6-1-2009

The Burden of Fetching Water: Using Caloric Expenditure as an Indicator of Access to Safe Drinking Water - A Case Study from Xieng Khouang Province, Lao PDR

Jeff La Frenierre
University of Denver

Follow this and additional works at: https://digitalcommons.du.edu/etd

Part of the Food Studies Commons, Geography Commons, and the Water Resource Management Commons

Recommended Citation
https://digitalcommons.du.edu/etd/352

This Thesis is brought to you for free and open access by the Graduate Studies at Digital Commons @ DU. It has been accepted for inclusion in Electronic Theses and Dissertations by an authorized administrator of Digital Commons @ DU. For more information, please contact jennifer.cox@du.edu,dig-commons@du.edu.
The Burden of Fetching Water:
Using Caloric Expenditure as an Indicator of Access to Safe Drinking Water –
A Case Study from Xieng Khouang Province, Lao PDR

A Thesis
Presented to
the Faculty of Natural Sciences and Mathematics
University of Denver

In Partial Fulfillment
of the Requirements for the Degree
Master of Arts

by
Jeff La Frenierre
June 2009
Advisor: Dr. Matthew J. Taylor
ABSTRACT

The Millennium Development Goals measure ‘access to improved drinking water’ using an indicator that defines access as the presence of an improved water source within 1 kilometer of a person’s dwelling. This purely linear measurement has significant shortcomings, including a lack of consideration for the difficulty of the terrain being traversed and the weight of the loads being carried. This paper examines in detail the human energy costs associated with fetching water, first using two Lao villages as case studies, then applying a predictive energy expenditure model to measure the potential caloric effect of variations in the age and gender of water fetchers and in the nature of the terrain they must traverse. Results indicate that these factors have a substantial influence on energy expenditure, with one study village resident who walks 1 km to fetch water during part of the year spending more than 30% of her daily caloric intake on this task. This finding may have important implications on policies relating to water provision in the developing world.
Acknowledgements

My thesis committee, Dr. Matthew J. Taylor (Advisor; University of Denver Department of Geography), Dr. Rebecca L. Powell (University of Denver Department of Geography) and Dr. Sandy A. Johnson (University of Denver Joseph Korbel School of International Studies) provided valuable guidance throughout the research and writing process. Invaluable translation, research, and logistical assistance (and friendship) in Lao PDR was provided by Fue Vue and Moua Kajsiab. Additional logistical support was provided by Rik Ponne and Julie Van den Bergh of UNESCO. The initial idea for this research was heavily influenced by Brett Machovina and Grace Carter (University of Denver). Tireless proofreading and many valuable suggestions were provided by my wife, Paula La Frenierre. Lastly, deep gratitude to the hospitable and ever-patient people of Ban Songhak and Ban Nakhompheng, Xieng Khouang Province, Lao PDR.
Table of Contents

1. Introduction ..................................................................................................... 1

2. Defining Access to Water ................................................................................ 7

3. Research Methods ............................................................................................ 11
   3.1 Measuring Energy Expenditure ................................................................. 11
   3.2 Field Data Collection .................................................................................. 14
   3.3 Applying Field Data to the Predictive Energy Expenditure Model .... 17

4. Water Fetching and Consumption in Xieng Khouang Province ...................... 19
   4.1 Water Consumption in Xieng Khouang Province ........................................ 24
   4.2 The Demographics of Water Fetching in Xieng Khouang Province .. 26
   4.3 The Burden of Fetching Water in Xieng Khouang Province ............. 27

5. Relating Variability in Gender, Age, Terrain Type and Terrain Steepness to Variability in Water Fetching Energy Expenditure ......................................... 31
   5.1 Relating Age and Gender to Energy Expenditure ..................................... 33
   5.2 Relating Terrain Type to Energy Expenditure ......................................... 36
   5.3 Relating Slope Gradient and Energy Expenditure ............................... 38

6. Conclusions and Future Research Directions ................................................... 42

References ............................................................................................................ 45

Appendices ........................................................................................................... 50
   Appendix A: Photographs ................................................................. 50
   Appendix B: Statistical Analyses ................................................................. 54
Adopted in 2000, the Millennium Development Goals (MDGs) are now the key standards in measuring progress in human development, and are widely acknowledged as defining the current spirit of global development efforts (Fukuda-Parr 2004; Attaran 2005). The MDGs significantly improve upon past internationally-set development goals in that they provide specific development targets, a structure with which to assess various national, international, and non-governmental poverty reduction strategies, a means of accountability for both developed and developing countries in efforts to achieve targets, and a way to measure the gap between ideal and actual development progress (Fukuda-Parr 2004; Haines and Cassels 2004). More fundamentally, the MDGs place – for the first time – health and well-being concerns ahead of economic growth as the most critical development objectives (Fukuda-Parr 2004).

One of the key commitments explicated in the MDGs is to, “halve, by 2015, the proportion of the population without sustainable access to safe drinking water and basic sanitation” (United Nations 2008a). The lack of access to adequate supplies of safe drinking water plays a prominent role in the perpetuation of poverty throughout the developing world. The health, economic, and social detriments associated with this lack of access are well-documented (Cairncross 1990; Gleick 1996; Gadgil 1998; Howard and Bartram 2003; WHO/UNICEF 2004; Bartram et al. 2005; UNDP 2006), and include
disproportionate incidences of debilitating water-borne disease, loss of economic productivity, and reduced opportunities for education, especially among young girls. The resulting ramifications for peace and prosperity at scales ranging from local to global are well understood, and for nearly fifty years the provision of improved water and sanitation services has been an international development priority. Access to water is viewed as a basic human right, and its universal provision is a component of efforts to reduce global poverty and improve sustainable management of global water resources (Jolly 2004).

Meeting the MDG for access to water is closely linked with potential success in achieving several other MDG targets, including reduction of child mortality, reduction of major infectious diseases, improved maternal health, greater gender equality and improved childhood school enrollment, especially for girls (Hutton and Bartram 2008).

The intergovernmental development sector widely touts progress towards meeting the access to water target, though in fact it is one of only two MGD targets that are on track for completion by the 2015 deadline (Fukuda-Parr 2004; Jolly 2004; United Nations 2008b). Nonetheless, meeting the target has proved to be more complex than initially expected (Börkey and Gillespie 2006), and there is legitimate concern that the indicator for access to drinking water may be insufficient in defining conditions where actual health benefits have been attained (Lee and Floris 2003; Satterthwaite 2004; Attaran 2005; Simpson 2006; O’Hara et al. 2008; Jiménez and Pérez-Foguet 2008). Of potentially significant but largely unspoken concern is the disparity between the 1.1 billion people who continue to lack access to improved drinking water as defined by the current access indicator (UNDP 2006) and the nearly 3 billion people who do not have a household water tap (estimated at 2.93 billion as of 2000; Howard and Bartram 2003). Stated
another way, nearly half of the world’s population is reliant on someone physically 
transporting water some distance from a source to their homes. This task is most typically 
accomplished by individuals who must carry heavy loads of water on their backs, 
shoulders or heads.

Fetching water is an extremely onerous task. The amount of time and energy 
individuals – typically women and children – must spend on this chore limits 
opportunities for obtaining education, becoming more economically productive and even 
relaxing and socializing at home (White et al. 1972; Charmes 2006; Blackden and Wodon 
2006). Furthermore, the physical effort required in transporting heavy loads of water over 
distance often has a substantial negative impact on a person’s physiological and 
nutritional health (Curtis 1986; Dufant 1988; Ivens 2008). The current definition of 
access accepted by the World Health Organization (WHO), the United Nations 
Development Programme (UNDP) and other intergovernmental agencies requires an 
“improved” water source (such as a household connection, public standpipe, borehole, 
protected dug well, protected spring or rainwater collection system) providing at least 20 
liters of water per person, per day, within 1 kilometer of a person’s dwelling 
(WHO/UNICEF 2008). The indicator’s explicit assumption that people who must carry 
water up to 1 km have nonetheless attained an important human development threshold 
deserves critical evaluation.

Despite the fundamental importance of community water development and the 
sheer number of people forced to fetch water, relatively few studies examine the practice. 
It is unsurprising, then, that the connections between definitions of access and the costs 
associated with water fetching are rarely considered. Most studies that consider water
fetching only do so tangential to some larger question: water consumption patterns in rural communities (White et al. 1972; Bein 1981; Green 1984; Hadjer et al. 2005); gender roles in the developing world (Sangodoyan 1993; Devasia 2002; Bimla et al. 2003; Blackden and Wodon 2006; Charmes 2006; Ivens 2008); or the time/energy costs of domestic life in the developing world (Bleiberga et al. 1980; Whittington et al. 1990; Mehretu and Mutambira 1992; Aiga and Umenai 2002; James et al. 2002; Sujatha et al. 2003; Rao et al. 2007). Studies that examine water fetching exclusively, in detail, and with a broad examination of the associated consequences on individual and community health are few and far between (see Curtis 1986; Dufant 1988).

These existing efforts to describe the burden of water fetching, none of which have been undertaken for the purpose of evaluating the access to water indicator, typically use one of two metrics: distance traveled or time expended undertaking the task. While both are useful, neither perfectly quantifies the actual effort expended by those responsible for water collection. Studies that calculate only the average distance traveled fail to consider the difficulty of the terrain being traversed and the weight of the loads. Time expenditure studies take a greater variety of factors into account and better illustrate the burden in terms of lost opportunities for other activities (see Cairncross and Cliff 1987). Nonetheless, time expenditure alone can overstate the actual physical burden of the activity because it fails to differentiate the pace at which an individual can walk based on their age, gender and overall health, and the amount of time that is spent queuing at the water source or socializing with others.

Caloric expenditure, the basic unit of human effort, is potentially a better metric for measuring the burden of fetching water. A calculation of the number of calories an
individual burns not only accounts for the distances traveled while fetching water, but also the steepness of the route to and from the water source and the weight of the load. While certain broad studies of energy expenditure comment upon water collection (see White et al. 1972; Bleiberga et al. 1980; Mehretu and Mutambira 1992; Panter-Brick 1992; Bimla et al. 2003), as of yet no systematic attempt to use energy expenditure to quantify the burden of fetching water exists. Human activity is ultimately limited by the number of calories we consume. Describing water fetching – and thus access to water – in terms of available human energy may provide a better assessment of whether or not a household has reached a health threshold consistent with the intended spirit of the water provision development goal.

There are two objectives to the research presented here. First, the water fetching behavior of two rural villages, Ban Songhak and Ban Nakhompheng, Xieng Khouang Province, Lao PDR, is described for the purpose of illustrating the energy costs of collecting water in villages that meet the 1 km linear distance requirement for access to water. Second, using characteristics of the “typical” Xieng Khouang water fetcher, a predictive energy expenditure model is employed to analyze the impact of variables excluded from simple linear distance measurements – age, gender, terrain type, and slope gradient – on those energy costs. The thesis begins with an examination of the development of the current access to water indicator, existing critiques of the indicator and the data collection methods behind its measurement, and the existing water fetching literature. The second part of the thesis describes the methods used to measure various water collection metrics in the two study villages, as well as the development and application of the predictive energy expenditure model used in this research. The third
part of the thesis describes the water collection and usage behavior in the two villages
and estimates the percentage of daily caloric intake expended while fetching water by
residents. The final part of the thesis describes the impact on energy expenditure as the
age and gender of the water fetcher and the nature of the terrain traversed during water
collections trips varies.

The physical toll on those who must fetch water should be a primary
collection in water development planning and analysis. While the impact upon
community health that arises from drinking unsafe water is well understood, this physical
toll is an oft-overlooked health dimension of the problem. While the reality is that the
need for people to fetch water will remain unavoidable for the foreseeable future, this
research is motivated by the desire to promote further discussion in both the academic
and policy communities about the definition of access, the health ramifications of
transporting water, and the most effective means of addressing the global disparity in
access to clean, safe water.
2. DEFINING ACCESS TO WATER

It is a challenging proposition to define “access” to water and sanitation and in the years since this type of community development became an international priority, a number of metrics have been used. The earliest official attempt to define access was made by the WHO (1981). In proposing metrics to measure progress towards improving health for all citizens by 2000, the organization suggested as a useful indicator the presence of a “safe and adequate” water source within a given walking time, though no specific walking time thresholds were recommended. This emphasis on collection time was supported by a case study from Mozambique (Cairncross and Cliff 1987), which found that following construction of a new water system in one village and a subsequent reduction in collection times from 5 hours to 10 minutes, water consumption in the village increased by a factor of 2.7 and incidence of trachoma dropped to half that of a neighboring community.

Gadgil (1998) describes nine different sets of standards for measuring access adopted by various developing nations during the 1990s. Some measured walking time between households and water sources (with access ranging from 5 to 30 minutes, each way), while others measured the linear distance (ranging from 50 m to 2 km, each way) between the two. International development agencies attempted to standardize the indicator, though their own definitions were often problematic. One early effort measured population with access to safe drinking water as the, “proportion of population with
access to an improved water source in a dwelling or located within a convenient distance from the user's dwelling” (UN Commission on Sustainable Development 2001: 89). While “convenient distance” was then defined for urban areas as no more than 200 m, in rural areas it was simply described as a distance such that people didn’t need to spend, “a disproportionate part of the day fetching water” (90).

The roots of the 1 km definition since adopted by the WHO and UNDP, and now used to measure progress on the MDG for access to water, appear to be in a series of independent studies synthesized by Cairncross (1990). Multiple studies, conducted in both Africa and Asia, found a consistent relationship between the time spent fetching water and the quantity of water consumed: water consumption dropped sharply as soon as the source was moved more than 100 m away from the home, but then plateaued at a level still supportive of minimal health standards until collection time exceeded 30 minutes, after which consumption again dropped considerably (Figure 2-1). These findings suggested that, assuming water was available within 30 minutes of an individual’s home, the same amount of water would be consumed regardless of whether or not collection time was ten minutes or thirty. The logical conclusion, then, was that it is an inefficient investment of resources to provide water as close to a house as possible if consumption wouldn’t increase unless the source was provided immediately adjacent to a person’s house. It appears that this 30 minute time threshold is what has been subsequently used to adopt the 1 km distance threshold, though no explicit statement to this effect exists in the literature.
The methods used to measure progress toward the MDGs are increasingly contested. Much of the criticism is aimed at the validity of information collected via household surveys, which often lack concrete quantitative information (Jolly 2004; Attaran 2005; Jiménez and Pérez-Foguet 2008). Three recent papers, however, specifically single out the access to water indicator as potentially flawed. Satterthwaite (2004) writes in a broad examination of the MDGs as tools for poverty reduction that:

Hundreds of millions of people classified as having “improved” supplies still have to fetch and carry water from distant sources and/or have to queue for long hours each day to get the water. There is no information on whether their access is “sustainable”, and large sections of both the urban and the rural populations suffer from irregular water supplies (34).
O’Hara et al. (2008) critique the specific access to safe water target of the MDGs from the perspective of a national-level case study in Kazakhstan. With regards to the definition of access itself, the authors write:

The emphasis on distance to source is an issue and there is a need to re-evaluate its use. Clearly no one should have to travel far for their water, but while a supply 1,000m away may not be a major issue for people in some parts of the world, for people living in areas where the climate is extreme, for example very cold and inhospitable, or where the terrain is difficult, going a 1,000m could be life threatening. As such the maximum distance to source needs to reflect the physical conditions of a given region or country (20).

Finally, in a consideration of liberalization in the water and sanitation sectors published by the OECD and World Bank, Simpson (2006) makes a point fundamental to the research described here:

Local geography matters hugely. Identical distances from water points can mean very different things in practical terms if there are, say, extreme climatic conditions or dangerous social conditions. Distance also does not measure such factors as queuing time, which may depend on population density (102).

Local geography does indeed matter. The amount of effort required of an individual collecting water for their household is, as this research will demonstrate, directly related to the specific environmental and topographic conditions present in their village, as well as their own age and gender. Measuring mere distance – or time – does not adequately describe whether or not there exists the conditions necessary for that individual to collect a sufficient quantity of water at a minimal cost of human energy.
3. RESEARCH METHODS

I divide the discussion of research methods into three parts: the method used to calculate energy expenditure during water fetching activities, methods of field data collection in the two study communities, Ban Songhak and Ban Nakhompheng, and the application of field data to the predictive energy expenditure model.

3.1: Measuring Energy Expenditure

During the 1960s and 1970s, analysis of human energy expenditure played an important role in cultural ecology (Moran 1982). In more recent years, this type of research has been largely confined to the field of human physiology. As a result, technological advances in the measurement of caloric expenditure in humans are focused on methods in which direct contact with study subjects, either via the placement of monitors on the subject’s body or analysis of subject’s urine, is permissible. Ainslie et al. (2003) describe the most common energy expenditure calculation techniques currently in use. Unfortunately, these techniques are either too expensive, too cumbersome for use in a rural, developing world setting, or inappropriate for the type of cross-gender, cross-cultural development research I undertake here.

Predictive energy expenditure models are an alternative option, and one that is most appropriate in my particular research environment. Though such models are less precise than the methods described above, they provide three distinct advantages: Data
acquisition for predictive models requires no physically intrusive measures (aside from weighing subjects with a standard scale); models account for variations in load weight as a discrete factor; and models can be used in hypothetical scenarios for analysis of the ways in which factors controlling energy expenditure – gender, age, load weight, terrain type and slope gradient – are related.

The predictive model used in my research was first developed at the U.S. Army Research Institute of Environmental Medicine (Pandolf et al. 1977) and builds upon extensive earlier research into the energy costs of walking and load carriage (see Passmore and Durnin 1955; Goldman and Iampietro 1962; Soule and Goldman 1969; Givoni and Goldman 1971; Pandolf et al. 1976). Duggan and Haisman (1992) assessed multiple energy expenditure models by comparing their predicted results with those obtained via indirect calorimetry measurements on human subjects. They found the Pandolf model to be the most accurate and concluded that results generated across the range of load and gradient combinations were reasonable.

The Pandolf model requires the following parameters: body weight of the subject, weight of the load carried, average walking speed, slope grade and a terrain factor that considers the relative effort required to traverse the surface. The specific equation is as follows:

\[ M = 1.5W + 2.0(W+L)(L/W)^2 + \eta(W+L)[1.5V^2 + 0.35VG] \]

where \( M \) = metabolic rate in watts; \( W \) = subject weight in kilograms; \( L \) = load weight in kilograms; \( \eta \) = terrain factor; \( V \) = walking speed in meters per second; and \( G \) is gradient in percent.
One key weakness of the Pandolf (and other) predictive energy expenditure models is its inability to determine energy expenditure for downhill movement due to the fact that multiple forces work simultaneously on the same muscle groups, including the effect of gravity and the metabolic costs of forward movement and the maintenance of stability. Researchers at the same institute have since developed a corrective algorithm that provides a value that, when subtracted from the value calculated by the Pandolf model, accurately predicts downhill energy expenditure (Santee et al. 2001; Santee et al. 2003). The algorithm ($CF$) uses the same parameters as the Pandolf model and is as follows (Yokota et al. 2004):

$$CF = M - [\eta(G(W+L)V/3.5) - ((W+L)(G+6)^2/W) + (25-V^2)]$$

The watt totals calculated using the Pandolf model and its downhill correction factor are converted into kilocalories (kCal) expended per second (1 watt = 1 joule/second = 0.00024 kCal/sec), then multiplied by the overall number of seconds per trip to determine the total caloric expenditure for that water collection trip. This total is multiplied by the number of trips made per day to determine the total daily water fetching energy expenditure for that individual.

Because measuring the true mean daily caloric intake of each sample household is beyond the scope of this study, I determine the proportion of an individual’s total daily caloric energy expended while fetching water by dividing their water fetching caloric expenditure by the daily average energy requirement for Laotians as determined by the FAO (2001: 27-28 and 41-46). For children (under 18), the daily average energy requirements are based on their age and gender. For adults, the requirement is based on their age, weight, gender, and their lifestyle (as defined by their PAL, or habitual physical
activity lifestyle). Energy requirements used in this study are appropriate for individuals with a “vigorous” lifestyle (2001: 39). I then use a proportional method to convert data from the 5 kg intervals reported in the tables to a specific value for each calculated body weight.

3.2: Field Data Collection

I collected water usage and water fetching data in Ban Songhak and Ban Nakhompheng, including the parameters required by the Pandolf model, during a two-week period in August 2008. Translation and logistical support were provided by two local men trained as eco-guides by the United Nations Educational, Scientific, and Cultural Organization (UNESCO). One of the translators is a native of Ban Nakhompheng. Permission to conduct research in the two villages was granted by the Xieng Khouang Provincial Governor’s Office and the respective village chiefs, with facilitation by UNESCO officials in Xieng Khouang Province. All survey questions were approved by the University of Denver Institutional Review Board.

For each village, the initial phase of data collection involved the creation of detailed community maps that identified all households, water sources and primary routes to water sources using survey-grade GPS hardware in concert with mobile GIS data collection software. Key informants provided detailed information about the names, seasonal variations, and general character of each water source, as well as basic demographic information such as the number of adult and child residents of each household. Once mapping was complete, I selected a subset of households for detailed investigation using a systematic random sampling technique that yielded 19 samples in
Ban Nakhompheng and 18 in Ban Songhak. When I could not interview a household selected for sampling (residents absent, consent refused, etc.), I selected the household in nearest proximity as an alternate.

At each sample household, I interviewed the adult resident primarily responsible for water management (typically the matriarch) concerning household demographics, water consumption patterns and typical water collection behaviors. I first asked the respondent to list all household residents by age and gender, then asked them to identify each individual as someone who either fetched water most days, some days or never. Next, I asked respondents to identify the water source they used most frequently during both the wet and dry seasons (only Ban Songhak residents are forced to use different dry season sources), and to estimate the amount of water consumed by the household each day in terms of the number of buckets of water transported. I measured the buckets used in each household to determine their capacity (I estimated a full bucket of water as 90% of bucket capacity to allow for sloshing during transport).

I then asked each respondent to estimate the number of buckets used per day in each of five water use categories (excluding water used directly at the source): drinking, cooking, personal hygiene (including bathing), cleaning of household objects, and other (which typically was limited to the watering of animals and household gardens). When the sum of the buckets used in each category exceeded the number originally reported for the daily transport question, I applied the proportion reported for each usage category to the original bucket count response in the overall household consumption estimates.

Once the interview was complete, I then accompanied the individual present who most often fetched water on a single collection trip. Before departure, I measured their
body weight using a digital metric bathroom scale, then, during the collection trip, I timed the subject (in seconds) on each segment of their route, both outbound and on return. I differentiated route segments as changes from uphill/level to downhill grades, sharp, sustained changes in same-direction gradients, or changes in terrain surface type occurred. I also asked each water fetcher to estimate the number of collection trips they themselves made each day. If the water fetcher used a different water source during the dry season, I asked them to specifically identify the route they used. In some instances, routes were sufficiently different that I asked subjects to walk to the dry season source, so that they could be timed on the outbound portion of their trip. I did not, however, ask these individuals to transport water back from the dry season source, since (where different) most were significantly farther away than the wet season sources used at the time of the field survey. At the end of the collection trip, I weighed each water fetcher with filled buckets. The difference between this measurement and their initial weighing determines the weight of the water load.

The final phase of field data collection involved GPS remapping of all water collection routes in order to verify precise walking distances. I used a differential leveling technique to measure the total elevation change along each segment of each water collection route (see Appendix A, Plate1), then classified each segment by the following terrain types: gravel road, packed dirt, grass, muddy dirt/clay, and extremely muddy clay (indicating deep and/or particularly slippery mud).
3.3: Applying Field Data to the Predictive Energy Expenditure Model

The five parameters incorporated into the Pandolf model are body weight, load weight, walking speed, terrain type, and slope gradient. I apply body weight and load weight directly from the measurements made during the household surveys and determine walking speed by dividing the linear distance of a route segment by the number of seconds needed by the water fetcher to traverse that segment. I make separate calculations for both outbound (empty buckets) and return (filled buckets) trips so that walking speeds can fall into one of four categories depending on the nature of the water collection route: uphill empty, uphill full, downhill empty or downhill full. I calculate slope gradient by dividing the elevation change of the segment by its linear distance.

Translating the terrain type classifications from this study into a reasonable terrain factor for use in the predictive model is somewhat inexact. The terrain factor is applied to the model as a simple multiple of one portion of the equation. Terrain with a factor of 2.0 is considered to be twice as difficult to traverse as a terrain with a factor of 1.0, and the subsequent caloric expenditure used to carry a load across the more difficult surface is thus adjusted accordingly. Some of the terrain types I identified in Xieng Khouang were not quantitatively defined in the study where they were first derived (Soule and Goldman 1972), thus I have assigned estimated values for the terrain present in the in the two study villages (Table 3b1).

Xieng Khouang Province experiences distinct wet (June – September) and dry (October – May) seasons. Where appropriate, model parameters are adjusted to account for variations in local walking and water usage conditions.
## Table 3-1: Terrain factors

<table>
<thead>
<tr>
<th>Terrain Type</th>
<th>Terrain Factor (η)</th>
<th>Soule and Goldman (1972)</th>
<th>This Study</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blacktop Surface</td>
<td>1.0</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Dirt Road</td>
<td>1.1</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Gravel Road / Dirt Path</td>
<td>—</td>
<td>1.1</td>
<td>—</td>
</tr>
<tr>
<td>Light Brush</td>
<td>1.2</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Grass</td>
<td>—</td>
<td>1.2</td>
<td>—</td>
</tr>
<tr>
<td>Heavy Brush</td>
<td>1.5</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Swampy Bog</td>
<td>1.8</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Muddy Clay</td>
<td>—</td>
<td>1.8</td>
<td>—</td>
</tr>
<tr>
<td>Loose Sand</td>
<td>2.1</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Extremely Muddy Clay</td>
<td>—</td>
<td>2.1</td>
<td>—</td>
</tr>
</tbody>
</table>
4. WATER FETCHING AND CONSUMPTION IN XIENG KHOUANG PROVINCE

Located in northern Lao PDR, Xieng Khouang Province is home to the so-called Plain of Jars, an important archeological resource that forms the basis of a proposed World Heritage Site (Appendix A, Plate 2). Although tourism is an increasingly important part of the provincial economy, Xieng Khouang remains one of the poorest provinces in one of Asia’s poorest nations, in large part due to the legacy of severe aerial bombardment on the part of the U.S. military during the Vietnam War. Unexploded ordinance is a substantial problem in many areas of the province, including both village sites. Aside from the approximately 12,000 people residing in the provincial capital Phonsavan, the province’s 200,000 ethnic Lao and Hmong residents live in rural, agrarian-based villages, more than 96% of which have populations under 1000. The two villages selected for detailed analysis are Ban Songhak and Ban Nakhompheng (Figure 4-1). At present, water fetching is ubiquitous in both villages, though with one dry-season exception all homes are less than 1 km from their water sources. As such, they make useful case studies for analyzing water fetching energy expenditure in communities that potentially meet the current definition of access to water.

Ban Songhak is a Lao ethnic community located 22 km northwest of Phonsavan (Appendix A, Plate 3). The village is adjacent to a jar site and is one of seven “community-based heritage tourism” target villages designated by UNESCO for economic development as part of the proposed world heritage designation of the
province. Ban Songhak’s 230 residents live in 37 households that are dispersed in smaller clusters around a large rice paddy complex (Figure 4-2). Though road access is reasonable, there is presently no water, sanitation, or electrical infrastructure in the village.

Water in Ban Songhak is obtained from a series of unprotected springs that are scattered around the village, generally ranging from 60 to 300 m in distance from individual homes. The springs closest to the majority of homes do not flow through the entire dry season, thus residents must travel more than twice as far on average (431 m vs.
204 m) to collect water during the two or three driest months of the year. Most springs seep into small ponds built to store the water. A small piece of pipe, plugged with a wooden stopper, typically protrudes from the pond’s earthen dam to form a spout for water collection (Appendix A, Plate 4). Because none of the springs are protected by an enclosed spring box, Ban Songhak’s water sources, with the exception of

Figure 4-2: Ban Songhak households, water sources and water collection routes.
one shallow well used by two households on the northeast side of the village, do not meet the UN/WHO definition of improved water sources.

Ban Nakhompheng is a Hmong village about 25 km east of Phonsavan along a paved national highway (Appendix A, Plate 5). Until recently, the community was a part of the adjacent village of Ban Tajok, which is centered at the intersection of the highway

Figure 4-3: Ban Nakhompheng households, water sources and water collection routes.
and a smaller local road, however it has since been administratively separated into its own political entity. There are approximately 800 village residents living in 112 households, most of which are located east of the national highway (Figure 4-3), though seven houses along the national highway are also considered part of Ban Nakhompheng. Though access from Phonsavan is good, there is no water, sanitation or electrical infrastructure in place.

The five springs associated with Ban Nakhompheng flow year round. Four of these are in close proximity to the main portion of the village (distance between house and spring ranges from 90 to 500 m with a mean of 280 m), and all are improved with concrete spring boxes (Appendix A, Plate 6). Most of the houses situated alongside the national highway use their own spring, called Tong Xe. Though this spring is not protected by a spring box, it is considered to be of excellent quality. Households that use this spring are located between 425 and 750 m from their water source.

In both villages, the typical mode of water transport regardless of age or gender is via two open buckets balanced on the end of a bamboo pole, balanced over the shoulder (Appendix A, Plate 7). In a few instances, women will transport water in a 20 L closed plastic jerry can carried in bamboo basket on their backs. Some very young children (typically less than 7 years of age) may also assist with water transport by carrying a single 5 L jerry can by hand. Water is not carried on heads in Xieng Khouang, nor are pack animals used for water transport in either village.
4.1: Water Consumption in Xieng Khouang Province

Water consumption surveys in the two villages yielded some surprising results (Table 4-1). Despite having less developed, more seasonally variable, and, in certain months, more distant water sources, residents of Ban Songhak reported per capita water consumption rates twice that of Ban Nakhompheng. Statistical outliers do not appear to be the cause of this discrepancy; median per capita daily water consumption in Ban Songhak is 35 l, while only 15 L in Ban Nakhompheng. The proportion of water devoted to each of five household usage categories (drinking, cooking, hygiene, cleaning, and other) is essentially the same in both villages, which suggests that some sort of reporting error may be responsible for the different rates. Although residents of the two villages are of different ethnic and cultural backgrounds, it would seem unlikely that people in Ban Songhak regularly drink twice as much water per day (4.5 L/p/day, based on a 12.8% drinking use rate of a daily total consumption of 34.9 l) as people in Ban Nakhompheng (2.3 L/p/day based on 13.1% of 17.9 l) considering the location and quality of their respective water sources. One explanation might be that data was collected in the wet season, when water sources in Ban Songhak are generally much closer to homes than in the dry season (though nearly all respondents claimed that they transported the same volume of water each day, regardless of the season). It is also possible that people in Ban Nakhompheng systematically underestimated their water consumption. Further water consumption analysis uses the aggregate values reported by both villages with the caveat that further investigation – especially during the dry season – is needed before any concrete conclusions can be reached. In any case, there is no statistically-significant
relationship between the proximity of a household to its water source and its per capita water consumption (Appendix B, Figures 1a and 1b).

If aggregate water consumption rates (Table 4-1) are compared to minimum requirements for basic needs suggested by Gleick (1996), it becomes evident that the need to fetch water has a potentially deleterious effect on household health and well-being. Drinking water consumption is estimated at 3.4 L/p/day, which is slightly above the absolute recommended minimum of 3 L/p/day but well below the 5 L/p/day minimum suggested for tropical environments. Cooking water consumption is approximately 7 L/p/day, again lower than the recommended 10 L/p/day.

A minimum of 15 L/p/day is recommended for bathing, with an additional 20 L/p/day for sanitation. In aggregate, the two study villages report using only 8.3 L/p/day for hygiene (which was defined as any cleaning of the human body) and 5.8 L/p/day for cleaning of household items. In both villages, but especially in Ban Nakhompheng where improved spring boxes are surrounded by concrete platforms, some bathing (especially by pre-pubescent children) and most laundry activities occur at the water source itself, thus reducing the amount of water each household must transport to meet its needs.

However, a more important factor in the low consumption level is that neither village is provided with an improved sanitation system. While this reduces the amount of water needed to flush waste, it also means that residents do not have convenient means to use water to wash their hands after performing toilet activities. As discussed earlier in this paper, a fundamental concern in community water development is reducing the incidence of disease through the provision of water for hygiene-related purposes. If the need to
Table 4-1: Water consumption in Xieng Khouang Province

<table>
<thead>
<tr>
<th></th>
<th>Ban Songhak</th>
<th>Ban Nakhompheng</th>
<th>Aggregate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean daily household water consumption (L)</td>
<td>188.7</td>
<td>128.1</td>
<td>157.6</td>
</tr>
<tr>
<td>Mean daily water consumption per person (L)</td>
<td>34.9</td>
<td>17.9</td>
<td>26.2</td>
</tr>
<tr>
<td>Mean % of water used – drinking</td>
<td>12.8%</td>
<td>13.1%</td>
<td>13.0%</td>
</tr>
<tr>
<td>Mean % of water used – cooking</td>
<td>23.8%</td>
<td>28.6%</td>
<td>26.3%</td>
</tr>
<tr>
<td>Mean % of water used – hygiene</td>
<td>30.0%</td>
<td>33.5%</td>
<td>31.8%</td>
</tr>
<tr>
<td>Mean % of water used – cleaning</td>
<td>25.4%</td>
<td>19.4%</td>
<td>22.3%</td>
</tr>
<tr>
<td>Mean % of water used – other</td>
<td>6.2%</td>
<td>5.4%</td>
<td>5.8%</td>
</tr>
</tbody>
</table>

fetch water hampers this essential activity, it is worth asking if the health motivations behind the access to water indicator are truly being addressed.

4.2: The Demographics of Water Fetching in Xieng Khouang Province

The demographics of water fetching in the two study villages generally mirror patterns identified worldwide: females, especially girls, are much more likely than males to be the primary water fetchers for a household (Table 4-2). While there are some differences between the two villages, they are not notable enough to suggest a cultural explanation between Lao and Hmong. In both villages, only 14.6% of individuals who fetch water most days are males under the age of 18. In Ban Songhak, females over the age of 18 are more likely to fetch water than females under the age of 18 while the reverse is true in Ban Nakhompheng, however the overall small sample size and the specific demographic breakdown in each village is probably more responsible for this effect than any conscious cultural decision. Indeed, the percentage of all girls between the ages of 8 and 17 who fetch water most days in both villages are essentially the same (70.4% in Ban Songhak vs. 70.6% in Ban Nakhompheng). By contrast, the number of adult men who fetch water both days is under 30% in both villages, and anecdotally, it
appears that men are only likely to fetch water if they are establishing a family and their wives are pregnant or tending infant children, or if young adult men still live with their families and there are no teenage females available to undertake this task. A final note about water fetcher demographics: men are no more likely to fetch water as the distance between house and water source increases. In fact, while there is no statistically significant difference between genders in mean water fetching distance ($n = 35$), of the 11 instances where per trip water fetching distance exceeds the overall sample mean of 362 m 10 are by women (Appendix B, Figure 2).

Table 4-2: Water fetcher demographics in Xieng Khouang Province

<table>
<thead>
<tr>
<th></th>
<th>Ban Songhak</th>
<th>Ban Nakhompheng</th>
<th>Aggregate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Median age of water fetchers</td>
<td>14.5</td>
<td>18</td>
<td>16</td>
</tr>
<tr>
<td>Mean % of household members who fetch water</td>
<td>34.8%</td>
<td>46.1%</td>
<td>39.4%</td>
</tr>
<tr>
<td>Mean % of water fetchers – male, ≥18 yrs</td>
<td>14.6%</td>
<td>14.6%</td>
<td>14.6%</td>
</tr>
<tr>
<td>Mean % of water fetchers – female, ≥18 yrs</td>
<td>20.8%</td>
<td>36.6%</td>
<td>28.5%</td>
</tr>
<tr>
<td>Mean % of water fetchers – male, &lt;18 yrs</td>
<td>22.9%</td>
<td>19.5%</td>
<td>21.3%</td>
</tr>
<tr>
<td>Mean % of water fetchers – female, &lt;18 yrs</td>
<td>41.7%</td>
<td>29.3%</td>
<td>35.7%</td>
</tr>
<tr>
<td>Mean % of males ≥ 18 yrs who fetch water</td>
<td>23.3%</td>
<td>30.0%</td>
<td>26.6%</td>
</tr>
<tr>
<td>Mean % of females ≥18 years who fetch water</td>
<td>33.3%</td>
<td>55.6%</td>
<td>44.1%</td>
</tr>
<tr>
<td>Mean % of males 8-17 yrs who fetch water</td>
<td>55.0%</td>
<td>53.3%</td>
<td>54.2%</td>
</tr>
<tr>
<td>Mean % of females 8-17 yrs who fetch water</td>
<td>70.4%</td>
<td>70.6%</td>
<td>70.5%</td>
</tr>
</tbody>
</table>

Note: Water fetchers are defined as those individuals who fetch ‘most days’.

4.3: The Burden of Fetching Water in Xieng Khouang Province

I examine water fetching in the two villages in terms of the two typical metrics, linear distance to water and time spent daily fetching water, as well as in terms of the water fetcher’s predicted energy expenditure (Table 4-3). In Ban Nakhompheng, water fetchers must walk an average of 305 m to reach their water source, making 2.6 collection trips each day and spending approximately 27 minutes on this task. During the
dry season, the mean energy expenditure of water fetching is 107.2 kCal, or 4.2% of the average daily caloric requirement. During the wet season, muddy paths increase mean energy expenditure to 138.0 kCal, or 5.5% of daily caloric requirement. These relatively low values are buoyed by the fact that many of the village’s households are located south of the secondary road, quite near the springs. Those individuals living on the north side of the secondary road in some cases use a substantially higher amount of energy fetching water each day (Figure 4-3).

Table 4-3: The burden of fetching water in Xieng Khouang Province

<table>
<thead>
<tr>
<th></th>
<th>Ban Songhak</th>
<th></th>
<th>Ban Nakhompheng</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Wet Season</td>
<td>Dry Season</td>
<td>Wet Season</td>
<td>Dry Season</td>
</tr>
<tr>
<td>Mean # of water fetching trips per person, per day</td>
<td>5.1</td>
<td>4.7</td>
<td>2.6</td>
<td>2.6</td>
</tr>
<tr>
<td>Mean one-way distance per water fetching trip (m)</td>
<td>204</td>
<td>431</td>
<td>305</td>
<td>305</td>
</tr>
<tr>
<td>Mean distance walked fetching water per day (km)</td>
<td>2.2</td>
<td>4.2</td>
<td>1.6</td>
<td>1.6</td>
</tr>
<tr>
<td>Mean time spent fetching water per day</td>
<td>46 min</td>
<td>1 hr 20 min</td>
<td>27 min</td>
<td>27 min</td>
</tr>
<tr>
<td>Mean energy expended fetching water per day (kCal)</td>
<td>215.7</td>
<td>318.8</td>
<td>138.0</td>
<td>107.2</td>
</tr>
<tr>
<td>Mean % of daily caloric intake expended fetching water</td>
<td>8.7%</td>
<td>12.8%</td>
<td>5.5%</td>
<td>4.2%</td>
</tr>
</tbody>
</table>

House #19, for example, is a newer residence inhabited by a young family who most likely had no other option for construction location. The 21-year-old woman who fetches for this household makes three trips per day, walking 502 m to her water source at Jua Tong. While she spends only an additional 18 minutes more per day doing so, her daily energy expenditure is more than double the village mean (10.0% wet season 13.6% dry season). This family is at a particular disadvantage – the father is permanently crippled due to a farming accident, leaving the young mother as the household’s sole
provider of physical labor – nonetheless, while walking only half as far as others who enjoy “access” to water according to current indicator, this woman must still use at least 10% of her daily energy budget simply collecting water, to say nothing of the effort required to cook, clean, grow crops, and otherwise provide for her family.

During the dry months in Ban Songhak (typically March, April and May), water fetchers must travel further than in the wet. Thus while the terrain becomes easier to traverse as it dries out, energy expenditure increases as a result of the longer walks (Figure 4-2). During the wet season the mean one-way fetching distance is approximately 200 m (100 m less than that of Ban Nakhompheng). However, because of higher water usage rates reported in the village, the number of collection trips per day (5.1), the amount of time spent fetching each day (46 min), the mean calories expended each day (215.7), and the percentage of daily caloric requirement (8.7%) are all higher than in Ban Nakhompheng. During the dry season, the mean fetching distance increases to 431 m, mean daily collection time increases to 1 hour 20 minutes, mean caloric cost increases to 318.8 and mean percentage of daily caloric requirement increases to 12.8%.

Several households in Ban Songhak have to travel much farther than the overall village mean to obtain water, especially during the dry season. One household, #38, is 1005 m away from their dry season water source, thus they offer a useful real-world example of the potential energy cost of the 1 km definition of access to water. Though there is a year-round water source within 300 meters of their house (Tha Bue), the household has chosen to obtain their dry season water from the Nam Ngum (river) south of the village (they also choose to use a separate wet season water source, Tha Bua, that is 504 m away; the women explain that demand occasionally exceeds supply at Tha Bue
and that the overall water quality, especially in the dry season, is much better at their preferred sources). A 16-year old female water fetcher was surveyed on a wet season trip to Tha Bua, and based on the measurements made during her trip, it is estimated that each dry season water collection trip to the Nam Ngum costs her 102.3 kCal. Multiplied over her 6 reported trips per dry season day, the subject potentially expends 31.8% of her daily caloric requirement.

Daily per capita water consumption at this house is reported as 35.8 L, slightly above the village mean of 34.8 L. It is perhaps surprising that water consumption is not reduced as a result of the increased distance to their water source, and survey/observation of water use during the dry season would increase confidence in this energy expenditure estimate. Nonetheless, even if the number of collection trips is somewhat inflated, the volume of water this number of trips provides is still less than 50 L p/day minimum consumption recommendation (the muddy river banks make it seem unlikely that much bathing/cleaning water use occurs at this source). Furthermore, while quite distant, the dry season terrain surface type (dry dirt) and the mean slope gradient (3.8%) on this route are both on the easier side of the spectrum, and as is described in the following section, these factors alone have a substantial influence on energy expenditure. In short, this household is located right at the threshold for access in terms of linear distance using the current access to water indicator, and the route is across easy, relatively gentle terrain. Even so, the 16-year old female who fetches water for this house potentially uses nearly one-third of her daily caloric requirement despite being at the most energy efficient age for this type of physical activity (see section 5.1).
5. RELATING VARIABILITY IN GENDER, AGE, TERRAIN TYPE AND TERRAIN STEEPNESS TO VARIABILITY IN WATER FECTHING ENERGY EXPENDITURE

The physiographic parameters identified for water fetching in Xieng Khouang Province can be applied to the Pandolf predictive energy expenditure model to analyze the effect of gender, age, terrain type and terrain steepness on the amount of calories required to transport water. Each model run requires a number of assumptions about the hypothetical water fetcher used in that particular analysis.

The body weight of the water fetcher is based on the age and gender selected for analysis and is calculated from the equation of best fit regression lines calculated from the data collected during the community surveys (Appendix B, Figures 3a – 3f). The water fetcher’s daily caloric requirement is also based upon the age and gender selected for analysis and is derived from tables published by FAO specifically for Lao PDR (FAO 2003). As with the actual water fetchers surveyed in this study, I utilized a proportional method to calculate caloric requirement of the hypothetic individual based on a specific body weight rather than using the rounded (to the nearest 5 kg) intervals provided in these tables. Basal metabolic rates (BMR) used in the energy expenditure calculations are determined by age and gender and are derived from FAO/WHO data (FAO 2001). It should be noted that a study of Vietnamese adults – who typically have similar diets and body types to Lao and Hmong – found that resting metabolic rates were overestimated by the FAO/WHO tables by anywhere from 7.4% to 13.5% depending on the age and gender
of the individual (Nhung et al. 2005). However, because this finding is not specific to the ethnicities of the population in this study, no correction factor is applied to this analysis.

The volume of the water carried per trip is also dependent upon the age and gender of the water fetcher and is based on observations made in the two study villages. The weight of the water load used in the hypothetical scenarios is governed by the volume transported, with an additional 1.5 kg added to account for the empty weight of the water buckets and balancing poles.

The volume of water an individual must transport each day is based on two factors: the amount of water required by each individual in a household each day and the proportion of water fetchers to total number of residents in each household. For the former, I used a value of 50 L per person, per day, based on research that indicates that this is the minimum requirement for healthy living in tropical environments (Gleick 1996). The latter factor incorporates the assumption that a water fetcher will carry water for some portion of the entire household, not just for his/her own personal consumption and is based on the observation in the two study villages that 39.4% of household members fetched water most days. I thus calculated the number of water fetching trips required each day by dividing the total volume of water a fetcher needs to transport each day by the maximum volume of water an individual of a given age and gender is able to carry each trip. (Note: where water fetching is required, water consumption is unlikely to reach the 50 L/p threshold; aggregate mean water consumption in the two study villages is 26.2 L/p/d).

The walking speeds used in the model are based on the age of the water fetcher and are determined from the equation of best fit regression lines calculated from collected
data collected in the two study communities (Appendix B, Figures 4a and 4b). Because I observed little variation in walking speeds between genders, I have made no such differentiation in this model. In all model runs, the water fetcher is assumed to walk downhill on the outbound, empty load portion of a trip, and return uphill with a full load of water. Where terrain type is held constant during a model run, I use a terrain factor representative of grassy terrain (1.2) while I use a value of 0.05 (5% slope) when slope gradient is held constant.

5.1: Relating Age and Gender to Energy Expenditure

To analyze the effect of age and gender on the amount of energy required to transport a load of water, I used the predictive model to calculate energy expenditure for both males and females at ages 8, 10, 15, 20, 40 and 60. As indicated in Figure 5b1, the results reveal that varying the age of the hypothetical water fetcher has a significant impact, while gender has a lesser but still notable influence on energy expenditure for teens and adults.

Of the six age classifications, peak energy efficiency occurs at age 15. At this age, males expend 21% of their daily caloric requirement transporting water while younger boys expend more than 30% of their caloric requirement transporting their water loads. Efficiency decreases in adulthood, though there is little variation between ages 20 and 40. By age 60, there is a steep increase in energy expenditure; the percentage of daily caloric requirement is nearly double that of a 15-year old.
The variation in linear distance represented by these variations in energy expenditure are striking (Figure 5-2). If the percentage of daily caloric requirement used to transport water is capped at the 21% value predicted for 15-year old male, the

Figure 5-1: The impact of age and gender on percentage of daily caloric intake expended fetching water 1 km

maximum allowable distance between house and water source becomes much closer, especially for children and elderly adults. The 1 km that meets the current definition of access must be reduced to under 650 m for 8-year old boys and barely 500 m for 60-year old men. Even young to middle-aged adults are limited to slightly more than 800 m if energy expenditure proportions are to be held constant across different age groups.

Gender has less of an impact than age, but the variations between males and females at all age classifications are nonetheless notable once young adulthood is reached. From age 15 onward, females consistently expend an additional 3-6% of their
daily caloric requirement transporting equivalent water loads. The disparity in maximum
distance between house and water source is considerable, though more so for young and

Figure 5-2: Maximum allowable distance to water source if percentage of daily caloric
intake is capped at 21%

middle-aged adults than for either children or elderly adults (Figure 5-2). For example,
the 1000 m traversed by 15-year old boys using 21% of their daily caloric intake is
reduced to slightly more than 800 m for girls of the same age.

Gender-based variations in energy expenditure results using this predictive model
are driven by the natural variations in body weight, basal metabolic rate, and daily caloric
requirements of males and females. The same factors influence the variations between
age groups, along with the slower walking speeds and lower load weight capacities of
children and elderly adults. Lower load weight capacities are an especially important
factor in the results generated from this predictive model. Observations from the two
study villages indicate that children and elderly adults use smaller water containers to
transport water, and I consider this factor in the application of the model. I do not, however, adjust the amount of water an individual must transport each day is not adjusted for various age groups, thus younger children and elderly adults require a greater number of round-trip excursions to transport the required volume of water to meet their share of total household supply. An increased number of trips each day obviously results in a greater number of calories expended. In actual practice, it is likely that compensation for lower load weight capacity is made within the division of household water fetching responsibilities. Children and elderly adults in households where other adults are available for water fetching may not be expected to make additional trips to account for their lower per-trip volumes (in fact, they may make even fewer trips where more able-bodied adults are present). However, because there are certainly households where children or elderly adults are the only ones available for water fetching, this analysis does not reduce their number of water fetching trips. Ultimately, if a household consumes $x$ L of water per day and only an 8-year old girl is available to fetch water, she will have to make as many trips as is necessary to transport that quantity of water.

5.2: Relating Terrain Type to Energy Expenditure

The nature of the terrain surface plays an important role in the calculation of energy expenditure using the Pandolf model. Terrain factors representing four common terrain surfaces are compared in this analysis (a terrain factor of 1.0 represents asphalt, the easiest terrain surface to traverse): hard-packed, dry dirt (1.1), grass (1.2), moderately-slick clay mud (1.8) and extremely-slick clay mud (2.1). As might be expected, an extremely slippery path takes more effort to traverse while carrying water
than does a smooth, dry path. Figure 5-3 illustrates the significant influence that variation in terrain surface has on the amount of energy expended by an 18-year old female.

Figure 5-3: Impact of terrain type on percentage of daily caloric intake expended fetching water (18-yo female, 50.5 kg body weight, 20.5 L water volume, 0% slope gradient)

Figure 5-4: Maximum allowable distance to water source by terrain type (18-yo female; 50.5 kg body weight, 20.5 L water volume, 0% slope gradient)
weighing 50.5 kg and transporting 20.5 L of water. In effect, a transition from dry to wet clay paths results in an additional 13% expenditure of daily caloric intake. Figure 5-4 demonstrates how much closer a water source must be if the percentage of energy expenditure for that same female is held constant. The model suggests that the number of calories she will burn while transport a load 1 km on a dry dirt path is exceeded at 651 m on an extremely slippery clay mud path. In Xieng Khouang Province, water fetchers can expect such treacherous paths for about four months of the year.

5.3: Relating Slope Gradient and Energy Expenditure

The parameter of greatest influence on energy expenditure while fetching water is the gradient of the slopes traversed between household and water source and the access to water indicator’s failure to consider the influence of this parameter on access is perhaps its greatest weakness. Many rural villages in the developing world are built on hilly (if not mountainous) terrain, and in many instances, the water source is located in a ravine or other downslope feature. As a result, not only must water fetchers contend with the linear distance between their homes and the source, they also face having to carry their heavy loads up or down steep grades.

As the Pandolf model indicates, even modest increases in slope can greatly increase the amount of caloric energy required to transport the water load. Using the same hypothetical 18 year old female, weighing 50.5 kg and transporting 20.5 L of water as in the terrain type analysis, an increase in slope gradient from flat to 5% increases expenditure of daily caloric intake by 5% while increasing gradient from flat to 15% nearly doubles energy expenditure (Figure 5-5). The proportion of the hypothetical water
Fetcher’s energy expended at 1000 m on flat terrain is exceeded at a mere 534 m when average slope gradient of the collection route is 15% (Figure 5-6).

A 15% slope gradient on a water collection path is likely to be a highly common occurrence, especially in mountainous areas. Ban Nakhompheng, for example, is built on a relatively flat bench and yet the average slope gradient of water collection routes surveyed in the village is still 5.9%. Ban Songhak is built on slightly more rolling terrain; the average dry season slope gradient here is 5.2% while during the wet season, the average gradient is 4.7%. In Ban Songhak, however, several route segments exceed 11%, and one portion of the dry season route used by residents of House 11 to access the upper spring at Tha Huai Sau (see Figure 4-2) is nearly 30% for more than 50 m.

Figure 5-5: Impact of slope gradient on percentage of daily caloric intake expended fetching water 1 km (18-yo female; 50.5 kg body weight 20.5 L water volume, terrain factor of 1.2)
Steep slopes are often found in conjunction with more challenging terrain types and are often especially treacherous when wet. While I have considered individually the effect of terrain type and slope gradient, it is illustrative to consider the impact on energy expenditure when a steep slope is combined with a muddy trail surface. Figure 5-7 describes the difference in maximum allowable distance between house and water source for the same hypothetical 18-year old girl as she transitions from a flat, dirt surface to a muddy 15% grade (terrain factor of 1.8), capping her energy expenditure at 20% of daily caloric intake.
Figure 5-7: Maximum allowable distance to water source, varying terrain type and slope gradient (18-yo female; 50.5 kg body weight 20.5 L water volume 20% expenditure of daily caloric intake)
6. CONCLUSIONS AND FUTURE RESEARCH DIRECTIONS

While access to safe drinking water is clearly a bellwether indicator of human development, defining what we mean by “access” is problematic. If it could be defined simply as “piped water service provided to the home”, then an unambiguous development target would exist and progress toward the ultimate goal of universal access would be easy to measure. Unfortunately, such a definition is hardly realistic given the economic conditions that exist in most areas of the developing world. Instead, policy makers are forced to balance the need to identify reasonable standards with the political necessity of setting obtainable goals. That said, it is crucial that any development indicator accurately measures real progress in improving human health and well-being rather than that which is simply expedient. O’Hara et al. (2008) make this point well:

It is evident that the definition of what constitutes access to safe water needs re-thinking. Having a definition is all well and good, but if that definition fails to encompass the full nature of access or is set to the lowest acceptable standard it will fail to promote progress in many countries and will also mask system deterioration and failures. This is not to say that definitions should not be used and that there should be a minimum standard—indeed there are advantages to having a series of clearly defined goals and definitions, which can be compared globally. But it is essential that the overall process is not driven by the need to present global figures (21).

The research presented here demonstrates two important points that receive too little attention in the water development sector. First, fetching water can represent a significant debt in a person’s daily energy budget, even when the distance they must
travel to obtain water is well inside 1 km. Second, factors such as the age and gender of the water fetcher, the type of terrain and the slope gradient they must traverse play a substantial role in the energy cost of fetching water, thus linear distance alone is insufficient for measuring access. While the first point may seem rather obvious, there exists no previous research that specifically quantifies how the proportion of a person’s daily energy budget spent fetching water varies as factors like terrain type and slope gradient vary.

The second point presents, from a practical perspective, a thornier dilemma. International policy makers are already struggling with the universal provision of improved water sources, and aside from the financial, political, and logistical difficulties, the struggle for a common acceptable definition clearly indicates that simply determining who does and does not have access in terms of linear distance has proved challenging. Incorporating additional complexities like terrain type and slope gradient into the definition is likely unrealistic if worldwide measurement of progress toward this Millennium Development Goal is to remain a reasonable process. However, this dilemma has ramifications that reach far beyond the mere counting of statistics: the way in which access is defined has a direct impact on the design and implementation of specific water development initiatives. At this local implementation scale, these additional complexities must be considered if the actual spirit of the MDG for access to water is to be achieved.

This research addresses these issues at a very preliminary level. Clearly, additional investigations are needed before any new policy prescriptions can be made. First, much additional work in water fetching behavior and its cross-cultural variation is sorely needed. Considering the number of people in the developing world still reliant on
water fetching, existing research is minimal and in many cases dated. Second, work is needed that explicitly examines the relationship between water fetching energy expenditure and quantifiable measures of household health. The research conducted here uses a predictive model to estimate caloric energy expenditure; such a study conducted in concert with an analysis of subjects’ caloric intake and overall nutritional health would be even more instructive. Finally, research is needed that helps define what is a reasonable distribution of caloric energy across various life tasks. The data from Xieng Khouang Province can lead to a qualitative statement that says using 30% of daily caloric intake on water fetching is unreasonable, but a quantitative analysis of the impact this burden has on other aspects of an individual’s energy budget is ultimately more useful.
References


FAO. See Food and Agriculture Organization


UNDP. See United Nations Development Programme.


WHO. See World Health Organization.


APPENDIX A: PHOTOGRAPHS

Plate 1: Differential leveling in Ban Songhak to determine elevation changes between water sources and households

Plate 2: Jar site near Ban Nakhompheng
Plate 3: Ban Songhak, near house #28.

Plate 4: Tha Noi spring at Ban Songhak.
Plate 5: Ban Nakhompheng, near house #71.

Plate 6: Washing laundry at Jua Tong spring, Ban Nakhompheng.
Plate 7: Ban Nakhompheng girl preparing to lift her water buckets for the muddy return to her home.
APPENDIX B: STATISTICAL ANALYSES

Figure 1a: Relationship between distance to water source and per person water consumption in Ban Nakhompheng.

Figure 1a: Relationship between distance to water source and per person water consumption in Ban Songhak.
Figure 2: Relationship between mean water fetching distance and gender.
Figure 3a: Predictive model for body weight by age; females 8-19.

\[ y = 2.8038x \]

Figure 3b: Predictive model for body weight by age; females 20-49.

\[ y = 0.2249x + 45.646 \]
Figure 3c: Predictive model for body weight by age; females 50-70.  

\[ y = 0.009x + 51.334 \]

Figure 3d: Predictive model for body weight by age; males 8-19.  

\[ y = 2.9529x - 0.0563 \]
Figure 3e: Predictive model for body weight by age; males 20-49.

\[ y = 0.1525x + 53.394 \]

Figure 3f: Predictive model for body weight by age; males 50-70.

\[ y = 0.0141x + 48.689 \]
Figure 4a: Predictive model for walking speed by age, uphill empty and downhill full.

Uphill Empty: $y = -0.0062x + 1.2326$

Downhill Full: $y = -0.0063x + 1.1258$

Figure 4b: Predictive model for walking speed by age, downhill empty and uphill full.

Downhill Empty: $y = -0.0046x + 1.2592$

Uphill Full: $y = -0.0055x + 1.1327$