The potential of eco-technological wastewater treatment for improvement of the drinking water quality of Matagalpa, Nicaragua

Inventory research on water quantity and quality of two watersheds

M.Sc. Thesis by Joost Jacobi

August, 2004

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Sub-department Environmental Technology

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Master thesis Irrigation and Water Engineering submitted in partial fulfilment of the degree of Master of Science in International Land and Water Management at Wageningen University, the Netherlands

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Cover picture: drawing of coffee plantation in Matagalpa (local artist)

“By imitating the examples which nature shows us, the creative- and formative- natural processes can be enhanced to a maximum output situation”

Viktor Schauberger (1885-1958)
(a far-sighted, unconventional ecologist and inventor)

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Acknowledgement

As part of my study at Wageningen University, this is an MSc thesis research on water quantity and water quality of the watersheds near the city Matagalpa, Nicaragua. The research is under supervision of the 'Irrigation and Water Engineering' group and the sub-department 'Environmental Technology'. The study has been conducted in cooperation with *Proyecto Cuencas Matagalpa* (PCM). PCM is an initiative of different governmental institutions and NGO's with the goal to contribute to the improvement of the living conditions of the population of the province Matagalpa, whereby special attention is given to the watersheds in the region.

This research is part of a Dutch research and implementation programme called 'The Waterharmonica' which considers natural treatment systems as an integral part of wastewater treatment, and is supported by Aqua for All, NOVIB, Lettinga Associates Foundation (LeAF), STOWA (Foundation for Applied Water Research), Water Board Hollands Noorderkwartier, Water Board Friesland and Royal Haskoning, all from the Netherlands.

I would like to express my gratitude to the staff of PCM and in particular Edgar de Leon, who introduced me to different stakeholders and provided me with useful information during my 4 months stay in Matagalpa. I want to thank my supervisor Adriaan Mels, working for LeAF, for the inspiring discussions we had and his well-founded comments on my work. Furthermore, I am grateful for the help of my supervisor Frans Huibers of the Irrigation and Water Engineering group of Wageningen University, who helped me with structuring the report in a scientifically approved way. My appreciation towards LeAF for their financial support which made my stay in Nicaragua possible. And last but not least, my gratitude towards the people of Matagalpa, Nicaragua, for their hospitality and their ever-smiling faces.

Summary

Growing water scarcity and water pollution is a subject of major concern all around the world. The situation in the middle-sized city Matagalpa (an estimated 160.000 inhabitants) in Nicaragua is already under stress. With a fast increasing population of the city, the water demand rises to a considerable level and it is getting more difficult to respond with an adequate drinking water supply. Moreover, the quality is a problem due to various (agricultural) activities in the two nearby watersheds.

An important part of the drinking water supply is coming from the rivers *Molino Norte* and *San Francisco*, of which is said that discharges have decreased in the last ten years. Coffee plantations (*fincas*) located in the mountain area of the cuencas Molino Norte and San Francisco catch most of their process water from the water streams for processing the coffee beans. After this process, polluted water is running towards the city Matagalpa. Also water intensive fern-nurseries are sources of pollution because of the many chemicals used for its cultivation. Furthermore, animal and human excrements, when washed down to the rivers, contribute to an increase of coliform bacteria concentrations in the water and form a serious health risk when in direct contact with human beings.

Considering the importance of the watersheds Molino Norte and San Francisco to contribute to safe drinking water for the city Matagalpa, the research objective is to gain more knowledge about the past, present and future situations of these two watersheds in respect to water use and pollution. It is important to investigate the water quantity and quality and to reveal the 'driving forces' that influence the water use activities. Part of the research objective is to explore the potential of a more secure wastewater discharge to the surface water by means of eco-engineered treatment technologies.

Although lack of hard figures, it is acknowledged that the river discharges of *Molino Norte* and *San Francisco* are decreasing. Since 2003, extra water is pumped from a valley situated 20 kilometers southeast from the city. There are serious questions about the quality of this pumped up groundwater and besides, drinking water prices have gone up three to four times due to high transportation costs. In the critical months (the dry season is from December until April when the water consumption of the city is higher than average) extra water is pumped from a nearby watershed (river Aranjuez) into the river Molino Norte.

Coffee production in the area is of great economic importance. In the two watersheds 15 *fincas* are responsible for 95 % of total coffee production. After harvesting of the coffee berries, river water is used for the wet process, which takes place at the farm. After de-pulping the coffee berries, the coffee bean undergoes a fermentation process and is being washed afterwards. The (polluting) by-products of the process are: coffee pulp, mucilage (slimy layer surrounding the beans) and the wash water. The pH of the coffee wastewater drops to 4 and the concentration of organic material (COD) is very high.

Besides the coffee wastewater, human and animal excrements form a serious threat for the quality of the river water and form a serious health risks. During the coffee harvest season, laborers come to the rural areas and live at the various *fincas*. The rural population in the two watersheds is then increased by fifty percent. Although 'latrine-projects' have been set up, most excrements end up in the fields.

Together with animal feaces they form a source of pollution for the drinking water. During the monsoon, the drinking water company mentions a high concentration of coliform bacteria (and suspended solids) at the beginning of the rainy season, when heavy rains wash away soils, including the excrements.

When extra water is pumped from Aranjuez into the river Molino Norte, another source of pollution has to be taken into account. Nearby the pumping station, water intensive fern-nurseries are located. The ferns are exported and are an attractive business from an economic point of view. Besides the high water demand of the ferns, a lot of pesticides are used. This year MARENA (ministry of environment and natural resources) doubted whether to pump this water from Aranjuez into the river Molino Norte because of its poor quality.

At some coffee farms, preventive actions have been taken to reduce the COD content (the Chemical Oxygen Demand is used to indicate the concentration of organic material in the water) of the wastewater. Coffee pulp is no longer dumped in the river but turned into organic fertilizer after composting. At most farms, *pilas* (infiltration pits) can be found in which the wastewater can infiltrate and evaporate. As valuable land is needed for the installation of such *pilas*, most of them have a limited and often insufficient capacity. At some bigger farms bioreactors (UASB) are installed to reduce the COD content of the wastewater. There is one example where an UASB is used in combination with aerobic treatment and the use of a bio-filter (pond with water plants) and which treated water is finally used for (sprinkler) irrigation. But in most cases farmers lack capital to invest in treatment systems (the international coffee price has dropped since a few years) and because of the incapacity of MARENA to do sufficient controls, coffee wastewater is still dumped into the rivers untreated.

Calculations on the COD content of the coffee wastewater were done with figures found in literature and up to date coffee production figures. These calculations resulted in very high COD contents of the wastewater and river water. It must be said that the existing treatment methods at the farms and the self-purification capacity of the rivers are not taken into account in these calculation. But the real COD load will still exceed the norm set by MARENA. Considering the technology, drinking water treatment cannot completely remove the COD load that is discharged (and probably also high loads of nutrients are discharged). Inhabitants of Matagalpa complain about the bad smell and odour of the drinking water during the coffee season and irritated skin after washing. People add extra chlorine at home or use some kind of filtration technique to minimize health risks. Those who can afford it buy bottled water.

Part of the research was to find out whether eco-engineered treatment systems can be a (partial) solution of the above-described water quality problem. The *Waterharmonica* is a Dutch research and implementation programme considering natural treatment systems as an integral part of wastewater treatment. The basic idea is that eco-engineered treatment systems may form an important ‘link’ between a basic wastewater treatment and safe discharge in surface water.

As became clear from the conducted research, eco-technological wastewater treatment seems a feasible option for the improvement of the river water quality and thus the drinking water quality. In the case of decentralised operating systems, focus should be on the 15 larger coffee plantations (mainly located upstream). Pre-treatment with a bioreactor can be followed by aquatic-based treatment systems in the form of e.g. constructed wetlands, aquatic plant treatment or aquaculture. Biomass production can make these systems attractive for farmers to generate an extra income.

The option of a more centralised system should focus on the riverbanks where constructed wetlands can create a buffer zone for both the settling down of sediments as for water storage. The latter is desirable as the river discharges strongly fluctuate during the year and a sufficient drinking water supply is in danger in the dry season. Well-managed plantations of suitable tree species can contribute to the increase of water holding capacity and the prevention of erosion.

Keywords: integrated water management, water quality, wastewater treatment, eco-engineering, Nicaragua

1. Background

1.1 Introduction

Agricultural activities are polluting the water streams in the region of the city Matagalpa. This forms a serious threat to a reliable drinking water supply (Wijbrandi, 2002). The assumed main pollutant is the processing of coffee beans that produces wastewater of high acidity and high concentrations of organic material and nutrients, depleting life-supporting oxygen from the water. Apart from this quality problem, there is a serious problem with regard to the quantity of the water. The discharge from the rivers that feed the basins downstream is almost halved in the last decade.

This research entails a study of the situation of the watershed in past, present and future concerning water quantity, water quality and the various water demanding stakeholders involved. This should pave the way to answer the question whether there is potential for eco-engineered or other technologies to solve the described problem. The research work is done within the framework of the programme '*Waterharmonica*'. Waterharmonica is a Dutch research and implementation programme considering eco-engineered treatment systems (or natural treatment systems) as an integral part of wastewater treatment, forming a 'link' between a basic wastewater treatment and safe discharge in surface water, making it suitable for reuse in aquaculture, agriculture or – in this case – as a raw water source for drinking water supply. The programme is supported by STOWA (Dutch acronym for the Foundation for Applied Water Research), Water Board Hollands Noorderkwartier and Water Board Friesland.

The results of this study will contribute to an ongoing programme *Proyecto Cuencas Matagalpa* (PCM). PCM is an initiative of different governmental institutions and NGOs in the Matagalpa region with the goal to contribute to the improvement of the living conditions of the population of the province Matagalpa, whereby special attention is given to the watersheds in the region. It is supported by NOVIB and Aqua for All, the Netherlands.

Part of the field research was to collect data on issues like types of pollution, existing wastewater treatment systems, agricultural activities, population growth, discharges, precipitation, and so on. This gives a picture of the current situation as well as the historical situation concerning the water quantity and quality. By distinguishing different 'driving forces', a broad outline of future trends can be given that form the base of the description of various scenarios. To come up with useful data, reports of former studies and other literature are used as well as the consultation of farmers, local government officials, co-workers of PCM, and other people that play a role in the watershed. Depending on the local facilities, physical measurements are executed to determine water quality. As this is only a random indication, also known figures of parameters that indicate the quality of wastewaters are taken from literature and related to the existing agricultural activities.

1.2 Research Background

Nicaragua

The surface of Nicaragua is approximately 129 500 km². Bordered in the north with Honduras and in the south with Costa Rica, in the west there is a coastal area of more than 300 km of the Pacific Ocean, and in the east a coastal line of 500 km of the Caribbean Sea. The climate varies in the different parts of the country, from a tropical one to the subtropical one, and the vegetation varies from rainforests to the subtropical vegetation of the highlands. In the populated regions of the country, located at the Pacific and in the western highlands, there is the dry season from December until April, and a rainy season from May until October.

The country can be classified in three main regions: the region of the Pacific, the central highlands and the coastal region of the Atlantic. The region of the Pacific is divided in the coastal plain and in the depression or the rift of Nicaragua, where there is a chain of the volcanoes.

Nicaragua has five million inhabitants approximately, of which the most live in the coastal region of the Pacific, where also agricultural production cattleman are concentrated. The north of Nicaragua is dependent on coffee tillage. After tourism, coffee is the one of the most important export products. The decrease of the international coffee-price has major consequences for the profits. In 2001, 150 million dollars was generated in the coffee industry of Nicaragua.

According to the Pan American Health Organization (PAHO), approximately 37 percent of the estimated total Nicaraguan population of 5 million people has access to treated drinking water (distributed by piping systems). The urban population is estimated to be 63.7 percent of the total population, or approximately 3.2 million people (PAHO, 1999). Of that urban population, it is estimated that 93 percent has access to drinking water services, while only 12 percent of the rural population has similar access. Of the urban population, 87 percent has access to sanitary disposal services (including the use of latrines), but only 54 percent of the rural population benefit from such services. In 1990, 70 percent of the public water supply systems in Nicaragua used ground water, while the remaining 30 percent used surface water (Figure 1.) (Horsley, 2002).

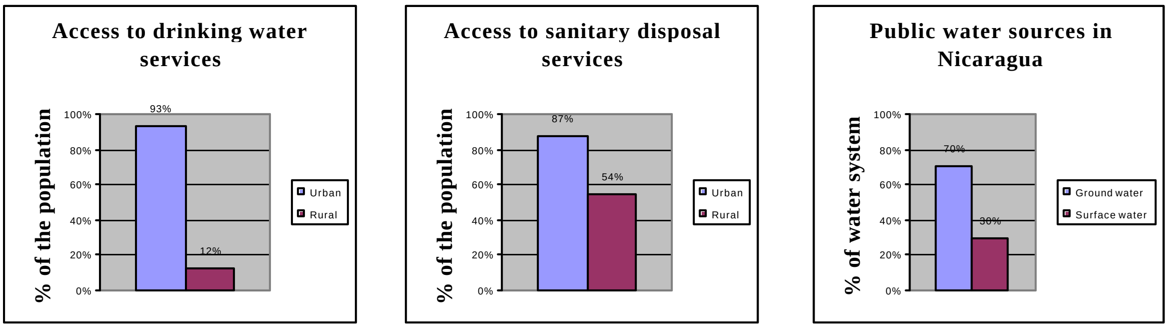


Figure 1. Access to drinking water and sanitary disposal services and public water sources in Nicaragua. (Horsley, 2002)

Matagalpa and its Cuencas

The triangular area known as the central highlands of Nicaragua lies northeast and east of the Pacific lowlands. This rugged mountain terrain is composed of ridges 900 to 1,800 meters high and a mixed forest of oak and pine alternating with deep valleys that drain primarily toward the Caribbean. Very few significant streams flow west to the Pacific Ocean; those that do are steep, short, and flow only intermittently. The relatively dry western slopes of the central highlands, protected by the ridges of the highlands from the moist winds of the Caribbean, have drawn farmers from the Pacific region since colonial times and are now well settled. The eastern slopes of the highlands are covered with rain forests and are lightly populated with pioneer agriculturalists and small communities of indigenous people.

The municipality Matagalpa, capital of the equally named province, is located in the north of Nicaragua, in the mountain area Cordillera Dariense. The city itself is situated next to the Rio Grande de Matagalpa at 700 meters above sea level. More than half of the population of the province lives in the city Matagalpa, which counts an estimated 160.000 inhabitants; the other part lives in the rural areas. Shortage of water ration forces people to leave their villages. In some villages in the area around Matagalpa there is no water at all with the result that people move to the big city and end up in the slums. The city of Matagalpa obtains its drinking water from the watersheds (cuencas) Molino Norte and San Francisco. The total extension of these basins is 32,2 km². Their degrees of latitude are N13°09'-12°53' and of longitude W85°59'-85°49 '. The cuenca Molino Norte is located in the north of the city Matagalpa and its river travels about 12 kilometres from the head until its outlet meets the river San Francisco, giving origin to the Rio Grande de Matagalpa.

The climate of the Matagalpa is subtropical, and has a temperature between 18-26° C. The average annual precipitation 1550 mm, and the annual evaporation is 1215 mm. The main agricultural activity is coffee production, but also elementary products are cultivated for own consumption such as corn and beans. For the export vegetable and ornamental ferns are grown in the area. Besides that, the area is covered with pastures and forest. The inclination of the slopes varies between the 4 and 75% and at some steep slopes mudflows occur, caused by the erosion.

Agricultural activities

Coffee production is of great importance for the economical development at both regional and national scale. Prior to coffee exportation, considerable processing takes place in order to prepare dried green coffee beans. This processing occurs in one of two basic approaches: dry or (semi-)[1]wet processing. In Matagalpa (as in whole Central America) wet processing is practiced with coffee wastewater as an important environmental problem.

Wet processing occurs in three stages. In the first step, the outer skin of the coffee fruit (known as 'pulp') is removed with the aid of

Textbox 1. History of Coffee

According to the legend, an Arabian goatherd named Kaldi found his goats dancing joyously around a dark green leafed shrub with bright red cherries in the southern tip of the Arabian Peninsula. Kaldi soon determined that it was the bright red cherries on the shrub that were causing the peculiar euphoria and after trying the cherries himself, he learned of their powerful effect. The stimulating effect was then exploited by monks at a local monastery to stay awake during extended hours of prayer and distributed to other monasteries around the world. Coffee was born.

Despite the appeal of such a legend, recent botanical evidence indicates that Coffea arabica originated on the plateaus of central Ethiopia and somehow must have been brought to Yemen where it was cultivated since the 6th century. Upon introduction of the first coffee houses in Cairo and Mecca coffee became a passion rather than just a stimulant. (www.coffeeresearch.org)

[1] The semi-wet process is similar to the wet process. During semi-wet processing, however, the time-consuming fermentation step is reduced as the mucilage layer is removed mechanically. After the mechanical removal of the mucilage, the wet coffee should ideally undergo a shortened 'finish' fermentation to fully remove remaining mucilage from the parchment followed by washing in order to produce an optimal quality (Becker 1999)

water in a 'pulper'. This produces a pulp wastewater as well as a humid solid waste, which is the pulp. In the second step, mucilage (a slime layer which surrounds the coffee bean) is removed by a fermentation process. During fermentation, pectic substances are hydrolyzed which solubilizes the slime layer. The wastewater formed by draining off the spent liquor of the fermentation process is known as the fermentation water. Finally, the beans are rinsed in a channel forming the wash wastewater. The fermentation liquor is usually diluted with the wash water and together form the so-called a*guas mieles*. The washed beans are partially dried in the sun and then sent from the coffee farm to a larger processing unit where the coffee beans are dried further. Once completely dry, the beans are mechanically treated in order to remove the hull. The dehulled green coffee beans constitute the product that is finally exported.

Besides coffee production there is an increasing development of fern nurseries in the study area. The ferns are exported and are very profitable. The fern is a water demanding crop and many pesticides are used to avoid diseases. Vegetables are grown for the export as well but also for own consumption. Furthermore, various types of cattle can be found in the watershed of which the cow is most common.

1.3 Problem Definition

Due to the increasing population, the water demand of the city Matagalpa is rising and it is getting more difficult to respond with an adequate water supply. Moreover, the quality has decreased due to increased (agricultural) activities in the two watersheds.

An important part of the drinking water supply is coming from the rivers Molino Norte and San Francisco of which it seems that discharges have decreased in the last ten years. Coffee plantations (*fincas*) located in the mountain area of the cuencas Molino Norte and San Francisco catch most of their process water from the water streams for processing the coffee beans. After this process, polluted water is running towards the city Matagalpa. Not only the coffee plantations but also the water intensive fern-nurseries are sources of pollution because of the many chemicals used for its cultivation. Furthermore, animal and human excrements, when washed down to the rivers, contribute to an increase of coliform bacteria concentrations in the water and form a serious health risk when in direct contact with human beings.

1.4 Research Objective

The research objective of this thesis was to gain more knowledge about the past, present and future situations of the two watersheds in respect to water use and pollution. Considering the importance of the watersheds Molino Norte and San Francisco to contribute in a sufficient drinking water supply for the city Matagalpa, it is important to investigate the water quantity and quality and to reveal the 'driving forces' that influence the water use activities. In this way the actual state of the watersheds can be defined and tendencies of water related activities can be revealed. Part of the research objective was to explore the potential of a secure wastewater discharge to the surface water by means of eco-engineered treatment technologies. To attain the research objective, the following questions are formulated.

Main Research Questions

1. *What are the past, present and future situations of the watersheds Molino Norte and San Francisco in the province Matagalpa, Nicaragua, with regard to water quantity, quality and what type of pollutions and sources of pollution of the water flows can be indicated?*

2. *What are the feasibilities of eco-engineered (or other) wastewater treatment technologies to function as a buffer between partially treated wastewater and the watersheds Molino Norte and San Francisco?*

The Sub Questions

Past situation
-What activities related to water use have been in the watersheds in the past?
-Which data are available on climatological patterns?
-What is the population growth of the city Matagalpa?

Present situation
-What are the current demands of the water uses/functions (driving forces)?
-What is the present state of the water system in terms of quality and functioning, using physical and chemical indicators?
    -What are the discharges of the different water flows in the watersheds of Matagalpa?
    -What sources of pollution can be indicated?
    -What type of pollution takes place in the water flows?
    -Can fluctuations of pollution of the water flows be indicated during the year?
    -What is the result of the pollutions for the river basins downstream?
-Are measures taken in the form of water treatment or recycling of wastewater?
-What are the impacts on the quality of the water of the measurements taken?
-What is the impact of the sources of pollution on the drinking water quality?

Future situation
-What are the (estimated) future demands of the water uses/functions?
-What trends can be identified regarding agricultural activity?
-Is it to be expected that action will be taken to reduce the pollution?
-What are the visions on the future/preferences of the different stakeholders?
-Can the DPSIR-method (see chapter 2.2) be used for revealing future trends?
-What are the feasibilities of eco-engineered (or other) wastewater treatment technologies?

1.5 Outline of the Report

After this introduction, chapter 2 contains the theoretical background of the various frameworks of within this study is executed. The third chapter consists of a description of the methods used during the research. Chapter 4 and 5 will cover the analysis of the results regarding water quantity and water quality respectively. Chapter 6 will give an overview and description of the already existing water treatment systems. In Chapter 7 the potential of eco-technological wastewater treatment systems is stressed out. Chapter 8 will give the conclusions of the conducted research and the report ends with recommendations and discussion in chapter 9.

2. Theory

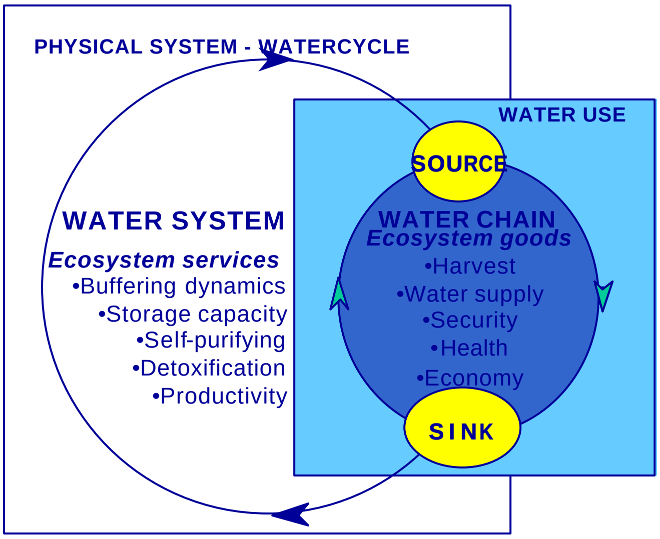
2.1 Integrated Water Management

This study falls within the framework of integrated water management. There are different definitions of integrated water management (not limitative: Meire & Coenen, 2003; Verhallen et al, 2001; Savenije et al, 1998; Heathcote, 1997; Mitchell, 1991; Ministry of Transport, Public Works and Water Management, 1989/1998; all to find in Santbergen, 2003). In the integrated water management courses at Wageningen University the following definition is applied:

A participatory decision-making process (including governments, groups of interest, non governmental organizations, individual citizens and scientists from various a, ß and ? disciplines), aiming at an identification, selection, implementation and evaluation of measures on a sustainable development and management of water systems on different spatial and temporal scales, based on their natural characteristics and interrelationships.

This research emphasizes the *identification* and *selection* of measures on a sustainable development and management of water systems, which should pave the way for additional steps as implementation and evaluation.
This definition is based on the following recognitions:
-Healthy, well functioning (aquatic) ecosystems are one of the major fundaments under human society, providing goods and services for humans, plants and animals and setting conditions on a sustainable use of available water resources -Integrated water management requires balancing of interests (of human and natural subsystems) related to the functioning of water systems; therefore legislative and institutional procedures are necessary on different spatial and temporal scales.
Figure 2 below provides a picture of the interrelated natural subsystem (physical system – water cycle) and the human subsystem (water use). A water system is defined as 'a geographically bordered, interrelated and functioning entity of surface waters, ground waters, sediments, banks and flood plains and technical infrastructure, including all intrinsic morphological, hydrodynamic, chemical and biological/ecological characteristics and processes'

Figure 2. The water cycle. and water use (Santbergen, 2003).



2.2 DPSIR indicator framework

The DPSIR indicator framework, as introduced by the European Environment Agency, will be applied for this research as a tool to access a water system inventory (see Figure 3 and Table 1). DPSIR stands for: Driving forces-Pressures-State-Impact-Responses. *Be aware: in the DSPIR framework, a water system inventory is more than a description of the state of a water system (quality and functioning) only.* According to Heathcote (1997; chapter 3): 'A watershed inventory (read: describing the state (S) of a water system) gives an overview of physical, chemical, and biological processes operating in a watershed ecosystem. It seldom, however, points the way to a clearly defined 'problem' to be solved by management actions. Yet disagreements about what problem is to be solved can create significant obstacles to effective watershed management, even if stakeholders agree on most issues and conditions in the system'. Thus; problem perceptions and visions on an 'ideal' water system will vary according to the specific water system/basin and the people living and working in it.

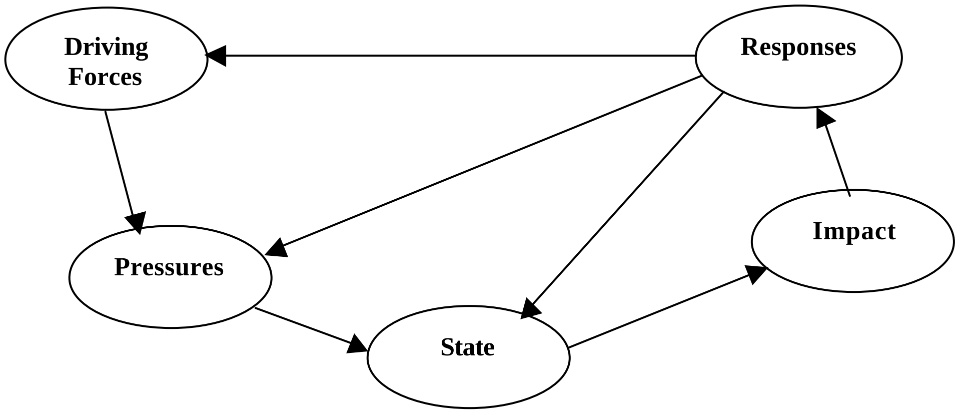


Figure 3. The DPSIR (Driving forces-Pressures-State-Impacts-Responses) indicator framework of the European Environment Agency (1998).

With regard to the DPSIR indicator framework, it is essential to distinguish between internal and external driving forces. Internal driving forces are human activities and water uses, from within the boundaries of a water system, that causes pressures on, and therefore influences the quality and functioning of a water system, and that can directly or indirectly be influenced by decision-makers within the water system.

External driving forces are forces or developments that reach beyond the boundaries of the studied water system, which will influence (future) water demands (and therefore potential water use impairments) and which are beyond the direct control of the decision makers within a water system (Verhallen et Ruigh-van der Ploeg, 2001; Heathcote, 1997). Examples are: population size/growth, economic growth or decline, a more anthropocentric or eccentric philosophy in a society, climate change, etc.

In the table below, the different indicators of this framework are defined and some examples of the indicators are given.

Table 1. The DPSIR indicator framework (after: EEA, 1998)

Indicator	Definition	Example(s)
D = Driving forces	They describe the human activities/functions/uses, like urbanization and agriculture that are the main sources of problems or threats. Driving forces can be external (from outside the water system) or internal (from inside the water system).	Number of inhabitants, land use patterns, amounts of fertilizers per ha. Coffee price
P = Pressures	They describe the stress that a driving force puts on the quality and functioning and therefore indirectly on the related functions/uses of the water system.	Nutrient loads, drinking water shortage
S = State	The state of the water system presents the historical and present quality and functioning of a water system, in terms of physical, chemical and biological/ecological characteristics.	Concentrations of BOD, phosphorus and nitrates and some historical trends in these concentrations.
I = Impact	The impact describes the changes in the quality and functioning of a water system and the related functions/uses as a consequence of the driving forces.	Polluted drinking water, algal blooms, fish kills
R = Responses	Responses describe the policies that have been or are being developed to deal with the recognized problems.	Introduction of good farming practices, investments in treatment capacity of waste water treatment plants.

Driving forces also include land-based activities that affect water resources in a water system. Most important among these are probably forestry, including the logging and replanting of trees, agricultural practices such as tillage, planting, harvesting, and drainage works, and construction activities (mostly examples of activities in the technical sub-system influencing the characteristics of the natural and socio-economic sub systems). Each of these activity classes has potential to affect local hydrological processes and soil quality and permeability. As a result, each can be important in altering sedimentation regimes and changing the ability of upland areas to retain moisture, thereby affecting the volume and patterns of surface and groundwater flows. These processes, if altered, can in turn have an impact on valued watershed features and activities such as potable water quality and wildlife habitat. Their influence cannot, therefore, be ignored in an evaluation of water uses and water-using interests in the basin (Heathcote, 1997).

The (internal) driving forces refer to the human interests related to use of the water system in which a problem is recognized. Each human function asks for special requirements/water demands; the water system characteristics will be influenced by each of the functions and/or combinations of functions.

An essential part of a water system analysis is to make an inventory of human functions/interests. What are the uses of the water system? What are their requirements/demands? How do these requirements/demands influence the water system characteristics and what is the impact on the other uses? What are consequences of shifts in water uses?

Most estimates of water demand require an estimation of population size and potential growth over the planning horizon. Population size is a key variable in determining not only water demand, but demand for other water-using activities such as electric power generation, manufacturing, agriculture, and recreation, and the intensity of these activities within the watershed. Forecasted population size is also a useful measure of the potential market for water-related goods and services (Heathcote, 1997).
Heathcote distinguishes three categories of water demand: *water withdrawals* (the total amount of water that is removed from natural systems for human use), *consumptive demand* (the volume of water that is remove by humans which is “consumed” in the removal and thus unavailable for return to natural systems) and *nonwithdrawal water uses* such as fishing, swimming and navigation. Although nonwithdrawal water uses do not extract water, they may require a certain volume of water to be present and thus must be included in any consideration of present or future water demands.
Generally speaking, water demand is influenced by population size and density, annual per capita income, social forces and life-style expectations, quality of supply, and annual rainfall. These variables can be used to make reasonable accurate predictions of water demand for a given area.
Estimating current water demand, like current population size, is a relatively straightforward task. The simplest approach is to estimate daily per-capita water demand and multiply per-capita use by the population served. This estimation can be extended into the future by using projected population figures and assuming the same usage rate as currently exists (Heathcote, 1997).
It is somewhat more difficult to estimate future water demand under circumstances of changing usage, especially under water conservation programs or, possibly, under an assumption of increased per-capita use. Like population forecasting, estimation of future water demand is an inexact science. Critical planning assumptions in demand forecasting are (Heathcote, 1997): estimated population growth rate over the planning horizon (1), estimated precipitation entering the area (2), estimated volume of surface and/or groundwater available for future extraction (3), nature of water-using industries, commercial establishments, and institutions in the basin (4), attitudes toward water use versus conservation in the basin (5).

Driving forces regarding the water quality aspects are mainly expressed as direct sources of water pollution. The external driving forces concerning water quality of a watershed can be e.g. the climatic conditions in the area and more specific the heavy rainfalls at the beginning of a wet season. Furthermore, factors that have its influences on type of land use in the region (e.g. international market) can be defined as an external driving forces. A description of the actual situation (state) concerning the water quality of a watershed can be done by calculations with figures derived from literature or by the execution of physical-chemical analyses of water samples. For the last case a longer period of time is needed in order to come up with reliable results. Furthermore a qualitative analysis can be conducted in the form of interviews at various levels.

2.3 Scenarios

The analysis of the water issue in the context of sustainable development requires the adoption of a long-view, in order to be able to account for the slow unfolding of some of the hydrological and social processes, and the necessary time for waterworks investments to yield their fruits. Projections of

trends in human affairs may be legitimate over the short-term, but they become unreliable as time horizons expand from months and years to decades and generations. Fundamental uncertainty is introduced both by our limited understanding of human and ecological processes, and by the intrinsic indeterminism of complex dynamic systems. Moreover, social futures depend on human choices, which are yet to be made (Gallopin et al. 1997).
Water must be viewed in a holistic manner, both in its natural state and in balancing competing demands upon it – domestic, agricultural, industrial, and environmental – in a way that ensures sustainability of the resource.
Scenarios are not projections or forecasts. Rather, they are stories about the future with a logical plot and narrative governing the manner in which events unfold (Schwartz 1991). A scenario is a possible course of events leading to a resulting state of the world. The development of scenarios generally begins with the characterization of the *current situation*. The end point of the scenario is an image of the future situation resulting from the unfolding of the scenario.

2.4 Wastewater Treatment based on Eco-technology

Wastewater is the liquid portion of waste and may be defined as a combination of the liquid, or water-carried wastes, removed form residencies, institutions, and commercial and industrial establishments, together with such groundwater, surface water, and storm-water as may be present. The immediate and nuisance-free removal of wastewater from its sources of generation, followed by treatment and disposal, is desirable and in some cases mandated from environmental point of view. Wastewater must ultimately be returned to receiving waters or to land and the complex question of which contaminants must be removed, and to what extent, must be answered specifically for each case (Metcalf and Eddy, 1995)
In the natural environment, physical, chemical, and biological processes occur when water, soil, plants, microorganisms, and the atmosphere interact. Eco-technological treatment systems are designed to take advantage of these processes to provide wastewater treatment. The processes involved in these systems include many of those used in mechanical or in-plant treatment systems - sedimentation, filtration, gas transfer, adsorption, ion exchange, chemical precipitation, chemical oxidation and reduction, and biological conversion and degradation - plus others unique to natural systems such as photosynthesis, photo oxidation, and plant uptake. In eco-technological systems, the processes occur at 'natural' rates and tend to occur simultaneously in a single 'ecosystem reactor' as opposed to mechanical systems in which processes occur sequentially in separate reactors or tanks at accelerated rates as a result of energy input (Metcalf and Eddy, 1995).

The term, *'ecological engineering'*, was introduced by Howard T. Odum in 1962 to indicate 'those cases where the energy supplied by man is small relative to the natural sources but sufficient to produce large effects in the resulting patterns and processes' (Ecological Engineering Group (EEG)-website, 2003)
Another definition relates to ecosystem management by human society. The Center for Wetlands University of Florida (CFW-UFL-website, 2003) states that: 'Ecological engineering is the design of sustainable ecosystems that integrate human society with its natural environment for the benefit of

both. It involves the design, construction and management of ecosystems that have value to both humans and the environment. Ecological engineering combines basic and applied science from engineering, ecology, economics, and natural sciences for the restoration and construction of aquatic and terrestrial ecosystems. The field is increasing in breadth and depth as more opportunities to design and use ecosystems as interfaces between technology and environment are explored.'

The *Waterharmonica* is a Dutch research and implementation programme considering eco-engineered treatment systems (or natural treatment systems) as an integral part of wastewater treatment. The basic idea is that eco-engineered treatment systems may form an important 'link' between a basic wastewater treatment and safe discharge in surface water, making it also suitable for reuse in agriculture or aquaculture.

An example of the Waterharmonica concept can be found on the Dutch island Texel. During dry periods the wastewater effluent from the wastewater treatment plant is considered to be a valuable source of water on the island, but even after treatment in a low-loaded activated sludge plant the quality is not good enough. Although the water is very clear, as it originates from drinking water (plus precipitation), from a biological point of view it is still 'dead' water, without treatment or dilution it is not suitable for fish. The main sewage treatment plant on Texel, STP Everstekoog, is located in the centre of the island. The effluent from Everstekoog flowed to the north in the direction of a brackish area, with high natural values, before being pumped into the Wadden Sea. It was pointed out that it is much more favourable to use the effluent in an area with high agricultural values south of Everstekoog treatment plant. For this purpose a diversion channel has been constructed.

To improve the effluent quality a full-scale constructed wetland was added to the STP and the full flow of the STP is treated in the surface-flow constructed wetland since 1994. The system consists of a presettling basin, nine parallel ditches with a length 150 m and a discharge ditch. The first part of each ditch is only 0.2 m deep and has vegetation of reed (*Phragmites australis*) or cattail (*Typha latifolia*). The deeper (0.5 m) part has been planted with submerged aquatic plants. One ditch is a control without macrophytes (Figure 4). (Kampf et all, 2003)

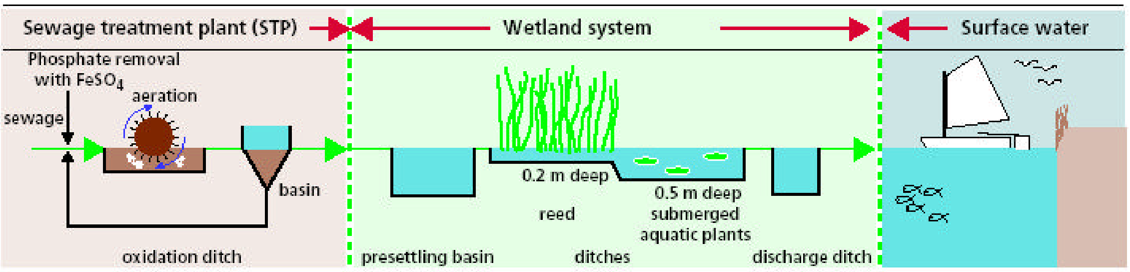


Figure 4. Example of wetland system as link between treatment plant and surface water (Kampf et al, 2003)

Good examples elsewhere are the Ekeby constructed wetland in Sweden; the famous Arcata Marsh in northern California and the 7-hectare Empuriabrave constructed wetland for polishing and reuse for nature and agriculture in the Costa Brava in Spain (Sala, L., Mujeriego, R., 2000)

A framework has been designed at Wageningen University (Martijn and Huibers, 2001 b) specifically for the use of treated wastewater in irrigated agriculture and with an emphasis on developing countries. This framework has been used successfully over the last couple of years by Wageningen

University and LeAF for the training of students and professionals and is modified for the use in the *Waterharmonica.* The modification basically entails a widening of the scope for options to use water and nutrients in: agriculture, aquaculture, landscaping, household, industry, groundwater, nature preservation and recreation (Figure 5).

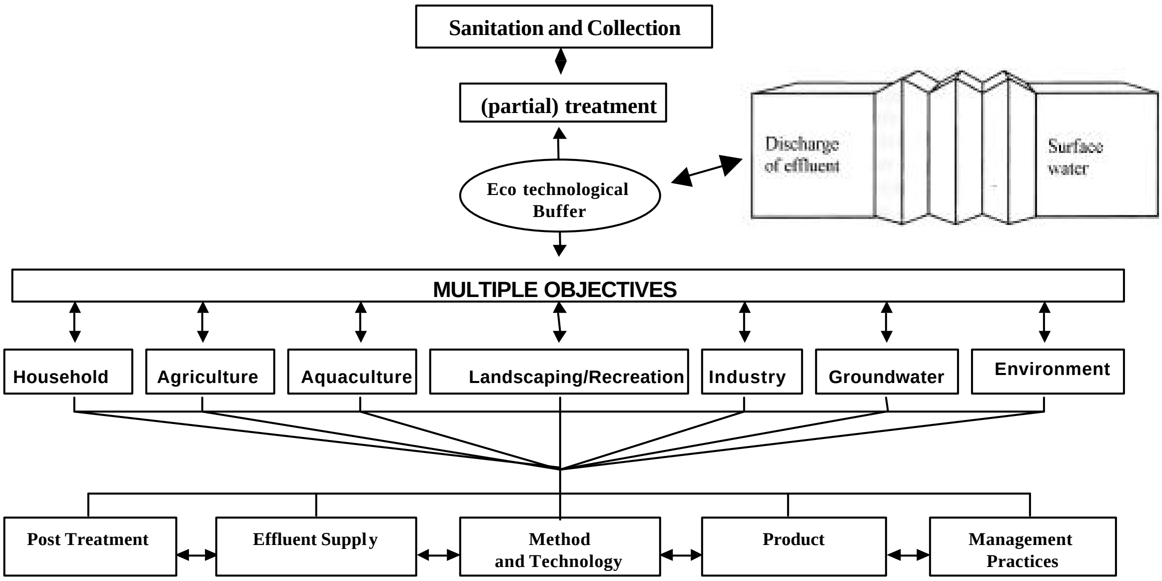


Figure 5. Framework for integrated planning and design of sanitation, wastewater collection, treatment and the use of water and nutrients for various uses (Martijn and Mels, 2003)

The *Waterharmonica* can be seen as an instrument for integrated planning of treatment and reuse with an eco-engineered system as the 'missing link'. Requirements for sanitation systems in transition countries tend to match quite well with the principles of ecological engineering, such as:

- Can be combined with agriculture and aquaculture (wastewater is potential source of water and nutrients)
- Easy to construct with locally available material;
- Relatively easy operation (although maintenance required!);
- Low or absent energy (electricity) requirement
- Especially feasible in rural, agricultural areas
- Wastewater treatment might turn into an economic activity (food chain approach; production of biomass)

3. Methodology

The type of research carried out is mainly based on literature research and fieldwork. As the parameters used for the qualification of water quantity and quality show a discrepancy during one day or even one hour due to rainfall and infrequent discharges of wastewaters, it is decided to distract these figures from literature instead of taking measurements during a relatively short period. Climatological data were analysed and interpreted to be able to draw conclusions on rainfall patterns and indirectly on (the fluctuation of) river discharges over a longer period of time. The quantitative field research takes place in the two watersheds (Molino Norte and San Francisco) and in the city Matagalpa.

In order to be able to give a description of the past and present situation of the watersheds in relation with water quantity and water quality, already in the area performed researches are studied as well as observations are made in the field. Observations in the field and interviews with farmers are executed to see what type of contamination sources exist, where they are located and to find out what processes and which stakeholders are involved in the production of wastewater. Furthermore, interviews were conducted with the various stakeholders; people at the drinking water company and at the treatment plant, local authorities, the Ministries of Agriculture and Environment, the University, inhabitants of Matagalpa and (coffee) farmers. Twenty-four inhabitants of Matagalpa were interviewed with the focus on frequency of drinking water supply, water quality and price (see Annex A for list of questions). During field visits, 21 farmers were questioned about subjects like landuse, water use, applied treatment systems, future plans, etc. (see Annex B). The interviews with the farmers were executed with the assistance of a staff member of PCM to bridge the gap of cultural differences and to create an open atmosphere in order to receive sincere answer. A quantitative analysis is conducted on the perception of the two interviewed groups (inhabitants and farmers), which can be used as an indicator for the actual state and tendencies of the various subject matters.

To integrate all collected date, the above-described DPSIR-framework is used as a base, starting with a description of the State-indicator concerning water quantity and quality of the watersheds. From here, the other indicators (Driving forces, Pressure, Impact and Responses) are further elaborated.
An other technique performed to integrate information is to use a topographic map of the watersheds as a foundation and overlay that map with transparencies showing other features such as land uses, slopes, sources of contamination, and so on. The overlays should reveal areas that are under particular stress. A composite map can be compiled for the present condition and, using land use and population growth projections, for various planning horizons in the future.

4. Water Quantity

Before starting on the elaboration of the results, first a remark on the conducted interviews and the interpretation of them. In the following chapters you will find statistic accounts of the interviews conducted with 21 farmers and 24 citizens of Matagalpa. The given numbers in the bars do not always correspondent with these figures (21 and 24). Sometimes, for some reason, people didn't answer the question and in some cases more answers were possible. The expression 'no answer' means that the specific question hasn't been asked because e.g. people didn't feel at ease or only had little time.
This chapter will start with an overview of the study area and all relevant locations concerning the water system. Then the results on the water quantity of the two watersheds will be presented. Looking at the water quantity in the study area, there are two important issues that are linked which each other: the amount of fresh water available and secondly the water demand. The availability of water will be discussed first whereby the focus will be on surface (river) water. From the DPSIR-framework point of view, we can distinguish two main (external) driving forces that form the sources of threat towards the water quantity issue. From the water availability perspective climatic factors play an important role. Population size and population growth is seen as the most important factor seen from the water demand side. Land-based activities in the rural areas (which could be classified as an internal driving force) is of minor importance with respect to water quantity as there is relatively little water taken from the rivers for on-farm practices. There is no significant use of water for irrigation in the area and most water used for coffee processing is returned to the rivers. These issues will be discussed in the chapter about water quality.

4.1 The Drinking Water Intake

Figure 6 below gives an overview of the two watersheds or so called *cuencas* in which the sources of water supply and the main treatment plants are marked with red dots and indicated with numbers.
The *cuencas* that supply water to the rivers *Molino Norte* and *San Francisco* are of the same names and are *sub-cuencas* of the *Rio Grande de Matagalpa*. The basins have surface areas of 22.3 and 30.0 km² (a total of 5.230 ha) and have longitudes of 8 and 7 km respectively. The area consists of slopes between 30-75% and is lying among peaks as high as 1.525 m above sea level; with the city Matagalpa lying at an altitude of 750 m above sea level.

The intake of the river Molino Norte (point 2 on map) for the supply towards the treatment plants is situated 3 km more upstream of the first, smaller treatment plant (point 3) and the water is distributed in a closed channel. The small treatment plant delivers drinking water for those houses lying above the level of the main treatment plant. Together with the main treatment plant (point 4) it accounts for 50 % of the drinking water supply of the city population. The water that is not channelled, lapses on its natural bed until arriving to the city of Matagalpa where unites to the Rio Grande of Matagalpa.
In the rainy season (starting in May) the discharge of the river Molino Norte exceeds the capacity of the drinking water treatment plant of Matagalpa and it is not necessary to pump water from the river San Francisco. The pumping station in the river San Francisco (point 5) was built in 1966 to increase

the water supply to the main treatment plant. It is out of order since 2 years now because of deteriorated materials. New materials are bought already but there is lack of money for the

1.	Pumping station of Jiguina	5.	Pumping station of San Francisco
2.	Intake point in Molino Norte	6.	Sewage Treatment Plant of the city wastewaters
3.	Small treatment plant (for drinking water)	7.	Distribution of pumped water from Sébaco
4.	Main treatment plant (for drinking water)		

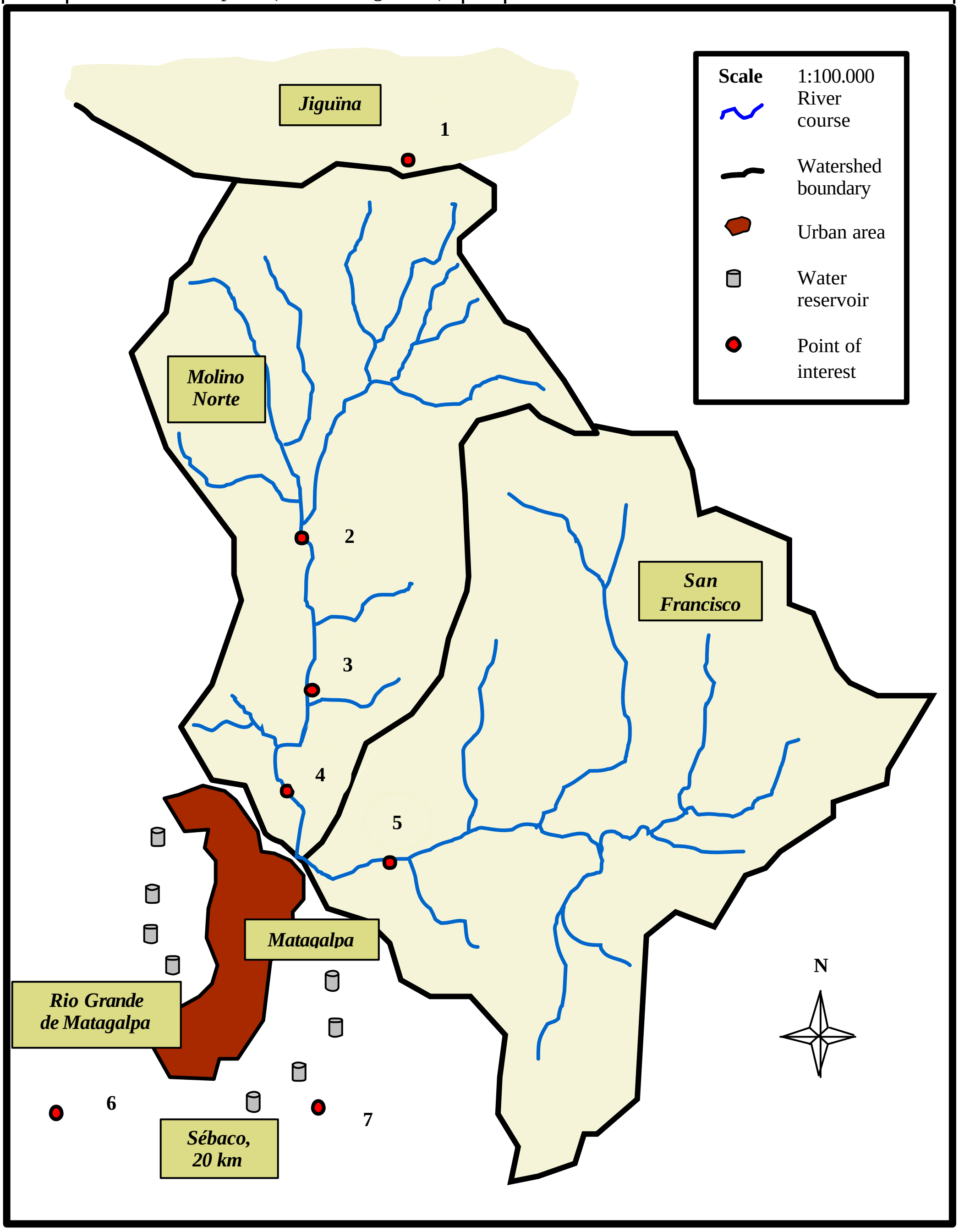


Figure 6. Overview of the sources and treatment plants of the (drinking) water supply of the city Matagalpa

construction. It is expected that within 2 or 3 years water is pumped again from the river San Francisco to the treatment plant. In this way it contributes in the drinking water supply for about 20 to

30 % of the total of both rivers. Since September 2003 a Nicaraguan-German executed drinking water project is running which covers the other 50 % of the drinking water supply. From Sébaco, a town 20 kilometres southwest of Matagalpa, groundwater from wells is pumped and distributed the entire way to the edge of the city Matagalpa. Here the water is treated and pumped to 8 different storage tanks spread out around the city at a level of 800 m above sea level (point 7).
The dry season (Dec-Apr) is the most critical period in respect to a sufficient drinking water supply due to low river discharges. During this critical period extra water is pumped from a the river Aranjuez situated in the *cuenca* Jigu×na lying north of the *cuenca Molino Norte* (point 1).

4.2 Water Availability

Reports executed by *Proyecto Cuencas Matagalpa* (PCM) as well as some local NGO's and Novib (Dutch organisation) state that the discharges of the rivers *Molino Norte* and *San Francisco* are decreasing substantially, especially during the last ten years. Also 77 % of the 13 interviewed farmers, when asked about the history of the rivers, mention a decrease of river discharges (Figure 7).

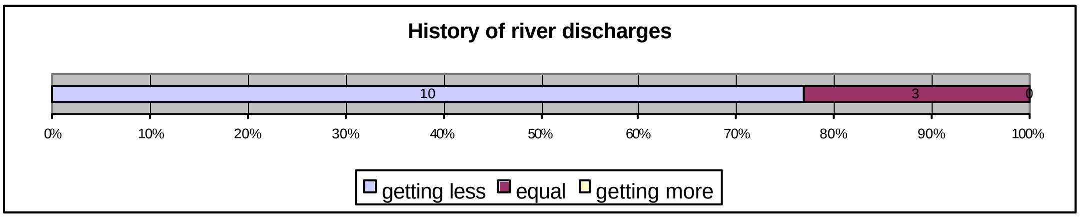


Figure 7. Farmers' perceptions on the history of the discharges of Molino Norte and San Francisco. (Interviews conducted in the dry season)

Nevertheless, there are little figures available to confirm this decrease of river discharges and the ones available do not directly implicate such a drastic decrease. First we have a look at a study carried out by the German GWK-consult as preparatory work before they started to implement the 'Sébaco-project' for the transportation of extra drinking water from the valley of Sébaco to the city Matagalpa. In history, no direct discharge measurements are taken in the two *cuencas*. Therefore, a model is used in which storm rainfall and all other rainfall events, soil type, land use and wet/dry conditions are incorporated (SCS-method) to calculate the river discharges. The results are shown in the Figure 8 below.

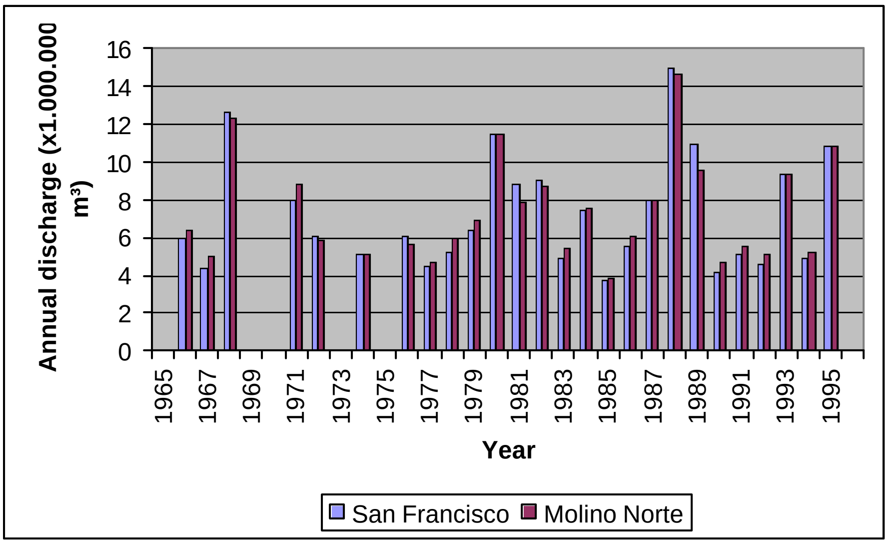


Figure 8. Annual discharges of the rivers San Francisco and Molino Norte (GWK, 1997).

No sufficient data were available for the years '65, '69, '70, '73, '75 and'96 and also the last eight years are missing. We see that the discharges of the two rivers are pretty much similar whereas in practice the river *San Francisco* has a higher discharge. This probably has to do with the shortcomings of the method used for the discharge calculations. But the conclusion to be drawn from this graph is that no clear trend of the river discharges over the period 1966-1995 can be identified.

To get more insight in the river discharges over the last ten years, which is a substantial missing part of the above graph, meteorological data were collected from the Nicaraguan Institute of Territorial Research in Managua (INETER). The whether station in Muy Muy, 30 kilometres southeast of Matagalpa, is the only station that lies relatively close to the study area and has up-to-date figures. Although the microclimate determined by specific local conditions in this particular place can differ significantly from that in the two *cuencas*, trends in temperature, precipitation and evaporation will be used in this case.

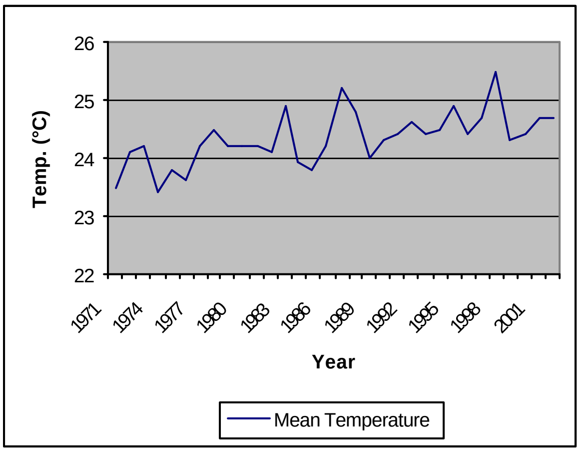


Figure 9. Mean temperature in Muy Muy (INETER, 2004)

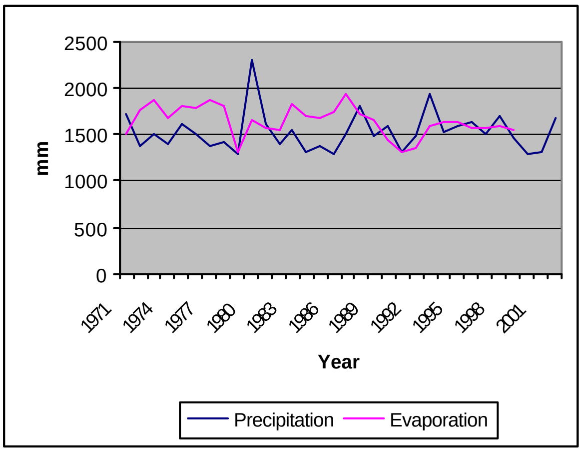


Figure 10. Precipitation and evaporation in Muy Muy (INETER, 2004)

After interpretation of the data, we see a clear trend of increase in mean temperature in the period between 1971-2003 (Figure 9). Surprisingly, this is not expressed in the evaporation curve in Figure 10 which shows no in- or decrease. This is also the case for the precipitation curve that stays around an average of more than 1500 mm per year.

Although the above-mentioned sources talk about a decrease of river discharges in the study area, this cannot be verified by the available data on this subject. Questions can be put on the reliability of the collected data, the method used for discharge calculation or on the operational whether station. But maybe the perception of the 'respondents' of diminishing discharges is wrong and that it actually fits in with the changeable character the river discharges have in this area over a longer period, as shown in Figure 8.

In many cases the vast deforestation of the last decade is indicated as the cause of the assumed decrease of river discharge. Theoretically, deforestation creates peak discharges (maximums as well as minimums) as the water holding capacity of the soil will get less. This means higher discharges during the rainy season (more run-off) and less discharge during the dry season (lower groundwater table). But also in this case, after the interpretation of the peak discharges (period 1966-1995), the figures cannot proof this phenomenon. (see Annex C). Still, it cannot be denied that land use and especially forestry, plays a crucial role in respect to water quantity and water quality. As a response, reforestation programs (PCM, MAGFOR), working with more than 22 different tree species, are set up alongside projects working on the diminishing of tree cutting. Of the latter we can think of the *briquetadora*, a technologies that produce alternatives for fuel wood out of rice or coffee chaffs, the improvement of efficiency of kitchen stoves and *biogestores* for the production of methane gas out of manure.

4.3 Water Demand

Studies that have been carried out in the demographic field have the limitations that they are studies of big territorial and administrative clusters (economic regions, geographical regions and departments) and very few studies on the population at local level have been executed. It is difficult to find the precise figures of the size of the population of the city Matagalpa. Very often official figure used for statistics by the government are not up to date and thus much lower then the real figures. For this study the assumption is made that the city Matagalpa counts a population of 160.000, which is a mean value of all figures found and also is used by local authorities.

As mentioned before, population size and population growth are the driving forces when talking about water demand. Figure 11 below is based on a population of 160.000 in the city Mataglapa and daily consumption of 120 litres (PCM, 2004) per person per day. This means in the year 2004 a drinking water supply to the city of 222 l/s is needed. The curve of the figure is further formed by the actual population growth rate of 4 % (PCM, 2004).
Before the implementation of the 'Sébaco-project' in 2003, the people from the city Matagalpa were dependent on the river discharges of *Molino Norte* and *San Francisco* and the capacity of the drinking water treatment plant for their drinking water supply. As can be seen in the Figure 12 below, there was a shortage of drinking water during the months of January till May.

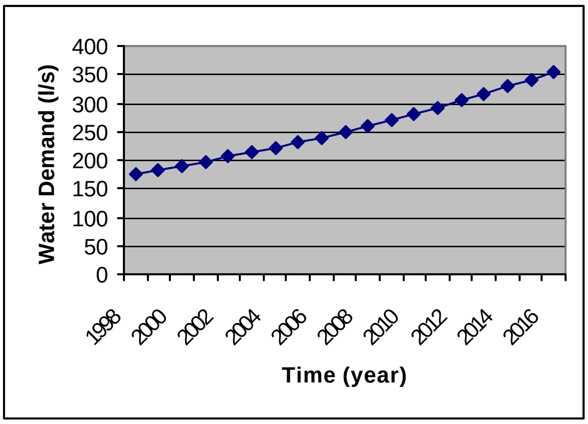


Figure 11. Drink water demand of the city Matagalpa over time.

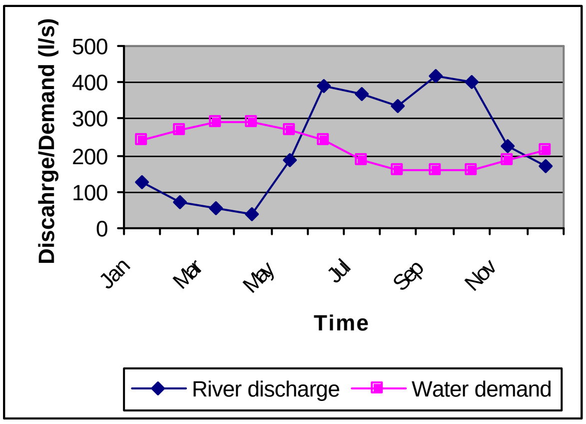


Figure 12. Comparison between the average river discharge of Molino Norte and the drinking water consumption of the city Matagalpa

This shortage is fed by an historical population growth (4%) which made that the total water demand very much exceeds the river supply of *Molino Norte*. By asking 24 inhabitants about the frequency of drinking water supply before the 'Sébaco-project', it becomes clear that the consequence for the population of Matagalpa was a drinking water supply of only two to three times per week (Figure 13). People were forced to collect water in e.g. barrels as means of reservoirs in order to have access to water during those days without water supply.

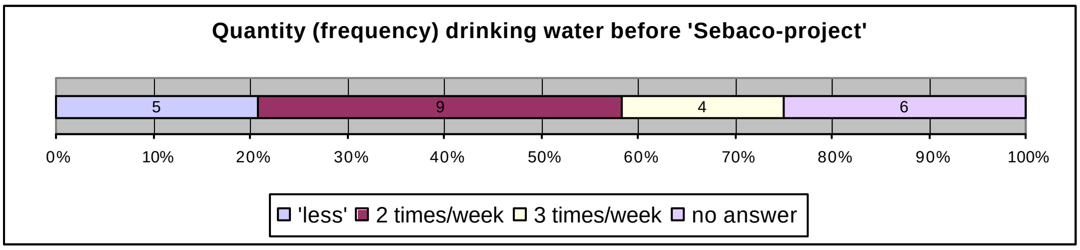


Figure 13. Frequency of drinking water supply before the implementations of the 'Sébaco-project' according to the residents of the city Matagalpa.

As a first response to this situation (shortage of drinking water and a still increasing population), a pumping station was constructed in a the neighbouring *cuenca* with a capacity to pump 50 l/s in the river *Molino Norte* of which 37 l/s reach the drinking water treatment plant. It only operates during the most critical months (Jan-May) and the amount of water pumped varies with the local climatic conditions (e.g. more rainfall, less water pumped). During the rainy season, the discharge of the river *Molino Norte* rises above the capacity of the drinking water treatment plant, and it is not necessary to pump extra water towards this plant.
A second response came in September 2003 as the Nicaraguan-German executed drinking water project (US $ 30 million) was implemented. Groundwater is pumped-up and transported over 20 kilometres to a distribution point just outside Matagalpa. In the dry season Sébaco accounts for almost 50% of the total drinking water supply of the city Matagalpa, namely 115 l/s. During the wet season the discharge from this pumping station is 70 l/s which is about 35%.

As a consequence of these supplementary drinking water supplies, the houses connected to drinking water system, have now access to drinking water during 7 days a week with some exceptions during the dry season. But a price has to be paid, as the electricity costs of the Sébaco-project are enormous and the whole installation has to be depreciated. Before, the citizens of Matagalpa paid a fixed price per month for their drinking water whereas now they pay per volume consumed with a minimum sum per month which means an average increase of the monthly price of about 3 to 4 times (Figure 14). This price increase is also a result from the fact that the World Bank invested in this project under the precondition that there should be return of money. (Note: those houses not connected to the drinking water networks, mostly situated on the outside areas of the city, depend on private or public wells for their water supply or in some cases on water directly taken from the river stream and collected rainwater.)

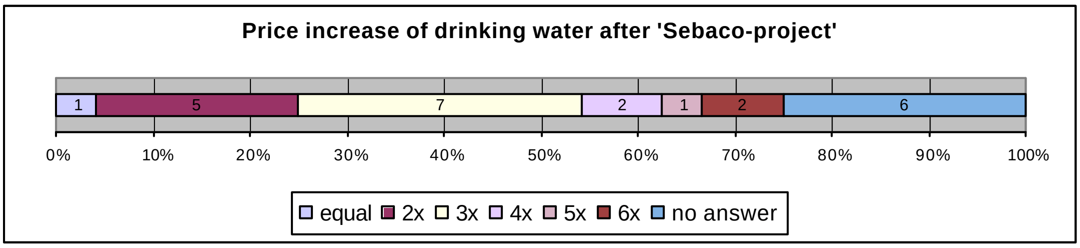


Figure 14. Price increase of drinking water after the implementation of the 'Sébaco-project' according to 24 interviewed residents of the city Matagalpa

A critical question can be put here whether this 'Sébaco-project' is a long-term solution. It is a fact that from the valley of Sébaco already two other pumping stations are built for extraction of groundwater for other 'nearby' villages. Undoubtedly, this will have its impact on the groundwater table in the valley where in addition the water-demanding crop rice is grown as a main agricultural activity. Left out of the discussion is the quality aspect, on which we come back later. But all this makes clear that, although a short-term solution on water quantity is there, the maintaining of secure river discharges from the *cuencas Molino Norte* and *San Francisco* is of great importance for the future.

DPSIR-analysis and discussion

What can be concluded when using the DPSIR-analysis (Figure 15) on the water quantity aspect of the study area is that the supposed climatic conditions and deforestation (although hard proof is missing), together with the population size and growth, form the driving forces that create a pressure on the functions and uses of the water system. This becomes visible when the state of the water quantity issue is expressed in water availability and water demand (before the 'Sébaco-project'), which shows us a

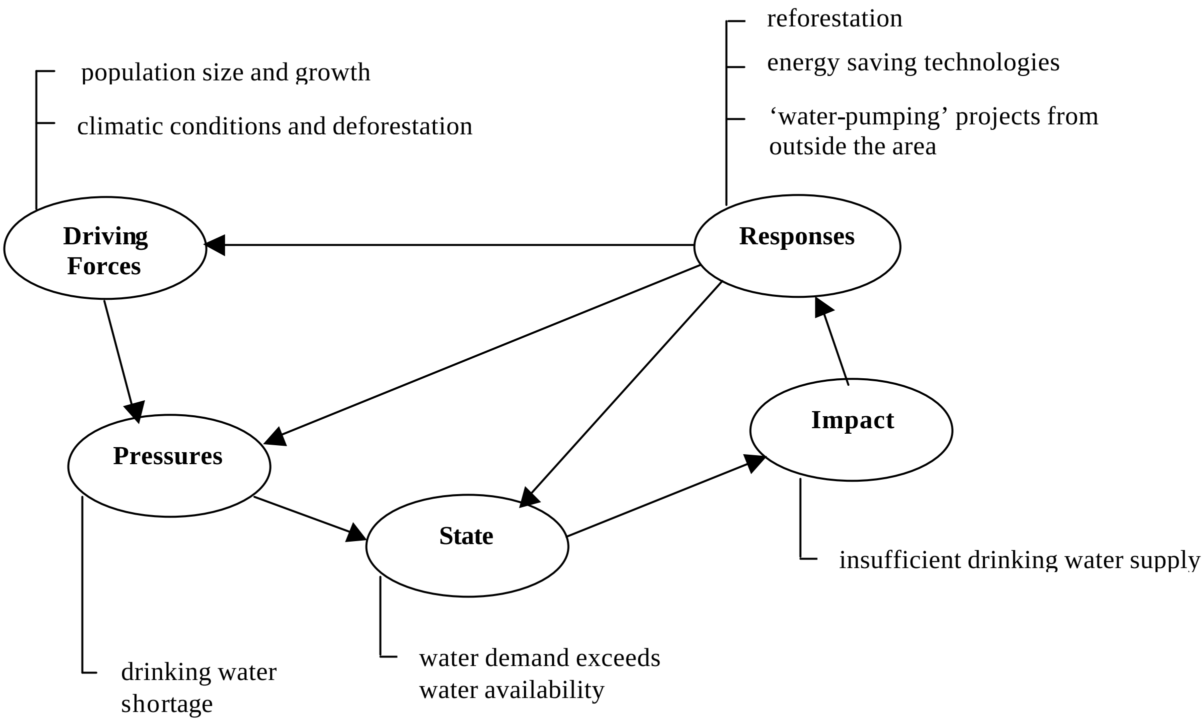


Figure 15. Schematic overview of a DPSIR-analysis on the drinking water availability

demand that exceeds the water availability of the river *Molino Norte*. The impact this has on the population of Matagalpa is a drinking water supply of only two days a week. Responses came in the form of projects which developed possibilities to pump water from outside areas towards the city Matagalpa to assure a sufficient drinking water supply.

In this way the actual situation is a new one, from where we again can start asking ourselves what driving forces are there that put a pressure on this actual state and what impact and responses can be expected. Or in other words, how sustainable is the present state when talking about the water quantity in this area and what can be expected in the future? For the moment it seems that with the new 'water pumping' projects there is a sufficient drinking water supply expressed in a '7-days-per-week-service'. The discussion when talking about future scenarios is whether the responses in the form of these water quantity projects together with reforestation and energy saving technology programmes keep pace with the water demand of the growing city Matagalpa.

5. Water Quality

As stated in the problem definition, a main issue is the bad quality of the river water which has its impact on the drinking water. We will have a closer look at what water use activities influence the quality of the water system. By quantifying the quality of the water system in terms of physical and chemical characteristics, the actual state of the water system becomes clear. It can be expected that poor quality water has its effect on (the biodiversity of) the ecosystem but the main focus in this study is on its impact on the quality of the drinking water supply of the city Matagalpa. Interviews conducted with residents of the city Matagalpa should give supplementary information on the drinking water quality. In chapter 6 the measures will be described that have been or will be developed and deal with the recognized problems. Special attention will be given to the potential of wastewater treatment systems based on eco-technology.

5.1 Sources of Pollution

Coffee farms

The (internal) driving forces are derived from land-based activities of which agricultural practices such as coffee processing, livestock farming and the use of pesticides are most important. Together with the influence of waste that is produced by the people themselves (e.g. soap, excrements), this can be of great influence on the river water quality and thus on the drinking water quality.

As we see in Figure 16 below, the area of coffee production increases in the Matagalpa and Jinotega region (these two departments provide 80% of the total coffee production of Nicaragua) from 1993 to 2003 onwards. In the same period, the coffee production has a maximum in the harvest period of 1999/2000 and decreases after this year.

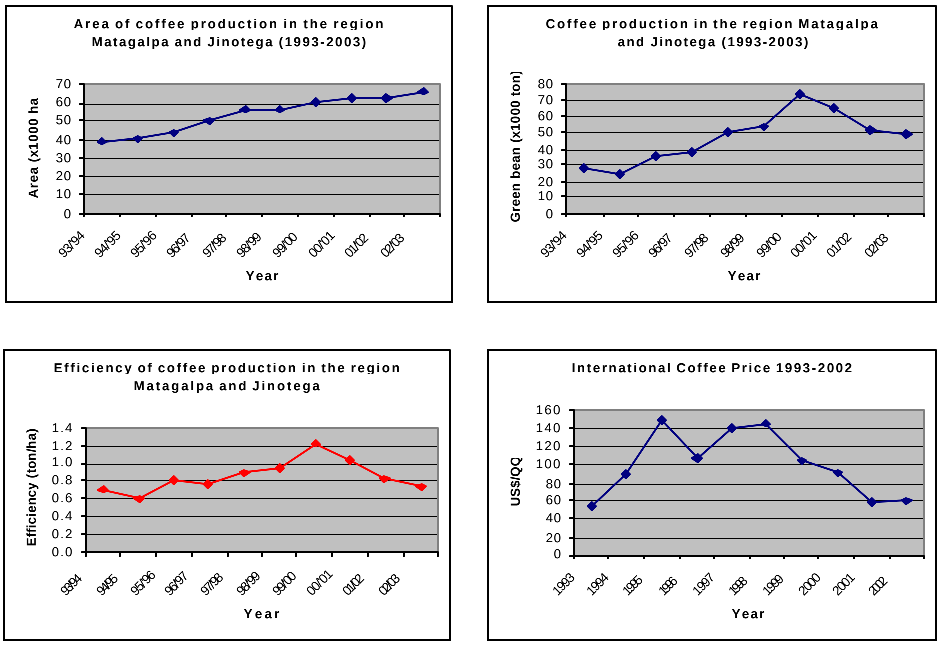


Figure 16. Clockwise: Area of coffee production, Coffee production, Efficiency and International coffee price

From these two figures we can compile a third figure about the efficiency expressed in ton green bean produced per hectare. It is clear that the efficiency drops after the year 2000. This behaviour is consequence from the lack of maintenance works at the coffee plantations due to low coffee prices in the last years.

The present analysis considers a period of ten productive cycles, and it is observed that the behaviour of the coffee production curve can be subdivided in two segments: the first segment includes the agricultural cycles 1993/94 till 1999/00, in which we can see that the production behaves in an upward way, reaching its maximum of 70.000 ton green beans. In the second segment of the curve that includes the cycles 2000/01 till 2002/03, it is registered that the production diminishes in a sensitive way, until a production of 50.000 ton green beans in the last cycle. The above-mentioned is explained mainly by the quick descent observed in the international coffee prices starting from the year 1999; this in its turn resulted in difficulties for the farmers to meet in their bank obligations and at the same time they are not able to carry out the required maintenance works at a appropriate level.

In the two watersheds *Molino Norte* and *San Francisco* there are a total of 138 farmers of which the cattle farmers together with the coffee farmers take the main position in terms of area . Table 2 gives an overview of the different land uses and their percentages of the total area. These figures are from a detailed research conducted by PCM but are not very up to date (1998). It can be expected that the area of coffee production has increased till now, as we can derive from Figure 16 above. Also pasture has increased, both at the cost of the forest area. In the study area there are 63 coffee farmers of which most combine coffee cultivation with other land uses. Of these 63 farmers we can distinguish 15 large coffee plantations, which are responsible for 95 % percent of the total coffee production in this area (see Annex D for locations of the coffee plantations).

Table 2. Area of land uses in the two watersheds (PCM, 1998).

Land use	**Area**
Coffee production	19.7 %
New coffee plants	5.3 %
Vegetables	1.6 %
Corn	1.5 %
Beans	0.6 %
Pasture	30.6 %
Fruit trees	0.6 %
Forest	25.7 %
Reforestation	3.0 %
Total cultivated area	91.6 %
Total area	100 %

By asking coffee farmers about their future plans in terms of crop cultivation, 60 % is saying they have plans to change from coffee cultivation into growing either vegetables or citrus (or a combination) or to have cattle and thus change their land into pasture (Figure 17). Furthermore, 32 % is not thinking about any changes and 8 % mention an increase of their coffee production area. This is, in the perspective of the declining international coffee price of the last of the last 5 years, somewhat surprising. Reasons behind these ideas can be the lack of investment capability to change their land use in combination of trust in the future and hoping for an increasing coffee price to come. Besides, being traditionally a coffee farmer for many generations, it is not an easy task to make a switch in your agricultural activity, or as stated by PCM: 'once a coffee farmer, always a coffee farmer'. It must be emphasized that these are just ideas and no concrete plans yet. Very much will depend on what the international coffee market will do in the coming years.

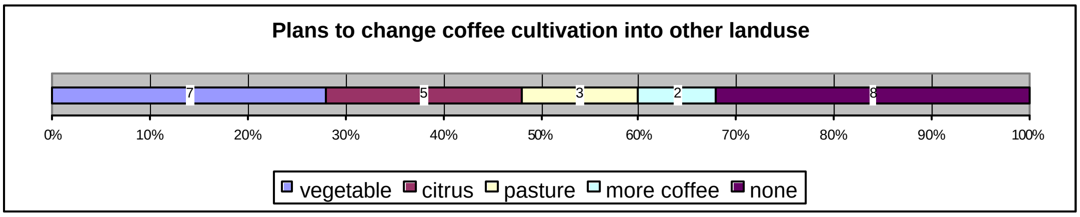


Figure 17. Ideas of the interviewed farmers about their future plans with regard to their landuse

Composition of coffee wastewater

As already explained in chapter 1.2, the wet processing of coffee beans occurs in three stages. In the first step, the outer skin of the coffee fruit (known as 'pulp') is removed with the aid of water in a 'pulper'. This produces a pulp wastewater as well as a humid solid waste, which is the pulp. In the second step, mucilage (a slime layer which surrounds the coffee bean) is removed by a fermentation process. The wastewater formed by draining off the spent liquor of the fermentation process is known as the fermentation water. Finally, the beans are rinsed in a channel forming the wash wastewater (Figure 18). The fermentation liquor is usually diluted with the wash water and together form the so-called *aguas mieles*.

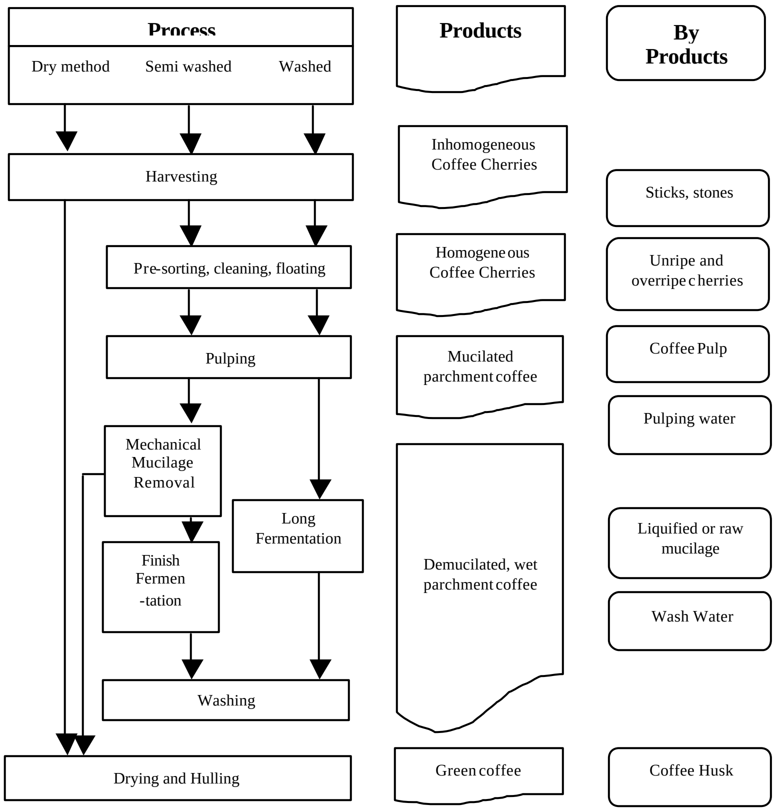


Figure 18. Coffee processing methods (von Enden, Calvert, 2002).

The main pollution in coffee waste water stems from the organic matter set free during pulping, particularly the difficult to degrade mucilage layer surrounding the beans. The mucilage contains mainly proteins, sugars and pectins. The sugars contained in the mucilage will quickly ferment to alcohol and CO_2. However, in this situation the alcohol is quickly converted to vinegar or acetic acid in the fermented pulping water. Other substances to be found in coffee wastewater are toxic chemicals like tannins, alkaloids (caffeine) and polyphenolics (see Table 3 and 4 for exact composition of mucilage and coffee pulp).

Table 3. Composition of mucilage (Gathuo et al, 1991)

Water	84,2%
Protein	8,9%
Sugars	
- *Glucose (reducing)*	2,5%
- *Sucrose (non reducing)*	1,6%
Pectin	1,0%
Ash	0,7%

Table 4. Composition of coffee pulp (Clifford and Wilson, 1985).

Ether extract	0,48%
Crude fibre	21,4%
Crude protein	10,1%
Ash	1,5%
Nitrogen free extract	31,3%
Tannins	7,8%
Pectic substances	6,5%
Non reducing sugars	2,0%
Reducing sugars	12,4%
Chlorogenic acid	2,6%
Caffeine	2,3%
Total caffeic acid	1,6%

During the fermentation process in the wastewater, the acidification of sugars will drop the pH to around 4 or less, and the digested mucilage will be precipitated out of solution and will build a thick crust on the surface of the wastewater. If not separated from the wastewater, this crust will quickly clog up waterways and further contribute to anaerobic conditions in the waterways. The remaining highly resistant materials left in the effluent water are acids and flavanoid colour compounds from coffee cherries. At around pH 7 and over, flavanoids turn wastewater into dark green to black colour staining rivers downstream from coffee factories. However, flavanoids do not do any harm to the environment nor add significantly to the Biological Oxygen Demand (BOD) or Chemical Oxygen Demand (COD).

The organic and acetic acids from the fermentation of the sugars in the mucilage make the wastewater very acidic (pH down to 3.8). (Under these acid conditions, higher plants and animals can hardly survive.) The organic substances in the wastewater break down by microbiological processes using oxygen from the water. This process causes problems as the demand for oxygen to break down organic material in the wastewater exceeds the supply, thus creating anaerobic conditions in surface waters.

Textbox 2. Explanation of terms BOD and COD.

In any wastewater, a complex mixture of organic and inorganic compounds is present. Several methods are developed to determine the concentration of organic compounds that cannot be analyzed completely chemically. The most common methods are Biochemical Oxygen Demand (BOD) and Chemical Oxygen Demand (COD). The BOD is the amount of oxygen needed for degradation of organic material in the wastewater during 5 days at a temperature of 20 °C. With this standard method 60-70% of the organic martial is oxidized. A removal of 95-99% would take about 20 day. The COD is a test that measures the oxygen equivalent of the organic material in wastewater that can be oxidized chemically using dichromate in an acid solution. It would seem logical that the BOD and the COD have the same value. However this is seldom the case. This is due to the fact that some organic material can only be oxidized chemically and not biologically, some of the inorganic substances present could be oxidized during the BOD test and certain organic substances may be toxic to the microorganisms used during the BOD test. (Metcalf and Eddy, 2003).

Values for BOD indicating the amount of oxygen needed to break down organic matter in coffee wastewater are high (up to 20.000 mg/l for effluents from pulpers and up to 8.000 mg/l from fermentation tanks). The COD should be reduced to less than 200 mg/l according to the national statutes, before let into natural waterways.

Resistant organic materials which can only be broken down by chemical means indicated by the COD make up around 80% of the pollution load and are reaching 50.000 mg/l and more (Treagust 1999). Luckily most of this material can be taken out of the water stream as precipitated mucilage solids and made into compost.

It must be said that the given values of BOD and COD are not fixed. Different literature sources give a wide range of BOD and COD values of coffee wastewater as. This is also the case with the concentrations of the main macronutrient Nitrogen (N), Phosphorus (P) and Potassium (K) that can be found in the wastewater. Very much depends on the management of the farmer for processing the coffee cherries. A high variety in values can be expected when different types of water treatment technologies are used or no treatment at all. Also the amount of water used for the processing and whether or water is re-circulated play an important role in this case. In summary, the combination of high acidity, and high COD, depleting life-supporting oxygen from the water, and nutrient concentrations are causing the problems in coffee wastewater treatment and need to be overcome.

Diffuse sources

Other so-called point sources of pollutions in the area, besides the coffee pulp and the *aguas mieles*, are the wash waters from the milk houses and from livestock housing which contains excrements of the cattle and thus coliform bacteria.

The most important diffuse sources of water pollution reported and observed in the field are synthetic chemicals coming from the soaps and detergents used for personal washing and washing ropes. Both activities are done in the open air nearby a water stream and the produced (grey) wastewater is discharged directly to the surface water without any kind of treatment. In addition, people have the habit to go to the 'toilet' in the open field. The excrements form a serious health risk because of the consistence of colifrom bacteria that can transmit diseases. The same counts for the cattle excrements that are washed away from the hill slopes after heavy rainfalls and end up in the water streams.
Furthermore, an important diffuse source of pollution is the pesticide use in the cultivation of various crops. This is especially the case in the area near the river Aranjuez in the neighbouring *cuenca* from

Figure 19. From left to right: Coffee plantation, grey wastewater disposal and a fern nursery (source: author, 2004)

where extra water is pumped during the critical months. In this area ferns for the export are grown which crop requires a lot of pesticides. Although there is a lot of critic on this source of pollution, and particularly the one coming from the fern sector, the fern production-area is still increasing. This has to do with the fact that the fern export is a very lucrative business and the largest farmer in this sector has political power and is protecting this business (see Figure 19 for images of the different sources of pollution).

The pressures on the water system coming forth from the different sources of pollution are enormous. The organic and acetic acids from the fermentation of the sugars in the mucilage make the coffee wastewater very acid (pH down to 3.8). Under these acid conditions, higher plants and animals will hardly survive. After the first fermentation of sugars in the wastewater took place, the organic substances diluted in the wastewater break down only very slowly by microbiological processes using up oxygen from the water. This process causes problems as the demand for oxygen to break down organic material in the wastewater exceeds the supply, dissolved in the water, thus creating anaerobic conditions in surface waters. Too high nutrient concentrations in the water cause difficulties at the drinking water treatment plant. Furthermore the coliform bacteria from excrements and the chemical residues of the pesticides can form health risks for human beings when in direct contact with this contaminated water or when drinking it.

5.2 Quantification of Water Pollution

For the description of the actual situation regarding the water quality, various sources are used. It must be said that there have been difficulties with collecting data, especially concerning the water quality of the 'Sébaco-project' and at the drinking water treatment plant. This probably has to do with the protection of data that might show negative results of projects, which have cost a lot of money. In this paragraph the focus will be on the quality of the water from the two cuencas.

Aguas Mieles

The wastewater produced at the coffee plantations for depulping and washing is called *aguas mieles* (for exact composition see Annex E) and the amount mainly depends on the used technology and the hydraulic design of the coffee plantation. The pulp produced during the coffee process (depulping) is left out of the calculations as in 90 % of the cases the pulp is separated and finally used as organic

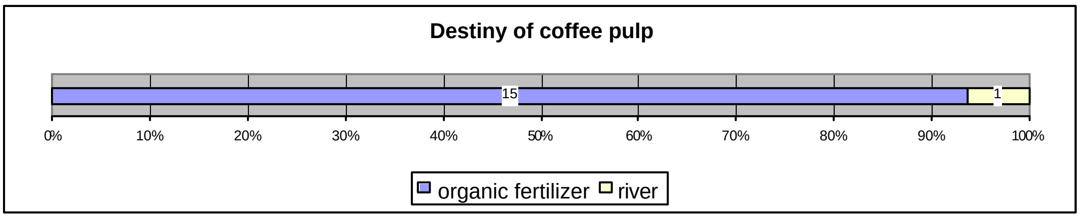


Figure 20. Destiny of coffee pulp. Data derived from interviewed farmers

fertilizer (confirmed by the coffee farmers, Figure 20). The main pollution from the *aguas mieles* is the high content of organic materials and thus the calculation will focus on COD concentrations.
Total coffee production in watershed Molino Norte in 2004 (by extrapolating the production figures of 1998 (PCM)) is 640 ton green beans and in San Francisco 990 ton green beans per year. The figures used for further calculations are estimates, as literature gives a wide range of wastewater production

and concentrations values. The figures used by Field (1990) are chosen as he worked in the area near Matagalpa and his figures lay around the average of all mentioned figures encountered.
With the calculation of the COD-concentration it is assumed that the depulping and washing process of 1 ton (= 1000 kg) green bean produces 31 m³ wastewater (*aguas mieles*) and 130 kg COD (Figure 21). This means a coffee wastewater production in these two watersheds of 19.840 and 30.690 m³ respectively.

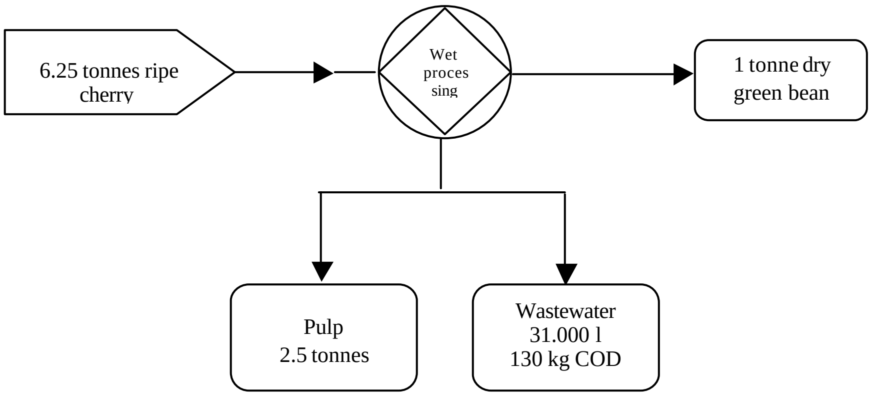


Figure 21. Mass balance coffee processing (von Enden and Calvert, 2002 and Field, 1990).

As we want to derive a figure for the peak period, the 2 months of highest production of the total 4 months of the harvest season are taken for the calculation of the water use per day. It must be emphasized that the coffee wastewater pollution in the rivers takes place during the coffee-harvesting period which coincides with the dry season when river discharges are lowest. This means the impact of the wastewater discharge on the quality of the river water is of even greater magnitude.

Table 5. Calculations on COD concentrations

Cuenca	Minimum discharge of river * (m³/day)	Coffee production (ton green bean)	Water use (m³/day)	COD production (kg COD/d)	Ratio wastewater/ river discharge (%)	Contamination conc. of waste water (mg COD/l)	Organic concentration river** (mg COD/l)	MARENA Wastewater Discharge Limit (mg COD/l)
Molino Norte	3200	640	332	1391	10	4200	420	200
San Francisco	6400	990	511	2140	8	4200	336	200

*Minimum discharge during harvesting season
**The existing information tells us that no pulp is released in the rivers in the two cuencas

What we see from Table 5 is a very high concentration of COD of the wastewater itself (4200 mg/l) whereas the Ministry of Environment and Natural Resources (MARENA) has set the norm at 200 mg COD per litre wastewater produced. Furthermore the calculation shows an expected high concentration of organic material of the rivers Molino Norte and San Francisco (420 and 336 mg COD/l respectively).

Not taken into account in these calculations is the fact that a large number of the coffee farmers do have some form of treatment system that reduce COD disposal at the river. A rough estimation tells us that 90 % of the coffee farmers do have some form of treatment system for the *aguas mieles* (see chapter 6.1 on 'Wastewater treatment systems at coffee farms'). In most cases this treatment system is in the form of *pilas*, holes in the ground where the wastewater is collected, that take out a substantial part indissoluble organic material. It is unclear how much of the pollution from the *pilas* reaches the river via percolate water. If we make a very rough estimate that in this way 50 % of the COD is removed, the COD concentration of the coffee wastewater in both watersheds is around 2300 mg/l, and still exceeding the set norm of 200 mg/l. Calculations on the organic load of the rivers *Molino Norte* and *San Francisco* will then result in COD concentrations of 230 and 184 mg/l respectively. Another interesting point left out of the calculation is the self-purification effect that the rivers can have. Actually, wastewater treatment based on eco-technology is actually derived from the self-purification effect found in river streams. We will come back to these aspects later in this report.

Nitrogen, Phosphorus and Potassium (N, P and K) are the most important (macro)nutrients which can be found in the coffee wastewater. The range of total concentrations of N, P and K in the wastewater are 186 to 246; 5 to 7 and 44 to 346 mg/l respectively (de Matos, 2000). Other substances to be found in small amounts in coffee wastewater are toxic chemicals like tannins, alkaloids (caffeine) and polyphenolics.

Domestic wastewater in the rural area

The rural population of the watersheds Molino Norte and San Francisco counts 1550 and 2300 people respectively which figures increase with 65 % during the coffee harvest season when labourers are attracted to these watershed for employment in the coffee sector (calculation based on figures from Jarquin, 1997). In the rural area of the two watersheds, houses are not connected to a central sewer system. Domestic wastewaters in the rural area are mostly discharged without any kind of treatment (Figure 22).

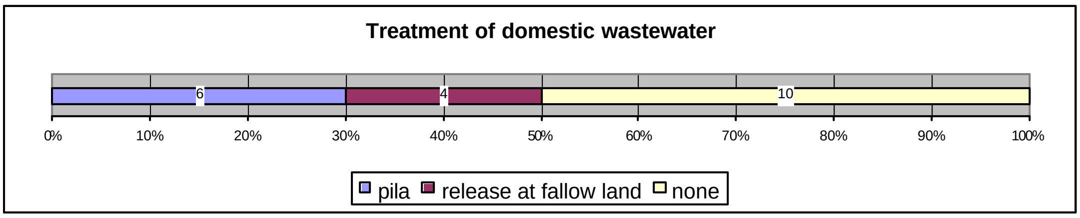


Figure 22. Treatment of domestic wastewater according to interviewed farmers

Many latrine projects have been initiated in order to avoid a direct discharge of human excrement into the river streams. In practice it is noticed that not many people make use of these latrines. Since generations people have the custom to do their stool in the open field. Many people find it unhygienic to go to a toilet that is used by many others. Beside that, it is unpractical and time-consuming for the workers in the field to walk a long distance to a latrine and they prefer a nearby location in the open field. Point here is that the concentration of rural people is highest around coffee plantations with a maximum during the harvest season when extra labour is needed and people settled near the coffee farms.

Table 6. Quantities of coliform bacteria and of faecal coliform bacteria of two samples of wells and eight samples of rivers in Matagalpa. Samples taken in January 2002 (YKL-UNAN, 2002).

Sample Point	Quantity of coliform bacteria /100 ml	Quantity of faecal coliform bacteria /100 ml
1. Los Lipes, well	8	2
2. La Cortuja, well	<2.2	<2.2
3. Aranjuez, reservoir (supply source)	9,000	1,700
4. Rio San Fernando	390	90
7. Rio El Ocote	5,000	170
9. Rio San Francisco, lower course	700	60
10.Rio Molino Norte	30,000	20
12.Rio Selva Negra	16,000	20
13.Rio San Pablo, La Suiza	160,000	24,000
14.Rio San Francisco, upper course	3,000	20

What can be expected and which also is the experience at the drinking water treatment plant, is a high concentration of coliform bacteria at the beginning of the rainy season (starting in May) when heavy rains wash away the human and animal excrements from the fields. Environmental specialists from Finland together with the local university (UNAN) have conducted several water quality analyses in January 2002. The contents of bacteria (see Table 6) indicate that the superficial waters of the *cuencas Aranjuez*, *Molino Norte* and *San Francisco* are contaminated. In *Molino Norte* the content of bacteria increases, going more downstream. At sampling point 12 (Figure 23; Annex F for description of sampling point), located in the upper course of the river a content of 16,000 bacteria /100 ml is sampled. Three kilometres more down-stream from there, at sampling point 10, the quantity is almost twice as much.

In the upper course of *cuenca* San Francisco (sample 14) the quantities of bacteria are higher than downstream (sample 9) which will be due to a polluting factor in the upper course or to dilution of the tributaries flow of the mountains and they end in the river. However, the quantity of the faecal coliform bacteria is higher downstream than upstream. The most polluted sample was taken from the river San Pablo (sample 13), of the superior course of *San Francisco*, in the area where the coffee cultivation is very intensive. From there 2,5 km toward the inferior course, at point 14, there was a considerably smaller quantity of bacteria.

These samples are taken in the month January whereas the highest amounts of faecal bacteria in the river water can be expected at the start of the rainy season (May) when heavy rainstorms wash away all excrements into the rivers. According to WHO standards concerning pathogenic microorganisms, less then 1,000 faecal coliform/100

ml are allowed for irrigation practices (depending on type of crop grown (crops likely to be eaten uncooked versus e.g. cereal crops) and type of irrigation (e.g. less direct contact with drip irrigation)). For drinking water no faecal coliform should be encountered in the water to avoid health hazards.

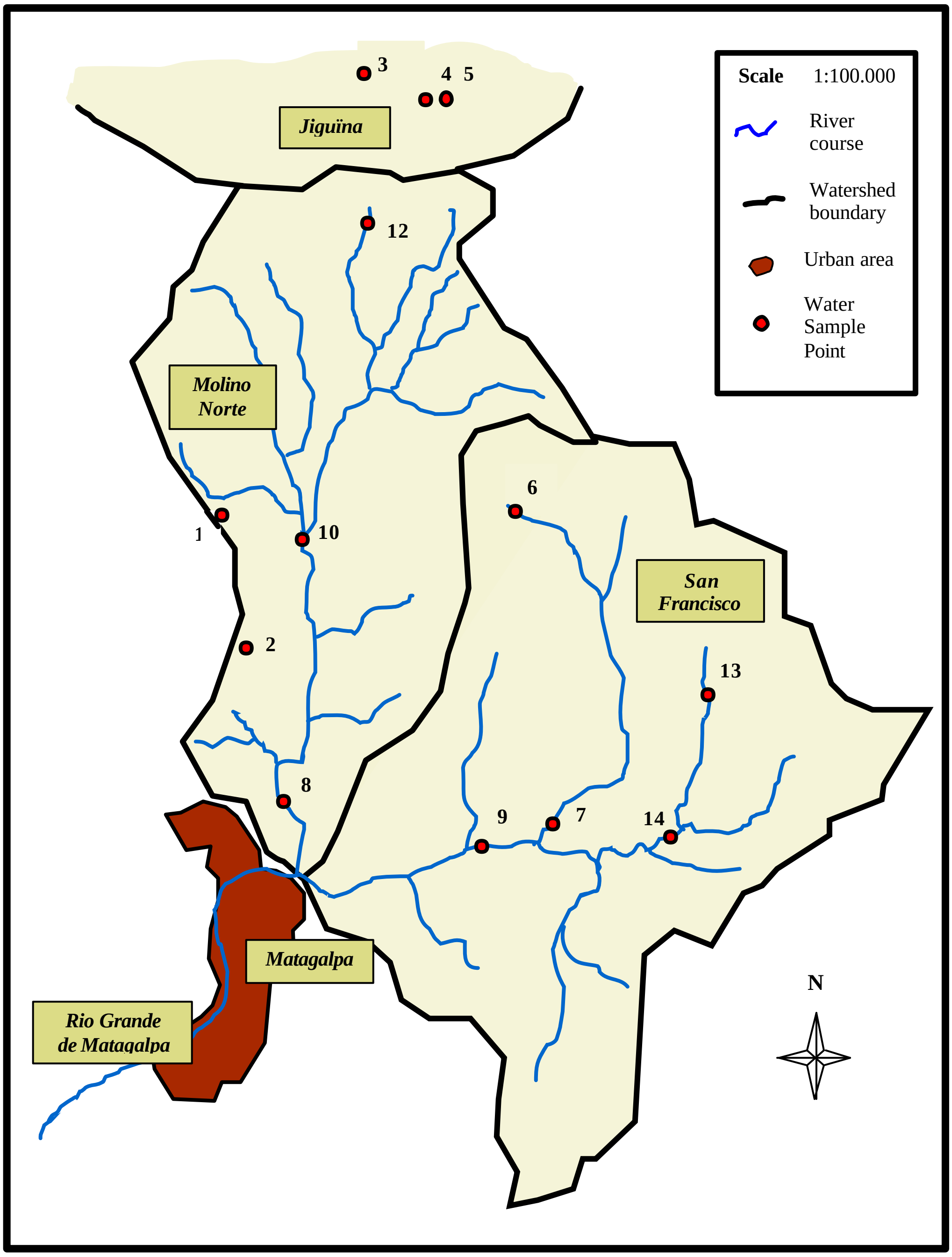


Figure 23. Locations of water sample points (Jacobi, 2004).

Pesticides in agriculture and other harmful substances for health

In the cultivation area of Matagalpa high quantities of pesticides are used, among others in the coffee, fern and flower sector. By asking farmers about the use of chemicals, 66 % of them confirm the use of some sort of chemical at their farm (see Figure 24). Main reason for those farmers who don't use any chemicals is the lack of money to buy them.

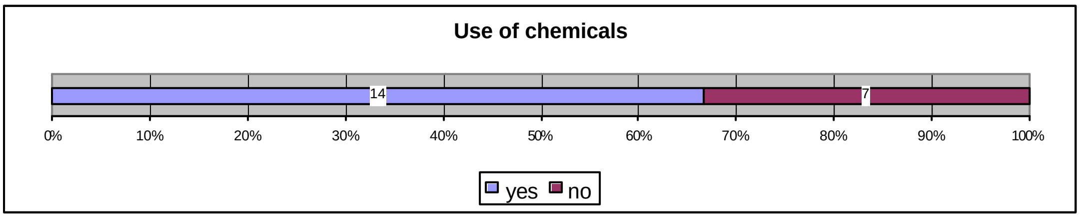


Figure 24. Responses of interviewed farmers on the questions whether they use chemicals or not

The most important demand for domestic water is that it should not cause damages for the health. Many elements dissolved in the water are important elements when encountered in very small quantities, but in high quantities they are harmful for the health. The speed of contamination of the ground waters depends for example on the thickness of the soil, on the type of grain and of the permeability of the soil, as well as on the quantity of changeable ions, the quantity of ground water and on the current speed. The speed of the decomposition of pesticides by bacterial decay also depends on the environmental temperature, soil type, acidity of the soil, as well as of the capacity of the light and of the groups of microbes to decompose the compound.

Pesticide residues like sulphates of metabolic endosulphate (a pesticide) were identified in a sample of sediments from a stream that runs through a cabbage field like as well as in the samples of the superficial soil and underground of the area where flowers are cultivated. In the superficial part of the cultivation of flowers there was also 0,09 mg/kg of indecomposable endosulphate. Near a coffee plantation in *Molino Norte* (point 10) DDT (a prohibited chemical product, see Annex G) was found, something that indicates its use at recent times. There were also endosulphate metabolites found in one of San Francisco's coffee plantations. The exact quantities of endosulphate could not be determined with the methods used, and therefore these quantities can vary a lot in those places where the residuals were found. (YKL-UNAN, 2002)

The contents of elements and anions in the underground and superficial waters are mostly low in the area of Matagalpa. The physical-chemical qualities of the waters are good in general; the content of heavy metals is also very low (see Annex H). According to the recommendations of the experts from Finland for the domestic waters (private wells) the manganese content exceeds the limit in four samples of the superficial water and the iron content in one sample of the superficial water. One of these sampling points is located in the *cuenca* of Aranjuez, in the stream that runs through the fields of ferns to the river San Fernando (sample 4, manganese content 190 µg/l). Another sampling point is located in the *cuenca* of Molino Notre in Selva Negra, at the plantation ‘La Hammonia’ (sample 12, manganese content 279 µg/l). The third sampling point is in *cuenca San Francisco* at the plantation San Pablo, in a tributary of the river San Francisco, called river San Pablo (sample 13, manganese content 229 µg/l). The fourth sampling point is also located in *cuenca San Francisco*, in the upper course of the river San Francisco (sample 14). Here the manganese content was 3190 µg/l and 1,49 mg/l of iron.

In the water of well 1 (Los Lipes) the highest electric conductivity and the highest contents of As, B, Cr, Li, Mo, P, Se, U, V, Na, Si, S, PO4, Cl, F and SO4 were encountered. In the perforated wells the contents of the dissolved substances are generally higher than the wells dug in the ground. In sample 14 (Rio San Francisco) there are the highest contents in Ba, Co, K, Mn, Ni, Sr, Ca, Fe and Mg. The manganese content is 3190µg/l while the recommendations for the domestic water in Finland say 100 µg/l. (YKL-UNAN 2002)

5.3 Impact on Drinking Water Quality

From the above-described quantification of the water quality of *Molino Norte* and *San Francisco* we now come to the impact of this situation on the drinking water quality, which is one of the main functions of the water system. But first, as already mentioned in chapter 4.2 on the water quantity, we have to consider the fact that since one year now, between 30 and 50% (depending on the season) of the drinking water supply of the city Matagalpa is coming from the Sébaco valley. This had a direct impact on the drinking water price the consumer has to pay. Before the operation of this World Bank project, the consumer paid a fixed amount per month for their drinking water consumption. Due to fact that the investments are made by the World Bank, the people were forced to pay a higher price (partially because of high transport costs and the depreciation of the pumping station). Now, one has to pay per volume consumed, whether you get your water from the central treatment plant (which means from *Molino Norte*) or from the groundwater of the Sébaco valley. This resulted in an average price increase of 3 to 4 times. A positive side effect of this price increase is the rising awareness of water use, expressed in a more water saving oriented behaviour. Finally, considering the impact of the Sébaco-project on the water quantity, there is a continuous water supply (with some exceptions) in contrast with the foregoing situation when the citizens of the city were connected only 2 times a week.

A qualitative analysis of the interviews held with the local population of Matagalpa about their experiences regarding the drinking water quality in the past and present, gave a picture of the impact of the sources of pollution. The most striking feature is that all interviewees refer to decrease of water quality during the coffee harvest season (see Figure 25). Complaints about bad odour and less taste are most common and in some cases skin irritation and a 'sticky feeling' after washing have been mentioned. These complaints are associated with the coffee wastewater production in the form of *aguas mieles* and the coffee pulp.

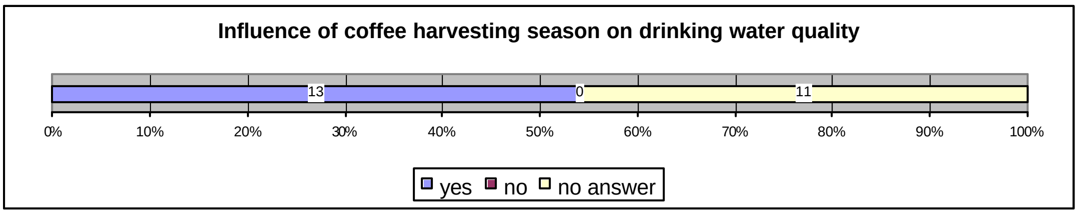
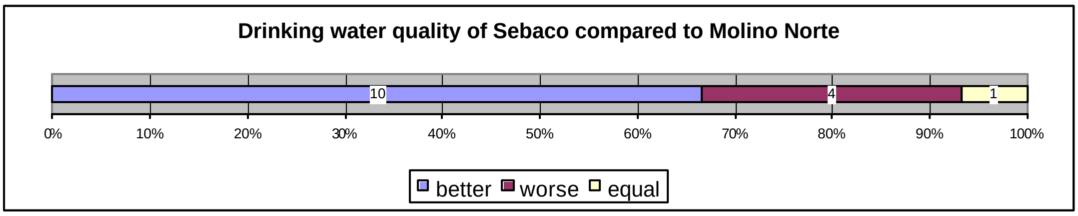


Figure 25. Influence of coffee harvesting season in drinking water quality according to residents of the city Matagalpa

Most people add the remark that the above features are of less magnitude in recent years which can be related to the fact that 90% of the coffee pulp is re-used as organic fertilizer and no longer thrown in the river streams as practiced before by all farmers (PCM, 2004).

The people living in those parts of the city that are connected to the Sébaco groundwater supply are an important source of information regarding the differences of water quality between Sébaco and *Molino Norte*. The first period after the 'Sebaco-project' was running, several respondents drinking the Sébaco-water mentioned stomach problems and they needed to accustom to a different quality of drinking water. Increased hardness ($CaCO_3$ -concentration, see Annex I) is pointed out as the main decline of the drinking water quality compared to the water coming from Molino Norte (source: inteviews). Furthermore it is said that the 'freshness' of the Sébaco water is less, which also can be expressed literally in the water temperature. This has to do with the origin of the two types of water; Sébaco as groundwater and Molino Norte being formed by springs out of a mountainous area. On the other hand, it is experienced as positive by the people connected to the Sébaco water, that there is no longer any influence of coffee wastewaters during the harvesting season, which aspect is of great weight when asking the residents about the difference in the quality of drinking water 'between



Sébaco' and 'Molino Norte' (Figure 26).

Figure 26. Drinking water quality of Sébaco compared to Molino Norte according to the residents of the city Matagalpa

In both cases (Sébaco and Molino Norte) there is the complaint about the taste of chlorine in the drinking water. Chlorine is the most commonly used disinfectant worldwide because it is highly effective against microbes, is widely available, and is inexpensive relative to other treatment options. Water from surface sources must be filtered of sediments and organic matter prior to chlorination. Chlorination of turbid water can be ineffective and chlorine can react with the organic matter to form harmful by-products such as trihalomethanes, haloacetic acids and chlorite (EPA, 2001a). Further, the amount of chlorine needed to treat all of the harmful bacteria in turbid water can far exceed safe levels for humans. In the Matagalpa case, this is mainly a problem in the beginning of the rainy season (May) when heavy rainfall causes high levels of pathogenic micro-organisms and sediment loads (turbidity) at the entrance of the central treatment plant (confirmed by the operational manager of the treatment plant). Besides, the addition of an extra amount of chlorine in the drinking water system can cause the forming of harmful chlorinated hydrocarbon (see Annex J for the amount of chlorine additions).

The potential impact of the high COD content (as calculated in chapter 5.2) of the untreated water of *Molino Norte* during the coffee harvest season (Nov.-Feb.) caused by wastewaters discharged in the river, is an insufficient COD removal. This means that dissolved organic material can be found in the drinking water networks, which in addition can cause the growth of bacteria in these networks.

Finally a remark on the impact of the pollution caused by pesticides used in agriculture, particularly at the fern plantations, to stress its negative effect on the health of human beings. According to an investigation in the years 1994-1995 (Beck, 1996) the inhabitants of Matagalpa suffered of the poisoning effects caused by pesticides, and this way they occupied the second worst place of Nicaragua. The Ministry of Environment and Natural Resources, MARENA, held a discussion this year (2004) about the serious quality problems of the river Aranjuez (caused by pesticides used at fern plantations in that area) from where water is pumped in the dry season. Main question was whether to pump water from this river into *Molino Norte* taking into account its pollution. After visiting the pumping station it was clear that also this year water is pumped from this water source, probably a decision that is made in order to answer to the high drinking water demand of the city Matagalpa.

The following can be concluded from the above-described quality analysis. Agricultural practices such as coffee processing, livestock farming and the use of pesticides together with the influence of waste that is produced by the people themselves (e.g. soap, excrements), are the main sources of pollution that have an influence on the river water quality and thus on the drinking water quality.
Calculations show a very high concentration of COD of the coffee wastewater (2300 mg/l after existing treatment) resulting in a high concentration of organic material of the rivers *Molino Norte* and *San Francisco* when these wastewaters are mixed with these water streams (COD content of 230 and 184 mg/l respectively, calculated with taking into account already existing treatment systems but without the self purification capacity of the river). Furthermore, at the beginning of the rainy season (starting in May), when heavy rains wash away the human and animal excrements from the fields, a high amount of pathogenic micro-organisms in combination with sediment loads is encountered at the entrance of the central treatment plant. The result is a decrease of drinking water quality, especially during the coffee harvest season. Complaints about bad odour and less taste are most common and in some cases skin irritations have been mentioned.
Because of high COD concentration during the coffee harvest season, which coincides with the dry season, there is potential of insufficient COD removal, resulting in dissolved organic material in the drinking water networks, which in addition can cause the growth of bacteria in these networks. Finally, the impact of the pollution caused by pesticides used in agriculture, particularly at the fern plantations, has a serious negative effect on the health of human beings.

6. Existing Wastewater Treatment Systems

Efforts to improve living conditions and environment, although small scale, do have their effects. Every square meter that is reforest contributes to more water holding capacity in the area. People get more aware of the importance of proper land use and treating water in a responsible way due to existing education programs. Various responses to the negative impacts of wastewater production on the water quality were introduced in the form of different treatment systems varying from simple holes in the ground (*pilas*) to more advanced systems like the bioreactor. At a few farms there is more attention towards recycling of sources. Coffee pulp is a good organic fertilizer for the plantations and already applied this way at a major part of the *fincas* situated in the study area. Recycling of the wastewater means a decrease of the fresh water use for the coffee bean process. Since a few years new water treatment techniques that reduce the amount of pollution of the process water are applied in the two cuencas.

6.1 Wastewater Treatment Systems at Coffee Farms

In the watersheds of Matagalpa there are 63 (part-time) coffee farmers, of which 15 farmers possess larger plantations that are responsible for 95 % of the coffee production in this area. Already 90 % of all coffee farmers recycle the solid coffee-pulp in the form of organic fertilizer. Since MARENA has set a norm for a limited discharge of coffee wastewater into the water streams, many farmers have taken measures. So-called *pilas*, holes in the ground, are constructed at the majority of the coffee farms in which the *aguas mieles* are collected. This relatively cheap construction has the function to let infiltrate and evaporate the wastewaters. Calc is added to bring down the pH and to reduce smell. Although dissolved organic materials still reach the ground water and finally the river stream, its results is in a strong reduction of COD discharged to the river. During field visits it became clear that many *pilas* have no sufficient capacity during the peak period of the coffee processing. This means that, although forbidden, still untreated coffee wastewaters are dumped in the river. This is confirmed by *Proyecto Cuencas Matagalpa* who also subscribes the lack of personnel at MARENA to carry out adequate controls.

In this area the Upflow Anaerobic Sludge Blanket (UASB) biogas reactor has been introduced at 6 larger coffee plantations of which 4 are still functioning. Proper operation of existing wastewater systems is needed in order to cultivate and maintain a healthy population of bacteria that are responsible for

Textbox 3. Installation Bioreactors

In 1986 a project called 'Biogas and use of agricultural waste-products' was initiated with the goal to promote the use of wastes from agriculture and cattle as alternative energy sources to reduce the consumption of fuel woods and so six UASB-bioreactors were built.

In 1987 they saw the possibility to adapt this technology to treat wastewaters of the wet coffee process. The technical feasibility to use an anaerobic treatment for the aguas mieles was tested in a laboratory and in a pilot project. This resulted in a proposal towards Novib with the goal to use bioreactors for the treatment of coffee wastewaters.

The project consisted of the development of the UASB technology and in the period between 1988-94 four UASB's were constructed and installed at coffee plantation with a harvest from 16 to 184 tons of green beans per year. At the moment two more coffee farmers are interested. (PCM, 1994) the wastewater treatment. Experience has shown that when left to the coffee farmers the reactors do not receive the proper attention. It is difficult for coffee farmers to monitor important parameters such as COD, VFA, alkalinity, pH and wastewater flow. And the coffee production itself has the highest priority. In order to overcome these type of logistical problems each coffee growing region should have a support organization - like the one being set-up successfully in Matagalpa - which sends technicians out to the coffee farms to help with the operation of the reactors. The technicians collect samples from the anaerobic reactors and monitor the flow of the wastewater. The samples are processed in a central laboratory and the results are evaluated by wastewater engineers. Based on the lab test results, recommendations for changing the operation are made. In addition of an effective treatment of the wastewater (up to 80 % COD reduction, Annex K), biogas (methane) is produced, which by-product can be and is used as a fuel. During the harvest season, many laborers (at big farms up to 700 people) have their warm meals, heated with the help of this biogas.

'La Hammonia'

Figure 27 below gives an overview of the water cycle at the plantation 'La Hammonia' which is a good example of an integrated treatment process. Here we first have to emphasize the exceptionality of the 'Hammonia-case'. The German owners of this large plantation have been here for five generations and expanded the location to what is more than just a coffee plantation. Besides coffee you can find cattle and chickens and greenhouses where flowers are grown. Because of the beautiful natural setting close to a protected native forest, they have been able to set up hotel and a restaurant where among others their own products are served. This all means that they have the capital to do investments and are able to survive when one of the sectors (like the coffee sector which is facing low international coffee prices at the moment) is not doing well. Besides treating wastewaters, their natural treatment system fits in their ecological philosophy of which the attraction of tourist is one of the spin-offs.

At the beginning of the treatment chain, the crust formed on the aguas mieles is removed and used as organic fertilizer. At the second reservoir, NaOH is added to neutralise the wastewater to a pH of 6-7, which is necessary for an optimal operation of the bacteria inside the (anaerobic) bioreactors.

A regulator determines the inflow of the two anaerobic reactors and varies between 5 to 10 l/s per reactor. After the two reactors a pump is installed that recycles the treated water partially back to the neutralisation tank. In this way, less NaOH is needed for lowering the pH and thus operation costs are reduced, as the use of NaOH is the major operating cost of the whole chain. Around 50% of the water is recycled this way, depending on the pH of the incoming wastewaters.

Further down, filtering and an aerobic treatment take place followed by two lagoons, which function is to regulate the outflow, depending on the discharge of the irrigation system at the end of the chain. Pasture (9 ha) is irrigated by a sprinkler system during the months December-April. Before the water is used for irrigation, it is once more treated by a bio-filter, a lagoon with shallow water plants where oxidation takes place. Also the washing water from the cowshed, from the chicken stable and wastewater of the slaughterhouse is led to this bio filter for treatment (an extra of approximately 1000 l/d). From there the water is distributed by gravity again to three smaller reservoirs from where it leaves to three different sides by tubes for irrigation purposes. After 3 years of trials and errors, this is the first year (2004) the whole chain functions well. The water is treated in such a way that is can be used very well for irrigation and any discharge of wastewater to the river is avoided.

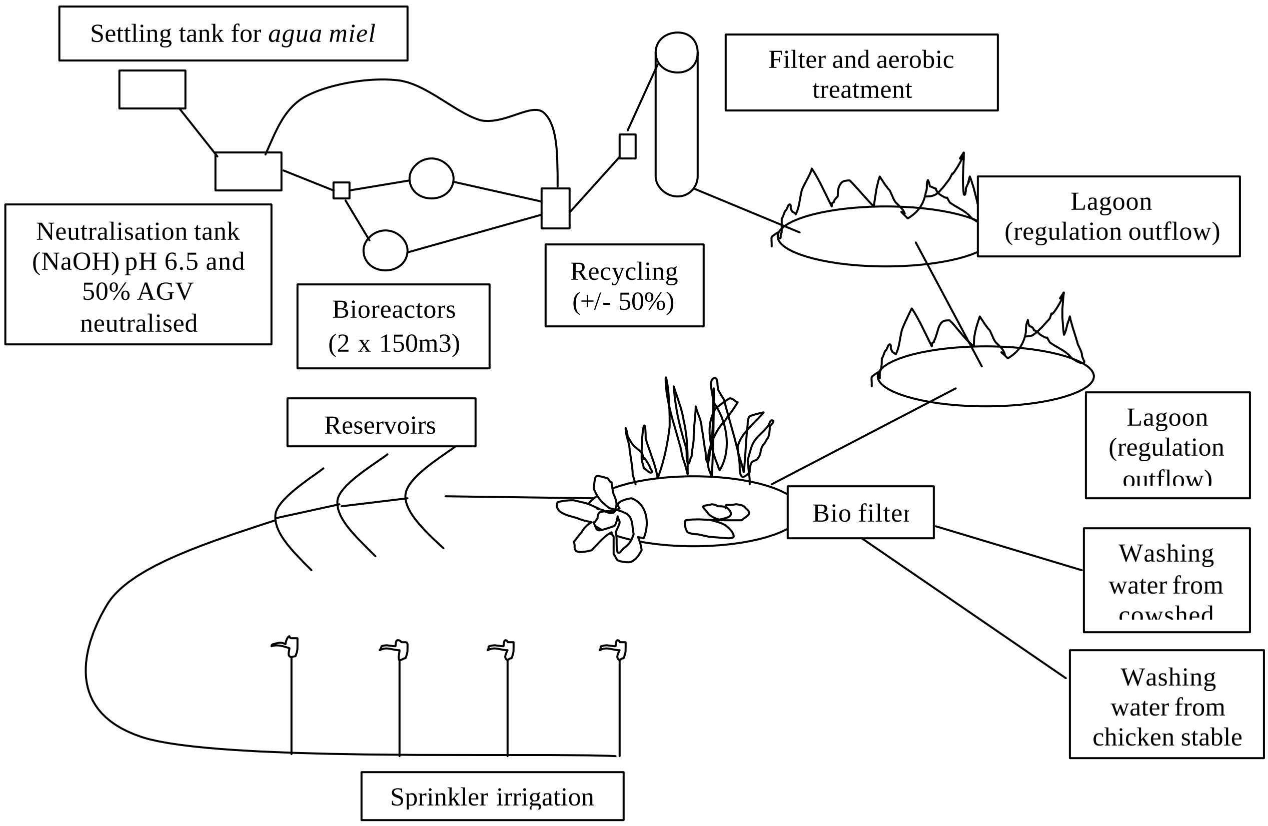


Figure 27. Overview of the water cycle and its treatments at the plantation 'La Hammonia'

To neutralize the coffee wastewaters, NaOH is used and not the cheaper calc. This is because the bioreactors use volcano rocks as habitat for the bacteria. Using calc in the wastewater would eventually fill all the little holes of the rock and the wastewater passes without treatment. In addition, there is a risk that pipelines will be clogged when using calc.

Latrines

To avoid high concentrations of pathogenic micro-organisms in the river streams, numerous projects have been working on the implementation of latrines. In these toilets black water (urine and excrement) is collected and composted. Since the 1980's several hundreds of these latrine have been installed. But in practice it less then half of them are actually used. By questioning people about not making use of the latrines it becomes clear that they consider it as unhygienic to sit at such a place where many other people (*todo el mundo*) stoop. Besides, coffee pickers working in the field experience it as very unpractical to walk a long distance to a latrine and prefer the open field. This is a practice of many generations and is difficult to change.

6.2 Drinking Water Treatment Plant

The majority of surface drinking water supplies in Nicaragua that receive treatment, uses a combination of filtration, settling basins, aeration, chemical additives (to assist in contaminant removal), and chlorination. Water from surface sources is filtered of sediments and organic matter prior to chlorination.

Treatment plants, such as the one in Matagalpa (Figure 28), also use other chemicals to remove bacteria. For example, aluminium sulphate and calcium oxide are added to the water in specified amounts during the treatment process, based on the quality of the influent water. These chemicals act as coagulants, and promote removal of suspended sediment, thereby enhancing the treatment process.

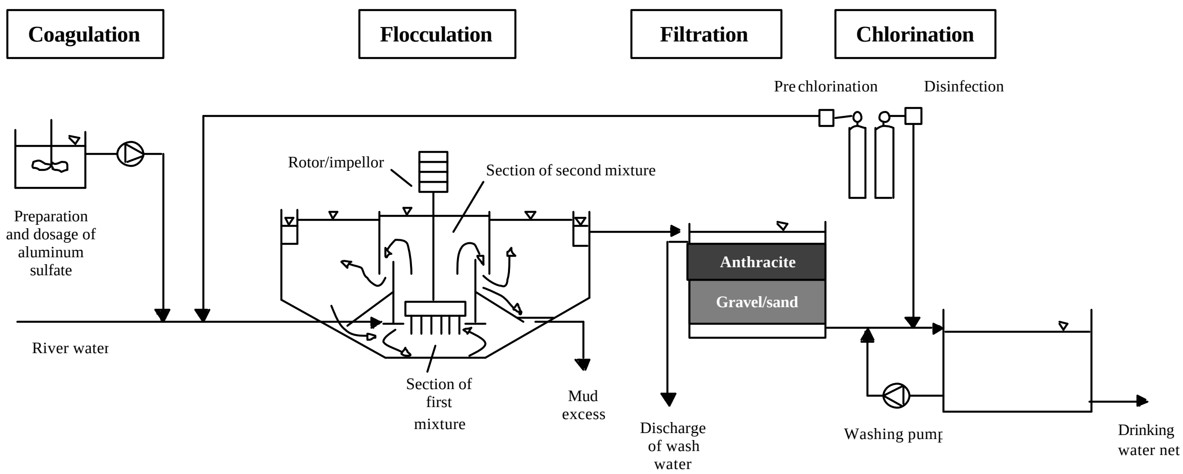


Figure 28. Scheme of the (physical-chemical) main treatment plant for the drinking water supply of the city Matagalpa

It is important to note that typical water treatment systems for either surface or ground water supplies do not remove some categories of contaminants, particularly nitrates, organic chemicals, and dissolved metals. For example, a drinking water source contaminated with agricultural chemicals, namely fertilizer and pesticides, or with metals like arsenic or copper from a mining operation, would not be cleansed by treatment processes that remove microbes. Prevention and management of pollutants in a source water area, therefore, play a key role in helping to protect drinking water (Horsley et al, 2002).

6.3 Drinking Water Treatment at Home

For people who do not receive treated drinking water from a public water supply system, simple filtration methods can be helpful. A sand filter can remove many contaminants from a surface supply of drinking water, including clays and silts, some micro-organisms, natural organic matter, iron, and magnesium. Sand filters can be used in individual homes or by small groups of several nearby households, as is done in some households in the Dipilto River watershed north of Ocotal (a nearby *cuenca*). They can also be installed to serve a larger number of people, such as occupants in a hotel or workers at a coffee farm. Coffee plantation ‘La Hammonia’ in Matagalpa uses sand filtration to treat water near its source on the mountainside before it is delivered to the hotel and the workers' community.

After water has been filtered, it is possible to disinfect it at home with chlorine, which can be purchased in liquid form in local stores. It is extremely important that people read, understand, and follow the directions for using this type of disinfectant because chlorine and its by-products can be toxic to human health if used improperly. While chlorination affects the taste of water, and may be objectionable to some people, the benefits of its use far outweigh the risks of exposure to microbes in drinking water (Horsley et al, 2002). Many people who can afford it financially buy purified bottled water at stores to avoid any risk (Figure 29).

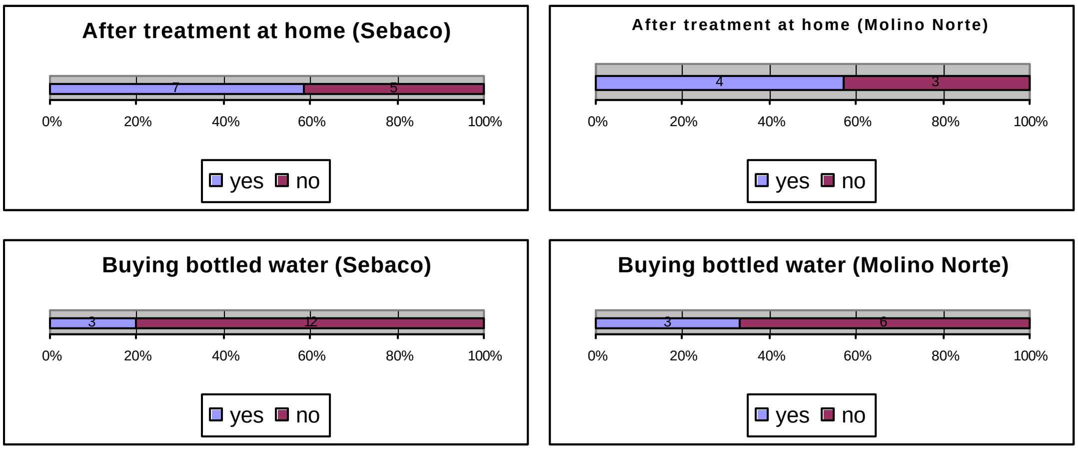


Figure 29. First two figures showing percentage of residents who treat their drinking water at home before drinking. Last two figures show percentages of those who buy and don't buy bottled drinking water

Of those interviewed people of Matagalpa who treat their tap water before drinking it (see figure 29 above), most mention the addition of chlorine as type of treatment. In some cases filtering is mentioned and only two times people spoke about boiling the water. In the same figure we see that 33% of the people receiving drinking water from Molino Norte buy bottled water whereas of those receiving their water from the Sébaco valley, this percentage is only 20. It must be said that this is not a direct reflection of the perception on the difference in drinking water quality of the two different water sources, as those people obtaining their water from *Molino Norte* live at the city centre where in general the wealthier part of the population lives. And thus, people living in the city-centre are more capable of buying bottled drinking water.

6.4 Sewage Treatment Plant

The sewage treatment plant treating the domestic wastewater from the city exists of various reservoirs where (among others) anaerobic processes take place before the water is released to the *Rio Grande de Matagalpa*. An extension of its capacity is planned for the year 2010. Till now only about 20% of the sewage water from the city Matagalpa is treated which is causing problems more downstream the *Rio Grande*. Here people use the water again for domestic purposes and in some cases as irrigation water of vegetables. Also some fisheries are affected by the contamination of the water and it is causing health risk for the local population.

DPSIR-analysis and discussion

The conclusions, which can be drawn from the results of the water quality aspects, can be expressed by using the DPSIR-analysis. As *driving forces*, which are mainly expressed as direct sources of water pollution, we can distinguish three main factors that have their influence on the water system which are: the coffee production, human and animal excrements and the use of pesticides. From these (land-based) activities there is a *pressure* on the water system in the form of wastewater production. The actual situation (*state*) concerning the water quality of the two *cuencas* is that water streams are polluted, expressed in high COD and nutrient concentration mainly caused by the coffee wastewaters. Furthermore residuals of pesticides are found in the rivers and high concentration of coliform bacteria due to excrements, which are washed away from the field into the river courses. The combination of deforestation and heavy rainfalls at the beginning of the rainy season causes high sediment loads.

The drinking water quality *(impact)* is based on the results of calculations and partially on a qualitative analysis derived from interviews conducted with citizens of the city Matagalpa. The potential impact of the high COD content of the untreated water of *Molino Norte* during the coffee harvest season (Nov.-Feb.) caused by wastewaters discharged in the river, is an insufficient COD removal. This means that dissolved organic material can be found in the drinking water networks, which in addition can cause the growth of bacteria in these networks. Turbidity of the river water causes even more difficulties in the removal of organic material. From interviews we can derive the conclusion that most people experience an effect on the drinking water quality from the coffee wastewater during the harvest season resulting in bad taste and odour and skin irritations. Health risks are caused by the poisoning effect of chemical residues in the water originating from pesticides, which are especially used in large quantities at the fern plantations. In addition, at the beginning of the rainy season when human and animal excrements are washed into the rivers, high concentration of coliform bacteria form a serious quality problem.

Responses came in the form of (small-scale) reforestation programs by *Proyecto Cuencas Matagalpa* in cooperation with the Ministry of Forestry (MAGFOR). Of the interviewed people, about 60 % treat their tap water (coming from both Sébaco and Molino Norte) in some way (mostly by adding chlorine) before drinking it. Those who can afford it buy bottled water. At farm level we see the introduction of bio-reactors for the treatment of (coffee) waters. Only four farmers are working with this technology whereas on the other hand, most farmers partially treat their coffee wastewater with the help of simple to construct *pilas*. At large scale coffee pulp is reused in the form of organic fertilizer avoiding extra pollution of the river flows. From political level there is set pressure on farmers with regard on wastewater disposal by setting a norm of maximum COD concentration.

In Figure 30 below, the DPSIR-analysis is set out in a schematic overview. Questions coming forth from this outline about the actual situation of the water quality in the study area are in the direction of future trends. In the case of the new norms on wastewater disposal set by the Ministry of Environment and Natural Resources (MARENA), it is a fact that there is a lack of personnel to really do adequate controls on this aspect. Furthermore, changes in landuse on the long term are difficult to predict but can be of great influence on wastewater discharges and thus on the water quality of the watersheds.

And finally, most coffee farmers do have a simple form of coffee wastewater treatment (*pilas*, of which many are actually undersized), but how can these treatments be improved in the future? Or in other words, how can a coffee farmer, who is lacking capital for investments, be persuaded to install a good working wastewater treatment system? Or is this more a task of other stakeholders? We come back on these questions in the next chapter about the potential of eco-technological treatment systems and in the discussion part of the last chapter.

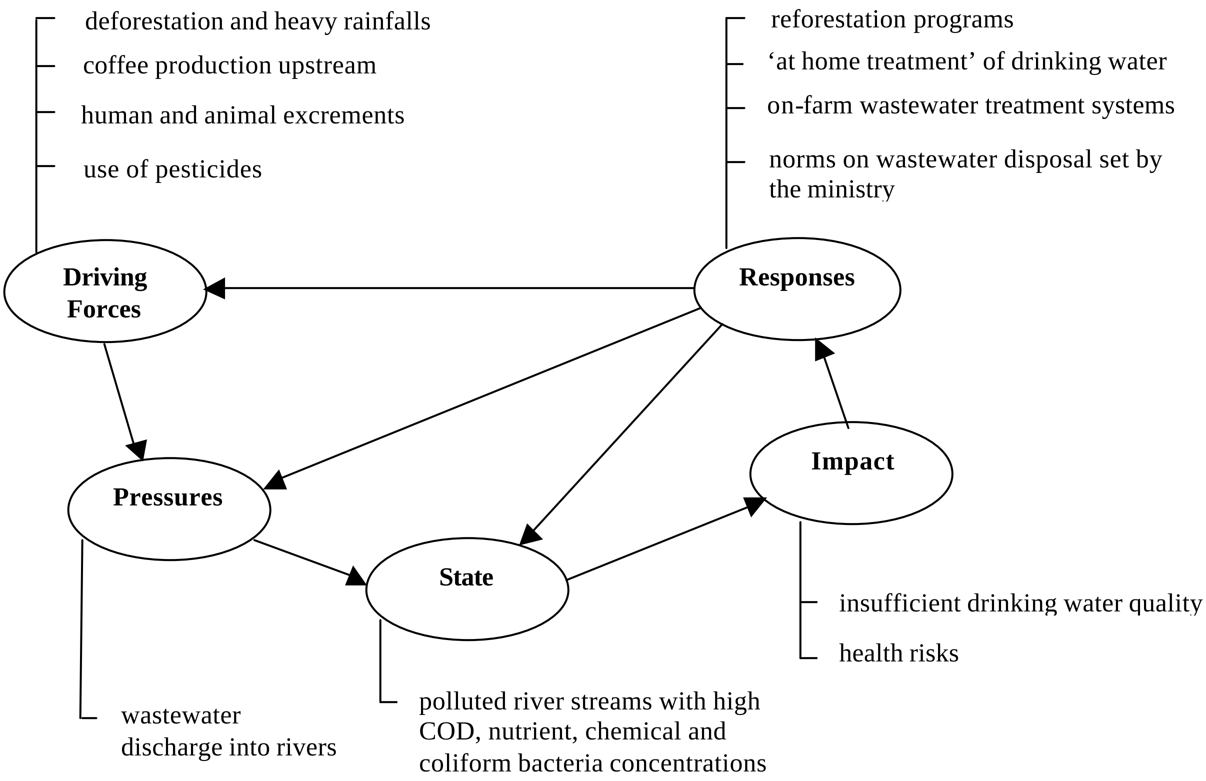


Figure 30. Schematic overview of the DPSIR-analysis on the drinking water quality

7. Potential of eco-technological wastewater treatment systems

Exploring and mapping the potential of eco-technological wastewater treatment in developing countries has a dual motivation. First of all, eco-technological wastewater treatment integrated with the use of effluent is generally cheaper than conventional treatment and can be implemented and managed more easily by the developing countries themselves. Secondly, eco-technological wastewater treatment with direct or indirect use of effluent is generally, more or less controlled (sewage collection systems and wastewater treatment) or uncontrolled (illegal, unguided, or unplanned direct and indirect use of raw, partially treated or diluted wastewater has been practiced for years without professional concern for the hazards (Martijn and Huibers, 2001b)), a daily practice in developing countries.

As such, the further development of these practices is the most feasible way to ascertain widespread wastewater management because it builds on existing experiences and capacities. For the sustainability of the latter it is crucial that developing countries themselves can copy, operate and manage systems according to their own capacity and needs (Mels, 2003). The requirements for sanitation systems in developing countries tend to match quite well with the principles of ecological engineering, such as (after Rose, 1999):

- Low to no use of electricity (or energy) because it isn't (reliable) or available;
- Permanent and continuous operation without too much interference and with more or less constant efficiency/effluent quality (i.e. robust system);
- Easy to operate without high skilled operators.

Constructed wetlands, as a type ecological engineering, are often forwarded as one to the most promising. Denny (1997; in Haberl, 1999) has mentioned thee reasons for the relatively slow spread of constructed wetlands to developing countries, which may actually be applicable to the slow spread of ecological technologies in general:

- Aid programmes from developing countries tend to favour technologies which have commercial spin-off for the donors;
- Developed world advisors are often unable to transfer their conceptual thinking to the realities and cultures of the third world;
- Rather than assisting developing countries to develop their own technologies the tendency has been to translocate northern designs to tropical environments.

The principles of re-using not only the water (volume), but also the nutrients still present in the wastewater will help to bring the nutrient cycles in balance, as stated by Gijzen & Mulder, 2001: "while the world population doubled between 1960 and 2000, the production of fertiliser nitrogen increased almost tenfold from 1 to $9x10^{10}$ kg/year. Current production is equivalent to about 37 % of the total amount of nitrogen input achieved via terrestrial and marine biological N_2 fixation (about $24x10^{10}$ kg/year)". To say the least it is an encouragement for re-use of nutrients, separation of wastes at the source, etc. (Mels, 2003).

Table 7 presents the types of treatment systems considered as natural (after Metcalf and Eddy 1995, Rose 1999, and Feigin et al 1991). The general physical features, design objectives and treatment capabilities of systems presented in this paragraph are well documented by various authors and well summarized by Mels, 2003. Here follows only short descriptions and sub-divisions of the various types of natural treatment systems.

Table 7. Overview of eco-technological wastewater treatment systems (Mels, 2003)

Principle of treatment	Type of system	Sub type
Land based treatment	Slow rate infiltration	
	Rapid infiltration	
	Overland flow	
Aquatic based treatment	Natural wetlands	Free water surface
	Constructed wetlands	Free water surface and sub-flow systems
	Stabilization ponds	Anaerobic, aerobic and facultative pond system
	Aquatic plant treatment	Floating plants such as water hyacinth and water lettuce
	Aquaculture	Fish farms, duck weed farms and algae ponds

Land-based treatment systems

Slow rate infiltration is the application of wastewater to vegetated land where surface runoff is usually collected and re-applied to the system. There are two sub-types of slow rate infiltration systems:
-Sub-type 1: the principle objective of infiltration is wastewater treatment by means of evapotranspiration and percolation through the soil profile.
-Sub-type 2: the principle objective of infiltration is direct water reuse for the purpose of irrigation.

Rapid infiltration is the application of pre-treated wastewater to land by spreading basins or high-rate sprinkling, with wastewater treatment as principle objective. The percolated wastewater may serve several purposes like: groundwater recharge and recovery by underdrains.

Overland flow or runoff systems apply pre-treated wastewater on graded and vegetated slopes, ranging from 30-100 m (2-6%), with low permeability to flow to runoff collection ditches at the bottom. When used as secondary treatment system, overland flow is not so efficient in reducing P levels and on a whole it is generally more efficient under warm weather conditions (after Feigin et al. 1991).

Aquatic-based treatment systems

Similar to land based treatment the sub-division of the aquatic-based treatment systems are not strict system definitions and many aquatic based applications consists of a mixture of various types of treatment and reuse principles and objectives.

Natural wetlands are generally considered as receiving surface water and are limited to polishing of secondary or advanced treated effluent with the principle objective to enhance existing habitats.

Constructed wetlands (CW) can be subdivided in free water surface and sub surface flow systems. Sub surface flow systems, also referred to as 'root zone systems' or 'rock reed filters' are channels or trenches designed with the objective or secondary or advanced levels of treatment. Primary treated wastewater is distributed over the wetland through surface or sub surface drainage pipes and is filtered through the sandy or rocky medium. Effluent is removed through sub surface drains.

Stabilisation ponds are large shallow basin in which wastewater is treated by natural principles. Waste stabilisations ponds were advocated by the WHO (1989) as suitable and affordable wastewater treatment systems for developing countries, intended to induce at least some form of treatment rather than disposal or use of raw wastewater. Usually the main objective of the pond is not the removal of organic material, but the removal of pathogens and/or nutrients.

Aquatic plant treatment uses floating or submerged aquatic plants that can be used with the objective to provide secondary or enhanced levels of treatment and beneficial use of the produced biomass. Treatment is usually done in parallel basins or channels. Floating aquatic plant systems are similar in concept to the constructed wetland systems except that the plants are floating species such as water hyacinth, water lettuce and duckweed. Water depths are typically deeper than wetland systems, ranging from 0.5 to 1.8 meter. (Metcalf and Eddy, 1995)

Aquaculture is aimed at growth of fish and other aquatic organisms or biomass, for the production of food sources. It is used in a variety of operations around the world, especially in developing countries where the main objective of the system is food and biomass production while wastewater treatment is a mere side benefit. Forms of aquaculture are fish farming, duckweed farming and algae farming.

The (cost-) effectiveness of eco-technological solutions will depend on a number of system-specific boundaries (Mels, 2003). As described in the previous chapter, 90 % of the farmers do have a coffee wastewater treatment system in the form of *pilas*. Although the efficiency of these systems in terms of COD removal are doubtful, at least they are easy to construct, have low investment costs and are easy to maintain and operate. These conditions are of great importance for (especially small) farmers who lack capital. *Pilas* can be classified as a *slow rate infiltration* system of sub-type 1 where the principle objective of infiltration is wastewater treatment by means of evapotranspiration and percolation through the soil profile. Sub-type 2 of this type of treatment, in which the principle objective of infiltration is direct water reuse for the purpose of irrigation, is less relevant under the existing conditions in the study area. Not many irrigation practices are noticed in the field which explanation is twofold: the coffee plant, as one of the main crop in the area, doesn't need irrigation, as the yearly rainfall is sufficient; secondly, the two watersheds *Molino Norte* and *San Francisco* cover an area with hill slopes ranging between 4-75 % which makes the application of irrigation practices very complicated (see Annex L for slope, profundity and texture of the soil). *Overland flow or runoff systems* are not applicable, as they require slopes of 2-6%.

Natural wetlands do not exist in the mountainous area of the watershed *Molino Norte* and *San Francisco.* When thinking about *constructed wetlands*, land availability is often the bottleneck when considering a decentral placement of such a system. Constructed wetlands cover a relative large surface area to make them functional and this will be at the cost of cultivated land. The application of a constructed wetland system would appeal for the use of communal land. Assuming that the riverbanks are such communal lands, this could be an ideal location with mutual functions. Beside the function of wastewater treatment, it can serve as a buffering zone for sediments, coming from the hill slopes, to settle down and in this way avoiding the mentioned problem of turbidity. Apart from the quality aspects, the wetland can function as a basin to store water, which is desirable in the case where river discharges strongly fluctuate within a year and over the years. High and low peak discharges of the river system during the year are levelled out, which can contribute to a more secure drinking water supply during the dry season.

To avoid too high COD concentrations and concentrations of toxic chemicals of wastewaters before entering a wetland system, adequate pre-treatment of wastewater is necessary. Anaerobic pre-treatment may play a key role in the treatment scenario to be selected. The use of Upflow Anaerobic Sludge Blanket (UASB) has many advantages such as minimal surface area required and, especially for hot countries like Nicaragua, it prevents high evaporation losses that may increase the salinity level of the effluent. Focus should be at the larger coffee plantations where the best results can be achieved in the sense of COD removal. In additions, these are the places where the produced methane gas (by-product of the processes taking place in the UASB) can be used in an optimal manner, namely as fuel for cooking activities needed to serve hundreds of labourers hot meals during the harvest period. Strong point for the Matagalpa case is the fact that the UASB technology has already been introduced in this area and that PCM has experience in giving technical assistance.

Pilot project Vietnam

Another example of coffee wastewater treatment with the aid of eco-engineered technology is a pilot project in Khe Sanh, Quang Tri, Vietnam described by von Enden and Calvert (2002) and pretty much resembles the existing treatment system at the coffee plantation 'La Hammonia' in Matagalpa. At the pilot project site they are testing for semi-washed coffee including finish fermentation and washing where at times of peak production around 100 tonnes fresh cherry are processed. Average water consumption has been brought from over 10 m³/tonne cherry down to around 4 m³/tonne cherry processed through recycling and reuse of processing waters (at 'La Hammonia' this recycling process has been stopped as it had a negative impact on the coffee quality). Total effluents reach 400 m³ a day at peak times.

The treatment system consists of an acidification pond (200 m³), followed by a neutralisation tank (25 m³) filled with ground limestone. After neutralisation of wastewater to pH 5.9 to 6.1, water is treated alternatively in an Upflow Anaerobic Sludge Blanket (UASB) biogas reactor before entering a constructed wetland planted with macrophytes for secondary treatment. In this treatment method, dissolved oxygen levels in the water are increased through diffusion of oxygen in the root zone of the macrophytes growing in the flooded gravel bed. The additional oxygen supplied is speeding up the aerobic decomposition of remaining organic matter. The water levels in the wetlands may also be artificially raised and lowered to assist the oxygen flow. In addition to aerobic bacteria close to the roots of the plants, anaerobic decomposition can also take place in a wetland. A construction of wetland is able to remove up to between 49 and 81% BOD loadings and lower the amount of suspended solids between 36 and 70% depending on initial BOD loadings and retention time (Biddlestone et al, 1991). In addition, macrophytes remove nutrients and salts from biogas digester effluents.

For tertiary treatment, wastewater runs through a water hyacinth (*Eichornia crassipes*) pond for water polishing before entering the open waterway. Water hyacinth are particularly active in the removal of both bacteria and heavy metals. In addition, fresh water inflow into the water hyacinth pond dilutes the organic loadings (von Enden and Calvert, 2002).

Biomass production

Treatment of wastewaters and biomass production maybe integrated and may form an attractive economic activity. This is important when realizing that farmers lack the money (now even more with a low international coffee price) to invest in wastewater treatment systems and besides, they are very little motivated. MARENA has set norms on wastewater disposal but there is a lack of staff members to carry out adequate controls resulting in the fact that restrictions on wastewater discharges are not (yet) complied with. To stimulate farmers in investing in treatment systems, valuable biomass productions can play an important role. As already mentioned, *aquatic plant treatment* and a*quaculture* are interesting options for the production of fish and other aquatic organisms or biomass, for the production of food sources. In the case of wetlands, one can think of the production of reed, which can be converted into charcoal, a widespread used fuel. Not mentioned in the above described natural treatment systems is the use and production of tree species. Besides the functions of wastewater purification, water holding capacity and erosion prevention, trees have a high economical value. Textbox 4 below describes an example of the set-up of biomass production in the form of hardwood tree species with the aid of coffee wastewater in Australia.

Stakeholders

Multiple-objective wastewater management schemes are more complex than conventional mono-objective facilities because they incorporate treatment of wastewater for both pollution control and the supply of effluent for various uses. Tackling this complexity is necessary if responsibilities for a sustainable closing/protection of the water cycle are to be acknowledged. An advantage of the integrated approach is that, once multiple benefits and beneficiaries of wastewater reuse are recognised, additional options may be available for sharing project responsibilities and costs among projects sponsors (after Asano and Mills 1990, in Metcalf and Eddy, 1995). Water users, for example, could be involved through the ‘polluter pays’ principle and by accepting source control facilities such as for separation of waste-flows. On the other hand, contributions from effluent users and the government can be negotiated, such as making land available for wastewater treatment facilities. The above illustrates that planning for the treatment and use of wastewater is governed by social-political-economical issues. In the ideal case this would be an iterative process concerning the involvement of stakeholders (Mels, 2003).

Local institutional capacity and willingness to work on solutions are important factors regarding the described issues. Annex M gives an overview of the relations between the stakeholders that are involved in water related issues within the study area. It is clear that PCM with 21 representatives of different institutions plays a central role. Questions arise on those who are responsible for a secure drinking water supply. What role can the semi-privatised drinking water company play and what can be expected from initiatives from the side of the farmers regarding the application of eco-technological treatment systems? We come back on this discussion in chapter 9.

Textbox 4. Example of biomass production in the form of hardwood tree species with the aid of coffee wastewater in Australia.

The Queensland Department of Primary Industries and Fisheries (DPI&F) recently developed a drip-irrigated native hardwood tree plantation at the Nestlé Gympie coffee factory. This innovative approach, designed and managed by the DPI&F, has resulted in the implementation of an environmentally sustainable solution to managing industrial waste.

The Nestlé Gympie Factory, based in Queensland, is the largest coffee factory in Australia, producing nearly 10,000 tonnes of instant and roast & ground coffee per year. One of the by-products of coffee manufacture is coffee wastewater, which is similar in colour and consistency to a cup of very weak black coffee. Since 1987, Nestlé Gympie has been irrigating this coffee wastewater via travelling irrigator onto a 14ha pasture, which is grazed by cattle. This method is a convenient and effective means of wastewater disposal, but Nestlé Gympie Factory was concerned with the long-term sustainability of pasture irrigation.

A number of trials commenced in 2002, including determining the effectiveness of growing trees and wetland plants with coffee wastewater, various methods of solids removal, and water reuse within the factory.

One of the first improvements made by Nestlé Gympie Factory was the installation of a triple effect wastewater evaporator. This allowed some of the highly coloured wastewater streams to be evaporated, resulting in a clear condensate stream. The removal of solids also contributed to a dramatic reduction in BOD, COD and nitrogen of the wastewater. Reuse initiatives of some clear streams within the factory helped contribute to reducing the total volume irrigated onto the paddock to approximately half of the previous volume.

In 2003, a full-scale irrigated forest project commenced, managed by the DPI&F. The area chosen for the purpose of growing drip irrigated native hardwood tree species was the vacant 9 ha of grassed land next to the irrigated site. Soil in this area consists of a shallow sandy loam with rocky surface horizon and clay subsoil. The climate is sub-tropical where the bulk of the annual rainfall (54 per cent) falls between December and March.

Fourteen native hardwood species were selected because of their capability to withstand conditions that they were likely to receive; the nature of their fast growth rates (which were a commercially economic consideration); and their ability to uptake both high levels of nutrients and water on a sustainable basis.

Measure plots within each species will record annually such things as tree diameter, height, leaf area, crown size and biomass. A key objective of this project is to confirm that irrigation of coffee effluent will not adversely affect tree growth performance. It is expected that thinning will be chipped at age three years and the total tree harvest will be at age 15-20 years.

Gypsum was applied over the undulating terrain followed by ripping and contour mounding at 4 meter intervals. Mounds created were sprayed with a knockdown herbicide just prior to planting in December 3003. Soil samples were collected prior to irrigation to have base data on the physical and chemical characteristics of the soil. Nine bores positioned within and outside the plantation site will be regularly inspected for changing water levels and sampled for chemical composition.

Dripper irrigation was chosen for the project, which allows wastewater to be irrigated over a greater area than the traveling irrigators, and also eliminates the issues associated with spray irrigation, notably odour from aerosols and spray-drift during windy days. Drip irrigation laterals were placed on mounds with emitters positioned every 60cm along the dripper line. The Netafim Uniram heavy-duty drip line selected has pressure-compensating emitters with a nominal flow rate of 2.3L/hr. This system was chosen for its reliability and low clogging hazard and provides significant control of effluent odour.

(http://www.onlineopinion.com.au/view.asp?article=2069)

8. Conclusions

This report is the result of an inventory research on the watersheds *Molino Norte* and *San Francisco* near Matagalpa, Nicaragua. During a 4 months stay in Matagalpa, field visits have been executed, interviews were held and literature sources have been studied. The objective of this research is to answer questions concerning the water quantity and quality aspects of the two watersheds and to investigate the potential of eco-engineered waster treatment technologies. Special focus will be on the impact on the drinking water supply coming from the various activities related to the functions of the water system. The objective is expressed in the following two research questions:

1. *What are the past, present and future situations of the watersheds Molino Norte and San Francisco in the province Matagalpa, Nicaragua, with regard to water quantity, quality and what type of pollutions and sources of pollution of the water flows can be indicated?*

2. *What are the feasibilities of eco-engineered (or other) wastewater treatment technologies to function as a buffer between partially treated wastewater and the watersheds Molino Norte and San Francisco?*

Water quantity

What can be concluded from the analysis of the results on the water quantity in the study area is that the population size and growth form the main driving force that create a pressure on the functions and uses of the water system. Besides, there is a feeling of decreasing river discharges. This becomes visible when the state of the water quantity issue is expressed in water availability and water demand (before the 'Sébaco-project'), which shows a demand that exceeds the water availability of the river *Molino Norte*. The impact this had on the population of Matagalpa is a drinking water supply of only two days a week. Responses came in the form of projects which developed possibilities to pump water from outside areas towards the city Matagalpa to assure a sufficient drinking water supply.
The questions on the sustainability of the present situation regarding the water quantity in this area and the expectations for the future are difficult to answer. There is a lot of pressure on the groundwater of the Sébaco valley (from where a substantial part of the drinking water for Matagalpa is subtracted) and the continuity of the river discharges of *Molino Norte* and *San Francisco* are at least doubtful. For the moment it seems that with the new 'water pumping' projects there is a sufficient drinking water supply expressed in a '7-days-per-week-service'. The discussion when talking about future scenarios is whether the responses in the form of these water quantity projects together with reforestation and energy saving technology programmes (bio-reactors and technology which makes briquettes out of rice and coffee chaff, both technologies reduce deforestation and thus support the water holding capacity) will keep pace with the water demand of the growing city Matagalpa.

Water quality

From the conducted water quality analysis, the following can be concluded. Agricultural practices such as coffee processing, livestock farming and the use of pesticides together with the influence of waste that is produced by the people themselves (e.g. soap, excrements) are the main sources of pollution that have an influence on the river water quality and thus on the drinking water quality.

From here, we can distinguish two kinds of pollutions taking place in different periods. Calculations show a very high concentration of COD of the coffee wastewater (2300 mg/l) resulting in a high concentration of organic material in the rivers *Molino Norte* and *San Francisco* (COD content of 230 and 184 mg/l respectively, calculated with taking into account already existing treatment systems but without the self purification capacity of the river). The result is a decrease of drinking water quality, especially during the critical period of November till February when the processing of coffee beans takes place and river discharges are lowest. Complaints about bad odour and less taste are most common and in some cases skin irritations have been mentioned. Because of the high COD concentration during the coffee harvest season, there is potential of insufficient COD removal, resulting in dissolved organic material in the drinking water networks, which in addition can cause the growth of bacteria in these networks.

Furthermore, at the beginning of the rainy season (starting in May), when heavy rains wash away the human and animal excrements from the fields, a high amount of pathogenic micro-organisms in combination with sediment loads is encountered at the entrance of the central drinking water treatment plant.

Finally, the impact of the pollution caused by pesticides used in agriculture, particularly at the fern plantations, has a serious negative effect on the health of human beings.

Responses

Responses to the vast deforestation of the watersheds came in the form of (small-scale) programs executed by *Proyecto Cuencas Matagalpa*. In cooperation with the Ministry of Forestry (MAGFOR), reforestation projects have been set up and ‘green’ energy technologies have been developed and introduced in the form of the *briquetadora* (a technologies that produce alternatives for fuel wood out of rice or coffee chaffs), the improvement of efficiency of kitchen stoves and *biogestores* for the production of methane gas out of manure.

At farm level we see the introduction of bio-reactors (UASB) for the treatment of (coffee) wastewaters. Only four farmers are working with this technology whereas on the other hand, most farmers (90 %) partially treat their coffee wastewater with the help of simple to construct *pilas*. At large scale coffee pulp is reused in the form of organic fertilizer avoiding extra pollution of the river flows. From political level there is set pressure on farmers with regard on wastewater disposal by setting a norm on maximum COD concentrations.

Of the interviewed residents of the city Matagalpa, about 60 % treat their tap water (coming from both Sébaco and Molino Norte) in some way (mostly by adding chlorine) before drinking it. Those who can afford it buy bottled water.

Questions coming forth from this outline about the actual situation of the water quality in the study area are in the direction of future trends. In the case of the new norms on wastewater disposal set by the Ministry of Environment and Natural Resources (MARENA), it is a fact that there is a lack of personnel to really do adequate controls on this aspect. Furthermore, changes in landuse on the long term are difficult to predict but can be of great influence on wastewater discharges and thus on the water quality of the watersheds. And finally, most coffee farmers do have a simple form of coffee wastewater treatment (*pilas,* of which many are actually undersized), but how can these treatments, which roughly removed only 50 % of the organic materials in the wastewaters, be improved in the future? Or in other words, how can a coffee farmer, who is lacking capital for investments, be persuaded to install a good working wastewater treatment system?

The answer can lie in the application of so called eco-technological treatment systems having mutual functions. Pre-treatment with a bioreactor can be followed by aquatic-based treatment systems in the form of e.g. constructed wetlands, aquatic plant treatment or aquaculture. These kind of eco-engineered treatment systems form a link between (partially treated) wastewater and surface water for which no high investments (in terms of material, land availability can be a bottleneck) are needed while operation and maintenance costs are low (although the organization of such can be difficult) and no skilled personal is required. In addition the mentioned treatment system are attractive in the sense of valuable biomass production. Examples are the water hyacinth and water lettuce, which can be used as animal feed or used to produce fuel (methane gas) in bioreactors. Duckweed is a good nutrient source for the production of fish and reed can be converted in charcoal. In this way, farmers can be stimulated to invest in these lucrative types of treatment systems at decentral (upstream) level and so contribute to the diminishing of river pollution.

Another option can be a more central system alongside the riverbanks with e.g. constructed wetlands in combination of the production of tree species. Beside the function of wastewater treatment, these basins can serve as a buffering zone for sediments to settle down and in this way avoiding the mentioned problem of turbidity. Apart from the quality aspects, the wetland can function as a basin to store water, which is desirable in the case where river discharges strongly fluctuate within a year and over the years. High and low peak discharges of the river system during the year are levelled out, which can contribute a more sufficient drinking water supply during the dry season. For the set up of such a project, stakeholders like the AMAT (drinking water company), MARENA and PCM should work together with the overall objective to improve both the quality as the quantity aspect of the drinking water supply of Matagalpa.

9. Discussion and Recommendations

This report is a partial study, which means that within the framework of the conducted research, not all relevant preconditions can be quantified. Main focus has been on the physical and technical aspects within the study area resulting in an underexposure of the social-political context. In spite of its relevance, it is therefore difficult to make far-reaching conclusions in this field.
This chapter first deals with some points of discussion which are relevant to the subject of the research but which are not totally lucid or need some more attention. The second part consists of recommendations for further research and/or for the implementation of certain eco-technological wastewater treatment systems. It needs to be emphasised that these are only recommendations which are open for discussion for all those different stakeholders involved in the ongoing project, in particular *Proyecto Cuencas Matagalpa* (PCM).

9.1 Discussion

-Before and during the research, different sources (NOVIB, PCM, farmers) have mentioned a substantial decrease of the river discharges of *Molino Norte* and *San Francisco*. As there are no instruments measuring discharges over a longer period in the study area, it was necessary to confirm the mentioned statements with climatological data and discharge models. This resulted in the fact that the decrease of the discharges could not be proofed scientifically. But there are some clear signals of deforestation and the observations made by experienced farmers should not be underestimated. This, together with the questionable reliability of the weather stations and the shortcomings of the models used, could justify the assumption of decreasing river discharges.

-The discussion when talking about future scenarios is whether the responses in the form of water quantity projects together with reforestation and energy saving technology programmes keep pace with the water demand of the growing city Matagalpa. It is clear that the 'Sébaco-project' contributes for a substantial and necessary part in the drinking water supply of the city Matagalpa. It has been very difficult to collect data around this project. It has been mentioned (PCM) that outcomes of a certain research on the quality of the groundwater of the Sébaco valley have been kept behind, possible because of negative results. It has been brought up that former mine activities in the area have had their impact on the groundwater in the form of high arsenic concentration. Furthermore, questions can be put on the sustainability of the project realising that 2 more pumping stations are subtract ing groundwater from this valley which, together with the water demanding crop rice grown there, will have its impact on the groundwater table. Independent research on this matter can be valuable.

-An interesting point left out of the calculation on the water quality is the self-purification effect that the rivers can have. Actually, wastewater treatment based on eco-technology is actually derived from the self-purification effect found in river streams. It can be interesting to do more research on this phenomenon, which can be helpful to do more precise calculation COD concentrations. Furthermore, observing this phenomenon can be supportive in the determination of both the location of an eco-engineered wastewater treatment system and of the composition of such a system.

-There has been little emphasis in this report on the prevention of wastewater production or in other words, on tackling the problem at its source. In the case of coffee wastewater production we can think of the so called dry processing of coffee beans, a technology wherefore less water is needed and which is practiced in e.g. the neighbouring country Costa Rica. We come back on dry processing in the recommendation part.
In the case of chemical use, it could be interesting to do more research on the management of pesticide use at the fern nurseries. It could well be possible that by using fewer quantities of pesticides, similar fern productions are achieved with the important differences of less stress on river water quality and money savings.
On the subject of the separation of black and grey wastewater flows, there has already been action in the form of latrine projects. Fact is that in practice only half of the local people (rough estimate from interviews) actually make use of this type of toilets and prefer the open field. In spite of this low percentage, there might be a trend of increased use, which makes the continuation of these projects sensible. Question is what lessons can be learned from these projects and what is needed to stimulate the separation of black and grey wastewaters.

9.2 Recommendations

As became clear from the conducted research, eco-technological wastewater treatment seems a feasible option for the improvement of the river water quality and thus the drinking water quality, although some more specific research is needed. Furthermore, there is a set of pre-conditions (future land-use, river discharges, financial situation farmer, etc.) on which predictions are difficult to make and which puts the recommendation in a certain light.

In the case of decentralised operating systems, focus should be on the 15 larger coffee plantations (mainly located upstream) that are responsible for 95% of the coffee production. Pre-treatment with a bioreactor can be followed by aquatic-based treatment systems in the form of e.g. constructed wetlands, aquatic plant treatment or aquaculture. Biomass production can make these systems attractive for farmers to generate an extra income.
The option of a more centralised system should focus on the riverbanks where constructed wetlands can create a buffer zone for both the settling down of sediments as for water storage. Well-managed plantations of suitable tree species can contribute in the increase of water holding capacity and the prevention of erosion.
For both cases (decentral and central) more study on suitable flora (and fauna), as being an important issue in the design of eco-technological wastewater treatment systems, is desirable and should be sought in the direction of local existing species. Here it is worth mentioning that in the two watersheds, many (foreign) studies have been conducted but little actions have been taken. Some follow-up research in specific areas can be necessary but, especially with eco-technologies, one can learn by doing !

The question has been raised before on who is responsible for what and from whom we can expect actions to be taken. It is clear that PCM can play a crucial role in the continuation of this project. They maintain a good relationship with the various stakeholders like coffee farmers, the municipal executive of Matagalpa and Dutch donors (NOVIB and Aqua for All). Further more it is interesting to see whether the drinking water company (AMAT) can be stimulated to participate in a follow-up project, as the improvement of the river water quality means a reduction of their operating costs.

Finally some remarks and recommendations at coffee farm level in the direction of water use reduction and ecological farming. Some recommendations are not new but in practice there has been little action.

To reduce the amount of water used in the wet processing of coffee you can think of the following: Recycling of water, depulping without the use of water, mechanical washing procedure with a minimum of water, no hydraulic transport of the coffee beans towards the machines and fermentation and transport of pulp without the use of water. All these contribute to a reduction of water use, but also ask for special attention for a few factors that can increase the concentration of organic matter in the water.

- When recycling the water, you also recycle the organic matter, which means high concentrations of COD can be reached (up to 40 kg COD/m³).
- When the mucilage is removed mechanically, the organic concentration can reach values of 75 kg/m³. This is due to the low volume of water in which the mucilage is diluted.

The following options are to improve the disposition, handling and treatment of the coffee wastewaters (*aguas mieles*).

- The rainwater falling on the roofs and the runoff of the terrain should not enter the *pilas* as it diminishes the capacity to hold wastewater from the coffee process. Only water from the wet processes (depulping and washing) should enter the *pilas*.
- Water used for cleaning the machinery should not enter the lagoons either and instead be collected and reused or drained to an area where it can infiltrate and evaporate.
- During mid day (10:00 am – 2:00 pm), when there is no rain, the wastewater can be used to 'irrigate' the gravel roads of the plantation with the object that the water will be filtered and evaporated and the organic material decomposed. This practice will reduce the amount of wastewater being discharged into the river directly and will reduce its contamination.

It is clear that a solution is not only technical based and that other factors have an influence on a change towards ecological production. In interviews with farmers it is often mentioned that there is a lack of money to buy chemicals. This is often seen as a motivation to start growing organically besides the fact of better prices for organically grown coffee (although market limited). Bottleneck is very often the $US 300 is which is needed for certification. Some ideas to improve the situation (partially based on GKW Consult ,1997):

-Campaign to make people aware of the negative consequences of certain activities;

-Qualified technical assistance with the transformation into an ecological coffee farm by various organizations;

-Promotion of exchange of technical experiences between neighboring countries;

-The performance of adequate controls on the norms set by MARENA about the use of water and the disposal of wastewaters at the coffee plantations;
-Active participation from the side of the semi-private drinking water company AMAT;
-Reduction of taxes by the local government for those farmers who want to change their farm into an ecological farm;
-To form associations in which farmers combine their strengths.

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Annexes

Annex A. List of questions as part of the interviews conducted with (24) residents of the city Matagalpa

Address *(Dirección):* Date *(Fecha)*:

1) What is the origen of your drinking water?
(¿Cuál es el origen de su Agua Potable?)
Molino Norte Sebaco Well (Pozo) River (Rió) Other (Otro)

2) For what activities do you use this water?
(¿Para cual cosas se usan este Agua?)

3) Do you treat this water in a certain way before using it? (chlorine, boiling, filter, ...)
(¿Se hacen un tipo de tratamiento con el agua? (cloro, hierva, filtrar,...))

4) How is the quality of the water? (taste, color, small animals, sediments,...)
(¿Come es la calidad del Agua Potable? (sabor, color, animalitos, sable,...))

5) How is the quantity of the drinking water? (sufficient, frequency,...)
(¿Cómo es la cantidad del Agua Potable? (suficiente, frecuencia, ...))

6) About the differences before and after the 'Sébaco-project respectively:
(Sobre la diferencia antes y después el proyecto de Sébaco en respecto:)
Frequency *(frecuencia):*
Price *(del precio):*
Quality (if there is any) *(de la calidad (sí hay)):*

7) How was the quantity (frequency) of the drinking water 10 till 15 years ago?
(¿Cómo estaba la cantidad (frecuencia) del Agua Potable como 10 a 15 años atrás?)

Notes:
(Noticias):

Annex B. List of questions as part of the interviews conducted with (21) farmers in the watersheds Molino Norte and San Francisco

1. General Data *(Datos Generales)* Date: *(Fecha:)*

1.1 Name of farmer *(Nombre del productor:)*

1.2 Name of the farm/plantation: *(Nombre de la granja / finca:)*

1.3 Address *(Dirección):*

2. The coffee farm: *(La granja / finca de café)*

2.1 Cultivated land *(Área cultivada:)*

CULTIVO	MANZANAS*	QQ** (/MANAZANA)	OBSERVACIONES
Caffee *(Café)*			
Corn *(Maíz)*			
Beans *(Fríjol)*			
Banana *(Plátanos)*			
Pature *(Pasto)*			
Others *(Otros)*			
Total			

* 1 manzana (mz) = 0.7 hectare (ha)
** 1 quintal (QQ) = 46 kilogram (kg)

Animals *(Animales)*

Type of animal	Amount

2.2 Production of green ripe coffee cherries/green beans of the last three seasons:
(Café uva/oro: Producción de la finca en las ultimas tres cosechas:)

Años Agrícolas	QQ uva/oro
1.	
2.	
3.	

3. Water *(el agua)*

3.1 What do you use your water for? (drinking water, irrigation,....)
(Para que se usen el agua (agua potable, riego,...))

3.2 Origen of the water: River Well Municipality Other
(Origen del agua: Rió Pozo propio Municipal Otro)

3.3 How is the quality and auantity of the water you use?
(¿Cómo es la cualidad y cuantidad del agua se usa?)

3.4 What is the amount of water used for the processing of 46 kg *(1quintal)* ripe cherry/green bean?
(Consumen de agua en el beneficio por quintal de uva o otra unidad)

3.5 What do you do with the coffee wastewater?
(Que hace actualmente con las aguas mieles?)

3.6 What is the destination of the domestic wastewater?
(¿Que hace con las aguas domesticas?)

3.7 What is the destination of the coffee pulp?
(¿Que es el destino actual de la pulpa?)

3.8 What type of chemicals doe you use?
(¿Que tipos de químicos se usa?)

4. Future/History (Futuro/Historia)

4.1 Have you been thinking of a change in land-use (explain the reason to change, e.g. change from coffee production to the production of other crop because of low coffee prices)
(¿Es pensando en cambiar el uso de suelo? (explica la razón de cambio por favor, por ejemplo: cambiar el cultivo de café por que el precio bajo del café?)

4.2 Have you been thinking of changing you farm/plantation into an organic farm/plantation? (what is the drive behind this?)
(¿Es pensando en cambiar la granja / finca en una orgánico? (y que es la razón para hacer eso?)

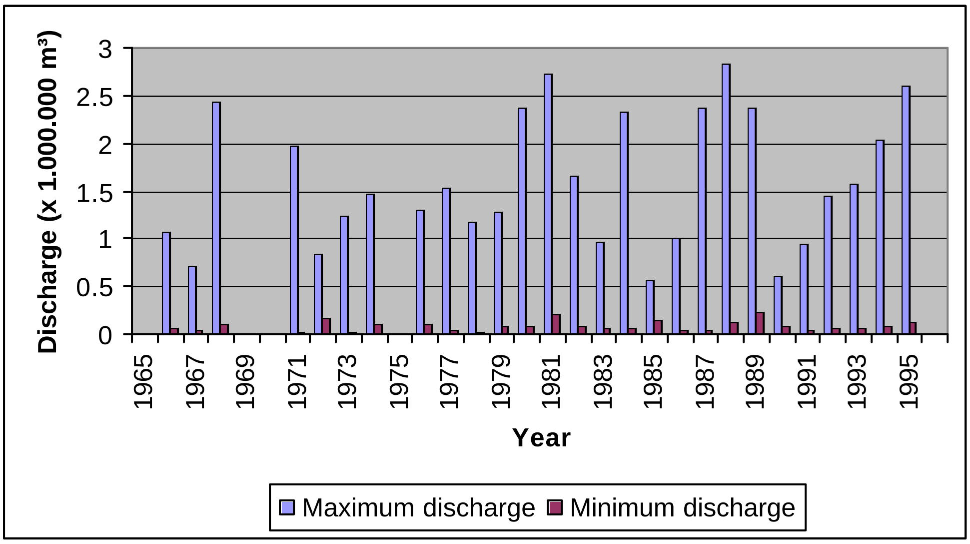
4.3 What do you think is the best type of treatment for the coffee wastewater?
(¿Que piensa es el mejor tipo de tratamiento por las aguas residuales?)

4.4 What do you consider as the main problem (in respect to cultivation activities) what would be the best solution for this problem?
(¿ Qué considera como el problema principal (con respecto a las prácticas de cultivo) y lo que sería la solución mejor para eso?)

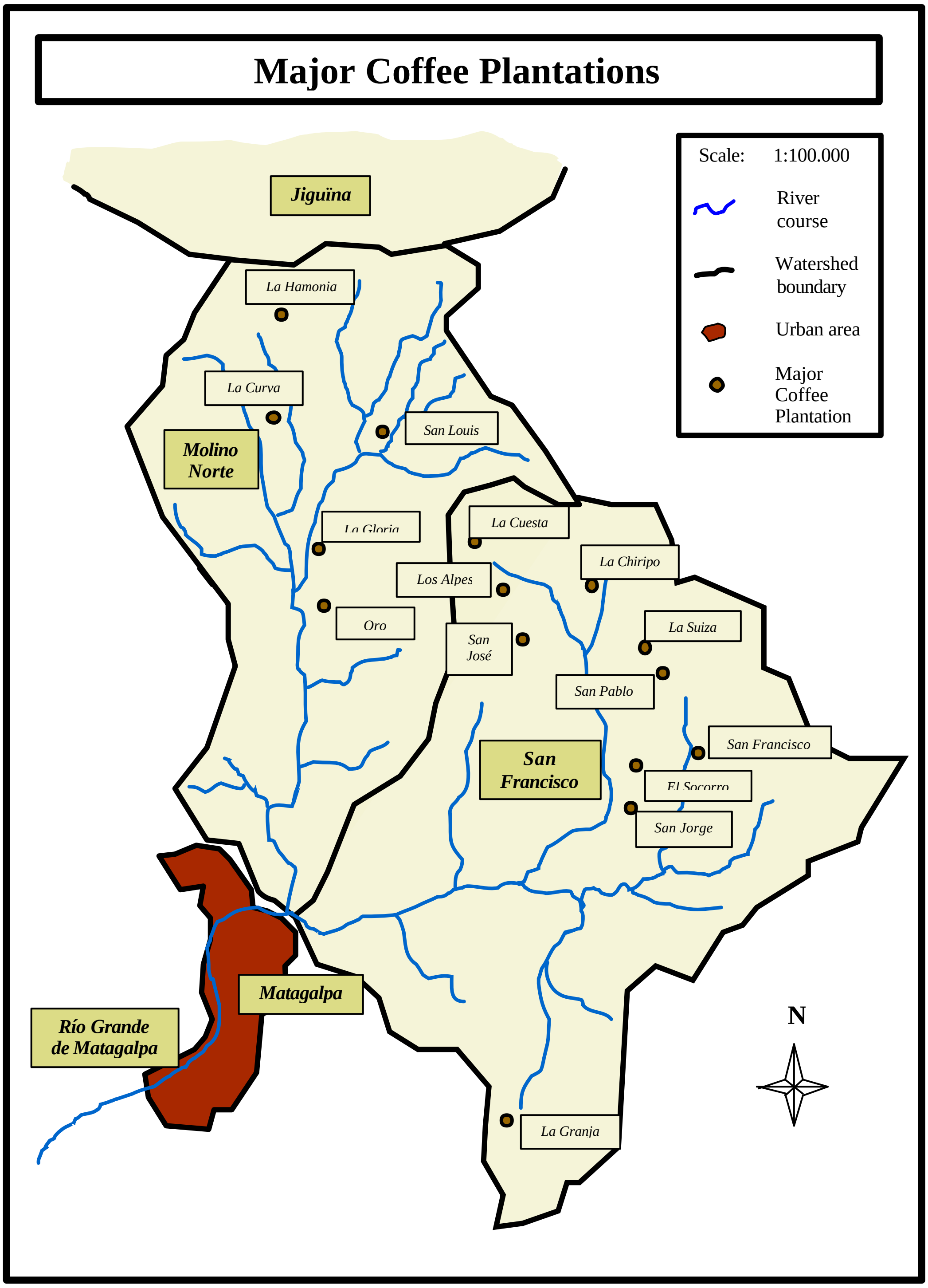
4.5 How is the river discharge at the moment compared to few or many years (3-40) ago?
(Historia del caudal del rio)

Notes:
(Noticias:)

Annex C. Maximum and minimum discharges of the river San Francisco during the period 1966-1995



Annex D. The 15 major coffee plantations in the watersheds Molino Norte and San Francisco



Annex E. Composition of coffee pulping water and of washing water

Composition of coffee pulping water (Lopez 1996)

Compound	**Concentration of coffee pulp (% dry matter)**	**Extracted material (kg/tgcp)**	**Estimation of COD (kg COD/tgcp)**	**COD (%)**
Proteins	12	3.5	5.4	8.9
Tannins	2.4	3.0	5.9	9.8
Chlorogenic acid	2.6	6.1	8.7	14.6
Caffeic acid	0.07	0.2	0.4	0.7
Caffeine	1.6	6.3	12.4	20.8
Sugars	8.3	24.6	27.0	45.3
Total			59.8	100

tgcp = tons green coffee produced

Composition of washing water(Lopez 1996)

Compound	**Composition of mucilage (% dry matter)**	**Extracted material (kg/tgcp)**	**Estimation of COD (kg COD/tgcp)**	**COD (%)**
Sust. Pecticas	35.8	31.5	26.1	29.4
Sugars	45.8	40.2	44.3	50.2
Cellulose	17.8	15.0	18.0	20.6
Total	98.6		88.4	100

Annex F. Sampling objects in the study area

Ground- and surface water of Matagalpa

Sampling objects in the study area *(YKL-UNAN 2002)*

Below follows a list of the sampling points taken in the watersheds Molino Norte and San Francisco. The most northern samples were taken out in the head of the river Aranjuez that runs to the north and from where water is pumped to the cuenca of the Molino Norte

Water samples taken in the cuenca Aranjuez:

Sample 3. The sample was taken from the reservoir from where the water is supplied to Molino Norte. Determinations: the physical-chemical characteristics of the water, quantities of coliform bacteria.

Sample 4. Rio San Fernando. The sample was taken from the stream that runs from the plantation of ornamental ferns. Determinations: the characteristics physical-chemical, the quantities of coliform bacteria, the residual pesticides.

Sample 5. Rio San Fernando. The sample was from of the stream that runs from a plantation of cabbages. Determinations: the physical-chemical characteristics.

Water samples taken in the cuenca Molino Norte from the superior course to the inferior course:

Sample 12. Finca La Hammonia. The sample was taken from the stream that runs through the property. Determinations: the physical-chemical characteristics, the quantities of coliform bacteria.

Sample 1. Los Lipes. The sample was taken from the public well which has a depth of about 40 meters. Determinations: the physical-chemical characteristics, the quantities of coliform bacteria.

Sample 10. Rio Molino Norte. The sample was taken from the river. Determinations: the physical-chemical characteristics, the quantities of coliform bacteria.

Sample 2. La Cortuja. The sample was taken from a well located 870 meters above sea level. Determinations: the physical-chemical characteristics, the quantities of coliform bacteria.

Sample 8. Planta. The sample of was taken from the fluvial water that apart from the fluvial water of Molino Norte also contains the superficial water that is pumped from the cuenca of Aranjuez. Determinations: the physical-chemical characteristics.

Water samples taken in the cuenca San Francisco from the superior course to the inferior course:

Sample 6. La Cuesta, Río Ocote. The sample was taken from the superior course of the river, at 960 meters above sea level. Determinations: the physical-chemical characteristics.

Sample 13. La Suiza, Rio San Pablo. The sample was taken from the river out at 870 meters above sea level. Determinations: the physical-chemical characteristics, the quantities of coliform bacteria.

Sample 14. Rio San Francisco. The sample was taken out from the river. Determinations: the physical-chemical characteristics, the quantities of coliform bacteria.

Sample 7. La Danesa, río El Ocote. The sample was taken from the inferior course of the river El Ocote (a tributary of the River San Francisco). Determinations: the physical-chemical characteristics, the quantities of coliform bacteria, the residual pesticides.

Sample 9. Río San Francisco. The sample was taken from the river, approximately two kilometres east of Matagalpa. Determinations: the physical-chemical characteristics and the quantities of coliform bacteria.

Annex G. List of forbidden chemical products in agriculture

According to the decision of the National Commission of Agrochemicals of Nicaragua, the Ministry of Agriculture published a law on August 8th, 1993 prohibiting the use of the following chemical products in agriculture (Beck, 1996): DBCP, aldrín, endrín, DDT, 2.4.5-t, heptacloro, EDB, clordan, BHC, dieldrín, dinoseb, pentaclorofenol, paratión etil, toxáfeno, lindano. It was also recommended the restrictive use of clordimeform, aldicarb and paratión métil. The World Health Organization (WHO) classifies these products as causing cancer.

Those pesticides made up the so-called The Damned Dozen or the Dirty Dozen which contain forbidden chemical products that are not recognised by means of their commercial names. The following compounds belong to the Dirty Dozen:

- PARATIÓN. Commercial name: Graxomone, Pillarxone. Used on cotton, vegetables, fruits and other cultivations. Very toxic.
- 2.4.5.-T. Causes abortions to women.
- PARAQUAT. Commercial name: Graxomone, Herboxone, Gramonol. It has caused many poisonings.
- DDT. Name commercial: Anofex, Diamekta, Pentachlorine. Known as very harmful.
- ALDRÍN/DIELDRÍN/ENDRÍN. Commercial name: Aldrex, Endrex, Panoram D-31.
- CHLORDIMEFORM (Galecon). Commercial name: Acaron, Bermat, Fundal. Used on cotton cultivations and tobacco.
- DBCP. Commercial name: BBC 12, Nemafume, Nemasat, Fumazone. Used on fruit cultivations, greenness and cotton. Causes cancer.
- CLORDANO/HEPTACLORO (C/H). Commercial name: Kypchlor, Corodane, Heptagran.
- BBH/LINDANO. Commercial name: Exagama, Forlin, Gallogama.
- EDB. Commercial name: Bromofume, Silbrom 40, Dowfuem W-45. Causes cancer
- TOXÁFENO. Commercial name: Attac 4-2, Camphpfene, Huileux. It accumulates in organism. Very toxic.

Annex H. Parameters of 13 water samples taken around Matagalpa

Parameters of 13 water samples taken around Matagalpa in January (YKL-UNAN 2002).

Parameter	Minimum	Maximum	Average	Medium	Max. recommended (Finland)
Temperature (°C)	19.8	25.7	23	23.4	
pH (field/laboratory)	6.9/5.7	7.1/7.2	6.7/7.0	6.8/7.0	6.5-9.5
Electric conductivity (mS/m) at 25°C (field/laboratory)	7.6/6.0	7.1/7.2	6.7/7.0	11.9/9.7	
Number of Color Pt (mg/l)	<5	35	6	5	
Alkalinity (mmol/l)	0.16	1.81	0.77	0.58	
KMnO4 consumptions (mg/l)	0.6	14	6.3	4.3	
Br (mg/l)	<0.1	0.1	<0.1	<0.1	
Cl (mg/l)	3.7	38	8.7	5.7	100
F (mg/l)	<0.1	0.2	<0.1	<0.1	1.5
NO3 (mg/l)	<0.2	3.3	0.9	0.9	25
PO4 (mg/l)	0.05	1.9	0.25	0.11	
SO4 (mg/l)	1.4	11	2.7	1.9	250
Ag (µg/l)	<0.01	<0.01	<0.01	<0.01	
Al (µg/l)	5.63	163	28.8	17.9	200
As (µg/l)	0.12	3.13	0.48	0.28	10
B (µg/l)	15.1	40.9	21	18.8	1000
Ba (µg/l)	4.98	143	46	42.9	
Be (µg/l)	<0.1	<0.1	<0.1	<0.1	
Bi (µg/l)	0.02	0.08	0.05	0.05	
Ca (mg/l)	0.78	30.1	11.2	8.73	
Cd (µg/l)	<0.02	<0.02	<0.02	<0.02	5
Co (µg/l)	<0.02	3.16	0.42	0.18	
Cr (µg/l)	<0.2	0.39	0.19	0.22	50
Cu (µg/l)	<0.1	2.07	0.7	0.55	2000
Fe (mg/l)	<0.03	1.49	0.2	0.12	0.4
K (mg/l)	0.55	4.54	3	2.83	
Li (µg/l)	0.13	7.62	1	0.32	
Mg (mg/l)	0.24	8.39	2.81	2	
Mn (µg/l)	0.34	3190	293.2	33.4	100
Mo (µg/l)	0.06	0.61	0.17	0.14	
Na (mg/l)	4	46.5	10.72	7.44	200
Ni (µg/l)	0.11	0.42	0.22	0.2	20
P (µg/l)	15.9	466	70.6	38.4	
Pb (µg/l)	<0.05	1.59	0.45	0.07	10
Rb (µg/l)	0.85	12.1	7.13	7.37	
Sb (µg/l)	<0.02	0.04	0.02	0.02	5
Se (µg/l)	<0.5	0.62	<0.5	<0.05	10
Si (mg/l)	10.3	31	18.2	17.3	
S (mg/l)	1.66	4.72	2.18	1.94	
Sr (µg/l)	4.64	280	100.4	83.2	
Th (µg/l)	<0.01	0.01	<0.01	<0.01	
Tl (µg/l)	<0.01	0.15	0.02	0.01	
U (µg/l)	<0.01	0.08	0.02	0.01	
V (µg/l)	0.56	5.22	17.62	1.50	
Zn (µg/l)	1.14	225	17.62	1.50	

Annex I. Chemical-physical analysis of groundwater in the valley Sébaco

Chemical-physical analysis of groundwater in the valley Sébaco (GWK 1997)

Hour **Date**	**Unit**	**Sébaco Chaguitillo** 11:00 am 28/11/96	**Sébaco Chaguitillo** 07:30 28/11/96	**Sébaco Beneficio Chaguit., S. Pedro** 28/11/96
Parameter				
Temperature	º C	25.7	27.0	24.3
Color	UC	1.0	1.0	3.0
Turbidity	UNT	0.3	0.2	0.3
Conductivity	µS/cm	710	710	700
Total Alkalinity	mg/l	301.2	297.4	278.4
Hardness	mg/l	254	244	254
pH		7.7	7.4	7.4
Calc	mg/l	71.7	70.1	62.4
Magnesium	mg/l	18.2	16.8	23.8
Total Iron	mg/l	0.02	0.0	0.0
Sodium	mg/l	34.8	33.5	32
Potassium	mg/l	1.0	1.2	0.9
Bicarbonates	mg/l	367.3	360.7	339.4
Carbonates	mg/l	0.0	0.0	0.0
Chlorides	mg/l	16.2	12.4	19.0
Sulfates	mg/l	23.6	16.7	26.2
Nitrates	mg/l	4.4	0.2	4.4
Nitrites	mg/l	0.02	1	0.02
Fluorine	mg/l	0.13	0.17	0.12

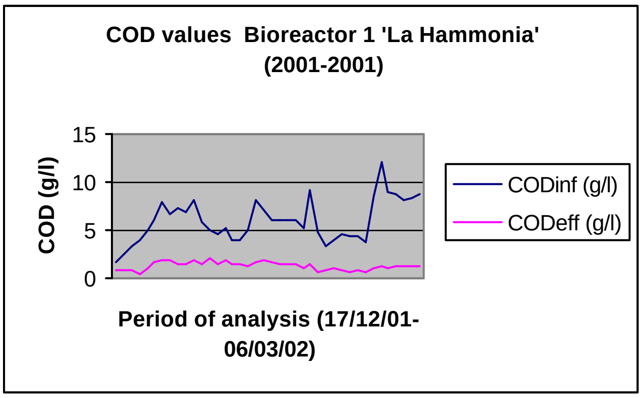
Annex J. Chemical additions for treatment of drinking water in January 2004

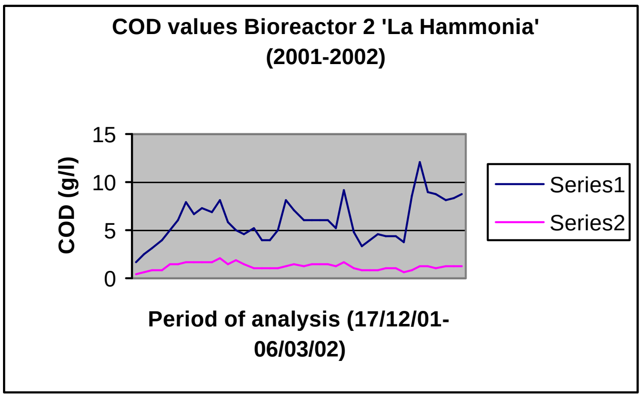
Chemical additions for treatment of drinking water in January 2004 (source: AMAT)

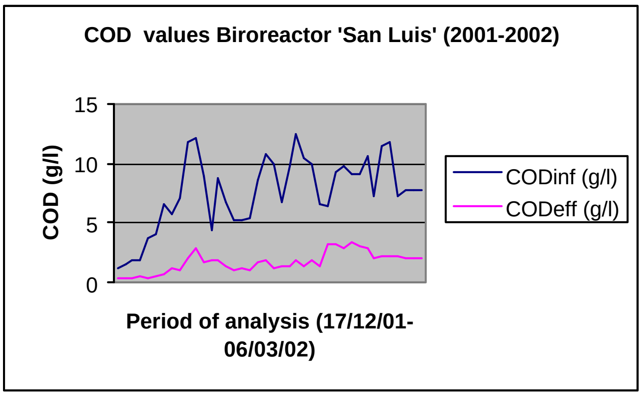
Place of treatment	Chlorine (gas) (kg)	Aluminium Sulphate (kg)	Cation Polymer (kg)	Lime (kg)	Sodium hypo chlorite (l)	Drinking Water (m^3)
Main plant	612	-	-	-	-	176.000
La Parrilla	68	-	-	-	5	55.000
Sebaco station	408	-	-	-	-	155.000

In December 2003, the main treatment plant consumed 476 kg Chlorine (g) and 640 l of Sodium hypo chlorite.

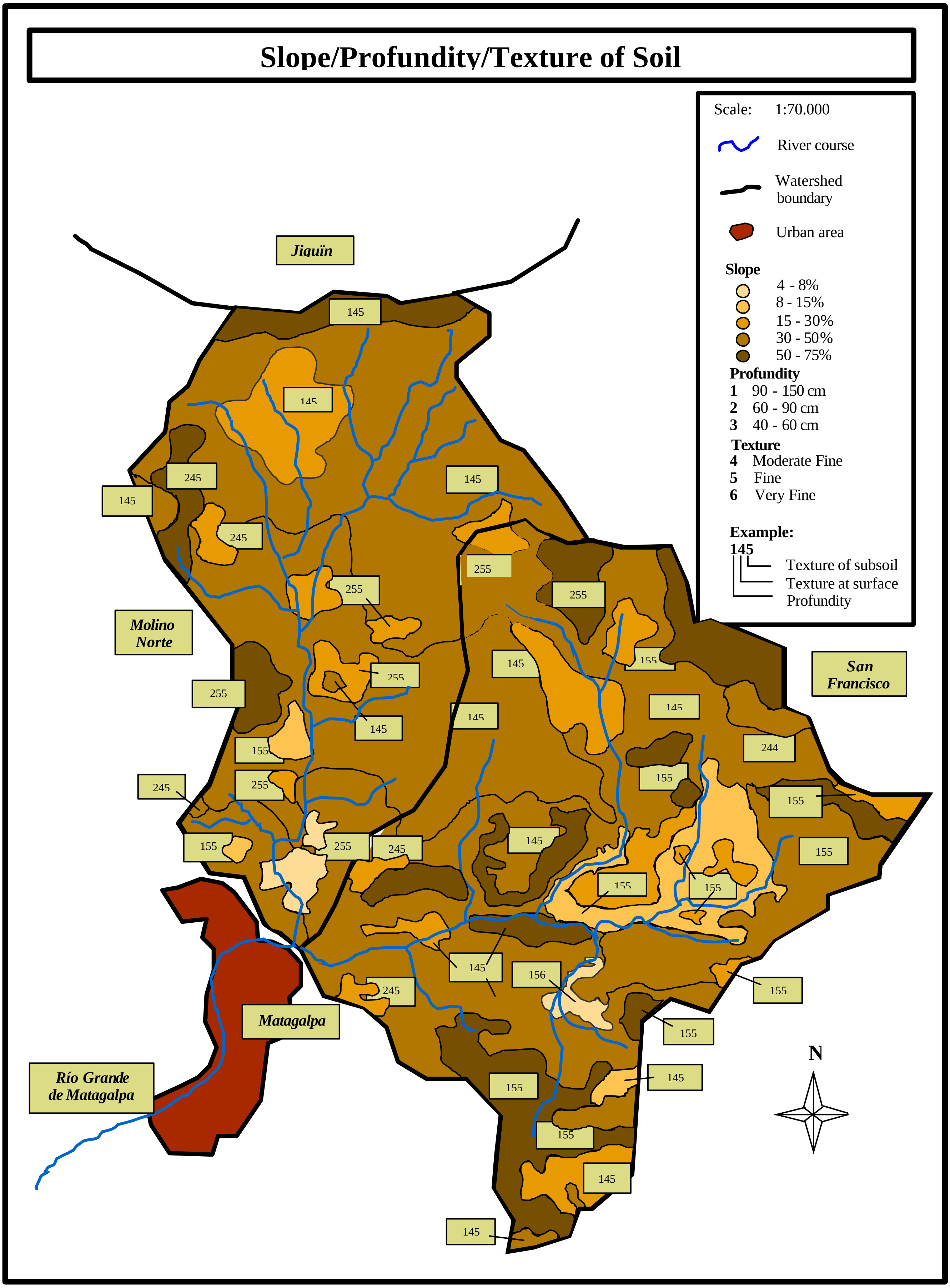
Annex K. Effectiveness of COD reduction of two bioreactors at 'La Hammonia' and one at 'San Louis'







Annex M. Slope, profundity and texture of the soil in the two cuencas (based on Orozco, 1994)



Annex N. Schematic overview of a stakeholder analysis of those parties related to the water system of the two cuencas