Causal chain analysis of the Madeira River Basin

This section aims to identify the root causes of the environmental and socio-economic impacts resulting from those issues and concerns that were prioritised during the assessment, so that appropriate policy interventions can be developed and focused where they will yield the greatest benefits for the region. In order to achieve this aim, the analysis involves a step-by-step process that identifies the most important causal links between the environmental and socio-economic impacts, their immediate causes, the human activities and economic sectors responsible and, finally, the root causes that determine the behaviour of those sectors. The GIWA Causal chain analysis also recognises that, within each region, there is often enormous variation in capacity and great social, cultural, political and environmental diversity. In order to ensure that the final outcomes of the GIWA are viable options for future remediation, the Causal chain analyses of the GIWA adopt relatively simple and practical analytical models and focus on specific sites within the region. For further details, please refer to the chapter describing the GIWA methodology.

Introduction

The Amazon Basin is the largest river basin on the planet and also one of the least understood. Its natural areas are still quite well preserved and relatively uninhabited. With the exception of Bolivia, the majority of the population of each of the seven countries that share the Amazon Basin (Brazil, Bolivia, Peru, Colombia, Ecuador, Venezuela and Guyana) is located in other regions of these countries outside the Basin. Within the Amazon Basin, only five cities possess more than 1 million inhabitants, two located in Brazil, two in Bolivia and one in Peru. Three more cities have populations that range between 300,000 and 1 million inhabitants, two in Peru and one in Brazil (Goulding et al. 2003).

The reduced number of urban centres in the Amazon Basin has helped preserve the ecological processes within the Basin. Unfortunately however, the relatively low population within the Amazon Basin also means that the level of attention that central governments dedicate to the area is disproportional to its size or its environmental importance. As a consequence, local administrations do not have sufficient capacity to implement ecologically and economically sustainable management due to the shortage of funds from federal budgets and lack of basic information or statistics. Although this situation might prevail in all Amazon countries, the specific situation varies among countries sharing the Basin and also between different regions within a single country.

The GIWA Causal chain analysis aims to identify the root causes that threaten the maintenance of the aquatic ecological processes upon which human survival depends. Considering the dimension and heterogeneity of the Amazon Basin, this analysis was not feasible for the entire region. Table 1 show the division of catchments within the Amazon Basin and their transboundary classification (national or international). The Madeira River has the largest catchment within the Amazon Basin and is the third biggest river in South America, surpassed only by the Amazon and Paraná rivers. Among the international basins of the Amazon (Caquetá-Japurá, Juruá, Madeira, Marañón, Napo, Nebro, Purus and Putumayo-Içá) (Figure 3, Table 1), the Madeira River is the most populated and possesses serious environmental problems. More than half of the population of Bolivia, including the capital La Paz, are located in the Madeira Basin (Table 4). Deforestation and mining activities are environmental concerns, mainly in Rondônia State, Brazil, as well as in the Department of Madre de Dios, Peru, (Figure 9) (Núñez-Barriga & Castañeda-Hurtado 1999). Owing to its size and socio-economic importance, the Madeira Basin was the focus of the causal chain analysis within the Amazon Basin.
System description

Geographic and demographic settings

The Madeira River is the largest tributary of the Amazonas River extending 3,352 km and possessing the largest drainage area (1,380,000 km²), the greatest flow (6,700 km³/year), sediment discharges (667.4 million tonnes per year), and oscillations in water level (21.8 m). The Madeira Basin represents approximately one fifth of the total drainage area of the Amazon Basin. Fifty percent of the Madeira Basin is located in Bolivia, 40% in Brazil and 10% in Peru (Carvalho & Cunha 1998, Dunne et al. 1998, Goulding et al. 2003) and, within these countries, it drains 14 different states.

The headwaters of the Madeira River are located near Cochabamba, in the upper Mamoré River, about 4,600 km away from the Atlantic Ocean. Four tributaries of the Madeira River are responsible for more than 60% of all freshwater discharge: Mamoré, Guaporé-Itenez, Beni and Madre de Dios. The Mamoré and Beni rivers have their headwaters in the Bolivian Andes, while the Madre de Dios originates in the Peruvian Andes and the Guaporé-Itenez River stems from the Brazilian Shield. These four rivers are navigable from below the foothills of the Andes until their confluence, near Guajará-Mirim. However, between Guajará-Mirim and Porto Velho, these rivers are united along a sequence of waterfalls, where navigation is impossible. Below the San Antonio Fall, 1,070 km from the mouth, vessels may navigate during the high water period. Otherwise, in the dry months between June and November, these reaches are only navigable by craft drawing less that 2 m of water (Goulding et al. 2003).

The Madeira Basin supports a significant Bolivian population, but it is sparsely inhabited in Peru and in Brazil. More than 50% of the Bolivian population is located in the Madeira Basin, including the capital La Paz. In contrast, less than 1% of the Peruvian and Brazilian population live in the Madeira Basin (Table 4). The Bolivian departments have three drainage areas: Madeira, Titicaca and Paraná. Some departments are drained by more than one basin, for instance: Madeira and Paraná (Santa Cruz, Potosi and Chuquisaca) and Madeira and Titicaca (La Paz). Only Pando and Beni lie completely within the Madeira River Basin.

The population of Peru is primarily concentrated on the Pacific coast and, while 16% of the Peruvians live within the Amazon Basin, only 0.4% reside in the Madeira Basin, mainly in the Department of Madre de Dios (Table 4). The headwaters of the Madre De Dios River is located in the Andes in the Departments of Madre De Dios, Cusco and Puno, but these departments are sparsely inhabited.
The majority of the Amazon River Basin is located in the North region of Brazil but it extends slightly into the Middle-West and Northeast regions. The Brazilian population, on the other hand, is concentrated in the Southeast and Northeast regions. Only about 7% of the entire Brazilian population reside within the North region and less than 1% in the Madeira Basin. However, despite its current low density, the present rate of population growth in this region is greater than in other parts of Brazil (Table 4).

Climatic and hydrologic characteristics
The climate of the Madeira Basin varies from cold and dry, in the Andes, to tropical and rainy in the Amazon lowlands. The climate in the Peruvian Andes can be divided according to altitude. In the Janca region, which is located over 4,800 m above sea level, the climate is extremely cold and the ground is permanently covered with snow. The Puna region, famous for its populations of alpacas and llamas, is situated between altitudes ranging from 4,100 m to 4,800 m, and is characterised by a dry and cold climate where the temperature oscillates between -10° and 20° C. The Suní or Jalca region located between 3,500 m and 4,100 m is generally cold with seasonal rainfall. The Quechua region ranges between 2,500 m to 3,500 m and is the most inhabited and modified region. The climate is dry with cold temperatures and seasonal rainy periods. The Yunga region situated on the lower slopes of the Andes ranges between 500 m and 2,300 m, is characterised by a spring climate and a dense and highly diverse cloud forest. The areas below 500 m are the Amazon lowlands, which, with the exception of the largest savannah zone in Bolivia, are generally covered by forests. In the lowlands of the Madeira Basin, the annual precipitation ranges between 1,000 mm and 2,500 mm, while the foothills of the Andes receive between 5,000 mm and 10,000 mm per year. Rainfall varies throughout the year with the dry season occurring between May and September and rainfall peaks occurring between November and April (Goulding et al. 2003).

The level of water in the rivers of Madeira Basin varies according to seasonal fluctuations in rainfall and exhibits peak in February along the foothills of the Andes, and between February and March in the downstream sections of these rivers. The Madeira River, below the Teotônio Falls, exhibits the greatest variation in annual discharge of any river in the Amazon Basin. This is due both to high rainfall and relatively narrow floodplains compared with the river discharge. In addition, the backwater phenomenon occurs in the lower Madeira rivers due to the natural dam effect caused by the greater elevation of water in the Amazon River. The peak discharge from the lower Madeira River occurs at least two months earlier than in the Amazon River (Goulding et al. 2003).

Principal economic sectors and processes
The main socio-economic activities in the region are gold mining, logging, fishing, cattle farms and agriculture (Figure 10).

Gold mining
Large alluvial gold deposits were discovered along the Tapajós, Madeira, Tocantins, Xingu and the Negro rivers between 1979 and 1987 (Hanai 1999). During the 1980s and 1990s, gold mining was very important in the Madeira Basin and mining activities are now concentrated in the region of Madre de Dios, in Peru (Núñez-Barriga & Castañeda-
Hurtado 1999) (Figure 11) where it is the most significant contributor to the region’s economy. Unfortunately, however, gold mining is also the biggest cause of habitat modification and pollution in the region.

Logging
Logging, especially of mahogany, is also an important source of foreign income for the region of Madre de Dios. Timber is transported along the river (Figure 12) or by road to Lima, where it is exported to foreign markets. Considering that timber cannot be extracted in areas isolated from the river and the roads, logging is limited to areas serviced by transportation routes and as a consequence, the impacts of logging are directly proportional to the density of roads in the region.

Fishing
Fishing is a common activity in the Madeira River plain (Figure 13) and provides an important source of high-quality, low-cost protein. As a result, fishing has a significant socio-economic function and maintains a formal and informal economy that employs hundreds of thousands of people and generates more than 10 million USD per year (Lauzanne et al. 1990, Cañas 2000, Goulding 1979). The main cities where the fishery landings take place in the Madeira River are: Puerto Maldonado, in Peru; Trinidad and Guayaramerin, in Bolivia; and Guajará-Mirim, Porto Velho and Manaus, in Brazil. Although the city of Manaus lies outside the Madeira River Basin, its port receives fish from the fleet that comes from the Madeira fishing grounds.

Grazing and agriculture
Although agricultural products are very important for local consumption, large plantations of soybean are being established primarily along the Brazil borders of the Amazon Basin for export. The cattle industry has traditionally been important for the local economy in Brazil. However, grazing is now beginning to dominate the economies of other countries in the Madeira Basin, usually at the expense of natural forests.

Other potential activities related to water resources

Generation of hydroelectricity
The Samuel hydroelectric plant located on the Jamari River in Rondônia State is currently the main source of hydroelectricity in the Madeira Basin. The generation of hydroelectricity in Bolivia and Peru is usually done in the Andes and does not require the building of dams. Despite the large hydroelectric potential of the region, the dispersed nature of urban centres in the Madeira Basin and the large distances that the electricity would have to be transported to reach consumers in the other regions of the country have resulted in diesel generators being the primary source of electricity in the region.

Tourism and leisure
Cusco, the capital of the Inca people, is the most important centre for tourism in the Madeira Basin and is located in the Peruvian section of the Madre de Dios Basin. This part of the Madeira Basin has great potential for ecotourism and, in the future, this activity should contribute significantly to the local economy and the preservation of this rich environmental and historical heritage.

River transport
The Madeira River has been an important commercial transport route for the region since the 19th century. The rubber industry brought significant economic investments to the region and also caused considerable changes in the composition of the population. Thousands of people died due to malaria and conflicts between indigenous people and colonists during the Rubber period. Several important infrastructure developments, such as the Madeira-Mamoré railway in Rondônia (Goulding 1979) and the Fitzcarrald adventure in the Manu River in the headwaters of Madre de Dios, were undertaken to transport rubber from the Madeira River regions to export markets.
The root causes that allowed or motivated such unsustainable scenery may be summarised as follows: (i) Law: there are no appropriate rules; (ii) Governance: there is no capacity of taking decisions, assume accountability, or develop programmes which could solve the problem; (iii) Economic: prices do not reflect the environmental values; (iv) Socio-economic: the basic demands of the population are sustained by diminishing natural resources, leading to poverty; (v) Demographic pressure: the capacity of support of the Basin is exceeded; (vi) Technology: there are no techniques that promote the sustainable use of natural resources in the Basin; (vii) Political: the society is not represented legitimately; and (viii) Knowledge: there is no dissemination of knowledge and information of the natural phenomena or the available technology.

Currently, the Madeira River is an important route for the transportation of soybeans from where they are grown in the centre of Brazil, particularly the State of Mato Grosso, to ports, such as Itacaotiara, for export to markets in Europe (Costa 2000).

**Water supply**

In most cities of the Madeira Basin, basic sanitation is poor. In the Brazilian part, less than one third of the population receives regular water supply, the sewerage network services only 3.2% of the population and, even then, only 1.4% of the sewage that is actually collected is treated. These standards are not only below the average for the whole of Brazil, but also for the Brazilian portion of the Amazon Basin (Table 5).

The Madeira Basin constitutes 18.4% of the area of the Brazilian Amazon Basin and 8.1% of Brazil. The Madeira River contributes 14% of the total volume of water discharged from the Amazon Basin (Table 6). The demand for water in the Madeira Basin stems primarily from the agricultural and grazing sectors but is relatively low compared with the availability of water. Even so, this represents 16.3% of the demand in the Brazilian Amazon Basin and only 0.47% of the demand in Brazil (Table 7).

The organic load discharged into the Madeira Basin is estimated to be 61 tonnes per day of Biological Oxygen Demand (BOD), which corresponds to 23% of the total load in the Brazilian Amazon, and 4% of the total load in Brazil (Table 8).

**Causal model and links**

The priority concerns identified in the Amazon Basin were Pollution and Habitat and community modification. These concerns were not only considered as a result of the environmental vulnerability of the Amazon Basin, but also as a consequence of this basin’s institutional and management framework.

The Causal chain analysis of Pollution and Habitat and community modification are summarised in Figures 14, and 15 respectively. Root causes of environmental and socio-economic impacts of Pollution and...
Habitat and community modification were identified as Governance failures, Market and policy failures, Lack of knowledge, and Poverty and demographic factors.

Immediate causes and sectors

Deforestation

Until January 1978, the deforested area corresponded to 85 100 km² (2.2% of the total area) as a result of four centuries of human action. After 1978, there was a significant increase in the occupation of the region, mainly due to governmental programmes, which resulted in an expansion of the deforested areas. In 1999, 440 630 km² (11.7% of the total area) were deforested. Data from the Brazilian National Institute for Space Research (INPE, Instituto Nacional de Pesquisas Espaciais) indicated that the total area deforested during 1999 and 2000 was 17 259 km² and 19 836 km² respectively. According to current estimates, approximately 15% of the original Amazon forest has already been destroyed (ANA 2003).

Pollution

Chemicals and suspended solids are the main pollutants in this region and originate primarily from gold mining activities in Peruvian and Brazilian rivers and from the deforestation of large areas, especially in the headwaters of the southeast Amazon Basin, in Brazil. At present, localised pollution problems exist, particularly around urban centres, but are still not a major overall concern for the Amazon Basin.

Chemical agricultural wastes and mercury contamination are the main cause of chemical pollution in the Amazon Basin. The impacts caused by these pollutants do not affect large areas because agricultural activities are not widespread and because gold mining activities occur in only a few concentrated areas. The present level of pollution is considered low when compared with historical data obtained from important agricultural areas in Brazil (Torres et al. 2002). The source of mercury contamination of organisms is still not completely understood because mercury might have originated from both gold mining activities and from natural regional sources. The problematic areas for chemical pollution are regions where gold mining activities are intense, particularly in the Andean region, the State of Rondônia (Brazil) and the Madeira River. Mercury levels in most fish species consumed by the Amazon population are below the limit recommended for consumption by the Brazilian legislation, but some areas show some contamination (Kehrig et al. 1998, Brabo et al. 2000).

The concentration of suspended solids in rivers arising from the Andean region is naturally high, but the rivers from the Amazon plain and Brazilian Shield, which usually have very low concentrations of sediments, have experienced an increase of solid residues in suspension. This is caused mainly by gold mining activities and the erosion caused by deforestation for agricultural and cattle raising activities.

The rivers and beaches close to the great urban centres exhibit large amounts of solid residues that affect the health of local people and tourism. The low percentages of collection and treatment of domestic sewage leads to significant pollution. Some small streams of the great urban centres are completely blocked by solid wastes and this increases health problems, specifically those related to insect-transmitted diseases (e.g. mosquito transmitted diseases).

Oil spills occur occasionally in areas where petroleum is exploited and during fuel transportation procedures. There are no records of great damages occasioned by oil spills so far.

Habitat and community modification

Habitat and community modification is a pivotal question among all the environmental concerns. The enormous area affected and the long duration of the consequences of the impacts brought by these factors are perhaps the main reasons for considering this concern so important and in need of management.

Deforestation is the main activity that causes loss of ecosystems in the Amazon Basin at the present time. Recently opened areas are clearly identifiable on satellite images in large regions of the Brazilian Shield, headwaters of the Guaporé, Aripuanã and others rivers. The oldest modifications to ecosystems occurred in the tundra-like vegetation, Puna, in the Andes zone, due to agricultural activities of the Andean people. The impact of such historical agriculture on the aquatic system is unclear, but the recent agriculture and cattle established in the floodplain areas, mainly in the lower Amazon, has cleared the flooded forest that represents a source of food for several important commercial fishes.

Fish community modification: The composition of fish species in most of the Amazon Basin is still determined by natural events. The introduction of alien species, such as trout and kingfish, has brought about permanent and negative consequences mainly in the Andean waters, rivers and lakes. Alien species have been introduced in other areas of the Amazon, but they have either not survived or have not yet established viable populations.

Habitat modification: Local extinction of species may occur as a result of large habitat modifications, such as the construction of hydroelectric dams. Although migratory fish are most affected by such
developments, poor knowledge of the aquatic fauna of the Amazon Basin certainly contributes to underestimating the consequences.

The dependence of the Amazon Basin on its rich hydrographic network is graphically illustrated when extreme hydrological events occur. For example, droughts reduce stream flow which, in turn restricts navigation in some waterways, while increased flows cause flooding over large areas of floodplain, influencing the dynamics of several animal and plant species and affecting the conservation of biodiversity within the Amazon Basin.

Root causes
The results of the causal chain analyses of Pollution and Habitat and community modification indicated that both concerns share the most important root causes: 1) Governance failures, 2) Market and policy failures, 3) Poverty, and 4) Lack of knowledge (Figures 14 and 15).

Root cause 1: Governance failures
Two aspects of Governance failures related to the complexity of the problem and the difficulty to practicable mechanisms to resolve conflicts between different interests were identified during the causal chain analysis. These aspects were related to: (i) the lack of legitimacy on negotiations commanding decisions regarding investments; and (ii) the absence of a basin-wide management plan.

Lack of legitimacy on negotiations commanding decision regarding investments: Three countries and 14 states administer the Madeira Basin. There are no effective fora in these administrative institutions, designated to discuss or decide on the development or conservation policies of this basin. The discussions that do occur consider each economic sector, such as mining, agriculture, logging and conservation, of each country independently. Consequently, there is an enormous lack of integration and legitimacy of negotiations associated with decisions concerning investments.

The most important forum for discussions in the Amazon Basin is the Amazon Cooperation Treaty (ACT) (see Annex IV). This treaty is a relevant multi-lateral agreement for the promotion of cooperation between the Amazon countries (Brazil, Bolivia, Colombia, Ecuador, Guyana, Peru, Surinam and Venezuela) to promote sustainable development in the region. However, this treaty is not implemented by the Amazon countries to make decisions or to implement policies related to the sustainable development in this region. Thus far, the Madeira Basin and the other catchments within the Amazon Basin do not possess an integrated institutional framework dedicated to integrated management of the Basin.

Basin-wide management plan not yet implemented: The lack of legitimate base of negotiations, governing decisions regarding investments, results in a precarious basin-wide management plan. One of the most important issue related to the development of the Amazon Basin is deforestation, which may modify habitats over an enormous area, resulting in unpredictable climate changes. The governments of the Amazon countries understand the necessity of preserving part of the forest to maintain the ecological processes in this basin. Parks and reserves have been established in many areas of the Amazon in order to preserve the region's biodiversity. However, it is not clear how much deforestation has taken place or which are the most important areas of the Amazon forest that should be preserved in order to maintain the ecological functions of the Basin. Unfortunately however, some habitat modifications have already occurred on a large scale but the knowledge and understanding of the ecological mechanisms that guarantee the equilibrium of this basin are relatively recent. Data illustrating the importance of the forest for maintaining the hydrological cycles in the region were only obtained during the 1970s and 1980s (Salati et al. 1978, Salati & Vose 1984). Also, the commercial exploitation during the 1990s of the large catfish, which undertakes long migrations between the estuary and the headwaters of the Amazon, illustrated the need of an international fishery management plan to regulate the exploitation of those stocks (Barthem & Goulding 1997).

In addition, some specific habitats have an enormous importance that is not immediately obvious. The flooded areas are traditionally used for grazing and the cultivation of rice and jute, and farmers remove the flooded forest to increase their production area. This economic expansion causes a negative impact on fishery, because the flooded forest is an important source of food and shelter for fish communities (Goulding 1980, Goulding 1981, Goulding & Carvalho 1982, Goulding 1989).

The implementation of a basin-wide management plan depends primarily on the legitimacy of the parts that must be able to negotiate decisions regarding investments, as well as on increased knowledge of the ecological processes occurring in the Basin.

Root cause 2: Market and policy failures: misconceptions about resource availability
There is a common misconception among resource users that the natural resources of the Amazon Basin are inexhaustible which leads to unsustainable exploitation, extinction of species and resource shortages. Many of the different economic sectors within the Madeira Basin have, at some time, held this belief and, as a consequence, not taken enough care to preserve their own investments. The deforestation caused by traditional activities such as timber extraction and agriculture
has had negative consequences. Dean (1997) highlighted the impacts of large-scale deforestation on the soil quality and the hydrological cycle in a tropical South American forest. Mining is another activity that has caused degradation of the aquatic system within the Madeira Basin, particularly when soil removed during the mining process is not controlled or when the river is used as a natural sewer.

The use of natural resources must be monitored by the governmental agencies that can prohibit the exploitation of a resource or determine and enforce sustainable quotas. The absence of a basin-wide management plan weakens government control of natural resources and thereby encourages unsustainable exploitation.

Root cause 3: Lack of knowledge: insufficient training in best land use practices
Some agricultural and mining techniques of soil and chemical use are available to make these activities more profitable and involving less environmental impacts. These relatively modern techniques are more quickly adopted by mining companies and by medium or large-scale farmers, than by informal miners or colonists. Training in best land use practices must be included in the basin-wide management plan. However, at present, the responsibility of training resource users within the Basin is scattered among several governmental and non-governmental institutions.

Root cause 4: Poverty and demographic factors
The majority of the human population that lives in the Amazon Basin is not wealthy and needs to exploit natural resources for their livelihood. Areas sparsely inhabited may be exploited with few negative consequences for the environment. On the other hand, densely inhabited areas generally show decreases in water quality, the abundance of fish and game, and the quality of soils. The increasing risks to human health are amplified by the immigration of people from other parts of the country, such as from the Andes or from the semi-arid zone.
in Brazil to the lowland forests of the Amazon Basin. During the 1980s, the State of Rondônia had the highest rate of immigration which lead directly to a greater number of slums in the largest cities and increased rates of deforestation (Léna & Oliveira 1991). In addition, immigration to the Peruvian Amazon has increased since the end of the terrorism that occurred during the last decade.

The Amazon Basin is one of the last frontiers and a land of opportunities for those that have few opportunities in their home lands. Moreover, the Amazon countries have encouraged this immigration, in order to augment the population of the region. Unfortunately however, the problems associated with increased immigration, such as increased poverty, probably represents the largest challenge for the future administration of this basin and should be addressed in conjunction with the other root causes identified by this causal chain analysis.

**Figure 15** Madeira River Basin causal chain analysis on Habitat and community modification.