TECHNICAL CAPACITY BUILDING OF EXISTING GRAVITY-FED RURAL DRINKING WATER SYSTEMS IN HONDURAS

By

John D. Simpson

A REPORT

Submitted in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE IN CIVIL ENGINEERING

MICHIGAN TECHNOLOGICAL UNIVERSITY

2003

This report "Technical Capacity Building of Existing Gravity-Fed Rural Drinking Water Systems in Honduras" is hereby approved in partial fulfillment of the requirements for the Degree of MASTER OF SCIENCE IN CIVIL ENGINEERING.

Civil and Environmental Engineering
Master's International Program

Signatures:

Report Advisor ______________________________

James R. Mihelcic

Department Chair ______________________________

C. Robert Baillod

Date ______________________________

[redacted]

Preface

This report is based on the 27 months I spent while living in Honduras as a United States Peace Corps Volunteer from July 2001 through October 2003. I worked as a Water and Sanitation Engineer in the city of Choluteca.

My service, as is every volunteer's experience, was very unique. I lived, contrary to popular belief of a Peace Corps Volunteer, in a city of 100,000 people with the majority of modern conveniences. I knew joining the Peace Corps would be a completely different life than what I was used to in the States, however I never imagined it would be different in the fact that I carried a cell phone and beeper and watched cable television to pass the down time.

This report is submitted to complete my master's degree in Civil Engineering from the Master's International Program in Civil and Environmental Engineering at Michigan Tech. It is focused on the work I completed during the times I got away from the city to work and enjoy the real Honduran lifestyle. For example riding buses, drinking coffee, riding horses, walking for miles and using a machete to chop my way through the jungle while at the same time trying to assist in the development of water projects.

Table of Contents

[redacted]

List of Figures

List of Tables

Acknowledgements

I would like to thank my advisor Jim Mihelcic for his constant support and guidance during my two years in Honduras. The program at Michigan Tech he has developed with Tom Van Dam is a very unique program that has provided me with unforgettable experiences. My graduate committee, composed of the aforementioned Dr. Mihelcic and Dr. Van Dam as well as Dr. Dave Watkins and Dr. Bruce Barna offered support for the entire 3 years I was involved in this program.

All of the people in Honduras with whom I worked were very supportive. The construction workers who built the systems I worked on are excellent examples for all of us. The people who worked all day voluntarily in extreme heat and then offered me what little food they had were the people I will never forget. The eighty year old men walking in flip-flops telling me to hurry up while I sweat uncontrollably show that hard work really pays off.

All of my family and friends who supported me should be thanked as well. Reina and Claudia Osorto will be remembered for their cold cokes, telephone, and free food. My family showed support by visiting and taking me on vacation. Raj and Nina Shaw were the best site mate ever, especially for the excellent vegetarian Indian food. Justin Martin, Kate Greenburg, Gina Malan, Diana Villella and Chris Moore provided me an escape on the weekends. Pamela Ortega was always my best friend. Chris Watson and Maggie McClain were a source of laughter on endless walks on surveys in the most remote village. And finally, the Peace Corps project manager for Water and Sanitation, Martin Rivera for developing such a successful program that is used as an example for others worldwide.

Abstract

Honduras is a developing country with scarce amounts of water available for human consumption. My Peace Corps service from July 2001 through October 2003 focused on improving the health of rural Hondurans through building new water systems and improving existing potable water resources.

Rural water systems, even when properly designed and built, commonly experience some type of problem that does not allow some or all of the users to obtain a quantity of water that they feel is sufficient for their daily activities. This may be due to lack of supply, a poorly operating tubing system, or increased use/misuse of water.

Technical capacity building refers to the altering of the physical and operational characteristics of a water system in order to increase a system's ability to provide safe and reliable drinking water. The lack of resources in rural Honduras makes diagnosis of problems in a water system critical, as an improper solution of the problem may only waste money or even worse, magnify the shortage of water. Many times, outside organizations or communities with little technical knowledge, will try to improve systems with techniques such as smaller tubing, larger intake structures, or water rationing. These techniques are usually ineffective. The steps involved in troubleshooting a system are easy, and with education, communities should be able to improve their own systems without outside support.

This report is based on my two years experience in Honduras on how technical solutions can be found to supply more water to an existing system and show how limited water may be more equitably distributed throughout the community. Water shortage is a very complicated issue that has many social aspects as well. Many times a social solution such as pressuring neighbors to use less water can be the best solution. There are however examples where a conveyance line, distribution line, or a tank may be undersized and a more technical solution is warranted. This report will help the reader to quickly and accurately determine why members of a community are not satisfied with the quantity of water supplied as well determine an appropriate course of action.

1.0 Introduction

1.1 Water Concerns in Honduras

To meet the demand for water, humankind has been modifying the hydrological cycle since the beginning of civilization by constructing wells and boreholes, reservoirs, aqueducts, water supply systems, drainage systems, irrigation schemes and similar facilities. Governments and public bodies spend large sums of money to develop and maintain these facilities. In 1995, some 20 per cent of the globe's population of 5.7 billion people still lacked a safe and reliable water supply, while more than 50 per cent were without adequate sanitation (CHP 2001).

Human health is dependent on a wholesome and reliable supply of water and safe sanitation. In the developed world these water services are largely taken for granted, but in the developing world they are prized by those who have them and coveted by those who do not. It is estimated that at any given time about half the people living in developing countries are suffering from water-related diseases caused directly by infection, or indirectly by disease-carrying organisms that breed in water, such as mosquitoes. Diarrhea, infections by parasitic worms, river blindness and malaria are among the most widespread of these diseases. More than five million people are estimated to die each year from diseases related to inadequate sanitation and hygiene practices, and drinking polluted water. Outbreaks of cholera can kill hundreds of people and cost hundreds of millions of dollars of lost income (CHP 2001).

Water and sanitation system development in rural areas can further the economic, social and educational development of a community. From a villager's point of view, the advantages of improved water and sanitation usually are convenience and prestige rather than health. A water supply project offers immediate and demonstrable results. Those who carry water long distances, especially women and children, have more time for other activities when a water supply is conveniently located to their houses. Village agriculture, livestock production and small industry will frequently expand with better access to greater quantities of water. Both individual and community productivity can rise because of the better health people enjoy as a to result of access and use of effective water and sanitation facilities (CHP 2001).

In the 1990's, it was reported that Hondurans' access to potable water rose by over 13% (Trevett 1998). International agencies and programs associated with the Honduran government were establishing water committees to be responsible for the maintenance and management of each new system. In the present, some 10-20 years after construction, these same water committees are expressing concern that these systems are not delivering sufficient water to the population and funds available for rehabilitation of existing systems are limited. Factors that may influence the performance of drinking water system in rural areas of low-income countries include: community motivation; use of technical and local information in system design; community capacity to maintain a new water supply system; protection of watersheds and access to water system facilities; and ongoing support from organizations outside the community (Gelting 1998).

1.2 Report Objectives

This report demonstrates the engineering requirements for building capacity to drinking water systems that no longer deliver the desired quantity of water to a community. This process starts with troubleshooting a system to diagnose the problems and then finding an economical solution to rectify the problems identified. The scope of this report analyzes methods to pinpoint where problems are located in a system and methods which can be employed to build capacity to existing systems by using the existing components of a water system when possible. This report draws upon my two years in Choluteca, Honduras while working for a variety of organizations to build and repair systems.

Chapter 2 provides background information on Honduras including geographical, demographic, historical, political, economic and international relationship. Then the objectives of Peace Corps Honduras, specifically the water/sanitation sector, will be explained as well as the current water situation in Honduras.

Chapter 3 discusses the development of a potable water supply system. The basic steps required to complete a rural water project are described.

Chapter 4 discusses specific measures to troubleshoot a failing system. It also discusses methods for the rehabilitation and reconstruction of a drinking water system.

Chapter 5 uses a case study in the community of Los Chaguites to show how the techniques described in Chapter 4 can be applied to improve the operation of a rural water system.

Chapter 6 gives basic recommendations and conclusions from experiences I gained while in Honduras.

2.0 Background

Figure 2-1: Honduran National Flag

2.1 Geography

Honduras is the second largest of the Central American Republics, with only Nicaragua encompassing more area. Honduras is bordered by Nicaragua on the southeast, El Salvador on the southwest and Guatemala on the northwest. With an area of 112,088 square kilometer (44,500 square miles), its size is roughly comparable to the State of Ohio (Peace Corps 2001).

There are four hundred miles of coast along the Atlantic Ocean that lies along the northern part of Honduras and a 77 mile arc of coast along the Gulf of Fanseco in the Pacific Ocean lies along the southern part (Peace Corps 2001). Figure 2.2 is a map showing the southern portion of North America, Central America, the Caribbean, and the northern portion of South America. Figure 2.3 is a more detailed map of Honduras. My site, Choluteca can be seen in the southern section of Honduras.

Figure 2-2: Map of Central America

http://www.lib.utexas.edu/maps/americas/americas_pol96.jpg

Figure 2-3: Map of Honduras

http://www.lib.utexas.edu/maps/cia02/honduras_sm02.gif

Except for two coastal strips, Honduras is a plateau, consisting of broad, fertile plains broken by deep valleys, and traversed by mountain ranges in a northwestern to southwestern direction. The mountains, which are volcanic in origin, rise to maximum elevations of more than 2800 m (9200 ft) (Microsoft 1994). Approximately 80% of the nation is between 3000 and 9000 feet in elevation (Peace Corps 2001).

Most of the country's rivers drain to the Atlantic Ocean. Navigable Atlantic rivers include the Ulúa, which drains approximately one-third of the country, and the Coco. Forests, covering about 31 percent of the land, yield valuable hardwoods and softwoods. Fertile pasturelands provide the basis for increasingly productive dairy farming and livestock raising (Microsoft 1994). It is estimated that only 17% of the landmass is suitable for agricultural development (Peace Corps 2001).

Valuable mineral deposits, such as lead, gold, silver, copper, iron, marble, limestone, salt and zinc, are also present. Oil exploration in the Caribbean Sea has taken place as well. However none of these deposits are expected to become a major factor in development in the near future (Peace Corps 2001).

With approximately 45% of the land covered with forests, the forests are one of Honduras' most valuable resources. Among the forests are woods such as palm, pine, and broadleaf, including mahogany, Spanish cedar, balsa and rosewood (Peace Corps 2001).

Salt and freshwater fish are available in commercially exploitable numbers. The Caribbean Coast, the Gulf of Fanseco in the Pacific, and Lake Yojoa are the main sources of fish (Peace Corps 2001).

The climate is described as tropical to subtropical, depending on the elevation. The prevailing climate pattern is characterized by a wet season from May through October and a dry season from November to April (Peace Corps 2001). The average annual rainfall ranges from 1016 mm (40 in) in some mountain valleys to 2540 mm (100 in) along the north coast (Microsoft 1994).

Natural hazards include hurricanes and frequent but mild earthquakes. On October 21, 1998, a tropical depression formed in the southern Caribbean Sea. One day later, the depression became a tropical storm and was given the name "Mitch." Tropical Storm Mitch moved very little over the next few days, drifting to the northwest and gathering strength. A sharp increase in intensity occurred between the afternoon of October 23 and October 26, during which time Tropical Storm Mitch strengthened from a tropical storm with 60 knot winds to a Saffir-Simpson Category 5 hurricane with winds of 155 knots. Not since the Great Hurricane of 1780, which killed approximately 22,000 people in the eastern Caribbean, was there a more deadly hurricane. The human toll of Mitch was estimated at 5,000 deaths, over 12,000 injuries, and over 8,000 missing in Honduras alone. Hunger and near-starvation were widespread in many villages due to a lack of food, medicine, and water. Epidemics such as malaria, dengue, and cholera were present. It is estimated that 70 – 80 percent of transportation infrastructure was destroyed. The majority of the country's bridges and secondary roads were washed away and airports were under water. At least 70 percent of crops were destroyed, including 80 percent of the banana crop. Large warehouses and storage rooms for coffee were flooded. Crop losses were estimated at $900 million. The damage by Hurricane Mitch to Honduran agricultural production will take years to recover (USGS 2002). Figure 2.4 shows the pathway of Hurricane Mitch, which passed over the entire country and then turned north through Guatemala.

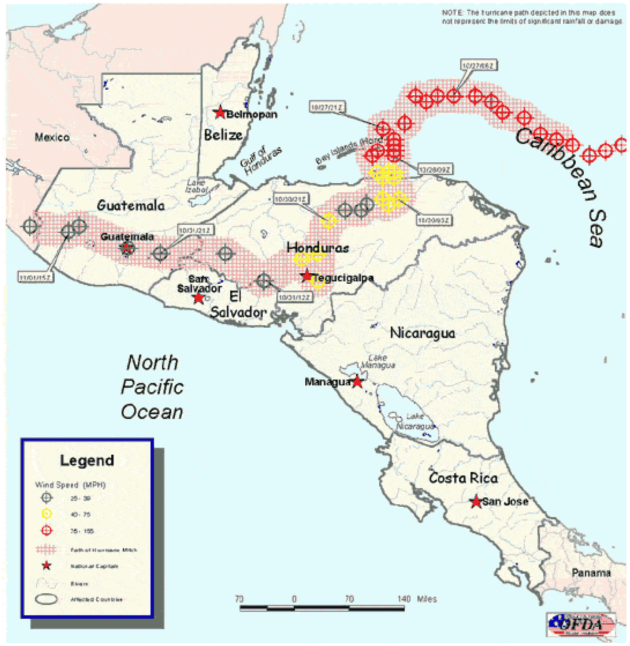

Figure 2-4: Pathway of Hurricane Mitch from October 26 to November 1, 1998

Source: http://mitchnts1.cr.usgs.gov/images/usaid_track_better.gif

2.2 Demography

Honduras has a population of approximately 6.6 million people as of 2002 (CIA 2002). Ninety percent of the people are of mestizo origin (mixed Indian and European), with the other 10% being of European, Arab, African, Asian, or indigenous Indians. The national language is Spanish. There are some people who speak English along the north coast, and some Native American communities have retained their language. Nearly 90% of the country is Roman Catholic; the remaining are mainly Protestant (Peace Corps 2001). Table 2.1 shows key socioeconomic indicators within Honduras. With a Human Development Index of 116 of 175 countries, it can be seen that Honduras is a poor country; however it does have potential for improved socioeconomic conditions.

Table 2.1: Key socioeconomic indicators of Honduras from various sources indicating state of development

Indicator	Data	Source
Population (millions)	6.7	CIA (2002)
GNP Per Capita (International Dollars)	$2600	CIA (2002)
Rate of Inflation	8.1%	Worldbank (2003)
Access to an improved water source	88%	Worldbank (2003)
Literacy: National	76.2%	CIA (2002)
Rural	71%	Trevett (2001)
Annual population growth rate	2.7%	WHO (2001)
Infant mortality	30.5 per 1000 live births	CIA (2002)
No. 1 cause of infant mortality	Acute respiratory infection	Trevett (2001)
No. 2 cause of infant mortality	Diarrhea	Trevett (2001)
Life expectancy: Urban	69 years	CIA (2002)
Human Development Index	116 out of 175 countries	Trevett (2001)

2.3 History

During the 1st millennium AD, Honduras was an integral part of the Mayan civilization, as evidenced by the ruins at Copan in western Honduras. When Christopher Columbus arrived in 1502, on his 4th voyage, the Mayan culture was already diminished in power. As more European settlers arrived, the native people were devastated by diseases brought from Europe. The current population is largely mestizo a mixture of races from the settlers and natives. Section 2.3 gives a brief history from the time of the explorers from Europe through the present. Information from this section was obtained from Microsoft 1994.

2.3.1 The Colonial Period

The conflict to obtain possession of Honduras began in 1524 as Spanish settlements in Mexico, Panama, and Hispaniola battled for possession of Honduras. Hernan Cortés, the conqueror of Mexico, went to Honduras in 1525 to establish a firm claim, but the discovery of gold brought attention from many others including Cortés's lieutenant in Guatemala, Pedro de Alvarado. Alvarado finally obtained possession of Honduras in 1539. The city of Comayagua, established in 1540, served as the capital during most of the colonial period. The city of Gracias, Honduras became the capital of Audiencia de las Confines in 1544, which includes the Central America region from Tabasco, Mexico through Panama. Gracias was originally named the capital due to the prospects of gold and silver. These prospects were unfounded and Gracias lost the title of the capital of the Audiencia in 1549 as it was returned to Guatemala.

Towards the end of the colonial period, mining in Tegucigalpa was progressing, which started the conflict between Comayagua and Tegucigalpa. In the meantime, the rest of Honduras was sparsely populated and relied on subsistence farming and ranching. Honduras was still a province of the kingdom of Guatemala under the control of the Spaniards.

2.3.2 Development after Independence

Honduras gained independence from Spain and Mexico in 1821 and 1823, respectively, and joined the United Provinces of Central America. Francisco Morazan led liberal forces to victory in a civil war between 1827 and 1829 and was president of the federation for its last ten years. Honduras declared its independence from the federation in 1838, and Morazan fell in 1840. Guatemala exercised great influence in Honduran politics throughout the 19th century. From 1840 to the 1870s the republic was frequently ruled by conservative dictatorships such as Francisco Ferrera, Juan Lindo, and Santos Guardiola. Revolutions continued, and the process of elections was unorganized.

Through the late 19th century and into the 20th century, the leadership was mainly liberal dictators, such as Marcos Soto in 1876. The culture developed more into a society utilizing modernization and exportation. Tegucigalpa was named the capital, indicating the movement towards the prospect of mining, financed largely by foreign investors. Honduras remained the least developed of Central American countries.

The introduction of the fruit companies, such as United Standard, in the 20th century shifted economic development towards exportation. The main export was bananas. However, the majority of the wealth laid in the hands of few people, and the general population remained poor and uneducated. San Pedro Sula, an important commerce center in present day Honduras, was developed as exportation increased

2.3.3 Honduras in Modern Central America

Starting in 1932, Tiburcio Carias obtained order in the political scene, which previously was in complete disorder. In 1948, the military and wealthy overtook power of the country from Carias, which greatly hindered development within Honduras until 1957. In 1957, Ramon Villeda Morals was elected by a constituent assembly and created many programs improving education and commerce. In 1963, with the concern of communism rising in Cuba and his programs, Colonel Osvaldo López Arellano led a coup and obtained power until 1974. In 1974, after a brief war with El Salvador and with an economy in poor conditions, López was removed from power after a $250,000 bribe from United Fruit Company was discovered.

López held the reins of government for 11 of the next 12 years. The fragile Honduran economy was further weakened during his regime by a brief but costly war with El Salvador in 1969 over heavy immigration from that densely populated nation. The final blow for Lopez was the exposure in 1974 of a $250,000 bribe paid to government officials by United Brands (successor to United Fruit). The armed forces helped Colonel Juan Alberto Melgar Castro take power in 1975. Three years later he was ousted in another coup led by General Policarpo Paz García.

The central problem for Honduras in the late 1970s and the 1980s was political instability in neighboring countries. In 1980 General Paz signed a peace treaty with El Salvador, and there was progress toward a constitutional government. In elections held in November 1981, the Liberal party candidate, Roberto Suazo Córdova, won the presidency, but the military retained considerable influence. Honduras became a base for thousands of guerrillas fighting the Nicaraguan government, and the United States began holding regular military exercises in an effort to put additional pressure on the Sandinista government. In 1985 José Azcona Hoyo, a civilian, was elected president; he was succeeded by Rafael Leonardo Callejas, the winner of the 1989 presidential election. His administration was beset by strikes as it struggled with a desperate economic situation. Carlos Roberto Reina, a longtime human rights and political activist, won the November 1993 elections over Callejas. Reina promised to institute economic reforms and exert civilian control over the army. Carlos Flores was elected following Reina, and in 2002 Ricardo Maduro was elected and is the current president.

2.4 Government and Political Environment

Honduras is a democratic constitutional republic with a structure of government similar to that of the United States. The three main branches are Executive, Legislative and Judicial branches. Ricardo Maduro was elected president in January 2002 from the National Party. The political history has been unstable with 12 constitutions and over 50 Presidents or Chiefs of State since 1824 (Peace Corps 2001).

The capital of Honduras is Tegucigalpa (850,000) in the department of Francisco Morazan. Honduras is divided into 18 departments (comparable to US States), and the departments are further subdivided into 282 municipalities (comparable to US counties) (Peace Corps 2001).

2.5 Economy

Honduras, one of the poorest countries in the Western Hemisphere with an extraordinarily unequal distribution of income, relies on expanded trade privileges under the Enhanced Caribbean Basin Initiative and on debt relief under the Heavily Indebted Poor Countries (HIPC) initiative. While the country has met most of its macroeconomic targets, it has failed to meet the IMF's goals to liberalize its energy and telecommunications sectors. Growth remains dependent on the status of the US economy, its major trading partner; on commodity prices, particularly coffee; and on containment of the recent rise in crime (CIA 2002).

2.6 U.S. – Honduran Relations

The United States and Honduras have a close and friendly relationship. Honduras is a member of the United Nations (UN), World Trade Organization (WTO), Organization of the American States (OAS), and the Central American Parliament (PARLACEN). The U.S. favors stable, peaceful relations between Honduras and its Central American neighbors. During the 1980's, Honduras supported U.S. policy in Central America opposing a revolutionary Marxist government in Nicaragua. The United States is Honduras' chief trading partner. The U.S. maintains a small presence at a Honduran military base conducting medical, engineering, peacekeeping, counter narcotics and disaster relief services (Peace Corps 2001).

2.7 Peace Corps Honduras

Over 5000 volunteers have served with the Peace Corps in Honduras since the program agreement was signed in July 1962. Currently there are over 250 volunteers serving in Honduras in the areas of water and sanitation, economic development, municipal development, natural resources, agriculture, youth development and health.

The Water/Sanitation sector focuses mainly on improving and developing drinking water, training and sanitation. The three main goals of the water/sanitation sector in of Peace Corps Honduras are:

1.) *Provide rural communities with immediate access to water and sanitation services.* This may include the rehabilitation, expansion or construction of potable water systems or construction of latrines.

2.) *Train rural communities on maintaining community water associations*. This may include training to administer, operate and maintain their own community water systems, protecting and managing the watersheds and encouraging the adequate use of water and sanitation systems. This may also include training plumbers to operate and maintain community water systems.

3.) *Train rural communities on issues relating to health and environmental education.* This may include groups such as water committees, health committees, and elementary school students receiving courses on health education that encourage understanding of water and sanitation and its relationship to the community's health. Also, these groups may receive courses on environmental education to encourage watershed management and the adequate disposal of garbage.

2.8 Current Potable Water Situation in Honduras

The drinking water availability in rural Honduras is improving following countrywide efforts to construct and repair systems damaged by Hurricane Mitch. Figure 2.5 shows the coverage of water services within rural Honduras, indicating that a large percentage of the rural population does in fact have access to potable water. Figure 2.6 shows the compilation of various studies by a number of organizations throughout the 1980's and 1990's. This figure indicates that determining the exact coverage is difficult, but a general pattern of increased coverage can be noticed, with a current coverage of over 80% of the total rural population. It should be noted that approximately 53% of the total population in Honduras is considered rural.

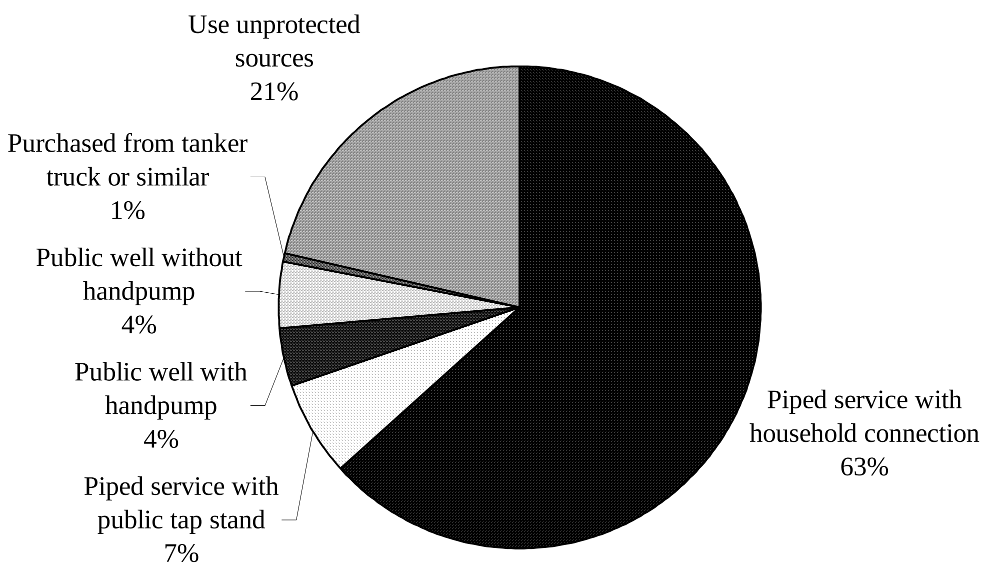

Figure 2-5: Rural water coverage in Honduras (Trevett 2001)

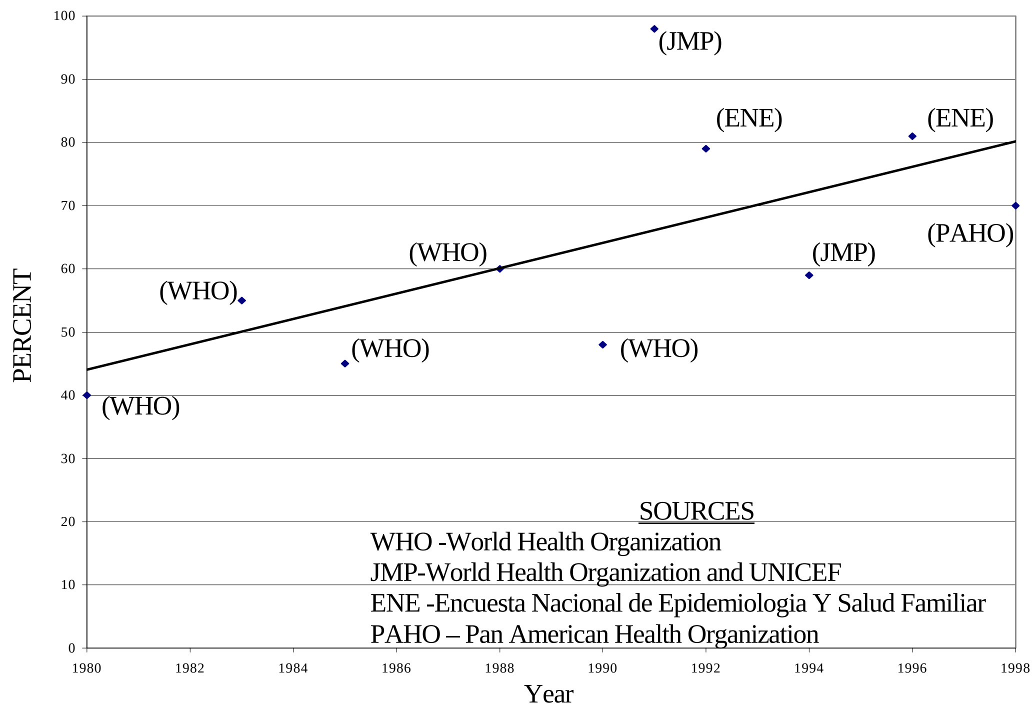

Figure 2-6: Rural water coverage in Honduras throughout 80' and 90's indicating improved water coverage (WHO 2001)

[redacted]

3.0 Development of a Rural Potable Water Project

The development of a rural water project starts with basic community contact, followed by more technical activities such as analyzing the source of the water, conducting a topographical survey, sizing of components and treatment of the water. Typical projects are sized for the population in 20 years assuming a growth rate of 3.0 – 3.5 percent. The typical allotment of water per person is 20 – 25 gallons per day. Projects should adopt flexible design standards that will prevent ad-hoc modifications that jeopardize water system integrity (Katz 1994). Typical examples of modifications include the use incorrect diameter tubing, incorrect material type or sectorization. Over-designing a project creates systems that communities are not willing to maintain.

A short summary is described in this chapter on the development of a water project. Refer to (Reents 2003) or (Niskanen 2003) for a detailed description of all activities in rural water system development. Figure 3.1 shows a schematic of a typical gravity-fed water system, consisting of a source, a conduction line connecting the source and the tank, and finally a distribution line to distribute the water to the houses within the community. Figure 3.2 shows the timeline and framework for a typical project. Initially, the relationship between the community and an engineer is very important, and after some years, there must be resources available to rectify problems in the system. This report concentrates on the maintenance of the system that occurs years after construction, as shown in Figure 3.2.

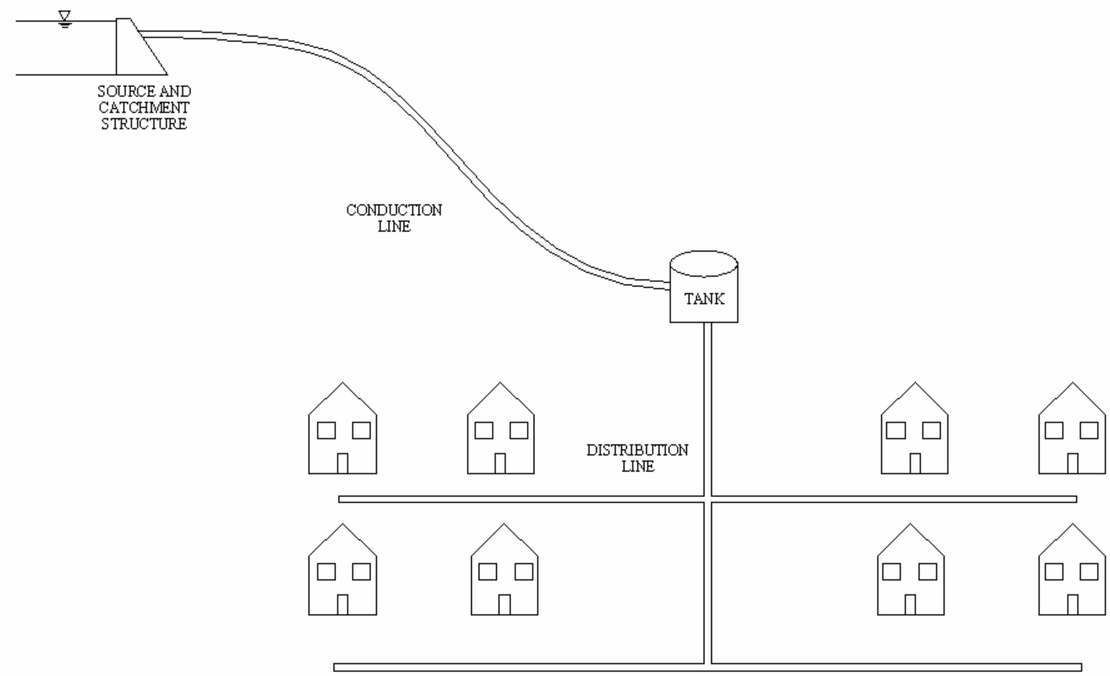

Figure 3-1: Schematic of basic rural water system in Honduras

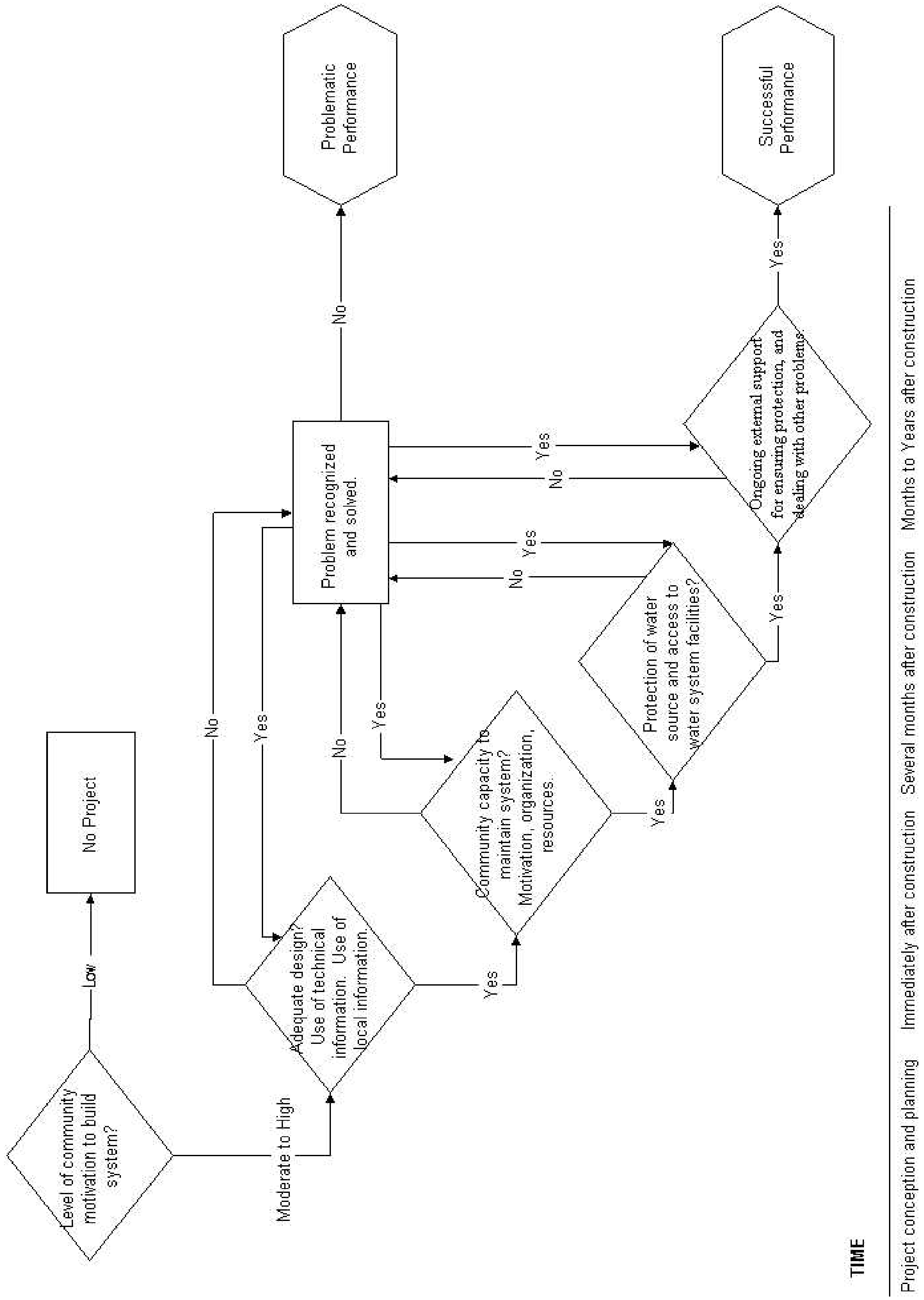

Figure 3-2: Timeline and framework for typical rural water project showing pathway for successful project (from Gelting 1998)

3.1 Community Contact

The first step in starting a project is the initial contact with a community member. There are numerous ways this may happen. Within the development organizations, word travels fast of projects and available resources. A member of the community must come forward and show willingness to work and that they can provide the necessary support to complete a project.

The development of water and sanitation systems and community involvement in projects will vary according to local circumstances. The relationship between the community and an action agency is critical. Action agencies may be non-governmental organizations or governmental organizations specializing in the development of water projects. Basic roles of the community and action agency apply to most project situations as explained below:

- *Community* - The community must identify its own water and sanitation problems. It must be willing to accept, to the extent it is able, the responsibilities for funding, developing, operating and maintaining local systems. If no appropriate local organization exists, the village should form a water and sanitation committee to represent local interests and work directly with the action agency's project planner and designer.

- *Action Agency* - An action agency should provide the community with technical expertise, economic advice and assistance in developing water and sanitation systems.

3.2 Source of Water

The most important aspect of a water system is to determine the source of the water. The decision of using surface water or ground water must be made. It must be determined if the source is reliable and if the quality of the water is acceptable. The primary function of catchment boxes is to capture water so it can enter into the conduction line. The purpose of catchment boxes is not to store water; therefore large, expensive structures should not be built contrary to popular belief of many local people. The catchment box can also be designed to operate as a settling tank. A larger catchment box will decrease the frequency of regular cleaning if sedimentation is a problem. See Jordan (1994) for details on designing sedimentation tanks.

Figure 3.3 shows an example of a surface-water catchment structure that also is used as a settling tank. The sediment is trapped in the chamber on the left-hand side as shown in the picture, and the right side chamber is equipped with a cover so no foreign material can enter. The shorter pipe (lower pipe) is opened to allow any sediment to be washed-out, and the longer pipe (upper pipe) carries water to the tank. The overflow can be seen on the left-hand side of the photo. This overflow location allowed for better performance, as only the quantity of water that the tubing could carry would enter the settling tank and box. Any flow over the capacity of the tubing was directed around the structure.

Figure 3-3: Example of concrete surface-water source with settling chamber for community of 150 houses, feeding a tank of 10,000 gallons, with capacity of tubing to carry 50 gallons per minute. Approximate flow rate of source as shown = 75 gallons per minute.

3.2.1 Surface Water or Ground Water

The source of water should be determined on a case by case basis for each system. If there is a choice between the use of ground water or surface water, there are benefits and drawbacks that must be considered, including quality and quantity of water. The majority of the time, however, local conditions completely remove one of the two options. A surface water source may not provide the necessary quantity of water or may not be owned by the community, for example. Conversely, groundwater may not be found at an acceptable level or a lack of electricity does not allow for an electric pump. It is common to find that gravity fed systems from a protected source tend to have fewer problems, and local materials and knowledge allow for easier maintenance.

3.2.2 Reliability of Source

Within Honduras the climate is characterized by a dry season and a wet season. The source selected should have the capability to provide the minimum amount of water during the dry season. Therefore, a flow rate measurement to determine the yield of the source should be done at the end of the dry season. A flow rate measurement can be conducted by using a stopwatch to record the time required to fill a container of a known volume.

3.2.3 Water Quality

The quality of the water to be used for drinking is critical. The purpose of building a water system is to eliminate health problems related to contaminated drinking water. If a contaminated source is selected, the project will in fact accomplish the opposite and spread sickness and diseases within the community. Laboratories within Honduras have the ability to analyze water for nitrates, pH, and fecal coliforms. Other tests for heavy metals or chemicals are not readily available and judgment must be used in selecting a source that is not within the transport pathway of a possible pollutant. Table 3.1 summarizes common contaminants, health effects of the contaminant, and the source for the given contaminant in drinking water. Local labs typically can test only for microbiological contaminants and nitrates.

Table 3.1: Examples of health risks from exposure to contaminated water (Taken from EPA 1994)

CONTAMINANTS	HEALTH EFFECTS	SOURCES
Microbiological	Acute gastrointestinal illness, dysentery, hepatitis, typhoid fever, cholera, giardiasis, cryptosporidiosis, etc	Human and animal fecal matter
Arsenic	Dermal and nervous system toxicity	Geological
Lead	Central and peripheral nervous system damage; kidney effects; highly toxic to infants and pregnant women	Leaches from lead pipes and lead-based solder, pipe joints
Nitrate	Methemoglobinemia ("blue baby syndrome")	Fertilizer, sewage, feed lots
Fluoride	Skeletal damage, dental fluorosis	Geological
Pesticides and herbicides	Nervous system toxicity, cancer risk	Farming, horticultural practices
Trihalomethanes	Cancer risk	Treatment by-product
Radionuclides	Cancer	Geological

3.3 Topographical Survey

When analyzing an existing system, or investigating the feasibility of a new system, a topographical survey is a very useful tool. For existing systems it is used to determine capacity of the system if the original design is not available. For new systems, a topographical study is used to determine both the horizontal and vertical coordinates of all points within the system to determine pressures at all points within the system.

The tool most commonly used for the volunteers in the southern region of Honduras is a theodolite. The accuracy of the topographical study is not extremely critical, and a basic theodolite with a tolerance of 5 arc minutes is more than sufficient. A topographical study can be completed with a standard surveying rod, theodolite, tripod, and a 10 foot measuring tape. It will give all the horizontal and vertical coordinates needed to analyze and/or design a water system. The topographical study is used to create a profile of the critical points along the line including the source, high points, low points, tank, and houses.

3.3.1 Procedures for Topographical Study

The common method of obtaining the necessary information to determine the coordinates of the critical points starts at the water source. The theodolite is set up on the tripod as close to the location of the catchment structure. An arbitrary location can be given to this point, or GPS can be used to set the datum. From this point, the theodolite is used to locate critical points along the alignment of the future line. Critical points include low points, as this is where pressure will be the greatest. These points also are suitable locations for clean out valves. High points are important to note in order to verify that all high points are lower than the source, and to verify that the elevation of the hydraulic grade does not fall well below the elevation of the terrain. Although it is physically possible for the hydraulic grade line to be below the surface, problems may arise with the accumulation of air in these zones, therefore restricting or completely cutting flow. All low points and high points should be measured to conduct an accurate survey. The majority of surveys can be completed with acceptable error if intermediate points are located in intervals of 100 meters. The elevation of a house should be measured if the house is located at an elevation much higher or lower than the proposed location of the main line. The proposed location of the tank should be measured and used to calculate the flow rate entering the tank and pressures supplied to the community.

3.4 Conduction Line

The conduction line is sized to transport the future maximum daily flow rate for the population expected in 20 years. The design standards in Honduras consider the future maximum daily flow rate to be 25 gallons per person per day with a peaking factor of 1.5, or 37.5 gallons per person per day with the future population given a growth rate of approximately 3.3%. The peaking factor of 1.5 is applied to account for seasonal variation in water demand, as in the dry season more water is needed by the community than in the wet season. PVC (polyvinyl chloride) and GI (galvanized iron) tubes are readily available in the following diameters: ½", 1", 1½", 2", 3", 4". Larger, more expensive tubes are rarely needed in rural water projects. Tubes are sold in 6-meter sections. Figure 3.4 shows a truck loaded and ready for delivery to the community. The larger tubes on top are 3" and 4" tubing for use in the distribution system of a community of 150 houses. Tubing of ½" diameter is located in the middle of the stack on the right hand side for household connections in communities of 150 houses and 19 houses. The majority of the tubing on the lower part of the stack is 1 ½" diameter tubing for use in the conduction line for a community of 19 houses.

Figure 3-4: Example of various diameter PVC tubing loaded on truck ready for delivery to 2 separate communities. The 3" and 4" tubing is for a community of 150 houses and the 1 ½" and 1" tubing is for a community of 19 houses. The ½" tubing is for both communities for the connections at each house.

3.5 Tank

The tank should have the capacity to store approximately 8 hours of flow from the source. This also could be approximated as 30-40% of the total water used in one day as calculated in the future. Saving water during the times of lower demand will ensure that sufficient water is available to supply the community during the times of greater demand. Typical designs are readily available in 5,000 gallon increments from 5,000 gallons through 25,000 gallons for reinforced brick tanks through the governmental water development program (SANAA) or through a non-governmental organization (Action Against Hunger). The designs vary slightly, but they generally all are circular brick tanks, reinforced with rebar in the walls, with a rebar reinforced roof. Figure 3.5 illustrates the construction of a 10,000-gallon tank for a community of 150 houses following the standards of the Honduran governmental water organization. A concrete foundation is built first, followed by construction of rebar reinforced brick walls and finally a rebar reinforced concrete roof.

Figure 3-5: Construction techniques of tank walls and roof for 10,000 gallon tank to serve 150 houses. Upper left photo shows mortar being applied to brick walls, upper right photo shows steel reinforcement in wall, and bottom photo shows steel reinforcement for concrete roof.

3.6 Distribution Line

The distribution line is sized to handle the maximum hourly flow rate calculated in 20 years. In Honduras, it would be 2.25 times greater than the minimum 25 gallons per person per day

(0.018 gallons per minute per person), or 56.5 gallons per person per day (0.039 gallons per minute per person). Figure 3.6 shows an example of a section of a distribution line before being placed in the trench. The distribution line is located on public property to avoid conflicts with permission from landowners. This section of trench (approximately 60 meters) was dug in one day with 6 men, and the tubing was connected in less than one hour.

Figure 3-6: 2" PVC tubing ready to be placed in 3' deep trench for distribution line in a community of 50 houses.

3.7 Water Treatment

The most typical treatment of water within Honduras is the use of chlorine. It should be assumed, however, that no treatment of the water will occur within the community; therefore, the best possible source should be selected. Reasons for not using chlorine to treat water include lack of money, difficulty in obtaining chlorine, lack of knowledge on the dosage, bad taste, or the community not having a plumber to perform regular chlorination. The most effective method to promote chlorination is through a community education program that encourages a regular schedule of chlorination. Other treatment methods such as settling tanks and sand filters are not regularly encountered. Many times, if an adequate quantity of water is available, the users may not be willing to financially support the treatment necessary to improve water quality (Austin 1987).

4.0 Capacity Building of Existing Systems

Rural water systems can fail for a number of reasons. With the fairly recent arrival of Hurricane Mitch in Honduras, the majority of work centering on the reconstruction of water systems has been to repair systems destroyed by Mitch. The definition of technical capacity building in context of this report strictly deals with the improvement of an existing water system that has failed due to normal use or lack of maintenance. It does not deal with natural disasters, as engineering a rural water system in a developing country that can withstand the energy delivered by natural disasters is often not feasible due to the use of locally available materials and money constraints. Table 4.1 summarizes typical problems, causes of problems, and solutions of the problem as observed in Honduras. Figure 4.1 provides for a summary of activities when analyzing an existing water system and provides a step by step flowchart that allows an experienced or inexperienced extension worker to locate the problem in order to develop a strategy to improve performance of the system.

Table 4.1: Typical problems, causes and solutions as observed in rural water systems in Honduras that are not delivering sufficient water to the community

PROBLEM	CAUSE	SOLUTION
Supply not sufficient	• Catchment structure faulty	▪ Repair structure or new structure
	• Capacity of source diminished due to environmental factors	▪ Reforestation, excavate source deeper
Tubing system unable to deliver sufficient water	▪ Undersized tubing	▪ Replace tubing or install additional tubing
	▪ Blockage in tubing	▪ Open clean-out valves, inspect tubing
Increased demand	▪ Community development (population or businesses)	▪ Educate community on water conservation
	▪ Seasonally dry, causing other water sources to become unavailable	▪ Educate community on water conservation
	▪ Misused water (lack of valves at each house)	▪ Repair leaking tubes. Replace valves.

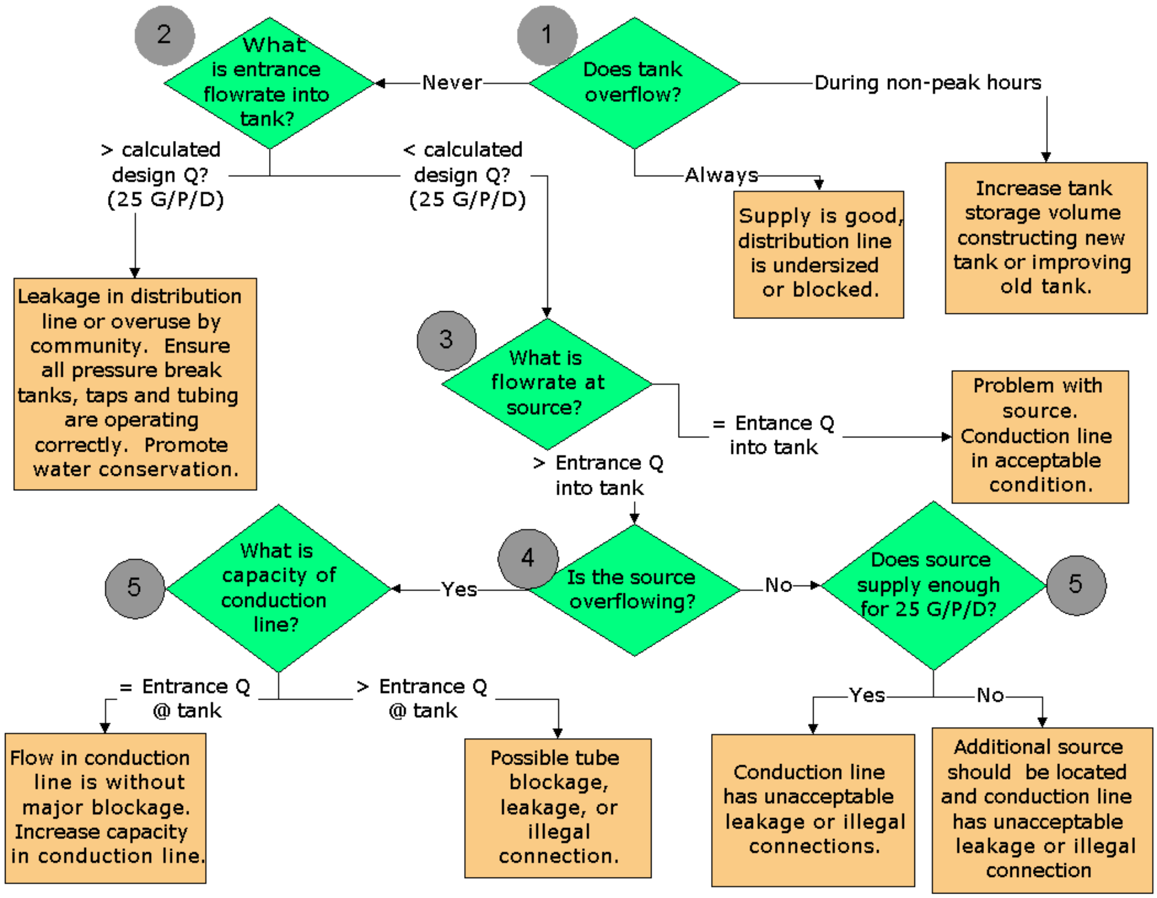

Figure 4-1: Flowchart for troubleshooting rural gravity-fed systems that are not delivering sufficient water to all members of the community

4.1 Reviewed Literature

Much of the current research analyzing water systems is devoted to larger, more developed communities. Basic principles and theories can be used in both large communities and small communities when analyzing the distribution network.

Kleiner (1998) states that deterioration of the water distribution network due to aging and stress causes increased operation and maintenance costs, water losses, reduction in the quality of service, and reduction in the quality of water. The structural integrity and the hydraulic capacity of every pipe in the system must be analyzed when determining if replacement of the tubing system is warranted. The deterioration of structural integrity causes increased breakage rates which result in increased pipe maintenance costs. The deterioration in the hydraulic capacity of pipes results in a reduction of the supply pressure. Kleiner addresses the issue of timing when considering pipe rehabilitation alternatives. For example if future demand is expected to rise, it may be economical to replace the pipe now by a larger diameter pipe rather than pay for the constant repairs. Kleiner uses dynamic programming to determine specific rehabilitation alternatives. For example, if a pipe's structural integrity is sound but its hydraulic capacity has lowered, then methods should be taken to improve the hydraulic capacity such as relining the pipe and replace the pipe in the future. Or alternatively, it may be feasible to replace an adjacent pipe instead now, thus improving hydraulic capacity without major modifications such as relining a pipe. Although the dynamic programming is not feasible for locals to complete, it illustrates how a case by case analysis must be carried out to determine the best methods to improve performance in the distribution system.

Austin (1987) states that a poor choice of technology, inappropriate construction, and lack of spare parts and supplies for maintaining equipment have led to the deterioration of water facilities. Austin notes that systems built 20 years ago now require rehabilitation and the problems encountered now were not expected at the time of construction. Interest in extending the life of existing systems is growing, however most young engineers employed by a water authority prefer to establish careers in designing and constructing new water facilities. Austin states that the improvement of existing systems must involve fewer skills and less complex test equipment. The methods described in this report involve equipment readily available in all communities, such as a watch and a 5-gallon bucket, as commented by Austin.

Austin comments that the rehabilitation of a water system can be a major undertaking and must be carefully planned. He offers a series of questions that must be asked to determine where a problem is being created by a specific aspect (design, construction, hydraulic overload, management, or financial difficulties, or quality of personnel). These questions are:

- Is there a problem?
- Is it a performance problem?
- What is the performance problem?
- How does one know when the problem is solved?
- Should resources be allocated to solve the problem?
- What are the possible causes of the problem?
- What evidence bears on each cause?
- What is the most probable cause?
- What general solution is indicated?
- What are the costs, effects, and development time of each problem?

Stephenson (1998) comments on causes of failure of water systems. He states the problems can be caused by poor design or the desire to save money, unknown materials, poor construction work which was covered up, poor management or maintenance after installation, or poor training of the managers. Stephenson offers that regular maintenance and replacements need to be considered to provide a reliable quantity of water. The system can be designed with loops to allow for maintenance on pipes while constantly supplying water. Looping a system will also reduce the minimum diameter required. For example, a 100 mm pipe may be reduced to 80 mm if a looped system is built. The material chosen to construct a system will affect the performance years later. He states that cast iron and ductile pipes have a life over 100 years and plastics such as PVC have a life of roughly 50 years.

4.2 Source

A typical design must start by measuring the flow rate of the supply that will be used for the projected community population considering a reasonable growth rate and service life of the system. A reliable source, in a well-forested area, providing the same flow rate as measured previously may not be sufficient for the steadily growing community.

In order to determine if the source is contributing to the failure or poor performance of a system, a simple flow rate measurement can be made. This most easily is accomplished by measuring the time required to fill a container of a known volume. This measurement should be done at the end of the dry season as the flow rate is the lowest at this time. If the community is experiencing problems in the wet season as well, then a flow rate measurement in the wet season can prove to be useful. If it is found that the source does not supply the required flow rate, it may be necessary to look for an additional source in order to augment the flow. This is assuming that no environmental measures have been made to decrease the available flow and that, simply put, all the possible water from the source enters the conduction line and is being used by the community. The most common environmental problem that leads to the decrease in the flow rate at the source is deforestation. Another common situation that leads to the decrease in flow rate available is the construction of other water catchment structures upstream from the given catchment structure.

4.2.1 Improvement of Existing Source

Catchment structures may lose their ability to catch all of the available flow. An inspection should be made at the source to determine if some flow is bypassing the catchment structure, whether superficially or through percolation. Many times, channel improvements such as the placement of grouted rip-rap to channel the water directly to the catchment structure may be sufficient to increase the flow. Spring boxes can be improved by creating infiltration trenches upstream, reforesting the watershed, or excavating if the source is from a spring.

4.2.2 Addition of New Source

Many times a community has access to a new source. An analysis should be made to determine if the tank is large enough to store approximately eight hours of water from the combined sources. If the tank cannot handle the additional water without excessive overflowing, the conduction line can be sized to only deliver the quantity that the tank can handle. Alternatively, the loss of water from the tank in the non-peak hours can be accepted in order to deliver a higher quantity of water for the other times of the day. However, under no conditions does a constantly overflowing tank warrant the need for a new conduction line. A constantly overflowing tank indicates the addition of another tank may be advised, as described in Section 4.4.

The additional source can be connected to the conduction line in a number of ways, however only after a careful hydraulic analysis of the proposed system is completed. If the new source is located at a higher elevation, the new source may flow directly into the old source. The conduction line should then be analyzed to determine if it has the capacity to carry the extra water if the same conduction line is to be used. Many times the old conduction line will be cut and a collection box will be built to join the two sources, in which all sections of pipe should be sized properly, as shown in Figure 4.2. This figure was generated from a student version of Haestad WaterCAD, a program used to analyze water supply systems. An alternative to the Haestad program is EPANet, which is available at no cost in both English and Spanish. This figure shows a new source with a junction box to be used to join the flows from the two sources. The existing tubing, with the addition of the junction box that also acts as a pressure-break tank, does not have the capacity to carry the combined flow, and a new section of pipe will be used in addition to the existing tubing to carry the combined flow into the tank. This example shows how existing components of a system with new components are used to improve performance.

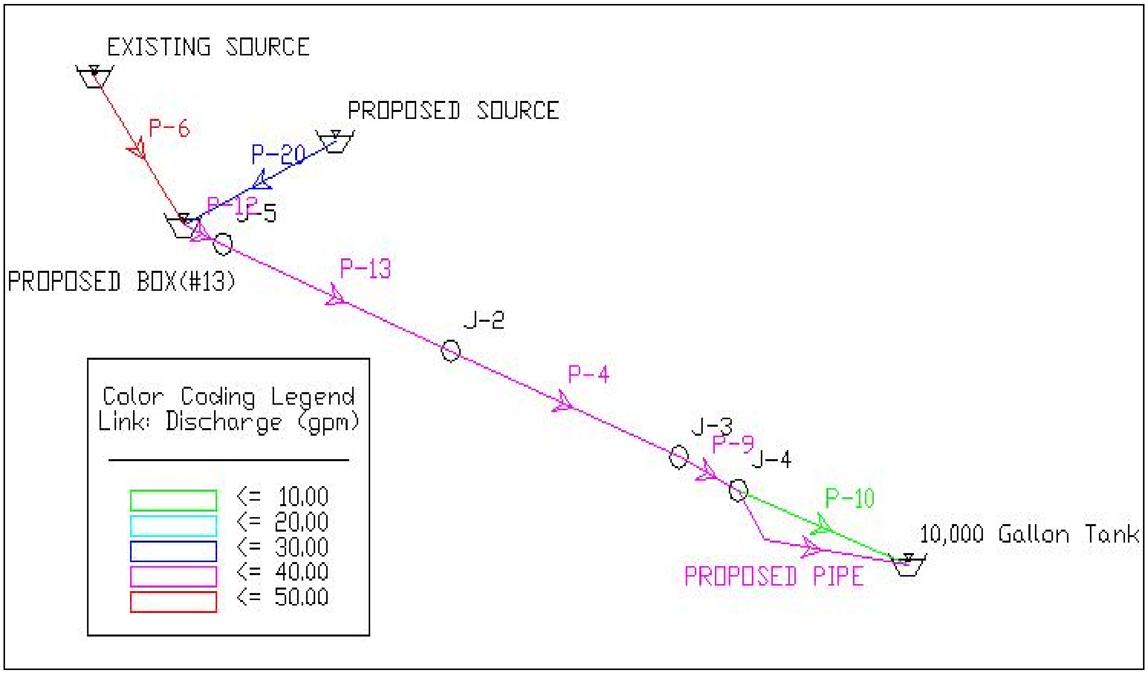

Figure 4-2 : Schematic of system with new source and use of juntion box to unite flows from two sources for a community of 150 houses. An additional pipe was deemed necessary in the lower reaches of the conduction line before the tank to carry the additional flow from the new source, partially due to the junction box acting as a pressure-break tank.

If the new source is located at a lower elevation, a junction box can be built to join the two sources. The location of the new source may serve as the junction box if local conditions warrant. A junction box will act as a pressure-break tank, and an analysis of the conduction line should be made to ensure the conduction line has the capacity to carry sufficient water to the tank. It is possible to join the two sources with a "T" connection; however the system should be carefully analyzed to ensure that the upper source is not flowing up the tube into the lower source. If the upper source is flowing into the lower source, the tank will receive less water, which will worsen the water situation in the community as is shown in Figure 4.3b where the tank will receive less water than the original configuration shown in Figure 4.3a. The use of a junction box as shown in Figure 4.3c will prevent the backflow situation, however the capacity of the conduction line is decreased from 83 GPM to 70 GPM as the hydraulic grade line is shifted down to the elevation of the junction box. The construction of a junction box assures that both sources are contributing.

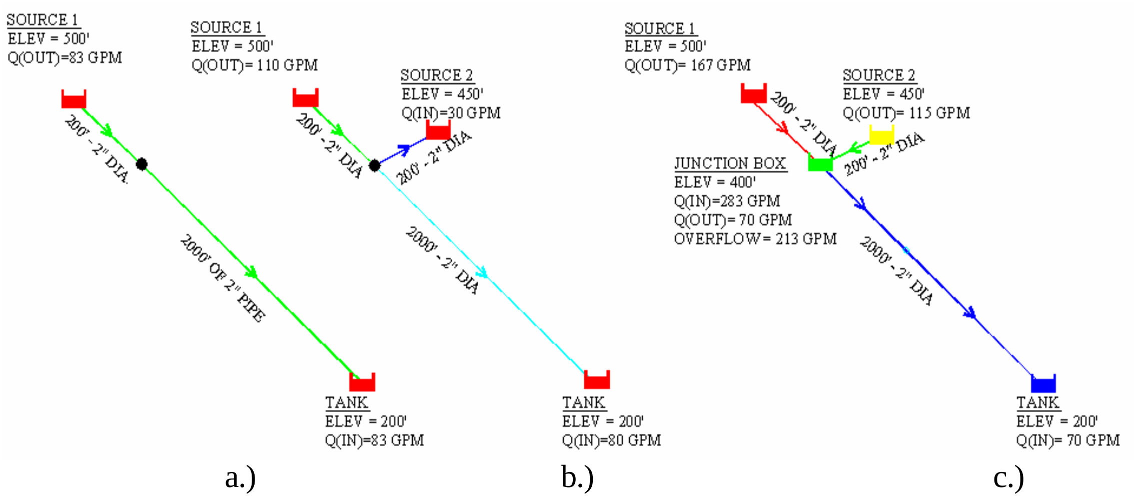

Figure 4-3: Schematic of addition of source which backflows into new source when joined by a tee

If the size and length of the tubing are shown in figure 4.4 (1" pipes from source to box compared to 2" pipe in figure 4.3), then the use of a "T" will prove to be beneficial and there will not be any backflow of water up into the new source. Figure 4.4b shows that water will flow from the new source to the tank, improving performance. Figure 4.4c shows that joining the two sources with a junction box will ensure that water flows from both sources. The use of a junction box in Figure 4.4c in fact increased the carrying capacity of the tube entering the tank when compared to the original shown in Figure 4.4a. This result is not always the case, which shows a careful analysis when adding a source must always occur. The additional capacity is due to the fact that the hydraulic grade line in the original system at the point of the junction box was below the elevation of the future junction box. This upward shift in the hydraulic grade line can also be noticed in the decrease in water flowing out of Source 1. Originally, the source supplied 42 GPM (Figure 4.4a), but with the hydraulic grade line being forced *up* to the elevation of the ground, the quantity of water from the original source lowered from 42 GPM to 27 GPM and the capacity of the tube entering the tank increased from 42 GPM to 70 GPM. There will only be 46 GPM of water entering the tank due to the capacity of the lines from the two sources to the junction box does not supply the maximum 70 GPM.

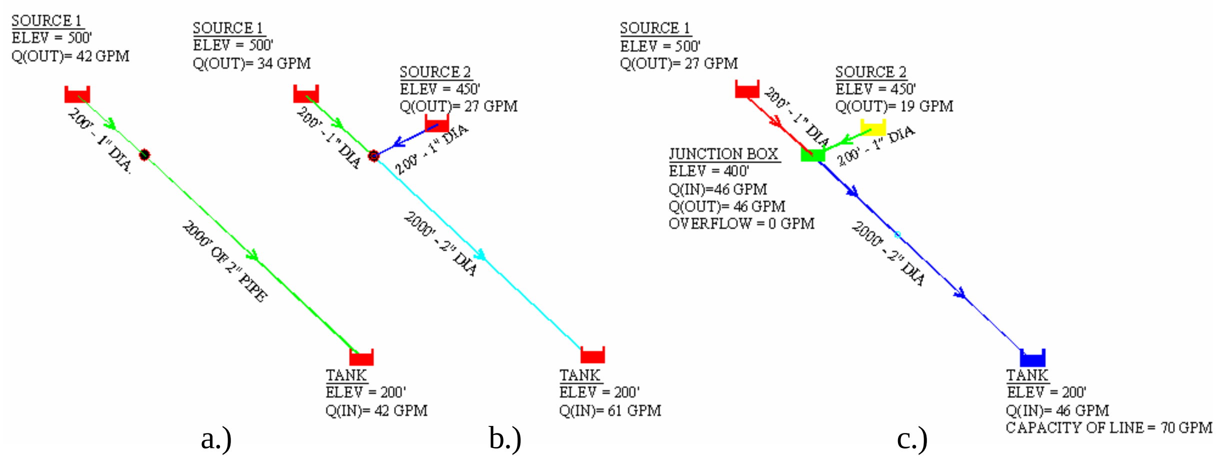

Figure 4-4: Schematic of additional source showing a.) original conditions b.) additional source flowing tog from source to tee c.) use of junction box to unite flows

A third option when a new source in encountered is to construct a completely new conduction line that starts at the new source and ends at the tank. This ensures there is no interference between the two sources.

4.3 Conduction Line

A conduction line is typically built to carry the maximum daily flow from the source to the tank for the future population. The tank then acts to store the water carried during the periods of lower demand for use during periods of larger demand. It is possible that the conduction line is not sufficiently sized to carry the necessary amount of water for the increased population, assuming the capacity of the line is not impeded by mechanical problems such as deposition in the pipes or losses along the line.

An undersized conduction line can be diagnosed by a source that is overflowing. It can be seen that the source is not the limiting factor, and that the problem lies within the conduction line. An undersized conduction line should not be confused with material failure or construction practices in which losses within the tubing do not allow for a sufficient supply of water to the tank. Good maintenance practices such as regularly opening clean-out valves should be completed by the community.

A test to help identify an undersized conduction line is a flow rate measurement at the entrance to the tank. This can be the first step in troubleshooting a project. However, a flow rate below the required daily flow does not necessarily mean that the conduction line is undersized. Exact diagnosis of an undersized conduction line requires analyzing the capacity of the theoretical flow in comparison to the measured flow. If the original design is not available, an as-built survey can be conducted in order to analyze the theoretical capacity of the existing tubing using basic hydraulics. Problems of conducting an as-built survey include locating changes in pipe material, pipe diameters, and minor losses. This is due to the fact that the system is buried and locating changes in the systems requires excavating and noting points of material changes or diameter changes.

When the measured flow rate is compared to the theoretical flow rate, the problem can be pinpointed. If the measured flow rate and the theoretical flow rate are equal, it can be assumed that the conduction line is undersized. If the measured flow rate is below that of the theoretical flow rate, then most likely the problem lies within construction practices, maintenance, or material failure. However, if the source does not supply at least a quantity of water equal to the theoretical capacity of the conduction line, then the observed flow rate entering the tank will be below the theoretical flow rate. The flow rate entering the tank should then be equal to the yield at the source.

If it is determined that the conduction line does not have the capacity to carry the required daily flow and the yield at the source is sufficient, an analysis of the system should be made to determine what measures are needed to increase the flow. This is most easily accomplished by installing pipe with a larger diameter in some or all of the conduction line. New pipe may be installed next to the old pipe and both can be used to carry the water. This is assuming the old pipe is still in good condition.

Caution should be taken in adding new pipes as the hydraulic grade will change in all sections, and problems such as air-blocks and unacceptable negative pressure must be avoided. The installation of larger diameter tubing in the upper reaches of the conduction line versus the lower reaches will create a situation in which the hydraulic grade line is flatter in the upper reaches and steeper in the lower reaches. This can be an advantage if very low or negative pressures are expected. This can be a drawback if the lower reaches are already under large pressures.

If it is determined that the conduction line does have the theoretical capacity to carry the flow but the measured flow rate at the tank is below the theoretical flow rate, the problem most likely lies within the maintenance or materials of the tubing. Clean-out valves should be opened in an attempt to flush out any sediment trapped in the system. The system should be inspected to verify that there are no illegal connections drawing water from the conduction line.

4.4 Tank Analysis

When analyzing existing systems, it is very useful to monitor the tank. The parameters to observe are the flow rate entering the tank as well as the level of water in the tank. The levels should be measured for at least 24 hours. It is very uncommon to see a system without a tank. Many tanks, however, serve no purpose. A tank is useful only if it is constantly changing levels, thereby storing water in non-peak hours and allowing for an increased flow during peak hours. Measuring the flow rate entering the tank is very important in analyzing a system, in that the flow rate entering the tank should be the same as the flow rate measured at the source. If this is not the case, and all of the water from the source enters the conduction line, then there are losses within the conduction line to the tank which should be located and repaired. If the source is overflowing, then an analysis of the conduction line must be made to determine the carrying capacity of the conduction line. This may be done if the previous design is available, or else a topographic study must be made of the as-built system.

Tank size does not change pressures within the conduction line or distribution line. Figure 4.5 shows an example of a 10,000 gallon tank for a community of approximately 150 houses. This tank was located approximately 30 meters above the highest house and 120 meters above the lowest house. The tank elevation and the level of the water affect pressures. A larger tank may store wasted water, therefore allowing more water to be available during peak hours. It is common to see a tank where the outflow of the tank exceeds the inflow of the tank for a long period of time, emptying the tank completely. The tubing system may then flow under open-channel conditions rather than pressurized flow. Many people will use smaller tubes thinking pressures increase. The transition from open-channel flow to pressurized flow does occur at a lower flow rate with smaller tubes in a given system, but flow rate and pressure must both be considered in design.

Figure 4-5: Construction of 10,000-gallon tank for community of 150 houses

4.4.1 Constantly Empty Tank

A tank that is constantly in an empty state indicates unacceptable losses in the community or that the source is extremely poor. Diagnosis of this problem is completed by measuring the flow rate into the tank. If it is determined that the flow rate entering the tank is acceptable (more than the necessary daily requirements), then there are problems in the distribution system. The most common problem in a community is houses without valves, houses with faulty valves or houses that leave the valves open. Houses without valves can easily be located and installed with a new valve. Houses with faulty valves can also be easily located and valves replaced or repaired. Houses leave the valves open due to the fact that the system is sectored, and that they only get water during certain hours. In order to ensure they have water, occupants will always leave the valve open. In this case, community awareness and fines for wasting water can help deter people from leaving valves open. Sectorization is extremely common; however, this practice usually amplifies problems as members of the community leave valves open and store as much water as possible.

The other commonly encountered problem when a tank is constantly empty is severe leakage in the distribution system. Locating major leakage can be done by visual inspection of the line. A common source of leakage comes from pressure break tanks. Pressure break tanks in the distribution line **must** be equipped with operating float valves so that the pressure break tanks never overflow at any time. Leakage in the joints or leakage due to pipe failure can commonly be located by walking the system as pipes are generally placed in a trench 1-2 feet in depth.

4.4.2 Constantly Overflowing Tank

A system with a constantly overflowing tank rarely has complaints from the community members. An overflowing tank is essentially not serving a purpose except to break pressure. An overflowing tank could prove to be useful later in its life as the demand increases and the tank empties and fills as designed.

A properly operating system will constantly have an overflowing tank for the first few years, before the community has grown significantly. This is due to the fact the inflow into the tank is always greater than the outflow out of the tank. The conduction line entering the tank is sized to serve the maximum daily requirements of the future population. This flow rate exceeds the current maximum hourly consumption in the distribution line. For example, as explained in Section 3, a community of 100 houses has a conduction line sized for the future daily requirement of 31 gallons per minute. However, the current maximum hourly consumption is 23 gallons per minute (assuming 6 people per house, 3.5% growth rate, 25 gallons per capita per day, daily peak factor 1.5, and hourly peak factor 2.25).

If the community is complaining of lack of water and the tank is constantly overflowing, the distribution line must be analyzed and blockages should be cleared, or else larger tubing installed, assuming all houses are located below the tank. An overflowing tank may indicate an oversized conduction line; however, this is usually not a major problem. An oversized conduction line is only a problem if the wasted water could be better used by another community who is using the same source. An overflowing tank more likely indicates a very common problem observed in Honduras, which is an undersized distribution line. Undersized tubing is mainly due to lack of technical knowledge that larger pipes in fact deliver water at a greater pressure, due to smaller frictional losses in comparison to smaller diameter pipes. Smaller diameter tubing is cheaper and therefore more likely to be bought and installed in communities with a limited budget. The additional cost of larger diameter tubing will be recovered, as installing smaller diameter tubing will only need to be replaced sooner due to community growth. A rule of thumb for a minimum diameter is 1". Branches off the main distribution line, while only serving a single house, have the possibility of serving more houses as new houses are built in the future. A more conservative rule of thumb is that 2" diameter will be sufficient for communities up to approximately 50 houses. Communities larger than 50 houses should consider using 3" or 4" tubing in the distribution line. These minimum diameters are only recommendations, as the elevation of the tank in comparison to the elevation of the houses will determine available pressure. There are systems with less than 5 houses that have 3" tubing due to the fact that the elevation of the tank is only slightly greater than the elevations of the houses.

4.4.3 Periodically Overflowing Tank

An overflowing tank that completely empties during peak hours may indicate that the tank is undersized. An additional tank can be expensive, and the new tank should only be the size of the quantity of water lost in one day.

Many times in rural Honduras, the plumber closes the outlet on the tank for the night in order to fill the tank creating an artificially overflowing tank. Houses without a valve are most often the source of losses as well as leaky valves, connections, etc. A possible solution is to close the valve from the tank to the community (assuming the water is put to better use during the day). This does require more maintenance as everyday the plumber must walk up to the tank to open and close the valve if a valve is not installed close to the community. Simple modification can be made to the tank to obtain maximum storage and prevent losses of water through the overflow pipe if the plumber does not open the tank before overflowing occurs. The best method is to connect the overflow pipe to the distribution line. This will allow water to be supplied to the community once the tank is full. An additional overflow pipe with the inlet located at a higher elevation must be installed as an emergency overflow in case the regular overflow pipe connecting to the distribution line is full or cannot carry the flow entering the tank from the conduction line.

4.5 Tank Modification Techniques

If it is determined that the tank is undersized, management of the water within the community can be encouraged, such as local storage of water at each house by filling containers during the night. This may not be a practical solution, nor a health conscience solution, as typically water harbors mosquitoes and therefore mosquito-born diseases. If proper storage techniques are employed such as storage of water in clean, covered vessels, then locally storing water in households is a cheap and efficient method of increasing storage. However, it may be deemed necessary to construct a new tank to increase storage capacity.

If it is decided to build a new tank, the two tanks should either be built so the overflows are at the same level, or if the overflows of the tanks are at different levels, then the lower tank should be equipped with a float valve that will stop flow when the tank is full. If a method to stop the flow from the upper tank to the lower tank is not implemented, the upper tank serves no purpose as it will always be emptying to the lower tank and the water will be lost in the overflow of the lower tank.

4.5.1 Equal Elevation Tanks

Figure 4.6 shows various arrangements to connect two tanks with the overflows located at the same elevation. A typical arrangement of pipes with tanks that have overflows at equal elevations is to have the two distribution lines from the two tanks joined immediately upon the exit of the tanks creating only one main distribution line (Figure 4.6a). There may be a tee installed in the conduction line to fill the two tanks before entering the tanks, or the conduction line may only enter one tank. If the conduction line enters both tanks, it is not necessary to interconnect the two tanks assuming both tanks are connected to the distribution line. However, if only one tank is connected to the distribution line, then the two tanks must be interconnected (Figure 4.6b)

In the case when the conduction line only enters one tank, then the two tanks must be connected (Figure 4.6c). The overflow of the tank in which the conduction line enters may be directed to the second tank, thereby providing an extra meter of head and the second tank must have an overflow to discharge excess water. Alternatively, the two tanks may be connected at the bottom rather than the overflow of tank 1, so that the levels are always constant.

Another typical arrangement of pipes with tanks that have overflows at equal elevations is to only have one tank connected to the distribution line and only one tank connected to the distribution line, in which case the two tanks must be connected at the bottom of the tanks (Figure 4.6d). The tanks will fill and empty simultaneously.

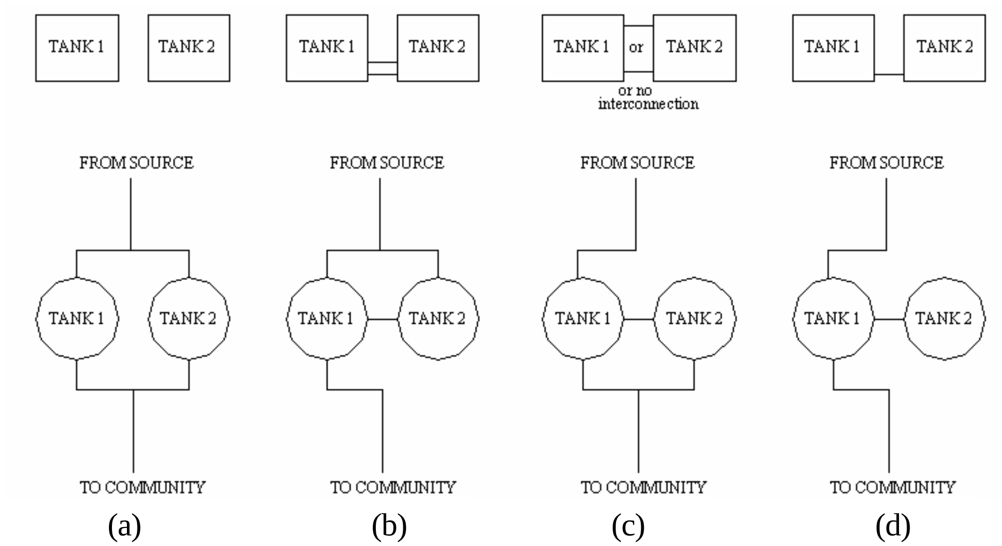

Figure 4-6: Options to connect tanks located at equal elevations for rural water systems

4.5.2 Unequal Elevation Tanks

Figure 4.7 shows various arrangements when a new tank is added and the overflows are at different elevations. Local conditions usually dictate if a second tank can feasibly be built at the same elevation, but if possible the overflows should be at the same elevation.

The lower tank must be equipped with a float valve. When the lower tank is full, a valve closes the entrance to the lower tank, and the tank at the higher elevation will then start to fill. The tank at the higher elevation then spills any flow that cannot be stored in the two tanks. The addition of a float valve does increase the maintenance and presents a possible problem if not maintained, which suggests that two tanks at the same level is preferable. If the lower tank does not have a float valve, the upper tank will lose all the storage capacity because the lower tank will be overflowing and therefore draining the upper tank. The pipe connecting the two tanks should be sufficiently sized to carry the maximum hourly flow. The lower tank should have an overflow pipe at an elevation higher than the entrance for emergency purposes, but overflows should only occur in the upper tank if the tank system is correctly operating.

Interconnecting the two-tank system is also more complicated when the tanks are located at different elevations. In the case when the exit of the upper tank (located on floor) is at an elevation below that of the entrance to the lower tank, both tanks must be connected to the distribution line so that all available storage in the upper tank is obtained. A check valve must then be installed on the outlet of the lower tank to prevent water flowing from the upper tank into the lower tank, thereby reducing the storage capacity of the upper tank. If the exit of the upper tank (located on the floor of tank) is at an elevation higher than the entrance to the lower tank, then the distribution line should only be connected to the lower tank. The conduction line will first enter the upper tank, and a float valve installed on the line from the upper tank to the lower tank will allow the upper tank to fill after the lower tank is filled.

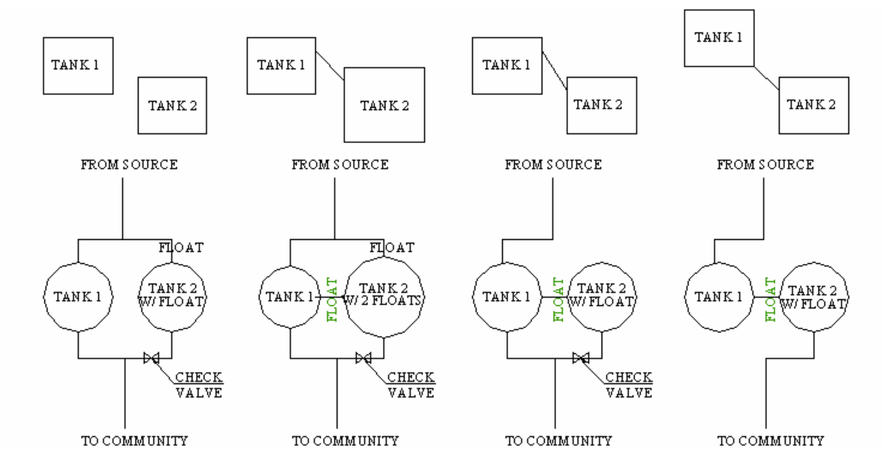

Figure 4-7: Connecting unequal elevation tanks

4.6 Distribution Line

Many times losses within the community cause problems in a system, such as unequal distribution of water. It is very common to notice the lower houses with plenty of water and the houses located at higher elevations with a shortage of water. This is caused by the overuse of water by those located at lower elevations. Some measures may be taken in certain cases, such as installing control valves (i.e. gate valves and globe valves) in the lower sections of the system to control the quantity of water that can flow to the lower houses so that the upper houses may receive water. Case by case examination of each system must be made for the proper installation of valves. Proper sizing of pipes may help prevent this problem as well. For example, if the lower houses lie farther from the tank than the upper houses, a smaller pipe can be used to give the proper quantity of water. Larger pipes will deliver water at a better pressure, assuming the demand remains constant. In effect, the smaller pipe is creating the head losses that a globe valve creates, thereby reducing the flow rate. It must be noted that the above suggestions should be used with caution, as there are many cases in which a smaller pipe or control valve will cause more problems or larger pipes will cause leakage to increase. Problems from using smaller pipe or control valves are due to the hydraulic grade line falling below the elevation of the houses due to increased frictional losses, in which case the houses will not receive water. Diameter reduction of pipes is only recommended in special cases where the reduction will occur in the lower most section of the system and the system does not continue to other houses located at a higher elevation. In summary, using smaller diameter tubing can be effective in controlling flow to certain sections; however this may cause water shortage to some houses if not properly evaluated, and therefore smaller diameters must only be used in specific occasions after a detailed evaluation of the system.

4.6.1 Engineering Practices to Improve Performance

A common problem is unnecessary losses from improperly installed valves, tubing, or accessories that allow water to leak from the system. Proper construction techniques should be used to install and repair any water system. The use of moving parts should be kept to a minimum. This includes all valves such as float valves in pressure break tanks, clean-out valves, and air-valves, as the moving parts can fail and are expensive to replace.

A common problem encountered may be a pressure-break tank with a faulty float valve. A pressure-break tank is designed to shutoff when full. Figure 4.8 shows a pressure-break tank in the distribution line of a community serving 150 houses with a 2" diameter entrance and 3" diameter exit. The tank as shown is filling and houses downstream are using water. Once all houses downstream close their valves, the tank will fill, raising the float and closing the valve, allowing for increased pressures upstream. The large storage tank will then start to fill as all the houses close their valves. However, if water continues to enter the pressure-break tank when in a full state due to a faulty valve, water is lost in the overflow tube of the pressure-break tank and the storage tank may never fill. For this reason, it is best to always try to minimize the number of pressure-break tanks in the distribution line, or eliminate them completely. Pressure restraints (typically 60 – 80 psi), however, should be maintained as close as possible because valves and accessories are more susceptible to problems under high pressure. The permissible strength of the tubing usually exceeds the required pressure to cause failure of the accessories, depending on the type of tubing purchased. The elimination of pressure break tanks can only occur by carefully locating the storage tank at the lowest elevation possible while providing a minimum of 15 pounds per square inch (psi) of pressure to all houses. Locating the tank occurs in the initial design phase, in which case an engineer working on an older system may be restrained in the removal and placement of pressure break tanks.

Figure 4-8: Pressure-break tank with 2" diameter float valve with valve currently open due to demand by houses downstream from pressure-break tank.

It was noticed in Honduras that air-valves should only be installed as necessary due to the possibility of the valve failing. Air blocks will free themselves with time assuming a small flow rate exists. It is best to install all tubes and test the system for a period of a day to verify if water is arriving to all required locations. The tubing system should be as empty as possible and then the system should be started. If the water arrives, air-valves can be omitted. However if it is noticed that no water arrives then an air-valve should be installed at the highest point in the system after the source or tank. Typically, air blocks occur where downstream there is a long section of pipe that continues with a negative slope.

Clean-out valves are very useful to clean debris from the system; however many cases have been observed where the valve has failed, in which water will be lost through the clean-out valve and will decrease or prevent flow. Valves most often failed due to failure of the mechanical parts due to normal use. Valves are also vulnerable to damage by humans, whether intentional or unintentional. Accepted construction practices must be followed when installing clean-out valves. The most critical point for a clean-out valve is usually at the first low point after the tank or catchment structure.

4.6.2 Sizing and Routing of Tubing

To avoid future problems, engineering norms should be followed; however, flexibility of design standards and proven creative solutions can improve performance. One of the most common problems encountered is water not arriving to all the houses. Proper sizing and routing of tubing can assist in creating a system in which all houses receive sufficient water.

The sizing of tubing is the most important factor in equal distribution of water. Using tubing with a diameter larger than the minimum recommended will improve pressures for systems in which sufficient pressure is not obtained, as larger diameter tubing creates smaller losses than smaller diameter pipes for a given flow rate. Using small diameter tubing was the most common problem noticed in my service. The use of small diameter tubing is due to the widely believed idea that smaller tubing has better pressure. This idea is completely inaccurate, as smaller tubing will create larger frictional losses, lowering the hydraulic grade line and therefore decreasing pressure available. This idea stems from people seeing water flow with a high velocity when using a reducing device, such as a nozzle. A reducer will increase velocity, however with an increased velocity comes increased frictional losses. It has been observed in Honduras where a community attempted to improve the system by using smaller tubing, but in fact this is a waste of money that makes the system worse. All household connections to the main line are ½” and will create large losses, acting as a self-regulator. All main lines should be a minimum of 1”. However, larger tubing will decrease friction and increase pressure. Larger tubing may make leakage worse; however it may be easier to locate leakage, and repairs can be made to faulty tubing.

On the construction side, designing a system with only one size pipe, typically 2” diameter or greater for rural systems, greatly eases construction as all the accessories and tools only need to be of 2”. Additionally, the engineer is not required to spend as much time on site as it is impossible to install the wrong size of tubing if there is only one size. Future repairs are easier for the community as they know exactly what size of pipe or accessory to buy in case of failure. The initial cost of materials may be greater, but the intangible costs such as supervision and ease of maintenance very likely outweigh the upfront cost.

Using creative solutions to install the tubing can improve pressure. Looping a system, or creating multiple paths for the water to flow will decrease the losses in pipes as the flow rate in an individual pipe will be decreased if two pipes are supplying a certain section. See Figure 4.9 for an example of a looped system, in which the water has multiple paths to arrive at the houses. This system has 3 loops, giving multiple paths for the water to arrive to each section of the community. This decrease in the quantity of water flowing through each tube decreases the frictional losses, leading to improved pressures. The drawback to looping a system is more control valves are required in order to have full control of the system (closing sections for maintenance). More powerful software programs such as EPANet or Haestad WaterCAD are used to determine expected pressures. The Excel program used by Peace Corps Volunteers in Honduras does not have the capacity to determine pressures when a closed circuit is encountered. See Reents (2003) for more information regarding the program used by Peace Corps Volunteers in Honduras.

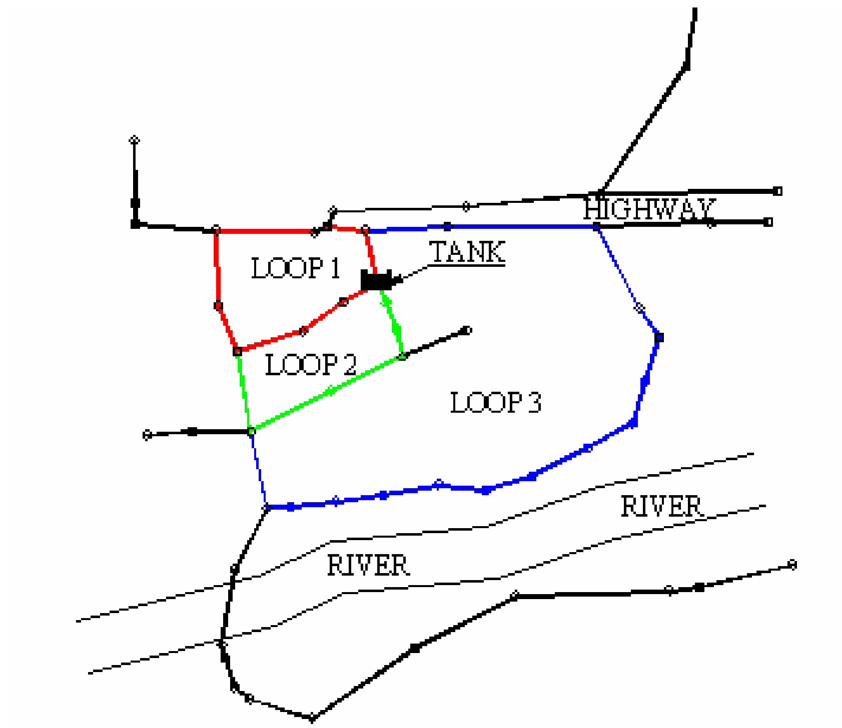

Figure 4-9: Planimetric view of system with 3 loops for community of 70 houses, providing multiple paths for water to arrive to many sections of the community. All tubing is of 2" diameter for ease of construction.

4.6.3 Sectorization

Sectorization, or manually opening and closing valves to parts of the community at various times of the day, is widely practiced in Honduras in hopes to create a more equal distribution of water. Upon examination, sectorization may create a larger disparity between those who obtain water (lower houses) and those who do not (higher houses).

Typically, rural water systems are designed to be operating 24 hours a day, with a peak hourly flow 2.25 times greater than the average hourly flow. During the morning hours as people are preparing for work, many faucets may be open, but during the night the valves are closed. The exact usage varies from family to family. Every family should have access at one point during the day, although lower pressures may be noticed during peak hours.

Sectorization creates a situation in which every house feels they must have the faucets fully-open continuously to receive water. Typical sectorization can range from a house receiving water once a week, or every day for only a few hours. Sectorization with periods of days shows the greatest problems, as a house will try to store a week's worth of water in a very short time. This sectorization increases the peak hourly factor many times, and therefore the losses created with high flow rates drops the hydraulic grade line leading to the higher houses receiving limited or no water. For example, a house receiving water once a week, with a daily demand of 100 gallons per day, will need to store 700 gallons in two hours, or a flow rate of 5.8 gallons per minute. Rural systems are designed for approximately 0.5 gallons per minute per house and assume the water will flow at various periods of the day. A single house can obtain well over 5 gallons per minute with a valve fully opened. In a situation when a few houses located in the lower sections are drawing these large quantities of water, the hydraulic grade line may fall below the level of the taps of the higher houses. In this case, the higher houses will have valves which actually "suck," or pull water out of reservoirs connected to the pipe system.

The use of control valves can help in cases in which lower houses receive water and the higher houses do not. The topography and system layout is very important and must be evaluated in the consideration of valves. For a system in which the higher section of houses is located farther from the tank than the lower houses, a control valve installed on the mainline will not accomplish the goal of raising the hydraulic grade line in the upper section (see figure 4.10). Only in the situation where the lower houses are located farther from the tank than the higher houses should a control valve be used.

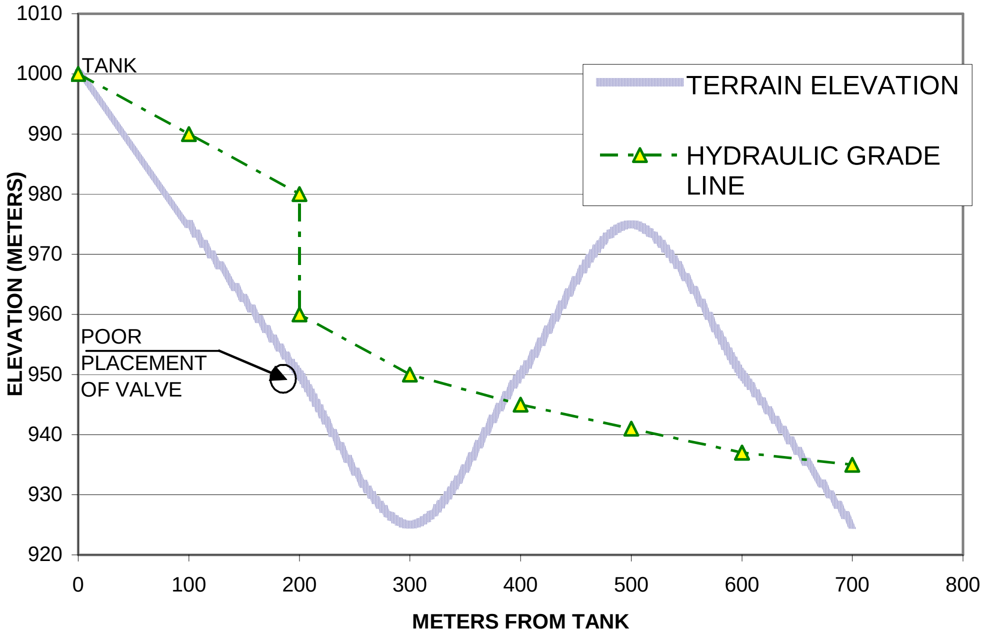

Figure 4-10: Example of poor placement of control valve in rural water system showing negative pressures in higher reaches due to losses created by control valve

A control valve will create large losses, or completely shutoff the flow of water to lower houses in order to deliver water to the higher houses. However, with a correctly operating system, all lower houses should close valves when not in use, in which case a control valve is not necessary. This concept is closely related to community education and emphasizing to those who live in lower houses the importance of careful water management.

There is one case in which sectorizing, or completely closing the exit on the tank so nobody receives water can benefit the community. This case is when the system is operating where household valves cannot close or voluntarily are left open. Closing of the tank will prevent losses in the community during the night, and the water will be stored in the tank. This is a worst case scenario. Sectorizing creates a situation is which everyone leaves valves open, so control valves must operated, leading back to the community leaving valves open. This is a cycle which may take some time to break as human behavioral patterns must be changed.

5.0 Case Study – Los Chaguites, Choluteca

Chapter 5 summarizes the improvement to the water system in the community of Los Chaguites, in the department of Choluteca. This case study first shows how a simple analysis of a system can avoid unwarranted changes to a system in an attempt to improve the distribution of water. The case study then shows how education of the community led to the water board correctly diagnosing the problem and rectifying the situation. Although this system was built less than two years previous to this analysis, the problems shown are very typical for all systems of all ages.

5.1 Overview of Community

Los Chaguites is a community of approximately 150 houses located in southern Honduras. The system consists of one catchment structure that feeds a tank of 10,000 gallons. The catchment structure is shown in Figure 3.3. The conduction line consists of approximately 750 meters of 3" tubing and 750 meters of 2" tubing. The majority of the tubing is PVC with sections of GI (galvanized iron) at locations where the tubing crosses streams or rivers. The tubing leading from the tank to the community is 3" in diameter, and decreases to 1" in the sections where the system is required to deliver water to ten houses or less. There are two pressure break tanks located in the distribution line, originally equipped with float valves.

5.2 Problem 1 – Houses Not Receiving Water

5.2.1 Complaints

Many of the houses located farthest from the tank were at an elevation higher than some houses closer to the tank. The houses at the farthest points were complaining water was not arriving or arriving with little pressure.

5.2.2 Analysis using Figure 4-1

The analysis began by observing the level of water in the tank and was observed that it would never reach a full state unless the valve leading to the community was manually closed. The initial measured flow rate into the tank was equivalent to 50 gallons per person per day. This flow rate was well above the required twenty-five gallons per person per day, indicating misuse of water or losses in the community were occurring. Although the analysis of the distribution line at this time would have been warranted, the source was first analyzed to determine if more water could be supplied before a more extensive analysis of the distribution line within the community would occur.

The source was observed to be operating well. A visual inspection indicated that the source was supplying a quantity of water well above the flow rate entering the tank, with a large quantity of water flowing through the overflow. The overflowing source indicated that the conduction line was flowing at capacity or experiencing blockage, leakage, or losses through an illegal connection. The community was informed on basic observations to monitor the operation of the source. The community was trained to monitor the overflow of the source. The community learned that installing a pipe from a nearby source to the original source in attempt to increase flow would not be beneficial as the additional flow would increase the quantity of water flowing through the overflow rather than increasing the quantity of water entering the conduction line. An analysis of the conduction line proceeded.

The design of the conduction line was available showing the expected flow rate of the tubing given the diameter of pipe, length of pipe, pipe material and elevation difference between the source and the tank. The capacity of the conduction line was determined to be the same as the entrance flow rate into the tank, showing that the conduction line was operating correctly and did not have any major leakage, blockage, or illegal connections. If the community would like to supply more water to the community, then larger diameter pipe would have to be bought. No changes were made to the source or conduction line. An analysis of the distribution line followed.

5.2.3 Distribution Analysis

The community had made modifications to the distribution line in an attempt to supply water to houses located at higher elevations. The community removed the float valve at the pressure break tank, believing it was restricting the flow into the pressure break tank. There was an increase in the flow rate entering the pressure break tank with the removal of the float valve, as the float valve did create some losses. The removal of the float valve in a pressure break tank located in the distribution line consequently created the following problems:

1. The pressure break tank overflowed when the houses located downstream of the pressure break tank closed their valves. This prevented the storage tank from filling due to the constant loss of water at the pressure-break tank.

2. The houses located upstream of the pressure break tank saw a decrease in water pressure due to the constant increased flow into the pressure break tank.

3. The empty storage tank caused the community to sectorize the system and ration the water by closing valves to certain sections of the community or all of the community.

4. The sectorization then caused an increased peak usage, as the members of the community attempted to store as much water as possible during their allotted period of access to water. The lower houses rarely closed the valves, and the upper houses rarely received water.

The sectorization was immediately discussed with the community and it was recommended to allow water to be supplied at all times during the day. Immediate improvements were not seen as it took some time for word to spread about the importance of closing valves at each house. After a period of a week, the water board expressed satisfaction in the fact that water was supplied all day.

The float valve was immediately reinstalled and periodic observations of the pressure break tank in the following months showed that the pressure break tank was usually in a full state and the float valve working well. The fact that the pressure break tank and storage tank were full indicated that community awareness of the importance of closing valves occurred. The section of pipe downstream of the pressure break tank was fully pressurized and the houses saw improvements in the pressure of water supplied. The concept of a controlled flow rate into the pressure break tank was contrary to the initial opinion that more water flowing into the pressure break tank would increase pressure, thinking more is better.

This particular example shows how Figure 4-1 initially indicated that the system was not operating at the desired level due to problems located in the distribution line. The analysis of the source and conduction line, although not shown as a necessary procedure from Figure 4-1, was completed because the exact quantity of water required in the community was unknown. It could have been possible that 50 gallons per person per day was not sufficient for this particular community. The solution of eliminating sectorization and installing the removed float valves was completed at no cost.

In this case, the community also wanted to augment the flow of water entering the source by purchasing a new source and installing tubes leading from the new source to the old source. In this case, if the community had continued the process of augmenting the existing source with a new source, the community members would have been required to donate time and money for construction and materials. The community would not have seen any improvement in the quantity of water supplied and faith in the water board would have been lost. Community members often stop paying the monthly fee when they feel they are not receiving sufficient water and a complete failure of the project could have occurred.

5.3 Problem 2: Lack of Supply

The community complained again that the storage tank would never fill, and there was not sufficient water for all parts of the community. From previous work with this community, this case initially was thought to be related to the poor management of water including sectorization and removal of float valves. The community then explained that a new catchment structure for a different system was built upstream from their water supply for the city of Choluteca. The water board explained that the source was no longer overflowing and that they would like to again look into obtaining a new source to augment the flow.

5.3.1 Analysis using Figure 4-1

The analysis once again started at the tank, and it was obvious that the quantity of water entering the tank had diminished compared to previous measurements. The quantity of water entering the tank did supply nearly 25 gallons per person per day for the current population.

From previous observations, it was known that the conduction line should be supplying nearly 50 gallons per person per day, indicating that an analysis starting at the source and continuing to the conduction line would be needed.

As shown in Figure 4-1, the first step to analyze the source is to measure the flow rate at the source. The flow rate at the source was equal to the flow rate entering the tank, indicating that a new source would be beneficial. The conduction line was operating without problems due to the fact that the quantity of water entering the tank was the same as the quantity of water at the source. The distribution line was reviewed to ensure all float valves were installed and no leakage was occurring.

The decrease in flow at the source was due to the fact that a new catchment was built upstream from the catchment structure for this community. The new catchment structure diverted a large quantity of water to the neighboring city of Choluteca. This water was originally used to supply the community of Los Chaguites. There were also a large number of illegal catchment structures upstream of the Los Chaguites structure used by small farmers.

Although the analysis and identification of the problem was very straightforward, the solution of this problem was quite complicated due to political differences and land-right issues. The community attempted to work with the city of Choluteca in order to allow more water to bypass the Choluteca structure. This solution was not agreed upon, at which time the community of Los Chaguites built a new catchment structure above the Choluteca structure. The new source then fed directly into the old catchment structure and resolved the problem in Los Chaguites. The process of progressively building catchment structures higher and higher in a watershed is not recommended. A large scale watershed management program would be much more beneficial in this case.

[redacted]

6.0 Conclusions and Recommendations

Many rural gravity-fed water systems built 10-20 years ago are now experiencing a wide range of problems that prevent sufficient quantities of safe water to be equally distributed to the rural population. With coverage of rural water services approaching 90%, there is expected to be a large number of communities that will be improving their systems due to community development, material failure, or decreased supply in the near future. When adding capacity to a water system, the system must first undergo an extensive examination in order to determine exactly how limited resources can be applied to allow more people to more equally access water.

The best way to avoid problems is through good management of the system. Preventive measures including reforestation to assure a good yield from the source, installation of working valves at every tap, removing debris from the source, community education, regular inspection of the tubing, regular inspection of valves (float valves, control valves, and household valves) and regular opening of clean-out valves. These measures can help to ensure all members of a community have fair access to water.

There are times when all preventative measures have been taken and the system is still poorly operating. Every community must have a specific evaluation to determine if a more technical approach is necessary to increase capacity. Inexpensive solutions such as a new source, improving a source, installation of larger tubes, or adding storage can all help to improve the fair distribution of water. The most commonly encountered problems are an undersized distribution line and a source which does not give an acceptable yield. Tank modifications are more complex and less common.

The easiest and most effective method to improve capacity of a water system, assuming all houses have an operational valve, is through the installation of larger diameter tubing. Under no circumstances should ½" diameter tubing be installed except for individual household connections. The use of only 1 size of diameter will ease construction and maintenance in the future. In most cases, 2" tubing for communities up to 50 houses is sufficient. The initial increased cost is offset by ease of construction, ease of maintenance, and improved performance in the future. It is very common to see outside organizations enter a community with the goal of simply installing a water system at minimum cost. This practice often creates tension within the community as an unequal distribution of water causes conflict between members of the community, refusal to pay for services, and eventual failure of the water system.

Another very common mistake in improving a water system is to try to build a very large catchment structure. A catchment structure cannot be built for rural communities with the volume to account for seasonal fluctuation of water supplied. A catchment structure solely is used to capture the quantity of water that allows the conduction line to flow at 100% of capacity. A storage tank then provides the storage volume needed to meet daily fluctuation in water demand. The other remedy used by communities in times of water shortage is sectorization. This process of turning off the water for days at a time may only cause a more severe disparity of water as the houses at lower elevations will attempt to store days' worth of water in a short period. The higher houses may then never receive water as the hydraulic grade line will fall below the elevation of the tap due to the increase flow rate.

In summary, Honduras is a country that is experiencing successful development in many areas, especially in the area of water systems. However, future resources should be devoted towards maintaining and improving the resources which Honduras possesses.

References

Austin, John D., and Jordan, James K. (1987). Operation and Maintenance of Water Systems in Developing Countries. *Journal of American Water Works Association,* vol. 79, no. 7, pp 70-77.

CHP Training. (2002). *Water and Sanitation Training Manual.* Santa Lucia, Honduras: CHP Publications.

CIA (Central Intelligence Agency). 2002. *The World Factbook-Honduras* http://www.odci.gov/cia/publications/factbook/geos/ho.html

EPA (US Environmental Protection Agency) (May 1994). *Drinking Water Treatment for Small Communities*. Washington, DC. http://www.epa.gov/ord/WebPubs/H20.pdf

Gelting, R.J., and Ortolano, L. (1998). A Model Describing Performance of Rural Drinking Water Systems in Honduras. *International Journal of Water Resources Development*, vol. 14, no. 2, pp. 199-215.

Jordan, Thomas D. (1984). *A Handbook of Gravity-Flow Water Systems.* London: Intermediate Technology Publications.

Kleiner, Yehuda, Adama, Barry and Rogers, Scott. (1998). Selection and Scheduling of Rehabilitation Alternatives for Water Distribution Systems. *Water Resources Research*, vol. 34, no. 8, pp 2053-2061.

Katz, Travis, and Sara, Jennifer. (1994). Making *Rural Water Supply Sustainable: Recommendations from a Global Study.* UNDP – World Bank Water and Sanitation Program. http://www-wds.worldbank.org/servlet/WDSContentServer/WDSP/IB/1998/11/17/000009265_3981005112156/Rendered/PDF/mulit_page.pdf

Microsoft Encarta. (1994) "Honduras" Microsoft Corporation. Funk & Wagnall's Corporation

Munson, Bruce R., Young, Donald F., Okiishi, Theodore H. (1998). *Fundamentals of Fluid Mechanics.* New York: John Wiley and Sons.

Niskanen, Matt (2003). *The Design, Construction and Maintenance of a Gravity-Fed Water Systems in the Dominican Republic*. Michigan Technological University Master's of Civil Engineering Report.

Peace Corps/Honduras. (2001). *Information Booklet.* Washington, DC: United States Government..

Reents, Nate (2003). *Design of Rural Water Systems in Honduras*. Michigan Technological University Master's of Environmental Engineering Report.

Stephenson, David (1998). *Water Supply Management.* Dordrecht, The Netherlands. Kluwar Academic Publishers.

Tchobanoglous, George (1981). *Wastewater Engineering: Collection and Pumping of Wastewater.* New York: McGraw-Hill, Inc.

Trevett, Andrew, Nunez, Omar (1998). AHJASA – Ongoing Management and Maintenance Support for Honduras; Community Water Systems in *Waterlines,* vol. 16. no. 3, pp.24-26. http://www.irc.nl/products/publications/ajw/v8n17.html

Trevett A.F (2001). The SANAA Technician in Operation and Maintenance Program in Honduras, in *Institutional Arrangements for Rural Communities, Strategic Paper No. 1, Case Studies on Decentralization of Water Supply and Sanitation Services in Latin America. Environmental Health Project, prepared for the USAID Bureau for Latin America and the Caribbean Project No. 26568.*
http://www.ehproject.org/PDF/Strategic_Papers/LACDEC/Honduras_TOM.pdf

United States Geological Survey. USGS Hurricane Mitch Program (Accessed November 1, 2002). *Hurricane Mitch Overview* http://mitchnts1.cr.usgs.gov/overview.html

United State Geological Service. USGS Hurricane Mitch Program (Accessed December 4, 2003). *Track of Hurricane Mitch Map.*
http://mitchnts1.cr.usgs.gov/images/usaid_track_better.gif

University of Texas at Austin. Perry Castañeda Library Map Collection. (Accessed December 4, 2003). *Political North and South America Map.*
http://www.lib.utexas.edu/maps/americas/americas_pol96.jpg

University of Texas at Austin. Perry Castañeda Library Map Collection. (Accessed December 4, 2003). *Map of Honduras*.
http://www.lib.utexas.edu/maps/cia02/honduras_sm02.gif

WHO/UNICEF (2001). Access to Improved Drinking Water Sources in *WHO/UNICEF Joint Monitoring Programme for Water Supply and Sanitation Coverage Estimates 1980-2000.*
http://www.childinfo.org/eddb/water/latam/honduras_water1.pdf

Worldbank (2003). "Honduras at a Glance". http://www.worldbank.org/cgi-bin/sendoff.cgi?page=%2Fdata%2Fcountrydata%2Faag%2Fhnd_aag.pdf

[redacted]