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WATER RESOURCES MANAGEMENT IN THE AMAZON BASIN ISSUES, CHALLENGES, AND OPPORTUNITIES

Introduction

The great rivers of the world have always been axes of human activities, playing essential roles in the prosperous development of Europe, North America, and certain other regions. These great rivers acted as avenues of transport and sources of life-giving waters for irrigation, industry, and more individual human uses. Some of humanity's earliest and most impressive engineering accomplishments stemmed from our compulsion to exert greater control over large rivers, and today the flows of many large rivers are fully under the control of water regulating agencies. This long history of intense human exploitation has severely transformed many great rivers, leaving them lackluster and only partial versions of their original forms. Consequently, research needs in relation to these rivers tend to focus on restoration of degraded systems and implementation of stronger controls to maintain a minimum set of ecosystem functions. One might say that these rivers are on "life support."

In light of the distressing condition that characterizes so many of Earth's great rivers, it is remarkable to consider that Earth's largest river system, the Amazon, remains in an amazingly pristine condition. Owing to a long list of fortuitous circumstances, not least of which is the torrid climate and virtual remoteness of the basin, the Amazon survived the industrial age and more recent development surges relatively unscathed. No dams interrupt 6000 km of flow along the river's mainstem, and only a very few major dams occur in other parts of the basin. No projects to channelize the river have occurred, and floodwaters still flow freely each year between the river and its nearly 1 million km2 floodplain. Fisheries are generally intact, with the exception of certain prized species in the vicinity of the basin's major cities. Similarly, the quality of the river waters remain excellent. Levels of oxygen remain high, while levels of heavy metals and organic matter remain low. Most importantly, the river's own set of self-cleansing mechanisms is intact.

The issue in the Amazon is not how to rescue or restore the system following a history of overuse and neglect. It is instead how to protect the system as processes of development proceed. This situation constitutes a rare opportunity in the sense that we may apply the know-how accumulated through failed policies in other rivers to develop the Amazon in a more sustainable fashion. It is as though we could go back in time and develop Europe or North America's major rivers again, knowing what we know today. What would we have done differently? What shall we do today in the Amazon?

Development of water resources in the Amazon river system does present a particular set of challenges, linked to the same set of characteristics that account for the preservation of the river. The Amazon basin is exceedingly remote and controlled by countries with limited capital and individual development priorities. Heavily engineered and capital intensive solutions are impractical today, and will likely remain impractical for decades to come. With the exception of potential new dams and reservoirs for hydroelectric generation, and infrastructures in a few large cities, technologies of water extraction, use, and discharge must be kept simple and appropriate to the training and economic situation of people from the region. Perhaps the best tools for maintaining water quality within the basin are natural water purification systems such as riparian zones, fringing wetlands, and floodplains. Preservation of these existing "water treatment" systems will offset, and make unnecessary more expense engineering solutions.

This paper will elaborate more on these topics, after first providing an overview of the environmental and socio-economic characteristics of the region drained by the Amazon. My message is one of optimism. By applying the 20-20 hindsight gained from Europe and North America, I believe many past errors may be avoided in the Amazon.

‘Characteristics of the Amazon Basin and River System

Natural setting

The Amazon Basin covers an area in excess of 6 million km2, which is divided between the countries of Brazil (66%), Peru (15%), Bolivia (12%), Colombia (5%), Ecuador (2%), and a small section of Venezuela (<1%). The basin consists of an east-west trending lowland surrounded by highlands. To the north and south, these highlands are formed by the Guyana and Brazilian Pre-cambrian shields, respectively. To the west, the Andean cordillera stands as a formidable barrier isolating the Amazon basin from the Pacific basin. The Andes were formed by a long series of orogenic events extending back to the Triassic Period, some 200 million years ago. However, the river system we see today in the Amazon is believed to have formed approximately 24 million years ago in the Miocene Epoch (Hoorn 1995), when the final gap in the Andes closed and the Amazon basin was permanently cutoff from the Pacific.

During the intervening 20 million years, the Amazon has been a site of unparalleled biological productivity and diversification. Favorable conditions of moisture and warmth punctuated by varied and dramatic phases of large-scale disturbance have produced a landscape containing as many as one third of Earth’s plant and animal species, and much more when projected numbers of insect species are considered (Erwin 1988). Terrestrial ecosystems of the Amazon range from savannas to rain forest to montane forest to alpine tundra distributed according to climatic variables in the basin.

The Amazon River has its source on the northern flank of Nevado Mismi in Southern Central Peru. From this beginning at 5100 meters above sea level, the river flows northward, dropping precipitously through the Apurimac valley. Along its course the river undergoes 10 name changes, becoming the Amazonas below the confluence of the Negro and Solimxes Rivers near the central Amazonian city of Manaus (Figure 1). At its mouth, the river’s mean discharge is greate than 200,000 m^3/s, or roughly 20% of Earth’s total freshwater runoff. Of this discharge, roughly 50% originates from the headwater countries of the basin outside of Brazil.

The disproportionately large volume of runoff of the non-Brazilian countries is due in part to orographic effects the eastern flank of the Andes cordillera. While annual precipitation across most of the eastern (Brazilian) Amazon ranges just above 2000 mm, annual precipitation in the northern and southern Peru and Ecuador exceed 3000 mm, and in more localized sites may exceed 5000 mm. Likewise there is an area of annual rainfall in excess of 3000 mm in the Colombian and NW Brazilian Amazon (IDEAM 1999). Precipitation generally becomes more seasonal to the East, where the dry season may extend as many as 5 months, creating seasonal water deficits (Nimer 1991). Temperatures across the lowland portions of the basin are quite stable seasonally and range between 24 and 26°C(ANEEL 1999). Temperatures in the mountainous portion of the basin, of course drop with increasing elevation, ultimately falling below zero on the highest snow-capped mountains.

Aquatic ecosystems of the Amazon range from small alpine streams to the enormous main Amazon channel and floodplain. Along the 2010 km reach of the mainstem Amazon river as it crosses Brazil, channel width ranges between 2 and 4 km, with average depths of 10 to 20 m (Mertes et al. 1996, Dunne et al. 1998). Adjoining this main channel is *a* floodplain extending over some 300,000 km2 (Junk 1997). Over the entire Amazon basin, floodplains are believed to occupy considerably more than 1 million km2 (Junk 1997). Approximately 1,700 Amazon fish species have been described so far, and estimates are that the total fish species diversity will approach 3000 (Goulding et al. 1996). The river also contains many charismatic species such as the pink dolphin (Inia geoffrensis), piranha (Subfamily Serrasalminae), and giant river turtle (Podocnemis expansa).

Socioeconomic Setting

Humans have been an integral part of the Amazon system for at least 10,000 years, when hunters and gatherers moved into the region, presumably across the Isthmus of Panama (Olsen Bruhns 1994). With time, many great cultures rose and fell in the region, culminating with the Inca Empire in the headwater regions and the Omagua and Marajoara Chiefdoms of the lowland floodplains. The lowland floodplain cultures developed especially close ties to resources and seasonal dynamics of the river system. At the time of the Spanish and Portuguese arrival, more than 8 million people are believed to have lived in the lowland forests of the Amazon (Denevan 1976). This number dropped to a low of less than 300,000 in the following centuries, as European diseases decimated the native population. Populations remained exceedingly low in the region throughout the centuries due to the difficult climate (by European standards) and extreme remoteness of the region's interior.

Today, the total human population of the Amazon basin is near 23 million (Table 1), about half of which live in Brazil. Only two cities in the basin. Belem and Manaus, have populations in excess of 1 million, and as much as 60% of the population lives in rural settings. Population growth in the basin accelerated greatly during the second half of this century, spurred on by governmental road building and other incentive programs financed by the World Bank. In Brazil, this was carried out as part of the Program for National Integration, which sought to bring the Amazon into the national economy (Foresta 1991). In Peru, similar goals were pursued through a set of Special Development Projects spread across that countries Amazon region ((Bedoya and Klein 1996). Additional coordination among the Andean nations led to the construction of the Marginal Highway, which stretches across the entire north-south extent of the basin.

Table 1

Amazon population by country.

Country	Population	(Year) Source
Brazil	11,290,573	(1996) Inst. Brasileiro de Geografia e Estatisticas
Ecuador	**576,746**	(1998) Ecodesarrollo de la Region Amazonica Ecuatoriana
Colombia	712,300	(1993) estimated DANE
Peru	6,798,322	(1996) Inst. Nac. de Estatнsticas y Informaciyn
Bolivia	3,534,008	(1992) Inst. Nac. de Estatнsticas
TOTAL	22,911,949	

Economic activities in the Amazon range from small subsistence farming to massive oil and mineral extraction projects. By far the most widespread activity is farming and ranching, which accounts for the greatest part of the 532,086 km2 deforested in the Brazilian Amazon between 1978 and 1997. This type of deforestation is exacerbated by unsustainable farming and ranching techniques in the region, which lead to high rates of intraregional migrations (Ozyrio de Almeida and Campari 1995). Petroleum extraction is increasingly important in the western part of the basin. In fact, Ecuador produces nearly 400,000 barrels of oil per day, and Amazon oil is that country's most important export. Peru, with a daily production rate of nearly 200,000 barrels of oil, is also carrying out an ambitious program to further develop this resource. Various forms of mining are underway throughout the basin. Large iron, bauxite, and gold mines have been excavated in the eastern lowlands, while copper, zinc, and lead top the list of metals mined in the mountainous west.

Water Use in the Amazon Basin

Rivers serve most of the water needs of the Amazon's native and colonial inhabitants. By far the most widespread use across the basin is water supply for domestic uses, although greater than 60% of the basin's inhabitants have no running water in their homes. In fact, when last examined in the early 1980s, only 20 % of inhabitants in the Peruvian Amazon had water service (INRENA 1996). Given the increased immigration of homesteaders into the region during the past 20 years this percentage is likely to be equivalent or less today. In Ecuador, only 51% of rural inhabitants nationwide have water service (CNRH 1997), and the number for the Amazon portion of that country is likely to be considerably less. An important consideration is that river water is generally drunk with no form of treatment, leaving the population susceptible to many forms of waterborne illnesses. As an example of officially tallied water use numbers, the Peruvian National Institute for Natural Resources (INRENA 1996) has calculated that water use in the Peruvian Amazon amounts to 9.3 million m^3/yr, of which 74% is directed to non-consumptive uses and 26% is directed to consumptive uses. Agriculture is calculated to account for 84% of the consumptive use, followed by 10% for human consumption, 2% for mining, 2% for industry, and 2% for animal husbandry. Given that the population of the Peruvian Amazon is approximately 6.7 million, the 9.3 million m3/yr presented above would amount to only 1.4 m3 per person per year. Clearly a large part of the region's water use is unregistered.

Water use in the Amazon also applies to the supply of fish, shrimp, and a variety of aquatic plants that are central to the diet of communities in the Amazon. Between 30,000 and 50,000 tons of fish are sold in the fish markets of Manaus each year, including more than 200 different species (Goulding et al. 1996). In the Peruvian Amazon, annual per capita fish consumption has been calculated at 36 kg in cities and 101 kg in rural communities. Few studies have quantified the dependence of the Amazon diet on rivers,

but at least one study conducted in the Peruvian Amazon found that fish account for 62% of the animal protein consumed by rural inhabitants (Pierret and Dourojeanni 1967). Furthermore, rivers and their floodplains and riparian forests provide important habitat for a large number of terrestrial animals that are hunted.

The steep gradients of Amazon rivers in the Andes make them enormous potential sources of hydroelectric power for industry and households, although no specific numbers are available to quantify this use. In the lowland Amazon, Brazil has constructed five large hydroelectric projects (Table 2), with a total combined capacity of near 4,500 MW. By far the largest of these projects is Tucuruн, which accounts for 88% of the total capacity. Tururuн reservoir covers an area of 2,400 km2. These reservoirs have been the object of considerable environmental discord in the region due to the large areas flooded and the method by which the flooding occurred. Rivers are also prime avenues of transport in the Amazon, much of which remains roadless. Products and people move by river. In 1992-93, a total of 1118 thousand metric tons of cargo were transported through the Peruvian ports of Iquitos, Pucallpa, and Yurimaguas. Cargo amounts in Manaus and Belem are likely much greater.

Table 2

Major hydroelectric dams in the Brazilian Amazon.

Dam	River	Date Operational	Capacity (MW)	Reservoir Area (km*)
Tucuruн	Tocantins	1984	4,000	2,400
Balbina	Uatumr	1989	250	2,300
Samuel	Jamari	1989	216	560
Curuб-Una	Curuб-Una	1977	30	78
Paredro	Araguari	1975	40	23
TOTALS			2,536	5,361

Source: Smith et al. (1995)

Finally, an important "use" of water in the Amazon may be ascribed to supporting the natural ecosystems of the region. Colombia, Ecuador, and Peru rank among the 10 most biodiverse countries on earth. Explanations for the region's biological richness have been linked to its climatic and fluvio-geomorphological diversity. In particular, the extreme spatial and temporal heterogeneity of the large floodplains of the lowland Andean Amazon rivers is hypothesized to have generated ideal conditions for the diversification of species. Overall, the Andean Amazon region contains a magnificent collection of interconnected aquatic ecosystems, beginning with alpine marshes and glacial outwash plains and extending to lowland swamps, oxbow lakes, and floodplains.

Present Water Management Policies in the Amazon

No broadly recognized water management policies have been formulated specifically for the Amazon basin. Within each of the five countries composing the basin, national water policies are aligned with international norms put forth in meetings such as the 1992 International Conference for Water and the Environment, held in Dublin, and the subsequent 1992 United Nations Conference on

Environment and Development (UNCED), held in Rio de Janeiro. In Brazil, these international norms have been incorporated into a new national water law (1997 Lei 9.433), which organizes water management activities according to eight major watersheds. The central decision making body within each basin is the Hydrographic Basin Committee (HBC), which serves as a forum to discuss and assess the technical, economical, and social viability of all proposed water related activities. Among the specific responsibilities of the HBCs are to 1) classify certain water bodies for certain predominant uses, 2) establish levels of quality and availability necessary for sustainability, 3) propose guidelines for the granting and licensing of water resources, 4) propose guidelines for costs of water use, 5) approve water management plans, 6) establish the compensation of municipalities, 7) coordinate plans within subbasins, and 8) settle conflicts that arise over water use in the basin. Furthermore, each basin is to formulate its own Master Plan to guide water management decisions and assist in the resolution of conflicts. HBCs have been formed for certain of Brazil's watersheds, and several preliminary Master Plans have been formulated, but until now neither of these activities have been realized in the Amazon (SRH 1999).

Ecuador, with financing from the World Bank, has recently completed an ambitious Strategy for the Integrated Management of Hydrological Resources in Ecuador (CNRH 1998). This strategy is based on five fundamental elements: 1) decentralize the government's role in water resources management and place more decision making authority in the hands of water users, 2) integrate water resources management at the level of hydrographic watersheds, 3) develop mechanisms of self financing for hydraulic works in three subsectors - potable water and health / irrigation and drainage / hydroelectricity, 4) control water contamination through monitoring, pollution prevention mechanisms, and the rehabilitation of surface and subsurface aquatic systems, and 5) develop management policies and instruments to control floods and the security of hydraulic works. This strategy is to be implemented through a series of short, medium, and long term actions. A commendable attribute of this strategy is its attention to environmental protection. Specific objectives are laid out to guard against the detrimental effects on water resources that result from deforestation, contamination, and erosion.

Similarly comprehensive and progressive text characterizes the official water management policies of the remaining countries of Peru, Colombia, and Bolivia. However, the reality of water management activities in the Amazon basin generally bears little similarity to the official policies.

Water Problems in the Amazon

Water scarcity is not a problem in the Amazon river basin. In the Brazilian Amazon, for example, water availability is calculated at more than 600,000 m^3/person/yr (SRH 1999). In the Peruvian Amazon, water availability is calculated at 240,000 m3/person/yr (INRENA 1996). Water is abundant and large rivers joint tropical rainforest as the two most distinguishing features of the basin.

Water contamination is also not a widespread problem in the Amazon, but there are several site-specific problem areas. In the headwater portions of the basin there are areas of potentially severe heavy metal pollution from mining activities. Cadmium, copper, lead, and zinc contaminate the Mantaro river of Peru. Copper is also a problem to the north in the Huallaga river (INRENA 1996). Mining related contamination is rather serious in the Bolivian Amazon, where there is a precedent for catastrophic mining related contamination. On August 29, 1996, a dyke ruptured at the Porco mine and released 235,000 tons of toxic tailing slurries (including arsenic, cyanide, lead, and zinc) into the Agua Castilla river (Garcia-Guinea and Harffy 1998). As many as three children are believed to have died of arsenic poisoning as a result of drinking water contaminated by the slurry. Although the Agua Castilla river ultimately drains into the Paraguay river and not the Amazon, the potential for a similar accident in the nearby Amazon headwaters is real.

An issue that has gained considerable press in recent years is mercury contamination linked to gold mining in the lowland Amazon. Near the end of the 1980's it is estimated that as much as 60 metric tons of mercury were being released annually into surface waters of the Brazilian Amazon, while an additional 70 t were released to the atmosphere (Pfeiffer and Lacerda 1988). It also appears that Amazon soils contain naturally high concentrations of mercury, which is mobilized into the river system by erosion (Roulet et al. 1996). Although no deaths or severe illnesses have yet been attributed to mercury pollution, the metal has been found to be accumulating in fish and hair from humans in the region.

Water contamination linked to petroleum exploration and extraction has been widely reported in Ecuador, Peru, and Colombia. In Colombia and Peru, severe contamination has occurred where guerrilla groups have dynamited oil pipelines. Guerrilla attacks have not been an issue in Ecuador, but at least two pipeline ruptures have been attributed to an earthquake and massive landslide (Hicks et al. 1990). Discharges of brine waters into rivers is another serious contamination issue linked to petroleum activities. In 1990, it is estimated that 113 million barrels of process waters were discharged into surface waters of Peru (INRENA 1996).

Severe contamination has been measured in waters impacted by major urban areas in the Amazon. Alarmingly high bacterial concentrations occur in the La Paz river as it exits the city of La Paz and extending more than 40 km downstream (Ohno et al. 1997). This bacterial contamination has been linked to a high incidence of diarrheal disease in the city of La Paz The Oropouche virus has been detected near the city of Iquitos in the lowland Amazon of Peru and was found to be transmitted to the population of the city and surrounding areas (Watts et al. 1997). Streams flowing through the urban areas of Manaus, Brazil, have been severely impacted by destruction of streamside habitats and uncontrolled discharge of industrial and human waste into stream channels (Silva and Silva 1993). High biochemical oxygen demand (BOD) characterize the streams, and unacceptably high levels of zinc, chromium, cadmium, and copper have been found in the fish. Consequently, the diversity of fish in the streams has been reduced by approximately 70% (Silva 1992).

Widespread deforestation in the Amazon basin has produced significant changes in the quality and quantity of water in many streams, but as yet no significant impacts have been confirmed in the largest tributaries of the region. In the Brazilian Amazon, Williams and Melack (1997) measured increased stormflow sediment loads in the deforested sections of the Braao do Mota stream. These authors also documented increased leaching of nutrients and other ions to the stream in deforested areas. Similar increases in nutrient leaching following deforestation were documented by Uhl and Jordan (1984) in the small area of Venezuela that drains into the Amazon.

Finally, decreasing fish biodiversity and yields of important fisheries can be viewed as a water problem to ‘the extent that alteration and destruction of aquatic habitat is to blame. The construction of five major dams in the lowland Amazon has blocked migration pathways of certain species. Goulding et al. (1996) point out that fish biodiversity above and below the Tucuruн dam has decreases by approximately 50%. There was also a 65% reduction in commercial fish and shrimp catches downstream of the dam. This decrease in biomass is more than compensated for, however, by increased biomass in the reservoir. Along the large lowland rivers, the most important fish nursery areas are on floodplains. These floodplains also contain excellent soils and are therefore heavily exploited by local populations. As floodplain forests are destroyed to make room for agriculture, fish nursery habitats are also destroyed. The consequences of this habitat destruction have not yet been quantified, but continued destruction will undoubtedly result in harmful impacts to fish biodiversity and biomass.

Water management challenges

The humid tropics, and the Amazon in particular, present a distinct set of challenges for water management. First, a rather major shift in manager mindset is required. On a global basis, water management revolves around water withdrawals from rivers, lakes, and aquifers. Of these withdrawals, 69% goes to agriculture (World Resources 1998). In the countries composing the Amazon, agricultural withdrawals are also the main theme in water management accounting for 85% of withdrawals in Bolivia, 59% in Brazil, 43% in Colombia, 90% in Ecuador, and 72% in Peru. Management, in this context, involves an engineering system capable of extracting the water and a political system capable of distributing it equitably. Furthermore, in a global sense, groundwater generally plays a central role in providing for domestic water needs due to often insufficient supplies and poor quality of surface waters.

The Amazon case is distinct. Today, extractive uses of water are significantly reduced because of a general absence of irrigation. Similarly, with the exception of isolated locations, industrial uses are also generally low. Hydropower has enormous potential in the region, but it too is relatively undemanding of water resources in the region. By far the most widespread issue in water resources management in the region today is the maintenance of water quality to benefit the health of the population and to maintain stocks of fish, shrimp, and other aquatic organisms on which the population depends.

Development is sure to be a major focus in the region over the coming decades, but it is unlikely to proceed evenly. The general lack of basic water-related infrastructure in the region makes the population highly susceptible to negative impacts of large development programs. For example, communities without water treatment facilities are acutely sensitive to contamination from upstream industrial activities such as petroleum exploration. Similarly, communities that are predominantly self sufficient and dependent on fishing in local waters will be vulnerable to malnutrition in the event that some upstream dam were to reduce fish biomass. Thus, a core set of priorities to protect water quality and fish habitats must be established in the Amazon now.

Any traditional water management program in the Amazon will face severe financial challenges. All of the countries composing the basin are experiencing grave economical situations and acute, higher priority crises in other parts of their countries. Colombia is in the midst of a disabling civil war. In fact, large portions of the Colombian Amazon are under the control of guerrillas. Bolivia is the second poorest country in South America, with a per capita gross national product (GNP) of only U$800. Ecuador is only slightly better off with a per capita GNP of U$1390. Brazil and Peru may be financially stronger, but severe poverty in the more densely populated portions of their countries commands the bulk of their development funds. Thus, it is unrealistic to expect that any comprehensive and integrated development program will be economically viable in the Amazon during the foreseeable future. Similarly, international lending organizations will be unable to independently finance such a large scale enterprise.

These financial limitations are accentuated when one considers the considerable logistical difficulties that would accompany any major engineering projects. Most of the Amazon remains roadless, making it necessary to transport supplies by air or by river. The electrical power network is similarly isolated. In addition to these limitations, the project manager would find a small to non-existent pool of skilled laborers, forcing the importation of large numbers of workers. Once constructed, installations are subject to accelerated decomposition processes brought by the region's intense precipitation and consistently high temperatures. Maintenance is a continuous and expensive requirement.

Water management opportunities

In spite of the water problems listed above and the considerable limitations to development, there is reason to be optimistic about the course of water resources management and development in the Amazon. This optimism stems from the natural integrity that still characterizes the river basin and the utility of these ecosystem components in regulating water quality. Intelligent use of these natural features, combined with strong community-based water management and protection of critical fish habitat, may provide an effective background system of water resource protection while more sporadic, engineering-intensive develop proceeds.

Research throughout Europe and North America over the past two decades has revealed that some of the most efficient means of water quality control lie in the use of natural ecosystem components. Riparian vegetation and soils have been shown to strip excess nutrients from subsurface runoff and to diminish the sediment concentration of overland flow. Wetlands and floodplains have revealed similar water cleansing properties, whether by sedimentation of particulates, neutralization of acid mine drainage, or stripping of excess nutrients. More recent research has shown how exchange with hyporheic waters surrounding the river channel can similarly strip undesired elements and compounds from river water. Finally, intact stream and river channels have been shown to contain an abundance of small-scale environments suitable for anaerobic processes that denitrify excess nitrate or reduce and precipitate heavy metals. These natural river ecosystem components, which served to control water quality in pristine systems, have sadly been lost from or diminished in many rivers of the developed world. Agricultural fields are cleared to the stream edge, wetlands are drained, floodplains are disconnected from river channels by levees, and in-channel structural heterogeneity is reduced by channel cleaning. Thus, countries in the North must now labor and invest to restore, where possible, these once natural components of the system.

In the Amazon, these natural features need not be restored because they remain mostly intact, along with approximately 85% of the original forest. While only a small amount of research has been conducted in the region, the results consistently demonstrate that riparian vegetation, wetlands, and floodplains possess the same capabilities of water cleansing as has been documented in the north. Unfortunately, no investigations have yet addressed processes in the hyporheic zones of the region's rivers, but one may assume that they also possess qualities similar to temperate rivers. Work by McClain et al. (1994) in the central Amazon basin of Brazil demonstrated that riparian vegetation and soils were capable of stripping 90% or more of incoming nitrate from adjoining uplands. Williams et al. (1997) showed that this capability was effectively lost with the removal of riparian vegetation. Similarly, Williams and Melack (1997) noted that riparian zones effectively retained sediments in water running off deforested uplands. Engle and Melack (1993) further demonstrated that both phosphorus and sediments were effectively stripped from river water as it exited the river channel and moved across the floodplain of the mainstem Amazon river. There is, therefore, mounting evidence that existing components of the Amazon river system may be used to manage water quality with essentially no external investment nor costly maintenance.

Protection and management of water resources in the Amazon basin will rely strongly on the participation of local people. Unlike developed parts of the world where the responsibility for water delivery, waste disposal, critical area protection, and flood control lies outside the control of end users, in the Amazon it is the end user that exercises essentially all control over the resource. This is of course not the case in the small number of cities and large towns that do have water supply and waste disposal infrastructures, but it is the case for the larger proportion of the population that lives in rural areas. Governments of the region should empower local people, through training programs and organizational workshops, to form watershed committees to plan and oversee programs in water resource management. Furthermore the governments should assign some protection (either as a national park or other protective designation) to areas critical for water supply, fish nurseries, water quality protection, and other unique aquatic systems. Budgets to finance the policing of these protected areas is unlikely to be available, thus local people must be encouraged, through culturally sensitive training and education programs, to police the areas themselves. Systems of water purification prior to drinking and proper disposal of human and other wastes must be devised that are appropriate for the financial means of municipal governments and local people. This would include systems constructed of locally available materials and not requiring significant outside funding (which is unlikely to be available and even more unlikely to be sustained). Such grassroots efforts are the only practical means of developing widespread water management programs in the Amazon.

An effort in line with these recommendations is currently being mobilized in the 27,000 km2 Pachitea river basin of central Peru. The main components of the project are the following:

1. Assess the current status of aquatic resources, adjoining land systems, and their use.
2. Assess the socio-economic and institutional constraints on current activities impacting aquatic resources.
3. Conduct a community workshop program to accomplish the following objectives
   - Present results of initial assessments (education)
   - Establish prioritized community goals for aquatic resource protection and management.
   - Devise community-based strategy to achieve goals using appropriate technologies.
4. Conduct a regional workshop of community leaders, government officials, and NGO representatives to integrate community plans, governmental plans, and others into a coherent regional plan.
5. Community implementation of plan.

It is hoped that this project may serve as a model for application in other areas. Its critical features are that it promotes a system requiring minimal external funding and ultimately looks to the local people for its application.

With a ubiquitous system of community-based water management, the Amazon region will acquire a level of self-sustained resistance against the inevitable negative impacts of a more engineering and capital-intensive development activities. This plan will also have set aside the region's most critical and sensitive areas so that they are left undeveloped and able to serve their important natural functions.

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