DRIVERS OF RURAL WATER SUPPLY SUSTAINABILITY:
A CASE STUDY IN THE ECUADORIAN ANDES

by

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Abstract

Past investments in the potable water sector of developing countries have been characterized by widespread breakdown and a persistent challenge of sustainability. Policy discourse on sustainability has been fragmented and partial, and has resulted in ineffective program strategies. The present study examines the critical factors, the drivers, of sustainability in a more comprehensive and holistic fashion, drawing on a multi-disciplinary, global literature. Fieldwork was undertaken in 15 rural communities in the Ecuadorian Andes. The study found that there are four important drivers of sustainability: appropriate technology, demand-responsive supply, the common pool resource nature of potable water, and environmental conditions. The study calls for scholars and practitioners to adopt a holistic approach that utilizes all four drivers in analyzing and promoting sustainability. Further research is recommended into the nature of and interaction among these four driving factors in a larger and more diverse sample of communities and regions around the world.

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Chapter 1: Introduction

1.1 Defining the Research Problem

Water is a basic necessity for life. The International Water Management Institute classifies water use into four categories; namely, irrigation, domestic, industrial, and environmental uses (Seckler, Amarasinghe, Molden, de Silva & Barker, 1998). This thesis will focus exclusively on the domestic use of water. More specifically the term water accessibility will be used exclusively in the context of domestic use, which refers to the water consumed for drinking, food preparation, personal hygiene, and sanitation (Gleick, 1996).

The Global Water Supply and Sanitation 2000 Assessment Report estimates that at the beginning of the year 2000 there were roughly 1.1 billion people who lacked access to safe drinking water (WHO/UNICEF, 2000). The report used technology as an indicator of water quality, which is not an accurate indicator. The figures presented therefore likely grossly underestimate the percentage of the population who lack access to an improved source¹ (WHO/UNICEF, 2000). Furthermore, the 2000 Assessment Report does not examine the adequacy of the quantity of water typically supplied through existing systems. Consequently, it is highly probable that many more than the estimated 1.1 billion people lacked access to safe drinking water.

Gleick (1996) undertook an extensive study on the quantity of water required to satisfy basic human needs and promote adequate levels of health. Based on his study, he recommended the adoption of an international basic water requirement standard (BWR) of 50 liters per capita per day (lcp) in order to satisfy basic domestic needs. Gleick (1998) later estimated that roughly 2.2 billion people worldwide are not meeting this

¹ Technology is not always a good indicator of quality; since it does not necessary take into account the method and degree of treatment and/or compliance with maintenance requirements. In practice, water supply systems in many developing regions operate intermittently, and do not provide reliable and adequate service(WHO/UNICEF 2000).

international basic water requirement. This result is consistent with the World Commission on Environment and Development's estimate that approximately 40% of the world's population suffers from serious water shortages (Hamidy & Scarascia-Mugnozza, 2003). Overall, it can therefore be concluded that more than 2 billion people worldwide lack access to safe drinking water.

Water supply and sanitation constitutes a major sector of aid. An Operations and Evaluation Department (OED) (2000) review of the World Bank's activities in the water supply and sanitation sector revealed that the World Bank lent \$1 billion in the sector between 1990 and 1998. In addition, the report stated that this funding was expected to double over the next two to three years. However, in reviewing the effectiveness of this aid the report found that only 43% of Bank projects were likely to produce sustainable results (OED, 2000a & 2000b). The issue of sustainability thus becomes critical.

An important problematic in the sustainable water supply discourse is in defining the term "sustainable". There is a substantial literature on the factors that affect the sustainability of water supply in a development context. This body of literature, however, is highly fragmented, by discipline and by field, and only a limited number of authors have attempted to look at the question of sustainability from a more holistic perspective.

Dunmade (2002) broadly examines the factors that affect the sustainability of foreign technology used in a development context. He develops a generic model of sustainability that is not specific to the type of technology used. Dunmade (2002) claims that the sustainability of a technology is dependent on its adaptability to its host environment. He defines adaptability to be the ability of a technology to improve the standards of living of the population without jeopardizing their welfare. The adaptability of a technology is location- and society-specific (Dunmade, 2002). According to his model, criteria for evaluating the adaptability of foreign technology may be classified into

four categories: technical, environmental, economic, and socio-political (Dunmade, 2002).

In the literature specific to the rural water supply (RWS) sector, Sara and Katz (1997) claim that there are three aspects to RWS sustainability: technical, institutional, and social. Technical aspects include issues related to the design and construction of the system. Institutional aspects are identified as those that relate to the institutional arrangements required to keep the system functioning adequately over time. Social aspects refer to the factors that affect the beneficiaries' willingness to sustain the service. This willingness may be affected by socio-economic factors such as income level, ethnic homogeneity, power differentials, and community perceptions of resources ownership and entitlements (Sara & Katz, 1997; Katz & Sara, 1998; Mukherjee & van Wijk 2002; Mukherjee 1999).

Mukherjee and van Wijk (2002) and Mukherjee (1999) contend that there are two additional dimensions of sustainability: financial and environmental. Financial sustainability refers to the ongoing costs of operation and maintenance, the cost of repair, and the availability and accessibility to replacement parts. Environmental sustainability refers to the environmental threats, such as over-extraction and contamination that faces the water resource use (Mukherjee & van Wijk 2002; Mukherjee 1999).

Lack of sustainability in any one of these individual components can cause the discontinued use or under-performance of the system. As a result, various policy recommendations, which claim to address each of these components, have emerged as a means to achieving long-term sustainability. The rural water supply literature is dominated by calls for appropriate technology, and demand-responsive (also referred to as demand-driven) supply. Although the literature acknowledges environmental

sustainability as an aspect of overall system sustainability, no explicit recommendations have emerged that are aimed at ensuring its fulfillment.

As explained above, the research problem framing this thesis is that of sustainability of water supply interventions. More specifically, this thesis will explore the drivers of sustainability for rural water supply systems for domestic use. It will also explore the recommendations or 'best practices' that emerge from the appropriate technology and demand-responsive supply literatures with evidence from the field. In addition, this thesis will examine environmental impacts on the sustainability of water supply technology, as well the how governance can affect sustainability. Finally, this work will apply all the above mentioned issues in a case study of 15 rural villages located in the Ecuadorian Andes.

The remainder of this chapter will examine the role that water supply plays in development, develop a definition for sustainability that will be used for the analysis conducted throughout this thesis, and contextualize the research by providing an overview of the case study region.

1.2 The Role of Water Supply in Development

In the development process, access to sufficient water of adequate quality for the fulfillment of basic needs plays a dual role, as both an input and an output. Regarded as an output, improved water access and quality is an important end in itself, as it directly improves human welfare by improving health and quality of life. Water may also be seen as an input to the development process because of the role it plays in facilitating human resource development by enabling investment in human capacity. Investment in human capital improves welfare by increasing opportunities and choices available to individuals and is thus directly correlated with increases in real income. This section will explore water's role in development, as both an output and an input, in greater detail.

Domestic water use profoundly affects personal health. According to the UN (1993), 80% of all diseases and more than 1/3rd of all deaths in developing regions are caused by consumption of contaminated water (UN 1993 in Gasana, Morin, Ndikuyeze & Kamoso, 2001). Consequently, studies have found that waterborne diseases represent the largest burden of disease globally (Zehnder & Yang, 2003). Clearly, water must be available in sufficient quantities to satisfy hygiene and sanitation requirements in order to stop the transmissions of pathogens, parasites, and disease (Mara, 2002; Helmer, 1999).

The most common water related diseases are diarrheal diseases (Howard & Bartram, 2003). Malnutrition and diarrhea are closely linked. Malnutrition increases the severity and duration of diarrhea, and diarrhea may cause malnutrition². Children in poor areas of developing countries typically suffer 6-10 episodes of acute diarrhea per year (Gasana et. al., 2001). Repeated episodes of diarrhea will affect the development and growth of children (Gasana et. al., 2001).

While receiving an adequate quantity of water is crucial, so is the quality of the water supply. Contamination of domestic water supply may also be caused by the presence of heavy metals, pharmaceuticals, and pesticides (Zehnder et. al., 2003; Helmer, 1999). An excessive concentration of heavy metals in water is a common problem in many developing regions and is most commonly caused by infiltration of mine water runoff.³ Pharmaceuticals are eventually excreted through human urine into wastewater, and this wastewater is frequently disposed directly into a freshwater source, which is often subsequently used as a source of drinking water (Zehnder et. al., 2003). Pesticides are intended to be used in the outside environment and natural processes (such as wind and rain) cause them to migrate, often finding their way into freshwater sources (Zehnder et. al., 2003). The chemicals and heavy metals discussed above are persistent at

² Diarrhea reduces the body's food absorption capacity causing loss of appetite, inabsorption of nutrients, and fever.

³ Of particular concern is the presence of copper, arsenic, fluoride, and/ or lead.

very low concentrations and are toxic to humans past certain critical levels. They can affect cognitive capacity; cause fatigue, have carcinogenic affects, and may lead to developmental abnormalities (Zehnder et. al., 2003).

Studies have found that improving water quality alone is insufficient to helping eliminate diarrheal disease and promote clean hygiene. Only appropriate water quantity coupled with is water quality can promote human health (Gasana et. al., 2001).

Sufficient water is required for hygiene purposes since hygiene practices play a critical role in the elimination of diarrheal diseases (Gasana et. al., 2001).

Health may also be considered an input in the development process. It is a fundamental component of human capital as it is a pre-requisite for increases in productivity. Todaro and Smith (2003) found that healthier people earn higher wages. Improvements in human health prolong and enhance the quality of life and thus increase productivity by reducing time lost to illness and by generally raising energy levels (Schultz, 1961). According to the United Nations (UN), “as much as 1/10 of every persons productive time is sacrificed to water related diseases” (UN 1993 in Gasana et. al. 2001). Longer life span also increases the length of participation in the labor force and therefore increases income.

As an input, improving water accessibility also has enormous potential to directly enhance human productivity and consequently household income. In many developing regions, water collection consumes a substantial amount of time. When access is improved, the time saved can be directly re-allocated into income generating activity⁴ (Levite and Sally, 2002). Furthermore, the process of collecting water is often physically demanding, and can entail an energy expenditure of greater than 1/3 of daily food intake (WEHAB, 2002). Heavy loads of water must often be carried over long distances, and

⁴ Aiga and Umenai (2002) effectively illustrates that improving access to water can substantially raises productivity and directly raise household incomes through their case study of the Zonal Improvement Program, which was implemented in several squatter communities in Manila.

when these distances are decreased, the physical energy saved may then be expended on other, more productive, activities (WEHAB, 2002). As a result, even if time allocated to income generating activities were to remain constant, a greater energy store would improve worker efficiency, defined as output per unit time, which would then translate into increased household income (WEHAB, 2002).

Time saved may also be re-allocated for investment in education and skill formation. This is of significant importance because it is typically women and children who are most frequently tasked with water collection (WEHAB, 2002). By freeing a child's time, it can be directly re-invested in education. Education is also directly linked with productivity because in increasing knowledge and skills, efficiency improves. Furthermore, education is critical for innovation and to develop a country's ability to absorb modern technology (Todaro & Smith, 2003).

1.3 Defining Sustainability

Now that the role that water supply plays in development has been established, the term sustainability must be defined. The concept of sustainable development emerged from a report entitled 'Our Common Future', which was published by World Commission on Environment and Development (WCED) in 1987 (Black, 1998). According to the report: "Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their needs" (WCED 1987 in Black 1998, p.28). The vocabulary of sustainability quickly spread to development theorists and practitioners, including those involved with water supply and sanitation (Black, 1998).

The notion of sustainability in the context of development is often vague and ill defined. Sustainability can mean different things to different people. This may mean that the various stakeholder groups, perhaps even within the same project, may define

sustainability differently (Kelly, 1998). Kelly (1998, p.453) thus states: “Sustainability should therefore be based upon the context of a given situation taking into account the general principles of sustainable development and the wants and needs of the people for whom it is being designed.” In the water supply and sanitation sector (WSS), several similar but distinct definitions have emerged.

Sara and Katz (1997, p.30) provide the most basic applicable definition of sustainability as, “the maintenance of an acceptable level of services throughout the design life of the water supply system.” Mukherjee and van Wijk (2002) add to Sara and Katz’s (1997) definition by stating that the WSS service must also be continuous and used effectively to be considered sustainable.

The Development Assistance Committee (DAC) of the Organization of Economic Cooperation and Development imposes further conditions on when the evaluation of sustainability would be appropriate. They define a program to be sustainable if it is able to provide an appropriate level of benefits for a substantial period of time, after the principle financial, administrative and technical aid from an external body has ended (DAC 1996 in de Sossa, Terrazas, Hurtado, & Coloma, 2003).

The International Water and Sanitation Reference Center (IRC) introduce environmental considerations into the definition and further specify criteria for acceptable service. They define a water or sanitation system to be sustainable when it provides the desired level of service, meeting quality and efficiency criteria for the duration of its design life. According to IRC, the system may be financed or co-financed with the users, should operate with a minimum of external support and technical assistance, and should be used in a manner that is efficient without causing a negative effect to the environment, in order to be considered sustainable (IRC 1997, in de Sossa et. al., 2003).

An element of ambiguity is inherent in all of these definitions of sustainability.

Terms such as acceptable, effective, appropriate, substantial, and desired are subjective in nature, and raise questions, such as what constitutes acceptable levels of service or its effective use.

For the purposes of this paper, we will use elements of the above definitions to construct our own definition. We will accept Sara and Katz's (1997) basic definition of sustainability. However, we will challenge their limitation of the timeframe to the design life of the system. Rather, we propose that, in the ideal, water supply systems should be sustainable indefinitely⁵. We reject Mukherjee and van Wijk's (2002) criteria that services must be used effectively in order to be sustainable, since the provision of a service is distinct from the way in which it is used. Instead, we will assume that if water supply were sustained that people would use it in an effective manner.⁶ We will accept DACs premise that all related aid from an external body should have ended⁷ before a determination of sustainability can be made and we adopt de Sossas' et. al.'s (2003) criteria that the system should be a minimum of five years of age before any evaluation of sustainability can be made. We recognize the importance of environmental considerations of water system use but will consider them as factors affecting sustainability rather than part of its definition.

⁵ We recognize that from an engineering perspective, it is impossible to design a system for indefinite sustainability. All physical systems will require repair and replacement of parts eventually. However, in proposing indefinite sustainability, we are requiring that communities have the ability to undertake these replacements and repair as required, such that the functionality of the system is not restricted to a specific period.

⁶ An integrated approach to the reduction of water-related illness includes water supply sanitation and hygiene promotion. Good hygiene practices are an important barrier to pathogen transmission. Effective use refers to hygienic uses of water (such as washing hands prior to food preparation and consumption and after defecation). This assumption is made for the purposes of this paper in order to restrict the analysis to the quantity and quality of water provided by water supply infrastructure in the case studies.

⁷ External support from aid agencies is not in itself problematic. However, the involvement of external agencies is rarely indefinite. Since external bodies are often involved for a limited time period, they can not typically be relied upon for long-term ongoing assistance. Community dependence on such organization can therefore cause failure in the long term and this forms the basis for our acceptance of this criteria for sustainability.

The definition that emerges is as follows: *A water supply system will be considered sustainable if an acceptable level of service is maintained indefinitely, in the absence of external support, and evaluated after a minimum of five years from the date of its implementation. An acceptable level of service will be considered to be one that is enjoyed by all⁸ community households and that meets the minimum daily BWR of 50 liters per capita to the minimum quality standard specified by the World Health Organization (WHO).*

This definition will be applied to classify the results of all water supply systems visited during field work. This classification will form the basis of the analysis that will be conducted in the remainder of the thesis.

1.4 Overview of Case Study Region

The Review of World Water Resources by Country report (FAO, 2003) divides South America into four sub regions: Guyana⁹, Andean, Brazil, and Southern¹⁰. Countries that possess three distinct parallel geophysical regions, known as the Coastal region¹¹, the Sierra¹², and the Oriente¹³, are categorized as the Andean sub region¹⁴. This region includes Bolivia, Columbia, Ecuador, Peru and Venezuela (FAO, 2003). This study focuses exclusively on the water supply in the Sierra or the Andean sub region. The Andean region is home to a large population and has received substantial aid for the extension of rural water supply coverage (FAO 2003, p.39). The Andean region shares common climactic and water scarcity characteristics across the countries included in the sub region (FAO, 2003). This case study seeks to examine the causes for the mixed

⁸ The criterion that all households within a community must have access to improved water supply in order to be considered sustainable, includes the requirement that the system be able to expand to meet the increased demand that results from population growth.

⁹ Includes Guyana, French Guiana and Surinam

¹⁰ Includes Argentina, Chile, Paraguay and Uruguay.

¹¹ The coastal region extends from the Pacific Ocean inland and rises in altitude from sea level to approximately 500 meters (FAO, 2000).

¹² The Sierra refers the Andes region. It is sandwiched between the Coastal region and the Oriente and rises in altitude from 500m to 6310m (FAO, 2000).

¹³ The Oriente is also referred to as the Amazon or jungle region.

¹⁴ Except Bolivia, which is included in this region but lacks a coast.

results that these programs have yielded. The Ecuadorian Sierra will be used as a case study to examine the conditions necessary for sustainability in the Andean region more broadly.

The province of Chimborazo in the Ecuadorian Sierra has been chosen as the study region. The location of the province of Chimborazo within Ecuador is shown in the figure below.

Figure 1: Provinces of Ecuador

1.5 Structure of Thesis

The second chapter of this work will outline the methodology followed for the selection and analysis of case studies. Chapter three will focus on the notion of appropriate technology. Chapter four will then analyze the elements of the demand-

driven supply approach. Chapter five will examine water supply sustainability from a new perspective in which water supply is considered as a common pool resource dilemma. Chapter six will explore the effect of environmental threats on technological sustainability as well recommendations for the mitigation of these effects and the promotion of sustainability. Chapter seven will synthesize the recommendations and conclusions generated throughout this thesis.

Throughout the thesis, cases of non-sustained systems will be examined to ascertain causes of failure. The thesis will also contrast successfully sustained systems with un-sustained systems in order to determine drivers of sustainability.

Chapter 2.0 Methodology

2.1 Overview of the Chapter

This chapter will detail the methodology used for the present research study. It will review the general research approach, the procedure for site selection and soliciting participation of communities, how the research instrument was selected, and the mechanism for data collection in the field. It will also discuss the barriers to research encountered and the limitations and integrity of the data.

2.2 General Research Approach

Field research was conducted in Ecuador between April and June 2004; in order to obtain the information required to address the research question posed in chapter one. Prior to the commencement of field research, application was made to the Carleton University Research Ethics Committee for permission to carry out research involving humans in the context of this study. The application was approved and a copy of the letter can be found in Appendix 4.¹⁵

The field research was divided into two phases. The initial phase was aimed at understanding the roles, activities, and effectiveness, to the extent possible, of all institutional actors in the sector at the national level, as well as the national legal and policy framework that governs domestic water supply in Ecuador. The second phase was aimed at developing an understanding, at the sub-national level, of the determinants

¹⁵ The research question has changed somewhat from its original conception. The original research question was: Why do fog water catchment systems fail or succeed in high rural communities in Nepal? Application to the Ethics Committee was made in accordance with this research question. However, shortly prior to the intended commencement of field research, the civil unrest and insurgencies in Nepal severely escalated, making the proposed research impossible. The letter of acceptance from the ethics board does not fully reflect the amended research question. However, the ethics committee was advised of the change and did not require an additional application. For more information, please see Appendix 3.

of sustainability for domestic water supply interventions from the perspective of the beneficiaries.

The initial phase took place in Quito and lasted one week. It consisted of several interviews with government officials from El Ministerio de Desarrollo Urbano y Vivienda (Ministry of Urban Development and Living - MIDUVI), El Consejo Nacional de Recursos Hídricos (The National Council on Water Resources - CNRH), El Ministerio del Ambiente (The Ministry of the Environment), and El Ministerio de Bienestar Social (Ministry of Social Well-being). In addition to being questioned about the role of their respective institutions, their activities, and their inter-relation with other organizations in the sector, officials interviewed were also questioned about their views regarding the major barriers to sustainability and why, in their view, past interventions had failed to be maintained.

The second phase of the field research lasted six weeks, and was conducted in the rural areas of the province of Chimborazo. This phase primarily consisted of speaking directly with the villagers who had received the type of intervention under consideration, in order to ascertain their views regarding the causes of failure or sustainability. In broad terms, villagers were asked about the current operation and adequacy of their water supply system, any changes in performance, operation and maintenance of the system since it was initially installed, and the causes of those changes. They were also asked about how repairs and maintenance were financed, their organizational structure, and how the system could be improved.

The perspectives and corresponding responses of the villagers are considered to represent the actual indicators of sustainability outcomes in this study, particularly in the case of failure. Once an aid organization has left a community, the community gains autonomous management and control over the system. The perspectives of community members are therefore critical to understanding the causes of success or failure, because,

it is those perspectives that inform the community members' decisions and cause their actions or inaction, which ultimately determines the outcome in terms of sustainability.

The perspectives of donor organizations were purposely excluded from this study. One criteria of sustainability in this study is that there be no current active involvement of any aid organization in the operation of the system. Since sustainability can only be determined after the aid organization has left the community, the perspective of the aid organization was considered to be superfluous to the research required to answer the question posed.

2.3 Site Selection

All research that occurred in rural communities was conducted in the province of Chimborazo. The province of Chimborazo is divided into ten cantons, which are further subdivided into parroquias. There are approximately 300 communities in the province of Chimborazo that have received some type of domestic water supply system in the past (Rosco, 2004, interview). This study compares and contrasts 15 cases, representing a roughly five percent sample size. In order to ensure that the study was relevant to the entire province, the 15 communities were distributed over five of the cantons, representing half of the region under consideration.

Canton Penipe was excluded from the study because Volcano Tungurahua, which began erupting on October 5, 1999, seriously threatened the region. The canton was subsequently evacuated on October 16, 1999 (Lane, Graham, & Whiteford, 2003). The volcano has continued to erupt over the last five years and only a fraction of the population has returned to the canton (Maldonado 2004, interview). As a result, it remains sparsely populated, causing the issue of sustainability to be relatively less important in this region. In addition, many systems had been neglected as dwellings were abandoned and this obviously weakened the objective of sustainability.

Two indicators were used to select five of the remaining nine cantons for this study: the percentage of homes with publicly provided private water connections inside their home, and water scarcity.

Data indicating the percentage of the dwellings with access to sufficient water through publicly provided piped water connections within their home are shown in Table 1. The public system refers to the publicly provided captivation and distribution systems, which may or may not include treatment processes (SIISE, 2003). The indicator does not take into account the quality of the water, or the schedule of its provision (SIISE, 2003).

We can see from this table that Canton Riobamba has the highest level of coverage for household water connections. The statistics for the city of Riobamba, which is both the capital of the canton and of the province, are included within the coverage indicator for the Canton of Riobamba. The city of Riobamba is a relatively large and modern urban center. It was felt that the indicator for Riobamba under-represented the extent of un-serviced homes within the canton because of the relatively high concentration of homes and the disproportionate population that lives in the city of Riobamba. As this study focuses on rural water supply, it was felt that the indicators should be corrected to reflect rural access to the extent possible. As a result, new values were tabulated by excluding the data for each of the Canton Cabeceros (capitals of the Cantons). The new value, representing the percentage of rural dwellings with publicly provided piped water connections within their home, are shown in table 2.

Table 1: Percentage of dwellings with a publicly provided piped water connection within the home

Canton	Total (%)
Guamote	9.4
Colta	10.9
Pallatanga	20.7
Alausí	23.3
Guano	27.5
Penipe	27.8
Cumandá	35.9
Chambo	36.4
Chunchi	36.4
Riobamba	63.9
Average	29.2

(Source: SIISE 2003)

This table shows that the cantons of Colta, Guamote, Alausí, Guano and Chunchi have the lowest coverage rate for dwellings containing piped water connections in the province. The next step was to establish the existence of fairly constant water scarcity levels in all study regions. The relative abundance of water throughout the province was ascertained through interviews with officials from the regional office of MIDUVI and CNRH. Through these interviews, it was ascertained that Chunchi did not face the same criticalness of water scarcity as the other cantons. As a result, Chunchi was excluded from the study.

Riobamba faced similar water scarcity and was the next canton with lowest percentage of publicly provided water connections in rural areas. It was therefore determined that research would be conducted in the five cantons of Alausi, Guano, Guamote, Colta, and Riobamba. The regional office of MIDUVI in Riobamba provided us with a list of communities that received assistance for provision of domestic water supply. Table 3 shows the number of water supply interventions that have been implemented per canton.

Table 2: Corrected values for the percentage of rural homes with publicly provided piped water connection within the home

Canton	Total (%) excluding capital of canton
Guamote	4.0
Colta	6.5
Alausí	14.7
Guano	15.7
Chunchi	16.5
Riobamba	18.9
Pallatanga	20.7
Penipe	22.3
Cumandá	35.9
Chambo	36.4
Average	19.2

Table 3: Number of water systems installed per canton

Canton	no. interventions	Percent of Total
Colta	72	26.4
Riobamba	52	19.0
Guamote	42	15.4
Guano	37	13.6
Alausi	19	7.0
Penipe	19	7.0
Cumanda	11	4.0
Chunchi	9	3.3
Chambo	7	2.6
Pallatanga	5	1.8
Total	273	100.0

(Source: MIDUVI Regional 4 2004)

Another table was constructed, including only the cantons participating in this study, allocating the number of study sites per canton according to the percentage of assistance that they had received.

It was decided that in order to ensure comparability, a minimum of two cases would be studied per canton. As well, in order to ensure geographic distribution such that no single canton dominated the study, a maximum of four cases per canton was established. The number of cases per canton was then adjusted according to these criteria.

The final regional allocation of cases is shown in the Table 5.

Fifteen communities, representing a roughly five percent sample size, have been included in this study. These communities are listed in Table 6:

Table 4: Case allocation according to percentage of assistance received per canton

Canton	no. interventions	Percent of Sample	# of cases
Colta	72	32.4	4.9
Riobamba	52	23.4	3.5
Guamote	42	18.9	2.8
Guano	37	16.7	2.5
Alausi	19	8.6	1.3
Total	222	100.0	15.0

Table 5: Regional Allocation of Case Studies

Canton	# of cases
Colta	4
Riobamba	4
Guamote	3
Guano	2
Alausi	2
Total	15

Table 6: Communities that Participated in Study

Community	Canton	Paroquia
San Javier de Tunshi	Riobamba	Licto
Santa Ana Saquon	Riobamba	Quimiag
San Pablo	Riobamba	San Juan
Santa Ana Guagñag	Riobamba	Licto
Pulcate Cuatro Esquinas	Colta	Columbe
Misquismi	Colta	Cajabamba
San Francisco de la Providencia	Colta	Columbe
Opote San Vicente	Colta	Santiago de Quito
San Miguel Pumachaca	Guamote	Palmira
San Antonio de Chacaza	Guamote	Guamote
San Francisco Billud	Guamote	Palmira
Alacao	Guano	Guano
Muelañag	Guano	Valparaiso
Pachamama Grande	Alausi	Tixan
Curiquinga	Alausi	Tixan

This distribution of communities is shown graphically in the figure below:

Figure 2: Location of research sites: Province of Chimborazo

- Thick lines represent Canton borders
- Thin lines represent Paroquia borders
- Shaded Paroquias contain communities that took part in field research

All communities chosen had received assistance for installing a water supply system for domestic water use between five and twenty years ago.¹⁶ Five years was chosen as the minimum age for the system because it was judged that, if the system were newer than five years, it would be premature to say anything about its sustainability. Twenty years was chosen as the maximum age limit for the water supply system as this is within a typical design life.

Communities were purposely chosen for variance on the dependent variable, sustainability. It was essential that some examples of success and some examples of failure be included in order to be able to contrast differences in order to facilitate drawing conclusions. Ingeniero Jose Rosco, of the MIDUVI regional office, was asked what percentage of systems are operating well, operating poorly, and operating somewhere in between. He responded that roughly 30 percent of systems are operating well, 30 percent very poorly and roughly 40 percent were working “a medias”, meaning somewhere in the middle. Although not done intentionally, the systems selected for study correspond roughly to this classification.

Communities were also chosen for variation in the type of technology used. Five distinct types of appropriate technologies are represented: gravity fed water systems (GFWS), electric pump systems, manual pumps, hydraulic pumps, and a fog water collection system. An attempt was made to collect several examples of each type of technology with variation on the dependent variable, in order to factor in the technology variable as a possible determinant of outcome. In the cases where this was not possible, the sites chosen had more than one intervention with different outcomes, which could permit the analysis of the technology variable in order to ascertain why different technologies were associated with different outcomes within the same community.

¹⁶ Many villages were visited that had no access to an improved water supply system and had never had any. These villages could not be included in the study because it would be impossible to say anything about system sustainability in the absence of a system at some point in time.

In order to control for culture, to the extent possible, all communities included in the field research were indigenous communities. Ecuador has many different types of indigenous groups throughout the country, but all communities included in this study were Quichua.

Some variance over population and size of the community was desirable, as these are factors that may have some impact on the result and that will be analyzed. Nonetheless, it was important to ensure that the context of the research remained consistent in that the focus of the research was on small rural communities. Three hundred houses was chosen as the maximum number of houses that would allow a community to be still considered a community, or villages, as opposed to a small town.

It is estimated that approximately forty rural villages were visited in total and fifteen are included in this study.

2.4 Field Procedures Followed for Locating and Soliciting Participation of Communities

The city of Riobamba is the capital of the province of Chimborazo. The provincial office of MIDUVI, located in Riobamba, provided a list of communities¹⁷ that had received some type of assistance for domestic water supply in the past. I obtained the assistance of a research assistant to help locate and visit the communities.

Communities selected for study in Canton Riobamba were chosen from the list provided by MIDUVI. The municipality of Guamote was asked for recommendations for communities we could visit as part of this study. They provided us the names of three communities. We could not locate one of the communities recommended, and therefore only two of their suggestions were included in the study. The third community that participated in Canton Guamote was selected when passing through various communities on the way to one of the communities suggested by the municipality.

¹⁷ We were told that the list provided contained roughly 80% of all villages that had received some type of water supply system.

Communities in Guano were selected by simply driving around in the region, looking for communities that satisfied our selection criteria and that agreed to participate. Opote San Vicente came recommended from an official with the municipality of Riobamba, and the other two communities in Colta were selected by simply driving around and finding them. Pachamama Grande, in Canton Alausi, was chosen on purpose because there was already literature on the sustainability of the fog water system installed in that community, and including it in the study would allow a comparison of results. The second site in Alausi was chosen for proximity to Pachamama Grande because this region was the most remote region visited in the province.

When entering a community, residents were asked some basic questions to ascertain eligibility for inclusion in the study. The sample selection mechanism used, as outlined above, is known as purposive sampling (Scheyvens and Storey, 2003). If the community met the selection criteria, we asked to speak to the president of the community. We explained to the president of the community who we were and objective of the study and asked for his participation. If the president agreed to participate, he¹⁸ would then call a village meeting on another day, in which we were to return to ask our questions. All communities asked to participate, agreed and did participate in the study.

2.5 Selecting the Research Instrument(s) for Communities

In developing the research design for this study, a major methodological question arose regarding which instrument would be most appropriate for data collection. The two mechanisms under consideration were sample surveys and participatory methods. The discourse surrounding the relative effectiveness of these two methods remains a subject of current debate within the research and academic communities.

¹⁸ All community presidents, with the exception of one, were male.

Survey methods have a long history of widespread use in qualitative research, and have historically dominated the investigation of social science inquiry. They have traditionally been perceived as means of obtaining objective, verifiable and replicable data, which can then yield precise and accurate results (Scheyvens & Story, 2003). One of their principal strengths lies in that they can inform policy by revealing broad patterns if sampling is done appropriately (Scheyvens & Story, 2003). Miles and Huberman (1984) suggest that tighter research design, such as that of survey methods, can also facilitate analysis by reducing data overload, and improve multi-site comparability by applying a common research framework.

Despite the prevalence of surveys as a research tool, or perhaps because of it, several potent criticisms of sample survey methods have emerged. Singer (1988) discusses the most important of these criticisms. She challenges the validity of retrospective surveys, stating that memory errors are large, non-random, and become substantial after a relatively short period of time. Other concerns addressed include; the inability of surveys that use standardized questions to capture the richness of the respondents' experience, and uncertainty with regards to the truthfulness of responses. Perhaps the most problematic issue that she raises concerns meaning, and consequently accuracy. Singer (1998) states:

A fifth objection really consists of a series of related difficulties involving meaning: (a) The distribution of responses to a question may change as a result of apparently non-substantive changes in wording of a questions; (b) response distributions may change if the question is embedded in a different context; (c) some respondents will answer a question even if they have no opinion about it, the limiting case being an opinion about something which does not exist; (d) many of the quantifiers used in opinion surveys – words such as many, large, or often – have been shown to mean different things to different respondents; (e) respondents tend to stay within the frame of reference provided by the survey researcher's response alternatives, so that these alternatives constrain the range of responses observed; (f) some respondents – Belson (1968) maintains at time as many as 80% - fail to understand the meaning of ordinary survey questions. (p. 420)

As a result, there has been a move away from extractive survey questionnaires towards participatory approaches (Chambers, 1994a). Participatory Rural Appraisal (PRA) encompasses a family of methods to allow for learning with and by rural people by facilitating knowledge sharing, reflective analysis, and enabling action (Chambers, 1994a). Several of the underlying principles of PRA include ensuring an active role of local people in learning and analysis, sharing of information, empowerment, removal or offset of biases, learning rapidly and progressively and reduction of the role of the outsider to that of an observer, convener, catalyst or facilitator. (Chambers, 1994b)

The critical question that then arises is whether the validity and reliability of the data collected using participatory methods is at least equivalent or superior to the data of the more costly sample survey. Davis and Whittington (1998) and Christiaensen, Hoddinot and Bergeron (2001) have conducted studies examining the coherence and concurrence of data collected using these two methods. David and Whittingson (1998) compare the two methods by simultaneously using household surveys and community meetings in Lugaszi, Uganda, in an attempt to assess household demand for improved water and sanitation services. Christiaensen et. al. (2001) uses household surveys and the construction of a community maps to examine whether the two methods yield comparable characterization of villages in Northern Mali. Both authors found that there was no significant difference in the results and the corresponding policy recommendations generated by the various methods.

Upon weighing the perspectives contained in the methodological literature, it was decided that this study would employ a hybrid approach consisting of both participatory and sample survey methodologies. Both participatory methods and case study analysis have several difficulties, as outlined above, when used independently. The credibility and validity would thus be improved by using a combined approach

2.6 Research Instrument in the Communities

Following several preliminary site visits, it became apparent that the initial research design needed modification. It quickly became apparent that there would be significant opportunity costs associated with individual interviews. If sample surveys were to be conducted, it would substantially decrease the number of cases that could be included in the study as there were often large agricultural lands separating dwellings and only a small fraction of the community was present at any particular moment in time due to migration. The proposed methodology would therefore have required many repeated visits, which was impossible due to the inaccessibility of most sites. As the redundancy that had been built into the research design would yield only marginal benefits but have major costs in terms of scope of possible coverage for the study, it was decided to forgo the sample survey component of the methodology.

We returned to each village on the date and time that was agreed upon with the president. Village meetings are typical and traditional in the region. All issues affecting the community are discussed collectively and all decisions are made collectively at such meetings. One member of each household is required to attend these sessions, and role-call is taken. Most of our sessions followed this model. In a handful of cases, the sessions were announced as an additional optional session that people could attend if they so chose. The smallest session that took place had 20 participants present, and the largest involved 90.

All sessions included a mix of both men and women present. Sometimes adolescents attended the meetings as representatives of their households. The sessions always began with the president calling the meeting to order and introducing us. We then introduced ourselves and explained the purpose of the study. Participants were then asked to for their consent for their participation and to be recorded. The sessions took the form of semi-structured discussions. We began by establishing basic facts about

the community and the nature of the system they had received. We then asked open-ended questions regarding how the system was operating, how it was managed, how repair and maintenance were handled, and other questions.

A comprehensive list of survey questions had been developed prior to undertaking the field research, and modified as needed in the field. These questions are included in Appendix 5. Discussions with villagers were semi-structured and free flowing. The survey questions served as a guide, and were used as a checklist towards the end of the session to ensure that all questions had been addressed in the course of discussion.

2.7 Research Barriers Encountered

Prior to my departure for Ecuador, several non-governmental organizations (NGOs) were contacted to solicit their help in locating and entering communities in which their organizations had provided assistance in the sector in the past. All NGOs were helpful and offered assistance but all insisted that I should go visit current projects. I tried to explain that since I was studying sustainability, that it was important that the system had been installed at least five years ago, and that there be no current NGO involvement in the community. No NGO encouraged a visit to a previous project site and some very strongly discouraged it. This finding was unexpected and surprising. Upon further consideration, it is believed that NGOs were hesitant to provide information on sites that had not succeeded as it was clearly not in their interests to do so because they often rely on funding to carry out their work and need to show that they are doing good and successful work in order to attain this funding. For this reason, the names of the NGOs that assisted the communities visited will be omitted from this document.

Early in the period in which the field research was being conducted, an outbreak of the Bubonic Plague occurred in canton Guamote. The canton was placed under an official quarantine and movement in and out of the canton was restricted. We refrained from entering the canton until the occurrence of a public announcement that the outbreak had been brought under control. Despite the public announcement, there remained uncertainty and concern about the region, and so we consulted with the municipality and followed their suggestions for communities to include that were considered to be in safe regions.

2.8 Data Analysis: Classification of Sustainability

In order to undertake the analysis described above, systems must be first classified in terms of their sustainability. In chapter one, a definition for the sustainability of a domestic water supply system was developed. The definition required that systems continuously provide an adequate quantity of water for an indefinite period of time, and that they are able to adapt to the demands of population growth and migration. An acceptable level of service was to be considered as one that is enjoyed by all community households and that meets the minimum daily BWR of 50 liters per capita and the minimum drinking water quality standard specified by the World Health Organization (WHO).

If this definition were strictly adhered to, none of the systems included in this study would be classified as sustainable. As a result, systems were not assessed on the basis of this holistic definition. Since each community was visited only once, we can only speak of the sustainability of any system up until the time of our visit and no projection is possible or attempted on future sustainability of the systems. In addition, water yield or consumption was not measured and no conclusion can therefore be drawn with respect to whether beneficiaries were either receiving or consuming the minimum

suggested 50 liters per capita per day. Community members were simply asked if the water that they receive from the system is sufficient to satisfy their daily needs and this provided part of the basis for the determination of system performance. Similarly, community members were asked about water quality, although no physical tests were conducted to empirically assess the quality.

An operational definition, based on field observations, was developed for sustainability. All systems were classified as abandoned, marginally sustainable or sustainable. The criteria for each of these three classifications are outlined in Table 7 below:

Table 7: Definition of Unsustainable, Marginally Sustainable, and Sustainable Water Supply Systems for classification of results from this study

	Abandoned	Marginally Sustainable	Sustainable
Use	None	Yes	Yes
Quality	N/A	Low	Adequate
Quantity of Water	N/A	Sufficient	Sufficient
Frequency of Water	None	Irregular	Regular
Max period inoper	Indefinite	Long periods time	One week
Coverage	N/A	<ul style="list-style-type: none"> • Infrastructure did not expand with population growth • Many communities choose not to use system • Insufficient quantity of water • Irregular or infrequent water yield 	majority ¹⁹
Reliance on System	None	Partial	Full

As shown in the table above, a system was classified as abandoned if it is no longer in use. A marginally sustainable system was considered to be one in which water came in insufficient quantities, irregularly, infrequently, infrastructure had failed to expand with population growth, or was of poor quality. Finally a sustainable system was

¹⁹ The actual extent of coverage of water supply could not be assessed as all information was derived from community meetings. The “majority” criterion was therefore satisfied if the community indicated that most households had access and used the improved source.

considered to be one that was used in the way in which it was intended, provided sufficient water of adequate quality, was consistently repaired, and was never non-operational for a period in excess of one week. It is important to note that both abandoned and marginally sustainable systems were considered to be failures, in the present study, since neither provided an acceptable level of service. This differentiation was made simply to distinguish between those systems that were no longer in use and those that continued to operate to some extent. In this research, only sustainable systems were considered as successes.

2.9 Limits on Methodology and Integrity of Data

Since all information was obtained through group sessions, all answers were received as a group voice. As a result, it was impossible to assess power and class distinctions that may have been present in the community. In addition, since men and women were questioned together, it was impossible to obtain information on the affect of gender and sustainability of the system.

All interviews and groups sessions were conducted in Spanish, which is my second language. The first language in all villages visited was Quichua and as a result, they too were speaking in their second language. Since both parties were functioning in their second language, it is plausible that the sense or some of the meaning of the questions and responses was lost.

One potentially more serious factor that may have skewed responses may have been the hope of aid. When we entered communities, and explained the purpose of the study, we explained that the study was being conducted for a thesis as a requirement for the university. Participants were told that the study was for the purpose of advancing knowledge so that similar projects in the future might be able to take into account the problems encountered in these communities and hopefully prove more sustainable than

many of the projects that came before them. Nonetheless, it was still clear that in some cases the hope of aid or funding for improving their system remained. The hope of intervention could skew the answers such that responses reflected more serious problems than existed in actuality. Since there is no way to gauge the extent to which responses accurately reflected the views of the participants, it will be assumed that these responses generally represent their actual thoughts, for the purposes of analysis in this study.

The analysis of sustainability conducted throughout this thesis is done at either the system or individual community level. Several examples are included of multiple communities sharing a water source and some infrastructure. The classification of sustainability used throughout this thesis does not take into consideration the sustainability of other communities that may be serviced by the same source or of other communities that may be included within a watershed.

In addition, this thesis uses hypotheses from the existing literature as part of the bases of analysis. While an attempt was made to highlight the linkages between factors, much of the analysis remains somewhat siloed, which reflects the fragmented nature of the current literature. More systematic research should be conducted in order to explore the interlinkages and relationships among factors.

2.10 Conclusion

Fifteen communities were visited in the province of Chimborzao, Ecuador in order to collect data to examine the research question posed in chapter one. Purposive sampling was used to select villages. Communities were selected that had water supply systems between five and twenty years of age, and that had no ongoing assistance from the donor organization. A framework was outlined for the classification of results of sustainability. This system will be used for analysis throughout the thesis. Several

barriers to research were discussed, including the eruption of Volcan Tungurahua. The data quality and was also discussed.

Chapter 3: Appropriate Technology and Sustainability

"It's not hi-tech or low tech but right tech."

Cowen Coventry, ITDG 2003

3.1 Overview of Chapter

This chapter will review the literature to develop an understanding of the nature and role of appropriate technology. The chapter will then establish evaluation criteria for small-scale rural technologies and apply these criteria to the technologies under consideration to assess their suitability, with evidence from the field cases researched for this study.

3.2 What is Appropriate Technology?

For technology used in development interventions, technical sustainability is typically assessed in terms of its technological appropriateness. The underlying assumption is that if the technology implemented is not appropriate for local conditions, its use will not be sustained. The term 'appropriate technology' emerged from the concept of intermediate technology.

Schumacher coined the term intermediate technology, which he defined to be technology that would greatly improve productivity over indigenous technology but that would be substantially cheaper than modern industrial technology (Schumacher, 1973). He further elaborated on the concept by stipulating that the equipment should be simple and therefore understandable, affordable, allow for immediate maintenance and repair, conducive to decentralization, not heavily dependent on scarce resources, and relatively adaptable to market fluctuations. Schumacher believed that technology with these characteristics would facilitate training and simplify supervision, as well as control and organization (Schumacher, 1973). Jéquier and Blanc (1983) explain that the concept of

intermediate technology is a relative one, since a traditional technology in one region may be considered an intermediate one in another (Jéquier and Blanc, 1983).

In practice, the terms intermediate technology and appropriate technology are often used interchangeably. Singer (1985, p.27) explains that the term 'intermediate technology' may be misinterpreted as a "technology, which is intermediate in efficiency between the low efficiency of present traditional technology and high efficiency of modern technology". However, for Singer (1985), intermediate technology is, in fact, the most efficient for the circumstances in which they are applied. Consequently, he explains that it is preferable to speak of appropriate technology rather than intermediate technology.

3.3 Criteria for Evaluation of Appropriate Technology

A technology may be considered appropriate if it is appropriate in terms of its performance, simplicity, and cost (Cairncross & Feachem, 1993; Shaw & Smout, 1999; Wicklein, 1998). A technology that is appropriate in terms of performance must be able to do the job required (Cairncross & Feachem, 1993). For water supply systems, this means that the technology chosen must be able to reliably provide sufficient water on a continuous basis. In addition, the technology should not introduce any additional health concerns that would not otherwise be present in the absence of the technology use.

A technology must also be appropriate in terms of simplicity, to allow the local population to carry out regular operation and maintenance activities (Cairncross & Feachem, 1993). Finally, a technology must be appropriate in terms of costs so that it is affordable in the context in which it is applied (Cairncross & Feachem, 1993).

All communities researched for this study received one of five distinct types of systems, all of which are typically considered as appropriate technologies for rural water supply. These are: gravity-fed water systems (GFWSs), electric pumps, hydraulic pumps,

manual pumps, and fogwater catchment systems. All of these will be evaluated in terms of the three criteria, performance, simplicity, and cost, with evidence from the field. Twenty water supply systems were included in the study, as several communities were recipients of more than one intervention and had thus received multiple technologies. Each technology will be considered individually to ascertain its appropriateness.

3.4 Evaluation of Field Technologies

The following sections will examine the appropriateness of each of the five technologies included in the case studies for the present study:

3.4.1 Gravity Fed Water Supply System

A gravity fed water supply (GFWS) system transports water from high ground to low ground using the force of gravity (USAID, 1982c). Consequently, the water source must always be located at higher elevation for the system to work. The water that can be delivered through use of a GFWS is a function of water head²⁰, pipe diameter, length, and material, and the water flow-rate in the pipe (USAID, 1982c). Relevant literature depicts GFWSs as efficiently and reliably able to provide adequate quantities of water, sufficiently simple such that they can be understood, operated, maintained and repaired using local skills and labor, and affordable over the lifetime of their use.

GFWSs may be installed with or without a distribution system. When the system is installed without a distribution system, water may be piped directly to a standpipe or it may be first diverted to a storage tank and before being piped to the standpipe. Similarly, water can be distributed directly from the source to the users through a GFWS or it may be first diverted to a storage tank before it is distributed.

²⁰ Water head is equal to the height of water above any point being considered in the system (USAID 1982d).

GFWSs are the preferred method of water delivery when conditions are suitable, and should be used whenever feasible (USAID, 1982b). They are very efficient and require no additional energy to operate. The amount of water that they are capable of delivering largely depends on the source. Assuming that the source contains an adequate supply of water, GFWS are able to meet performance requirements, meaning that they are able to reliably and consistently deliver sufficient quantities of water.

GFWSs are very simple and easy to understand. They can be constructed using local materials and local labor. In addition, the system does not require any mechanized parts, which significantly reduces the likelihood of failure, and/or the need for specialized skills for repair (USAID, 1982c). GFWSs do require periodic maintenance, which primarily consists of checking for cracks and leaks in the pipeline, clearing the pipeline of sediment and blockages, and clearing vegetation from around the pipelines. This routine maintenance may also be carried out using local skills and labor.

Operation and maintenance costs of GFWSs are negligible in monetary terms. Maintenance activities do require time; however, these activities must be done only relatively infrequently²¹, and can be carried out with few people. As a result, maintenance activities can be performed on a rotating basis among members of the community, thus reducing the time burden on any particular individual. Initial capital cost for piping is relatively expensive compared with other methods of supplying water. However, the durability tends to be greater. Repair expenses can also be relatively costly, but since repairs for this type of system would have to be performed less frequently than repairs on other types of system, an effective water tariff system should be easily able to cover these costs.

GFWS were the most common type of technology found in the region. Ten examples of this technology were included in our sample. The results for sustainability

²¹ This activity can adequately be done monthly.

varied considerably for GFWSs. These have been classified according to the procedure outlined in chapter two and are summarized in Table 8 below.

Table 8: Results: Sustainability Classification for GFWSs

<i>Community</i>	<i>Canton</i>	<i>Type of Systems</i>	<i>Sustainability</i>
San Javier de Tunshi	Riobamba	GFWS	Sustainable
Santa Ana Saquon	Riobamba	GFWS	Abandoned
San Pablo	Riobamba	GFWS	Sustainable
Santa Ana Guagñag	Riobamba	GFWS	Sustainable
Pulcate Cuatro Esquinas	Colta	GFWS	Marginally Sustainable
Opote San Vicente	Cola	GFWS	Abandoned
Alacao	Guano	GFWS	Marginally Sustainable
Muelañag	Guano	GFWS	Marginally Sustainable
San Miguel Pumachaca	Guamote	GFWS	Marginally Sustainable
San Antonio de Chacaza	Guamote	GFWS	Marginally Sustainable

All GFWSs assessed in the communities operated in a similar manner, and the technology variable can thus be considered constant amongst these cases. Since there was large variance on sustainability despite the use of a similar technology, we may conclude that technology was not a determinant of sustainability for GFWSs. In addition, since there are examples of sustained GFWSs, we can conclude that GFWSs were a suitable technology for the context in which they were applied. This was confirmed by comments made by the community Santa Ana Guanag. When asked what the most significant problem that they have had with their water supply, the community responded:

Mayor problema hasta hoy, hasta que llego el agua hace diez anos? No hay problema. No hemos tenido ningún problema. Hemos estado tranquilos con el agua. (Santa Ana Guanag, interview)

[The biggest problem until now, since the water has come ten years ago? There isn't a problem. We haven't had any problems. We have been satisfied with the water.]

The community was then asked what their greatest need is. They responded:

Hablando en eso. Alcantarillo o agua de riego. (Santa Ana Guanag, interview)
[Speaking of this. Sewer systems and water for irrigation.]

We will see in later chapters that cases of unsustainable GFWSs are explained by other factors that are external to the factors that determine the appropriateness of a technology.

3.4.2 Hand Pump Systems

A hand pump is a type of positive displacement pump. Positive displacement pumps (PDPs) are so named because they displace a volume of water that is equal to the distance that the piston, which it contains, travels (Pickford, 1991; USAID, 1982e). PDPs may be driven by a variety of power sources. Hand pumps specifically refer to PDPs that are driven by human generated power. The amount of water that can be produced is a function of the lift force (suction), diameter of the piston, length the piston travels, and the frequency of the piston (Pickford, 1991; USAID, 1982e).

Hand pumps produce relatively low levels of water at or near the source (USAID, 1982e). Nonetheless, they are able to reliably produce adequate quantities of water for all users for domestic purposes whenever needed. In addition, they are not affected by population growth, assuming that the groundwater source contains adequate water to support this growth.

Hand pump operation is extremely simple and can be carried out by anyone in a village. The system requires routine maintenance, such as lubrication of parts, painting of exposed iron (to prevent rusting), tightening of bolts and pins, and checking valves and for cracks in concrete (Pickford, 1991; USAID, 1982e). This routine maintenance can be taught during the project implementation. It is simple, does not require any special skills, and can be carried out by local people.

Initial capital costs, as well as operation and maintenance and repair costs, are very low in monetary terms (USAID, 1982b). In addition, groundwater is often of good quality and does not usually require further treatment, thus avoiding the costs associated with it. However, hauling is the least efficient method of extracting water and has hidden costs coupled with it. It is labor intensive and physically demanding, and may consume many hours of work (USAID, 1982b), especially for women (Palmer-Jones & Jackson, 1997).

Despite this, hand pumps are capable of reliably and consistently providing adequate water. The design is also simple and operation, maintenance and repairs can be carried out using local materials, skills and labor. Initial capital costs as well as ongoing costs are low. As a result, the technology continues to be considered appropriate according to the literature.

Three examples of hand pump systems were included in this study. The sustainability of these systems was classified, as shown in Table 9 below.

Table 9: Results: Sustainability Classification for Manual Pumps

<i>Community</i>	<i>Canton</i>	<i>Type of Systems</i>	<i>Sustainability</i>
Misquismi	Colta	Manual Pump	Sustainable
Opote San Vicente	Colta	Manual Pump	Sustainable (mixed)
San Francisco de la Providencia	Colta	Manual Pump	Sustainable

The communities of Misquismi and San Francisco de la Providencia reported that the systems installed in their communities were still working well and providing adequate quantities of water. The community of Opote San Vicente, reported that four of the seven manual pump systems continue to function well while the other three had been abandoned.²² As was expected, members of these communities also reported that the quality of the water has not changed since the initial installation of the system. As a

²² The sustainability of the systems in Opote San Vicente are classified as mixed because while some continue to work adequately, others have been abandoned.

result, it may be concluded that hand pumps appear to be an appropriate and sustainable technology in the case study region.

However, despite this finding, hand pump use was not found to be fully sustainable. In both San Francisco de la Providencia and Opote San Vicente, some members chose not to use the improved sources and continued to use traditional source. The distance to the source was the most significant determinant of usage. The time for the return trip to the water source and for water collection may be considered as part of the opportunity cost of system use.

Beneficiaries indicated that access to and the use of clean water was a priority for them. Nonetheless, it was clear from the field research that when the opportunity cost was perceived to exceed the expected benefits, beneficiaries discontinued use of the system. Opportunity cost is a direct function of water collection time, and consequently distance to source. If the distance to the improved source was significantly greater than the distance to a traditional source²³, users tended to continue to use the traditional source. The question then arises as to what constitutes a 'significantly greater distance.' This will clearly be function of the value users place on the quality of their water for domestic use. The field research for the present study was not able to explain this issue further; it is an important area for further investigation.

3.4.3 Electric Pump with Distribution System

Most pump systems can be powered by electric motors, including PDPs, which can also be operated manually. Electricity enables the movement of large volumes of water and is considered to be most efficient and flexible means of moving and producing water. Electric motors are available for a large range of power outputs, and thus allow water to be extracted from greater depths (USAID, 1982a). The capital costs of electric

²³ The term 'traditional source' is used to mean a water source that either occurs in nature (such as an unprotected spring, river, lake, pond) or an unprotected human constructed water source (such as an open well).

motors are highly variable and can range from very low to very high. Operation and maintenance costs are typically considered to be low (USAID, 1982a). The systems are characterized as simple, and have long useful lives. If electricity is already present and is already used for other purposes, the use of the pump should be associated with very little additional cost (USAID, 1982a).

Five of the communities visited had received an electric pump system. The sustainability of these systems is shown in Table 10 below.

Table 10: Results: Sustainability Classification for Electric Pumps

<i>Community</i>	<i>Canton</i>	<i>Type of Systems</i>	<i>Sustainability</i>
Pulcate Cuatro Esquinas	Colta	Electric Pump	Marginally Sustainable
Misquismi	Colta	Electric Pump	Abandoned
Pachamama Grande	Alausi	Electric Pump	Marginally Sustainable
Curiquinga	Alausi	Electric Pump	Marginally Sustainable
San Francisco de la Providencia	Colta	Electric Pump	Abandoned

As the table shows, all examples of electric pumps assessed in this study have been classified as failures. Of the five electric systems, three had been rated to be marginally sustainable, while the other two had been completely abandoned. In all communities, the electricity bill would have to be paid at the end of the month and if the community was unable to pay, the electricity would be cut and they would be left without water. All communities indicated that the electricity bill was very high and would often change unpredictably, despite relatively constant electricity demand from month to month.²⁴ Communities with this type of system would wait for the electricity bill and then divide the cost of the bill equally amongst all households in the village, regardless of water consumption. Since communities were barely able to pay the cost of electricity, they were not able to contribute any additional funds beyond this amount.

²⁴ There is only one Electricity Company in Ecuador and it is state owned.

Consequently, these communities never acquired any reserve funds that could be used to finance system maintenance and repairs.

Maintenance was therefore rarely carried out, and when repair was necessary, a community collection would be taken up. Communities indicated that they were unable to meet the costs of the electricity bill on a regular basis and would therefore have to go long periods of time without water until they were able to raise sufficient funds. These systems were classified as marginally sustainable because they performed to an adequate standard when operational, but they also could be out of operation for periods of up to four months. Since there are no examples of success in this group, and since the complaints with respect to the technology remained consistent across all of the villages, electric pumps were assessed to be an inappropriate technology within the context of the study region.

The community of Misquimi provides evidence of the inappropriateness of this technology. This community has, sequentially, received three distinct water supply systems for domestic water use. The community had received a system of manual pumps prior to the electric pump system and a hydraulic pump system later. Both the manual pump and hydraulic pump systems were used at the time of the site visit and had been sustained by the community. The system of manual pumps was sustained until the community received a superior system; namely the electric pump system. The electric pump system was superior because it was coupled with a distribution system and thus delivered water directly to the homes. This resulted in increased water use, reduced probability of contamination and time-savings over the manual pump system. The community managed to marginally sustain the use of the electric pump system for two years before they abandoned it.

When asked about why they had abandoned the system, the community replied “gastamos mucho consumo del luz y no podíamos cancelar ya. Es que es muy caro.”

(We used a lot of electricity and we couldn't pay anymore. It is very expensive.) The community was then asked if they continued to use the electric system until they received the hydraulic one. A representative replied:

No, paro a funcionar, creo. Por el tiempo que venga, ya paro. Es que no alcanzamos ya. Ya no funcionaba. Ya no funcionaba por el exceso de la luz. O sea por el pago. (Misquimi)
 [No, it stopped working, I believe. By the time we got, it had stopped. It's that we couldn't support it anymore. It already didn't work. It stopped working because of the excessive electricity. Or in other words, because of the cost.]

3.4.4 Hydraulic Ram Pump with Distribution System

A hydraulic ram pump uses the force of falling water to pump water to higher elevation (USAID, 1982d). Water is directed through a pipe, known as the drive pipe, from the source to a ram, which is located at the lowest point in the circuit. A drive force is created within the ram by compressing air and this pushes a fraction of the water, through the delivery pipe, to a higher elevation than the initial source. This type of system requires a high flow rate of at least 12 liters per minute, and a minimum fall of 50cm (USAID, 1982d). The pumped water is usually collected in a storage tank and then fed to the distribution system.

The use of this system requires an abundant water source. The system will function well if the source can provide at least seven times more water than the ram must pump (USAID, 1982d). When these conditions exist, a hydraulic ram system is the technology of choice, as it requires no external power source and can reliably pump water around the clock.

The hydraulic ram system is a simple design. It may be operated, maintained and repaired using local skills and labor. It requires very little maintenance and these activities should therefore not consume much time. The regular maintenance simply consists of keeping the drive pipe clear of trash, sand, and other sediments. If these materials enter the pump, this may cause a blockage and impede the function of the

system. In this case, the pump would have to be cleared. The pump should therefore be cleared periodically as preventative maintenance. Other maintenance activities would be those normally associated with pipelines; namely, clearing vegetation, and detecting and repairing cracks and leaks. Hydraulic ram systems only contain two moving parts, thus reducing its complexity. This minimizes fatigue and reduces the frequency of repair and the likelihood of failure. According to the USAID, these systems are capable of providing years of trouble free service (USAID, 1982d).

Hydraulic ram systems are extremely cost effective. There are no operating costs associated with the system, and the initial capital cost and ongoing maintenance and repair costs are also low.

Only two examples of hydraulic pumps were found within the communities included in this study. The sustainability of the hydraulic pump systems were classified as shown in Table 11.

Table 11: Results: Sustainability Classification for Hydraulic Pumps

<i>Community</i>	<i>Canton</i>	<i>Type of Systems</i>	<i>Sustainability</i>
Misquismi	Colta	Hydraulic Pump	Sustainable
San Francisco Billud	Guamote	Hydraulic Pump	Abandoned

The community of Misquismi was very happy with their system. They claimed that it reliably provided a sufficient quantity of water consistently. Their response also indicated that the system was easy to understand and that they were able to repair it using local labor and knowledge.

In contrast, the community of San Francisco Billud had completely abandoned its system. When asked about the performance of the system while it was operational, community members replied that it had worked well and reliably. Since both systems seemed to work well while in operation, the question then becomes: What differences

existed in the operation, maintenance, and repair of the system between the two communities?

The first major difference became evident when the communities were asked about system repair. The excerpt below quotes the community of San Francisco Billud, when asked about the repair of its system:

Q: ¿Cómo lo arreglaron?
(How did you repair the system?)

Q: Fuimos a comprar los repuestos en Riobamba.
(We went to buy the parts in Riobamba.)

Q: Encontraban todos los repuestos ahí?
Did you find all the parts there?

A: No. No, no, no. Los empaques, no sabíamos a encontrar. Eran mandado. Eran de Bélgica. Hicimos a pedir a través del ingeniero.
(No. The washers, we didn't know where to find them. They needed to be sent. They were from Belgium. We had to ask for them through the engineer.)

Q: Entonces ustedes tuvieron que ordenar para tener el empaque?
(So you had to order the washer?)

A: Sí. Eso sí. Y eso demoraba porque tenia que llegar de Bélgica. Y por eso quedamos sin agua.
(Yes. This yes. And this took some time because it had to arrive from Belgium. Because of this we were left without water.)

Q: Y este ingeniero, ustedes todavía estan en contacto con él?
(And this engineer. Are you still in contact with him?)

A: Ahora? Actualmente ya no. Nos dejaron.
(Now? Actually not anymore. They left us.)

(San Francisco Billud)

We can see from the above passage that the community of San Francisco Billud was dependent on external help to acquire the parts necessary to repair the pump. When asked about repair, the community of Misquimi also indicated that the washer wore out periodically and needed to be replaced. They too indicated that they needed to order the replacement part from Belgium through the project engineer. However, when asked if they are still in contact with the project engineer, the community of Misquimi replied

that, in fact, they were. The longer-term sustainability of the system in Misquimi thus becomes somewhat questionable.

A system cannot be considered sustainable if the community must remain fully dependent on a single person or on a particular organization, whose presence is transient or unstable, for ongoing assistance. If a community is reliant on a person or particular organization to obtain parts, they must know, at a minimum, how to obtain these parts in the absence of that person or organization. Failing this condition would mean that if the person or organization left the region, the community would not know where to obtain parts and their system would eventually fail and be left un-repairable. As a result, this situation cannot be considered sustainable, or, consequently, appropriate.

A second important difference between the two communities was the frequency that repairs were necessary. In Misquimi, the washer only needed replacing approximately every two years, whereas in San Francisco Billud it needed replacing every three to four months. This meant that the operation costs for San Francisco Billud were much higher than for Misquimi. It is unclear why the washers wore down so much faster in San Francisco Billud than in Misquimi. Nonetheless, this raises further questions regarding the suitability of the technology.

3.4.5 Fogwater Catchment System

As the name suggests, fogwater catchment systems use large mesh catchment systems to harvest water from fog (Alejandro, 1998). Fogwater catchment systems operate by using a large vertical mesh to trap fogwater droplets as they collide with the net. These systems are enabled by the presence of wind which carries fog towards the collecting mesh (Schemenauer & Cereceda, 1994b). Water droplets collected by impaction fall into a trough at the bottom of the net. From there, the water is directed by gravity through a pipe to a collection system (Schemenauer & Cereceda, 1992). The

amount of liquid water collected from a fog catchment system is dependent upon the efficiency of the collector, the surface area of the collector, and the wind speed (Schemenauer & Cereceda, 1994a). Mountainous regions with moderate wind speeds are often selected as potential sites for fogwater collection systems (Schemenauer & Cereceda, 1994b).

The expansion of fogwater catchment systems to a variety of locations is considered to hold great potential for supplying arid and semi-arid regions with water. Before such systems can be implemented, a lengthy study of the meteorological conditions and topography of the site must take place (Schemenauer & Cereceda, 1992). The location, size and orientation of the fog collection system will be based on this preliminary work in order to maximize water output (IDRC, 1993).

Although its use remains comparatively rare for rural domestic water supply, it has generally become recognized as an appropriate technology and its use continues to expand. Water quality from the incoming fog and fog collectors can be expected to be of good quality (Schemenauer & Cereceda, 1992a; IDRC, 1993). The initial capital costs, ongoing operation and maintenance costs, as well as repair costs for fogwater projects have also found to be low, and local materials and labor could be used for construction. (Schemenauer and Cereceda, 1994a).

Only one community that was visited, Pachamama Grande, had received a fogwater catchment system. The sustainability classification for the system is shown in Table 12 below.

Table 12: Results: Sustainability Classification for Fogwater Catchment System

<i>Community</i>	<i>Canton</i>	<i>Type of Systems</i>	<i>Sustainability</i>
Pachamama Grande	Alausi	Fogwater	Abandoned

The fogwater catchment system at Pachamama Grande has been completely abandoned. In the absence of other study sites with the same technology, no firm

conclusions on the appropriateness of the technology can be drawn. Nonetheless, the information obtained from the community provides strong evidence that the system was unsuitable in practice and did not meet the needs of the community. The information also provided strong evidence that it was this unsuitability that led to the system abandonment.

When questioned about the technology and system performance, the community made the following remarks:

Dos años aguantó no mas esa maya. Vuelta ya después con mucho viento no aguantaba todito, se rompió. Rompió efectivamente por el mes de agosto. Hace dos años estaba bien captando, y si utilizamos. Eso funcionó solo en el invierno (Pachamama Grande).

[The mesh lasted for only two years. After that, it fell over and ripped completely. It ripped in the month of August. It captured water for two years and we did use it during that time. It only worked in the winter.]

En el verano, casi nada ya. No juntaba agua ya. Además, se destruyeron. En el verano, con el viento, se derrotan (Pachamama Grande).

[In the summer, we got almost nothing. It didn't collect water anymore. Even more than that, it was destroyed. In the summer, with the wind, it ripped.]

The community was further asked to specify the months in which they received water from the system. Their response was as follows:

Enero, febrero, marzo, abril. Hasta Mayo no más. Diciembre también hay neblina acá, pero no mucho. Desde mitad de diciembre hasta mayo. Habremos tenido agua aquí seis meses. Pero no avanzaba bastante. Tampoco había bastante agua durante ese tiempo (Pachamama Grande).

[January, February, March, April. Not longer than May. In December there is also fog, but not much. From the middle of December until May then. We had water for roughly six months. But even then, it didn't advance enough. There wasn't enough water during that time either.]

From these statements, it is evident that the technology was inadequate in terms of performance. The environmental conditions of the site only permitted the system to function for roughly half of any given year due to an absence of fog during the remainder of the year. In addition, the system failed to provide an adequate water supply to meet all domestic water needs even during the months when it was working at its peak. As a result, daily trips to collect water from the river remained necessary.

In addition, since fogwater only accounted for a fraction of the human water requirement, the overall quality of water consumed did not improve and thus the incidence of water-related diseases remained unchanged. It may therefore be concluded that the system was largely ineffective, as it failed to reduce the number of trips or time allocated to water collection, lower the incidence of disease, or decrease the incidence or frequency of diarrhea.

Furthermore, use of the system resulted in a significant additional cost to the community. The strong annual winds that occur between August and October cause substantial damage, and leave the system in need of major repairs on an annual basis. Repair of the system demands monetary as well as non-monetary costs (such as time, labor, and local materials). In addition, fogwater harvesting systems require several operation and maintenance activities that are crucial for the technical sustainability of fogwater catchment systems (Mukerji et. al., 1993). These activities include: daily inspection and tightening of cables and fasteners, regular clearing of pipes, periodic repair of rips in the mesh, mesh cleaning²⁵, and periodic cleaning of the storage tank²⁶. The regular maintenance and repair of the system that is required to ensure technical sustainability is very costly, particularly in terms of the time commitment requirement. Since the system does not yield any appreciable benefits from its use, but yields notable costs, the cost-benefit calculus faced by rational decision-makers would produce incentives to neglect the system-- which is what was seen in practice.

A previous study was conducted on the sustainability of the fogwater catchment system at Pachamama Grande. The study also found that strong winds during the dry season ripped the mesh and it was never repaired. Henderson and Falk (2001) appear to

²⁵ Long-term use of the mesh can result in an accumulation of dust on the mesh and can cause algae growth

²⁶ Tanks must be cleaned periodically with a concentrated calcium chloride solution to prevent the accumulation of fungi and bacteria on the storage tank walls.

attribute the lack of maintenance and repair of the system to apathy of community members and their inability to carry out these activities. Henderson and Falk (2001, p.283) state: “Maintaining the system and its components was beyond their [the villagers] ability and cultural norms.”

The study assumes that the fogwater catchment was able to capture an adequate amount of water. It describes the number of fog collectors that were installed and volume of the storage tank that was constructed. However, the paper fails to state how many liters per capita per day were actually captured. As previously described, villagers detailed the gross inadequacy of the system during the community meeting. Based on their account, their decision to abandon their system seemed fully rational. This finding highlights the importance of collaborating with the villagers throughout the process to understand their point of view. Ultimately, it is their perceptions that will inform their actions and result in the sustainability or non-sustainability of the system.

3.5 Conclusion

All communities included in this study had received at least one of five main types of water supply technologies: gravity fed water systems, hand pumps, electric pumps, hydraulic ram pumps, or fogwater catchment systems. In total, 20 systems had been received among the 15 communities. All of these systems are considered to be appropriate technologies for rural water supply, according to the literature. Field evidence showed that GFWSs and hand pumps were clearly suitable technologies for the region under study. In contrast, the inappropriateness of the electric pump and fogwater catchment systems for the local context of the study region clearly attributed to the non-sustainability of these systems. As a result, communities that had received electric or fogwater systems will be excluded from the remaining analyses in this thesis. The hydraulic ram pump was deemed to be an inappropriate technology due to the lack of

availability of local replacement parts. Nonetheless, the inappropriateness of this technology had not yet caused failure in the community of Misquimi. As a result, this community will continue to be included in subsequent analyses.

Chapter 4.0 Demand Responsive Supply:

"In a world of seemingly unlimited demands and limited resources, DRA²⁷ provides critical tools for assessing local demands and allowing communities to engage in a 'self-selection' process."

WEDC 2005 p.2

4.1 Overview of Chapter

This chapter will begin by outlining the historical move towards the demand responsive supply (DRS) approach by the World Bank and many other donor agencies. It will continue to examine the components of the DRS approach in some detail. These components will then be analyzed in relation to the data collected during field research in order to draw conclusions.

4.2 The Move Towards Demand-Driven Rural Water Supply

Many development interventions are reliant on foreign technology to meet their objectives. Development interventions have traditionally been implemented using a top-down or social engineering approach (Gass, Biggs & Kelly, 1995). In this model, governments or donor agencies identify which communities should receive water aid (OED, 2000a & 2000b). The installations offered by these programmes were provided in the name of public health and were considered as a free public good (Black 1998, p.14). The top-down approach conceptualizes decisions as a choice between a clearly defined set of alternative techniques (Pahl-Wostl, 2002). The issue of sustainability thus became one of choosing the 'right' technology (Gass & Biggs, 1993). The main elements of this approach are summarized in Table 13.

The "choice of technique" approach has tended to dominate the design and implementation of development interventions that rely on technology. The dominance of this approach is largely due to historical perceptions of technology. Technology has typically been viewed as a passive component in the formulation of economic and social

²⁷ DRA = Demand responsive approach.

policy. It has generally been considered to exist outside or at the margins of society, particularly in developing countries (Gass & Biggs, 1993).

By the late 1980s, it had become apparent that the top-down approach was, for the most part, not yielding sustainable results. Many of the water systems installed under this approach fell into disrepair and were subsequently abandoned (Black, 1998). This caused a significant shift in the approach advocated by the World Bank, and taken by many governments and other donors. A general consensus emerged that the failure of many projects could be explained by the lack of involvement of local people (Black, 1998). As Black (1998, p.31) states:

The top-down, hierarchical structure of many governments was inhibiting the engagement of communities in activities intended for their benefit and thus seriously compromising their results. Until project beneficiaries became full-fledged consumers, services of any kind were unsustainable.

In an effort to improve sustainability of outcomes, the top-down approach was modified to take on a more participatory orientation, which became known as the community-based approach (OED, 2000a & 2000b). The principal elements of this approach are also summarized in Table 13.

The World Bank (OED, 2000b) study “Rural Water Projects: Lessons from OED Evaluations” found that the participatory elements of the community-based approaches were difficult to incorporate into large-scale service extension programmes. It concluded that a fundamental shift, from centralized ownership of systems to local ownership and control, was required. Black (1988) explains that in order for this to occur, approaches would have to cease to be supply-driven, and instead become demand-driven. By the 1990s, it became apparent to many donor organizations that success or failure of water supply systems was largely determined by demand. Demand-driven interventions thus became the mainstream approach (Black, 1998).

The principal elements of the demand-responsive approach are summarized in

Table 13. This approach will be further examined below.

Table 13: Three Approaches to Water Supply Interventions

<i>Traditional (Top-Down) Approach</i>	<i>Community-Based Approach</i>	<i>Demand-Responsive (Demand-Driven) Approach</i>
<ol style="list-style-type: none"> 1) Supply-driven 2) Centralized beneficiary selection 3) Top-down decision-making 4) Maintenance a governmental (utility) responsibility 5) Government-controlled spare parts distribution 6) Government selection of technicians 7) Weak local water committees, if any 8) Water given out free or at very low cost 	<ol style="list-style-type: none"> 1) Significant local participation 2) Maintenance is often local (community) responsibility 3) Private sector spare parts distribution 4) Community selection of repairmen 5) Strong local water committees 6) Full cost-recovery of operation and maintenance (O&M) and replacement costs 	<ol style="list-style-type: none"> 1) The focus is on what users want, are willing to pay, and can sustain 2) The local community initiates, plans, implements, maintains, and owns the system (increasing its sense of responsibility) 3) Water is treated as an economic good 4) The private sector provides goods and services 5) Local water committees, in which women play a key role, are strong 6) Full cost-recovery is expected on O&M and replacement 7) The more users pay, the more likely a project is to be demand-driven

(Source: OED 2000:19-22)

4.3 Demand Responsive Supply

The demand-driven approach is primarily based on two principles that were articulated and endorsed at the International Conference on Water and the Environment, held in Dublin in January 1992. The principles are as follows: “(1) Water is an economic, as well as social, good and should be managed as such; and (2) Water should be managed at the lowest appropriate level, with users themselves involved in the planning and implementation of the project” (Boydell, 1999, p.2).

Mukherjee and van Wijk (2002) identify three aspects of demand-responsive initiatives: user-demand, responsiveness to demand, and satisfaction of demand. In order to ensure user-demand, service should follow, not precede, a community expression for desired service improvement (Boydell, 1999). According to Cleophas (1997), water can be categorized into essential or non-essential uses, and demand should be prioritized in the following order: people’s essential needs, productive purposes, and consumptive, non-essential use.

Cost-recovery (or cost-sharing) is also a major tenet of the demand-responsive approach (Black, 1998). The amount a community is willing to contribute (cash or in-kind) is typically used as a primary indicator of user demand (Mukherjee & van Wijk, 2002). Communities are generally expected to eventually assume the full cost of operation and maintenance (O&M) and repair. They are also expected to make a substantial contribution to the initial capital cost of the project (Boydell, 1999).

Cost recovery of O&M and repair costs implies the introduction of a regular (typically monthly) water-use tariff. Tariff payment is seen as encouraging more effective and sustainable use of water resources (Akuoko-Asibey, 1996). It is also seen as instilling a sense of ownership within the local community and thus empowering them to maintain it (Narayan, 1995). The amount users are willing to contribute has also been used as an

indicator of their ability to manage the domestic water source (Machingambi & Manzungu, 2003).

Options regarding technology and service level form an integral part of this approach; the emphasis is on decision-making based on the preferences of the local users (Boydell, 1999). The value of the contribution towards capital costs should be tied to the level of service so that communities can have some control over how their contributions are spent and make informed choices (Black, 1998). When people feel as though they have no control over how their contributions are spent, their willingness to pay (WTP) drops off significantly (Black, 1998). In addition, it is not possible to assess WTP with any accuracy in the absence of full information (Mukherjee & van Wijk, 2002). The degree to which users make informed decisions regarding technology options and service levels, based on full information about financing and management arrangements, is used as an indicator for the responsiveness of demand.

Satisfaction of demand relates to the extent to which demands of all users (men and women in wealthier and poorer households alike) are met by the system, and the satisfaction of these groups with the system and its management in relation to their community (Mukherjee & van Wijk, 2002, p.21). Clearly, users will be more likely to sustain services that they are satisfied with.

The satisfaction of all three criteria for demand requires continuous and active participation of users throughout and beyond the project. The following two sections will further explore each of the two principles of the DRS approach.

4.3.1 Water as an Economic or Social Good

Some controversy remains as to whether water should be treated as an economic or social good. Both sides of the debate will now be presented.

It has been argued that water should be considered and treated as a social good because of the significant positive externalities generated by increased access and improved quality. According to this view, these externalities (improved health, time-savings, increased productivity and income) cause the inability of the market to supply the socially optimal level of water service. In addition, the crucial role that water plays in human resource development, economic development, and the fulfillment of development objectives more broadly, has given rise to a body of literature that advocates for the consideration of water as a human right. Both of these perspectives have led to a school of thought that views water as a social good. According to this school of thought, states should be obligated to provide sufficient access to water of adequate quality to its population for the satisfaction of basic water needs.

In practice, however, there are substantial difficulties with treating water as a public good. Providing unlimited water free, or water at substantially reduced costs, can only be done by governments because it would require continuous financial losses. Water has traditionally been supplied by state run agencies in most developing countries. Historical evidence has shown that these utilities have often been run inefficiently and have not been able to meet the needs of the population (Alexander, 2002). Infrastructure for the provision of water is often in disrepair, since there is typically insufficient money for their repair, operation, and maintenance. Furthermore, the incorporation of water as a human right into international law would have sovereignty implications that many states would likely be unwilling to accept, since it could impose an obligation on states with an abundant water supply to transfer resources to areas with scarce and/or

inadequate resources. These arguments have given rise to the school of thought, which believes that water should be treated as an economic good.

Robbins (1935 in Perry, Rock & Seckler, 1997, p.2) defines economics as "the science that studies human behavior as a relationship between ends and scarce means which have alternative uses." From this perspective, water satisfies these criteria and can therefore be clearly viewed as an economic good. Many proponents of the economic view contend that the production and allocation of potable water should be left to market forces (Perry, Rock & Seckler, 1997).

The willingness-to-pay (WTP) paradigm arose from the realization that service costs must be recovered in order to meet the consumer needs (Kayag et al., 2003). WTP is integral to the demand-driven approach to rural water supply and is the most common indicator used to measure user demand. The WTP represents a shift from the previous supply-side emphasis to an economic analysis of demand (Merrett, 2002). As Briscoe argues: "Like any other good, consumers will use water so long as the benefits from the use of an additional cubic meter exceed the costs so incurred." He continues: "The value of water to a user is the maximum amount the user would be willing to pay for the use of the resource" (Briscoe in Perry, Rock, & Seckler 1997, p.4). The WTP approach is based on the premise that successful project design must embody the preferences of individual households. The new paradigm suggested that domestic water supply programs could only be sustained and replicated if they respond to the potential market for water services (Kayag, et. al., 2003).

Merrett presents a strong argument challenging the validity of the willingness to pay approach. He states that there are two ways in which water can be billed: as a price per unit volume, or as a fixed price for unlimited volume (Merret, 2002). This distinction is rarely made explicit in WTP surveys, and the concept fails to be meaningful if applied to per unit prices (Merret, 2002). As well, the willingness to pay concept is used in

practice by water demand researchers to mean both willingness and ability to pay (Merret, 2002). This introduces substantial ambiguity, which undermines the utility of the findings, with some respondents interpreting the WTP question as inclusive of affordability, while others taking it as exclusive of that dimension.

Ultimately, water serves many different objectives and has the properties of both a private and public good. “Depending on the quantities supplied to individuals, water can be either a basic human need, a merit good, or an ordinary private good; it can also be allocated by the public sector or by the private sector depending on these quantities” (Perry, Rock & Seckler, 1997, p.6). A merit good was defined by Perry, Rock and Seckler (1997) as a good people should be encouraged to consume because the benefit of consumption generally exceeds the cost of provision.

Provision of adequate water to meet basic human needs is essential for continued survival and plays a critical role in enabling human development and consequently promotes both economic growth and development. The currently advocated demand-driven approaches neglect social characteristics of domestic water. The debate regarding the treatment of water as a public or economic good relates to how ongoing operation, maintenance and repair costs should be treated. Although this is an important debate that deserves further examination and research, the present study focuses exclusively on communities that are not receiving any type of ongoing external assistance. By definition, this means that these communities are absorbing the full costs of sustaining the service. This also implies that water is generally being treated as an economic good. Consequently, all communities that are included in this study will have followed at least some elements of the demand-responsive approach.

4.3.2 Participation, Empowerment and Sustainability

Narayan (1995, p.7) defines participation as “a voluntary process by which people, including the disadvantaged (in income, gender, ethnicity, or education), influence or control the decisions that affect them.” In the water supply sector, participation is seen as a means of obtaining the desired project goals of improved water supply systems, the development of human, organization, and management capacity and the ability to solve problems as they arise in order to sustain services.²⁸

Participation has been advocated as a means of achieving four main project objectives: effectiveness, efficiency, equity, and empowerment (Narayan, 1996, p.26). Project effectiveness is defined as the degree to which project objectives are achieved. Efficiency describes the relationship between achieving any given outcomes and its costs and inputs. Empowerment refers to a redistribution of power and/or resources to those who previously lacked power. Narayan (1996, p.26) states: “Any activity that leads to increased access and control over resources and to acquisition of new skills and confidence, so that people are enabled to initiative action on their own behalf and acquire leadership, is an empowering activity.” Empowerment is considered the leading indicator of successful capacity building, and is believed to occur through beneficiary participation in decision-making.

Four distinct levels of participation have been identified: information sharing, consultation, decision-making, and action initiation. According to Paul (1987 in Narayan, 1995), information sharing refers to a uni-directional flow of information. The flow of information may be in either direction. The information may flow from the project staff to the beneficiaries to facilitate collective or individual action or it may flow from the beneficiaries to the organization by means of baseline of feasibility studies. Consultation refers to a two-directional information flow in which agency staff share

²⁸ Participation is not seen as an end in itself in this context.

information with beneficiaries and also seek their opinions. Decision-making refers to a more intense level of participation in which the beneficiaries are either exclusively or jointly (with the external agency) involved and responsible for making decisions related to the program. This level of participation often promotes capacity building and empowerment and thus yields benefits that are incremental to those of consultation. Initiating action within the framework established by the external agency is considered the highest level of participation and is a clear indication of empowerment of beneficiaries.

Following the delineation of the four types of participation, Narayan (1995, p.22) further specifies the definition of participation to be “the extent to which beneficiaries were involved in information sharing, consultation, decision making, and initiating action in program activities.” Narayan and her associates carried out an extensive study in 1995 entitled: “The Contribution of People’s Participation: Evidence from 121 Rural Water Supply Projects.” The study conducted econometric analysis on the data obtained from 121 rural water supply systems to ascertain the effect of participation on sustainability. Narayan (1995) found that beneficiary participation contributed significantly to project effectiveness and improved sustainability. The study also confirmed that participation directly improves capacity building and empowerment (Narayan, 1995).

Rural infrastructure is developed in four broad phases: design or planning, construction, operation, and maintenance (Narayan, 1995). The study found that participation in all stages has a significantly greater impact on outcomes than participation in any single stage (Narayan, 1995). Participation was found to be the single most important determinant of overall quality of implementation. The study recommends that participation be viewed as a long-term process where beneficiaries are involved in decision-making throughout the project. Narayan (1996, p.63) found that

“instituting a community self-selection process based on “hard choices” (a substantial cash contribution by the community for example) is essential at the subproject level.”

Narayan’s findings are somewhat contradictory. She states that “participation is not a nebulous concept; it can be defined measured and observed” (Narayan, 1995, p.76). However, the study later finds that participation in decision-making is an iterative process without clearly marked stages, and advocates that the community itself should decide how it will participate. In addition, while Narayan’s study examines the impact of participation on sustainability, her research does not specify the extent of participation, what constitutes appropriate representation, or provide any recommendations on how to implement a successful participatory process.

Cleaver (1999) examines the role of participation in development and also finds that the literature tends to depict participation and empowerment with either great clarity, using a limited set of specific indicators as a basis for evaluation, or “conveniently fuzzy”. He finds that empirical evidence does not support the claims of long term effectiveness of participation in improving sustainability. He follows this up by stating “Participation has therefore become an act of faith in development; something we believe in and rarely question” (Cleaver, 1999, p.597). Cleaver notes that it is often unclear who should take part and how participation is to be achieved. He argues that the development literature generally neglects an analysis of power, structural and political factors.

Jackson and Gariba (2002) examined community water management in northern Ghana. They found that: “Change may well be faster and cheaper ‘closer to the ground’, but local dynamics among stakeholders can, in fact, be complex and unpredictable” (Jackson & Gariba, 2002, p.136). They found that it is not obvious how stakeholders can be coordinated effectively. As a result, they argue that effective methods to be developed in order to enable coordination, both horizontally and vertically (Jackson & Gariba,

2002). Participatory development relies upon effective stakeholder coordination. As we have already seen, from Narayan (1995) and Cleaver (1999), the literature on participatory development tends to be ambiguous with regard to details, and fails to address issues such as the one raised by Jackson and Gariba (2002).

Mansuri and Rao (2004) also study community participation in World Bank projects and find that it has not been particularly effective at targeting the poor. Their review of the literature concludes that no single study was able to establish a causal relationship between outcomes and participatory elements of development projects. In fact, Mansuri and Rao (2004) find that not all participatory processes are beneficial. They state that, at its worst, genuine participation may actually lead to psychological or physical duress, since it may require that stakeholders take a position that is contrary to the interests of powerful people/groups. They note that there is an underlying assumption that the benefits of participation are greater than the costs, but that in reality, these authors argue that this may not hold true (Mansuri & Rao, 2004).

Agrawal and Gibson (1999) are also critical of the benefits that can be attributed to participation. They note that the discourse on participation typically refers to *community* participation. This literature tends to consider communities as unified and as such, it tends to neglect differences within the community (Agrawal & Gibson, 1999). Agrawal and Gibson (1999) challenge three underlying assumptions of communities; “community as a small spatial unit, as a homogeneous social structure, and as shared norms.” They find that solely focusing on a community’s shared space and limited population may be incomplete and misleading. In their analysis of homogeneity, they find that perfect homogeneity within a community does not exist and it is unclear at what point a community may be considered homogeneous. This is especially true when it is unclear which common characteristics are critical to resource management (Agrawal & Gibson, 1999). Finally, they note that the shared norms and common interests are a

function of the perception of members within the community, rather than something that can be judged by outsiders (Agrawal & Gibson, 1999).

Finally, Kleemeier (2000) undertook a study of the impact of participation on the Malawi rural piped water supply scheme. She notes that the Malawi rural piped water scheme has been highly praised for its participatory approach. She found that despite the initial appearance of sustainability, field research in 1997-1998 yielded evidence of severe breakage and blockage problems, and an unwillingness of members to respond to others' needs and cooperate. As a result, necessary repairs were neglected for long periods of time. Kleemeier (2000) thus also concludes that participation does not guarantee sustainability.

4.4 Demand-Driven Supply and Participation in the Field

This section will examine hypotheses derived from the literature, reviewed above, in the context of the case studies included in the present study. For this section and the remainder of the field-research analysis sections, sustainability will be considered at the community, rather than system, level. If a given community was the beneficiary to more than one technology type, the analysis will be based on the most recent technology received.

Based on the earlier analysis of the appropriateness of the technologies installed, and considering only the most recent system in communities that have received multiple interventions, eleven communities were assessed to have received systems appropriate for the local conditions.

The independent variables contained within the hypotheses generated from the literature on the demand-driven approach and participation have been examined and classified for each of these 11 study villages. The classification of these variables is shown in Table 14 on the following page.

Table 14: Variables in Hypotheses on Demand-Driven Supply and Participation

	Sustainability	Assistance formally requested and initiated by community	Community participation in construction	Cash contribution	Contribution of local materials	Choice of technology type and service level	Choice of water source or location of the system/tank	Involvement in all aspects of decision-making	Ownership of system and land and tank
San Javier de Tunshi	Sustainable	?	yes	30% + land purchase	yes	yes	Source, system, tank	yes	Comm. owned
Santa Ana Saguon	Abandoned	yes	yes	no	yes	?	?	?	Co-owned
San Pablo	Sustainable	yes	yes	no	yes	?	?	?	Co-owned
Santa Ana Guagñag	Sustainable	?	yes	no	no	?	?	?	Comm. owned
Misquismi	Sustainable	?	yes	land	no	no	no	no	Comm. owned
Alacao	Marginally Sustainable	no	yes	no	yes	?	?	?	Comm. owned
Muelañag	Marginally Sustainable	yes	yes	no	yes	?	?	?	Comm. owned
San Miguel Pumachaca	Marginally Sustainable	yes	yes	no	yes	?	?	?	Community member
San Antonio de Chacaza	Marginally Sustainable	no	yes	no	yes	no	no	no	No
Opote San Vicente**	Sustainable (mixed)	no	yes	?	yes	no	no	no	Community member
San Francisco Billud	Abandoned	?	yes	no	no	?	?	?	Owned privately

*This table does not include communities assessed to have received inappropriate technologies.

**Sustainability results for Opote San Vicente are mixed, with some hand pump systems fully maintained and some completely abandoned. This section will only consider the sustained systems.

The first hypothesis that emerges from the literature is that if communities' request improved water services, they are more likely to sustain them. Data was collected on this variable from seven of the study sites. Of the seven sites, only one site was assessed as sustainable. One additional site, Opote San Vicente, had mixed result, with several examples of fully sustained wells and others of abandonment. The community of Santa Ana Saquon had completely abandoned their system, and the remainder of the seven sites was classified as marginally sustainable. Of the examples of sustainable systems, only one of the two communities indicated that it had requested and initiated the procedure for receiving assistance. Similarly, amongst the failed systems, three communities reported that they have actively sought out and requested assistance. Overall, it may be concluded that no correlation was found, amongst the case study sites, between the community requesting assistance to improve their water supply and project sustainability.

The next hypothesis is that if communities make a substantial contribution towards the capital costs of the project, they are more likely to sustain the service. Ten observations on this variable were made and the results are summarized in Table 14. Four communities with observations on this variable were classified as sustainable, four as marginally sustainable, and two as abandoned. Only two communities indicated that they contributed to capital costs. Both of these communities bought the land that the system rests on. For its part, San Javier de Tunshi also contributed an additional 30% of capital costs. The systems in the both communities that made financial contributions towards capital costs were rated at maximum sustainability. Conversely, all communities with systems that were rated as unsustainable were found to not contribute any funds towards capital costs. It can be cautiously concluded that some correlation may exist between up-front monetary contributions and long-term sustainability. However, two cases exist that were rated as

sustainable in which no initial financial contribution was made. This implies long-term sustainability is not entirely dependent on an initial monetary contribution towards capital costs, although the field evidence does suggest that outcomes may be improved due to these contributions.

A related hypothesis might be that the more users contribute, the more likely the system was expected to be sustainable. No data were collected on the numerical value of the financial contribution made by the communities. In addition, the systems in both of the communities that made financial contributions were ranked equally; there was, therefore, no variability in the outcomes of these communities. In the absence of both variation on the dependent variable, and data on the independent variable, no conclusion can be made regarding the impact of varying financial contributions.

Table 14 also shows land and system's ownership as a variable of sustainability. Observations on land and system tenure were made in all communities included in the study. Of the eleven communities that received appropriate technologies, five communities owned their systems, collection tanks and corresponding land, and two communities co-owned the tank, system, and/or land with another community. There were also two communities in which tanks that were intended to be communal were placed on land that belonged to an individual community member. There was also one example of a community whose system lay on the private property of an individual that was not part of the community. Finally, there was one community that did not own the land on which the system was located and that did not know who the owner of the land was.

Of the five communities that collectively owned the system and land, three of these communities had sustainable systems. These results may indicate that community ownership of resources may improve outcomes. The results become more ambiguous when the land is

not communally owned but rather is owned by an individual member of the community. In this case, the data show that ownership may positively or negatively affect sustainability, depending on the arrangement that is set up between the community and the individual community member involved.

It is interesting to note that both of the communities that made financial contributions towards capital costs also communally own their system, tanks, and the land on which they sit. This means that it is unclear as to whether improved sustainability corresponds with an initial financial contribution and/or with resource ownership. A monetary contribution towards capital costs is used as an indicator that the community prioritizes and values improved services. Resource ownership may signal that the community will take more responsibility for a system of which they have full control and ownership. Financial contributions and resource ownership are often linked; when financial contributions are made, they are often made in order to gain control of resources. This makes it difficult to isolate the component that may lead to improved outcomes. The most that can be said is that these factors combined appear to lead to improved sustainability.

Another hypothesis that emerges from the literature is that full cost-recovery of operation, maintenance (O&M), and repair costs increases sustainability. Since none of the cases included in this study were receiving any external support, all the communities would have to cover all O&M and repair costs in order to be sustainable. It is unclear if full cost-recovery leads to sustainable outcomes or if it is a result of sustainable projects. Consequently, no conclusion can be drawn on this hypothesis.

An additional hypothesis is that enabling community choice with respect to technology and service-level increases sustainability. Only four observations on this variable were made in the study communities. Of these four cases, three were rated as sustainable

and one as marginally sustainable. Only one community indicated that it had selected the technology and service level. Therefore, among this limited sample of sites, there did not appear to be any correlation between technology and service-level choice and sustainability.

Finally, the literature tends to advocate for community participation in construction of infrastructure and for their contribution of local materials. This is thought to increase the sense of ownership of the system and thus improve the likelihood that it will be sustained. The data collected for the present study shows that all communities provided local labor for the construction of their systems. Since the sustainability outcomes varied considerably despite this constant variable, it would appear that community participation in construction does not significantly affect the long-term sustainability of the systems. In addition, eight of the eleven communities under consideration contributed local materials for the construction of the system. Nonetheless, two of the communities that did not provide any local materials to assist the project were rated at maximum system sustainability. This suggests that the contribution of local materials also does not necessary improve sustainability.

4.5 Conclusion

The demand-responsive approach has two underlying principle: (1) the treatment of water as both an economic and social good; and (2) management at the lowest appropriate level. This approach stresses cost-recovery, community initiation of assistance, and full beneficiary participation. Findings suggest that community initiation of the development assistance project does not improve sustainability. However, data shows that financial contributions towards capital costs and ownership of resources may correspond with increased sustainability. Data showed that cost-recovery of O&M and repair costs did not appear to improve sustainability, nor did participation in decision-making with respect to

choices regarding technology and service level. Finally, community participation in construction of the infrastructure and contribution of local materials also appeared not to significantly affect sustainability outcomes. These results must be taken in the context of the limited numbers of villages included in this case study.

Chapter 5.0 Water as a Common Pool Resource: Implications for Sustainability

"The most important ingredient for sustainability is to get institutions right"

Braden and Van Ierland 1999, p.18

5.1 Overview of Chapter:

This chapter will examine the challenges of water supply management from a nuanced perspective of common pool resource (CPR) governance. It will begin by reviewing the characteristics of CPRs and three options for CPR management, namely, state governance, privatization and collective management. The effectiveness of these options on the sustainability of water supply provision will then be examined with evidence from the field. Finally, the chapter will then take a closer look at the critical factors that determine the successfulness of collective CPR management.

5.2 Common Pool Resources: A New Look at Domestic Rural Water Supply Systems

Common pool resources are resources that possess two defining characteristics: *rivalness* of consumption and *non-excludability* (Mankiw, 2002; Seabright, 1993; Chamberlin, 1974; Tang, 1991; Ostrom et al., 1994; Dolšak & Ostrom, 2003). Rivalness of consumption signifies that increasing the quantity of a good consumed by one individual reduces the amount that is available for others (Seabright, 1993, Dolšak & Ostrom, 2003). Non-excludability refers to the inability of prohibiting users from consuming the resource (Dolšak & Ostrom, 2003).

Both the physical water supply systems and the water resource itself may be considered CPRs. The non-excludability characteristic applies to rural water supply systems, as they, like other types of rural infrastructure, tend to be large systems with many users, and from which it is difficult and costly to preclude potential beneficiaries (Ostrom et. al.,

1993a). In addition, use of the system causes normal wear and tear such that, without appropriate upkeep, the system's condition will gradually decline. Thus, water supply infrastructure may be considered rival since each additional user causes the condition of system to decline slightly, which in turn results in an incremental decrease in the performance of the system for others. Water itself may also be considered a CPR since it is often also difficult to exclude people from withdrawing it, either from nature or through the use of a water supply technology. In addition, if the collective overall rate of extraction is greater than the recharge rate of the source, then water consumption, in CPR terminology, is rival.

When a good is characterized by non-excludability and rivalness, and hence is classified as a CPR, negative externalities such as over-consumption and a decline in the quantity and/or quality of the resource result, in the absence of effective control mechanisms (Seabright, 1993; Chamberlin, 1974). The depletion of the quantity or quality of a CPR is known more popularly as the "Tragedy of the Commons" (Hardin, 1968). When a good possesses these characteristics, rivalness and non-excludability, the way in which it is managed is crucial to its sustainability.

Patterns that emerged during field research for the present study suggest that standard CPR issues were likely prominent in affecting the sustainability of systems both within and between communities sharing water resources²⁹. While a significant body of literature exists on the management of common pool resources (CPRs), this literature

²⁹ Budescu and Tung Au (2002, p.39) found that: "Players who are assigned to earlier position in a sequence act as if they have an advantage over the others, and request more." Much of the region in which the field research was conducted used a gravity-reliant system (including GFWS and HWS) to channel water from high mountain sources. Furthermore, within communities, residences were typically distributed at varying levels of elevation, which enabled the majority of communities to have a household level distribution system. However, this enabling factor also caused water users to frequently be positioned in sequence in terms of their water extraction and consumption. The pattern observed by Budescu and Tung, as quoted above, was the first to become evident during the field research component of this study, and is a characteristic present in all cases included in this section

generally fails to include case studies of domestic water use for the satisfaction of basic human needs. Rather, it focuses on *productive* activities, with typical case studies investigating means of managing of pastures, fisheries, forests, and irrigation systems. For its part, the literature on the sustainability of water supply systems focuses on appropriate technology and the demand-responsive supply approaches, and completely overlooks this factor in its considerations and resultant policy recommendations. Kollegal (2000, abstract) concurs with this and states: “The learning from the large body of work on CPR remains unabsorbed in the drinking water sector because neither the users nor the donors or the state has viewed the ‘installed equipment’ clearly as ‘common property resource’.”

This chapter will examine how properties of CPRs affect their sustainability, drawing both on the literature and on evidence from the field. The analysis in this chapter will be restricted to communities that possess a gravity-reliant household-level distribution water supply system. In addition, communities that received inappropriate technologies will be excluded from this chapter. The communities that are to be included in analysis for the remainder of this chapter are therefore:

Table 15: Communities with a distribution system

Community	Canton	Sustainability
San Javier de Tunshi	Riobamba	Sustainable
Santa Ana Saquon	Riobamba	Un-sustained
San Pablo	Riobamba	Sustainable
Santa Ana Guagñag	Riobamba	Sustainable
Pulcate Cuatro Esquinas	Colta	Un-sustained
Misquismi	Colta	Sustainable
San Miguel Pumachaca	Guamote	Marginally Sustainable
Alacao	Guano	Marginally Sustainable
Muelañag	Guano	Marginally Sustainable

5.3 Three Approaches to Management of the Commons

The literature on the management of the commons proposes that there are three possibilities for ownership of a resource and thus for CPR governance: state governance, privatization, and collective action (Dolšák & Ostrom, 2003). These three options function by creating property rights with respect to a resource. Property rights determine the actions that can be taken by individuals or firms in relation to other actors with respect to a specific good (Agrawal, 2003; Tang, 1991). In state governance, the ownership of the resource and the corresponding rights rest with the state. In privatization, a CPR is transformed into a private good and can then be allocated by market forces. Collective action defines the property rights of a good as joint rights, which are shared between clearly defined group members. In collective action scenarios, the group collectively possesses property rights. The following sections explore these three options in greater detail.

5.3.1 State Governance

Many analysts have advocated state responsibility for CPRs in order to overcome the problems of joint use (Ostrom et. al., 1993b). The underlying assumption driving this policy prescription is that individuals seek their own short-term interests even when joint returns could be significantly increased through cooperation (Ostrom, 1999). This assumption has led many analysts to conclude that only external authorities can effectively devise, impose and enforce rules to reduce overuse on local users (Ostrom, 1999). Ostrom (1999, p.507) observes that, “this has been the foundation for most policy prescriptions regarding the regulation of common-pool resources during the second half of the twentieth century.”

Practice, however, has shown that publicly owned water utilities in transition economies have frequently under-performed, and have been unable to provide water in

sufficient quantities and of adequate quality to meet basic needs and to promote economic growth and development (Alexander, 2002; Ostrom et. al., 1993a; Grafton, 2000; Ostrom, 1999; Tang, 1991). The primary reasons for this under-performance are insufficient resources and lack of accountability.

Field research revealed that public agencies in Ecuador have also been unable to provide adequate water supply services. The decision-making authority for water supply is decentralized in Ecuador, with each municipality possessing the responsibility for providing services to both the urban and rural areas within their jurisdiction. In all of the regions (cantons) visited, the municipalities have failed to extend services to the rural areas.

An interview was conducted with an engineer from the MIDUVI regional office in Riobamba. He explained that the municipality has very little funds to carry out its work and that requests for assistance outnumber what it is able to attend to. He also explained that they are short on human resources and therefore cannot conduct and monitoring, follow-up, or enforcement. The following is an excerpt taken from this interview:

A mi criterio muy personal de mi experiencia de aquí de Chimborazo, porque ya trabajo ya 22 años en la área de agua y saneamiento, considero que la falta de presupuesto para realizar un seguimiento a las actividades de operación y mantenimiento es la causa porque estén malos. No seguimiento. Luego tienen tarifas muy bajas. Precisamente eso es por la falta de seguimiento. Por falta de presupuesto de la institución para estos trabajos no ha podido hacer un seguimiento. (Ing. Rosco, interview)

[In my personal opinion from my experience here in Chimborazo, because I have already worked here for 22 years in the area of water and sanitation, I consider the lack of budget for monitoring of activities, for operation and maintenance, is the cause of the poor state they [rural water supply systems] are in. No follow up. Then there are also very low tariffs. Precisely for the lack of follow-up. Because of the lack of budget for the institution for this work, we haven't been able to follow up.]

5.3.2 Privatization

The term privatization is normally used to refer to the transfer of assets or operations of public water systems to private firms (Gleick et. al., 2002; Nellis, 1994; Nellis, 1999). In light of widespread poor performance of state-owned firms, public ownership and governance of resources has been re-examined, and privatization has emerged as a possible policy solution.³⁰ The underlying assumption behind policy prescriptions advocating privatization of CPRs is that efficiency in resource allocation will improve when an individual or firm owns the property rights to the resources³¹ (Seabright, 1993, p.124). This also presumes that benefits of privatization are greater than the costs of excluding an individual from the CPR (Grafton, 2000).

Privatization of state owned services has become an increasingly popular component of development interventions that seek to correct for government inefficiency and ineffectiveness. While privatization is not a new idea, the extent of privatization, public awareness and attention to problems associated with initiatives has reached a historical high and continues to grow (Gleick et. al., 2002). The World Bank, other donor and aid organizations, together with several water associations such as the World Water Council, are increasingly pushing the privatization option (Gleick et. al., 2002).

Nonetheless, privatization remains quite controversial throughout much of the world and empirical evidence on the outcomes of privatization is sparse and largely inconclusive (Clarke et. al., 2004). Critics of privatization charge that it benefits the rich and neglects the

³⁰ Privatization challenges the underlying assumption for the state governance prescription, that the public good characteristics of water and the emergence of economies of scale in production should lead the government to assume full responsibility for water provision.

³¹ Gleick et. al. (2002) list a number of functions of water supply that may be privatized, including: design, planning, budgeting, finance, and construction of capital improvements, operation and maintenance of facilities, establishment and conduct of monitoring and enforcement of water quality and other service standards, as well as pricing decisions, management of billing, and revenue collection.

poor, exacerbating socio-economic disparities. Empirical evidence has shown that prices generally tend to increase in the post-privatization phase, and poor people at the margin may thus no longer be able to afford service (Nellis, 2000). Privatized services are also thought to neglect the rural poor and increase the urban bias of service delivery. The extension of services involves high capital costs associated with infrastructure. Rural populations are often diffuse, and the marginal cost per additional user is therefore relatively high. Low population densities also mean that fixed costs must be shared among relatively few people (Powell & Starks, 2000). These factors combined can cause very low return on the extension of services to the rural poor (Powell & Starks, 2000).

None of the communities studied during field research had any type of private sector involvement in any aspect of their water supply. As a result, no analysis could be conducted on the effectiveness of such arrangements or the relative effectiveness of various types of privatization.

5.3.3 Collective Action

Ostrom (1999) explains that extensive empirical evidence has shown that multiple users are capable of devising solutions to the commons dilemma that successfully prevent the “Tragedy of the Commons” phenomenon. The third policy prescription that has emerged in the CPR literature is management of CPRs through the collective actions of the users themselves. This occurs when users form an organization that manages the property of a resource (Ostrom, 2003; Grafton, 2000). Proponents of collective management emphasize that group membership must be limited by recognized and enforceable rights so that free access by additional exploiters is preventable (Seabright, 1993). Collective action organizations provide a ‘platform’, or forum, through which stakeholders analyze and

negotiate varied interests and come to agreement on action strategies (Ravnborg & del Pilar Guerrero, 1999).

Seabright (1993) observes that cooperation is difficult to sustain since many CPR problems involve high discount rates on long-term gains or relatively high benefits from defection in the short run. Nonetheless, there is substantial evidence that cooperation can be sustained in the long term, and that collective management can be an effective solution. Ostrom (1999) identifies several advantages of collective CPR management as compared with other types of management, including: maximized incorporation of local knowledge, development of rules that are better adapted to the local context, lower enforcement costs, and incorporation of social norms and values in governance structures.

As we have already seen, despite possessing the official authority and responsibility for water supply, the public sector is virtually absent in the rural areas of Province of Chimborazo in Ecuador. We have also already ascertained that there is no involvement of the private sector in any of the case studies. As a result, most of the communities studied have had to be self-reliant in the management of their own water resources. The remainder of this chapter will thus focus on examining the factors that affect the sustainability of collectively managed resources. The next section will examine the theory and field evidence pertaining to the factors that affect individuals' motivation to engage in collective action. The final sections of the chapter will examine the most prominent variables that affect sustainability of collective action.

5.4 Incentives for Collective Action

The literature on collective management of CPRs highlights two propositions that explain why people cooperate and participate in collective action. The first perspective

suggests that cooperation is motivated by prospects of improved economic gains. The second considers sustained cooperation to depend upon social capital (Nemarundwe & Kozanayi, 2003). The CPR literature tends to give more weight to economic incentives for cooperation. Even when case studies in this domain discuss the contribution of social capital to sustainability, there are usually also economic incentives present within the same study. In contrast, the literature on water users associations emphasizes the importance of social capital but completely neglects possible economic motivations for cooperation. The following sections examine these two perspectives in the context of rural water supply in greater detail, with evidence from both the literature and the field.

5.4.1 Economic Incentives

Economic incentives are broadly defined to be: “the positive and negative changes in outcomes that individuals perceive as likely to result from particular actions taken within a set of rules in a particular physical and social context” (Ostrom, 1993b, p.8). According to this definition, some of the positive incentives that we would expect to promote cooperation would include: improved health and decreased sick time, decreased water collection time, and financial incentives generated by increased time that could be invested in productive activities. All of the communities included in this study would have possessed these positive incentives, yet their record of sustainability is still found to be quite low.

This finding is consistent with the literature on common pool resources. As Nemarundwe and Kozanayi (2003, p.193) state: “Theories of collective management of water resource concentrate on productive irrigation water, thereby reinforcing notions of economic motivations for collective action.” While the term “economic incentives” is used frequently in the literature, it can be inferred that the literature is actually referring to

financial incentives. The study of collective action for management of non-productive activities has largely been neglected. Collective action in the absence of financial incentives faces additional challenges, and more study is needed in this area.

The case study of the community of San Pablo can be used to examine economic incentives in greater depth. Empirical evidence from the community of San Pablo strongly suggests that tangible and direct financial incentives are a driver of collective action. San Pablo shares its GFWS system and water source with another community, Chorrero Mirador. San Pablo is located at a lower elevation than Chorrero Mirador. However, because the gradient of flow is much steeper leading to its community, San Pablo is also privy to a relatively high flow rate and better water pressure than the other community.

Interviews revealed that Chorrero Mirador is a clear free rider on the efforts of San Pablo. The community of Chorrero Mirador refuses to contribute financially or to participate in maintenance or repair of the system. Initially, a joint water users association was formed and a joint water board, with members from both communities, was set up to oversee the management of the system. Each family in both communities contributed a monthly water fee to a fund, which was supervised by the board, to support the operation, maintenance and repair of the system. At the time of the site visit, the water users association was no longer in operation and the water board had stopped meeting roughly two years earlier. Community members explained that loans had been given out to various community members from the reserve established under the water fund, and the loans were never re-paid. Community members were insistent that they would not contribute any more money to the fund until all monies owed are returned. When the communities ceased monthly payments, the operations of water users association and board halted.

Despite this, the community of San Pablo continues to chlorinate the water, repair the system as needed, and diligently perform regular maintenance tasks. Community members from San Pablo explained that water conflicts are ongoing between the two communities. At times, the community of Chorrero Mirador will shut off the water supply leading to San Pablo. The question then becomes: why does the community of San Pablo continue to prioritize its water supply so highly that it is willing to maintain it at a high level despite the free riding and conflict with the other community?

Part of the answer is that the community of San Pablo was the recipient of another development assistance project. The aim of the project was economic development and income generation. With the help of an NGO, the community of San Pablo built 'Casa Condor', a modern-type housing unit (cabaña) that can accommodate up to four people comfortably. This cabaña was meant to house senior high-school and university students who would volunteer with the community for a semester for academic credit or as part of an internship program. The students would volunteer to teach in the local school or assist with agricultural activities during their stay. The NGO helped San Pablo establish links with several institutions with which they now work regularly. In return for hosting the students, the community of San Pablo receives a stipend for providing accommodations and food, in addition to the assistance they receive in their community. This "tourist business", as it is called, has substantially augmented the income of the community.

The water supply in 'Casa Condor' is connected to the same distribution system as the rest of the households in San Pablo. Community members explained that Casa Condor is equipped with running water, through faucets in the kitchen and bathroom, and with a

proper bathroom, including a shower and flushable toilet³². They further explained that their ability to receive tourists was contingent of maintaining these services. The community of San Pablo prioritizes its water supply because its tourist business is dependent upon it.

Representatives of San Pablo explained that the water conflicts are in part due to the fact that San Pablo uses a much greater quantity of water due to the tourists than Chorrero Mirador. This is reflected in the following statement:

Porque nosotros tenemos turistas aquí y como allá no tienen turistas, ellos tienen una capricho como a decir entonces dicen a nosotros no tenemos turistas, entonces a ves no cierran las llaves o a veces hay unas problemas arriba, siempre hay dificultades entre los dos". (San Pablo)

[Because we have tourists here and since they don't have tourists, they have a problem, as we say. And so to us they say, we don't have tourists and so sometimes they close off the water. Sometimes there are some problems up there. There are always difficulties between the two.]

The meeting held in San Pablo provided clear evidence that positive financial incentives are linked with sustainability. All communities that receive an improved water system should have had the same positive incentives of improved health and reduced water collection time. Yet these incentives have proven to be insufficient on their own to ensure sustainability. Even within San Pablo, these traditional incentives were not considered to be sufficient to sustain the system. This is demonstrated by the following comment:

Entonces a nosotros la comunidad nos dicen ustedes la comunidad tiene escuela, tiene cabañas, tienen casa Condor, entonces nosotros necesitamos una cantidad de agua. Ellos como no necesitan, como solamente son usuarios para ellos, ellos no les importan, no le importa cuidar, en cambio a nosotros si nos interesa a cuidar, poniendo el cloro, y mantenimiento de agua." (San Pablo)

[And so to us the community, they say – you the community have a school, have proper dwellings, have Casa Condor, and so we need a certain quantity of water. They don't really need it, as the water is only for them, it doesn't matter to them. It doesn't matter to them to take care of the system. In contrast, for us yes it interests us to take care of it, chlorinate it and maintaining it.]

³² Note that Casa Condor was the only building in the community with these facilities. All other dwellings are impoverished. Household water connections mean that each household has a standpost outside of the dwelling. In addition, none of the dwellings have built-in sanitation, and cooking and washing still take place outside.

Interestingly, the community of San Pablo appeared not to recognize the financial value of water, despite clearly stating that its members maintained their water source because of their tourist business. When asked if the income within the community had increased since receiving their water system, a community representative replied:

Creo que no. No. El agua es algo puro, para la salud sí, pero no para lo económico. Si, no creo que haya mejorado lo económico, no.
[I don't believe so. No. Water is something pure, for health yes, but not for income. Yes, I don't believe that income has improved as a result, no.]

Several conclusions emerge from this case study. First, we can see that financial incentives can indeed motivate sustainability. There is little indication that any other type of economic incentive could produce the same results. These other incentives existed in all other cases, yet the record of sustainability in these other cases was found to be quite low. Second, we have observed that while financial incentives have motivated sustainability, water was not necessarily recognized to have a direct economic value. These two conclusions lead to the rather nuanced policy prescription that assistance in the area of water supply should be provided in conjunction with another economic development initiative that depends upon the existence of the water. The community of San Pablo represents only one case study. No similar situations were found in any of the other communities in order to substantiate this hypothesis. Consequently, further research is recommended in order to ascertain whether the sustainability of water supply systems is indeed improved when these interventions are implemented in conjunction with other associated initiatives that provide a direct financial incentive.

5.4.2 Social Capital

The second hypothesis evident in the CPR literature is that social capital motivates collective action. Social capital is “located” in the relationship between actors and is based on trust and shared norms (Coleman, 2000). It is also based on communication, as this provides a common context and understanding between parties (Lesser, 1998). For the purposes of this paper, we will adopt Woolcock and Narayan’s (2000, p.226) definition of social capital. They broadly define social capital as “the norms and networks that enable people to act collectively.” The underlying principle is that social structure constitutes an important asset, which people may leverage for material gain. Woolcock and Narayan (2000) identify two types of social capital, namely: bridging and bonding social capital. Bonding social capital is defined as intra-community (horizontal) ties, whereas bridging social capital refers to extra-community (vertical) networks.

Most water supply projects require the formation of water users committees and/or management committees, whose purpose is to coordinate and regulate the actions of community members in order to ensure continued service delivery (Kähkönen, 1999). In the existing literature on community-based rural water-supply delivery, pre-existing social capital is identified as a principal determinant of the effectiveness of newly formed organizations (Dikito-Wachtmeister, 2001; Kähkönen, 1999). If community members are already organized, there is a social basis for collective cooperation. Kähkönen (1999, p.16) observes: “Communities that have strong social ties often work well together because they share values about mutual assistance.”

The existing level of social capital within a community is difficult to ascertain. Woolcock and Narayan, (2000) note that it is impossible to obtain a single, accurate measure

of social capital, because it is multi-dimensional in character and shifts over time. Moreover, social capital is dependent on trust, and reciprocity, and these are difficult to quantify (Lesser, 1998). Nonetheless, some indicators that may be used to understand the existing level of social capital are: prior organization of water users; the existence, membership and participation in other community groups; and coordination with other communities or with any level of government.

Since it is difficult to measure social capital, the extent of social capital present in each of the communities visited for the present study could not be ascertained. A rigorous comparison across communities of the effect of social capital on collective action could therefore not be undertaken for the sites visited. Nonetheless, evidence did emerge that suggests that (1) a breakdown or decrease in either bridging or bonding social capital can negatively affect collective action, and (2) that financial incentives are stronger than incentives produced from social capital to sustain cooperation.

The community of Santa Ana Saquon can be used to illustrate the first observation. Community members explained that their water supply system is in complete disrepair and has been abandoned. Instead, community members have resorted to obtaining their drinking water from a highly contaminated irrigation canal. The community meeting revealed that Santa Ana Saquon initially had had a very good water supply system, which had been sustained and performed very well for the first three years of operation. Community members reported that, during those three years, each household had paid monthly fees, based on their water usage. These fees were used to buy chlorine and pay a water operator who carried out regular maintenance activities. Any extra funds that accumulated were saved in a formal bank as a reserve fund for any repairs that might be necessary. The community further explained that its members had stopped paying the monthly tariff roughly eight years

earlier when the bank that they had stored their money in went bankrupt. At that time, the community lost all reserve funds that it had accumulated. Members insisted that they would not contribute any more money to this fund until the banks repaid the money owed.

Community representatives also explained that the system began to deteriorate when payments ceased. They stated that their water board now exists in name only and is not active. No maintenance activities were carried out once they stopped paying their water operator. In addition, the community reported it no longer had any reserve funds for repair. This case suggests that a breach in trust, corresponding with a decrease in social capital, can have significant negative effects on the sustainability of collective action and consequently on the sustainability of water supply.

In the case of San Pablo, reviewed earlier in this chapter, there was also a breach of trust that occurred within the community. The water board of San Pablo had allowed reserve funds to be lent to members of the community. When these members of the community failed to repay their loans, remaining community members refused to continue to contribute monthly water tariffs to the board. The board then ceased to exist in practical terms. However, as we saw earlier, the community of San Pablo remains highly organized and continues to treat its water and maintain its infrastructure. We have suggested that San Pablo undertakes these activities because it has a strong financial incentive to do so.

As a result, two hypotheses emerge. The first is that social capital facilitates collective action, and that a decrease in social capital can negatively affect sustainability. The second hypothesis is that financial incentives can be a stronger driver of sustainability than social capital. Further research should be conducted in order to further explore these hypotheses.

5.5 Collective Action Criteria for Sustainable Water Supply

Assuming that the motives for cooperation are present in a community, there is an extensive and growing body of literature that delineates criteria for achieving and sustaining cooperation. Despite this, the literature fails to develop a succinct and concrete set of prescriptions for the sustainable management of the commons³³. Agrawal (2001, 2003) notes that the most significant problem in the field lies in the large number of variables that appear to be of importance for successful collective management of resources. Currently, CPR literature outlines numerous variables that may affect the outcome of a collective action situation. This paper will therefore restrict its analysis to the primary factors that most authors agree are of importance. Tang (1991) finds that all relevant variables may be classified into one of three categories: characteristics of institutions, characteristics of participants, and physical characteristics of the resource. These categories form the framework for analysis that will be applied to the remainder of the chapter.

Only one paper was found that directly addresses the characteristics of community level 'water and sanitation associations' (WASAs) that are focused on water supply for domestic uses. The paper, entitled "User Organizations for Sustainable Water Services", published by the World Bank (Subramanian et. al., 1997), acknowledges that very little work has been done in the area of communal management of domestic water sources and that most of the recommendations are thus imported from the irrigation sector, which has been studied for much longer (Subramanian et. al., 1997). Despite this, the paper does not explicitly focus on the problem of water supply management from a CPR perspective, but rather advocates the use of community management as a means of advancing the demand-

³³ Edwards & Stein (1999) explain that the CPR literature has tended to neglect contextual factors in its analysis and recommendations.

responsive supply agenda³⁴. Nonetheless, the findings from this paper are very pertinent to the present study and will be considered whenever possible. In addition, literature on collective management of the irrigation sector is also be examined and applied to the extent possible. The application of theory from the irrigation sector to the domestic water sector must take into consideration important differences that exist between the sectors. These differences will also be highlighted.

5.5.1 Institutions³⁵: Criteria for Sustainability

The CPR literature highlights several types of institutional rules that play a critical role in effective and sustainable collective governance, as follows: boundary rules³⁶, congruent allocation-provision rules, monitoring mechanisms, enforcement of rules³⁷, and conflict resolution mechanisms³⁸. Since the CPR nature of both water and the water supply infrastructure tends to be neglected in the literature, and only became evident during field research, it was not foreseen in the present study as a significant variable in advance of site

³⁴ Local community groups are thought to be able to better express preferences and thus better manage demand for services.

³⁵ Institutions are defined to be rules and regulations that govern resource use (Nemarundwe and Kozanayi 2003). In contrast, organizations are considered to be structures with some specific objectives and goals.

³⁶ Boundary rules clearly define resource users, and how they gain authority to enter and appropriate resource units from a CPR (Ostrom 1999, Morrow and Watts Hull 1996). Boundary rules can facilitate collective action by limiting the number of users such that the demand does not exceed supply (Tang 1991). Tang (1991) suggests that case studies typically use one of four predominant types of boundary requirements: land tenure, ownership of shares, membership, or fee payment. In his study of irrigation institutions, Tang (1991) found that cases that used land as the sole boundary condition corresponded with a higher rate of insufficient water supply, low rule conformance, and poor maintenance. Other combinations of boundary conditions were found to produce relatively better results, although no single boundary requirement or combination of requirements is prescribed.

³⁷ The enforcement of rules is also critical for compliance (Ostrom 1990, Ostrom *et al.* 1993a, Nemarundwe and Kozanayi 2003). Enforcement rules act as a deterrent for those who might otherwise be tempted to break the rules (Ostrom 1990). In order to be effective, the infringement of rules must have credible and tangible negative consequences for the deviator (Seabright 1993).

³⁸ Conflict resolution mechanisms are also typically considered important for the sustainability of collective management institutions. According to Ravnborg and del Pilar Guerrero (1999), conflicts relating to watershed management are often sensitive. They therefore suggest that third party facilitators be used to resolve such situations. In addition, Dolšak and Ostrom (2003) and Ostrom (1990) highlight the importance of having the locally developed institutions recognized, legitimized, and supported by external governmental authorities.

visits. As a result, communities were not explicitly asked about the rules that govern their water supply or the way in which these rules were established. However, the communities were asked about tariff levels, compliance with tariff payments, and maintenance activities. As a result, some analysis can be conducted with respect to congruent allocation-provision rules, and monitoring mechanisms. These two factors are explored in greater detail below.

Allocation rules specify the procedures and requirements for individuals to withdraw resource units from the CPR (Ostrom, 1990; Tang, 1991). Provision rules are concerned with the required inputs, such as labor, materials, and/or funds (Ostrom, 1990). Several authors discuss the importance of congruence between allocation and provision rules (Ostrom, 1990; Morrow & Watts Hull, 1996; Tang, 1991; Dayton-Johnson, 2000; Trawick, 2001). Congruent allocation-provision rules are thought to improve perceptions of fairness. In addition, they tend to improve accountability and transparency in the governance of the system. Dayton-Johnson (2000) examines four possible combinations of allocation and provision rules for the management of irrigation systems in Mexico, as follows: proportional division of both irrigation water and maintenance labor in relation to land holding; equal division of both water and labor; proportional allocation of water with respect to land holding and equal division of costs; and, equal division of water and proportional division of costs with respect to land holdings. Overall, Dayton-Johnson (2000) finds that rules with congruent cost-sharing and water allocation rules result in higher levels of compliance. Trawick (2001) examines governance of the commons in the context of irrigation systems in the Peruvian Andes. Trawick (2001) also attributes the successful and sustainable management of the irrigation system in Huaynacotes, his case study region, to the proportionality of rights and duties.

Ostrom et. al. (1993a & 1993b) study the sustainability of irrigation systems. These authors (Ostrom et. al., 1993b, p.89) state that: “For infrastructure facilities whose flows are highly subtractive, institutional arrangements related to the allocation of the flow of services are intimately tied to the problem of maintenance.” Ostrom et. al. (1993a) further explain that farmers located at the head of an irrigation system are not motivated to provide maintenance, since they receive relatively greater benefits irrespective of the contribution that they make. Conversely, farmers at the tail of the system are also be disinclined to contribute to maintenance efforts since they may not receive their full share of water (Ostrom et. al., 1993b). These characteristics of irrigation systems are shared with systems of domestic water supply. While Ostrom et. al. (1993a & 1993b) emphasize the importance of financial contributions, the allocation-provision rules for the provision of maintenance is the greater challenge. No suggestions were made by these authors regarding how water allocation could be tied to maintenance obligations in order to improve outcomes.

In all of the communities visited for the present study, allocation rules were found to be rudimentary, with the possession of a water connection being the sole requirement for the right of withdrawal. Provision rules in all relevant communities pertain to financial contributions in the form of monthly tariffs. Six of the nine communities under consideration possess some type of congruent allocation-provision rule. Four of the six communities pay a fixed monthly amount regardless of the quantity of consumption. The other two communities pay a fixed price for a base quantity and then pay an additional amount for excess use. Seven communities possess ‘medidores’, a water meter, which measures water consumption. However, only four of these communities reported that their medidores were still functional. In addition, only two of them, San Javier de Tunshi and Misquimi, reported using their medidores for determination of their monthly tariff.

Members of the community of San Javier de Tunshi pays one dollar per month for the right to withdraw ten cubic meters of water per household per month. Each additional cubic meter requires the payment of an additional 25 cents. In contrast, the community of Misquimi requires each household with a water connection to pay 25 cents. This payment does not correspond with withdrawal rights but simply maintains the household's inclusion in the water distribution system. In addition, the household is required to pay an additional 15 cents for each cubic meter of use. As shown in Table 15, both San Javier de Tunshi and Misquimi are classified as possessing sustainable systems. It is important to note that these two communities represent two thirds of the sustainable systems included in this study. This leads to the hypothesis that rules that display congruence between water withdrawal rights and financial contributions may improve sustainability.

The engineer interviewed from the MIDUVI regional office in Riobamba indicated that the recommended minimum tariff for the region is one dollar per household per month for 15 cubic meters (15,000L) of water. The following table summarizes payment data for the communities that continue to pay a monthly tariff:

Table 16: Tariff Data

Community	Base quantity	Tariff/household	Excess use payment	Equivalent Cost for 15m ³ /month
San Javier de Tunshi	10m ³	\$1/month	20 ¢/m ³	\$2.00
Santa Ana Guagnag	N/A	25 ¢/month	N/A	\$0.25
Muelañag	N/A	\$4/yr	N/A	\$0.33
Alacao	15m ³	50 ¢	\$1	\$0.50
<i>Pulcate Cuatro Esquinas</i>	N/A	20 ¢	N/A	\$0.20
<i>Misquimi</i>	0	25 ¢	15 ¢/m ³	\$2.50

The table above shows that, in fact, San Javier de Tunshi and Misquismi are also the only two communities that meet the minimum recommendation regarding tariff payment. It is therefore possible that this level of payment also corresponds with improved sustainability.

None of the communities visited had allocation rules tied to labor inputs, for example, for maintenance. As Ostrom et. al. (1993a & 1993b) suggest, lack of routine maintenance can be a major barrier to sustainability. Only two communities, San Javier de Tunshi and San Pablo, indicated that they undertake routine maintenance. The community of San Javier de Tunshi has elected an 'aguatero', a water operator, to operate³⁹ and maintain⁴⁰ its system. The aguatero in San Javier de Tunshi explained that maintenance activities are carried out every 15 days and the trip occupies the entire day. For each trip, he is paid \$15 for his work from the tariff funds collected from water users. In contrast, despite the fact that San Pablo does not pay a monthly fee for water use, the community remains highly organized and undertakes the appropriate regular maintenance. We have already seen that the community of San Pablo undertakes these activities because it has a strong financial incentive to do so. The fact that the aguatero in San Javier de Tunshi performs his duties diligently and is paid for his further reinforces the notion that financial incentives can sustain cooperation.

The second type of rule mechanism that can be considered with evidence from the field is that of monitoring. Monitoring is also an essential criterion for sustainability, as it is critical in order to identify non-compliance with established rules and for the enforcement of compliance. Monitors must be accountable to those who have the authority to intervene and take appropriate action when defection is detected (Ostrom, 1990). In addition, rules

³⁹ Operation entails buying supplies as required and chlorinating the water on a daily basis.

⁴⁰ This consists of visiting the source to verify that nothing is obstructing or limiting it. It also involves traveling the length of the pipelines to inspect them for cracks, and leaks and to clear obstructing vegetation.

must be transparent⁴¹ in order to enable effective monitoring. The World Bank paper on WASAs recognizes the importance of transparent rules and monitoring. Subramanian et. al. (1997) elaborate by stating: “When the entire community knows how the system should work, who should benefit, and what each member’s responsibilities are, any deviation from this becomes immediately apparent” (Subramanian et. al., 1997, p.118).

However, Ostrom et. al. (1993a & 1993b) suggest that monitoring maintenance contributions may be difficult for rural infrastructure. They explain that the benefits of maintenance are often subtle and time-delayed. As a result, the frequency and quality of maintenance activities may not be easily observable (Ostrom, 1993b). In addition, since the neglect of routine maintenance causes the infrastructure to gradually fall into disrepair, substantial investments are often requirement by the time infrastructure deficiencies are noticed (Ostrom et. al., 1993a).

Fieldwork revealed that monitoring of financial contributions was carried out in all communities that collect user fees. A water board, established in each community, is responsible for reading the water meters in the communities that had functioning medidores, to ensure that users pay the proper amount. Water fees are always collected during the ‘assemblea general’, the general community meeting, which takes place each month. In all cases, payments of fees are officially recorded, and this provides transparency and accountability between members for compliance with financial obligations. All communities reported that there is 100% compliance with fee payment and that this has never posed a problem.

In contrast, it was found that there is no monitoring of maintenance activities. All communities reported having a water board responsible for overseeing the operation,

⁴¹ Transparent rules are clear and explicit. Additionally, they are known by all participants.

maintenance, and repair of the system. As we have already seen though, no regular maintenance activities were found to be performed in seven of the nine communities. Perhaps maintenance obligations are neglected in these communities precisely because there is no monitoring. However, because of the length of pipes and tubes, it is also very costly to undertake monitoring of such activities, and thus they could not be incorporated into the everyday routine of the members. More research should be conducted on how monitoring arrangements can be structured in order to reduce its cost. Improving monitoring can improve transparency and accountability and reduce shirking. Since the water board is really not accountable to its user group under the current system, shirking occurs and duties are neglected.

5.5.2 Participants: Criteria for Sustainability

Most CPR literature concurs that the following variables play a role in the sustainability of collective management: group size, degree of dispersion of resource users⁴², and heterogeneity of group members⁴³. No data were collected during field research on the effects of degree of dispersion and heterogeneity of group members on sustainability. However, it is possible to assess the effect of group size on the sustainability of cooperation.

⁴² Subramanian *et al.* (1997) explain that settlement density affects how people interact. When group members are highly dispersed, collective action becomes more difficult since transaction and monitoring costs also increase, as in the case of augmented size described above.

⁴³ The effects of heterogeneity, in terms of ethnicity, gender, religion, culture, and preferences, on their ability to cooperate is ambiguous. Several authors, including as Ostrom *et al.* (1993b), Ostrom (2003), and Cornes *et al.* (1986), suggest that relatively homogeneous assets and preferences would facilitate collective action since they would produce a common understanding of rules and a common interpretation and reaction to incentives amongst group members. However, Subramanian *et al.* (1997, p.117) explain that most communities are not homogeneous and water and sanitation associations (WASAs) “typically replicate the community’s stratified society.” Subramanian *et al.* (1997, p.117) explain that if local elites have a private stake in the outcome of collective action, then they will have an incentive to initiative and sustain collective efforts. He further elaborates that the interests of the better off and worse off members of a community may not diverge. If interests are common, and the powerful members have a direct stake in outcomes, then heterogeneity may indeed be beneficial to joint management.

Small groups are generally thought to be more conducive to collective action than large groups (Chamberlin, 1974; Ostrom et. al., 1993b; Ostrom, 2003; Dolšák & Ostrom, 2003). Ostrom (2003) finds that group size is positively correlated to transaction and monitoring costs. Transaction costs are thought to increase with group size, since the cost of reaching agreement increases when more participants are added. Monitoring costs might also increase with group size, since each individual would be responsible for a reduced share of the collective burden, and neglect of individual responsibilities may therefore become less obvious (Dolšák & Ostrom, 2003). Monitoring costs for larger groups are also higher simply due to the increased numbers of people that must be monitored. In a study of group-owned irrigation wells in Southern India, Aggrawal (2000) confirmed this finding when he observed that defection became more obvious in small groups and the efficacy of peer monitoring was thus improved.

So far, the present study has considered collective management within the context of an individual community. The World Bank has recently begun to recognize multi-village⁴⁴ systems as an additional challenge from the standpoint of governance. In 2001, the Bank published a field note entitled “Multi-Village Rural Water Supply Schemes: An Emerging Challenge”. The paper acknowledges the importance of governance, and advocates local management through water users associations (WSP, 2001). Increasing the number of communities drastically increases the size of membership. It would therefore be expected that the effect of multi-village systems on cooperation to be similar to the impact of increasing size of group membership. Monitoring also becomes exponentially more difficult and costly with multi-village systems as the length of pipeline increases dramatically.

⁴⁴ Multi-village distribution systems are defined as ones that contain one rural source that serves several villages.

In the present study, size was found to have a notable impact on the effectiveness of collective management. The number of households per community is known for seven communities, and is shown in the following table:

Table 17: Number of households per community

Community	Sustainability	no. of houses
San Pablo	Sustainable	52
Muelañag	Marginally Sustainable	60
San Javier de Tunshi	Sustainable	76
<i>Misquisni</i>	Sustainable	80
Santa Ana Saquon	Abandoned	85
Alacao	Marginally Sustainable	180
San Miguel Pumachaca	Marginally Sustainable	240

This table clearly indicates that communities with fewer households possess more sustainable systems than the others. Muelañag is the only community amongst the smallest four with a system that is not sustained. The reason for this is that Muelañag is the “lowest” community of three that share a distribution system. Water was found to be overused in communities higher up in the system. Thus, only a limited quantity of water reaches Muelañag, regardless of its organizational strengths.

Multi-village systems were generally found, in this study, to pose an additional challenge. The table below indicates the numbers of communities served by each source:

Table 18: Number of Communities per Source

Community	Sustainability	# of communities/source
San Javier de Tunshi	Sustainable	3
Santa Ana Saquon	Abandoned	5
San Pablo	Sustainable	2
Muelañag	Marginally Sustainable	3
Alacao	Marginally	9
<i>Pulcate Cuatro Esquinas*</i>	Abandoned	26
San Miguel Pumachaca	Marginally Sustainable	1
<i>Misquisni</i>	Sustainable	1

The table indicates that communities that belong to distribution systems that served between one to three communities were generally more sustainable than those that shared their source with more than three. The results with respect to the effects of size and number of communities per source should correlate, which they have been shown to do. Increasing the number of communities per source also increases the number of resource users.

5.5.3 Resources: Criteria for Sustainability

Relatively little attention has been paid to the affect of physical characteristics of a resource on collective action (Agrawal, 2003). Nonetheless, Blomquist et al. (1994) focus on two physical features of resource systems: mobility⁴⁵ and storage⁴⁶. Blomquist et. al. find that these factors have an impact on management because of their relationship to information. Greater mobility of resources and difficulties of storage make management more difficult for users because of problems associated with reliability and costs of information. Dolšak and Ostrom (2003) also note that when resource units move large distances, the number of users increases substantially, and this also makes collective management more difficult. In

⁴⁵ Mobility refers to a resources' ability to move on its own.

⁴⁶ Storage refers the ability to collect and hold the resource.

addition, Schlager and Blomquist (1994) and Ostrom (2003) find that unpredictability and risk also increase when resources are mobile and storage is lacking.

The mobility and storability of the resource, namely water, remained constant across cases assessed for the present study. As a result, no analysis could be carried out on the effects of these particular variables on collective action.

5.6 Conclusion

This chapter has recast the challenge of sustaining water supply service as a common pool resource, or CPR, management problem. Three management strategies were examined: state governance, privatization and collective action. State governance of water resources has been largely ineffective, in practice, in many developing countries, including in Ecuador. Privatization has largely not expanded to rural areas. Most communities are therefore left to self manage their water supply once external aid has terminated. Much CPR literature advocates the creation of water users associations, but few recommendations are presented on how these associations should be effectively organized and governed. Field research suggests that congruent allocation-provision rules improve the likelihood of sustainability. The sustainability of water distribution systems has also been shown to be closely linked to maintenance. More research should be conducted generally on collective management of water supply systems, and particularly on how to improve incentives to carry out routine maintenance. In addition, one case study community provided some evidence that integrating non-productive water services with commercial activities can improve the sustainability of the basic service. Further research should be conducted to explore this issue in more detail.

Chapter 6.0 Environment and Technological Sustainability

“The system of nature, of which man is a part, tends to be self-balancing, self-adjusting, self-dearing. Not so with technology... Technology recognizes no self-limiting principle – in term, for instance, of size, speed, or violence. It therefore does not possess the virtues of being self-balancing, self-adjusting, and self-dearing. In the subtle system of nature, technology, and in particular the super technology of the modern world, acts like a foreign body, and there are now numerous signs of rejection.”

Schumacher 1973, p.156

6.1 Overview of Chapter

This chapter will begin by examining the interplay between environmental factors and technology sustainability in the context of the case-study region. Both natural environmental threats, as well as those caused by anthropogenic activities, will be considered. The chapter will then analyze the information obtained through field research to ascertain how these factors exerted an impact on the technology in practice. The chapter will conclude with an examination of mitigation strategies and their effectiveness.

6.2 Natural Environmental Threats in Chimborazo: Potential Effects on Water Supply

This section will investigate the environmental threats present in the province of Chimborazo that may affect the sustainability of small-scale water supply systems. The natural environmental effects that will be investigated include: volcanic and seismic activity, and landslides. The anthropogenic environmental threats that will be explored include: land-use change, agricultural practices, deforestation, poor sanitation and lack of wastewater treatment.

The Government of Ecuador has ranked the environmental threats present in each canton on a scale of zero to three. The ranking for the cantons included in the present study are shown in Table 19 below. A ranking of zero represents no risk and a ranking of three represents the maximum risk of occurrence.

Table 19: Environmental Threats in Chimborazo

<i>Province</i>	<i>Canton</i>	<i>Environmental Threat</i>					
		Seismic Activity	Volcanic Eruptions	Tsunami	Flooding	Drought	Landslides and Rock Falls
Chimborazo	Riobamba	3	1	0	0	0	3
Chimborazo	Alausi	2	0	0	0	0	3
Chimborazo	Colta	3	0	0	0	0	3
Chimborazo	Guamote	2	1	0	0	0	3
Chimborazo	Guano	3	3	0	0	0	3

(Source: SIISE 2003)

We can see from the table that the most prevalent risks in the province of Chimborazo are of seismic activity, landslides and rock falls, and in some instances, volcanic eruptions. These environmental threats are closely related. An eruption is often triggered when an earthquake occurs beneath a volcano. Similarly, a volcanic eruption will always result in seismic activity⁴⁷ (USGS, 2000). Earthquakes and volcanic eruptions are also major causes of landslides. Landslides may occur in any area composed of weak or fractured materials resting on a steep slope⁴⁸ (USGS, 2002). Erosion caused by rivers and glaciers can result in over-steepened slopes, which also causes landslides.

These environmental hazards, which are prevalent in Chimborazo, can significantly affect the sustainability of small-scale water supply systems. They can block channels and canals, breach dams, and damage pipelines and storage tanks. Of even more importance, they may change the physical characteristics of the catchment area such that the source may physically yield less water or become channeled in another direction (IRC, 1991).

⁴⁷ When magma rises into the reservoir beneath the volcano, the pressure rises, forcing the magma to rise. A high-frequency earthquake is triggered when the increasing pressure causes rocks to break. If the increasing pressure is relatively low, the rising magma will only cause the internal cracks to vibrate, resulting in a volcanic tremor, or low-frequency earthquake (USGS 2000).

⁴⁸ Snowmelts and heavy rains, or the accumulation of excess weight, can weaken rock and soil slopes (USGS 2000).

In addition to the natural environmental hazards, there are several anthropogenic environmental burdens that affect the quantity and quality of water resources in Ecuador, including; land-use change, agricultural practices, deforestation, poor sanitation and lack of wastewater treatment. Consequently, these may impact and threaten the sustainability of small-scale rural water supply systems.

Land-use change typically results from population growth. As population increases, more land is required to support increased economic activity. Furthermore, additional land is brought under cultivation in order to directly sustain the growing population (IRC, 1991).

High-altitude grasslands, known as *Páramos*, are the principal source of water in the Ecuadorian Andes. *Páramos* are typically used for agricultural purposes and burning and tillage are part of the agricultural procedures practiced in the region⁴⁹ (Poulenard et. al., 2001). Increased population growth therefore often leads to more frequent burning and tillage of surrounding land. Poulenard et. al. (2001) found that these activities reduce water infiltration into the soil and increase erosion. Decreased water permeability of the soil, increased surface runoff and increased erosion, together cause changes in the hydrodynamic characteristics of the catchment areas, and reduce the water quantity available for captivation (Poulenard et. al., 2001).

Agricultural land is often treated with fertilizers and pesticides, which can also affect the water available for captivation. As more land is cultivated, the use of fertilizers and pesticides grows as well. Some of the fertilizers and pesticides that are applied to the agricultural land find their way into surface water, and leach into groundwater after a rainfall (ECN, n.d.). The fertilizer that is applied contains nitrogen, potassium and phosphorous

⁴⁹ *Páramos* are often used as grazing land for sheep and other livestock. Before the sheep are introduced to the land, the native (tussock) grass layer is first burned. Then, once the *Páramos* have been grazed, farmers often till the soil to grow potatoes (Poulenard et. al. 2001).

compounds. This acts to increase the nutrients in the water, which proliferates algal blooms and accelerates the process of eutrophication⁵⁰.

As the organic load on the reservoir increases, water circulation decreases. The water reservoir slowly converts itself into a swamp as the organic load continues to increase and exceed the natural self-cleaning mechanism of water body. As a result, the water volume that flows to communities downstream decreases and may eventually stop, thus exacerbating water scarcity.

Land use change can also adversely affect water quality. The ecological impacts of pesticides in water are determined by the pesticide toxicity, persistence⁵¹, degradation and environmental fate⁵² (FAO, n.d.). Pesticides affect aquatic life and may kill off some species. Ingestion of pesticides in sufficient quantities can cause serious effects in humans, including: suppression of the immune system, disruption of the endocrine (hormonal) system, reproductive inhibition or failure, and cancers and tumors (FAO, n.d.). As a result, communities that obtain their water for consumption downstream from sources of contamination will consistently ingest large quantities of pesticide, and thus may be subject to the negative health effects outlined above.

In addition to land-use change, several other factors may result in contamination of water resources. Lack of adequate sanitation is an important cause of contamination. When sanitary facilities are absent, and open defecation is practiced, wind and rain can transport faecal material into water sources. Animals are also an additional source of faecal and parasitic contamination. Furthermore, wastewater seepage may result from poorly

⁵⁰ Eutrophication is a process whereby the dissolved oxygen concentration in the water decreases causing aquatic species to die off.

⁵¹ The pesticides that have been applied, until very recently, have been non-biodegradable. As such, they can be assumed to be highly persistent.

⁵² Environmental fate refers to the chemical behavior of a substance when released in nature.

constructed or poorly maintained latrines. Water sources may also be directly contaminated when they are used for multiple purposes, such as washing, which is common. Finally, even when the quality of water provided by the system is preserved, water may become polluted if it is stored and/or transported in contaminated container (IRC, 1991).

Da Rosa (1995) explains that the quality of water resources in Ecuador has continuously deteriorated over the last twenty years. The majority of rivers in the country have been found to have worrisome levels of pathogenic microorganisms. She goes on to explain that one of the most significant problems in Ecuador is the use of surface water as domestic and industrial wastewater receptors⁵³. The use of pesticides, insecticides and fungicides has also grown significantly throughout Ecuador, and these treatments are being deployed without the proper precautions. These products contain substances that have been banned in other countries due to their high degree of toxicity and high persistence in the environment (i.e. DDT, lead). In addition, increased erosion, due to deforestation, results in increased levels of suspended solids in affected surface water (Da Rosa, 1995).

6.3 Effects of Environment Threats on Technology: Evidence From the Field

During my initial week of field research, I conducted an interview with an official from the Ecuadorian Ministry of Environment.⁵⁴ The official was asked which environmental factors she believed would impede water-supply sustainability in rural Andean villages. Deforestation and increasing contamination of water resources were the primary concerns identified. The official further specified that increased productive and agricultural activities, as a consequence of a growing population, were important causes of declining water quality and water availability. The suggestions made by this official of the Ministry of

⁵³ Wastewater is often discharged into water resources without any pre-treatment.

⁵⁴ The official from the Ministry of the Environment requested that her name not be used.

Environment support the evidence provided by the literature regarding the human-caused environmental threats to water supply sustainability, as outlined above. The official did not mention the effects of natural environmental hazards. The remainder of this section will examine the factors, both natural and anthropogenic, which have affected water supply from the point of view of the users.

We have already seen that the entire province of Chimborazo is subject to seismic activity, which results in rock falls and landslides. Rock falls and landslides primarily affect systems that use pipes to transport water and/or rely on springs or other surface water sources. Ten communities received systems that were found to be appropriate, as reported in chapter three, and use pipes to transport water from a source to the users. In community meetings, six of these communities indicated that rock-falls and landslides had affected the performance of their water supply system. The six communities are as follows:

Table 20: Communities where rock falls and landslides have affected their water supply system

<i>Community</i>	<i>Canton</i>	<i>System Type</i>	<i>Sustainability</i>
San Javier de Tunshi	Riobamba	GFWS	Sustainable
Santa Ana Saquon	Riobamba	GFWS	Abandoned
San Antonio de Chacazo	Guamote	GFWS	Marginally Sustainable
Pulcate Cuatro Esquinas	Colta	GFWS	Marginally Sustainable
Muelñag	Guano	GFWS	Marginally Sustainable
Alacao	Guano	GFWS	Marginally Sustainable

These communities explained that rock falls periodically crack or break the pipes and that landslides cause blockages. However, all of these communities⁵⁵, including the ones whose systems were working only very marginally and irregularly, indicated that the communities also fix the tubes when they break and clear blockages when they occur.

⁵⁵ The community of Santa Ana Saquon had completely abandoned their domestic water system. They had resorted to using a nearby irrigation canal as their source of water. The community cleared blockages that resulted from landslides from the canal. The distribution system was not repaired since the irrigation canal did not serve the distribution system and their previous system was no longer in use.

The community of San Javier de Tunshi was the only community with a sustainable system amongst this group. When asked about the maintenance that is performed on their system, community representatives of San Javier de Tunshi responded as follows:

Otro problema que tenemos es en el sifón. Tenemos, ah, como se llama esto? Existe unos derrumbos que recién de la otra semana nos arreglamos la tubería. Existen unos derrumbos, bajan las piedras y caen en el tubo, y rompe. (San Javier de Tunshi)

[Another problem that we have is in the bend of the pipe. We have, how do you call it? There exists some rock-falls that recently, only last week, we had to fix the tubes. There exists some rock falls, the stones come down and fall on the tubes and break them.]

The community of Alacao, which had only a marginally sustainable system that only delivered small quantities of water roughly every third day, was also able to repair its tubes as needed. When asked about whether the community treated its water, community members responded as follows:

Bueno, hay que ser un poco más sincero. Lo que pasa es que el pago es bastante baja y eso no alcanza para poder clorar, cuesta bastante no. Además que eso, es para el mantenimiento que tenemos. Y gracias a lo poco que se recoge pues, tenemos mas que dos mil dólares en fondos para emergencias que presenta con la tubería. Es que a veces cuando se llueve, se va llevando todo o se rompe alguna tubería, entonces si no [pagamos] podemos pasar siete meses sin agua (Alacao).

[Well, we should be a little more sincere. What has happened is that the payment is so low that it is insufficient for chlorination, which costs a lot. And more than that, it's for maintenance that we have. And thanks to the small amount that we have collected, we have more than two thousand dollars in funds for emergencies that present themselves with the tubes. It's that sometimes, when it rains, it brings everything with it and it breaks a tube. If we don't pay, we could pass seven months without any water.]

Despite this, not all of the communities fix the pipes with equal effectiveness. The community of San Antonio de Chacazo indicated that it did not collect a monthly tariff for water usage, and consequently could not afford to repair the pipes. As a result, that community repairs tubes with old car pipes that it obtains from the scrap yard. This introduces a serious level of contamination into their water and substantially undermines the effectiveness of the system.

Nonetheless, because all communities reported that they were able to cope with the effects of rock falls and landslides by repairing and clearing tubes, it must be concluded that these environmental phenomena did not adversely affect the sustainability on these systems.

In total, three communities brought up the effects of the volcano of their system. Volcano Tungurahua began erupting four years ago. This has significantly affected the cantons of Guano and Penipe, and to a lesser extent, the cantons of Riobamba and Guamote. The three communities that mentioned the volcano were as follows:

Table 21: Communities that discussed the effect of the volcano on their water supply system

<i>Community</i>	<i>Canton</i>	<i>System Type</i>	<i>Sustainability</i>
San Javier de Tunshi	Riobamba	GFWS	Sustainable
Santa Ana Saquon	Riobamba	GFWS	Abandoned
Muelñag	Guano	GFWS	Marginally Sustainable

According to the communities of San Javier de Tunshi and Santa Ana Saquon, the volcano has caused rock falls and landslides. As we have already seen, these would also occur in the absence of the volcano. Accordingly, the effect of the volcano on these communities could be said to be simply increased frequency of rock falls and landslides. The accounts given by the communities confirm the ranking that the Government of Ecuador had given to the region, as shown in Table 21 above. The government ranking, and the accounts given by the communities, show that the regions, and consequently their water supply systems, are indeed affected by the volcano, but not very significantly. Since these communities are equipped to handle periodic rock falls, the marginal increase in frequency of rock falls, caused by the volcanic tremors and eruptions, were found not to threaten the sustainability of their systems.

In contrast, the community of Muelñag is located in the canton Guano, which was given the maximum ranking for the degree to which volcanic eruptions affect the region.

Muelñag reported that both the frequency and intensity of tremors and rock falls have increased since the volcano began erupting. Community representatives explained that the eruptions have changed the shape of the spring that supplies their system, and that the amount of water available has substantially decreased. They also noted that the ash from the volcano has contaminated their water source, and that the color, taste and odor have all deteriorated as a result. Finally, they reported that the ash from the volcano burns their crop and they believe that it is also drying out their water source.

The community of Muelñag was also the only community to mention the effects of deforestation on the technology. After the discussion on the effects of the volcano, the community was asked if there were any other environmental conditions that they feel have affected their system. Their response was as follows:

Vegetación no hay. Además, están trabajando por arriba al vertiente allá en el Páramo donde nace la agua. Eso también es la falla. Si, antes había mas vegetación. Había paja y después se aportaron. Bastante votaron. Los dueños del terreno están usando el terreno para sembrar papas. Y la paja se usan para construir casas.
(Muelñag)

[There is no vegetation. In addition, they are working up high by the spring, and over there in the Páramo. There was straw, and then they took it. They have taken a lot. The owners of the land are using the land to sow potatoes. And the straw is used to make houses.]

As we have seen in chapter five, however, Muelñag is also subject to the common pool resource dilemma, as outlined in chapter six. Consequently, the evidence provided above is thus insufficient to attribute the cause of non-sustainability of the system to environmental factors alone. However, the evidence provided does indicate that environmental factors were likely a contributing factor to the reduced capacity of their water supply system

However, it must also be considered that Muelñag has always been subject to the CPR problem since the implementation of the project. According to the community's

account, the system functioned well and provided sufficient water until the volcano started erupting. Perhaps the source originally contained so much water that even if water was severely overused and wasted by communities located at higher elevation, there would still be sufficient water to reach local residents. If the water has diminished due to environmental problems, then one of two things is occurring: The first possibility is that there truly is no longer enough water to adequately serve three communities. The second possibility is that there remains sufficient water if the water were managed properly, but that water must now be conserved higher up the system so that it may reach “lower down”.

The community of Alacao is also located in canton Guano, where the effects of volcanic eruptions are ranked at their maximum. The community informed us that their water source had dried up significantly, although they did not attribute this to any particular cause. This is reflected in the following quote:

Desgraciamente, ahora estamos un poco escasos por la situación de la acequia. Se sequió bastante. Bueno, el problema del sistema es que tenemos agua bastante irregular. Y además para que les haga, no hay como arreglar. En este sentido pues, hemos tratado a ir sectorizando pero sin embargo por la deficiencia que tenemos mismo de agua porque físicamente los hoyos han bajado un poco mas abajo. Y nos toca hacer unas nuevas captaciones. Entonces estamos en eso ahora para ver si podemos volver a tener la misma cantidad que tuvimos antes. (Alacao)
[Unfortunately, now we have a bit of a problem with the stream. It has dried up significantly. The problem that we have with the system is that it is very irregular. And more than that, there is not way to repair it. In this light, we have tried to divide the system into sector because of the deficiency of water, because the water level in the holes is physically going down. We will have to do new captivations. So this is where we are now, to see if we can go back to having the same quantity of water that we had before.]

The community of Alacao informed us that they had an analysis carried out on their water source and found that the source flow-rate had diminished from seven liters per second when the system was installed to three liters per second currently. Alacao is also subject to the CPR problem examined in chapter five. However the scientific analysis of its source provides concrete evidence that environmental conditions have significantly affected

the sustainability of its system. It remains unclear, however, which particular environmental phenomenon (landslide, rock falls, deforestation, volcano, and land-use change), is the cause of the community's diminishing water supply. In all likelihood, it is probably a combination of several or all of these factors.

One final consideration that must be raised in assessing the reasons that a source may 'dry up' is that of over-extraction. Over-extraction occurs when the water withdrawn is greater than natural recharge of the source. Over-extraction may occur due to excessive demand or poor demand management. Excessive demand in rural villages is primarily due to unanticipated population growth. When appropriate technologies are designed, an estimated population growth rate is often assumed. When population growth is significantly higher than expected, the source may not be able to provide adequate water to satisfy the true demand. This may cause the source to eventually dry up. Alternatively, when water is not metered and consequently not properly managed, water can be wasted and more water than is needed (or that the source was intended to provide) may be extracted.

Finally, only two communities raised the issue of deteriorating water quality: San Antonio de Chacazo and Muelñag. The water quality in San Antonio de Chacazo was substantially reduced because they used old car parts to fix their pipelines. The water quality in Muelñag had decreased due to the sulphur expelled from the volcano. None of the communities in this study mentioned the affects of pesticides and fungicides on water quality. In addition, no community mentioned the effects of increased erosion, or increased water turbidity, due to land-use change. This does not necessarily mean that these effects are not present. These effects tend to be less tangible, and so it is possible that the communities have not generally associated these causes and effects with one another. In addition, the decreased quality that results from pesticide and fungicide use is not visible to the naked eye.

It also does not alter taste or odor. Consequently, the communities may not be aware of this contamination.

6.4 Control of Environmental Factors Affecting System Sustainability

No literature was found that holistically addresses means of mitigating the effects of environmental conditions and occurrences on small-scale water supply systems. Specifically, ways in which the affects of natural environmental phenomena (seismic activity, landslides, rock falls, and volcano eruptions) on water supply systems could be mitigated have been generally overlooked in both scholarly and professional discourse. The majority of the 'environment and water supply' literature that does exist concentrates on the prevention of contamination of water supplies. The IRC (1991) suggests three means of preventing the affects of deforestation, land use change, and other contamination of water, as follows: risk assessment, technological solutions, and legal mechanisms.

Risk assessment is aimed at avoiding the risk of contamination by "human waste, agricultural chemicals, livestock faeces and industrial discharge" (IRC, 1991, p.35). Risk assessment should be carried out during the planning stage and consists of taking into consideration the present and future risks in order to select the sources and sites with the lowest risk of being affected by environmental conditions and potential changes (IRC, 1991). By evaluating the risk from the outset, better decisions can be made during system design. Preventative activities can also be planned and incorporated into a maintenance strategy.

Technical solutions are another means of preventing contamination and the effects of land-use change and deforestation. Technical solutions include sanitation, source protection, health and hygiene training, soil and water conservation techniques, and wastewater treatment and reuse. Providing adequate sanitation, typically by building latrines

that are accepted and used by the local population, can ensure that excreta is contained and reduce the risk of contamination of source water. Taking into consideration the multiple uses of water and properly designing for them should also reduce the risk of contamination. Education and training play key roles in this area, as well. Source protection is another technical solution and consists of providing a physical barrier between the water and contamination. Examples of source protection include: providing a cover for wells and erecting a fence⁵⁶. In addition, wastewater treatment and reuse are also advocated for the prevention of contamination⁵⁷.

There are several soil and water conservation techniques that can be employed and incorporated into regular agricultural practice. Re-forestation is a technique that is recommended to reduce soil erosion⁵⁸. Water conservation techniques include water metering, and paying tariffs based on water use. Soil conservation techniques and other water conservation techniques that are specific to agricultural practices would often be overlooked during a stand-alone water supply and sanitation project. In order to effectively address these issues, water supply and sanitation projects could be integrated with agricultural development projects. We have already seen in chapter five that the likelihood of system sustainability increases when it is integrated with other development projects that have economic value.

⁵⁶ Protecting a source in this way may also protect the immediate surroundings of a catchment area from deforestation and agricultural activities, which in turn assists in the prevention of diminishing water availability from the source.

⁵⁷ If wastewater can be collected, it can be prevented from contaminating the surrounding environment. Water used for irrigation does not have to meet as stringent water-quality requirements as that of drinking water. The wastewater that is collected can then be treated so that it is safe for discharge into the environment and used productively, i.e. for irrigation.

⁵⁸ Re-forestation may, however, not be very realistic in the context of the Ecuadorian Sierra, because the land is typically in use for grazing or growing potatoes. Re-forestation would make more sense in a context where the trees are being cut down for construction materials and the land on which they sat remains out of active use.

Finally, legal mechanisms are another way of preventing harmful contamination.

“The primary objectives of regulatory instruments are to limit public health risk and environmental damage” (WEDC, 2003, p. 1.12). In order for water quality standards to satisfy their primary objective (as stated above), they must be realistic, effective, regulated and enforceable, and yield a balanced or positive cost-benefit calculation (WEDC, 2003).

6.5 Effectiveness of Prevention Strategies at Preserving Catchment Areas and Water Supply

The effectiveness of risk assessment could not be assessed during field research in Ecuador, as the specific aid organizations that were involved in the respective projects were not interviewed. As a result, no conclusion can be reached regarding the effectiveness of these procedures.

However, some of the effects of technical solutions could be assessed. All of the communities that were visited were asked if they had received latrines. They were also asked if the latrines are still functional and if the majority of the community uses them. The results are presented in Table 22 below:

Table 22: Latrine Presence, Condition and Usage in Communities

<i>Community</i>	<i>Have Latrines</i>	<i>Latrines in Working Order</i>	<i>Use Latrines</i>
San Javier de Tunshi	Yes	Yes	Yes
Santa Ana Saquon	Yes	No	No
San Pablo	Yes	Yes	No
Santa Ana Guagñag	Yes	Yes	No
Pulcate Cuatro Esquinas	Yes	No	No
Misquismi	No	No	No
Alacao	Yes	Yes	No
Muelañag	Yes	Yes	Yes
San Miguel Pumachaca	No	No	No
San Antonio de Chacaza	No	No	No

Table 22 continued: Latrine Presence, Condition and Usage in Communities

<i>Community</i>	<i>Have Latrines</i>	<i>Latrines in Working Order</i>	<i>Use Latrines</i>
Opote San Vicente	Yes	Yes	No
Pachamama Grande	No	No	No
Curiquinga	Yes	No	No
San Franscisco de la Providencia	Yes	No	No
San Franscisco Billud	No	No	No

Of the fifteen communities that were visited, ten communities had received latrines. Of those ten communities, only six indicated that their latrines were still in working order. In addition, only one community indicated that it was actually using the latrines in practice. These results clearly indicate that simply providing proper sanitation facilities does not ensure that they will be maintained and used. This also means that providing proper sanitation cannot be assumed to reduce the risk of faecal contamination of water sources.

Communities were not specifically asked about source protection during field visits. However, these were observed on several occasions. All hand-pump systems functioned with a protected and covered well. In addition, fencing of catchment areas was commonly evident. The fencing area, however, was typically quite small and was intended solely for keeping animals out. Agricultural activities often surrounded the fenced area and it was not clear that the fenced area was sufficiently large enough to protect the source from the effects of land-use change.

The official interviewed from the Ministry of Environment in Ecuador indicated that Ecuador had developed a re-forestation plan. She explained that this plan only applied to trees and excluded other vegetation, such as the type that is native in the Páramos. However, she also explained that the Ministry did not have the resources to implement the plan and, as a result, no re-forestation had begun yet.

It was found that the communities visited were somewhat effective at avoiding contamination from multiple uses of a water source. All communities that were visited used different sources of water for domestic water and for irrigation. In addition, it was found that laundry tended to be washed in a river that typically did not serve as the source for either their drinking or irrigation water. Wastewater collection, treatment and re-use were non-existent in all of the communities visited.

Ecuador has developed environmental standards and guidelines, however, they have not been widely adopted in practice. The Ministry of Environment (MoE) official stated that there is no monitoring and/or enforcement of the environmental standards that they establish. The MoE representative noted that the municipalities have control and responsibility for the resources within their jurisdiction. This authority of the municipalities includes that of compliance with environmental standards and regulations. However, there is no system of accountability between the municipalities and the MoE to ensure consistent standards of performance. Furthermore, wastewater generated in rural villages falls largely outside the scope of the standards, and no institution has accepted responsibility for waste collection, treatment, and/or disposal in these settings.

6.6 Recommendation for Mitigating the Environmental Effects on Water Supply Sustainability

One case encountered during site visits provided evidence that backup systems could be implemented to ensure that communities have continuous access to clean water. The community of Misquimi has received three sequential water supply systems through three distinct water-aid initiatives. The community is primarily dependent upon a hydraulic ram pump with a distribution system for their domestic water supply. We have already seen that this system has been classified as sustainable. Nonetheless, community representatives

explained that this system is still rendered inoperational periodically when the system is in need of repair⁵⁹. Community representatives further explained that during such times, the community relies on the hand pumps that are present and still functional from the previous initiative. As a result, the community of Misquimi is the only community encountered during field research that enjoys continuous and constant access to a safe water source.

Standard engineering practice dictates that attention should be paid to safety for all designs (Juvinal & Marshek, 1991; Kumar, 1999). Common engineering practice includes the use of safety factors, and redundancy. The use of safety factors ensure that systems are designed for peak loads that are greater than that encountered during normal usage. In the case of water supply systems, safety factors could be applied to the water demand assumed, prediction of population growth, and for water flow rates. In addition, redundancy should be considered whenever possible, since this minimizes the risk of failure (Kumar, 1999).

It would appear that these engineering concepts have generally not carried over into the field of appropriate technology. In design, safety is recognized as a relative concept as there are always tradeoffs between safety, size and cost (Juvinal & Marshek, 1991). Perhaps these practices have not fully carried over to appropriate technology designs since appropriate technology is purposefully kept simple and as cost-effective as possible. However, if the lack of redundancy or adequate use of safety factors result in the underperformance of systems, or cause villagers to resort back to traditional sources while they are being serviced, perhaps these practices should be re-examined. This may be one of the few ways to mitigate the effects of spontaneous environmental events, such as volcanic eruptions, landslides, and earthquakes.

⁵⁹ The system is in need of repair when a washer gets worn out or when there is seismic activity, causing blockages in the pipe and the occasional cracking.

6.7 Conclusion

There are many ways in which regular environmental conditions (such as seismic activity, landslides and rock falls), together with the emergence of spontaneous environmental threats (i.e. volcanic eruptions), can influence the yield and quality of water supply systems. Many human activities also lead to diminishing water supplies and to environmental contamination. While there are no strategies to mitigate the effects of natural hazards on appropriate technology, there are several means of dealing with user-caused changes. However, these means have been found to be largely inadequate and ineffective in the context of the case study region.

Chapter 7 – Conclusion

Currently, it is estimated that as many as 2.2 billion people worldwide lack access to sufficient clean water to satisfy basic needs. Water plays a fundamental role in development. An important end in itself, water is essential to improve health and quality of life. Water may also be considered a critical input to development as it frees time for productive or educational activities, and enables greater worker efficiency. Water-related diseases represent the largest burden of disease worldwide. Water supply for domestic purposes is of critical importance as it profoundly affects human health.

Water supply and sanitation constitutes a major sector of international development assistance. Domestic water supply was considered as a priority sector for development assistance throughout the 1980s, known as the “water decade”. Investment in the sector continued in the 1990s. The World Bank lent \$1 billion in the sector between 1990 and 1998. However, a review of the effectiveness of this aid found that only 43% of Bank projects were likely to produce sustainable results (OED, 2000). An extensive literature documents the unsustainable results of similar initiatives.

The issue of sustainability is critical. This thesis examined the drivers of sustainability for rural water supply systems. The rural water supply literature is highly fragmented, and includes few attempts to address the issue of sustainability holistically. This literature gives prominence to appropriate technology and demand-responsive supply approaches as key drivers of sustainability. Some of the literature acknowledges that environmental factors can affect sustainability, but fails to provide explicit recommendations to mitigate their effects.

For the present study, the following definition of sustainability was adopted: *A water supply system will be considered sustainable if an acceptable level of service is maintained indefinitely, in the absence of external support, and evaluated after a minimum of five years from the date of its implementation. An acceptable level of service will be considered to be one that is enjoyed by all community households and that meets the minimum daily BWR of 50 liters per capita to the minimum quality standard specified by the World Health Organization (WHO).*

It was not possible to use this definition to classify the performance of all water supply systems visited during field work. As a result, an operational definition of sustainability, based on field observations, was developed. All systems were classified as abandoned, marginally sustainable or sustainable, and this classification formed the basis of the analysis that was conducted for this thesis. This study examined sustainability over the 15 year period that occurs after the initial five years that follows construction, and found that there is a poor rate of sustainability during this period. As this field develops and systems become more sustainable, future research should shift towards an examination of longer-term sustainability, that is, beyond the 20-year initial period of a system.

The present study was conducted in province of Chimborazo in Ecuador. This province is one of the poorest provinces in Ecuador, and faces water scarcity conditions that are prevalent throughout much of the Andes. Fifteen communities -- representing a roughly five percent sample of communities in the province that had received assistance to establish a water supply system -- were visited in order to collect the necessary data to address the research question. The communities were geographically spread over five of the ten cantons in the province.

The present study showed that appropriateness of the technologies is indeed a factor that drives the sustainability of rural water supply systems. Field research indicated that

implementation of inappropriate technology does, in fact, cause failure. However, at the same time, the study found that use of appropriate technology is insufficient on its own to ensure sustainability. It is therefore a necessary but insufficient driver of sustainability.

There are now a host of technologies that have been labeled “appropriate”. This present research highlights the importance of considering each technology in the context of the local environment. In evaluating the “appropriateness” of a technology, long-term affordability must be considered. If the technology is dependent upon ongoing operational inputs, the market volatility for these inputs must be considered. In addition, technology decisions should not be made on the basis of price alone. Local availability of replacement parts is equally important. It is essential that communities be able to obtain replacement parts as needed, independent of external assistance.

The study also investigated elements of the demand-responsive approach, which gained prominence in the 1990s. The first prong of this approach states that water should be managed as both an economic and social good. The literature interprets this to mean that beneficiaries should be required to pay a portion of initial capital costs, and typically, all ongoing operation, maintenance and repair costs. In addition, the users must officially request and initiate the assistance. However, field research from the present study suggests that willingness-to-pay may not accurately represent the value users place on a clean and accessible source of water. Interviews revealed that water supply was viewed as a priority in most villages and that it was highly valued. In addition, maintenance was found to be a more critical issue with respect to sustainability, compared with tariff payment. Most communities indicated that they face few issues related to non-payment. However, neglect of maintenance was found to be widespread. More research is needed into how incentives can be designed to encourage effective and continuous maintenance.

The second prong of the demand-responsive approach states that water should be managed at the lowest appropriate level. The focus within this component is on full user participation. Field results for this study suggest that while participation is strongly encouraged since it allows systems to be designed and implemented in the manner most consistent with the needs of the beneficiaries; such participation appears to be insufficient to ensure sustainability. The literature tends to focus extensively on participation, and substantial literature exists that attributes failure of water supply systems to a lack of adequate participation. While this component is still considered very important, the findings of the present study suggest that perhaps this factor has been given an undue amount of attention as a driver of sustainability.

The present study introduced a third analytic framework: that of common pool resources (CPR). The CPR literature tends to focus on productive natural-resource management, and deals in the water sector only with irrigation systems rather than potable water. Nonetheless, field research for the present study assessed CPR dimensions of the sampled communities, and found that the issue of governance is central to sustainability. More specifically, congruent-allocation provision was found to improve the likelihood of sustainability. That is, rules that demonstrate congruence between water withdrawal rights and financial contributions may improve sustainability. In addition, evidence from one community indicated that integrating non-productive and commercial activities related to water may improve sustainability. Much further research is merited to assess in detail the CPR nature of domestic water supply systems.

Finally, environmental conditions were found to affect the sustainability of infrastructure in the region under study. The literature widely acknowledges this but fails to specify policy recommendations to mitigate their effects. While the literature on water

supply sustainability documents the effects that the environment can have on sustainability, it focuses on prevention mechanisms and fails to provide any meaningful recommendations for mitigation of the effects. Environmental factors were examined for the villages researched here. Environmental conditions were, in fact, found to have an impact on water supply sustainability. One recommendation generated by the study is that a “backup” system be considered in the design of future initiatives. Possessing more than one type of system improves the probability that the community will have continuous access to a clean water source, even when one of the systems must be taken out of operation for repair because of environmental factors.

Overall, the present study has found that there are four important drivers of sustainability: appropriate technology, demand-responsive supply (notably tariff payment and participation), the common pool resource nature of potable water (especially with regard to governance and rules), and environmental factors. This thesis has interrogated a global multi-disciplinary literature, as well as conducted local level, community-based field research, in order to arrive at this conclusion.

There are several implications of this overall finding. First, there is a strong case to be made for scholars and practitioners to take a more holistic approach to the theory and practice for potable water system sustainability. Fragmented, “silo-ed” approaches that remain locked solely in, say, the fields of engineering, community development, or environmental management, are clearly insufficient to understanding accurately and effectively how sustainability can be achieved. This thesis has attempted to address the issue of sustainability from a holistic perspective. Nonetheless, much work remains to be done in this area. Further research is encouraged to investigate how the linkages between and across these four areas could be assessed systematically.

Second, the blending of CPR and environmental frameworks with those of appropriate technology and demand-responsiveness offers greater analytic power than any two or three of these frameworks combined. All four are necessary for a full and accurate analysis of obstacles to, and solutions for, sustainability.

Third, there is more research needed on specific issues within each of these frameworks. The interplay of affordability and accessibility of replacement parts, incentives for continuous maintenance, the interaction of community participation with sustainability drivers, the comparative effectiveness of allocation-provision regimes, the role of back-up systems in mitigating negative environmental conditions, and the relationship between equity and sustainability are all examples of issues worthy of further research.

Of course, the present study field research was limited to a small number of communities in a very particular part of the world. Caution must be exercised in generalizing from these “on-the-ground” findings. However, the field research served as a useful milieu for the testing of global trends in policy and practice, and to gain insights within and across the drivers of sustainability. Further research should be undertaken to examine these drivers in a larger number, and wider range, of communities and regions.

Water is essential to life. More than 2 billion citizens of developing countries still lack access to adequate drinking water systems. System sustainability is crucial for effective poverty reduction. It is time for scholars, practitioners, and development agencies to adopt a more comprehensive and holistic approach to sustainability of potable water systems. It is a matter of life and death.

Appendix 1: List of Acronyms

Acronym	Meaning
BWR	Basic Water Requirement
CNRH	El Consejo Nacional de Recursos Hidricos
CPR	Common Pool Resource
DAC	Development Assistance Committee of the Organization of Economic Cooperation and Development
DDT	Dichloro-Diphenyl-Trichloroethane
DRS	Demand Responsive Supply
FAO	Food and Agriculture Organization
GFWS	Gravity Fed Water Supply System
IDRC	International Development Research Center
IRC	International Water and Sanitation Reference Centre
ITDG	Intermediate Technology Development Group
lcp	liters per capita
MIDUVI	El Ministerio de Desarrollo Urbano y Vivienda
NGO	Non-Governmental Organization
O&M	Operation and Maintenance
OED	Operations and Evaluation Division of the World Bank
PDP	Positive Displacement Pump
PRA	Participatory Rural Appraisal
RWS	Rural Water Supply
SIISE	Sistema Integrado de Indicadores Sociales del Ecuador
UN	United Nations
UNICEF	United Nations International Children's Emergency Fund
USAID	US Agency for International Development
USGS	U.S. Geological Survey
WCED	World Commission on Economic Development
WEDC	Water, Engineering and Development Center
WEHAB	Water, Energy, Health, Agriculture and Biodiversity
WHO	World Health Organization
WSP	Water and Sanitation Program
WSS	Water supply and sanitation
WTP	Willingness to Pay

Appendix 2: List of Interviews

Individual Interviews:

Jose Rosca, Engineer, Ministerio de Desarrollo Urbana y Vivienda (MIDUVI) Regional Office Riobamba, Ecuador

Rodrigo Carpio, Technical Director, Programa de Agua y Saneamiento Para Comunidades Rurales y Pequeños Municipios PRAGUAS and MIDUVI, Quito Ecuador

Marcia Perez, Social Consultant, PRAGUAS, Quito Ecuador

Ministerio del Ambiente, Quito Ecuador

Juan Moscoso, Engineer, Consejo Nacional de Recursos Hídricos, Quito Ecuador

Community Meetings (all are in the Province of Chimborazo, Ecuador:

San Javier de Tunshi, Parroquia Licto, Canton Riobamba,

Santa Ana Saquon, Parroquia Quimiag, Canton Riobamba

San Pablo, Parroquia San Juan, Canton Riobamba

Santa Ana Guagñag, Parroquia Licto, Canton Riobamba

Pulcate Cuatro Esquinas, Parroquia Columbe, Canton Colta

Misquismi, Parroquia Cajabamba, Canton Colta

San Francisco de la Providencia, Parroquia Columbe, Canton Colta

Opote San Vicente, Parroquia Santiago de Quito, Canton Colta

San Miguel Pumachaca, Parroquia Palmira, Canton Guamote

San Antonio de Chacaza, Parroquia Guamote, Canton Guamote

San Francisco Billud, Parroquia Palmira, Canton Guamote

Alacao, Parroquia Guano, Canton Guano

Muelañag, Parroquia Valparaiso, Canton Guano

Pachamama Grande, Parroquia Tixan, Canton Alausi

Curiquina, Parroquia Tixan, Canton Alausi

Appendix 3: Change in Research Question

The research question has changed somewhat from its original conception. The original research question was: Why do fog water catchment systems fail or succeed in high rural communities in Nepal? Application to the Ethics Committee was made in accordance with this research question. However, shortly prior to the intended commencement of field research, the civil unrest and insurgencies in Nepal severely escalated, making the proposed research impossible. Since fog water systems had also been implemented in South America, it was decided that the same research question could be investigated there. The Ethics Committee was informed of this change. Since there were no fundamental differences from the initial application in terms of methodology, the Committee approved the change without the need for a new application. This change is shown in their letter of approval, which is included in Annex 4.

In preparation for field research, new concerns emerged as a result of the change in geographical region. The systems installed were scattered between different countries and over very large distances, making the practicalities of the proposed research more difficult. While all of the systems in Nepal had been implemented to supplement water for domestic use, some of the systems implemented in South America had been implemented for irrigation. It was felt that the sustainability of systems implemented for irrigation could not be compared with the sustainability of systems implemented for domestic water use because the incentives facing the beneficiaries would be substantially different. It was therefore decided that this study would focus exclusively on water as a basic need and would consequently restrict itself only to domestic uses of water. This decision further restricted the cases available for study in the region.

In addition, all fog water catchment systems installed in South America were implemented in partnership with one particular NGO. A concern emerged that by maintaining the aid NGO constant in all cases, the study would result in an evaluation of the methodology of that particular NGO instead of the conditions for sustainability more broadly. Finally, variation on the dependent variable, namely sustainability, was necessary in order to draw any conclusions. The search for study cases, prior to field research, failed to turn up any sites that met this study's criteria for sustainability. It appeared that all fog water catchment systems implemented in South America had been unsustainable and a study of the determinants of sustainability would therefore not be possible. As a result, the scope of the study was broadened slightly to examine the factors that affect sustainability of rural water supply systems for domestic water use generally. This gave rise to the research question that is the subject of this study. As the final research question did not fully emerge until field research was already underway, these changes could not be reflected in the letter of approval from the Research Ethics Committee, although they were informed of the possibility of this change.

Appendix 4: Letter of Approval from Ethics Committee

OFFICE OF RESEARCH SERVICES

Research Ethics Committee
Room 511A Tory Building
1125 Colonel By Drive
Ottawa, ON K1S 5B6
Telephone: 613-520-2517; Fax: 613-520-2521

29 March 2004

Ms. Evelyn Noy
M.A. Candidate
Norman Paterson School of International Affairs
Carleton University
1125 Colonel By Drive
Ottawa, Ontario
K1S 5B6

Re.: Ethics Clearance

Dear Ms. Noy,

The Carleton University Research Ethics Committee has reviewed your application for your M.A. thesis research entitled *Sustainability of Appropriate Technology Development Projects: A Case Study of Fog Water Catchment in South America* and given it approval.

The guidelines governing ethics approval are as follows:

1. Ethics clearance is valid for one-year (from date of this letter). If you do not complete the research portion involving human participants indicated in your proposal within that time frame you must contact the Research Ethics Committee so the research project can be considered for an extension.
2. Should there be any significant changes to the proposal you are obligated to contact the Carleton University Research Ethics Committee with the changes.
3. Should any participant suffer negatively from the research please report this to the Research Ethics Committee and indicate what steps you have taken to resolve the situation.

4. Please find enclosed a Completion of Project Report to be submitted at the end of the human participation portion of your project. It is important to complete and return the report, as it is necessary to either continue or close your file. Please note that all files remain with the Research Ethics Committee for a period of seven years. All files are then destroyed.
5. Finally, please include the date of ethics approval on the top right hand corner all consent forms. Should there be any changes to your project or consent forms this will allow you and the committee to track the changes.

Please note that the authority of the Carleton University Ethics Committees is in accordance with Article 1.2 of the *Tri-Council Policy Statement: Ethical Conduct for Research Involving Humans*. The Carleton University policy states: "**Carleton University Ethics Committees are mandated to approve, reject, propose modifications to, suspend, or terminate any proposed or ongoing research that is subject to ethics review pursuant to this policy.**"

If you have any questions please do not hesitate to contact me. On behalf of the Carleton University Research Ethics Committee I wish you the best of luck with your research.

Yours truly,

Leslie J. MacDonald-Hicks
Research Ethics Committee Coordinator
511A Tory Building
613-520-2517
Leslie_MacDonald-Hicks@carleton.ca

cc/I. Weibust
J. Chevalier

Appendix 5: Question Guide for Community Meetings

Impact of Technology on Villagers:

What do you use water for during the day?

Where do you get the water for domestic use (e.g drinking, cooking, hygiene, and sanitation)?

Who collects the water for domestic use?

How is the water collected?

What other sources of water do you use and for what?

How did you get your water for this purpose before you had the improved technology?

How much time do you spend collecting water during a typical day?

How far do you have to go to collect water?

Has the distance you must travel to collect water changed since the system was installed?

How has your use of time changed as a result of receiving your water from this source?

Has the physical effort required for water collection or related activities (such as washing) changed since the system was installed?

Is the system convenient to use? Is it comfortable to use?

Has the amount of water you use changed since you have received the improved system?

Have your uses of water changed since you have received the improved system?

How much water can each people withdraw? How is it measured?

Has the incidence of disease changed amongst children under-5 since the improved water source was installed? (e.g. diarrhea, malnutrition)

Has the incidence of disease changed amongst everyone else since the improved water source was installed? (e.g. diarrhea, malnutrition)

Has the use of the water supply technology impacted your household income?

Has anything been lost by switching to the improved technology? What?

Technology implementation:

How was this project initiated?

How was this particular technology chosen?

How was the community involved?

Please explain to me how technology works.

How did you learn how the system works?

Who decided where to locate the system?

Who designed the system?

Who participated in the construction of the system?

How much money and/or what materials did you (personally) contribute for the construction of the system?

How much money and/or what materials did the community contribute for the construction of the system?

Does the organization that built the system ever visit the community? How often?

Have they provided any support for the system since it has been complete?

Can you contact them with questions or for help?

Economic Viability of Technology:

Do you have to pay for the water that you take? How much? To whom? When?
 What tools are required to repair the technology? Do you have these tools?
 Where can you get replacement parts if needed?
 How are replacement parts paid for?
 If the system breaks and you don't have sufficient funds to fix it, can you borrow the necessary funds?
 Who owned the land that the system is built on before it was constructed?
 Who owns the system and the land that it sits on now?
 How was the land obtained?

Interaction between Environment and Technology:

What is the climate like here?
 How does the weather affect the performance of the system?
 What impact does the technology have on the surrounding environment (e.g. land)?

Institutions and Management of Technology:

Who is responsible for maintaining the system?
 How often does the system need to be maintained?
 What does maintenance consist of?
 How long does it take?
 Who is responsible for operating the system?
 Who is responsible for repairing the system?
 How did you learn to repair the system?
 Is there a water users committee? Who is on it?
 What does the water users committee do?
 How often do they meet?
 What other organization exist in the community?
 What is the method for discussion and decision-making?
 Are there any social or political barriers to water usage?

Sustainability and Conclusion:

How long have you had this system in place for?
 What happens if the system gets damaged or breaks down?
 How long does it take to repair normally?
 What's the longest your system has been broken for?
 Why did it take so long to fix?
 Where do you get your water while the system is not working?
 How could the system be improved?

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