Water Treatment and Supply in Kayes, Mali, West Africa:

Treatment Processes, Operations, and Economics

By

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Acknowledgements

I would like to thank the people of Africa for their patience.

Preface

This report was prepared from research conducted at the Water Treatment Plant in Kayes, Mali during the years 2002 and 2003. Permission was granted from the Kayes Regional Director of Energy of Mali/ Saur International, Hommad Ag-Mohamed, prior to the beginning of research at the Kayes Water Treatment Plant.

Research was coordinated with the following persons: my advisor, Dr. James Mihelcic of Michigan Technological University; my Peace Corps “boss,” Sogoba Togota, Peace Corps Mali’s Associate Director of Water/ Sanitation; Mr. Diarra and Mr. Ag-Mohamed in Kayes of Energy of Mali/ Saur International.

Abstract

A high quality and sufficient water supply is essential to human health, but is often missing in life in West Africa. In Mali, only 65% of the population has access to improved drinking water sources (CIDA, 2002). As Sogoba Togota, Peace Corps Mali's Associate Director of Water/ Sanitation says, "When entering a town or village to look at its health situation, it's more telling to see if there's a water tower than to count the number of hospital beds." In this report, research was performed at the Drinking Water Treatment Plant in Kayes, an isolated city of 100,000 people in western Mali.

The objective of this report is to detail the Treatment Processes, Operations and Economics of Kayes' Drinking Water Treatment Plant and Supply. A part of this report will describe the unique environment of a large city in West Africa, the challenges involved in working in this city, and how the local population overcomes the challenges to provide reliable drinking water.

In addition to research at the Water Treatment Plant, an economic survey was performed by interviewing 30 randomly selected households located throughout the city of Kayes. This survey provides revealing information about the state of water supply in Kayes, Mali. The average monthly water usage for a household size of 5 to 10 people was estimated to be 300 liters per day. This value increased to 1,100 liters per day for a household of greater than 25 individuals.

The results of the survey also suggested that households in Kayes are paying on average 23% of their monthly income for water. People in Kayes are also paying more than three times the price of water in the United States. The range of water price determined from the survey ranged from $1.50 to $2.00 per 1,000 liters in Mali versus $0.52 per 1,000 liters in the U.S. In addition, some households must purchase more expensive water from street vendors or use river water because they do not have sufficient funds to pay the utility on a monthly basis.

Chapter 1 – Introduction

A good quality water source is essential to human health, but is often missing in life in West Africa. Just 65% of Mali's population has access to improved drinking water sources (CIDA, 2002). As Sogoba Togota, Peace Corps Mali's Associate Director of Water/ Sanitation, says, "When entering a town or village to look at its health situation, it's more telling to see if there's a water tower than to count the number of hospital beds." In fact, a water tower is a rare sight in Mali. You would be lucky to find a water pump in working order. Most common are traditional wells. These wells are constructed by hand and often lack proper casing. In the cities there are water towers and drinking water distribution systems, but the water is highly priced. Much of the town's center may have water faucets in the homes and offices, but out in the further reaches of the cities people rely on randomly placed faucets in the streets or wells as they do in villages.

History of Kayes

This research focuses on the city of Kayes' water supply. The Kayes region is the first region of Mali and is located in the west. See the map of Mali, Figure 1-1. The Kayes region is home to many ethnic groups. The Bambara, Sarakole, Kosinke, Pulaar, and Wolof have traditional villages scattered throughout the Kayes region. The city of Kayes, however, was developed as a frontier post for the French into the interior of West Africa and it was an administrative center for the colonial government. The French arrived in Kayes in 1880, conquered resistance in 1898, and left with Mali's independence in 1960.

Figure 1-1. Map of Mali

Since Mali's independence Kayes has been the regional capital of the western region, one of five regions of Mali. It is commonly said that the Kayes region has been forgotten over these years of independence by the politicians in the capital Bamako. Kayes is isolated from the rest of the country, but represents the midway point for trade between Dakar and Bamako, about 80 km east from the border of Senegal and 400 km west from Bamako. Kayes is an expanding metropolis, with people coming from the villages and surrounding countries to work in trade and commerce. There is now even an international airport with direct flights to Paris. The permanent population is 80,000, but increases to 110,000 during the dry season when there is no farming in the villages.

Kayes is located along the Senegal River, which runs from the mountains of Guinea northeast down into Mali and then turns to the west before passing Kayes and continuing towards the Atlantic Ocean at Saint Louis, Senegal. Although the river flows full of fresh water, Kayes is situated in the Sahelian climatic zone. The Sahel is a desolate zone that stretches from the Atlantic Ocean east along the southern edge of the Sahara desert. It is made up of sparse vegetation and receives minimal rainfall. Kayes receives on average 635.5 mm of rain per year, falling mostly in the time period from June to September (Landsea and Gray, 1991). The unsupportive climate has led scientists to describe a concept called desertification. This is the gradual flux of the Sahara desert. It is exacerbated by the locals' desperate living situations, such as deforestation in order to obtain cooking firewood.

City Water Supplies

When traversing the country it is clear that city Water Treatment Plants are the most reliable source of clean drinking water in Mali. They are a very important water supply for the people. The French did not build a Water Treatment Plant in Kayes before leaving in 1960.

The first Water Treatment Plant in Kayes was built in 1970 by a German group. The original plant consisted of a water intake, coagulant addition and sedimentation, and disinfection. The plant was designed to serve a 20 year projection of the population. In 1986, the plant was upgraded by a French/African group. This new plant added sand filtration, a building for chemical addition, and a reservoir. See Appendix Figure A-1 for the plans of the Water Treatment Plant. In 2000, the plant was taken over by a French multinational company called Saur International. Saur International kept in place the local staff and integrated management control via Bamako.

Because of the desperate state of water supply in Mali, Water Treatment Plants (WTP) provide a key source of drinking water for many users. With the appropriate expansion of a known water supply more and more people can gain access to clean drinking water. Kayes' WTP sits alongside the Senegal River, which is not adversely impacted to a great extent by upstream industrial discharge or significant agricultural runoff. However, Kayes' WTP is currently running beyond capacity. In addition, people living on the edge of Kayes do not have reliable access to water.

While, as stated previously, the WTP has been taken over by a large French company, the plant continues to be operated by local Malian staff, and the staff lacks the expertise to command the complexities of a large water treatment plant. Chlorine levels are occasionally erratic and sometimes non-existent when the chief is away. Appropriate water quality testing technology is also lacking.

As part of my project, I translated into French certain chapters of the American Water Works Association's 5th edition Water Quality and Treatment Handbook for Community Water Supplies (1999), and went over these with the Water Treatment Plant chief, workers, and the Health Center Technician.

Perceptions of Water in Mali

Malians generally view natural ground or surface water as acceptable and even the best drinking water, based on my experience. If they are thirsty many would prefer to drink water straight from the river rather than from a faucet. If they are in a village many would prefer water from a traditional well rather than from a pump. When I explained once to my friend that water from a faucet is cleaner and safer he said white people are weak. Since approximately 80% of the population is uneducated, there is no understanding of the germ theory of disease. In fact, water borne diseases are endemic in Mali, although no one can be sure of the rates of disease incidence. Even among educated classes there is a cultural tendency to accept water from any source without discriminating based on cleanliness.

Objective

The objective of this report is to detail the Treatment Processes, Operations and Economics of Kayes' Drinking Water Treatment Plant and Supply. A part of this report will describe the unique environment of a large city in West Africa, the challenges involved in working in this city, and how the local population overcomes the challenges to provide reliable drinking water.

Chapter 2 provides an overview of Mali and its water resources. It then details the progress into my personal struggle to get involved in detailed research at the Water Treatment Plant. Chapter 3 concentrates on the details of the Water Treatment Processes and Operations at the plant. Chapter 4 goes through an analysis of the plant based on AWWA's criteria for Water Treatment Plants. Chapter 5 explains a study of Economics of water supply and usage throughout the city of Kayes. Chapter 6 provides a brief conclusion. Chapter 7 lists references, and Chapter 8 appendices.

Chapter 2 - Mali's Water Resources and my Internship at the Kayes Water Treatment Plant

Mali's Surface Water Resources

Mali is a landlocked country in the heart of West Africa. Mali itself means Hippopotamus in Bambara, the local language. Her culture goes back to pre-historic times. Human culture in this region of the world developed over thousands of years. People developed into various essential groups: herders and farmers and fishermen. These groups grew peacefully to trade amongst each other. In the 14^{th} century, the Kingdom of Mali stretched through virtually all of West Africa and traded large amounts of gold and salt across the Sahara Desert. In 1880 the French came to conquer the region of Mali and remained until 1960 as the governing power until Mali achieved independence September 22, 1960.

Figure 2-1. Map of Mali with Senegal and Niger River networks

Figure 2-1 shows the two major river systems through the country of Mali. Most of Mali's 10 million people live in villages scattered across this vast country. The two major rivers which dissect the country are the Niger and the Senegal. The Niger River draws its source from the small mountains of Guinea and flows in a broad eastern arc across Mali, passing through the capital Bamako and past the legendary city of Timbuktu before continuing through Niger, and curving to the south to its Atlantic Ocean mouth in Nigeria.

The Senegal River also has its source in Guinea and flows slightly to the northeast before turning back east and merging with the Bafing River (home of the mega Manantali

Dam), then passing through the city of Kayes and continuing to form the border of Mauritania and Senegal before flowing to the Atlantic Ocean. See Figure 2-1 for a map of the Senegal River basin. The extent of the basin is described by the largest dashed line. The basin covers much of western Mali, northern Senegal, and southern Mauritania. The dotted line shows the actual Senegal River and its tributaries.

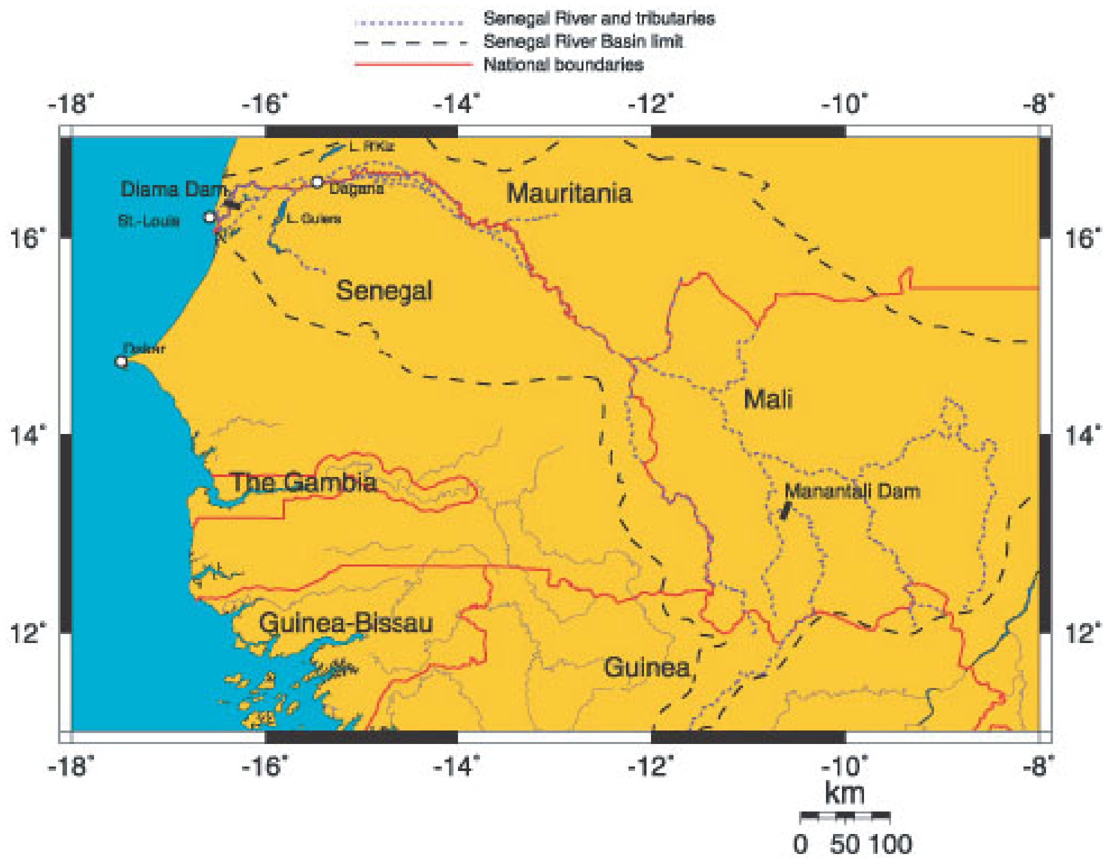

Figure 2-2. Map of Senegal River Basin

These two rivers provide a highly valued reprieve from the otherwise dry and harsh climate of Mali. The Niger River provides a source of drinking water to the capital Bamako of 1 million people, and to the large cities of Mopti and Gao. The Senegal River provides a drinking water source to Kayes and Saint Louis, Senegal and many other small cities on its way to the Atlantic Ocean. According to a study by the Board on International Scientific Organizations, the Senegal River flows at 300 meters cubed per second approximately 100-km downstream of Kayes at Bakel, Senegal (BISO, 2003). The river's flow is regulated by the mega-dam at Manantali, upstream of Kayes.

Research Methods

Setting up my Internship

From the beginning, it was difficult to obtain detailed information and research data at the Water Treatment Plant (WTP). I had been introduced to the Kayes Health Center water and sanitation technician and had accompanied him for a couple weeks on his bi-weekly water quality testing at city faucets and the water treatment plant. After I decided to focus my research on the Kayes WTP I went to the plant to express my interest in doing training and research there. The head of the plant, Mr. Diarra, said he would be pleased to work with me but it would have to be approved officially. I then asked the Peace Corps Water/ Sanitation director, Sogoba Togota, in the capital Bamako, how to get official approval and he said to ask my Service Director (Mr. Kimba Camara) at the Center for Social Development in Kayes. I explained to Mr. Camara my personal interest in the water treatment plant and he sent a letter to the local director of Energy of Mali/ Saur International (Mr. Hommad Ag-Mohammed) who is the head of Kayes' power and water infrastructure. After two weeks of no response, Mr. Camara called and asked the status of the inquiry. I was told to go talk with Hommad Ag-Mohammed at that time. After a brief interview he approved me performing an internship at the water treatment plant. He then drove me there and introduced me to Mr. Diarra, the head of the plant.

Examples of my Daily Observations

I began going to the water treatment plant every morning. Mr. Diarra first explained how he does water quality testing twice a day. He obtains water samples from the intake faucet and measures them for pH, turbidity, and chlorine. He then obtains water samples from the faucet of treated water and performs the same measurements. He uses a turbidometer, a pH meter, and chlorine meter.

Mr. Diarra then led me on a tour of the plant. Figure 2-2 shows a schematic of the water treatment plant. The water enters from the intake tower which is located one kilometer from the WTP. There is a valve for automatic coagulant addition, and then the water flows by gravity into three parallel settling tanks and then three parallel sand filters. The water is then disinfected through addition of chlorine by adding sacks of dry chlorine to mixing basins which is then pumped into the water, and is then channeled to a large reservoir and then pumped to the city.

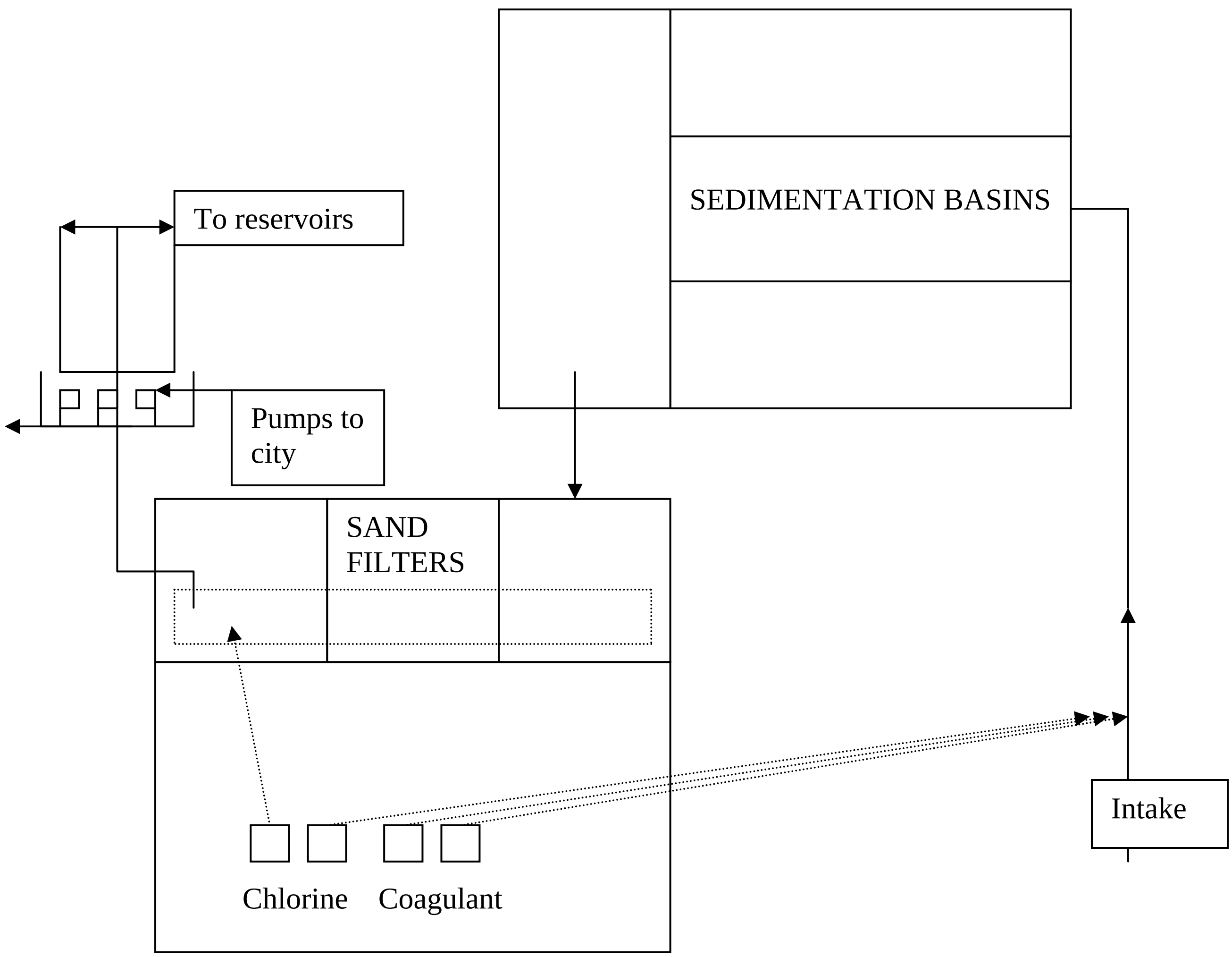

Figure 2-3. Flow Diagram of the Kayes Water Treatment Plant

The daily activity at the plant is primarily centered on pump repairs. For example, one day when I arrived at the plant, Mr. Diarra was in the midst of repairing a chlorine addition pump with his trusted mechanic Sungalo Traore. Ultimately a rubber spacer needed to be replaced so that the pump would be correctly aligned and not leak. The spare parts were stored in storage sheds behind the plant. There was an extensive supply of parts, all apparently supplied through the company, and coming from the capital Bamako.

Most days when I arrived Mr. Diarra was repairing pumps. I would observe for an hour or two. If there was an opportunity we would talk in the office and do some water quality testing. Figure 2-1 shows the plant's laboratory where water quality testing is performed.

Mr. Diarra showed me how they perform the Flocculation Trial, using the Floc Lab Water Mixer-6. One liter of intake water was added to 6 one liter beakers. Then aluminum sulphate was added to simulate possible doses for flocculation. Previously prepared solutions of Aluminum sulphate were added in various doses of 0.6 to 1.6 mL for the six 1,000-mL beakers: (i.e.: 0.6, 0.8, 1.0, 1.2, 1.4, 1.6 mL). The beakers were placed under full speed (100 rpm) rapid mixing for one minute. They were then mixed for an additional 10 minutes at 40 rpm. pH was then recorded for each beaker followed by a measurement of turbidity. The beaker with the lowest turbidity was then selected, and the aluminum sulphate dose for this beaker was recorded as the optimal dose.

Figure 2-4. Laboratory at the Kayes Water Treatment Plant. The flocculation trial equipment is located to the left of the photo.

However, Mr. Diarra informed me that in reality he has a lot of experience with the operation of a WTP so he can actually judge the optimal dose of aluminum sulphate without performing the Trial Flocculation. He said the most difficult times to make a correct dosage are during the rainy season when there are high and rapidly fluctuating turbidities of intake water. In these cases the intake water quality is changing so quickly that there is not enough time to do Trial Flocculations.

On another occasion in February I had the opportunity to go with Mr. Diarra to observe the intake from the river. One other occasion, in March, I observed repairs on one of the main pumps which pump water to the city. A bolt had been stripped. The proper bolt was found and replaced.

At one point Mr. Diarra went to Bamako for a seminar on hydraulics. The purpose of the seminar was to prevent dangerous pressure buildups in the water distribution systems. In summary, these are my recorded observations of the typical day-to-day routine of the plant manager.

Performing a Turbidity Study

From the beginning of my internship at the water treatment plant I discussed the idea of performing a turbidity study that would investigate the turbidity removal across various unit processes in the water treatment plant. Turbidity is a measurement of suspended sediment and particles in water and its value is reported in Nephelometric Turbidity Units (NTUs). This study may have provided valuable information about the effectiveness of the water treatment processes in removing suspended solids and contaminants.

I first brought up the idea with the health center sanitation technician who is in charge of water quality testing for the city. He said he would not be able to do any additional water quality testing than what he already does without additional funding. At the water treatment plant, Mr. Diarra seemed supportive of the idea of a detailed turbidity study; however his turbidometer was malfunctioning, and providing inaccurate and imprecise readings. I tried various ideas for repairing the machine, but it was not working properly at anytime during my period at the WTP.

After the American Water Works Association's 5th edition Water Quality and Treatment Handbook (1999) arrived in the mail from my advisor, I changed my research approach. I began translating key chapters of the text into French and presenting these to Mr. Diarra and to the health center technician. I ultimately focused on the following chapters: Chapter 1, Drinking Water Quality, Standards, Regulations and Goals; Chapter 3, Guide to Selection of Water Treatment Processes; Chapter 6, Coagulations and Flocculation; and Chapter 16, Water Treatment Plant Residuals Management. Mr. Diarra and Mr. Cissoko showed appreciation of these handbook summaries and asked several appropriate questions as I explained what I had translated. This represented a positive turn around in my work at the water treatment plant and seemed to contribute something to their knowledge of water treatment.

The Kayes Water Treatment Plant on the Senegal River represents one of Mali's most significant utilizations of its water resources for its people. Kayes is the capital of a desolate region in western Mali, making it essential to understand the supply of drinking water.

Chapter 3 – Kayes Water Treatment Plant

The overall goal of my research was to understand the operation and maintenance of the Kayes water treatment plant, including the various unit operations of the plant, management of solid residuals, source water quality, economics, and local and national drinking water standards.

The operations of the plant were observed over an 8-month time period from January to September 2003. The plant staff consists of a chief (or boss) and five technicians. The chief controls all decisions and commands all aspects of water quality and technology operations. The technicians perform tasks for the chief such as repairing pumps and adding coagulant and chlorine.

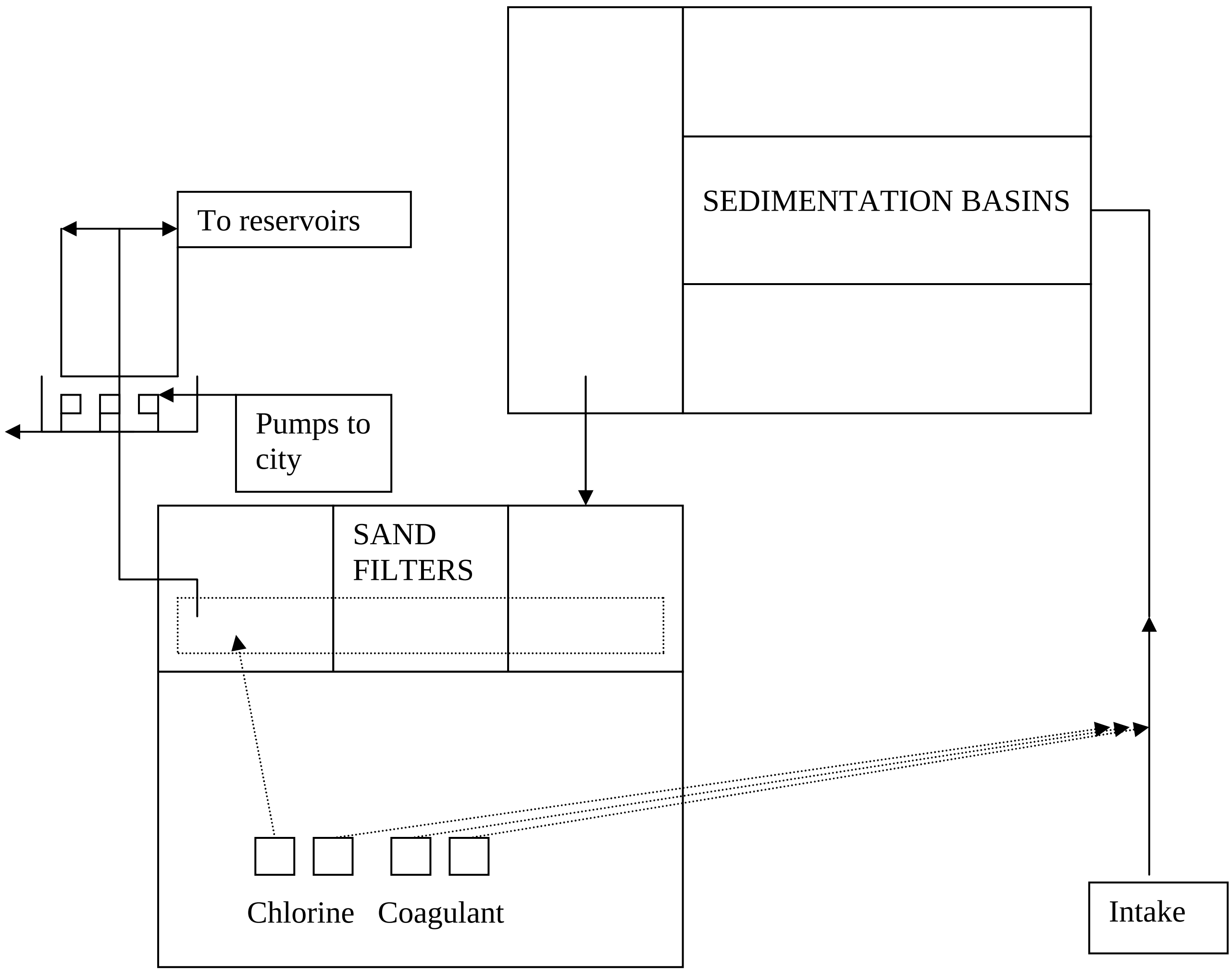

Figure 3-1. Flow Diagram of the Kayes Water Treatment Plant

Figure 3-1 shows the unit operations of the plant that consist of the basic processes of coagulant addition, sedimentation, sand filtration, and chlorination. The sedimentation tanks are approximately 31 x 6.4 meters, the base sedimentation tank is approximately 19.5 x 7 meters, and the sand filters are approximately 6.4 x 3.2 meters. These measurements were made in the field by the author.

Figure 3-2. Photo of Solid Residuals Management at the Kayes Water Treatment Plant which shows Seydou Diawarra turning the valve to release the solid residuals to the outlet to the Senegal River.

Solid residuals are gathered and disposed of manually by the plant technicians. Figure 3-2 shows Seydou Diawarra “managing” the solid residuals. The coagulation process uses alum (i.e., aluminum sulphate) resulting in the formation of an alum sludge residual that is formed according to the following process:

$$Al_2(SO_4)_3{\cdot}14\ H_2O + 6\ HCO_3^- = 2\ Al(OH)_3{\cdot}3H_2O + 6\ CO_2 + 11\ H_2O + 3\ SO_4^{2-}$$

The economics of water usage in Kayes were investigated with questionnaires provided to selected households along with information obtained from Energy of Mali, the national energy company which is now owned by a French multi-national company called Saur International. The local population resignedly accepts rather strict payment plans imposed by Saur International. The price of water is 122 CFA per m^3 (1 m^3 = 1,000 L), or $0.22 per 1,000 L, or $0.00022 per L. Towards the end of my stay (October, 2003) 565 FCFA equaled $1 USA. The specifics of energy and water costs were negotiated by the government of Mali as part of the purchase of Energy of Mali by Saur International.

Drinking water standards were observed by the author accompanying of the local health center technician on bi-weekly tests of the WTP and city faucets from January to September, 2003. National government standards were researched at the capital with the assistance of Sogoba Togota, the Peace Corps Mali Associate Director.

History of the Water Treatment Plant

The Kayes Water Treatment Plant was built in 1970 by a German group. This original plant consisted of sedimentation basins, filters, and chlorine addition. The Germans stayed and worked at the plant for five years. The plant was owned by the

Mayor's office. It later passed ownership to Energy of Mali, a national owned company which also operated the country's electricity. In 1989 the plant was expanded. The expansion was done by SATOM, a mixed French and African group based in Bamako, the capital of Mali. The new plant kept the intake and sedimentation basins, but added sand filters, chlorine pumps, mixers and the main building, the laboratory, main pumps, and the reservoir. The plant is now owned by Saur International, a private French company.

Description of the Water Treatment Plant

The flow of water through the Kayes Water Treatment Plant begins with the intake. The intake tower was part of the original construction of the plant in 1970. It rests on the south bank of the Senegal River 1-km to the east of the water treatment plant. The intake points directly out into the middle of the river just above the ground level. A large pump is situated at the base of the intake tower. The top of the tower is configured with an air pressurizer to protect against the high water pressure within the water distribution network. The water is then pumped 1-km to the water treatment plant.

Figure 3-3. Sedimentation Basin at the Kayes Water Treatment Plant

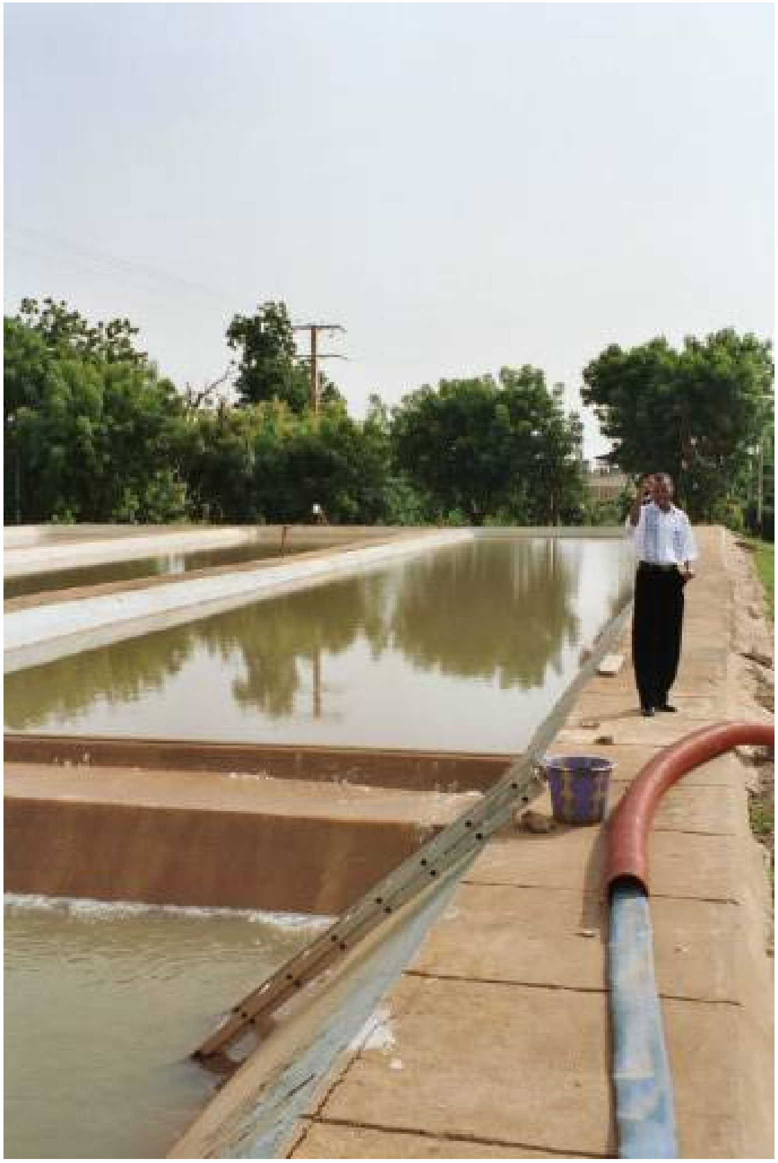

Figure 3-4. Sedimentation Basins at the Kayes Water Treatment Plant under Mr. Diarra's supervision.

Figure 3-5. Base Sedimentation Basin at the Kayes Water Treatment Plant

At the water treatment plant the water first contacts a chemical addition valve for addition of coagulant. The water then continues in a pipe for 50 feet. The intake pipe then branches out to three pipes with outlets to each of the sedimentation basins. Three long sedimentation basins run parallel (See Figures 3-3 and 3-4). At the base is another sedimentation basin (referred to as the base sedimentation basin) that collects effluent from the three long sedimentation basins (See Figure 3-5). This water is then piped by gravity directly to three parallel sand filters (See Figure 3-6). The sand filters effluent is below the building where chlorine is added (See Figure 3-7 and 3-8). After disinfection the water continues to a reservoir. Finally the water is pumped to the city's distribution system with three large pumps (See Figure 3-9).

Figure 3-6. Sand Filters at the Kayes Water Treatment Plant

Figure 3-7. Sacks of dry Chlorine awaiting use at the Kayes Water Treatment Plant

Figure 3-8. Chlorine Mixing Basins at the Kayes Water Treatment Plant

Figure 3-9. Main pumps to the Kayes' Distribution System

Figure 3-10. Water Treatment Plant Technician, Sungalo Traore, sitting under a mango tree with his assistant.

Daily Operation and Maintenance

Often when I arrived at the Water Treatment Plant in the morning I found the workers sitting out under the tree talking and drinking tea. This is a favorite activity of Malian people, and many can spend all day in this fashion. I would make my best effort to sit down and talk with them, joking around a little also. Then I would ask if the chief of the plant was present. About half of the time he would be there. I would then go into his office and chat a little. I would then steer the discussion towards my research priorities.

If a pump were broken the workers would be repairing it. Occasionally there would be a special project. For example, every six months the workers clean the surplus water tower which is in town, near the train station and every few months they clean the sedimentation basins. At one time they were changing the pressure regulator pump at the intake tower.

Figure 3-11. Treatment Plant Technician, Seydou Diawarra, at the flow controls of the Water Treatment Plant.

The plant personnel are made up of the boss, Monice Diarra, and four agents de conduits. Their names are Seydou Diawarra (see Figure 3-11), Sungalo Traore (see Figure 3-10), Mamadi Coulibaly, and Oumar Aya. The agents work is mostly related to repair of pumps (e.g., they repair the main pumps, chlorine pumps, and river intake pump). They can also do repair on pipes located in the city's distribution system. According to Seydou Diawarra, a lot of their time is spent repairing the main pumps.

Besides repairing the pumps, chlorine addition is another main job of the workers. The main building of the plant is equipped with two large chlorine mixers (as shown in Figure 3-8). As Seydou Diawarra described it to me, two 8-kg sacks of dry chlorine (most likely NaOCl) is added to each of two mixing chambers every 4 or 5 hours (See Figure 3-7). This process is repeated constantly year round. When the chlorine is depleted in the mixers an alarm will sound, and additional sacks of chlorine are added.

Coagulant is also added at the plant as aluminum sulphate. According to the water treatment plant chief and Seydou Diawarra, coagulant is normally added at the rate of one 50-kg sack per day. In periods of heavy rain and high turbidity of the source water coagulant addition can reach as high as sixteen 50-kg sacks, or 800-kg per day. The pretreatment formula is added by automatic valves and the workers provide only the daily sacks of coagulant and chlorine to the mixing basins.

Calculations

Some standard calculations can be performed in order to improve understanding of the treatment processes. Mr. Diarra told me the average flow rate of water through the plant is 400 meters cubed per hour. Based on this value and the size of the sedimentation basins, a value for the surface overflow rate can be calculated.

Surface Overflow Rate, $OR = Q/A = (400\ m^3/hr)/\ (3 \times 31 \times 6.4\ m) = 2.0\ m^3/m^2\text{-}hr$

Other parameter calculations were attempted, however sufficient background information was not available. The surface loading rate for the sand filters depends on grain size distributions and the head loss over the filter. The G parameter for coagulant addition depends on the detention time. Unfortunately, I was not able to obtain this information while working under Mr. Diarra.

Water Quality Standards

For the duration of my research period I accompanied the Health Center technician on his bi-weekly testing of Kayes' water quality. He would travel to one location in the city to test the water quality of post-distribution, and then to the Water Treatment Plant to test the quality of the post-treatment water supply. He would test for temperature, conductivity, pH, residual chlorine and total chlorine. On occasion he would test for the presence of coliforms in the water.

At the treatment plant Mr. Diarra tested for turbidity, pH, residual chlorine, and total chlorine. Turbidity is required to be less than 5 NTU. pH is required to be between 6.5 and 8.5. Chlorine levels are required to be between 0.2 and 5 mg/L. Table 3-1 summarizes the testing that is performed and the local water quality standards.

Table 3-1. Water Quality Testing in Kayes, Mali

Parameters the Health Center Technician Tests	Parameters the Water Treatment Plant Chief Tests	Local Water Quality Standards
Temperature	-	-
-	Turbidity	< 5 NTU
Conductivity	-	-
pH	pH	6.5 - 8.5 mg/L
Residual Chlorine	Residual Chlorine	0.2 – 5 mg/L
Total Chlorine	Total Chlorine	0.2 – 5 mg/L

In the case of a water quality violation the health center technician would issue a verbal warning to the Water Treatment Plant workers. He told me that over the many years he has performed water quality testing there has never been any major incidents of violations. At most he has notified the workers of a violation verbally and encouraged them to correct the problem. The violations occur mostly when the water treatment plant chief, Mr. Diarra, is away.

Residuals Management

Residuals management at the plant is controlled by manual valves. Residuals are captured in a catch basin below the sedimentation basins. Valves are simply opened regularly by hand to release the solid residuals stream from the catch basin into pipes which flow out to the Senegal River near the plant (and downstream of the intake). A large valve is located at the head of the three large sedimentation basins for their residuals drainage. A second valve is located at the base of the large perpendicular sedimentation basin for its residuals drainage (See Figure 3-2).

This method of solid residuals management is relatively simple. The solids are gravity settled from the sedimentation basins and discharged with a valve to the river, downstream of the intake. In the United States this solid waste would be required to undergo further treatment before disposal to the river, or would require discharge to a more secure location such as a landfill.

Chapter 4 – Analysis of Kayes Water Treatment Plant

As described by the American Water Works Association's 5th edition Water Quality and Treatment Handbook (1999), factors to be considered in decision making for selection of water treatment unit processes are listed in Table 4-1. These factors can be used to evaluate the Kayes Water Treatment Plant.

Table 4-1. Factors to be considered in Analysis of Water Treatment Plants

Factors of WTP
Contaminant removal
Source Water Quality
Reliability
Existing Conditions
Process Flexibility
Utility Capabilities
Costs
Environ. Compatibility
Dist. system water quality
Issues of process scale

Contaminant removal is obviously a very important aspect of water treatment. Maximum contaminant level regulations may be viewed as an upper level that should be seldom approached, rather than as a guideline. Many water utilities choose to produce water that is much higher in quality than water that would simply comply with the regulations. Some may do this by operating their processes more effectively. Others may employ additional treatment processes to reach higher levels of water quality (AWWA, 1999).

At the Kayes Water Treatment Plant water quality testing is performed for turbidity, pH, residual chlorine, and total chlorine, as shown in Table 4-2. In the USA, the effluent standard for turbidity is less than 1-NTU, whereas in Kayes the standard is less than 5-NTU. Kayes' effluent water quality standards are based on the World Health Organization's (WHO) guidelines for water quality.

Table 4-2. Comparison of Water Quality Standards in the United States and Kayes, Mali.

Criteria	**U.S. Water Quality Standard**	**Kayes, Mali Water Quality Standard (based on WHO)**
pH	6.5 - 8.5	6.5 - 8.5
Turbidity	< 1 NTU	< 5 NTU
Chlorine	0.3 - 4 mg/L	0.2 - 5 mg/L

Table 4-2 shows that the water quality guidelines are more flexible in Kayes when compared to the U.S. Also, the Kayes Water Treatment Plant certainly views the WHO guidelines as just guidelines. Contaminant levels frequently approach and sometimes surpass these guideline values. However the Water Treatment Plant chief does say he is aware of the importance of the guidelines. As mentioned earlier in Chapter 1 the obsession with water purity and sterility common among the American public does not exist in Mali.

In the United States some utilities may even treat for aesthetic qualities such as taste, odor, hardness, high mineral content, iron, and manganese. This is important because customers judge overall water quality based on aesthetic qualities (AWWA, 1999). Kayes' utility is of course not required to treat aesthetic qualities. The most obvious aesthetic quality in Kayes' water is the high turbidity during the rainy season. The local population generally believes this poses no health risk, and regards it as a very minor nuisance. For the local population, ideal drinking water quality would be similar to water taken directly from the river or a well. Again there is not a general concern about the sterility of water – there is a preference for "natural" water. For example, when crossing the Senegal River in a row boat, one of the women will often scoop up a cup of water from the river to drink, and then provide some to her child.

"Source Water Quality" is the next factor listed in Table 4-1 used for selection of water treatment processes. According to AWWA, understanding and testing of source water versus treated water is important. Kayes' utility regards the Senegal River as a very good water quality source. The main issue is high turbidity during the rainy season. At this time it is only necessary to closely monitor the variations in coagulant addition. As stated in Chapter 3, typically 50-kg of coagulant are added per day. In the rainy season, up to 800 kg may be added per day. Chlorine is added to a mixer which alerts when the chlorine in the system is finished. It is added as dry chlorine by 8-kg sacks. Furthermore, according to Mr. Diarra, natural organic matter (NOM) has been tested in the Senegal River and is not considered to be a risk for the formation of disinfection byproducts.

According to AWWA, the "reliability" of a water treatment plant is based on a number of factors: the range of source water quality versus the range of quality the process can successfully treat; the rate of change of source water quality – slow and gradual or very rapid and severe; the level of operator training and experience; the staffing pattern; mode of operation – continuous flow or varying flow related to water system demand; amount of instrumentation; ability to maintain instruments and keep them calibrated; reliability of electric power supply; and, capability to prevent source water deterioration long term.

The range of source water quality is affected most dramatically in the rainy season. Rainfall in the vicinity of Kayes and upstream runoff causes large increases in turbidity of the river water. The water in the dry season is clear and blue, but in the rainy season is dark and murky. The Water Treatment Plant is often ineffective in reducing the turbidity before it reaches the faucets. Treated drinking water is often very turbid during the rainy season and is a subject of public discussion, although very little public concern. The Water Treatment Plant manager increases the levels of coagulant at these times in order to ensure sufficient contaminant removal. Thus the Water Treatment Plant can treat all ranges of source water quality, but not to an ideal level. After heavy rains the source water quality can change dramatically. The Water Treatment Plant manager is often watching closely the increases in chemical dosages through periods of heavy rains.

The level of operator/staff training is very low. They have mostly learned from hands on experience. The Water Treatment Plant manager does have significant water treatment plant experience. Before his position in Kayes, he was water treatment plant manager in the city of Gao for several years. His education is in electro-mechanics so his experience at the water treatment plant has afforded his understanding of the science of water treatment. Some of the remaining staff have very long experience at the water treatment plant. For example, one individual has been working there for 30 years. Unfortunately there is no supplemental training available.

The amount of instrumentation is minimal. There are instruments that regulate the flow rate and pumps and there are the water quality testing instruments. My research focused mainly on the water quality testing instruments. In attempting to perform a turbidity study I came to realize the lack of reliability of the instrumentation. At the time I was attempting to perform the turbidity study the turbidometer was not in working order. It was giving readings that were neither precise nor accurate. I repeatedly questioned the Water Treatment Plant manager about methods of repairing the turbidometer, including calibration methods, which he attempted. I also asked him about receiving a new turbidometer from the company. After a few weeks I gave up on the idea of performing a turbidity study. I learned at the end of my service that the plant has now received a new turbidometer. The laboratory also contained a pH meter and a meter for measuring chlorine levels.

The electric power supply in Kayes is somewhat unreliable. It often cuts out, especially during the rainy season. This is mainly due to high winds knocking down power lines, and power surges. However there is a backup power generator for the Water Treatment Plant, so this is not a huge concern for operation and performance of the plant.

Robustness is defined as “the ability of a filtration system to provide excellent particle/pathogen removal under normal operating conditions and to deviate minimally from this performance during moderate to severe process upsets” (AWWA, 1999). Unfortunately there is not excellent particle/pathogen removal at all times of plant operation. For example, during moderate to severe process upsets the system is not capable of providing excellent particle/pathogen removal. In these instances of highly turbid source water, the coagulant is simply super-loaded into the system. There are not other procedures taken to ensure stabilization and settlement of the coagulant and particles, so the treated water turns out quite murky.

“Process flexibility” is a factor to be considered for the future life of the water treatment plant. This plant is a very conventional plant. Thus if resources were available simple upgrades could be made. However there are not adequate financial resources for an upgrade. Given the existing plant, there is some room for flexibility in location for addition of coagulant or chlorine.

“Management attitudes about water quality were a key factor in attaining or failing to meet water quality goals” (AWWA, 1999). As discussed earlier it can be seen that management attitudes are partly preventing the attainment of an excellent water treatment. However this is mainly due to a lack of resources to the Water Treatment Plant manager. From the author’s experience, the Water Treatment Plant manager is not looking to perform studies to analyze the effectiveness of the treatment process, nor actively considering the impact that his water supply is having on the city’s population. In many ways he is performing his role within Energy of Mali/ Saur International, which includes a lot of paperwork and only doing what he is ordered to perform.

“Environmental compatibility” is an important factor to control. In Mali there are no tough regulations about water pollution. At this point the solid residuals from the sedimentation process are collected underneath the sedimentation basins. And then two conveniently located valves can be opened to release the solid residuals into pipes which feed out to the Senegal River.

The distribution system water quality was best observed through my research with the health center technicians. We observed water quality at the termination of the distribution system, or the faucet, and then at the treatment plant. Often the chlorine levels would be slightly lower at the faucet as can be expected. And sometimes the temperature at the faucet could get quite high due to the heat. Overall distribution water quality is acceptable considering the generally low state of infrastructure in Kayes.

When considering all of these factors in analysis of the Kayes Water Treatment Plant, we can have a better idea of the state of water quality and treatment in Kayes' water supply. The system as a whole is operating at a minimal level of acceptance based on standards of the United States. However when considering the serious limitations at the Kayes Water Treatment Plant (limited financial and technical resources, and isolation), this plant is probably operating near the best of its abilities.

Chapter 5 – Economic Study

At the end of my service I conducted a survey of 30 households randomly distributed throughout the city of Kayes. The survey was a great way to end my two-year service in Kayes. It was here at the households that I saw the real impact of the water supply. Unfortunately the most common message I received from the people was that the water bills are too expensive.

The collection of homes identified for the survey accurately represents the types of households in Kayes. I randomly selected 5 homes from each of the 6 neighborhoods of the town. I selected a range of houses which included poorer and wealthier households. These houses represent the typical household for the vast majority of the city.

Unfortunately I was not able to obtain household income for the survey. Requesting this information would be culturally inappropriate and furthermore impossible, as no one would be willing to provide an honest answer to the question. Accordingly, I estimated an income based on the number of working people in the household and calculate incomes based on average salaries for workers in Kayes.

Economic Surveys such as these are best performed as simple questionnaires, according to summaries of the research literature (Stoveland Consult, 2002). Many surveys get disparate data based on cross-cultural communication challenges, and confusion of responses arising from a complicated series of surveys.

The simple questions of the survey performed for this study were:

1) How many people are in your household?

2) How much water do you use per day? (# of barrels)

3) How much is your monthly water bill?

4) What is your source of water? (house faucet, street faucet, barrels sold in the neighborhood)

I was accompanied on the survey by a close friend, a local young man named Yeli Sissoko of Kayes. He aided me by explaining in Bambara our reasons for doing the survey, which developed an essential sense of trust and honesty.

People were able to quantify their water usage based on the number of barrels of water they use per day for the household. These barrels are all a uniform 200-liters. People were also very open with providing information on the cost of their water bills. However, sometimes they had difficulty providing me a figure for the water portion of the bill only (without electricity). All the data obtained from the survey is provided in Table A-1 of the Appendix.

Figure 5-1 shows the average monthly water bill (U.S. $) for a given household size (5 to 10 people, 11 to 15 people, etc).

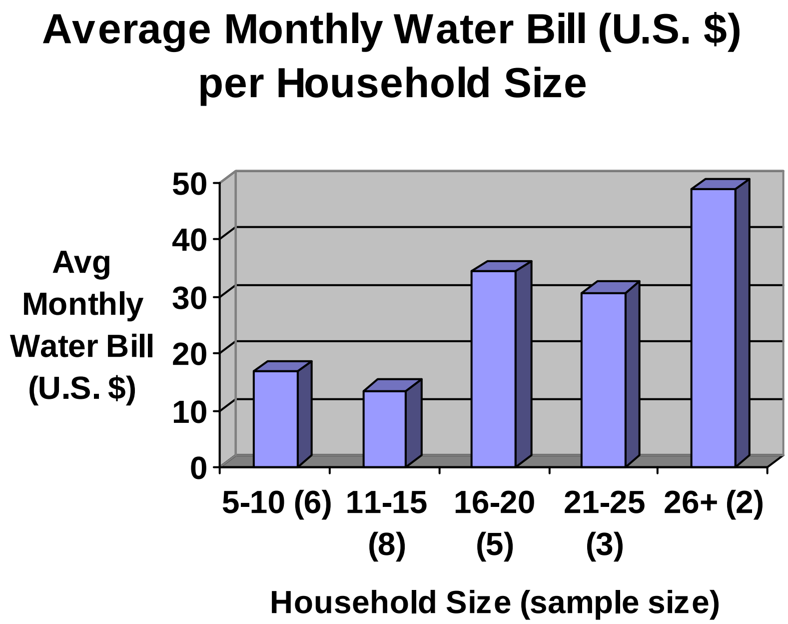

Figure 5-1. Average Monthly Water Bill (U.S. $) per Household Size

Figure 5-1 shows that the average monthly water bill for a household of 5 to 10 people is approximately $17. As the household size increases the average monthly water bill generally increases to $49 for a household of greater than 25 individuals.

Figure 5-2 details the average monthly water usage per household size. This figure shows that the average monthly water usage for a household size of 5 to 10 people is approximately 300 liters per day. This value increases to 1,100 liters per day for a household of greater than 25 individuals.

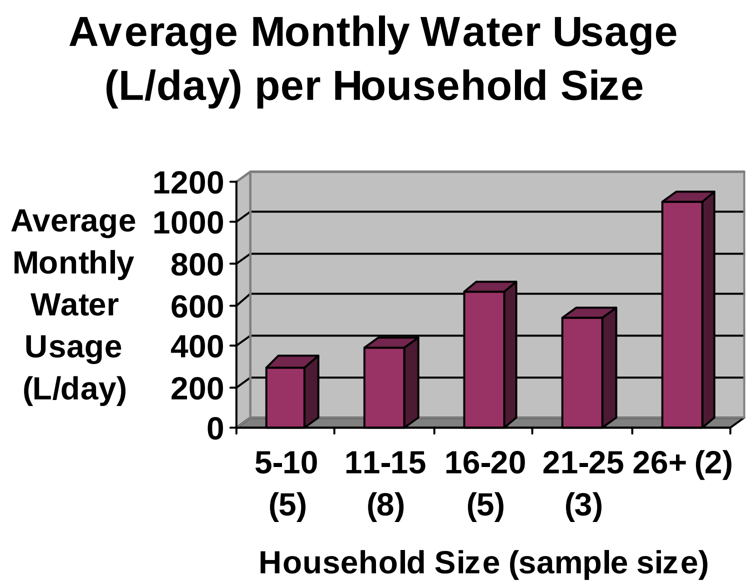

Figure 5-2. Average Monthly Water Usage (L/day) per Household Size

According to the Global Water Outlook (GWO) for 2025, "In 1995, household water use in rural areas of sub-Saharan Africa was estimated at 18.8 cubic meters per person per year for households with connections to piped water, while the rate for connected urban households was 55 percent higher, at 29.2 cubic meters per person per year" (IFPRI, 2003). The Global Water Outlook figure of 29.2 meters cubed per person per year converts to 29,200-liters per person per year. Averaging the values obtained in this study's survey, the average person in Kayes uses 11,295-liters per year. Thus, the data collected for this report suggests that in Kayes, Mali, one of the hottest cities in Africa, the average person uses much less water than the norm for Sub-Saharan Africa. As a check of the survey value, let us calculate the water usage per person per year based on the given flow rate at the Water Treatment Plant, 400 m^3/hr. The average population of Kayes is 100,000 people.

$$400 \text{ m}^3/\text{hour} * 8760 \text{ hours/year} = 3{,}504{,}000 \text{ m}^3/\text{year}$$

$$3{,}504{,}000 \text{ m}^3/\text{year} / 100{,}000 \text{ people} = 35.04 \text{ m}^3/\text{person/year} =$$

$$35{,}040 \text{ L/person/year}$$

We can subtract from this calculation assumed losses from the distribution system, however this check indicates that the survey's values for water usage are generally underestimated. Thus, we can conclude that people have underestimated their water usage, and thus the calculations for the price of water in Kayes are overestimated.

Looking at the discrepancy contrarily, the cost of water in Kayes has also led to household water conservation. For example, one family described their method of water conservation. They are a household of 17 people, but manage to use only ½ barrel (or 100 L) of water per day, which costs them 3,000 CFA, or $5.31 (U.S. $) a month. The man of the house described their conservation as a matter of watching closely and controlling their water use as much as possible. All the families surveyed controlled their water usage to some extent, although maybe not as stringently as this family. Some of the families I talked with had their water cut off by the water company because of not paying their bills. They resorted to buying water on a daily basis from a man who sells water in the neighborhood (See Figure 5-3). Men selling barrels of water are a common occurrence throughout West Africa. One barrel of water often sells for 200 CFA ($0.35) per barrel in Kayes. The barrels are uniform in size and hold 200-liters. Many families also put locks on their faucets in order to control water use. When water is needed the faucet is unlocked.

Figure 5-3. My survey assistant, Yeli Sissoko (left), with the Man selling Barrels of Water in the Khasso neighborhood of Kayes.

According to conversations the author had with the Saur International / Energy of Mali headquarters in Bamako, the price of water they provide in Mali is a uniform 122 FCFA/m^3 (1 m^3 = 1,000 L) for up to 20 m^3 (20,000 L) per month. Thus the uniform cost of water is $0.216 per m^3 (1,000 liters). Most households use under 20,000 L of water per month, but some use more as seen in Table A-1 of the Appendix. Water usage over 20,000 L per month costs 322 FCFA/m3 (1 m3 = 1,000 L), or $0.57 per m3 (1,000 L).

Figure 5-4 provides the overall price of water per household size. This figure lists the price of water in $ per 1,000 L which is the same units used for the official water price given by Saur International. Using the data provided in Figure 5-4, the survey results can be compared with the official price of water provided by the Saur International / Energy of Mali headquarters in Bamako, Mali. From Figure 5-4, it is observed that the price of water ranges from approximately $1.50 to $2 per 1,000 Liters. This value is much greater than the price of $0.22 per 1,000 Liters given by Saur/ Energy of Mali.

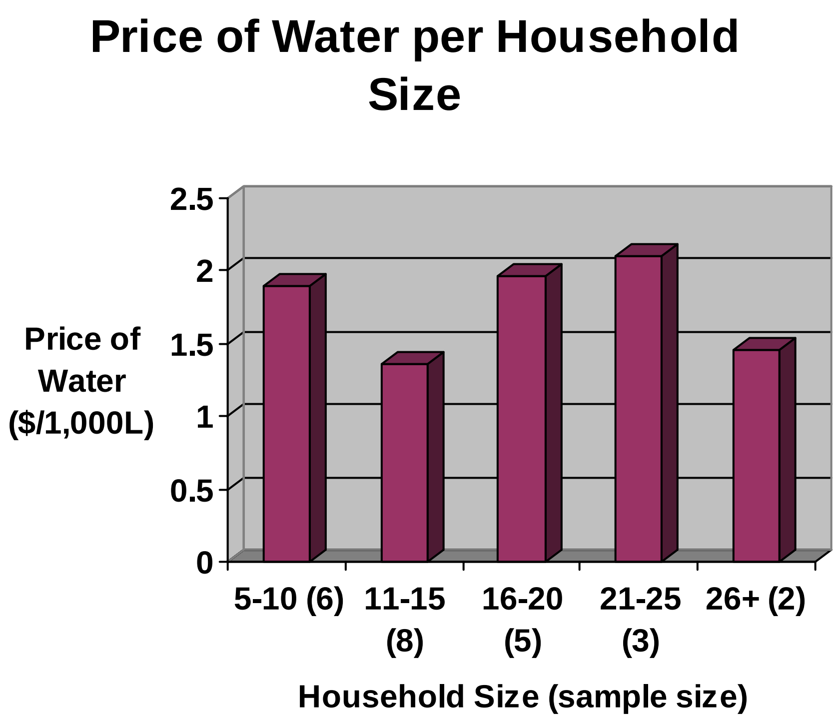

Figure 5-4. Price of Water (U.S. $/ 1,000 L) per Household Size Determined from Survey.

This data shows that the price of water determined from the survey is greater than the price of water set by Saur International / Energy of Mali headquarters. In all likelihood, the households may have underestimated their water consumption when answering the survey questions. For example, any extra water taken directly from the faucets would not have been included in their estimates during the survey. And in some cases the higher cost of water is because their source of water is not directly from the utility's faucet, but is from the men selling water in barrels. Also, the official price of water given by Saur International / Energy of Mali may not include taxes (the author was able to confirm this prior to departing from Mali).

The data obtained from the survey can provide some useful understanding of the cost of water in Kayes. Figures 5-1 and 5-2 show that the monthly water bills (U.S. $) and monthly water usage (L) generally rise with respect to increasing household size. This suggests that the survey is generally reliable. However some of the data provided, as shown in Table A-1 of the Appendix, is inconsistent. For example, one household of 20 people reported a monthly water bill of $88.50 while another household of 22 people reported a monthly water bill of $14.16. Possibly in this case the former household reported their combined water and electricity bill versus simply the water portion of the bill. However they reported that they used 2,000 Liters of water per day, much more than any of the other households. Thus there are some discrepancies in the results, but overall the data is useful, given the difficulty in obtaining such data.

Consider that each household contains mostly women and children. There may also be several elderly people per household and at most 2 or 3 working men per household. The women also work in many cases, selling goods. Thus, a typical household of 16 people may include a man with two wives and seven children, two grandparents, along with the man's younger brother and wife and two kids. The household's monthly salary could be approximately 35,000 CFA for each working man, and an additional 15,000 CFA from the women. In this case, the total household income would be approximately 85,000 CFA, or $150.00. If the monthly water bill is $35 (taken from the survey for a 16 - 20 person household), or 23% of the household's monthly income, then we can see the significance of this expense.

Another item performed in this study was to compare the price of water in Kayes to the average price of water around the world. As mentioned previously, the official price of water in Mali provided by Saur International / Energy of Mali was $0.22 per 1,000 Liters and the survey results suggested that in Kayes, water costs $1.50 to $2.00 per 1,000 Liters. According to a survey conducted by NUS Consulting Group, the following is the ranking of the surveyed countries and their average water price in U.S. Dollars per 1000 L: "(1) Germany, $1.52; (2) Denmark, $1.46; (3) United Kingdom, $1.11; (4) The Netherlands, $0.98; (5) France, $0.93; (6) Belgium, $0.75; (7) Italy, $0.62; (8) Spain, $0.58; (9) Finland, $0.53; (10) United States, $0.52; (11) Sweden $0.51; (12) Australia, $0.48; (13) Canada, $0.37; (14) South Africa, $0.34" (Arizona Water Resource, 2002). As can be seen from this ranking, the prices I obtained from households in Kayes say that Kayes' water is more expensive than Germany, which is the most expensive in the world according to this survey. Whereas the official price obtained by Saur International's Mali headquarters say that the official price of water in Mali is less expensive than South Africa, the least expensive water in the world of developed countries.

The overall conclusion from this water survey of households throughout the city of Kayes is that water is a very expensive commodity for people in Kayes, and on average may cost a household 23% of its monthly income. The survey results also suggest that water usage in the city of Kayes is less than the average water usage in Sub-Saharan Africa.

Water is a central aspect of life in West Africa. Women pass their days collecting water and using it throughout the day to wash clothes and dishes, provide water for their husbands and children to bathe, and use the water for cooking. The women wake up before sunrise in order to begin their day's work. Living on expensive and rationed water does not present any new difficulties for these people. They are used to being treated like this, and pass each day joyfully, and thankful for the water they do have.

Chapter 6 – Conclusions

An extensive study at the Kayes Water Treatment Plant reveals the treatment processes, operations, and economics of water supply. The people of Kayes are struggling to afford the water they need to live. The local operators barely have the expertise and resources to manage their water treatment plant. Yet the people of Kayes are succeeding at providing one of the best water supplies in the country of Mali. People coming from around the country enjoy the luxury of tap water after spending many hours of every day for many years pulling water from a well. The people of Kayes are most limited by their lack of financial resources. Major upgrades to the water treatment plant must come from outside sources. This leaves the local people without control over their own water. As the general population is struggling just to pay for the water they do have available, an upgrade is out of their realm of possibilities. In the hottest city in Africa people regard water simply and cherish it.

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Chapter 8 – Appendix

Figure A-1, Kayes Water Treatment Plant Plans [ATTACHED]

Table A-1. Survey of Water Usage and Monthly Bills

Household Size (# of people)	Monthly Water Bill (U.S. $)	Barrels per Day	Liters of water per day	Liters per person per day	Liters per month	$ per 1,000 Liters
17	31.86	2	400	23.53	12000	2.70
15	8.85	3	600	40	18000	0.50
10	21.24	2	400	40	12000	1.80
15	21.24	2	400	26.67	12000	1.80
25	35.40	3	600	24	18000	2.00
20	88.50	10	2000	100	60000	1.50
15	22.12	2.5	500	33.33	15000	1.50
13	11.50	3	600	46.15	18000	0.60
17	5.31	0.5	100	5.88	3000	1.80
16	26.55	2	400	25	12000	2.20
35	61.95	6	1200	34.29	36000	1.70
		3	600	24	18000	0
5	7.96	1.5	300	60	9000	0.90
17	19.47	2	400	23.53	12000	1.60
10	19.47	2	400	40	12000	1.60
8	10.62	1	200	25	6000	1.80

Household Size (# of people)	Monthly Water Bill (U.S. $)	Barrels per Day	Liters of water per day	Liters per person per day	Liters per month	$ per 1,000 Liters
7	13.27	1	200	28.57	6000	2.20
22	14.16	3	600	27.27	18000	0.80
9	27.88	1.5	300	33.33	9000	3.10
12	5.31	1	200	16.67	6000	0.90
50	35.40	5	1000	20	30000	1.20
13	5.31	1	200	15.38	6000	0.90
13	10.62	2	400	30.77	12000	0.90
25	42.48	2	400	16	12000	3.50
14	23.01	1	200	14.29	6000	3.80

Photo #1. Mr. Diarra