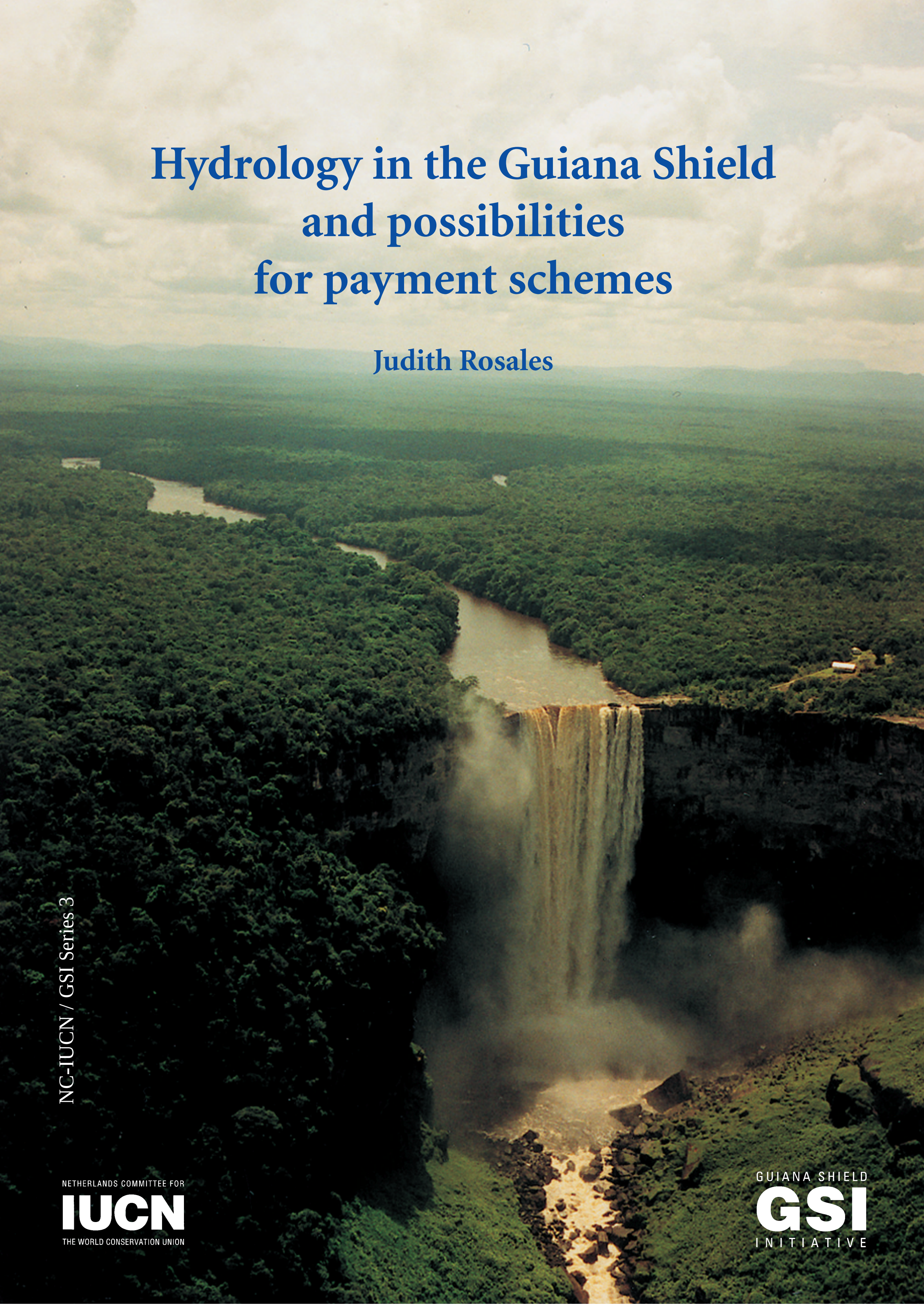
Hydrology in the Guiana Shield and possibilities for payment schemes

Judith Rosales



NC-IUCN / GSI Series 3

NETHERLANDS COMMITTEE FOR
IUCN
THE WORLD CONSERVATION UNION

GUIANA SHIELD
GSI
INITIATIVE

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Amsterdam 2003

GUIANA SHIELD GSI INITIATIVE

Hydrology in the Guiana Shield and possibilities for payment schemes is the third in a series of documents to be published by the Guiana Shield Initiative (GSI) of the Netherlands Committee for IUCN. The GSI received funding from the Ministry of Foreign Affairs of the Dutch Government to lay the foundations for a long-term eco-regional project to finance sustainable development and conservation of the unique ecosystems of the Guiana Shield. This eco-region encompasses parts of Colombia, Venezuela, Brazil and the whole of Guyana, Suriname and French Guiana.

Rosales, J. (2003). Hydrology in the Guiana Shield and possibilities for payment schemes

Universidad Nacional Experimental de Guayana
Centro de Investigaciones Ecológicas de Guayana
Urbanización Chilemex, Calle Chile, Puerto Ordáz
Edo. Bolívar, Venezuela
Email: jrosales@uneg.edu.ve

Produced by Dave Zwaan and Cas Besselink, NC-IUCN
Layout and cover by Edith Cremers
Coverphoto: The Kaieteur Falls in Guyana. Photo: H. Muntingh

Published December 2003
by the Netherlands Committee for IUCN
Plantage Middenlaan 2k
Amsterdam, The Netherlands
Websites: www.nciucn.nl, www.guianashield.org

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PREFACE

As Guiana Shield Initiative (GSI) we are very happy with this report on the hydrological services in the Guiana Shield region. These services the Guiana Shield provides not only to its own population and nature, but also to the global community.

Publication of this report also has a significance appearing during the United Nations' International Year of Fresh Water 2003. It is estimated that the Guiana Shield eco-region contains 10-15% of the world's fresh water reserves and the Shield is, of course, part of the larger Amazon Basin – the largest fresh water reserve on earth.

We are fortunate that one the most prominent experts on the hydrology of the Guiana Shield, and its ecological significance for the region and the world, Dr. Judith Rosales of the Universidad Nacional Experimental de Guayana (UNEG), Venezuela, has been willing to expand her contribution to the Priority Setting Workshop for the Guiana Shield region in April 2002 in Paramaribo, Suriname, into this report.

The maps and reports of the April 2002 Priority Setting Workshop (available in the national languages of the six countries of the Guiana Shield) have recently been published. Other GSI publications on the Guiana Shield region are a report on the vital role of indigenous communities in the management of the region, as exemplified by the Colombian *resguardos*, and a report on the Non-Timber Forest Products of the region. Shortly, a publication about the monitoring of the ecology of the Guiana Shield will also be available. Together with these publications, we feel that Judith Rosales' report on hydrology completes a solid body of science-based arguments to foster international cooperation for the preservation of the ecological, and cultural integrity of the Guiana Shield region.

Wouter Veening
Head GSI

I

INTRODUCTION

Growing demands for and scarcity of freshwater are now evident in many parts of the world, thus making hydrological services of terrestrial and aquatic ecosystems of extreme relevance. This issue was recognized in Johannesburg at the World Summit for Sustainable Development in 2002, and was recently fully discussed at the third Water Forum in Kyoto, Japan in March, 2003. All major world-leading water institutions have shown data demonstrating that natural ecosystems deliver invaluable hydrological services to humanity.

As water becomes more scarce or polluted, its value becomes higher and the approaches followed by researchers or water managers grow in complexity. Indeed, water cycle is in itself a complex system directly, or indirectly, regulating environmental quality and human health. When analysing environmental services in a given region, we must take into account the perspectives of different researchers to see if they can be applied under particular conditions of this region. These perspectives reflect different human perceptions, or values, about terrestrial or freshwater ecosystems, and have been reproduced in the myriad of existent classification systems.

One of the first widely accepted approaches was presented by Constanza *et al.* (1997) for whom ecosystem services consist of the flow of materials, energy and information from natural capital stocks, combined with manufactured and human capital services to produce human welfare. More recently, De Groot *et al.* (2002) provide a more comprehensive integrated framework to interpret flow of materials and energy driving the interactions between biotic and abiotic components of the ecosystems in ecosystem functions. Their framework involves the translation of ecological complexity (structure and processes) of ecosystems into ecosystem functions, which in turn provide the ecosystem goods and services valued by humans in terms of ecological, socio-cultural and economic values. Following this framework, hydrological goods and services from terrestrial and aquatic ecosystems to which people could give value in the Guiana Shield region, can be derived from the following ecosystem functions:

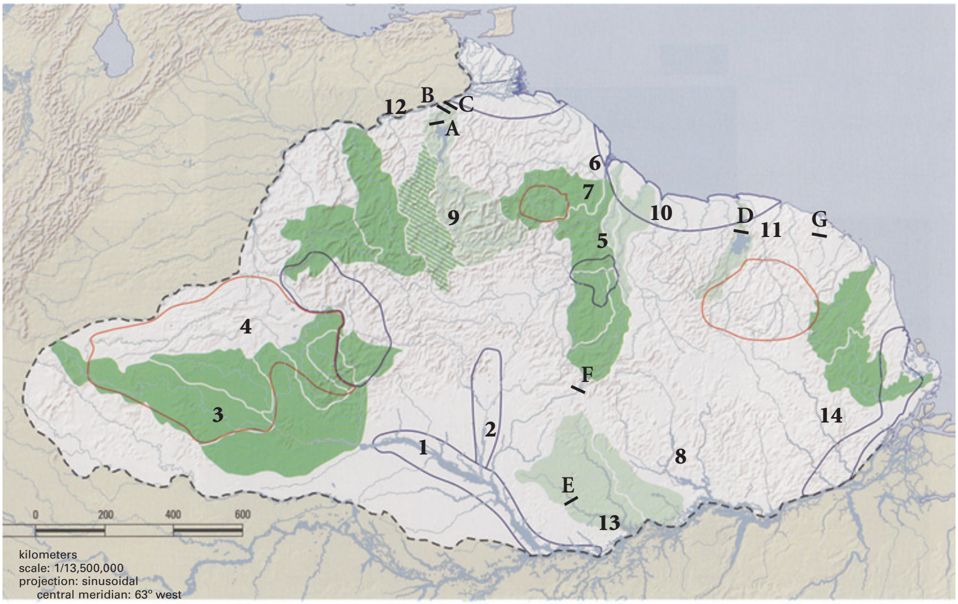
1. Regulation functions of terrestrial ecosystems (water regulation, water supply, soil retention implying erosion control and sediment retention, nutrient regulation);
2. Regulation functions of riparian and aquatic ecosystems (hydro energy, waste treatment, dispersion, sediment retention, flood prevention, soil formation);
3. Habitat functions of riparian and aquatic ecosystems (refugium, nursery);
4. Production functions of riparian and aquatic ecosystems (food *e.g.* fish, raw materials, genetic resources, medicinal resources, and ornamental resources);

5. Information functions of riparian and aquatic ecosystems (aesthetic information, recreation *e.g.* fluvial ecotourism, water sport, cultural and artistic information, spiritual and historic information, science and education).

When considering river basins as the natural unit for water management, it is important to recognize that water regulation, water supply, erosion control and sediment retention are all terrestrial ecosystem regulation functions that in turn determine the regulation, habitat and information functions of riparian and aquatic ecosystems. A river's flow regime drives variation in the ecological structure and the functioning of riparian and freshwater ecosystems, *e.g.* fish populations, riparian vegetation composition, bird's habitats, insect's communities, freshwater nutrient cycling, aquatic trophic chains and hence water quality. Therefore, hydrologic variability in a river basin influences riparian and aquatic ecosystem structure, processes and functions related to important ecosystem goods and services that if appropriately valued could determine scientifically sound policy and management strategies.

The system used by Bucher *et al.* (1997) specifically addresses the importance of valuing freshwater ecosystems. Bucher *et al.*'s classification shares similarities with former frameworks in terms of the inclusion of what both De Groot *et al.* (2002) and Constanza *et al.* (1997) identify as functions why the ecosystem is valuable to people. Bucher *et al.* propose that freshwater ecosystems give three classes of ecological benefits to humans: (1) freshwater ecosystem functions such as water supply, flood regulation, protection from natural forces, sediment retention, nutrient retention, toxical removal, biomass export, microclimate stabilization, carbon sink, water transport, and tourism; (2) freshwater ecosystem products, including forest, wildlife, fisheries, forage, agriculture, and energy; (3) freshwater ecosystem attributes in terms of habitat for sustaining productivity, species richness, endangered species, genetic diversity, and cultural significance *i.e.*, aesthetic values or values relating to religious or spiritual beliefs and activities. They say the benefits listed in the first two classes can be assigned direct monetary values. The monetary value of the third category, however, relates to opportunity costs.

Considering the different values of freshwater ecosystems, the aim of this report is to analyse for the particularities of the Guiana Shield some relevant issues that can be of help in establishing possibilities of payment for hydrological services in the region. The regional and global importance of the Guiana Shield eco-region in terms of hydrological services is discussed. It manages data and maps authored by the physical geography group that were used in the preparation of the final report of conservation priorities for the Guiana Shield (Huber and Foster eds. 2002). In this report, specific information is given about previously identified important water-catchments areas that would need protection to maintain hydrological services to increasingly populated areas. The report considers previous information, and focuses on how major land use patterns at the river basin level are actually impacting, or could potentially, impact hydrological services in the Guiana Shield. To demonstrate this, examples where mining, logging or dams have had a negative impact on the water supply of another area are given, considering especially trans-boundary cases. The report ends by discussing possibilities for financing hydrological functions, using the Caroní River as a case study, with suggestions for priorities in research and action for future phases of the GSI.



Map: Conservation International, NC-IUCN/GSI, UNDP

This map of the Guiana Shield shows the notable watersheds. The numbers show the largest rivers in the Guiana Shield in terms of drainage area and discharge (see also chapter 3): **1** Rio Negro (with the largest tributaries: **2** Rio Branco, **3** Vaupés and **4** Guainía), **5** Essequibo River (with the main largest tributaries **6** Cuyuni River and **7** Mazaruni River), **8** Trombetas River, **9** Caroní River, **10** Corentyne River, **11** Marowijne River, **12** Upper Orinoco River, **13** Uatuma River, and **14** Jari River. The lettering shows some of the largest operation hydroelectric dams (see also paragraph 4.2): **A** Guri Dam, **B** Caruachi Dam and **C** Macagua Dam, **D** Brokopondo Dam, **E** Balbina Dam, **F** Alto Jatapu Dam, and **G** Saut-Petit Dam.

2.

REGIONAL AND GLOBAL IMPORTANCE OF THE GUIANA SHIELD REGION IN TERMS OF HYDROLOGICAL SERVICES

Trend analysis from many water-leading institutions suggest that one of the biggest challenges for this century will be to satisfy humanity's water demands, whilst simultaneously protecting the ecological support functions of freshwater ecosystems. It is necessary to take into account that water availability is unevenly distributed around the world. Meeting this challenge will, therefore, require sound water management in areas of low water, but also sound management and conservation of water sources in areas with high water availability.

Data from UNEP (2000) relating water production and total population numbers show that many countries have lower than average quantities of freshwater resources available to their populations (*e.g.*, Egypt 26 m^3/capita/year, United Arab Emirates 61 m^3/capita/year). South American countries with some exceptions like Chile are some of those with the highest values. An estimate of the discharge for the whole Guiana Shield region is 113,557 m^3/second (Rosales *et al.*, 2002a). Values of about 170,000 m^3/sec for the discharge of the Amazon River (Richey *et al.*, 1989), and 36,000 m^3/sec for the Orinoco River (Weibezahn, 1990) indicate that the Guiana Shield as a whole produces nearly half of the discharge of the sum of both rivers, which are first and third in the world in terms of discharge. Therefore, given the worldwide water problems predicted for 2025, the conservation of the Guiana Shield hydrological services can be considered of global importance in terms of water resources and related freshwater ecosystems. Conservation of the hydrological services could include the following benefits to humanity:

1. supply clean water for consumptive use if exported to areas of water shortages;
2. maintain levels of evapotranspiration and atmospheric humidity which regulate global circulation patterns, and climate through complex interactions with temperature and precipitation;
3. maintain healthy freshwater ecosystems and associated fisheries or other potentially exported products derived from their specific and genetic biodiversity;
4. maintain healthy and highly productive coastal areas given the nutrient enrichment that the Amazon, the Orinoco, the Essequibo and other rivers draining from the Guianas provide in their way to the Atlantic Ocean;
5. maintain riparian areas of high aesthetic and spiritual value for recreation, ecotourism, sports potentially used for the global community;
6. maintain areas of high scientific and educational values potentially used for the global community.

According to the Food and Agriculture Organisation of the United Nations (FAO, 2003), French Guiana, Guyana and Suriname (completely located in the Guiana Shield region) are within the top six countries in the world in terms of water availability per person per year. Venezuela, Colombia and Brazil occupy the 23rd, 24th and 25th places respectively. If we, however, only consider the Guiana Shield parts of Brazil, Venezuela and Colombia, similar water availability is found as in French Guiana, Guyana and Suriname. Estimates for water availability are shown in Table 1. Some areas in these countries have a very low population density (mostly inhabited by indigenous and rural populations) in relation to water discharge.

COUNTRY	STATE	AREA km^2	POPULATION Year 2000 # of inhabitants	POPULATION DENSITY Inhabitants	WATER ESTIMATE PER CAPITA m^3/capita/year
French Guiana [1]		91,000	172,605	1.9	**812,121**
Guyana [1]		214,970	697,286	3.2	**316,689**
Suriname [1]		431,303	431,303	2.6	**292,566**
Venezuela [1]					**51,021**
	Bolívar [2]	238,000	1,306,652	5.1	414,024
	Amazonas [3]	177,000	70,000	0.4	4,377,722
Colombia [1]					**50,635**
	Guainía [4]	72,238	13,491	0.2	14,050,083
	Vaupés [5]	65,268	18,235	0.3	6,866,120
Brazil [1]					**48,314**
	Roraima [6]	224,118	324,152	1.5	498,081
	Amapá [7]	142,816	475,843	3.3	390,780

1 UNESCO, 2002.
2 Caura River at San Luis gauge station 3,080 m^3/sec draining 45,955 km^2 (MARN 1969-1993).
3 Ventuari River at Canararipo gauge station 2,381 m^3/sec draining 40,655 km^2 (1970-1982 MARN).
4 River Guainía at Cucuy gauge station 4,872 m^3/sec draining 58,554 km^2 (LBA Hydronet).
5 River Vaupés at Taraqua gauge station 2,721 m^3/sec draining 44,732 km^2 (IDEAM).
6 Rio Branco at Caracarai gauge station 2,855 m^3/sec draining a surface of 124,980 km^2 (LBA Hydronet).
7 Porto Platon Araguari gauge station 965 m^3/sec draining 23,373 km^2 (LBA HydroNet).

3.

IMPORTANT BASINS FOR CONSERVATION

The largest rivers in the Guiana Shield in terms of drainage area and discharge (see map on page 7) are according to Rosales *et al.* (2002):

1. Negro River Basin (Brazil, Colombia and Venezuela – Amazon drainage), with the largest tributaries being the Rio Branco, the Vaupés (Colombia-Brazil) and the Guainía (Colombia);
2. Essequibo River Basin (Guyana and Venezuela – Atlantic drainage) with its largest tributaries being the Cuyuni and Mazaruni Rivers;
3. Trombetas River Basin (Brazil – Amazon drainage);
4. Caroní River Basin (Venezuela – Orinoco drainage);
5. Corentyne River Basin (Suriname and Guyana – Atlantic drainage);
6. Marowijne River Basin (Suriname and French Guiana – Atlantic drainage);
7. Upper Orinoco River Basin (Venezuela – Orinoco drainage);
8. Uatuma River Basin (Brazil – Amazon drainage);
9. Jari River Basin (Brazil – Amazon drainage).

The Marowijne or Maroni River is an important river between Suriname and French Guiana.
Photo: D. Zwaan

Furthermore, when establishing conservation priorities for the Guiana Shield, river basin delimitation and additional specific criteria were used to assign three large areas of outstanding value in the Guiana Shield (Huber and Foster eds. 2002): (I) Upper Orinoco and Upper and Middle Rio Negro Basin including Casiquiare and the lowlands of the Atabapo, Inirida, Guainía; (II) Ventuari, Caura, Paragua Upper Basins; and (III) the Upper and Middle Essequibo and Caroní River Basins. The main additional criteria include:

1. highlands with heights over 1,000 m above sea level (asl), as they guarantee runoff regulation and the protection of river sources and biogeochemical cycles of major watersheds of the Guiana Shield region;
2. areas with higher water yield values at the regional level (average calculated from available data ranging from 55.0 to 85.0 litres/sec per km^2 as they guarantee abundant freshwater);
3. areas important for watershed conservation (*i.e.*, watersheds of rivers close to major cities, as they guarantee enough freshwater supply for human use).

Other criteria used were fluvial dynamics, confluence zones of major rivers, oligotrophism and geological diversity. For each country, however, other river basins are very important at the national level in terms of water provision: the Upper Demerara-Berbice-Courantyne-Nickerie, Coppename, Saramacca, Suriname, Commewijne, Marowijne, Mana, Sinamary, Comte, Approuague and Oyapock Rivers are very important in sustaining nearly 90% of the population, which is located along the coast line, in Guyana, Suriname and French Guiana. The same holds for the Cataniapo River, which directly provides water to Puerto Ayacucho, the capital city of the Venezuelan State of Amazonas.

The Oyapock River, the borderline of French Guiana and Brazil. Photo: W. Veening

4.

LAND USE IMPACTS ON HYDROLOGICAL PROCESSES IN THE GUIANA SHIELD

Land use practices can severely affect the hydrological processes of watersheds thereby affecting water quantity and quality. Regions with high provision of water are no exception. In South America, however, Bravo (2002) states:
"*Based on statistical analysis of the historical river data for several rivers there is no clear evidence of long-term trends or changes in the mean stream flow. After examining hydro-meteorological records extending back nearly 90 years, no clear unidirectional trend of stream flow is evident for the record analyzed to date. In particular, there is no apparent trend in the historical data of the Rio Negro, the main tributary of the Amazon River, which might be expected due to the impact of deforestation of the region (as shown by General Circulation Models (GCM) experiments of deforestation). It can be difficult to distinguish climate-induced trends that may exist in river stream flow from man-made effects. The lack of continuous high quality rainfall and river data in many regions has made the task of finding climatic trends in the components of the hydrological cycle very difficult. A clear modulation by the El Niño Southern Oscillation (ENSO) is evident in the interannual variability of stream flow in several regions of South America, as compared to North America or Europe. The signal of some El Niño events has been found from the rainfall of Northeast Brazil, while only very strong events seem to affect the hydrology of the Rio Negro in the northwest portion of the Amazon Basin.*"

Three significant direct effects on rivers hydrological processes especially important in the upper portions of river basins are:
1. Water use from rivers and aquifers, such as surface abstractions and/or the pumping of ground water affects the quantity of water;
2. Point source pollution, such as wastewater discharge into rivers, affects water quality;
3. Sedimentation derived from erosion affects water quality and fluvial geomorphology.

Furthermore, there are two very important indirect impacts:
1. Land use that changes the water cycle and the quantity of water (*e.g.* evapotranspiration, interception, infiltration and runoff) or river flow;
2. Non-point source pollution (also called land-based pollution), which influences the water quality.

Any intensification of land use from natural forests to plantation or agriculture increases the probability of reduced water quality. Even if the water cycle is unchanged, use of fertilizers, insecticides, herbicides or other substances may pollute water resources downstream. Siltation is also a problem where erosion rates increase because of removal of vegetative cover. As runoff increases, non-point source pollution is likely to become a serious threat to water quality. In many cases, point source pollution has been reduced in recent years, whereas non-point source pollution has increased and is a much greater threat.

These hydrological effects are a potential problem in the most populated areas of the Upper Caroní Basin and the Upper Rio Branco Basin. In addition, in the Upper Cuyuni Basin, where a growing population exists with associated mining, forestry and agricultural activities, pollution and sediment are increasing.

Non-point pollution problems are already present in La Gran Sabana in the Venezuelan Guayana; fires every year contribute to the loss of extensive forested areas and continuing gold and diamond mining are destroying forests and delivering high loads of sediments into the freshwater ecosystems. The effectiveness of the Guri Dam in the Caroní River has been impaired due to these activities. Urban and industrial centres, where most of water withdrawal is needed for sustaining national economies, are concentrated at coastal centres and in most cases are currently presenting problems of water supply and waste disposal. Furthermore, given the high mineralogical potential for mining, river basins like the Essequibo, as well as the Caroní and Paragua and Upper Orinoco, are currently subject to severe environmental impacts. In a similar way that has been reported for other areas in the world, extracting more freshwater for agriculture, industry, and urban development is placing the health of aquatic ecosystems at risk.

At a regional level, it is also important to consider how land usage in one country impacts the health of freshwater ecosystems, and water quantity and quality in another country. Morel and Corredor (2001) have shown a potential positive impact during the seasonal extension of the Orinoco River plume throughout the eastern Caribbean Sea by a nitrogen fertilization mechanism. That fertilization is related to the dynamics of dissolved organic matter (DOM) but it could also be associated with transportation of metals from urban and industrial sources. Increasing population, forestry, agriculture, industrial development, and mining in the upper basins of the tributaries can have negative effects downstream. This is currently an issue to consider in shared basins specific to the Guiana Shield; there are several examples: (1) the Essequibo River Basin shared by Venezuela and Guyana, (2) the Courentyne River shared by Guyana and Suriname, (3) the Marowijne River shared by Suriname and French Guiana, (4) the Oyapock River shared by French Guiana and Brazil, (5) the Negro River shared by Brazil, Venezuela and Colombia, and (6) the Atabapo shared by Venezuela and Colombia.

4.1. Forestry and Agriculture

Most of the forest management in the Guiana Shield has emphasized “sustained yield” timber extraction rather than sustainable management. Although some alternatives for sustainable forest management are currently in development, we are not yet able to ensure forestry is not having an effect on the hydrology. To do so, sufficient data is needed about the water cycle (rainfall, evapotranspiration, interception, infiltration and runoff). Very few complete climatic stations currently exist in the Guiana Shield region however, or they have not been operating for long enough (at least 10 years is needed). Rapid deforestation is currently occurring in some areas of the Guiana Shield rainforests especially in areas of increasing population such as Imataca Forest Reserve (Miranda *et al.*, 1998; Mueller *et al.*, 1998). It leads to a decrease in interception and an increase in runoff, promoting erosion and the delivery of sediments to the rivers. Furthermore, agriculture continues after deforestation and, with this, withdrawal of water for irrigation, increasing erosion and sedimentation of rivers – all impacting their hydrological dynamics. Finally, fertilizers, pesticides and herbicides (the latter being toxic to both plants and animal aquatic life) wash into the freshwater ecosystems changing the ecosystem chemical status.

In the vicinity of Manaus, the Rio Negro joins the Rio Solimões to become the Amazon River. This is the so-called 'meeting of the waters'. Photo: D. Zwaan

4.2. Hydroelectric dams

Some river systems in the Guiana Shield region are highly regulated and fragmented by dams. Among these, the largest in operation (see map on page 7) are:

1. the series of dams in the lower Caroní River, Guri (the second largest of South America), Caruachi and Macagua Dams;
2. the Brokopondo Dam in the Suriname River;
3. the Balbina Dam in the Uatuma River;
4. the Alto Jatapu Dam in the Jatapu River; and
5. the Saut-Petit Dam in the Sinnamary River.

Most of the rivers have a high gradient and are considered to have potential for hydroelectric power generation. This can pose a threat to biodiversity conservation. Higher threats to freshwater ecosystems are found in those basins where river regulation is proposed, for instance the Eutobarima Dam in the Upper Caroní, a river that is already regulated in its lower basin, the Caura-Paragua interbasin water diversion in the Caura River, or the dam and diversions projected in the Mazaruni Sub Basin affecting the Kaieteur Waterfalls among others.

In general terms, it is known from the literature, that damming of rivers affects freshwater ecosystems in several ways. The upstream segment of the river is largely unaffected by the dam, however, the segment of the river directly downstream of the dam is. In the section downstream of the dam native fish populations are severely affected. It is well known that dams also block the upstream migration of fishes. This has particular importance for migratory species because dams must be bypassed to reach river headwaters for reproduction in a suitable spawning habitat. Dams alter the flow and sediment load of rivers downstream, and thereby may induce changes in channel formation in alluvial rivers. By reducing the magnitude of frequent, moderate floods, dams may lead to channel narrowing as riparian vegetation invades the active channel that was formerly scoured of vegetation by frequent floods. By trapping sand and gravel in reservoirs, dams deprive downstream reaches of their normal sediment load and release sediment-starved water also known as 'hungry water'. This tends to erode its bed and banks, unless the dam has reduced flood magnitude so much that sediment accumulates on the riverbed instead (Kondolf, 1997). Furthermore, other important hydrological impacts of dams to freshwater ecosystems are the increase in evaporation rates decreasing flows downstream of the reservoir, as well as affecting the regulation of flood peaks influencing wetlands downstream.

4.3. Mining

Mining is very important for the economy of the region. Gold, diamond, iron, bauxite, manganese and kaolin mining are the main activities; all of them influence the sediments dynamics of rivers. Many publications have also shown the dangers of mercury contamination; cyanide contamination is also related to gold mining in Caroní and Cuyuni in Venezuela, Omai in the Essequibo in Guyana, and Brokopondo in Suriname. Large impacts have been demonstrated from manganese extraction in Amapá (Queiroz *et al.*, 2001). The impact of iron and bauxite mining is not only impacting through the delivery of sediments, but also from chemical effects associated with an increase in metals like iron and aluminium, which changes the acidity (pH) and dissolved salts (conductivity) variables of water.

5.

POSSIBILITIES FOR PAYMENT SCHEMES

Freshwater degradation and water related problems arise from ineffective management that is invariably connected to social and economic issues, but also institutional and political issues. Bucher *et al.* (1997) address water misuse in Latin America and the Caribbean, asserting that widespread ignorance about the importance of freshwater ecosystems has contributed to the notion that they are useless – and has promoted their destruction and degradation. Preserving water resources for future use does not appear to be a primary consideration in the planning and implementation of water use projects. Water development tends to favour privatizing profits while socializing costs, thereby providing little encouragement for conservation and sustainable use. By heavily subsidizing water, governments give the impression that it is abundant while in many cases evidence suggests the contrary. NGO's and civil societies in the different countries of the Guiana Shield must effectively participate in the monitoring and decision-making of water issues at local and regional levels. This requires technical skills, knowledge of their watershed, financial capacity, and political will for enforcement. Improving the information base and public awareness of the importance of the water cycle and the need for better management are also crucial in order to institutionalize the concept of sustainable, integrated water management in the region.

There are, however, some countries in Latin America (*e.g.*, Costa Rica, Colombia, Ecuador) that already started programs of Payment for Environmental Services (PES) and the hydrological service of the watersheds is an important financial benefit. In Costa Rica there is an example of payment for hydrological services that includes provision of water for human consumption, irrigation and energy production (Malavasi and Kellenberg, 2002).

Pagliola *et al.* (2003) suggest payment for environmental services could be based on the principle that those who provide environmental services should be compensated for doing so, and those who receive the service should pay for their provision. The rationale is that payment for the conservation by downstream beneficiaries can help make conservation an attractive option to land users thus inducing them to adopt it. The payment must obviously be more than the additional benefit of the alternative land use (otherwise they will not change their behaviour), and less than the value of the benefit to downstream populations (otherwise they will not pay for it). The authors warn however, after analysing PES applications in several countries, that aspects that might prevent or limit the participation in a PES program are likely to be correlated with poverty, including insecure land tenure, lack of title, small farm holdings, and lack of access to credit. PES programs could help alleviate poverty but should not be planned with poverty reduction as the primary objective. Service recipients should be satisfied for the service, otherwise they will not pay for it. This would result in both poverty reduction and conservation or management will be successfully achieved.

To establish possible payment schemes that allow for the protection of the hydrological services of watersheds and freshwater ecosystems, it is necessary to start with an economic direct market valuation of what might be of primary concern to most of the Guiana Shield population, including the poorest. More awareness about ecosystem importance among different society sectors is needed if indirect market valuation, contingent valuation or group valuation approaches are going to be used. For example, the willingness to pay, willingness to accept compensation for the availability or loss of ecosystem services, hedonic pricing of housing close to attractive scenarios (as presented by Constanza *et al.*, 2003) are not primary concerns to perhaps more than 90% of people living in the Guiana Shield. Although water is not scarce in the region, it is possible to say without doubt that for downstream users water supply and water quality are regulation functions of high importance since they are related to basic human needs and welfare.

Addressing the direct market valuation regarding water supply network and wastewater disposal where most of the intensive water use is concentrated is, therefore, significant. That means areas in the highly populated urban centres, most of which are located along the lower reaches of the major tributaries draining to the Amazon River, the Orinoco River or the Atlantic Ocean. Payment schemes, though, should be linked to mechanisms that allow funds to be used for the protection and sound management of terrestrial and freshwater ecosystems in river basins.

Economic theory establishes charges to customers for the marginal cost of supplying them with water and a sum equal to the marginal damage caused by their wastewater. In general, people charged less than those amounts consume too much water, or discharge too much wastewater. Implementing the theory requires effective consumer metering and full knowledge of marginal costs. This is far from reality in most countries of the Guiana Shield. Therefore, specific studies are needed to fulfil this requirement. Furthermore, satisfactory tariffs are required for providing water services in the amount and quality required (World Bank, 1996).

In terms of water supply and waste disposal, Lee *et al.* (2001) calculate for several European countries the costs of the necessary infrastructure to supply freshwater and drain wastewater and storm water, based on an annual water consumption of 180 to 220 m^3. The results indicate the internal cost per inhabitant (cost for treatment, storm water retention basin, pumping, inlet, manhole connection, gully, main network) is on average US$ 1,000 - US$ 1,300. Furthermore, the external costs are calculated to be between US$ 300 - US$ 400 per inhabitant (cost for environmental protection) and US$ 300 per inhabitant for connection. These numbers do not include domestic connections. This results in a total of between US$ 1,600 and US$ 2,000 per year per inhabitant to establish a fully supplied and connected system that would further allow for appropriate metering.

Given the low income per inhabitant of the countries of the Guiana Shield (US$ 3,400/year in Suriname, US$ 4,800/year in Guyana, US$ 6,000/year in French Guiana, US$ 6,200/year in Venezuela, US$ 6,200/year in Colombia, US$ 6,500/year in Brazil), the initial capital investment would be difficult to achieve. This is in contrast to developed countries, for example Portugal (US$ 15,800/year), Spain (US$ 18,000/year), the United Kingdom (US$ 22,800/year), France US$ 24,400/year, the Netherlands (US$ 24,400/year), and the US US$ 36,200, have far higher Gross Domestic Product GDP per capita than Guiana Shield countries and clear differences in terms of investment possibilities (from world statistics of the United Nations for year 2000). Payment schemes in these developed countries have proved to be effective in terms of water services with efficient new technologies. Therefore, international aid from developed countries could help local Guiana Shield governments and institutions in financing first seed investments for sustainable water management programs in the region.

After analyzing three financing channels (taxes, water user fees, and water price) for initial investments, Lee *et al.* (2001) conclude that the shortest channel i.e., the price of the service, is the most logical and equitable as well as being the option that implies the costs have to be reduced to the poorest. Furthermore, in terms of means of financing they compare subsidies, fees, self-financing and borrowing or capital contribution, demonstrating that borrowing passes the costs onto future end users, which should not be encouraged in sustainable schemes for the Guiana Shield. Water is a resource for the future of the world; however poor countries cannot afford an increase in their external debts by increasing loans from multilateral agencies. Furthermore, without including initial investments, operating costs could be afforded for people in the Guiana Shield. According to the International Water Supply Association, operating costs of water supply give an average of US$ 85 for 100 m^3 of water per year and a combined system of wastewater and storm water disposal gives US$ 60 to US$ 95 for 100 m^3 of water per year. These amounts could be afforded by most citizens, if the range of US$ 3,000 to US$ 7,000 average GDP per capita, reached equally all inhabitants including poor people. However, there is a high inequity in the GDP distribution to the populations of all countries in the Guiana Shield, where many poor people earn less than US$ 100 per year.

Social welfare must, therefore, be considered; the financing of initial capital investment can be very high, as well as the continuous funding for operation and maintenance of the services provided in terms of the mean annual income of the population. Willingness to pay will probably depend not only on the income but also on public awareness about the following issues: their environment and ecosystems and the hydrological services they provide, knowledge of the natural water cycles, water services cycle (resources and treatment, transmission, distribution, demand, sewerage and sewage treatment), rights to have access to drinking water with adequate quantity and quality together with its relation to public health and hence people's welfare. It implies public education that may take up to several decades, by which time the ecosystems as they are now will probably not exist even in the currently pristine areas as the Guiana Shield.

Therefore, national and international NGO's as well as governmental agencies and industries directly depending on adequate water provision should start looking for the initial investment funds for the establishment of regulations and institutionalisation. They should also arrange proper financing channels for operational water management activities, including internal, but also, external costs such as environmental management, or freshwater ecosystem restoration at the river basin scale. Lundqvst and Turton (2001) analyse the social, institutional and regulatory issues relating to water services provision referred to as integrated water management. They propose the need for modification of social and institutional responsibilities and a proper partnership between the formal and the informal management institutions and organizations.

5.1. Case Study: the Caroní River Basin in the Venezuelan Guayana

Local and regional importance of basin hydro services can be drawn through an example in the Caroní River Basin of Bolívar State, Venezuela. The Caroní is the most heavily used river in the whole Guiana Shield. In Bolívar State, 53.1% of the population is concentrated in Municipio Caroní (Ciudad Guayana), located downstream on the Caroní River; these people depend entirely on this river for water supply. Municipio Heres (Ciudad Bolívar), with 24.1% of the population, receives water supply from the Guri Dam on the Caroní River and from the Orinoco River. Water quality and quantity of the Caroní River is, therefore, very important at the state level for water supply, but also for energy given that the Caroní River completely supplies energy for domestic and industrial activities in the main urban centres of Venezuela.

Water quality problems are currently an issue in Ciudad Guayana given that most of the domestic and industrial wastewaters are not treated and there is only one small special waste facility with insufficient capacity for the current population. The Macagua Dam is currently suffering from this pollution, thereby threatening the recreational values of the beaches along the reservoir and the capacity to treat drinking water to maintain a potable water supply to the city provided by the reservoir (Rodriguez, 2001). In order to institutionalize and establish a participatory mechanism for water management in the lower Caroní River, a proposal for a new water council is currently being analyzed by local authorities (Monzón, 2003). An investment of US$ 20 million has been announced from the

Venezuelan Minister of Environment for a new bigger special waste facility. San Felix, the poorest sector at the east of Ciudad Guayana however lacks this service and has more than 60% of the Ciudad Guayana population.

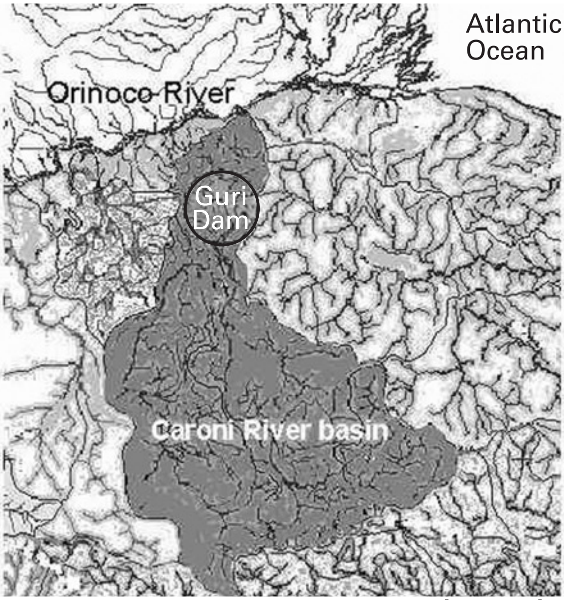


Image by J. Rosales

Besides urban citizens and other industries, CVG-EDELCA, the state hydroelectric enterprise is a very important user of the Caroní River water, the quality and quantity of Caroní waters is extremely important for the country as a whole. Two hydroelectric projects (Guri and Macagua) in operation produced 59,066 Gigawat hours (GWh) in 2001 (US$ 1,054 million with a net benefit of US$ 53 million) supplying 65% of the electricity to the country and all of the electricity to the industrial park (mainly aluminium and iron industries – second of importance to the GDP of Venezuela). The Caruachi Dam starts its operation this year 2003 (producing 2,160 Megawatts) and Tocoma Dam is proposed to start in five years (producing 2,160 Megawatts). It is a political issue to use less petrol to produce electricity, saving petrol for exportation and thereby having lower CO_2 emissions per KWh produced (however, methane and CO_2 conversion from reservoirs should be accounted for, especially in shallower dams flooding forested areas). Furthermore, the Caroní delivers 100% of the electricity exported to Boa Vista in Brazil, and to Cuestecitas and San Mateo in Colombia. Therefore, water provision from the Caroní River is important not only directly at the national level but also indirectly at international level.

On the other hand, it is important to consider that 2% of the total population in Bolívar State lives in the Gran Sabana municipality, which is the source of the

Caroní River. Sixty percent of the population in this municipality is indigenous. In the main city, Santa Elena de Uairén, potable water is distributed to most of the population but wastewater treatment facilities are not available. Similarly, less than 1% of the population lives in the Paragua River Basin, the most important tributary of the Caroní draining directly to the Guri Reservoir. From that population, more than 70% is indigenous from Pemón ethnic origin. Given the low resilience of the ecosystems in the Upper Caroní River, fires commonly used for communication, hunting, and other traditional activities of the Pemón culture are associated with continuous degradation of the water source. The indigenous people need water directly for drinking, food preparation, washing-up, cleaning and navigation and also indirectly as habitat for fish and wildlife and for the maintenance of wetlands providing important products. This is roughly the same for most rural areas adding, however, water for irrigation in agricultural lands. Small-scale gold and diamond miners also live in rural areas and use water for their mining activities. These mining activities cause non-point and point sources of pollution to the freshwater downstream. Most of these populations lack water services and currently use septic tanks which when close to groundwater also contaminate the river downstream. The magnitude of the point source of pollution depends on population density.

The role that rural and indigenous populations play, in the conservation and sound management of hydrological services of terrestrial and aquatic ecosystems and maintenance of clean water sources, should be recognized due to the high local and regional relevance of the Caroní River. This might be included in the new GEF project for the Upper Caroní. However, to encourage local and indigenous peoples' willingness to work for conservation, restoration and sound management of these ecosystems and to adjust problematic activities, a payment scheme that directly involves these people as ecosystem managers could be devised.

Downstream, the Caroní River joins the Orinoco River, which leads to the Orinoco Delta, constituting the border of the Guiana Shield. Here, river regulation has affected the hydrodynamics of the associated wetlands where the Warao indigenous population lives. Water quality has also been impaired by domestic and industrial wastes, which are delivered from Ciudad Guayana and other major cities mainly without treatment. This might be increasingly affecting freshwater ecosystems downstream. Water related epidemic diseases have been the cause of extensive mortality of a large portion of the Warao population. This event together with increasing poverty probably stimulated the migration of some families to other areas, like Ciudad Guayana, where they have ended up living in extremely unhealthy conditions. Therefore, when analysing water management and payment schemes for the Caroní River Basin, it should be viewed as three action zones: (1) the Upper and Middle Basin to the Guri Reservoir, (2) the Lower Basin including Ciudad Guayana and (3) the Orinoco River to the Delta. Poor people downstream in the Delta will not pay for the environmental service upstream and that is important when establishing a PES.

Appropriate water management of the Caroní River Basin for providing the ecosystem services and a payment scheme in this case could be established through Aguas Bolívar, a new proposed water agency. However, given that public sector management is not always effective, this should be a mixed Private-State enterprise that also meets other stakeholders, such as NGO's, universities, and community sectors, at decision-making levels. The main investors in this case should be Electrification of the Caroní River enterprise (EDELCA) and the state due to the key importance that the Caroní River has for the country.

In terms of the hydrological service of energy generation only and using the size of the Caroní River Basin as a rough basis together with the earlier mentioned income values for 2001, the economical value of the basin ecosystems for CVG-EDELCA can be estimated as about US$ 1,000,000 per hectare per year, and from the net benefit, US$ 50,000 per hectare per year. As an indication: Energia Global pays a similar value to private firms in Rio Volcan and Rio San Fernando watersheds in Costa Rica (Malavasi and Kellenberg 2002). A local community of 100 people of the Upper River Basin would be more than happy to be paid US$ 10,000 per year for working on the conservation of 100 hectares of forest. This would still leave a net benefit of US$ 40,000 per hectare per year to the hydroelectrical enterprise. Similar valuation could be made for water supply benefits to the water enterprise of Bolívar State.

A project for precise calculation of water commodities per person, industry and public sector is needed, based on modelling using hydrologic data from EDELCA and the distribution network from CVG-GOSH, the water enterprise of Bolívar State. Currently, not all the population is served, especially the poor, and many of them are drinking water stolen from the industrial distribution network.

In addition, a GIS system is needed to quantify the amount of wastewater disposal going to the rivers without treatment and to quantify the number of owners that is responsible for it. An appropriate water education program should be established to raise awareness within urban populations about water commodities and to increase their willingness to pay for adequate water services. Furthermore, based on the new Venezuelan constitution, the possibility for indigenous land ownership, as well as the appropriate allocation of lands both in urban and rural areas, opens up the possibility of a direct payment scheme to those landowners working for watershed conservation and restoration activities. A fund for paying the hydrological services of the terrestrial and freshwater watershed ecosystems should be established and direct payments made to these people. In addition, this fund should pay for the internal and external costs of a combined system of water distribution and wastewater disposal.

6.

PRIORITIES FOR RESEARCH AND ACTIONS FOR FUTURE PHASES OF THE GSI

Some specific questions need to be addressed by the next phase of the Guiana Shield Initiative if PES schemes for hydrological services are encouraged for helping in conserving water for the year 2025:

1. What is the level of awareness about the importance of water for different stakeholders in the Guiana Shield region of the different countries of the Guiana Shield? The results of this specific question will give information about willingness to pay, and provide data for guiding the necessary environmental education programs.
2. Based on existent hydrological data, the calculation for the earlier mentioned basins of the price per hectare of different vegetation formations, and simulate changes in price under different restoration scenarios in disturbed areas or land use change.
3. How can hydrological processes be affected by different scenarios of land use patterns, climate change or El Niño at multiple temporal and spatial scales from local to nested aggregation of river basins of the Guiana Shield region? What is the impact of these scenarios in the continental or global hydrology?

For the next phase of the GSI, detailed analyses of case studies should be conducted for each of the important and threatened river basins of the Guiana Shield. Specific research, education and training projects could be conducted with the launching of a specific Guiana Shield Hydrological Services Program of Biodiversity (GSHySPB) aiming to produce sound scientific hydrological and socio-economic data in which to base the strategy to be followed for water conservation for the Guiana Shield.

Some specific activities to be challenged by the GSHySPB are also:

In order to design a sustainable water policy regarding water supply of different states within a country or international waters, a careful water budget is essential. The program should encourage river basin agencies authorities to meet with representatives from the different states of the country or the different countries for carrying on local, national and regional plans for sustainable water policies.

For the rivers selected of regional importance, accurate long-term measurements of surface flows, evapotranspiration, net aquifer recharge, and groundwater levels are necessary. Reservoir operations, effective land use planning, mining, agricultural and urban water conservation all play an important role in a sustainable water future for the region. Appropriate training of local indigenous people for working in hydroclimatological data collection is needed as well as the installation of automated stations in remote uninhabited areas.

The Orinoco River south of Puerto Carreño, Colombia. Photo: W. Ferwerda

Forecasting future hydrological patterns is important for guaranteeing human water supplies, scheduling irrigation and hydroelectric power generation, moderating flooding, and coordinating recreational activity. Hydrologic forecasts predict future changes in hydrology using weather forecasts and current hydrologic conditions. Stream gauges stations and monitoring programs need to be increased within the Guiana Shield so that future policies can be based on adequate scientific data. Most of the current gauge stations are located in areas where there is an interest for hydroelectric projects rather than for water supplies. Long-term discharge data is integral to stream monitoring programs and to the development of strategies to mitigate effects of hydrological modifications such as dams and water withdrawals. Many of the stream gauge sites have also been recently established and do not meet the minimum 10 year record length which is necessary to support a statistically reliable flow analysis. According to the information published in the web by LBA-Hydronet (http://www.lba-hydronet.sr.unh.edu/), the most complete databases of long-term stations are found mainly for Brazilian rivers.

It is important to further develop interdisciplinary partnerships between governmental land management institutions and scientists of the different countries of the Guiana Shield. Such partnerships will play a critical role in developing science-based guidelines to manage hydrologic connections across public land boundaries. Interdisciplinary research is needed to help managers evaluate the extent to which the ecosystem hydrological services are maintained. Further actions are needed to inform public land managers how different threats interact with each other. Accordingly, there is a need for the development of science-based tools that can predict future hydrological problems within the Guiana Shield region. Ecohydrology defined as the integrated study of ecosystems and hydrological characteristics and processes can be useful to establish a conservation strategy for freshwater ecosystems.

GIS, modelling and remote sensing capabilities for managing water supply are needed for the entire region. The program should focus on leading a proposal for a regional strategy for conservation of riparian corridors based on holistic reasoning. The strategy should start with an agreement between the countries that share the basins to develop:

1. A network of modular riparian landscape nodes appropriately selected for the maintenance of heterogeneity through the maintenance of riparian regional, and landscape diversity, of the lowlands.
2. The inclusion of a range of pristine river basins representative of different geological regions.
3. Establishing mechanisms for the integration of local human populations in conservation and management activities for sustainability of the riparian network.

Following riparian ecohydrological principles, the overall policy of the strategy needs to make the environmental management of riparian ecosystem biodiversity an important and integrated part of the social and economic activities of the local people. It is only possible to achieve this with an understanding of the social context of the various inhabitants that directly benefit from, or are negatively impacted by, the dynamics and commodities associated with the physical and biological riparian corridor system.

To summarize, the Guiana Shield Initiative should encourage countries in the region to: (1) promote "water reserves" to ensure that riparian ecosystems receive the quantity, quality, and timing of flows needed to support their ecological functions and their services to society; (2) legally recognize the surface and renewable ground waters as a single coupled resource; (3) improve monitoring, assessment, and forecasting of water quantity and quality for allocating water resources among competition needs; (4) protect critical habitats such as groundwater recharge zones, riparian landscapes or entire watersheds; (5) conduct a realistic valuation of water and freshwater ecosystem services; (6) create stronger economic incentives for efficient water use in all sectors of the economy; (7) continue the improvement in eliminating point and non-point sources of pollution; (8) develop a well-coordinated regional plan for managing the diverse and growing pressures of negative land use that impact freshwater systems and to establish goals and research priorities for cross-boundary river basins; (9) support the governments of different countries in the Guiana Shield with implementation of the GSHySPB to promote adequate water management systems and equitable payment schemes for water resources.

REFERENCES

Bravo, L. 2002. *Climatology White Paper*. Guayana Shield Conservation Priority Setting Workshop 5-9 April, 2002. Physical Geography Group, Paramaribo. Url: http://www.guayanashield.org/ev.php?URL_ID=1497&URL_DO=DO_TOPIC&URL_SECTION=201&reload=1066418303

Bucher, E., G. Castro and V. Floris. 1997. Freshwater ecosystem conservation: towards a comprehensive water resources management strategy. In: *Technical Report No. ENV-114*. Inter-American Development Bank, Washington D.C., p. 38.

Costanza, R., R. d'Arge, R. de Groot, S. Farber, M. Grasso, B. Hannon, K. Limburg, S. Naeem, R. V. O'Neill, J. Paruelo, R. G. Raskin, P. Sutton, and M. van den Belt. 1997. The value of the world's ecosystem services and natural capital. *Nature* 387;6630:253–260.

De Groot R., M. Wilson, and R. Boumas. 2002. A typology for the classification, description and valuation of ecosystem functions, good and services. *Ecological Economics* 41:393-408.

FAO 2003. Review of world water resources by country. *Water Reports No. 23.* Rome.

Huber, O. & M. Foster (eds.). 2003. *Conservation priorities for the Guayana Shield: 2002 Consensus*. Conservation International – CABS, Netherlands Committee for IUCN/Guiana Shield Initiative, UNDP, Washington DC. p. 99 (English, Portuguese), p 101 (Dutch, Spanish).

Kondolf, G. 1997. Hungry water: effects of dams and gravel mining on river channels. *Environmental Management* 21(4):533-551.

Lee, T., J-L. Oliver, P-F. Teniere-Bouchot, L. Travers and F. Valiron. 2001. Economic and financial aspects. In: C. Maksimovic and J. Tejada-Guilbert (eds.). *Frontiers in urban water management*. IWA Publishing UNESCO, London. pp. 313-343.

Lundqvist, J. and A. Turton. 2001. Social, institutional and regulatory issues. In: C. Maksimovic and J. Tejada-Guilbert (eds.). *Frontiers in urban water management: deadlock or hope*. IWA Publishing UNESCO, London. pp. 344-398.

Malavasi, E. and J. Kellenberg. 2002. *Program of payments for ecological services in Costa Rica*. Url: *http://epp.gsu.edu/pferraro/special/lr_ortiz_kellenberg_ext.pdf*

Miranda, M., A. Blanco-Uribe, L. Hernández, J.G. Ochoa, E. Yerena. 1998. *All what glitters is not gold. Balancing conservation and development in Venezuelan frontiers forests*. World Resource Institute Publications, Washington DC.

Monzón, M. 2003. *Propuesta de plan de vigilancia y control de la calidad de agua para el Embalse Macagua*. MSc Thesis in Environmental Sciences. UNEG, Puerto Ordaz.

Morel, J. and J. Corredor. 2001. Photomineralization of fluorescent dissolved organic matter in the Orinoco River plume: estimation of ammonium release. In: *Journal of Geophysical Research* 106:16807-16813.

Mueller, B., M. Grimmig and C. Aicher. 1998. *State resource politics in the realm of crisis: the Forest Reserve Imataca under dispute*. SEFUT working paper No. 4, Freiburg.

Pagiola, S, A. Arcenas, and G. Platais. 2003. *Ensuring that the Poor Benefit from Payments for Environmental Services*. Environment Department. World Bank. Workshop on Reconciling Rural Poverty Reduction and Resource Conservation: Identifying Relationships and Remedies. Cornell University, Ithaca, New York, May 2–3, 2003.

Queiroz, J., J. Stutaro, and P. Riedel. 2001. *Geostatistic mapping of arsenic, manganese and iron contamination risk in the port of Santana, Amapa, Brazil*. 2001 Annual Conference of International Association for Mathematical Geology, Cancun Mexico, Sept. 6-12, 2001. p. 16.

Richey, J., C. Nobre, C. Deser. 1989. Amazon river discharge and climate variability: 1903 to 1985. *Science* 246:101-103.

Rodriguez, I. 2001. *Caracterización Bacteriológica y su influencia en la calidad sanitaria del agua del Embalse Macagua II*. MSc Thesis in Environmental Sciences. UNEG, Puerto Ordaz.

Rosales J., O. Vargas and M. Rodriguez. 2002. *Hydrography and ecohydrology of the Guiana Shield Ecoregion*. White-paper and maps presented at the Guayana Shield Conservation Priority Setting Workshop 5-9 April, 2002, Paramaribo.

Tejada, J. and C. Maksimovic. 2001. Outlook for the 21st century. In: C. Maksimovic and J. Tejada-Guilbert (eds.). *Frontiers in urban water management: deadlock or hope*. IWA Publishing UNESCO, London, pp. 399-409.

UNEP. 2000. *Global Environment Outlook Past, present and future perspectives*. Earthscan Publications Ltd, London.

UNESCO. 2002. Water availability per person per year. In: *World water development report*. Url: *http://www.unesco.org/bpi/wwdr/WWDR_chart1_eng.pdf*

Weibezahn, F. 1990. Hidroquímica y sólidos suspendidos en el alto y medio Orinoco. In: F. Weibezahn, H. Alvarez, and W. Jr. Lewis (eds.) *The Orinoco River as an Ecosystem* Universidad Simón Bolívar, Venezuela, pp.150-210.

World Bank. 1996. Indicators 2nd edition. *Water and wastewater utilities*. TWUWS. International Bank for Reconstruction and development. The World Bank, Washington DC.

Zedler, J. 2003. Wetlands at your service: reducing impacts of agriculture at the watershed scale. In: *Front. Ecol. Environ.* 1:65-72.