GIS Representation and Assessment of Water Distribution System for Mae La Temporary Shelter, Thailand

By
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Submitted to the Department of Civil and Environmental Engineering
in Partial Fulfillment of the Requirements of the Degree of

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ABSTRACT

ArcGIS is used to analyze water access in Mae La, Thailand, home to 45,000 residents living as refugees in a temporary camp. Drinking water for the shelter is supplied at public tap stands while water for hygienic purposes such as bathing and laundry is available via covered rope-pump wells which reach shallow ground water; stream and river surface water; and hand-dug wells. In all, 7,117 homes were identified using Google Earth and the corresponding proximity to the nearest tap stand and rope-pump well was calculated. ArcGIS was used together with an EPANET water-distribution model created by Rahimi (2008) to evaluate the predicted daily volume of drinking water available per home. Overall this research shows that the vast majority of residents in Mae La have sufficient access to water. Homes located further than 115 meters from a tap stand, located further than 180 meters from a rope-pump well, or having access to less than 50 liters of water per day were considered a cause for concern. Approximately one in four homes met these criteria. Only 5% of homes are located more than 115 meters from a tap stand. Approximately 14% of homes did not meet the rope-pump proximity criterion, and 15% of homes did not meet the available volume criterion. The tap-stand proximity results provide a much higher degree of confidence compared to the other results. Alternative sources for hygienic water besides rope-pump wells exist, suggesting the number of homes with sufficient access to hygienic water is likely underestimated. Flow rates, predicted by the EPANET model, are highly dependent on the elevation of distribution system infrastructure points (e.g. storage tanks and tap stands), which are difficult to determine accurately. Thus, while the final results show one in four homes are a cause for concern, the reliability of the rope-pump well proximity assessment and volume per home assessment is insufficient, and the findings could be overly pessimistic.

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Title: Senior Lecturer of Civil and Environmental Engineering

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My teammates and coaches have defined my time at MIT. Thank you for your intensity and passion and a special thanks to the soccer players who, against all rational judgment, decided living with me was a good idea… "Clear eyes, full hearts, can't lose."

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1 INTRODUCTION

A geographic information system (GIS) is a useful tool to understand spatial relationships and visualize problems in new ways. This work utilizes a GIS in coordination with a computer model created by Navid Rahimi (2008) to better understand the condition of water supply within Mae La camp, Thailand. This chapter and the next are collaborative works from the author, Katherine Vater and Navid Rahimi who worked together as a project team under the Master of Engineering program in the Department of Civil and Environmental Engineering at MIT.

Mae La camp is located along the border of Thailand and Myanmar and the features of this region are reflected within the camp itself. This chapter lays a cultural framework for the water system within the camp, which is described in detail in Chapter 2.

1.1 THE THAILAND – MYANMAR BORDER

Mae La camp is a refuge for thousands of people seeking protection from persecution in Myanmar. Ongoing turmoil shapes the lives of the people within the camp. Understanding the available water resources within the camp requires knowledge of not only the regional climate and geography, but the reasons people are living in Mae La and the conditions found there.

1.1.1 Politics

In September 1988 a military junta took control in Burma killing as many as 10,000 people (Lanser, 2006). The military regime has placed restrictions on work and civil liberties and has become increasingly brutal, especially towards ethnic minorities. As a result, a large number of people from Myanmar have fled to escape poverty or persecution. It is estimated that the largest number, about 2 million people, have migrated into Thailand, although the exact numbers are unknown. Of these, about 140,000 reside in United Nations (UN) sanctioned camps and 500,000 are registered migrant workers. The rest remain unregistered and attempt to stay unnoticed to avoid being deported back across the border (Fogarty, 2007).

Wages in Myanmar are not sufficient to meet the basic needs of most families, and so many workers are forced to look for work outside Myanmar's borders. Migrants can apply for legal working papers in Thailand which affords them one (and only one) year of legal work. With these papers, workers have the best chance of receiving at least the minimum wage and experiencing decent working conditions. Many Thai business owners rely on illegal workers for an unending supply of cheap labor. In Mae Sot, the closest city to the Mae La camp, it is estimated that around 50% of the 80,000 Myanmar people have papers (McGeown, 2007).

Illegal residents are often forced to pay bribes to Thai authorities to avoid being captured. When these authorities do take action, the person is forcefully returned to Myanmar. In most cases of deportation, however, the migrant can often merely pay a small bribe to the Myanmar border guard and return again to Thailand. In other cases, the Thai authorities report the migrant to the Myanmar government and heftier governmental fines must be paid in order to avoid jail time (McGeown, 2007).

Much of the challenge for these migrants stems from the fact that Thailand is not a signatory of the UN Refugee Convention. Accordingly, the government only grants asylum to those fleeing combat as opposed to those fleeing human rights violations (Refugees International, 2007). This makes the situation complicated as the UN-sanctioned camps along the border are officially called temporary shelters by the Thai government, while in reality many families have lived in these camps for more than 20 years. It is the intention of the Thai government that the residents either return to Myanmar or move on and repatriate to another nation. It is illegal, yet common practice, for camp residents to work in the surrounding Thai towns. They will generally try to find whatever day labor is available and send money earned back to Myanmar to provide for remaining family members (D. Lantagne, personal communication, October 19, 2007).

Native hill tribes, which historically lived impartially across Northern Thailand and what is now Myanmar, make up a large majority of the resettling group. The Karen, Karenni, Shan, and Mon are the main tribes that are being driven from their homes by the Myanmar military (McGeown, 2007). Within Myanmar there is some resistance from the Karen National Liberation Army (KNLA) which is fighting for an independent Karen state. There were additional rebel armies, but over the past 20 years most have agreed to ceasefires with the military junta. Many of the refugees in the camps in Thailand are sympathetic to the KNLA, and some have even served in it (McGeown, 2007).

The Karen believe strongly in the value of family. As a result, decisions to leave the camps and repatriate are difficult and must be made as a family. Generally, the teenagers and young adults who have lived most of or all of their lives inside the camp want to repatriate elsewhere while older generations hope to return to Burma if it is restored (D. Lantagne, personal communication, October 19, 2007).

1.1.2 Economy

As described above, there is a significant amount of poverty in Myanmar as a result of the military junta’s overbearing controls and inefficient economic policies. Inconsistent exchange rates and a large national deficit create an overall unstable financial atmosphere (CBS, 2007). Although difficult to accurately assess, it is estimated that the black market and border trade could encompass about half of the country’s economy. Importing many basic commodities is banned by the Myanmar government and exportation requires time and money (McGeown, 2007). Timber, drugs, gemstones and rice are major imports into Thailand while fuel and basic consumer goods such as textiles and furniture are exported (CBS, 2007).

By night, the Moei River, which divides the two countries, is bustling with illicit activity. Through bribing several officials, those who ford the river are able to earn a modest profit (for example around 2 USD for a load of furniture) and provide a service to area merchants and communities. Thailand benefits from a robust gemstone business that draws dealers from all over the world. The Myanmar mine owners would get a fraction of the profit by dealing directly with the government (McGeown, 2007).

1.1.3 Climate in Northern Thailand

The Tak region of northern Thailand is characterized by a tropical climate with wet and dry seasons (UN Thailand, 2006; ESS, 2002). The rainy season lasts from June to October, followed by a cool season until February. The weather turns hot and sunny between March and May (UN Thailand, 2006). The northern region of Thailand has an average temperature of 26ºC although there is significant variation over the year due to the elevation. Typical temperatures range from 4ºC to 42ºC (Thailand Meteorological Department in ESS, 2002). The average annual rainfall in Mae Sot, Thailand is 2100 millimeters (mm) (GOSIC, 1951-2007), and Figure 1-1 shows the monthly rainfall averages over the past 56 years. The rainy season is clearly visible, and more than 85% of the annual 2100 mm falls during this period.

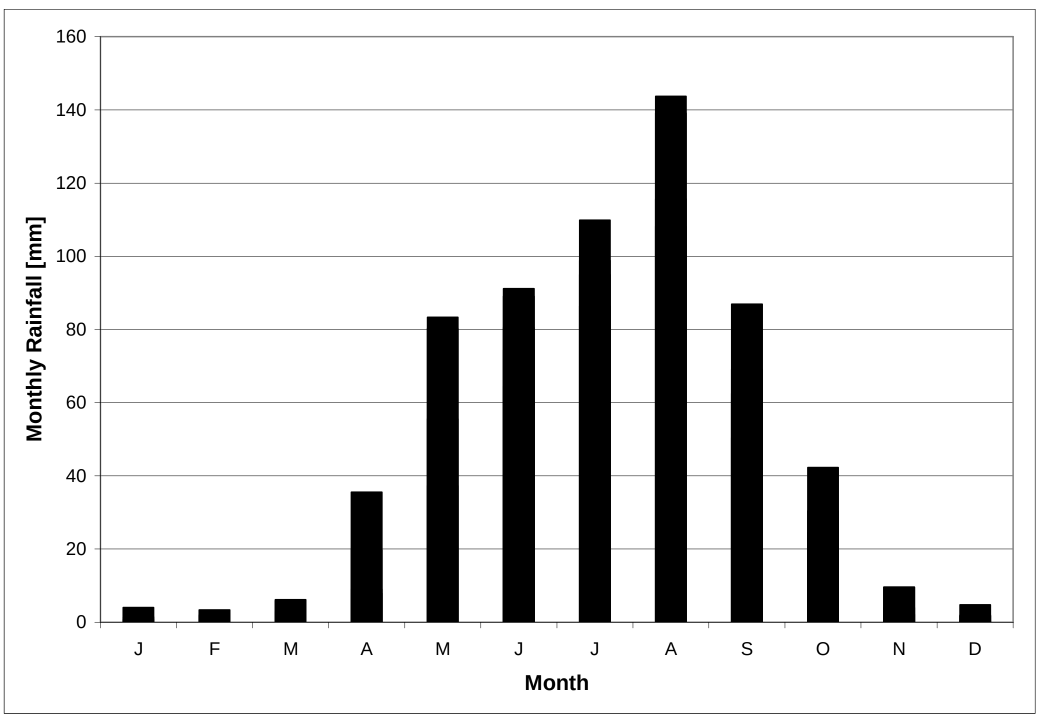

Figure 1-1: Average Monthly Rainfall for Mae Sot, Thailand (GOSIC, 2007).

1.2 MAE LA CAMP

The Mae La camp is a refuge for people seeking protection from the Myanmar government and from warfare along the Thailand-Myanmar border (McGeown, 2007). The camp is run by the United Nations High Commissioner on Refugees and has existed since 1984 (TBBC, No Date).

1.2.1 Location and Demographics

Mae La is located near 16º30'N and 98º30'E in the northern region of Thailand about ten kilometers from the border with Myanmar (TBBC, No Date). The camp location is shown by the red circle in Figure 1-2. Mae La is home to about 45,000 refugees, mainly of the Karen ethnic minority (UNHCR, 2007; TBBC, No Date). There are reportedly more than six million Karen people living in Myanmar and about 400,000 living in Thailand (KarenPeople, 2004), although these numbers may not account for the approximately 150,000 Karen refugees living in refugee camps in Thailand (UNHCR, 2007). Figure 1-4 shows the relative populations, ethnicities, and age demographics of the UN refugee camps in Thailand; Mae La is the largest of these.

The camp is located in a valley surrounded by two ridges, which rise about 300 meters above the camp. These hills are distant extremities of the Himalayan mountain range which is mainly located northwest of Thailand. A UN-protected road links the camp with the nearest Thai city of Mae Sot. These features, along with the location of some drinking water storage tanks and source springs, are visible in Figure 1-3.

Mae Sot has a population of about 40,000 Thai and an unofficial count of about 80,000 illegal Burmese residents (TBBC, No Date; Brinkhoff, 2007; McGeown, 2007). Mae Sot is approximately an hour away from Mae La by car. The nearest larger city is Tak; Bangkok is about 500 kilometers southeast of Mae Sot (Google, 2007) and about nine hours by car.

Figure 1-2: Location of Mae La Refugee Camp (http://www.maps-thailand.com/map-mekong-subregion.php).

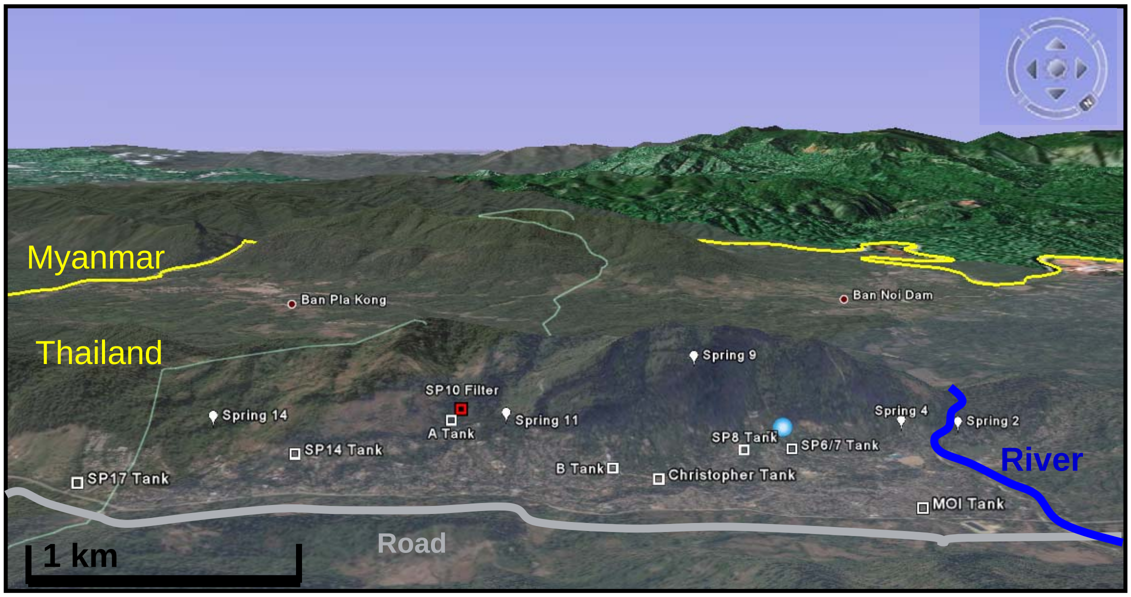

Figure 1-3: Mae La Location, looking southwest (Data from Lantagne, 2007).

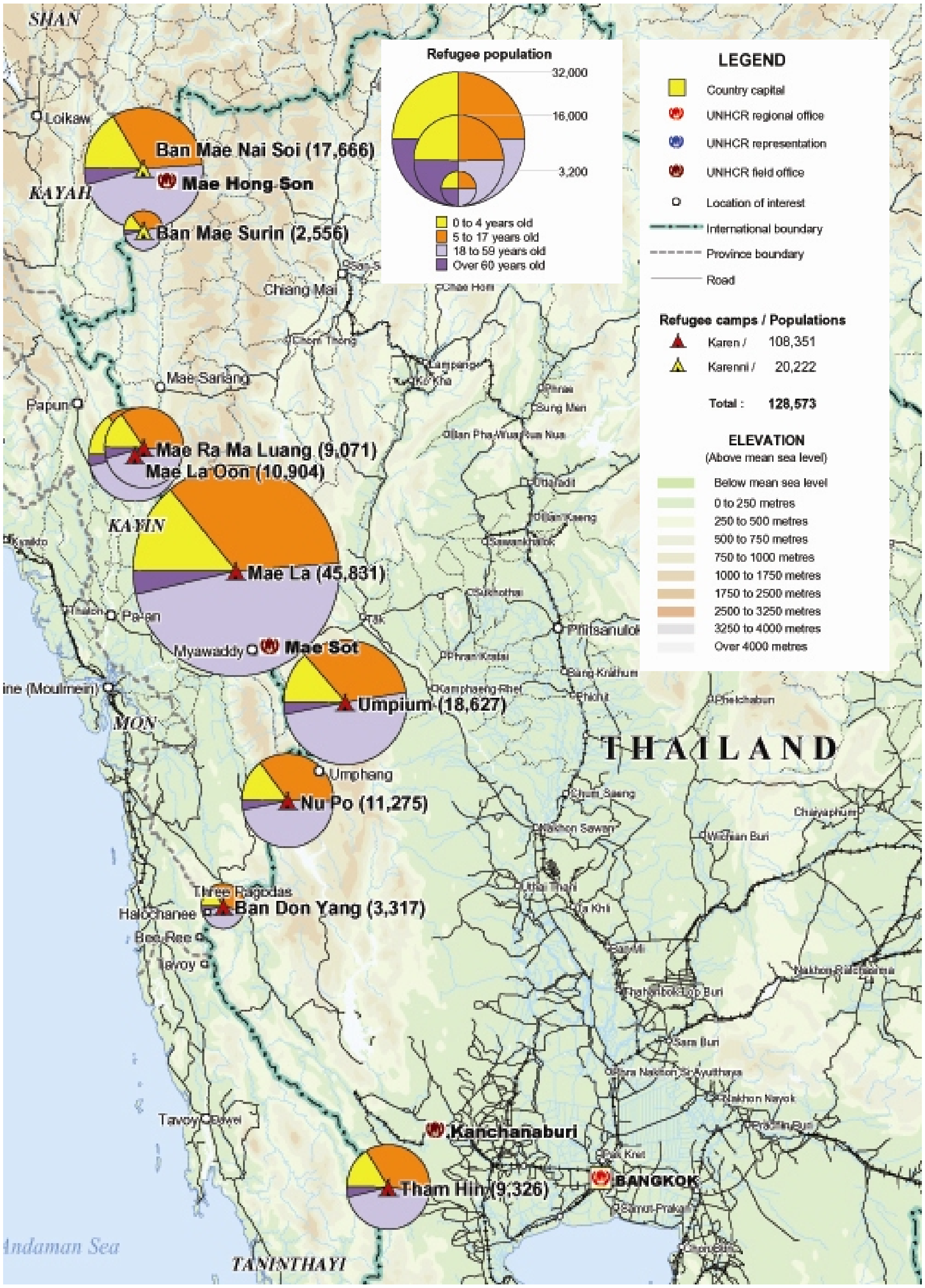

Figure 1-4: UN Refugee Camp Populations and Demographics (UNHCR, 2006).

1.2.2 AMI & Soldarités

Created in 1979, Aide Médicale Internationale (AMI) works to restore systems related to people's health. Currently they have approximately 25 projects in 9 countries. The projects are related to improving drinking water access, education, healthcare, and job opportunities; and resisting religious, sexual and ethnic discrimination (AMI, 2007b).

In 1995, AMI took over healthcare and some water and sanitation services for Mae La and two other camps in the region from Médecins Sans Frontières (Polprasert et al., 2006). Maintaining and running the water supply system of the Mae La camp is a major component of AMI's involvement. A team of about 30 AMI employees and camp residents work each day to ensure camp residents have access to clean water. Between August and December 2008, AMI will turn over their water responsibilities to Soldarités, the NGO currently responsible for the camp's waste disposal (F. Pascal, personal communication, October 30, 2007). Having one NGO responsible for both water and sanitation is logical. The two systems are linked as drinking water quality is affected greatly by waste contamination and having the two systems coordinate should increase overall health (Polprasert et al., 2006).

2 WATER SUPPLY AND USE IN MAE LA

When Mae La first opened in 1984 there were approximately 6,000 residents and water was supplied through shallow hand-dug wells (Brizou, 2006). With the closure of other nearby camps, the population surged to 20,000 by the mid 1990s. Throughout the 1990s, numerous springs were captured for drinking water use and the first electric pump for river water collection was installed in 1996 (Brizou, 2006). The systems of water access within the camp were developed incrementally as the camp population grew. As a result, the system is a heterogeneous mix of sources and includes many disjointed parts.

There are two main types of water access within the camp: consumable water and hygienic water. Consumable water is used for drinking and cooking, and hygienic water is used for bathing, laundry, hand and dish washing. Consumable water is provided by public tap stands, while rope-pump wells, hand-dug wells or surface water serve as the sources of hygienic water. A series of deeper boreholes exist throughout the camp but are not currently used due to contamination and disrepair. These infrastructure points are visible in Figure 2-1.

People tend to store their water in containers on their porches and in their homes. An example of this is shown in Figure 2-2. If water goes unused, it is discarded and the containers are refilled the following day (Lantagne, personal communication, October 19, 2007). This makes understanding the actual water demand of the camp difficult, because not all the water collected is used.

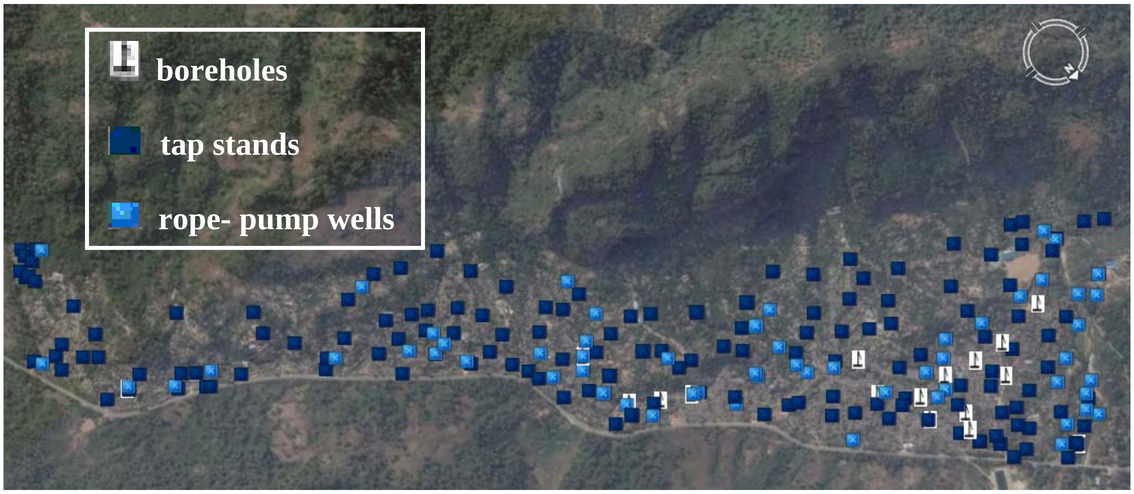

Figure 2-1: Distribution of boreholes, rope-pump wells and tap stands (D. Lantagne, personal communication, 2007).

Figure 2-2: Water Storage Containers on Porch (Lantagne, 2007).

2.1 CONSUMABLE WATER

The public tap stand distribution system provides consumable water and is supplied by the adjacent river and a series of springs along the southwest ridge. Water is pumped from the river or fed by gravity from higher elevation springs to several storage tanks. There are six main tanks: A tank, B tank, C tank, Christopher tank, MOI tank and Spring 17 tank. The MOI and C tanks are the largest, with the MOI tank providing water to the densely populated north corner of the camp. These tanks are connected to several pipe networks supplying tap stands. There are only a few cross connections between systems. Figure 2-3 shows the available water volume by month and source.

Once at the storage tanks, the water is disinfected through the manual dumping of chlorine into the tanks before being distributed through a complex system of pipes to tap stands. Chlorine is a common disinfectant for treatment of water against disease-causing bacteria. In August 2007, the distribution system was shown to have sufficient disinfection at the tap stands (Lantagne, 2007).

Most of the tanks, including the main ones listed above, are opened for distribution twice a day, generally for 3 hour periods from 6 to 9 AM and 3 to 6 PM. There is ample demand at the tap stands and people must wait in line to receive water. Typically, water is continuously collected throughout the distribution time and all available water is taken.

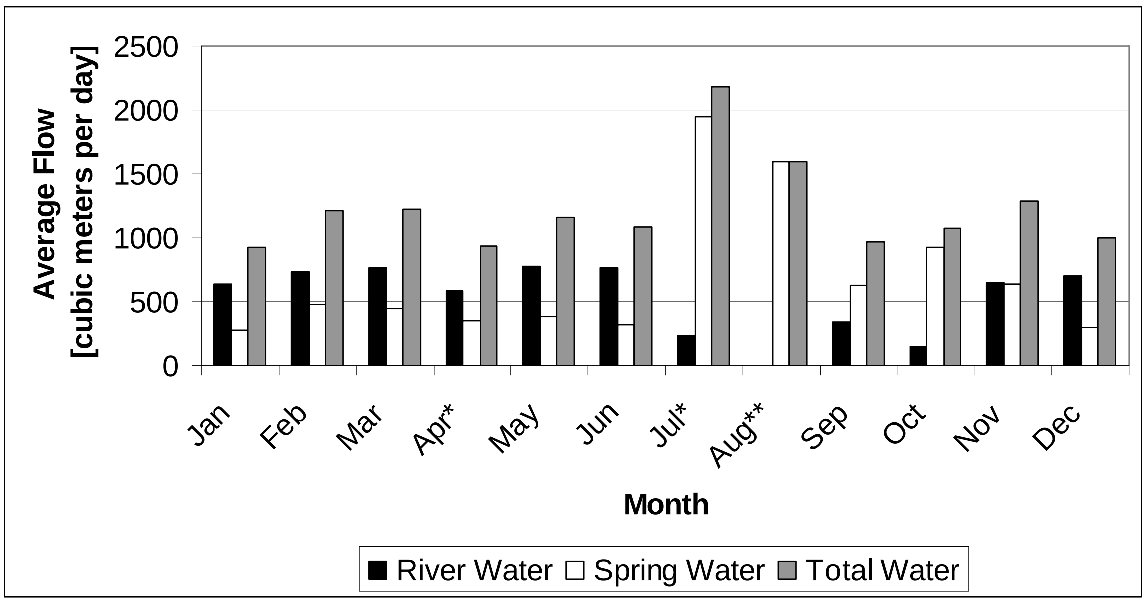

Figure 2-3: Division of 2007 Flow Volume from Storage Tanks by Source.
***Data from 2006, **Pumped Water Flow Rate Unavailable**

Some of the smaller and isolated spring systems are always open as the spring water flows directly to tap stands.

Some private standpipes exist (such as those for the school or the hospital), but the vast majority of the tap stands shown in Figure 2-1 are public. It is estimated that tap stands provide the majority of the water supply to over three-fourths of the population (Lantagne, 2007). The water is free for residents of the camp.

There are three pumps used to drive the river water to tanks: Tim pump, Christopher pump and MOI pump. Tim pump brings river water to tanks A, B, C and Christopher; Christopher pump to both the Christopher and MOI tanks; and MOI pump to the MOI tank and recently, on an intermittent basis, to a storage pond located across the road from the camp.

A lower pumping rate occurs during the dry season because of the lack of available river water. Additionally, more water is available from the springs in August, so there is less need to pump water from the river.

2.2 HYGIENIC WATER

Since it is not necessary that water for bathing, washing and other non-consumable water be disinfected through chlorination, there are a number of alternative access points throughout the camp. The primary alternate sources are the 63 rope-pump wells that are located mainly at lower elevations in the camp. An example of a rope-pump well is shown in Figure 2-4. By UN definition it is an improved water source since there is a cover and concrete drainage area, but some of the wells are contaminated by sewerage (D. Lantagne, personal communication, October 19, 2007).

In order to collect water using a rope-pump well, users place a container for collection beneath the opening of the blue PVC pipe and pull outwards on the pump’s metal handle. This mechanically drives water from a shallow ground water source to the surface and out the blue pipe. In order to bathe, users will either collect water in a container to pour over themselves or place extremities at the opening of the pump one at a time to rinse off.


Figure 2-4: Typical rope-pump well (Lantagne, 2007).

Some regions of the camp have very shallow ground water levels that can be accessed through hand-dug wells. These sources are generally discouraged as the open stagnant water is a breeding ground for disease carrying mosquitoes and the water is much more likely to be contaminated by sewage from nearby latrines.

Many people utilize the major river as well as a small stream that cuts through the camp as sources for hygienic water. In the heart of the dry season, this stream can run dry and the river can run very low, decreasing or eliminating use.

3 GEOGRAPHIC AND MODELING TOOLS

The process of data collection, management, analysis, and display for this thesis required the use of several geographic tools. This chapter provides an overview of how a geographic information system (GIS) is used and how information was transferred between programs with various data types.

3.1 COORDINATE SYSTEMS

While manipulating and comprehending global spatial data, every GIS encounters a major challenge in the need to portray three-dimensional data in a two-dimensional space. Various data sources and software platforms utilize different coordinate systems and global projections. It is important to understand how these systems and projections are related in order to easily transition between sources and/or platforms, and these relations are described below.

Lines of latitude and longitude are the most common coordinate system. Surface location is defined by the angle from the center of the Earth between a given location and the plane of the equator (latitude) or Prime Meridian (longitude). Latitude and longitude coordinates can be described using two main notations: Degree:Minute:Second (DMS) and Decimal Degree (DD). For DMS, each degree is divided into 60 parts (minutes) and each minute is further divided into 60 seconds. For DD, the minutes and seconds are represented by digits (typically four) following the major degree and a decimal. To convert between DD and DMS, multiply the decimal first by 60 to get the whole number of minutes and then multiply the resulting decimal remainder by 60 again to find seconds. For example, for a DD of 17.8200º the corresponding DMS notation would have 0.8200 x 60 or 49.2 minutes and 0.2 x 60 or 12 seconds. Written in DMS form the equivalent notation is 17º49’12’’.

The Universal Transverse Mercator (UTM) coordinate system divides the globe into 60 zones based on an ellipsoidal model of Earth and specific locations within zones are referenced in meters (ArcUser, 2008). For this project, the UTM coordinates are based on the World Geodetic System of 1984 (WGS 84) reference frame for the earth. WGS 84 is a coordinated global standard defined using Doppler satellite surveying and the reference frame for GPS (NGS, 2007).

As a reference, the northeast corner of the camp where the river crosses the main camp road is located, in DMS, at about 17º08'10"N and 98º22'35"E and this corresponds to a grid position within UTM zone 47N of 433633 meters east and 1894732 meters north. Direct translation from UTM coordinates to degree coordinates is not a simple task because the UTM system varies non-linearly due to the projection of spherical space onto a two-dimensional grid. Many online conversion tools exist including one by the National Oceanic and Atmospheric Administration, U.S. Department of Commerce (NOAA, 2008).

3.2 GEOGRAPHICAL INFORMATION SYSTEMS

Geographic Information Systems are utilized to improve efficiency, decision-making and communication by integrating various multiple and complex sets of information. The systems provide a framework for management, analysis and display of geographic information. There are three major components of a GIS: the data sets and models which represent the raw information, the maps and globes in which this information is placed, and the processing and manipulation that can be applied.

For this project, the data sets are largely comprised of the home, tap stand and other important locations within the water distribution system. The maps and globes allow the 3-D setting to be more easily understood in a 2-D space, and geoprocessing can create new data and representations to interpret. One hope is to create intuitive and cognitive tools that will help people across cultures and disciplines work efficiently together (ESRI, 2006).

Important features for the GIS related to this project are flexibility and availability of data manipulation tools and multiple scales. There is a need to add new and updated data as the population and water system at Mae La continue to change with time. Tools are necessary to understand more about the available data. For example, if the population nearest to a particular tap stand is defined, a next valuable piece of information would be the percentage of this population that actually utilizes this tap and the frequency of use.

As a result of the depth and extensive nature of geographical data, it is important for collaboration especially regarding the creation and maintenance of data sets. There exist many open forums for GIS users to collaborate as well as an international standards group, Open Geospatial Consortium, Inc., which keeps users in sync with one another.

3.3 ARCVIEW

Environmental Systems Research Institute (ESRI) has been the world leader in producing GIS software which includes a wide array of applications. The nomenclature of software packages and applications available within ArcGIS can be confusing and are summarized below. ArcView is the major program for mapping, data use, and analysis within the ArcGIS Desktop family. There are additional families of programs focused on servers and mobile GIS use (ESRI, 2006).

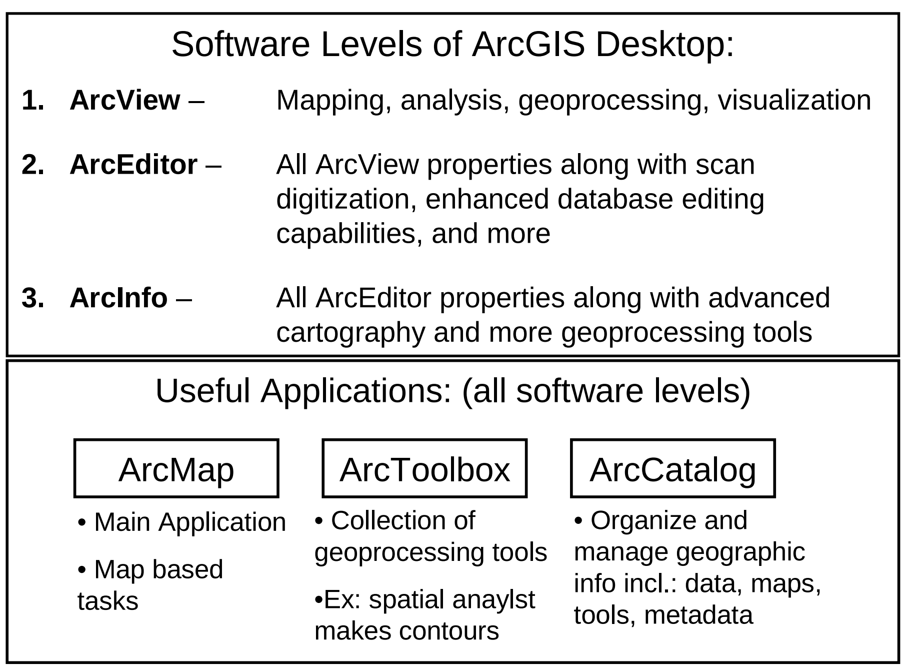

Figure 3-1: Software and Applications for ArcGIS Desktop.

Unlike Google Earth discussed below, ArGIS software is not free and requires licensing. Additionally, given the wide range of features and capabilities, this program is not intuitive and does take some familiarization in order to use effectively. There is an extensive amount of training and support including forums and script downloads available on the main ESRI website. In addition, Appendix A contains useful information on the ways ArcGIS was utilized for this project.

3.4 GOOGLE EARTH

Google Earth has been gaining popularity as a way of displaying and manipulating geographic information. A major draw of the product is the fact that it is free and available for download through http://earth.google.com. While additional, more advanced products are available for purchase (Google Earth Plus and Google Earth Pro), for the scope of this project the standard program was sufficient.

Google Earth utilizes Keyhole Markup Language (KML) files which are used for defining a set of geographic information features such as points and images in two or three dimensions (Google Earth, 2007). The KML file can be grouped (zipped) with icon and/or overlay images as a cohesive KMZ file.

New point, shape, and image overlay files can be created by selecting options from the Add menu. The nomenclature changes slightly from ArcView ("Point" becomes "Placemark", "Polyline" become "Path", etc.) but the general functions remain the same.

3.5 DIGITAL ELEVATION MODELS

A digital elevation model (DEM) is a representation of the ground surface elevation. Most commonly a raster, or grid of squares, is used to section an area and each grid is assigned an elevation. A distance modifier associated with a DEM refers to the precision of the data. For example, a thirty-meter DEM would have a grid size of thirty by thirty meters. The smaller the grid size, the more precise and detailed the data.

3.6 EPANET

This section is the result of collaboration between the author and Navid Rahimi.

EPANET is a computer program that simulates hydraulic and water quality behavior within pressurized pipe networks. It was developed by the United States Environmental Protection Agency (EPA) and presents the great advantage of being available on the internet free of charge. It can model networks of pipes, nodes, pumps, valves and storage tanks or reservoirs and tracks the flow of water in each pipe, the pressure at each node, the height of water in each tank, and the concentration of a chemical in the network during a time stepped simulation.

Some of the key hydraulic capabilities of EPANET include no size limitations on the network, handling multiple head-loss equations, simulating time-varying demand, and pump operation control (e.g. based on tank water levels). No model can perfectly reflect the underlying system but these capabilities enhance the realism of the simulation (Rossman, 2000).

One important scenario that is not built into the EPANET software is the intermittent flow case which is relevant for Mae La as well as many developing countries or situations of crisis. It is possible to vary the demand or supply of the system with time, but EPANET assumes a constantly pressurized system, with full pipes at the start of the period.

The model results are easily exported from EPANET for further analysis in coordination with geographic home location. Modeled flow rates and pressures can be viewed in the GIS interface.

Figure 3-2 illustrates a sample EPANET model output from a section of the Spring 17 system. Variations in flow rates are shown through different colored pipes, while pressure is depicted as a number and color at each node (tank, tap stand, or valve). For this sample, all of the pressures are less than 25 meters and depicted in dark blue.

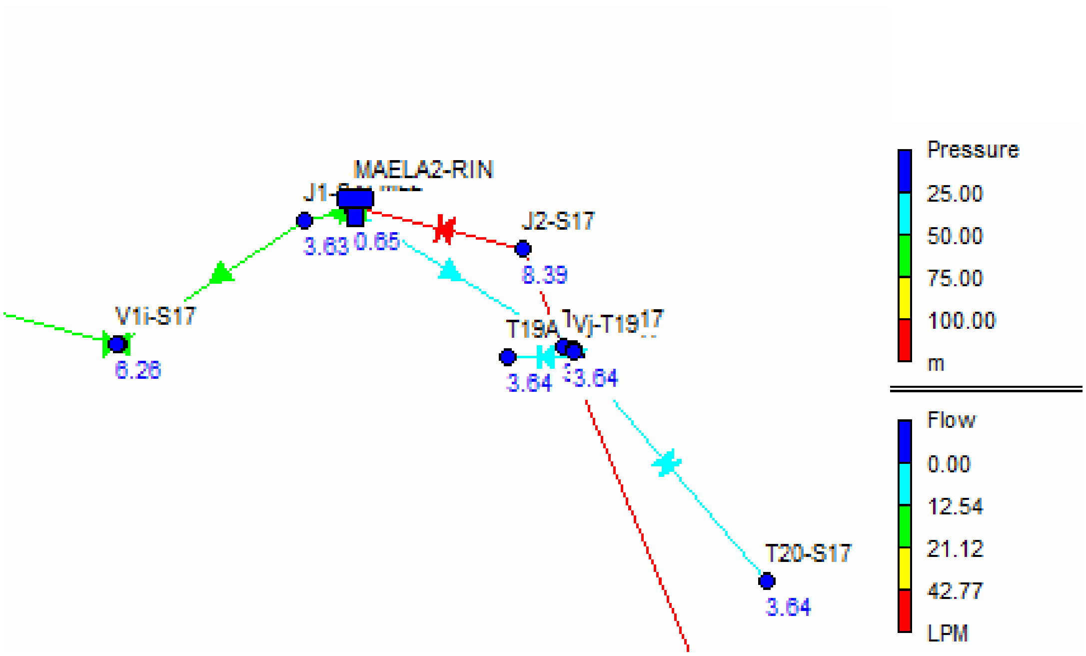

Figure 3-2: EPANET model of Section of Spring 17 in Mae La.

4 DATA COLLECTION & ANALYSIS

I used several different data sources for this work. Before a site visit to the Mae La camp, significant Global Positioning System (GPS) data was received from Daniele Lantagne and some pipe network specifications from Joel Terville, the Logistics Coordinator for the Mae La camp through AMI. The site visit consisted of going to a large portion of the tap stands related to the major tanks as well as measuring pipe lengths and recording diameters. Additionally, Dr. Bunlur Emaruchi from the Faculty of Civil Engineering of Mahidol University in Bangkok supplied a DEM which was received during the site visit. Upon return to Cambridge, home location data was collected through inspection of Google Earth images.

4.1 ON-SITE COLLECTION

While on-site, more than 130 of the 152 tap stands were visited and referenced using a Garmin eTrex Vista handheld GPS device. Figure 4-1 shows the location of all the tap stands in the camp (D. Lantagne, personal communication, 2007) noting which were visited in January 2008. The pipe network specification data (e.g. distance between nodes in the system) was checked using a laser range finder. Diameters were confirmed through visual inspection. The previously supplied data was found to be largely inaccurate. Most of the general layout of the pipe system and connections portrayed was the same as found in the field, but the distances we measured were very different than those supplied. In one case, a pipe length was recorded as being around 90 meters and our measurements resulted in twice that value. As a result, the AMI-supplied data is not used in this work even though it does contain information for parts of the network that we did not visit.

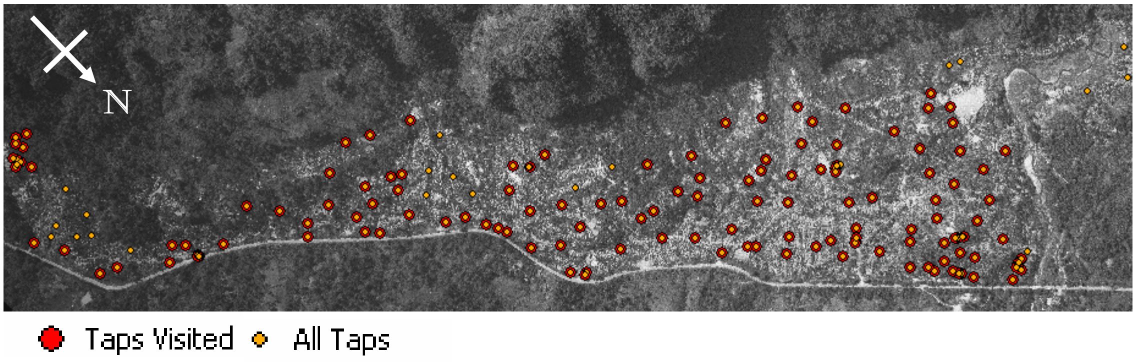

Figure 4-1: Tap Stands in Mae La Camp.

4.2 HOME LOCATION DATA

Homes were identified through visual inspection using Google Earth, and in the first attempt, 6,704 homes were found. Buildings that were obviously not homes like the hospital and NGO offices were not included in the set. In Figure 4-2, the large, rectangular building with the blue roof in the upper right section is not selected as a home.

According to Frédéric Pascal (personal communication, April 21, 2008) it is estimated that the actual number of homes in the camp is between 8,500 and 9,000. A more careful examination of the camp was completed while being less discriminating about potential homes in areas where the picture was not entirely clear. A final number of 7,117 homes were found and the discrepancy between this number and the likely actual number of homes can be attributed to vegetation cover and to the precision of the aerial photographs.

Since the highly populated areas, such as in the northeast section of camp, have sparse vegetation cover, it is likely that more homes were unidentified in the less populated areas. This may affect the results since the less populated areas also tend to be further away from infrastructure points of interest such as tap stands and rope pump wells. It is thus possible that the results are skewed so that a fewer number of homes, both as a percentage and a raw number, are identified as being undesirably far from water points.

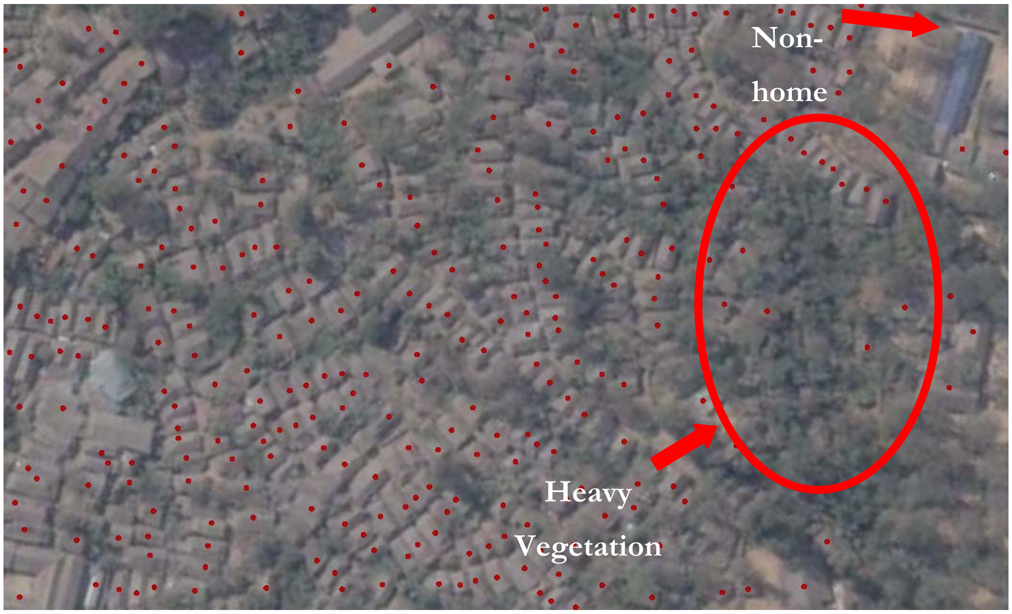

Figure 4-2: Visual Inspection Identification of Homes.

4.3 ELEVATION DATA

Elevation was measured with the built-in barometric, or pressure, altimeter in the handheld GPS. However, atmospheric pressure varies from day to day, introducing error into the altimeter readings. Differences in elevation measurements at the same point were found to be upwards of forty meters. We recorded the time of each measurement and took several measurements at a reference point throughout the day. We adjusted each measurement assuming that the elevation change was linear between reference point data. After taking the overall average elevation for the reference point over the three weeks, we adjusted all other measurements to this benchmark based on the measured reference-point elevations before and after the measurement.

For example, suppose a benchmark for the reference value was decided to be 175 meters or the average value throughout the site visit. On one particular day suppose we measured elevations of 185 meters at noon and 195 meters at 4PM. Between noon and 4PM we made measurements at other points. Suppose we measured an elevation of 250 meters at 2PM. Based on our prior and subsequent measurements of the reference point, we would interpolate the reference value to be 190 meters at 2PM. Since this is 15 meters higher than the benchmark elevation of 175 m, we would subtract 15 meters from the elevation measured at 2PM to arrive at a corrected elevation of 250 – 15 = 235 meters. While this does account for some of the local variation in pressure, we were not very comfortable with the linear assumption and with the overall degree of change.

As an alternative to the altimeter readings, a two-meter DEM was received for the entire camp area (B. Emaruchi, personal communication, March 26, 2008). By definition, a two-meter DEM defines areas of four square meters as having a single elevation but variations within those grids remain hidden. This DEM reports elevations to the nearest meter. Error in the latitudinal and longitudinal locations of our points along with variation within the four square meters determines the accuracy of the elevation data using a DEM. Product specifications for the eTrex Vista state that the device is accurate to within 15 meters horizontally 95% of the time (Garmin, 2008).

By comparing the latitude and longitude measured in January 2008 with the already available infrastructure point locations from Daniele Lantagne, we were able to get a concrete sense of these errors. The differences are grouped by tap stands associated with the various tanks (A, B, Spring 6/7, etc.) within the distribution system. The average error is shown as a triangle in Figure 4-3 with the vertical bars representing the standard deviation. It is important to note that this XY error is not with respect to a known actual datum but rather two measurements taken, about five months apart, with different equipment.

Using the DEM we were able to ascertain an average and standard deviation of elevation error associated with changes in XY position. The average XY measurement differences found correspond to changes in altitude of around three meters as shown in Figure 4-4. Examining the DEM in areas near the start of the steep mountain ridge along the southwest border of the camp, however, differences in 15 meters in XY location can be associated with changes of elevation as high as 10 to 15 meters.

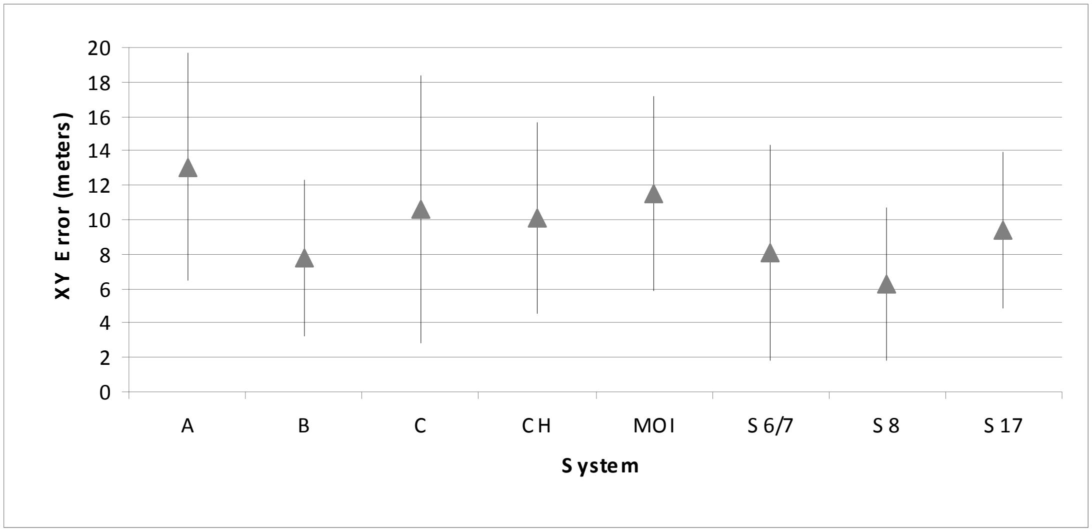

Figure 4-3: Average and Standard Deviation of Error Between Geographic Positions Measured by MIT and Daniele Lantagne.

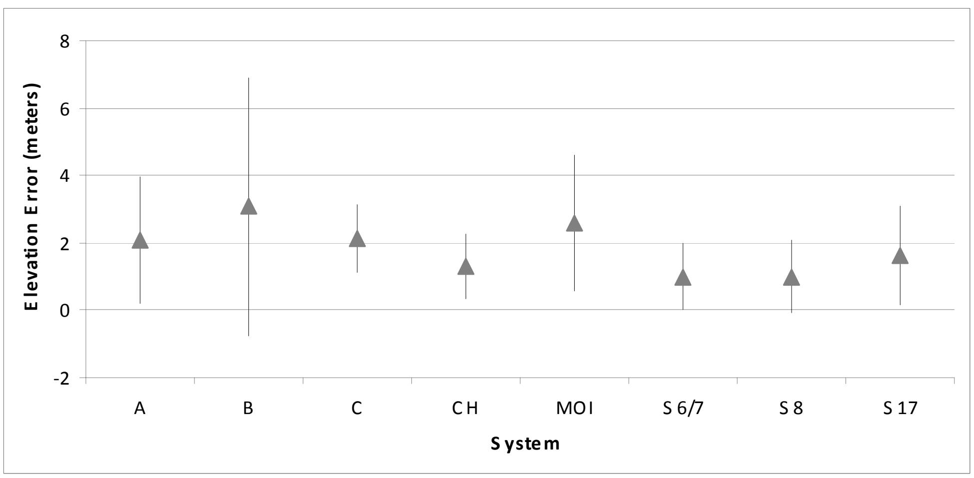

Figure 4-4: Elevation Error Based on DEM Information and Corresponding XY Error.

Most of the tap stands are located in the lower lying regions of the camp with less drastic elevation change, but the tanks and certain systems are closer to the ridge and thus the same errors in XY location create more drastic errors in the associated elevation. From Figure 4-5, the large MOI system is not as much a concern for elevation error as the A system. The cluster of taps in the Spring 17 (S17) system located in the upper left of the figure represents the secluded tuberculosis quarantine village (TB) which was not included in the EPANET model.

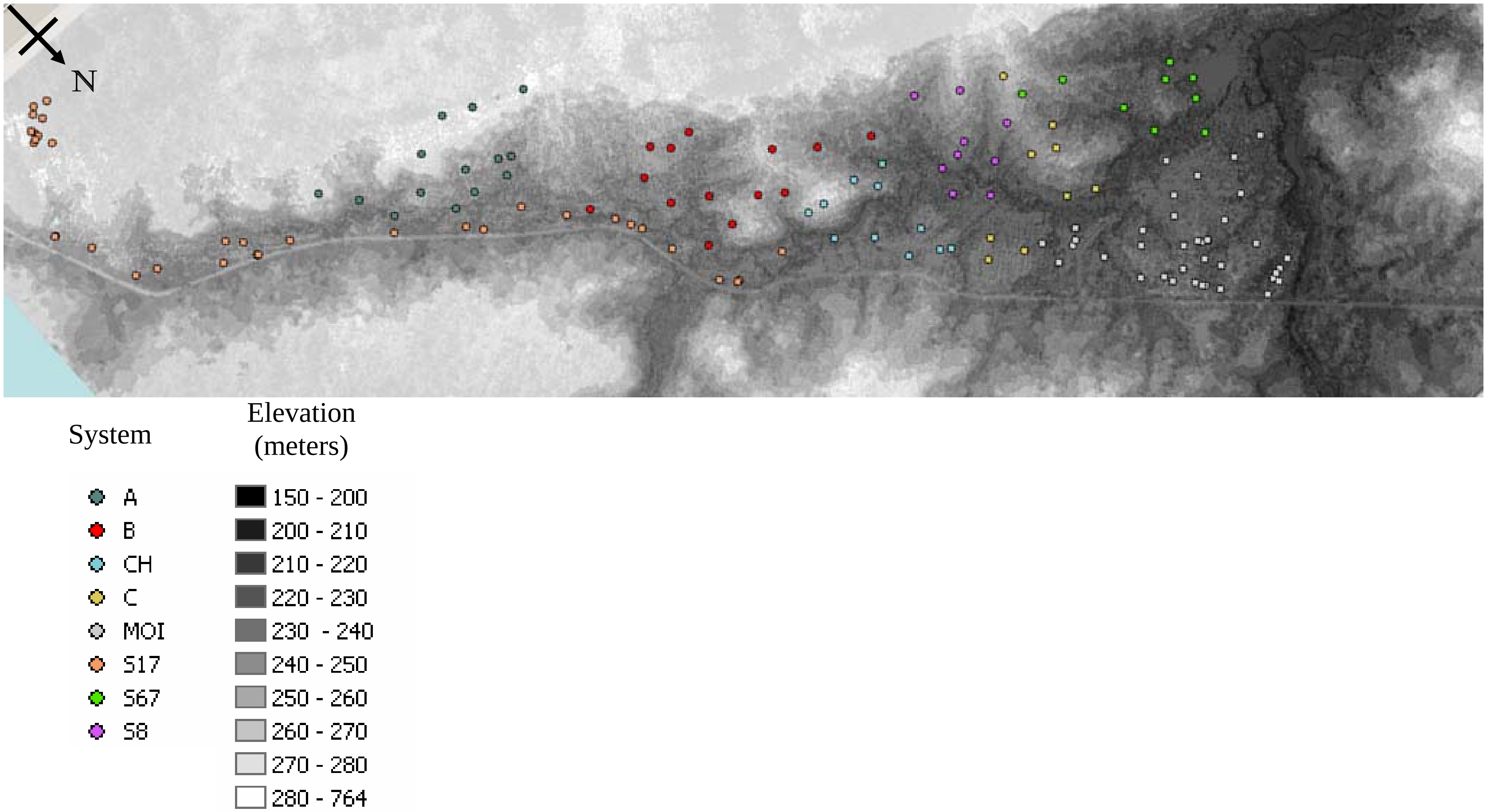

Figure 4-5: Modified DEM with Tap Stand Locations by System.

5 RESULTS

Through the analysis of home, tap stand, and rope-pump well locations along with outputs from the EPANET model, the effectiveness of water access within Mae La camp is accessed. This chapter identifies homes and regions with inadequate service concerning one or more of the following:

1. Location at a distance to tap stand that impacts consumption
2. Location at a distance to rope-pump well that impacts consumption
3. Insufficient daily water volume availability

5.1 TAP STAND PROXIMITY

It has been shown that the amount of time needed to collect water (round-trip) correlates strongly with consumption (WELL, 1998). In the case of the Mae La camp, this time is especially difficult to characterize due to multiple water access points. Water for drinking is normally collected from public tap stands, and water for washing, laundry, and other hygienic purposes can be collected from rope-pump wells or the surface water that crosses through the camp.

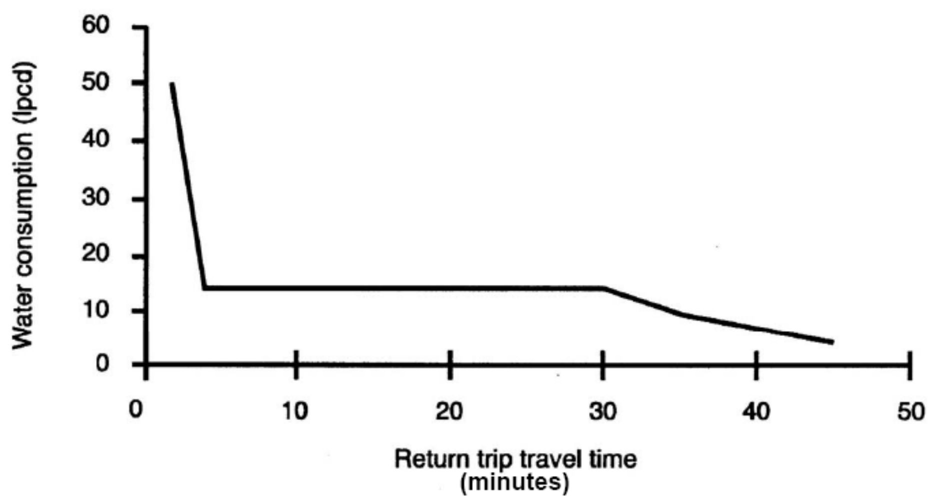

Figure 5-1: Consumption and Travel Times (WELL, 1998).

While most families gather drinking water from the public tap stands, others have direct connection within their homes. When the camp logistic team discovers unauthorized connections, they confiscate the pipes and communicate with owners about proper use of the public system. These connections are obviously unknown and therefore not accounted for in the analysis. Connections that take overflow water from springs by placing a pipe downstream of the system intake point are permitted although only utilized by a small percentage of the camp. Tracking homes with these connections is beyond the scope of this project, and authorized private connections are therefore not considered. This analysis also assumes that each home gathers drinking water from the nearest public tap stand.

As shown in Figure 5-1, when the return-trip travel time to source water is less than about three minutes, water consumption drastically increases. Tap stands should be located at a distance that will take the water carrier 1.5 minutes to travel. The range of comfortable walking pace considered was 75-85 meters per minute (Bohannon, 1997). It is customary in the camp for the strongest population group, young men, to fetch water for the household. Children carrying water is discouraged in part by AMI's practice of intentionally breaking tap handles which makes them more difficult to operate with small hands. Even though a healthy and presumably fast walking group fetches the water, a conservative walking speed of 75 meters per minute is used. Additionally, the topography of the camp adds to walking difficulty and a large quantity of water must be carried for half the journey making the lower end of this range more suitable. Assuming this speed and that each home should be within a 1.5 minute walk, the maximum allowable tap stand distance is 115 meters.

Figure 5-2 shows an overall view of the camp with homes represented by different colors based on distance to the nearest viable tap stand. Tap stands are considered viable if public drinking water is provided for collection. For example, public latrines and private taps for NGOs are not included.

Figure 5-2: Home Distance to Nearest Tap Stand.

There are 349 of the 7,117 homes identified (less than 5%) located further than 115 meters from the nearest viable tap stand. Many of the homes of concern (in red) are located in the upper right corner of Figure 5-2 near the Spring 2 system. This region of the camp happens to be very well supplied by natural springs and the population tends to acquire water from outside the distribution network (Terville, personal communication, January 2008). For this reason, the calculated distance to a viable drinking water source is likely inflated.

Only 210 or less than 3% of homes lie outside a 115 meter distance to a public drinking water source when these Spring 2 homes are not considered. Fifty percent of homes are located between 30 and 60 meters from a drinking water source. Figure 5-3, a histogram of the results, includes the Spring 2 homes. When these homes are not included, the number of homes with tap stands located more than 200 meters away is reduced by 60%.

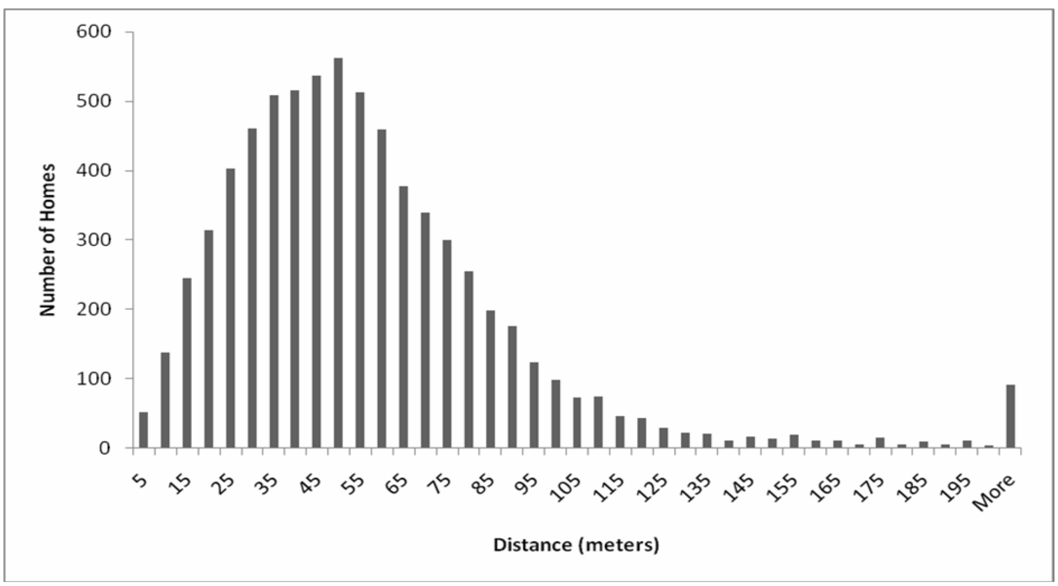

Figure 5-3: Home Distance to Nearest Tap Stand - Histogram.

From Figure 5-2, we see a large cluster of homes of concern located between the Spring 17 and A systems ("Low Coverage Region") in addition to the Spring 2 region. Besides these two major regions, homes of concern are sparingly distributed mostly along the mountain ridge that runs along the camp border furthest from the access road. Placing taps along this ridge is difficult as the slope becomes very steep and many of the homes are located at higher elevations than the system storage tanks. Since the systems are run by gravity, it is impossible to supply tap stands at these elevations.

Improvement appears possible for the “Low Coverage Region” highlighted in Figure 5-2. This is a large cluster of homes and the elevations are not prohibitively high in comparison to the A and Spring 17 tanks.

5.2 ROPE-PUMP WELL PROXIMITY

It is also important to have access to hygienic water for laundry, bathing, and hand washing, which does not need to be disinfected through chlorination. For this, residents do not use the twice-daily distributed water, but rather one of the 61 working rope-pump wells or surface water that cuts through the camp. During most of the year these surface water sources are plentiful, but deep in the dry season will often run low or dry (Terville, personal communication, January 2008).

It is customary for people to bathe at the rope-pump wells and bring their laundry to the well to wash near the water. This way, large amounts of water do not need to be carried back to the home and use mainly occurs at the well. Since use is at the source, the “return trip” time is not as relevant as with the consumable water. This would make it reasonable to set the distance for concern limit at twice that for the tap stands. There is a disadvantage of each member of the home needing to walk to the well as opposed to one person who can bring consumable water for all back to the home. Also, a moderate to small amount of water is carried to the homes from the wells for at-home hand washing, dish washing, in-home latrines, and for those who cannot or will not bathe at the rope-pump wells (e.g. sick and elderly). Heavy, wet laundry must also be carried back from the wells. Since much of the water use occurs at the rope-pump well but some at the home, the critical distance limit is set at 180 meters or approximately one and a half times the critical tap stand distance. This criterion is used in Figure 5-4 to identify homes that are problematically distant from a rope-pump.

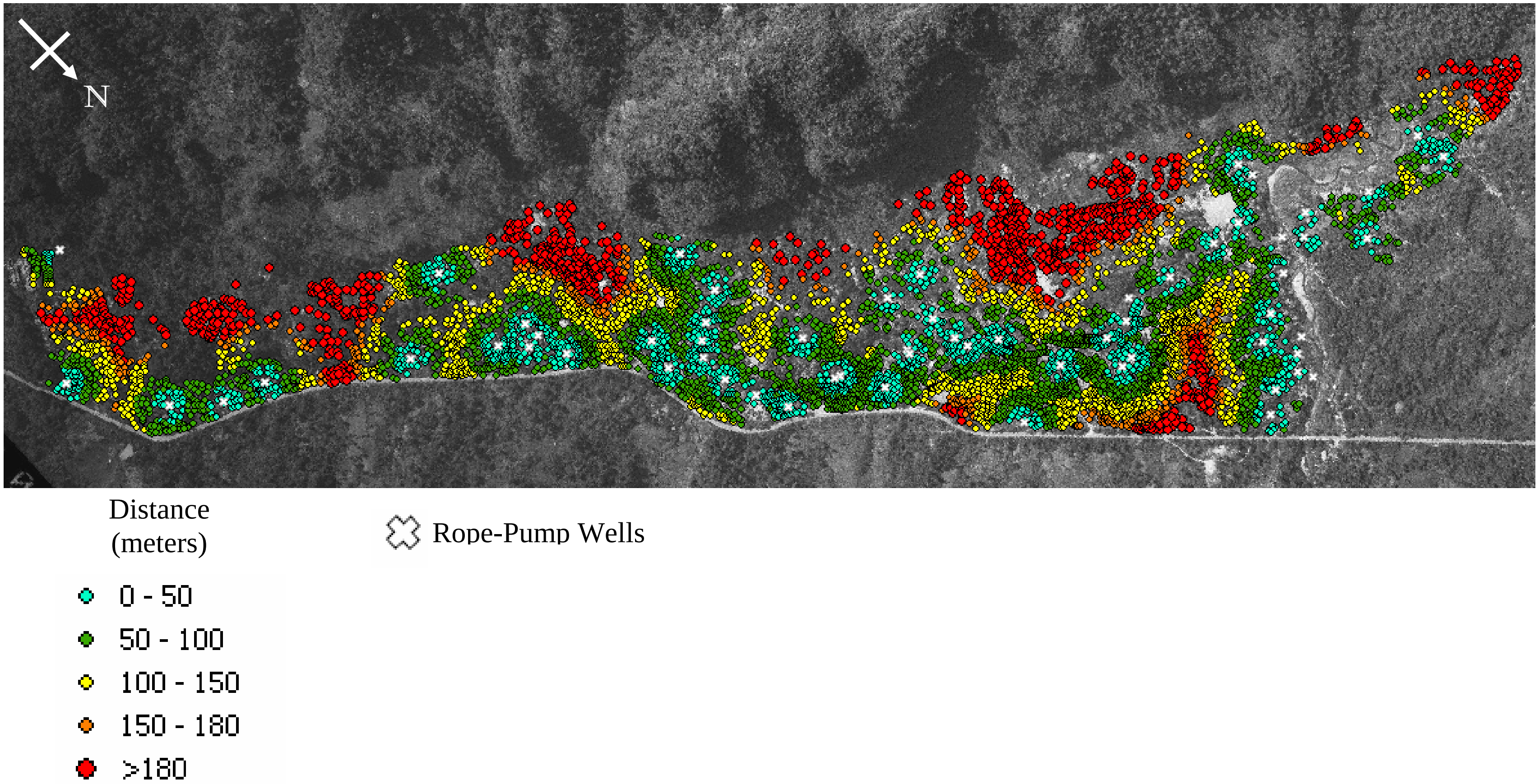

Figure 5-4: Home Distance to Nearest Rope-Pump Well.

Under this criterion, just over 1000 homes, or 14%, are an unreasonable distance from the nearest rope-pump well (Figure 5-5). Over one half of the homes have a rope-pump well somewhere between 30 and 100 meters away. There is a much greater number of homes located far from rope-pump wells, but this may not be easily remedied and there are additional sources of washing water. Also, there is a stream that runs west through the camp to the river in the northwest which can act as an alternative supply. While many of the homes in red are along the mountain ridge at the top of the Figure 5-4 are far from the river and stream, these sources do afford some homes a closer water source than the wells.

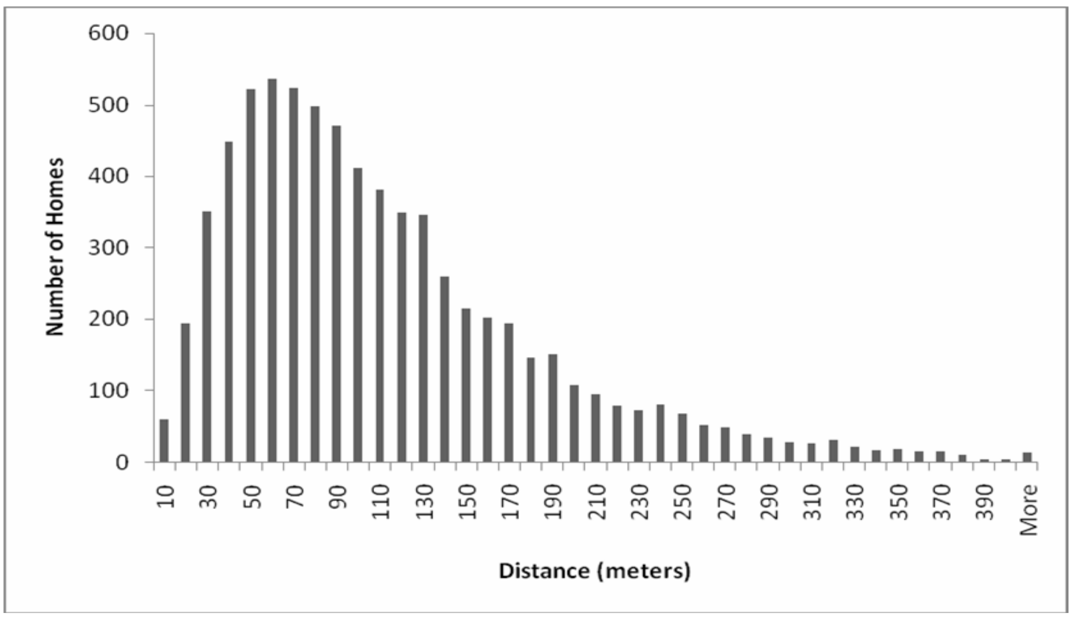

Figure 5-5: Home Distance to Nearest Rope-Pump Well - Histogram.

It is likely that drilling wells along the mountain ridge is not economically feasible given the greater depth to the water table from the increased elevations. Since a rope-pump well relies on the ability of the user to pull water from the water table to the surface, the wells are ill suited for locations where this distance is large. The areas of concern correlate with the high regions of the DEM. Figure 5-6 shows that many of the homes in red are located in the highest elevation zones within the camp.

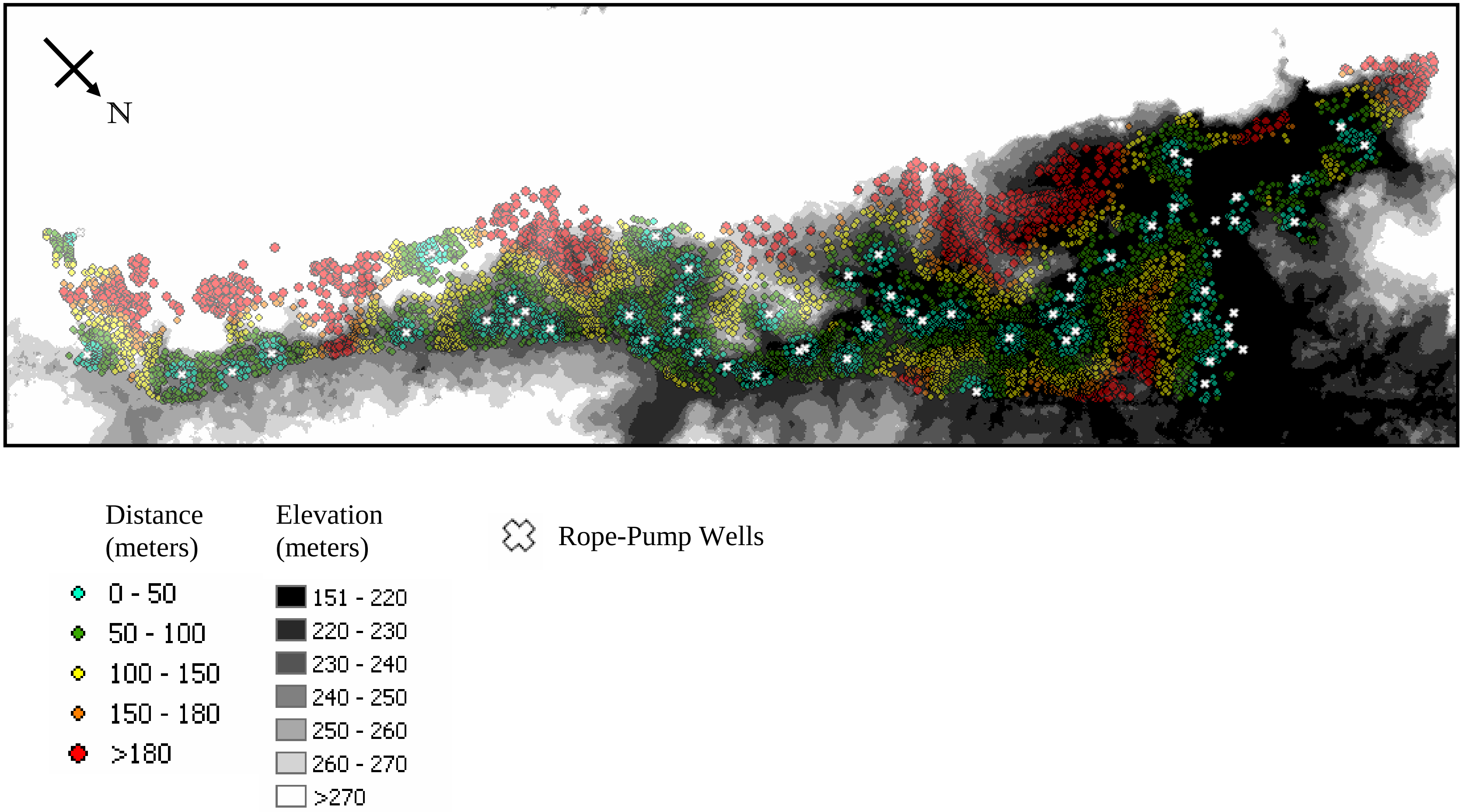

Figure 5-6: Nearest Rope-Pump Well and DEM.

5.3 VOLUME OF WATER PER HOUSEHOLD

Through linking the results of Navid Rahimi's EPANET model (Rahimi, 2008) with home locations, an estimate of available water volume per home is made. Rahimi's model predicts the average flow rate for 102 of the 139 viable tap stands. He shows that flow rates are very nearly constant throughout the six hours of operation and tanks do not run dry with normal use. Therefore, flow rates can be multiplied by distribution time to find daily available volume.

A conservative estimate for a minimum amount of consumable water is 7.5 liters per day per capita (UNDP, 2006). This includes about two liters per day for drinking and the remainder for food preparation. Since residents in Mae La camp use tap stand water for consumption only, this is an appropriate number for an analysis of tap stand water volume.

We use homes as a proxy for population. While this is not a perfect fit since some homes or regions of camp may be more densely populated than others, when looking at a broad view of the entire camp it should be a suitable approximation. Assuming an even distribution of a population of 45,000 among an estimated 8,500 homes, there would be between five and six people per home (F. Pascal, personal communication, April 21, 2008). Thus, 50 liters per home per day is a conservative estimate for the minimum amount of consumable water.

Some of the small spring systems were not included in the EPANET model which accounts for only 102 available predicted flow rates. Of the over 7,000 homes visually identified, 5,500 are included in the volume analysis. These are the homes whose closest viable tap stand is one of the 102 included in the model.

For each home, daily flow volume for the nearest tap stand was divided by the total number of homes associated with that tap stand. The distribution of daily availability of drinking water per home and shown in Figure 5-7.

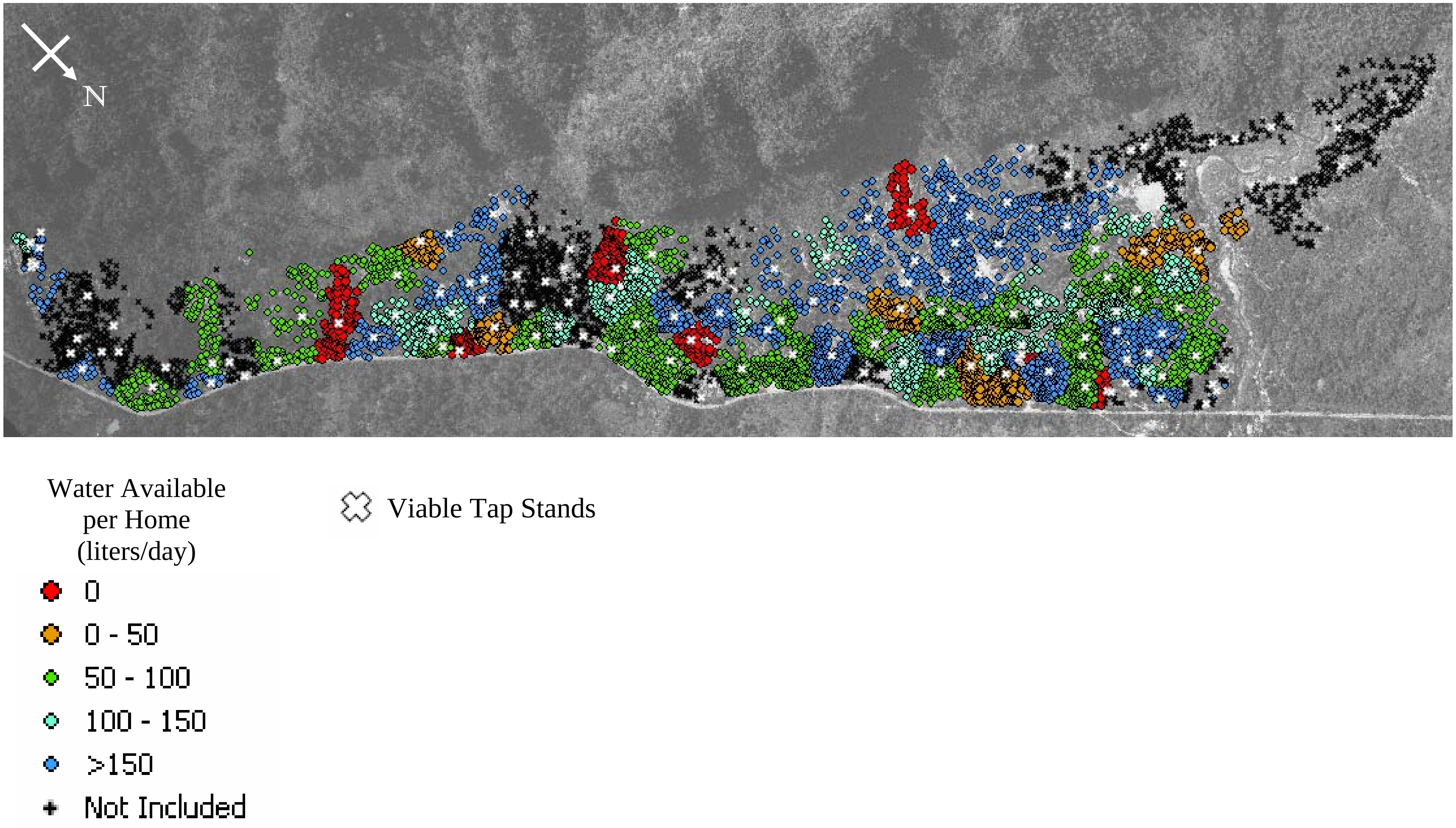

Figure 5-7: Daily Home Water Availability.

The homes of concern, shown in red and orange, are scattered throughout the camp. There is no single subsystem within the overall network where flow is low and no geographic similarities between the homes of concern, such as being located along the steep mountain ridge. Homes for which the closest viable tap stand was not included in the EPANET model are shown in black.

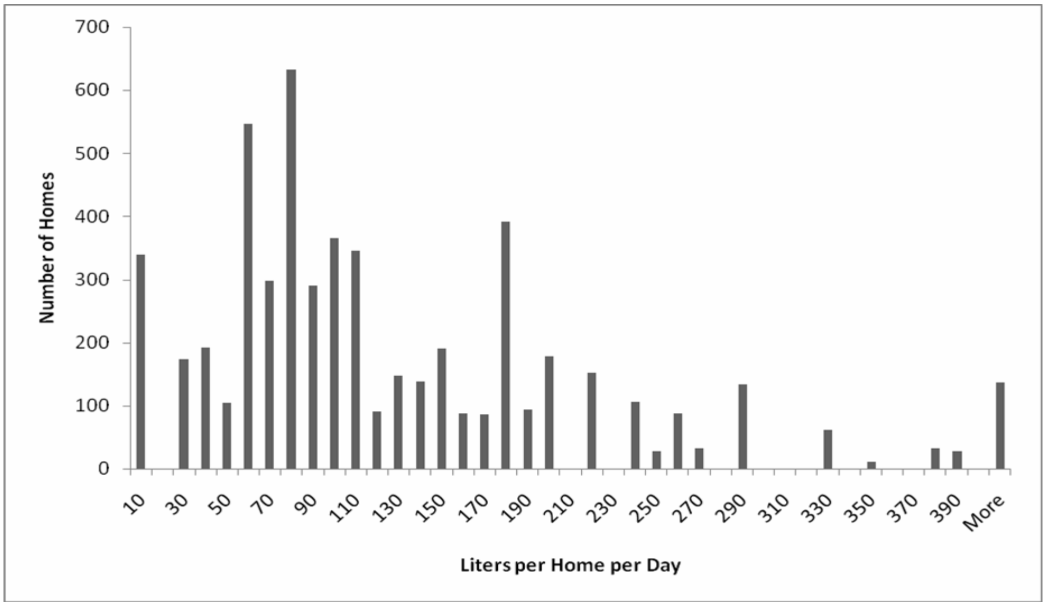

Figure 5-8: Water Volume Distribution - Histogram.

A total of 809 homes, or 15% of those considered, are categorized as unable to obtain 50 liters of water per day (Figure 5-8). By tracing these underserviced homes back to the originating taps, we find that there are 15 tap stands of concern.

There is definitely error in the model results because the model predicts flow rates of zero liters per minute at nine of the tap stands. Flow was observed at these tap stands during the site visit, however. It is most likely that these errors are related to the elevation assigned to the tap stands based on the GPS location. As discussed in Section 4.3, the GPS location error can create significant error in elevation. Since the model is driven in large part by these elevation differences, the model results are sensitive to these errors (Rahimi, 2008). Excluding the nine tap stands with zero flow, 365 homes, or 7%, are unable to collect sufficient water volume.

Potential interventions to address this issue include increasing pipe diameters to tap stands with low flow and installing additional tap stands near homes with inadequate availability. It is recommended that a more thorough evaluation of the tap stands of concern be completed before investing money in improvements. A survey of the residents utilizing the tap stand of concern as well as nearby tap stands should be completed. It is possible that people have adapted to traveling to further tap stands in order to collect adequate water.

Table 5-1 lists the tap stands of concern and water volume per home per day. The number of homes for which that particular tap stand is the closest viable option is also listed.

Table 5-1: Tap Stands with Inadequate Water Volume.

System	Tap #	Volume/Tap/Day (liters)	Homes/Tap	Volume/Home/ Day (liters)
AT	10	0	88	0
AT	11	1346	82	16
BT	6	4093	67	46
BT	9	0	97	0
BT	13	0	90	0
CH	11	3874	33	40
CT	2B	0	85	0
MOI	1	0	80	0
MOI	3	2844	166	23
MOI	7	5602	89	47
MOI	29	1786	32	31
MOI	NEW	0	96	0
S17	12	0	53	0
S17	B4	0	60	0
S8	4	0	18	0

6 CONCLUSION AND RECOMMENDATIONS

Overall this research shows that the vast majority of residents in Mae La have sufficient access to water. A water use survey is recommended in order to verify the findings of this research and modify the GIS tool for future work. The assumptions that every home utilizes the rope-pump well or tap stand that is of closest proximity may or may not be valid. A major area of concern, especially regarding the EPANET model results, is in attaining accurate locations and especially elevations of tap stands and water infrastructure points within the camp.

6.1 OVERALL WATER ACCESS

This research used GIS to assess three major indicators—home distance to tap stands, home distance to rope-pump wells, and volume of drinking water per home—with results summarized in Table 6-1. The overall results show that the access issue of least concern is proximity to public tap stands.

Table 6-1: Summary of Homes with Inadequate Access.

Homes with Far Taps*	349	(5% of 7,117)
Homes with Far Rope-Pump Wells	1,017	(14% of 7,117)
Homes with Low Volume	809	(15% of 5,500)

*Reduces to 210 (3%) when not including Spring 2 region

There are homes that fail more than one test, however. Table 6-2 shows a breakdown of the results considering that some homes will have multiple problems. Of homes identified, 73% are adequately serviced. Roughly one fifth of these homes are located nearest to tap stands not included in the EPANET model and therefore the volume test was not completed.

Table 6-2: Breakdown and Overlapping Burdens for Home Water Access.

	Flow Data	No Flow Data	Total
Far Tap, Far Well & Low Volume	18	-	**18**
Far Tap & Low Volume	18	-	**18**
Far Well & Low Volume	52	-	**52**
Far Tap & Far Well	78	93	**171**
Far Tap Only	37	105	**142**
Far Well Only	471	305	**776**
Low Volume Only	721	-	**721**
Near Tap, Near Well & High Volume	4,105	1,114	**5,219**
Total	**5,500**	**1,617**	***7,117***

6.2 POTENTIAL IMPROVEMENTS

There are a variety of concerns regarding these results and what service is actually provided in the camp. As mentioned in Section 5.2, the proximity to the nearest rope-pump well may not relate directly to water use since there are additional sources for non-drinking water such as bore holes and surface water. A water use survey that gathers information from a variety of homes dispersed throughout the camp would help better understand the extent of these alternative sources. The survey should account for seasonal change either by clearly asking questions about the different season or by surveying at multiple points throughout the year.

This survey could strive to understand how different groups, based on geography, wealth, ethnicity, gender, or age, access and utilize water. While logically homes located in the very steep sections of camp far from a public tap may adapt to using less water, there may be other subtle differences about the use of bore holes based on age or gender. The survey should ask which tap stands are frequented by the home. Do different members of the home prefer different tap stands and what are the perceived benefits? It was observed during the field visit that some systems (B System, for one) had perceivably higher pressures which resulted in shorter lines at the tap stands. How much further is a person willing to walk in order to avoid waiting for water?

A major improvement to the existing GIS information would be to obtain more accurate elevation and XY-location information for infrastructure points. This would help create a more accurate EPANET model which in turn produces the flow results that are viewed through the GIS program. There is a significant portion of the underserviced homes attributable to tap stands for which the model predicts flows of zero liters per day, when in fact water was observed at these stands. These and perhaps other erroneous predictions are the result of errors in measuring the elevation of water system components.

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APPENDIX A: DATA TRANSFER

There were a variety of data types and software used throughout this research. The existing data received from Daniele Lantagne and our determination of home locations are Google Earth compatible files. Geographic locations collected using the handheld GPS was compiled using Microsoft Excel. Excel was also used as an intermediary program to move data between Google Earth and ArcView 9.2. This Appendix describes how information was transferred between programs with various data types and is included to facilitate any future use and modification of the dataset by AMI and Soldarités.

A.1 CREATING FILES WITH GOOGLE EARTH

Using Google Earth, new points can be added to a map by selecting "New Placemark" from the "Insert" menu or simply typing Control+Shift+P. The placemark was moved onto the center of a home's roof and all home points were saved in one folder. Zooming in and out using the scroll button on the mouse was helpful for getting a better sense of home boundaries. Also, it was helpful to change the tilt which gave the camp a three-dimensional look and made some houses more visible. This can be done either by moving the tilt bar which is located above the compass rose in the upper right of the screen or by holding Control and using the scroll button. Additionally, by clicking on the compass rose the orientation of the view can be changed.

A.2 KML AND SHAPEFILE CONVERSIONS

Using shape and KML files interchangeably was important for this project in order to use the analysis capabilities of ArcGIS and the high quality aerial photos available on Google Earth.

To work with the Google Earth-created homes file in ArcView, a necessary step was to convert the Google Earth KML file into a shapefile. The most efficient means of conversion found was to use a freeware program called “Kml2shape” available at http://www.zonums.com/kml2shp_down.html. Once downloaded the program is simple to use. After selecting the “Open KML” button and choosing the file, select “Export SHP”. The datum is then specified as WGS84 and UTM coordinates selected along with the proper zone for Mae La camp (47 North). Finally, select an output file name and click “Accept”.

This new shape file can then be opened with ArcMap.

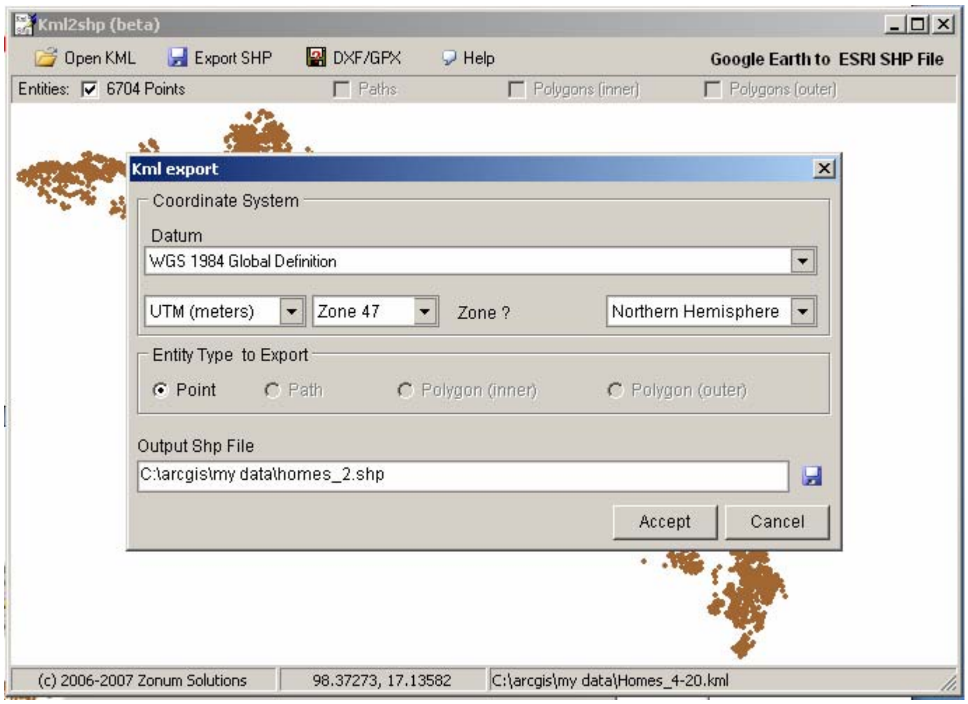

Figure A-1: Kml2shp Export Screen Shot.

A.3 FROM HANDHELD GPS TO COMPUTER

For location data taken on site with the Garmin eTrex Vista, a free program by the Minnesota Department of Natural Resources, DNR Garmin, was used to transfer all latitude, longitude and point name data onto the computer. After setting and opening the appropriate port (e.g. USB) from the GPS menu, “Waypoints” or point data can be uploaded to the program’s data sheet. At this stage data can be easily manipulated either in DNR Garmin or can be opened through Excel after saving as a tab delimited text file. Empty columns and extraneous information is removed, while information such as the number of taps per stand and the type of tap (e.g. latrine, private office source, public tap stand) is added.

The elevation data from the built-in altimeter and time and date information could not be automatically taken using the eTrex Vista GPS with DNR Garmin software. A DEM of the area, created by Dr. Bunlur Emaruchi became the source of our elevation data, and it was unnecessary to add the altimeter information.

Once the data was cleaned and columns added for tap stand information and type, the file was saved as a text file that could be opened with ArcMap. One particularly tedious feature of ArcMap is that the title fields of all data columns cannot contain spaces and can only begin with a letter. For example, "X_Coord" was a typical name designation.

A.4 ADDING DATA TO ARCMAP

Once a shapefile or text file is created, it could be included in the ArcMap view of the camp. After selecting "Add Data" the file appears as a layer in the bar on the left hand side of the screen. By right clicking on the layer and selecting "Display XY data" the proper column headings for the latitudinal and longitudinal coordinates can be selected. The matching coordinate system can be linked to the data within ArcMap by selecting "Edit" near the bottom of the prompt screen and navigating through Select→ Projected Coordinates → UTM → WGS84 and finally selecting the file with 47 North zone.

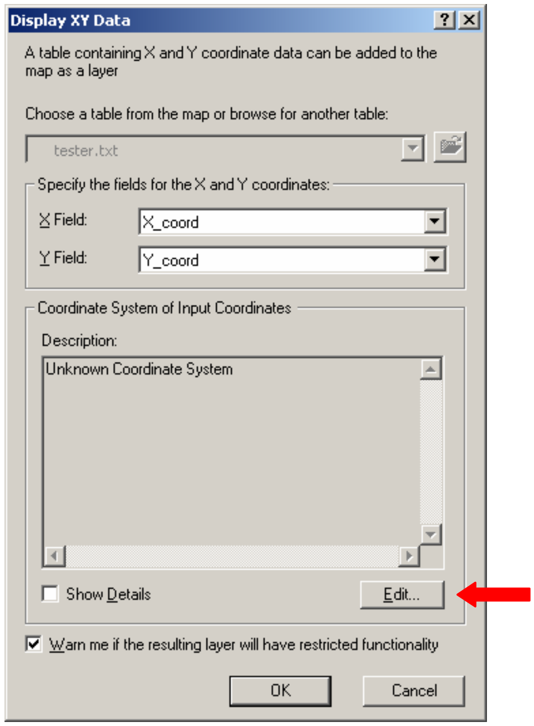

Figure A-2: Adding XY Data to ArcMap and Setting Coordinate System.

The data cannot be manipulated until it is reloaded which is done by right clicking again on the name and selecting Data → Export Data. After choosing a name for the new file, ArcMap will prompt to see if the new file should be automatically added to the map. If you choose against this, the now projected file can be added later with the “Add Data” feature.

When all of the layers are visible it is possible to change which layer appears on top or above another by moving the layer up or down in the left hand column.

The shapefiles that originated as Google Earth files do not display the X- and Y-coordinates in the associated attribute table. To view the coordinates open the attribute table and select Options → Add Field and type a label. Next, right-click on the newly created field and add the following code to the text box that appears in the Field Calculator window:

```
Dim dblX as double
Dim pPoint as IPoint
Set pPoint = [Shape]
dblX= pPoint.X
```

The last input box in the field calculator window appears underneath a display of the new field label and an equal sign. Type dblX here. Replace all the "X"s in the above steps to show the Y-coordinate values.

A.5 ARCMAP ANALYSIS

Once information was added to ArcMap, further analysis could be completed. The following is a summary of important information:

1. DEM (Dr. Bunlur),
2. Major water system infrastructure location (D. Lantagne)
3. Additional tap stand position (collected during site visit in January 2008)
4. Home locations (Google Earth, visual identification)
5. EPANET model flow rates

A.5.1 Joining Elevation Data

The elevation of infrastructure points withing the system could be assigned using the XY location and DEM. These elevation were necessary inputs to the EPANET model by Rahimi (2008) so pressures and flows could be calculated. To link the location and elevation infromation, the DEM must first be exported as a raster (right click on the layer and select Export Data). An "Export Raster Data" prompt box appears displaying the name of the selected layer. Next, the imbedded elevation information, which is displayed through varying colors, must be converted to an explicit number.

Within the Spatial Analyst extension, which is selected and made visible through the "Tools" menu, select Convert → Convert Raster to Feature. In the value field for this conversion, output polygon is selected since each square (polygon) within the raster grid is assigned an elevation number. Once successfully converted, the elevation data should appear as a number in the data set's attribute table (right click on the layer and select Open Attribute Table to confirm).

Next, the data set containing the XY coordinates for system points must be joined to the layer now containing explicit elevation data. Right click on the system point data layer and select Joins and Relates → Joins. In the prompt, select the proper DEM layer keeping the default options to join based on spatial location and to assign each point the attributes of the polygon that it falls inside. Choose a name for the output shapefile which can be added to the map and will have additional columns in its attribute table compared to the base system point data layer. There will be a column identifying the polygon ID from the DEM layer and the corresponding elevation.

Given the large number of polygons needed to describe the DEM, this process may take some time for the program to complete. The attribute table can then be exported as a text file which once manipulated to the proper format can be fed to the EPANET model software.

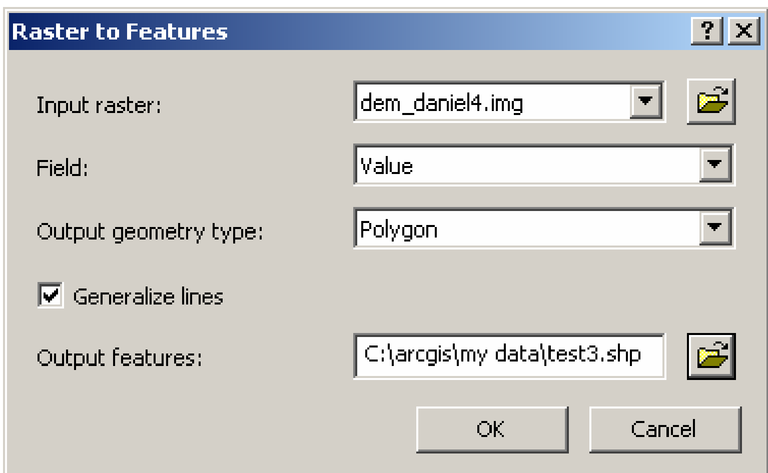

Figure 0-3: Converting Raster to Features.

A.5.2 Nearest Point Data

Another analysis included finding the nearest tap stand or rope pump well to each home within the camp. For the tap stand analysis, the first step was to select the set of viable drinking water taps from the library of system points. Only taps from which the public could collect drinking water were included which meant removing taps which fed into public latrines, private offices, and temples. Once the data set is prepared, the calculation can run quickly.

Within the toolbox, find Analysis Tools → Proximity → Near. In the Input Features, select the layer containing the homes and the Near Features will be the taps or wells.

Search radius can be omitted and make sure the desired units for distance are selected. After some calculation time, the attribute table for the homes data set will have two more important columns. “NEAR_FID” contains a number associated with the ID number of tap or well which is closest to that particular home and “NEAR_DIST” is the distance to this designated feature.