EVALUATION OF POINT OF USE DRINKING WATER TREATMENT SYSTEMS FOR COLONIAS IN THE SOUTHWEST UNITED STATES

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Dedication

To my Father the first and greatest engineer
To my father who was an engineer in every respect except for the degree
To my wife who does the impossible: love me back
To my mother who gives herself away to serve others
To my advisor who taught me to learn
To my friends in whom I can always depend

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Abstract

Clean drinking water is often taken for granted in first world countries, such as the United States. However, thousands of *colonias* residents (settlements in the Southwest US that lack access to basic infrastructure) still lack access to clean drinking water. Such is the case in the Paso Del Norte Region. In Doña Ana County, NM, and El Paso County, TX, *colonia* residents typically rely on shallow domestic wells and hauled water, respectively. However, both water sources can pose health concerns from elevated total dissolved solids and microbiological contamination. With connection to centralized water treatment and distribution still years away, *colonias* require a more immediate and effective solution for their current situation. This research proposed that such a solution could be achieved with a point-of-use (POU) water treatment system. The goal of this project was to provide *colonia* residents with an economically, socially, and environmentally sustainable water treatment system. The objectives of this study were to: (1) assess user preferences and actual water quality data in order to design a household-level water treatment system; (2) develop a holistic point-of-use technology evaluation system that can be used by residents to screen and select a POU drinking water system for their home; and (3) evaluate methods for preserving water quality in drinking water storage tanks. First, focus group studies were conducted in colonias to discuss possible water treatment options and record residents' perceptions and preferences. Water samples were collected from willing participants and analyzed for basic drinking water quality parameters. Second, many types of commercially available water treatment technologies were reviewed and analyzed, and a five-component evaluation and ranking system was developed to facilitate selection and implementation in *colonias*. Third, experiments were performed to evaluate the efficacy and feasibility of using copper and/or hypochlorite treatment to control algae and preserve water quality in storage tanks. The research performed in this study showed that *colonias* that rely on groundwater face more challenges, in the form of microbiological contamination and high salinity, than *colonias* that rely on hauled water. A treatment train of basic cartridge filtration and point-of-use desalination was proposed to address the water quality issues in *colonias* relying on well water or hauled water. It was also determined that the most economically, socially, and environmentally sustainable system was an under-the-sink reverse osmosis (RO) unit. This research also yielded a system of preserving water quality in drinking water tanks, which includes chlorine monitoring and dosing, periodic tank cleaning, and the possible use of copper as an algaecide.

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Chapter 1: Introduction

BACKGROUND

Access to basic water infrastructure is generally taken for granted in the United States. However, throughout the United States, it is still possible to find communities that have either less than adequate or non-existent water infrastructure. More than 12.3 million people live in these *colonias* (a name given to unincorporated communities in the Southwest with minimal infrastructure), along the US-Mexico border (Donelson, 2004). The exact cause of lack of access to basic infrastructure is site-specific, but analysts believe that these reasons, in general, include high infrastructure costs and weak political influence (Olmstead, 2004).

The lack of basic services is more than an inconvenience for the *colonias* residents; because of the conditions that *colonia* residents experience, such as unclean water, health problems are common (Davidhizar and Bechtel, 1999). While it is possible for *colonia* residents to purchase bottled water for drinking, some must drive up to 30 miles to be able to do so (Davidhizar and Bechtel, 1999), and bottled water is not a practical source of water for general hygiene such as bathing and domestic washing.

While legislation aimed at improving conditions in *colonias* has been approved (Mier et al, 2008), and programs improving water services have been created (Wescoat, 2006), *colonias* still face daunting challenges of implementation. Some *colonias* are being connected to centralized water treatment and distribution systems, but there are some communities where the economical and political conditions are such that a connection to the public water supply will take many years, if ever realized. Several of these *colonias* can be found in Doña Ana County

(southern New Mexico, northwest of the City of El Paso) and El Paso County (Far West Texas, east of the City of El Paso), as shown in Figure 1.1.

Figure 1.1: Research study area – *colonias* in the Paso del Norte region

PROBLEM STATEMENT

Colonias in eastern El Paso County rely predominately on certified water haulers for water supply. These water haulers are legally required to be certified by the Texas Commission on Environmental Quality (TCEQ) and provide water that comes only from sources approved by TCEQ (TCEQ, 2013). While the water sources may be good quality, water at the point-of-use may suffer from re-contamination due to the storage of water for several weeks. Indeed, post-collection microbial contamination has been recognized as a problem for households who collect water from other sources and later transport to their homes (Gundry, 2004). Beyond microbiological contamination, research has also shown that algae inside water storage tanks are a problem for *colonia* residents of eastern El Paso County (Campos et al, 2013). For example, Figure 1.2 shows the inside of a water tank, which has been contaminated by algae in the Hueco Tanks area.

Figure 1.2: Algae contamination inside of a household water storage tank in Hueco Tanks

The main water source for colonias in Doña Ana County, NM is shallow groundwater wells, and groundwater in this area is known to be contaminated with high total dissolved solids (salinity). While well water is generally assumed to be less prone to pathogenic contamination (*e.g.*, parasites, bacteria, and virus), it is still possible for the water to become contaminated at the point-of-use because of the lack of residual disinfectant.

GOALS AND OBJECTIVES

In light of the water quality problems faced by *colonias*, the goal of this research is to address concerns caused by inadequate quality of drinking water through a point-of-use (POU) and/or point-of-entry (POE) water treatment system. To accomplish this goal, the objectives of this research are to:

1) Assess user preferences and actual water quality conditions in order to construct a conceptual design for a household-level water treatment system.
2) Develop a holistic point-of-use technology evaluation system that can be used by household residents to screen and select a POU drinking water system for their home.
3) Evaluate the efficacy and feasibility of using copper and/or hypochlorite treatment for preserving water quality in household water storage tanks in *colonias*.

Chapter 2: Determining the Technical and Social Requirements for a Water Treatment System for *Colonias* in the Southwest United States

INTRODUCTION TO *COLONIAS* AND THEIR INFRASTRUCTURE NEEDS

More than 12.3 million individuals live in *colonias* (Spanish word for "settlement"), which are communities with minimal infrastructure along the US-Mexico border (Donelson 2004) that have minimal governance (Colonias Development Council 2009). A group of *colonias* can be found in the Paso Del Norte Region, particularly of Dona Ana County, NM and El Paso County, TX (Figure 2.1). Although the story varies as to how these *colonias* arrived at their current state, the general reasons include high costs of developing infrastructure and little to no political influence (Olmstead 2010). Colonia residents in Doña Ana County (northwest of the City of El Paso) rely primarily on domestic well water, while most households in *colonias* in El Paso County (east of the City of El Paso) obtain their water through certified water haulers (25 TAC §229.83 2006).

When there is a lack of water infrastructure, health problems are common (Davidhizar and Bechtel 1999). Indeed, *colonias* residents have previously had issue with stomach and skin illnesses, which in some *colonias* have been attributed to microbiological contamination and/or algae. Other *colonias* residents have had problems with clogged pipes and broken appliances (Campos, Walker, Walton, et al. 2013).

Whereas legislation aimed at improving *colonias* has been approved in some parts (Mier et al. 2008), as well as programs that focus on improving the water service (Wescoat, Headington, and Theobald 2007), some *colonias* are still far from obtaining clean drinking water. A more immediate solution could come in the form of point of entry water treatment devices.

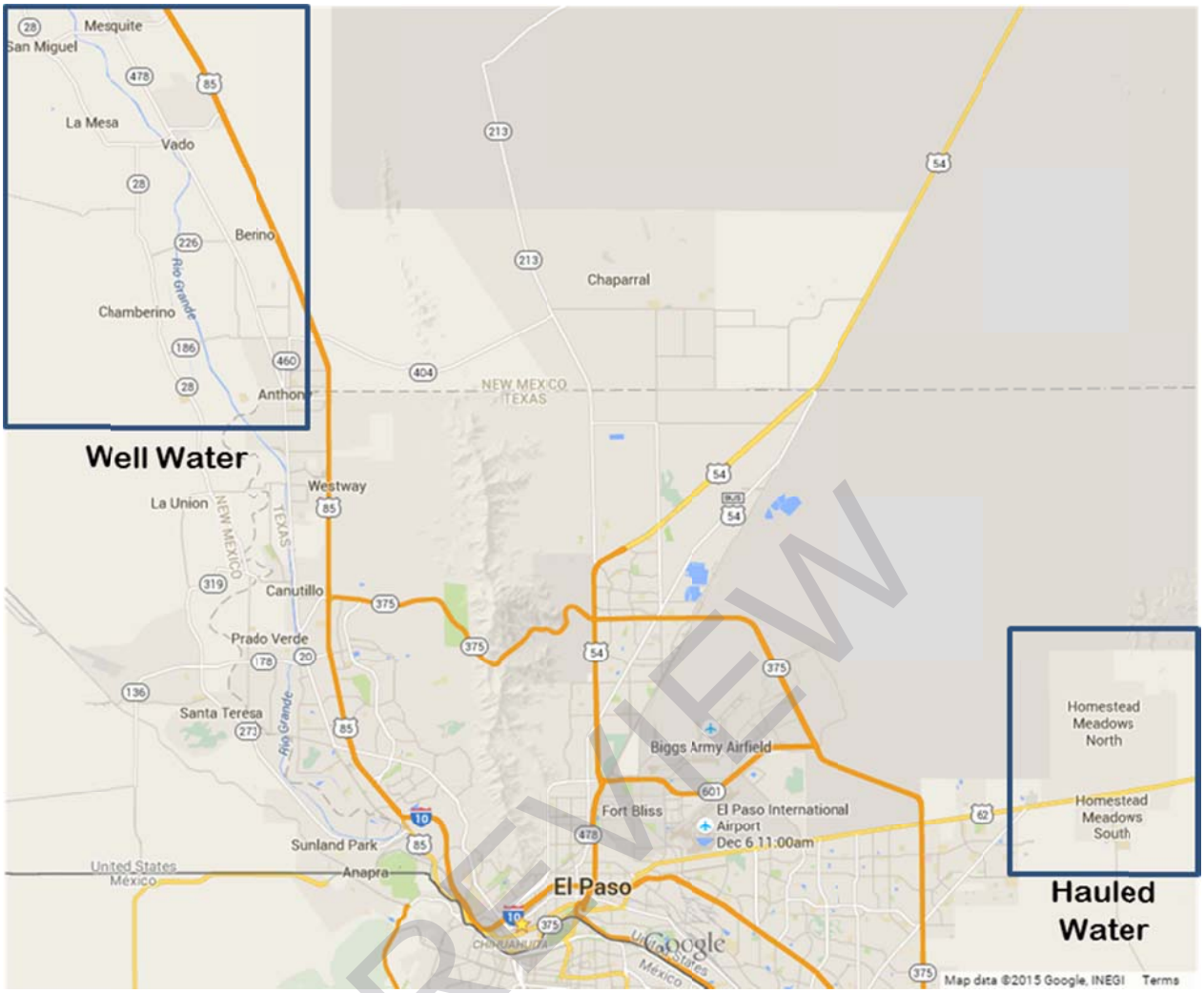

Figure 2.1: Locations of the Paso Del Norte *colonias* engaged in this research

With regards to POE or POU implementation, *colonias* pose a conundrum as they do not meet the EPA definition of a public water system – that is, they do not have at least 15 connections or regularly serves an average of at least 25 individuals daily for at least 60 days of the year (40 CFR §141.2 1996) Furthermore *colonias* are also composed of people who, unlike their counterparts in the developing world, have other options to obtain drinking water and are reluctant or unaware to use the less expensive but more traditional POU devices such as gravity powered filters (Campos, Walker, Santiago, et al. 2013), which are popular in developing countries. *Colonias* have, what can be referred to as, an "expectation problem", as they believe

that the water that reaches their house should be as good, in terms of quality, quantity, and pressure, as the water provided by a public utility. Many things can be said about the problem in itself, but the reality still remains that residents are very likely to forego using a water filtration system if it does not provide them with what they perceive to be "clean drinking water".

The ideal solution for the *colonias* could be a POE system, as it would provide good clean water for the entire household. However, POE systems pose another problem in the form of capital cost. The high cost of POE filtration can be attributed to providing drinking water quality to all fixtures within a home, which may not all require drinking water quality. Whole house devices often feature a cartridge filter followed by a large microfiltration (MF), ultra filtration (UF), or reverse osmosis (RO) membrane. Utilizing an all-membrane system has the advantage of requiring less maintenance by the residents, but it also greatly increases the capital and operational costs. An alternative to membrane filtration is chemical disinfection. Chemical treatments have the advantage of usually costing much less than a membrane. However, if not properly designed and implemented, chemical treatment could prove to be ineffective or altogether more damaging (e.g. DBPs).

Goals and Objectives

There is a need to determine the technical and social sustainability requirements to provide a water treatment system for residents of the Paso Del Norte *colonias*, which may also represent the general requirements needs The goal of this study was to develop a conceptual design for a household-level water treatment system. The first objective was to engage the heads of households through focus groups and determine the social sustainability requirements for a water treatment system. The second objective was to sample and analyze the *colonias'* water supply so as to understand the water quality issues they face. The third objective of this research was to

develop a conceptual design for a water treatment system for the *colonias* and to create a set of educational materials that would help them improve their water quality, even if no system was provided for them.

METHODOLOGY

Focus Groups

A research protocol was developed and approved by the institutional review boards (IRBs) of the University of Texas at El Paso (UTEP), New Mexico State University (NMSU), and the Environmental Protection Agency (EPA) to engage human subjects. The approved IRB protocol for the focus groups allowed researchers to recruit participants, provide them with an informed consent, administer a questionnaire for participants, engage with participants in an open-group discussion, and provide them with a meal and a $30 incentive for participating in the project.

The sampling method for recruiting participants for the focus groups was convenience sampling. The participants in the focus groups were recruited by *promotoras* (Spanish for female "promoters"), who were contacted through the Southern New Mexico Promotora Committee and through El Paso Health and Human Services office. Promotoras and promotores (Spanish for male "promoters") are community health workers who, with or without compensation serve as liaisons between health services, social services, and the community (Texas Department of State Health Services 2015). The focus groups ranged in size from about 5-15 households per focus group. Participants consisted of *colonias* residents in Doña Ana County, NM and El Paso County, TX. A total of five focus groups were conducted; three were conducted in Doña Ana County, NM on Jan 25, 2013, Feb 1, 2013, and March 1, 2013 and two were conducted in El Paso County on Dec 3, 2012 and March 8, 2013. Focus groups consisted of two parts: the first

part consisted of completing a written survey while the second part consisted of a presentation and group discussion. The moderators guide was written by Dr. Rebecca Palacios, and the evaluation team (Dr. Palacios, Dr. Tomaka, and Alma Torres), developed the evaluation survey. The focus groups were conducted by Dr. Palacios, Dr. Tomaka, and Alma Torres from NMSU, and Dr. Ivonne Santiago, Isaac Campos Flores (author of this dissertation), and Lydia Garcia from UTEP.

A demonstration system was assembled with three different types of point-of-use treatment units for display during the focus group presentations, as shown in Figure 2.2. The first type was a pitcher unit, shown in part (a) of Figure 2.2. The second type (shown in part (b) of Figure 2.2) consisted of a five-gallon bucket, a hose, and an in-line gravity-driven filter attached at the end of the hose. The third type (shown in part (c) of Figure 2.2) consisted of a kitchen sink and cabinet with a standard cartridge filter housing and an in-line membrane filter inside the cabinet. The three types of treatment units in the demonstration system were selected to gauge the participants' willingness to use a particular type of filter. The results of this part of the study were qualitative, as they were performed during an open group discussion.

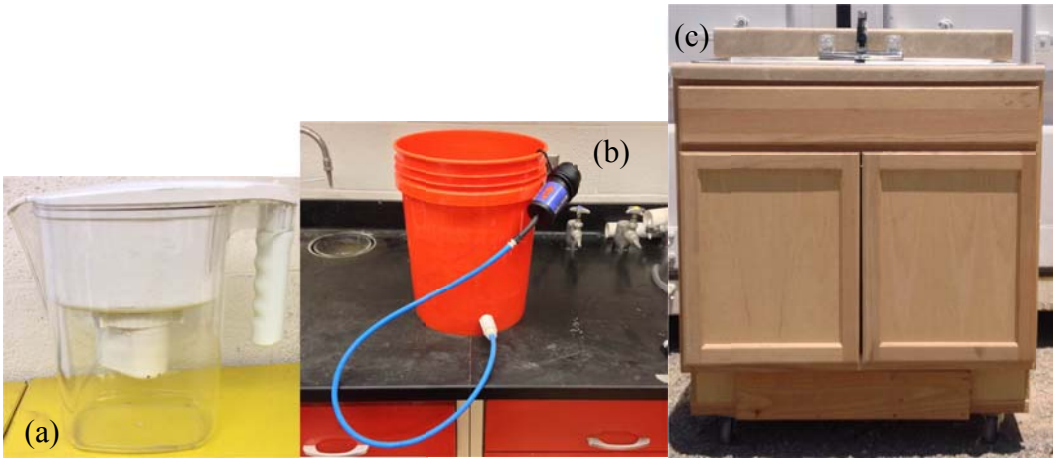

Figure 2.2: Types of point-of-use water treatment units demonstrated during focus group studies: (a) pitcher, (b), gravity driven, and (c), in-line water treatment system presented during the focus groups

Water Sample Collection

After the focus group studies, 22 water samples (eight from households in El Paso County and 14 from Doña Ana County) were collected from the homes of willing participants. The specific *colonias* that were sampled for water were Chamberino, Anthony, and La Mesa in New Mexico (shown in Figure 2.3), and Hillcrest and Buena Suerte Estates in Texas (shown in Figure 2.4). Two separate water samples were collected from the kitchen faucet in each household that was visited. Both sample sets were collected according to Standard Method (SM) 9060 A (AWWA 2012). The first sample set was collected in an IDEXX sterile bottle (with sodium thiosulfate) for estimating the concentration of the pathogenic indicators, total coliforms and E. Coli. The first sample was placed in a cooler with ice while it was transported to the laboratory where it would be analyzed. If the analysis did not take place immediately, samples were stored inside a refrigerator at approximately (±2) 4° C; all microbiological samples were analyzed within 24 hours after collection. The second set of samples were collected in either a