THE NEED FOR EFFECTIVE ENGINEERING: A LOOK AT THE FACTORS CONTRIBUTING TO GLOBALLY SUCCESSFUL AND SUSTAINABLE SOLUTIONS

by

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Abstract

In 2000, world leaders adopted the United Nations Millennium Declaration in hopes of drastically reducing the amount of people affected by poverty by 2015. One of the goals of the report pledged to "halve the proportion of people who are unable to reach or afford safe drinking water" (Juma, et al., 2001). For developing countries, where the water crisis is most concentrated, the achievement of this goal is nowhere close to being realized. With a world that is becoming increasingly interconnected, the ability to generate change on a global scale and in areas with the most need is attainable. The focus of engineering education today should prepare students to provide sustainable solutions worldwide.

Engineering curricula, especially in regions of the world with standardized tests (e.g. United States and Canada) look toward preparing students for licensure. However, a need for more diversified, interdisciplinary education would benefit the future success of engineering designs. Knowledge of appropriate social, economic, and environmental needs must be considered to ensure sustainability and effectiveness of solutions. A case study focused on water quality tests located in Nyeri, Kenya enforces the importance of international pre-professional engineering experience. The study also demonstrates the need for increased efforts needed to achieve the drinking water target outlined by the Millennium Development Goals by 2015. In order for students to be successful, education must be targeted to cover both cultural and technological aspects of designing and especially the externalities associated with international design.

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Chapter 1 - **Introduction**

The design of a house is no longer the simple combination of parts to form an adequate shelter. A car is no longer the result of primitive assembly lines devoid of future considerations, such as the resulting environmental and social consequences of exhaust fumes and oil reliance. The realization that every action does, in fact, have a reaction is clearly evident in the environmental degradation resulting from previous development efforts. The innovators, inventors, engineers, and designers of the world today no longer have the advantage of blindly creating without considering the ripple effects ricocheting throughout all social, economic, and environmental sectors. Many lessons have been learned from past mistakes. However, many more could be avoided through an increase in educational awareness. Just as everything is evolving with changing times and new realizations, so must engineering education. James J. Duderstadt, President Emeritus and University Professor of Science and Engineering at The University of Michigan, stated that, "today's engineers no longer hold the leadership positions in business and government […] because neither the profession nor the educational system supporting it have kept pace with the changing nature of both our knowledge-intensive society and the global marketplace" (2008).

The engineering profession has made great strides in the last century. Due to the accomplishments of past engineers, there is a greatly improved standard of living for many on this planet; however the ability to sustain such improvements is now in question. The future of the engineering profession lies in the capabilities of today's students to develop ways to combine social and economic development without causing environmental harm. As stated in *Our Common Future,* "sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (WCED, 1987).

Can engineers live up to this challenge? Only by adopting an education system that requires students to participate in global experiences, study a versatile and inter-disciplinary curriculum, and effectively apply affordable and flexible technologies to areas in most need.

Chapter 2 - **Literature Review**

Globalization

Globalization has touched every aspect of life on earth. It is changing the way people interact, and the way knowledge is shared and communicated. It has affected our planet as populations consume more and more and the earth becomes more and more crowded. The pressure of a growing population and the subsequent increased demand on resources is beginning to take its toll on the earth's ecosystems. The ability to balance the needs of a growing population within the carrying capacity of the earth's ecosystems is the challenge facing society, especially engineers.

While globalization has allowed for increases in trading of goods and services, it has not resulted in a significant transfer of technology between countries or an increase in the development of locally appropriate technology. Currently, one third of the world's population is technologically deprived (Juma, 2001). The results of globalization have served many purposes, but as with all things the good comes along with the bad. As Thomas Friedman (2005) warns, "The playing field is being leveled. Countries like India and China are now able to compete for global knowledge work [outsourcing of jobs] as never before. And America had better get ready for it"; thus inciting a sense of competitiveness between nations such as China, India, and the United States. The struggle for innovation in research and development fields will be directed toward discovering the "next big thing", instead of focused toward international development. Within engineering literature, the subject of globalization is surrounded by pressures faced by the United States to out-compete India and China for technology and research and development achievements. A differing view of the goals fueled by increased globalization is the ability to increase knowledge mobilization directed toward the needs of developing countries, especially in areas of communication, health, agriculture, and environmental needs (Juma, 2001).

Directing the progress experienced by industrialized nations and the rising economies of China and India toward collaborating with developing countries could serve two purposes: 1) stop the race for materialist achievements and ultimately, permanent environmental harm, and 2) encourage symbiotic relationships for the sustainable development toward the achievement of the Millennium Development Goals (MDGs). The concerns facing globalization are best put by Friedman (2005), "Globalization has empowering and disempowering, homogenizing and particularizing, democratizing and authoritarian tendencies all built into it." As a consequence, globalization must be directed in a positive manner to achieve the most good. The use of science and technology should be as an instrument, not for economic development or market competition, but for improving the human condition (Juma, 2001).

Millennium Development Goals

In 2000, world leaders adopted the United Nations Millennium Declaration in hopes of drastically reducing the number of people affected by poverty by the year 2015. The aim of the Millennium Development Goals (MDGs) is to encourage development by improving social and economic conditions in the world's poorest countries. According to the United Nations Development Programme, the MDGs are unique due to the inclusion of a framework that requires the entire international community (both industrialized and developing nations) to combine efforts toward a common goal of eliminating extreme poverty worldwide. The MDGs are as follows (United Nations Development Programme, 2003):

Goal 1: Eradicate extreme poverty and hunger

Goal 2: Achieve universal primary education

Goal 3: Promote gender equality and empower women

Goal 4: Reduce child mortality rates

Goal 5: Improve maternal health

Goal 6: Combat HIV/AIDS, malaria, and other diseases

Goal 7: Ensure environmental sustainability

Goal 8: Develop a global partnership for development

For engineers, the achievement of goals one and seven are especially relevant. However the MDGs have three primary foci for improving human development: bolstering human capital, improving infrastructure, and increasing social, economic, and political rights. The ability of engineers to improve millions of lives lies in the ability of engineers to help reach the MDGs and specifically the objectives outlined for improving infrastructure. These objectives include improving infrastructure through increasing access to safe drinking water, energy and modern information/communication technology; amplifying farm outputs through sustainable practices; improving transportation infrastructure; and preserving the environment (United Nations Development Programme, 2003). Since the initial declaration of the MDGs in 2000, progress has been made in many countries toward meeting the goals. However, this progress has not been uniform around the globe, with some regions of the world exceeding the MDGs, while others fall seriously behind.

Progress toward reaching the MDGs

With five years remaining before the target date to reach the MDGs, a group of international experts spearheaded by the Department of Economic and Social Affairs of the United National Secretariat, assessed the progress of the world's countries. Using a set of MDG indicators the following graphs were compiled (United Nations, 2010).

Figure 2-1 shows progress toward eradicating extreme poverty and hunger. Some regions will fall short of reaching the MDG target by 2015. The regions predicted by the MDG Report generated in 2010 that will not meet the target are sub-Saharan Africa (SSA), due to slow growth in all sectors, and Western Asia and parts of Eastern Europe due to the transition in planned to market economies. However, even with the 2008 global economic crisis, all other developing regions are expected to achieve the MDG target.

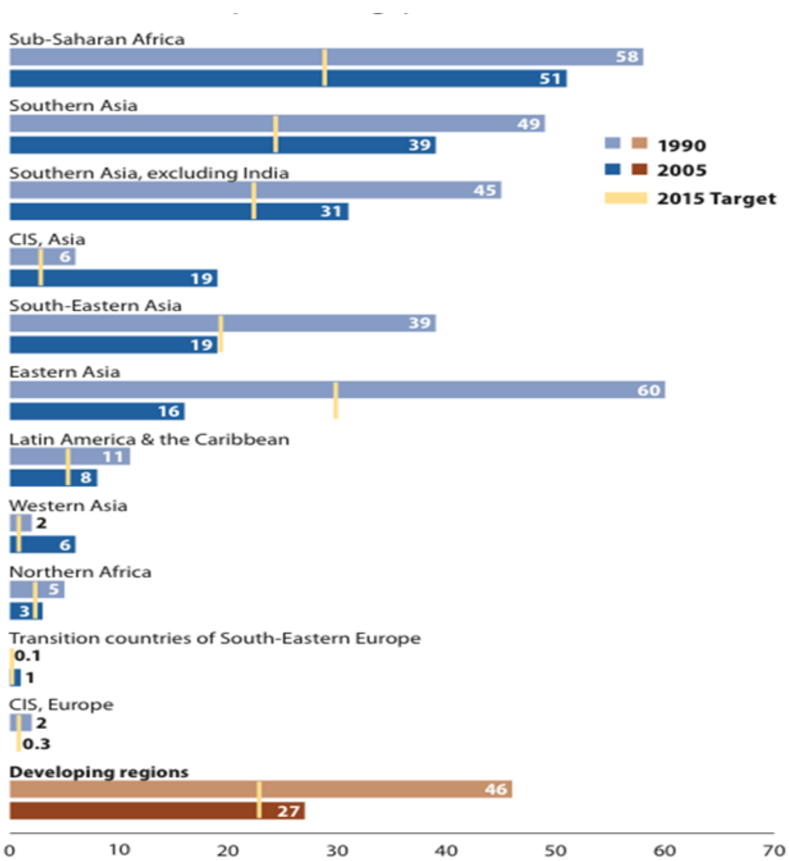

Figure 2-1 Proportion of people living on less than $1.25 a day (United Nations, 2010)

With lots of work remaining to be done to reach the poverty target by 2015, especially in SSA, Figure 2-2 below depicts the progress that has been made toward increasing access to improved water sources. Many regions are close to, or have already achieved, the MDG drinking water target. According to the UN report (2010), "the world is on track to meet the drinking water target," but the report also emphasizes that SSA and Oceania are areas where much work remains to be done. Despite progress being made in SSA (21% improvement), it still remains that only 60% of the population is served.

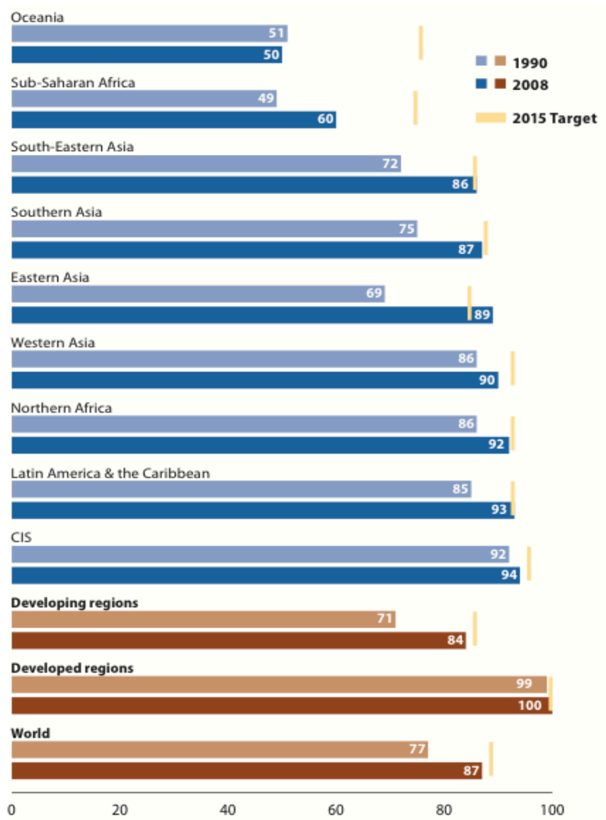

Figure 2-2 Proportion of population using an improved water source (United Nations, 2010)

The final image of progress in achieving the MDG goals (Figure 2-3) displays progress toward achieving the hunger target. Sub-Saharan Africa, as a region, struggles across all spectrums of the MDGs to reach the targets by 2015. While the prevalence of hunger is represented to be declining throughout SSA, it is not declining fast enough to compensate for the population growth for that region.

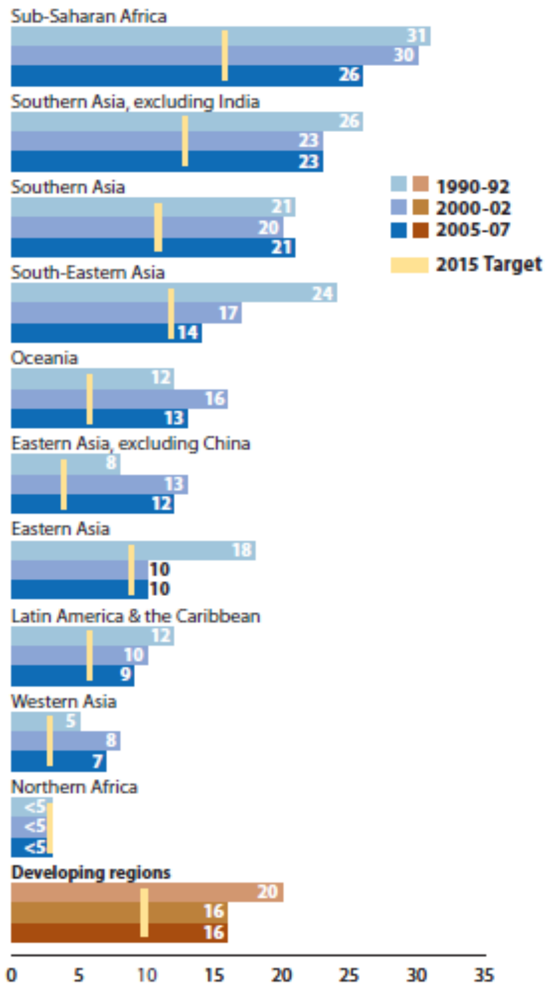

Figure 2-3 Proportion of undernourished population by percentage (United Nations, 2010)

When looking at the figures of progress toward reaching the MDGs, it is clear that one area is considerably lacking. Sub-Saharan Africa is largely untouched by the original Green Revolution, and is currently lagging behind the rest of the world in progress toward achieving the MDGs. Increased agricultural production through improvements made in low-yield, rain fed agriculture throughout SSA is largely believed to be the best prospect of alleviating poverty and hunger. Research indicates that a 1% growth in the agriculture sector results in a corresponding 2.5% growth in income for the related population (Tenywa & Bekunda, 2009). Research has also shown that improvements in agricultural production are largely attributed to better water management (Hanjra and Gichuki, 2008). The ability for countries in SSA, and developing countries in similar, agriculture-reliant situations, to improve agricultural water management is limited by freshwater availability and the ability to effectively manage existing resources. Engineers have the opportunity to help develop solutions to combat the poverty and scarce resources faced by many living in developing countries, and especially SSA. As engineers play vital roles in helping to achieve the MDGs, the importance placed on improved education to allow American engineering students to function successfully on such a global scale is heightened astronomically.

The Need for Engineered Solutions

Engineers play a critical role in the future of achieving the MDGs. The basis for successfully halving the proportion of the world's people who suffer from hunger and are unable to reach or afford safe drinking water lies in the hands of engineers. For this to be accomplished, Bernard Amedie, professor at the University of Colorado, Boulder suggests the adoption of a new mission statement for the engineering profession, "to contribute to the building of a more sustainable, stable, and equitable world" (2004). The two areas that require the most focus, and will reap the most benefits, are in the areas of 1) water conservation and remediation and 2) improved agricultural production. As the figure below (Figure 2-4) demonstrates, there is a clear correlation between human development and water resources development. The indicators, or lines, graph the "% not $1 a day poor," "human development index," and "water poverty index" across the 20 countries included in the study. Figure 2-4 shows that locations where a higher proportion of people who make less than $1 a day also tend to have higher levels of human development index and higher water poverty index values. The water poverty index provides a multidimensional indicator that depicts a country's access to water resources, with higher values indicating better overall water resources management. The "human development index" provides a multidimensional indicator of the overall level of human wellbeing in relation to poverty. The "% not $1 a day poor" is an indicator adapted from the World Bank's "$1 a day poor" which is an indicator illustrating overall human welfare. As the values increase, better solutions are approached for all three indicators: better water resources, higher level of human well-being, fewer impoverished persons.

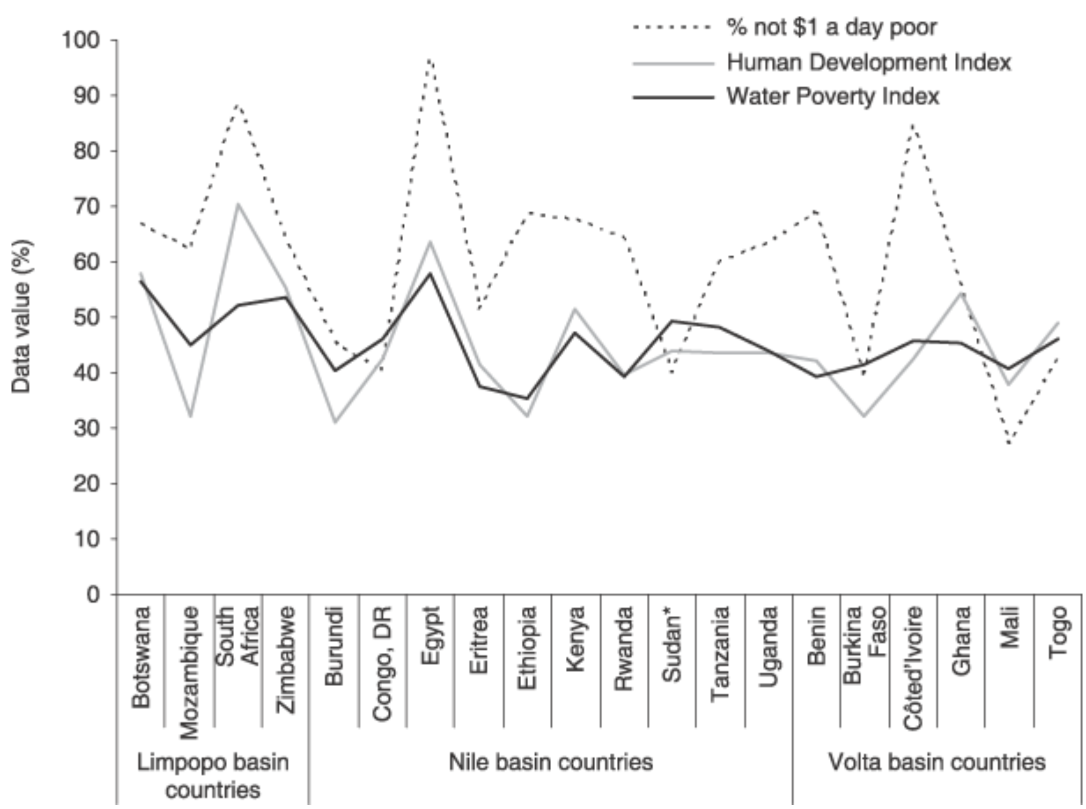

Figure 2-4 Water resources development and human development are intimately linked (Hanjira & Gichuki, 2008)

The freshwater crisis already facing many developing countries only threatens to worsen with the expanding population, climate change, and urbanization of the Earth's surface. One third of Africans, approximately 300 million people, lack access to adequate water supplies (World Water Council, 2006). Water scarcity contributes to limited social and economic development, and is closely linked to incidences of poverty, hunger, and disease. A combination of factors, such as inefficient agricultural use, untapped resources, and unequal distribution, contribute to water scarcity. To the engineering profession, these factors represent the potential Africa has for improved water resource management and improved livelihoods within developing countries.

Synonymous with water, agriculture has played a pivotal role in the success or demise of nations since the earliest civilizations. In today's world, there are new challenges facing agriculture and the pressure for continuously increasing production. The ability to supply a booming population using fewer resources and on less land has focused research and development toward creating innovative agricultural practices. While both food production and crop yields are on the rise, similarly is the rate of environmental degradation increasing. According to data provided by the Institute for African and Middle East studies (IAMES), the green revolution in Asia and Latin America contributed to 27% and 12% increases, respectively, between 1980-1995 in the average food production per capita per year compared to an 8% decrease for Africa over the same timeframe (Dinh & Huong, 2010). The future of poverty alleviation in Africa is through achieving a successful green revolution for improved agricultural production within African countries.

In the year 2025, the world will house roughly 8.5 billion people with over three quarters living in developing countries (Bunders, et al., 1996). Current levels of agricultural production are not enough to meet the future food demands. This is especially true for developing countries where the majority of the population is reliant on agriculture for survival and current and future trends for agriculture production are stagnant. Even with viable design approaches, the need for effective implementation and technology transfer of solutions is still essential and seen to be currently lacking in many engineered designs. Engineers hold the solutions to helping meet the MDGs. Technically, students are well educated to design and create agriculture and water saving technologies. This technical knowledge must be combined with a global perspective afforded by international experiences.

The future for engineers holds many challenges but also great influence, which is a thought seconded by Maurice Strong, Secretary General of the 1992 United Nations Conference on Environment and Development. His statement, “sustainable development will be impossible without the full input by the engineering profession” (Amadei, 2004) is true and further evidence that the engineering profession must undergo a transformation in the way it currently views the importance of cultural influences and natural systems. The potential and need for life-saving solutions is great and in the hands of the determined, global-minded engineers.

Developmental Engineering

Engineers have always played an important role in international aid and development. The engineering profession is unique in that engineers have a hand in the science behind developmental designs, the resources used, and the construction and implementation processes. For these reasons, it is imperative that engineers gain a better understanding regarding the impacts of developmental work abroad. Research provided by Parsons (1996), investigating the breakdown of actual development projects attempted in low-income countries, provides clear and logical evidence as to why projects were either a success or failure. According to Parsons, nine specific areas exist in which engineers abroad can cause more harm than good when instigating projects:

1. Long-term effects overlooked
2. Lack of attention to social and economic context
3. Root of "problem" not considered
4. Lack of comprehensiveness in project design
5. Too much focus on hardware
6. Right questions about project were not asked
7. Problematic attitudes of foreign workers
8. Lack of attention to codes of ethics
9. No evaluations done

Parsons refers to the former as "hit-and-run" projects (1996). Most engineers are included in development projects after fundamental decisions regarding the funding, locations, and project specifics have already been decided. For this reason, it is easy for engineers to take the easy road and just get the job done. It is critical for engineers to be more aware of their role in development projects and strive to understand the possible repercussions surrounding their work. The lack of appropriate social and economic contextual knowledge can also damage the long-term viability of projects. Without fully gaining an understanding of the root of issues within the community, the wrong problem, gender, economic class, etc., can often get addressed, ultimately ending in project failure.

Study Abroad

Studying abroad is seen as a pipedream by most engineering students. It is merely a vacation from campus afforded those in less rigorous degree programs. As a nation, only 3.2

percent of undergraduates in engineering study abroad (Hicks, 2011). The reasons behind such a low statistic are attributed to the lack of flexibility in the core requirements of engineering curricula, combined with the lack of importance placed on international experience by institutions. Students wanting to study abroad would need to decide and plan space in their schedule as early as their freshman year. However, the importance of studying abroad is rising on educators' minds as, "global experience is increasingly perceived as essential to career success in science, technology, engineering, and math" (Leggett, 2011). More and more schools are looking into improved programs for engineering students that would allow for engineering education abroad without prolonging students time to graduation. Miller (2007) provides the following three benefits associated with studying abroad:

1) an ability to work productively on teams involving those with very different cultural values, attitudes, and abilities;
2) a sensitivity to the opportunities and challenges presented to engineering endeavors in other regions of the world;
3) an appreciation of the limitations of the U.S.-centric view of the world, including international perceptions of U.S. strengths and weaknesses.

Such achievements are necessary for the future success of American engineering students. Without gaining global experience, the ability of American engineering students to effectively create sustainable designs is much lower, if not all together impossible. While conducting research involving the development of cultural intelligence, Sharma & Mulka (1993) determined, "U.S. students who studied abroad have a greater global perspective and greater international career aspirations" (as cited in Crowne, 2008, p.396). While it is clear the benefits associated with studying abroad, engineering students can also benefit with efforts associated with educating for sustainability.

Educating for Sustainability

With a world that is becoming increasingly interconnected, the ability to effect change on a global scale and in areas with the most need is attainable. The focus of engineering education today should prepare students to provide sustainable solutions worldwide. Engineering curricula, especially in regions of the world with standardized tests (e.g., United States and Canada) look toward preparing students for licensure. However, a need for more diversified, interdisciplinary education would benefit the future success of engineering designs (Huntzinger, et al., 2007). Knowledge of appropriate social, economic, and environmental needs must be considered to ensure sustainability and effectiveness of solutions. In order for students to be successful, education must be targeted to cover both cultural and technological aspects of designing and especially the externalities associated with international design.

The following is an excerpt of a speech made by Stephen Bechtel in 2005 to members of Tau Beta Pi, the national engineering honor society:

> You must be technically competent, of course. But also you must be highly effective communicators, especially cross-culturally. You need to know the world and the other people who work in it. You must acquire more interdisciplinary knowledge […] You must have the ability to acquire new knowledge quickly and apply it to emerging problems. You must be open minded and objective.

Bechtel is far from the only advocate for integrating interdisciplinary education into engineering curricula. However, it is profound that his speech addresses the oldest engineering honor society in the United States in his avocation of gaining a global perspective for improved engineering education. In order to have an increase in global-minded thinking, engineering education would be benefited by the inclusion of international research and project experience. Connected with this experience is the need to study relevant solutions for achievement of the MDGs including soft approach solutions. Whereas hard engineering principles usually focus more on controlling natural processes with man-made structures, soft engineering looks to ecological solutions and working with nature. Below is a look at some proposed soft approach solutions for use in developing countries, and the externalities associated with engineered designs that go along with them.

Soft Approach Solutions

The multitude of challenges facing agricultural production and thus, ultimately, the achievement of the MDGs requires solutions that are effective, affordable, and economical. The ability of soft approaches like bioremediation and rainwater harvesting that aid in sustainable water management have wide implications for helping to alleviate poverty within developing countries. It is important to remember that each approach is not meant as an all-encompassing solution, but rather as a piece of a complex puzzle that includes non-engineered solutions such as infrastructure development and political and economic reforms.

Bioremediation

A soft technology approach with high potential for success is bioremediation. Bioremediation is the use of naturally occurring microorganisms like bacteria, fungi, and protists to break down organic materials. Bioremediation provides the opportunity to not only remediate contaminated water sources for increased agriculture or household use, but to also remediate contaminated soils. Improving soil conditions would allow for increased cultivated land area for crop production. Ho (2004) reported that potential contamination sources known to be effectively remediated by microorganisms are, “sewage, crude oil, petrol […], nitrogen from fertilizer, and […] toxic chemicals […] used in heavy industry, and pesticides used in agriculture, […].” The extensive application for bioremediation allows for infinite possibilities for application in developing countries. The ability to tailor a bioremediation design specifically to a system’s needs in order to be successful necessitates interaction between local populations with an incorporation of indigenous knowledge. Including local community members in the initial development and design of the bioremediation systems will ensure the adoption of a technology that the community understands and can afford to implement. This includes the ability of a local community to afford bioremediation financially, to provide an adequate amount of materials, and to grasp the process behind the technology. A major advantage of bioremediation is the positive influence it has on the surrounding environment, while still effectively remediating the site. Furthermore, bioremediation processes usually provide for either harvesting or grazing of vegetation used during the remediation process, which can offset system costs and allow for simultaneous crop or livestock production. The use of local plants and microorganisms, affordability, and effectiveness of bioremediation all make these systems an extremely useful soft approach to help offset contaminated soil and water sources located in developing countries.

Rainwater Harvesting

Improving water quality is the focal point for achieving several of the MDGs and is directly linked to reduced child mortality, hunger eradication, and improved maternal health (Fry, et al., 2010). Another area of water research usually not considered a priority is that of water quantity and its ability to help achieve the MDGs. Using a case study produced by Fry, et al. (2010), a study of 37 African cities was conducted and the effect of increased water quantity and point of use treatment on reductions in disability-affected life years (DALYs) were analyzed. The method of improved water quantity was achieved through the installment of rainwater harvesting systems capable of capturing varying amounts of water within these selected urban settings. The case study is unique because of the emphasis placed on integrating engineering analysis with that of public health and policy research. The need for a combined analysis of engineering, public health, and social science efforts to produce applicable solutions to improve overall public health is emphasized.

Results of the study demonstrated a significant contribution of improved water quantity to reducing DALYs on highly populated urban areas. The combination of rainwater harvesting systems and a point of use treatment system demonstrated the largest reduction in DALYs for all cities. However, the importance of this study also rests in the conclusion that improving water quality, often not an option due to material and technological costs, is not the only way to reduce diarrheal related illnesses and deaths. What is important is the combination of several sectors: public health, policy research, and engineered analysis and design and the ability to think creatively and all-encompassing as an engineer. According to Amadei (2004), past experiences demonstrated that a knowledge of "soft issues" and the aspects associated with "social, environmental, economic, cultural, and ethical aspects are often more important than the technical aspects."

Project Objectives

Significant emphasis has been placed on the need for engineers to develop a more global approach in today's changing world. The majority of the literature targets the current engineering curricula and the need for more experiential learning through either a study abroad or international research experience with a focus on providing economical, effective and flexible technologies to the developing world. The goal of this study is to test the validity of these arguments by conducting research directed at achieving the MDGs by testing water quality in rural, central Kenya. Information gathered through the personal experience of conducting research in a developing region of the world helps illustrate the unique externalities associated with international design and the benefits and challenges of conducting international research. A case study focused on water quality tests located in Nyeri, Kenya enforces the importance of international pre-professional engineering experience, while also demonstrating the need for increased efforts toward achieving the drinking water target outlined by the Millennium Development Goals by 2015. The primary objective of this study was to provide guidance for future students preparing for a developmental engineering project, so that they may be better prepared to act effectively and in the context of local needs.

Chapter 3 - **Case Study**

Gaining experience abroad for engineers necessitates more than just a semester spent studying abroad. Miller (2007) advocates developing a global perspective and a better understanding of world views through experiencing varying perspectives of the world from differing countries viewpoints. In order to achieve this, engineering education should strive to incorporate research and project implementations abroad in various locations to better educate students for sustainable development. For this study, as an experiment into the multi-faceted arena of developmental engineering, research was conducted in Nyeri, Kenya measuring the water quality of five different sites located throughout the Central Province.

Pre-Departure Preparation

An important aspect of research conducted abroad is the preparations made before departure. As an undergraduate student at Kansas State University, I had already made several trips abroad as part of my educational experience. A semester spent studying abroad in the Czech Republic combined with a course geared toward service-learning followed by ten weeks spent in Kenya, were two experiences I thought had more than adequately prepared me to measure water quality in Kenya. However, even with these international experiences I found myself caught off guard on more than one occasion. In order to be successful as a developmental engineer, a sound technical background, extensive knowledge on the local culture especially social and economic constraints, and a strong relationship developed with community members are all necessary. The following sections will highlight areas where I tried to follow these guidelines for successful developmental engineering and describe some of the challenges I came up against before, during, and after returning from my research project in Kenya.

Coursework/training

As an engineering student, I have taken years of required technical courses; however, only a couple courses have stood out as being directly useful in a developmental engineering setting. As a student who was interested in subjects outside of engineering, I experimented with classes in other departments like geography, anthropology, history, and even a language course. This interdisciplinary background, while untraditional, has allowed me to better grasp the many influences that must go into a developmental engineering project. Perhaps the class that prepared me the most for my time in Kenya was a course associated with a ten week service-learning project. Even though this is an obvious choice, as my ten weeks were spent at the location I returned to for this water quality project, it was my time spent learning about the culture, political history, current events, and creating an comprehensive travel guide that most prepared me for my time in Kenya. I do not want to discredit the invaluable information I gained in my engineering courses, especially ones that included soft-approaches like ecological engineering; however, the combination of this background with an in-depth study on the country I would be travelling to, is essential to provide sustainable and effective, engineered solutions.

Communication Challenges

The next step in the successful framework needed for developmental engineering was developing a strong relationship within the community I worked with for my project. My interest in the MDGs, water quality, and my previous experience in Kenya made the choice of a sample site easy: Nyeri, Kenya. Since only the summer previously I had spent ten weeks teaching, volunteering, and touring Kenya, I had developed several close relationships with members of the Children and Youth Empowerment Centre (CYEC). Along with these contacts, I was interested in visiting the Jomo Kenyatta University of Agricultural and Technology

(JKUAT) and working with a Kenyan man I had briefly met the summer previously that had ties to both the CYEC and Engineers Without Borders (EWB). I tried to contact the Kenyan man with ties to EWB to discuss my plan to measure water quality in Kenya and get any suggestions on location, information on any past or current projects similar to this, and who to contact at JKUAT for a meeting. After several weeks of hearing no response, with a couple follow-up emails from my end and my departure date fast approaching, I finally received a response. Although my contact expressed much excitement and encouragement about my plans, he was unable to provide any suggestions and was unsure if he would be able to meet with me at all during my brief stay (ten days) in Kenya. With this disappointing response, I gathered up my water quality kits and headed off to Kenya with only my friends at the CYEC and hopes that my previous summer in Kenya would be enough preparation to make my trip successful.

In-Country Work

Once on site in Kenya, it quickly became apparent that I was neither fully prepared, nor had allowed myself enough time to adequately address the needs of the community and water quality within the area. However, the primary objective of my project was geared more toward documenting how to be effective as a development engineer, thus by documenting challenges and setbacks of my experience, I can provide future students the necessary information to avoid similar setbacks. The following sections provide more in-depth information on my site, testing procedures, and the results of the water quality tests. Following my research methodologies, which are included to provide a framework for water quality testing, I will discuss the main challenges I came up against in Kenya and the lessons learned from these experiences.

Site Description

All of the water samples were taken centered around and within the Children and Youth Empowerment Centre (CYEC) located on the outskirts of Nyeri, Kenya. The CYEC is an initiative of the national program for street dwelling persons and is intended to play a central role in the innovation of holistic and sustainable solutions for the population of street dwelling young people in Kenya. Nyeri is located approximately 109 miles north of Nairobi, in the Central Province of Kenya. All water sampling sites were located in Kenya's Central Province, which covers an area of 5,093 square miles and is located to the north of Nairobi and the west of Mt. Kenya (Figure 3-1).

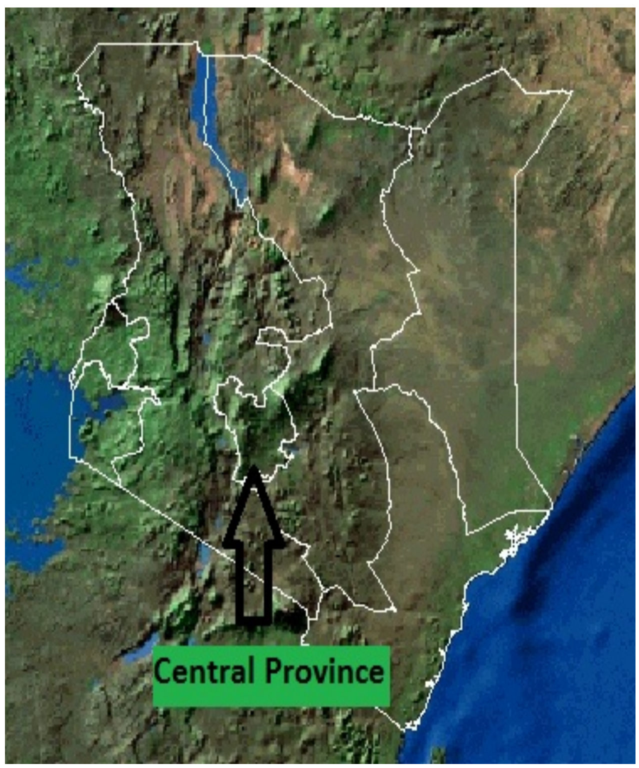

Figure 3-1 Map of Kenya with the eight administrative provinces outlined (Adapted from NOAA Satellite Image, 1999)

The Central Province is a region with high altitude in Kenya causing it to experience a cooler climate with fairly regular rainfall occurring within two seasons. A season of long rains occurs from early March to May with a shorter rain season occurring during October and November (McSweeney, New, & Lizcano, 2009). No significant bodies of water exist in the region surrounding Nyeri; however, streams from Mt. Kenya and the Aberdare Mountain Range supply water to the area (Kenya National Bureau of Statistics).

The image below is a photograph taken of the river at the CYEC where water was sampled for the first water quality test.

Figure 3-2 Photograph taken of the river running through the base of the CYEC that provides water for agricultural production (June 2011)

Along with the water sampled at the river crossing the CYEC, a sample was taken at a river that supplies the larger Thunguma Village community. The CYEC lies within Thunguma Village boundaries and the youth at the center use the river pictured in Figure 3-2 above, as well as the river pictured below for drinking water, bathing, recreational purposes, and agriculture production.

Figure 3-3 Photograph taken of the river supplying the village of Thunguma, youth from the CYEC are pictured swimming in the water (June 2011)

Eco-Villages in Lamuria and Othaya were two other locations used for water quality testing sites. Othaya and Lamuria were sites chosen by Pennsylvania State University in 2010 as potential locations to provide a sustainable and eco-friendly village for the students of the CYEC. Lamuria community is located approximately 17 miles north of Nyeri town. Othaya community is closer, located around 9 miles south Nyeri town. Below are photographs taken at both site locations. The Lamuria and Othaya rivers serve as the primary water supply for the whole community as well as the future eco-villages to be developed on site by Pennsylvania State University in collaboration with the CYEC graduating youth.

Figure 3-4 Photograph taken of the river supplying Lamuria community (June 2011)

Figure 3-5 Photograph taken of the river at Othaya community (June 2011)

A second water sample was collected in Othaya. The site chosen was a bamboo water spout that was channeling a stream running off land in agricultural production before entering the larger river, which is pictured in Figure 3-5 above. The figure below shows an image of the site.

Figure 3-6 Photograph taken of the stream running down to the river that supplies the Othaya community (June 2011)

The last site was located within Nyeri town on the property owned by the YMCA. In the summer of 2011 the YMCA was undergoing a transition to bring the field back under agricultural production. A well (Figure 3-7) was dug in the field and used for drinking water and water for agricultural production.

Figure 3-7 Photograph taken of the well that provides water for agricultural development at the YMCA in Nyeri (June 2011)

Figure 3-8 is provided to help illustrate the spatial relationship of the sample locations. Sites are located as near to the sampling site as possible, however most samples were collected without a clear geographical awareness of the location. A lack of clear, locational data for the sites in Figure 3-8 required the sites to be placed over a general area and as near to the actual sampling location as possible under the unmapped circumstances of the research. A key in Table 3-1 is provided for the coding of the site locations.

Figure 3-8 Location of water sample sites throughout the Central Province, the corresponding location of the numbered sites is provided in Table 3-1 below (Adapted from: "*Nyeri city guide*")

Table 3-1 Sample sites and their corresponding locations

Site 1	Lamuria
Site 2	YMCA, Nyeri
Site 3	CYEC River
Site 4	CYEC Shamba
Site 5	Othaya
Site 6	Othaya Bamboo
Site 7	Total of all Sites

Water Samples

Water quality was measured using Citizen Science Testing Kits provided by Dr. Rhonda Janke, Associate Professor of Horticulture Forestry and Recreation at Kansas State University. Citizen Science is a program developed by Kansas State University to aid in on-farm soil and water quality testing (Janke, Snavely, Cable, & Powell, date). Each water sample was tested for pH, nitrogen (nitrate, nitrite, and ammonia), total coliform and *Escherichia coli* (*E. coli)* bacteria. Seven different sites were sampled and the water quality tested. All sites were located in Central Province, Kenya. Each site was sampled three times from June 1-June 6, 2011. The average temperature was approximately 65°F and zero participation was recorded over the sampling dates.

Water Quality Testing Procedure

Nitrogen Testing Procedure

Citizen Science tests for the inorganic forms of nitrogen that contribute to eutrophication by increasing algae and other plant growth. Field test kits were used to measure levels of nitrate, nitrite, and ammonia. Test strips produced by Hach Company were used to measure water quality. Test strips are recommended for use because they are inexpensive, easy to use, require little time, and are relatively accurate (W-4, 2006). Below is an image of a nitrate/nitrite test.

Figure 3-9 Image reproduced from Citizen Science W-4 demonstrating ease of use of nitrate and nitrite test trips (2006)

The Citizen Science fact sheets also provided ratings based on results of the test strips. The below images are interpretations provided by Citizen Science for the water quality test results.

Nitrate Rating			
4 – Best	3 – Good	2 – Fair	1 – Poor
No detectable nitrate nitrogen.	Nitrate nitrogen detectable, but less than 1 ppm.	Nitrate nitrogen between 1 and 10 ppm.	Nitrate nitrogen higher than 10 ppm.
Nitrite Rating			
4 – Best	3 – Good	2 – Fair	1 – Poor
No nitrite nitrogen detected.	Nitrite nitrogen detectable, but less than 1 ppm.	Nitrite nitrogen between 1 and 2 ppm.	Nitrite nitrogen higher than 2 ppm.

Ammonia Rating			
4 – Best	3 – Good	2 – Fair	1 – Poor
Total ammonia nitrogen level is zero or non-detectable.	Total ammonia level is detectable, but below the level that would cause chronic toxicity to aquatic life (Table 1).	Total ammonia level is high enough that it is within the chronic toxicity range, but not acute (higher than Table 4-1, but lower than the value in Table 4-2).	Total ammonia nitrogen level would cause acute toxicity to aquatic life (exceeds value in Table 4-2).

Figure 3-10 Ratings for water quality based on Nitrate/Nitrite and Ammonia test results (W-4, 2006)

The results from all water quality tests were rated according to the standards outlined above.

E. coli/Coliform Bacteria Testing Procedure

The citizen science test uses a Petrifilm E. coli/Coliform Count Plates to test for the presence of total coliform bacteria and *E. coli* simultaneously. The plates are a ready-made culture medium system that contains nutrients, a cold-water-soluble gelling agent, and red and blue indicator dyes to help identify and count bacteria colonies. A sterile 1-milliliter (ml) pipette is also needed for this test (Citizen Science Fact Sheet W-6). Below is an image of the count plates.

Figure 3-11 3MTM PetrifilmTM *E. coli*/Coliform Count Plates

The plates use a special dye in the gelling agent to distinguish between coliform and *E. coli* coliform forming units. For bacteria, the gelling agent will turn pink in the presence of a coliform colony forming unit, but will turn blue and possibly form a gas bubble if an *E. coli* colony forming unit is present. Unopened plates should be stored at temperatures below 46°F, and then removed in enough time for plates to reach room temperature before testing. Opened pouches can be resealed for up to one month, making sure to maintain moisture in the pouch, and stored in a cool dry place before the plates expire.

After obtaining a water sample using the 1 ml pipette and applying it to the center of the Petrifilm plate, the plate must be laid flat and sealed in a plastic bag to reduce the risk of the plate drying out. Incubation time for the plates can range depending on the temperature and length of time of incubation. For this test, temperatures of approximately 70°F were used, and an incubation time of five days before the bacteria coliforms successfully formed. The plates should be kept out of high intensity light of sunlight, and should not exceed temperatures of 95°F during the incubation period. Once the coliforms have formed, the plates should be brought to a well-lit area for counting. An interpretation of the results from the indicator tests is provided below. These ratings are based on Citizen Science Fact Sheet W-6.

***E. coli* Rating**			
4 – Best	3 – Good	2 – Fair	1 – Poor
None detected. (For drinking water, this is the only acceptable level.)	*E. coli* detected, but less than 2 colony forming units per plate. (Safe for contact recreation, such as swimming.)	*E. coli* between 2 and 20 colony forming units per plate. (Not safe for contact recreation, but acceptable for non-contact recreation, such as boating.)	*E. coli* greater than 20 colony forming units per plate. (Not considered safe for non-contact recreation.)

Total Coliform Rating			
4 – Best	3 – Good	2 – Fair	1 – Poor
None detected. (For drinking water, this is the only acceptable level.)	Less than 20 colonies per plate.	20 to 200 colonies per plate.	More than 200 colonies or too many to count

Figure 3-12 Ratings for water quality based on total coliform and *E. coli* test results (W-6, 2006)

All results from the water quality tests were rated according to the figure above. The ratings were based on the use of *E. coli* and total coliform bacteria as indicators of contamination. The presence of *E. coli* suggests that human waste or manure has contaminated the water supply. This increases the risk of ingesting harmful pathogens when in contact with the water supply resulting in increased risk of diarrheal disease. Diarrhea is one of the leading causes of death in children and can be directly attributed to contaminated drinking water. A statistic produced by Luis, Bada, and Carreazo (2008) identified, "94% of diarrhea morbidity

[…] to environmental and associated with risk factors such as unsafe drinking water, poor sanitation and hygiene" (p.108).

Results

All water samples were collected on site and then transported back to the CYEC to be tested and analyzed. All tests were in accordance with the procedures and materials from the Citizen Science testing kit as described previously. In general, all results indicated zero, or extremely low, levels of Nitrogen. Similarly, the pH levels of all sites tested fell within the ideal range. This indicated that all sites tested were at a very low risk of eutrophication. However, each site contained varying levels of coliform and *E. coli* bacteria. The results ranged from sites receiving a rating of moderately concerning all the way to ratings of extremely severe. All sites tested contained some level of coliform and *E. coli* colony forming indicators. The only acceptable level for drinking water is zero colony forming indicators.

All sites received a rating of a two (fair) or lower for the *E. coli* test results. According to the rating system provided by Citizen Science (Figure 3-10), the sites were not considered safe for contact recreation, such as swimming and bathing. The sites at Lamuria, Othaya, and Thunguma received a rating of one, poor, and are considered not safe for all non-contact recreation as well. The average results of the water quality tests from all sites are recorded in the following table along with the standard deviation of the three tests.

Table 3-2 Results of water quality tests

	pH		**Nitrate**		**Nitrite**		**Ammonia**		**T.Coliform**		***E. coli***	
units			ppm		ppm		ppm		cfu/1 mL		cfu/1 mL	
	Avg	StD	Avg	StD	Avg	StD	Avg	StD	Avg	StD	Avg	StD
1	7.8	0.3	0	0	0	0	0.2	0.1	170	42	380	6.4
2	6	0	0	0	0	0	0	0	TMC	n/a	2.3	2.1
3	6	0	0	0	0	0	0	0.1	190	14	33	3.2
4	6.5	0.5	n/a	n/a	n/a	n/a	n/a	n/a	500	n/a	3.7	3.8
5	5.7	0.3	0	0	0	0	0.1	0	150	61	55	18
6	6.2	0.3	0	0	0	0	0.1	0.1	300	20	4.0	3.6
7	5.7	0.6	0	0	0	0	0.1	0	230	24	110	22

*Avg = Average
*StD = Standard Deviation
*cfu = colony forming units
*TMC = greater than 600 colonies per plate

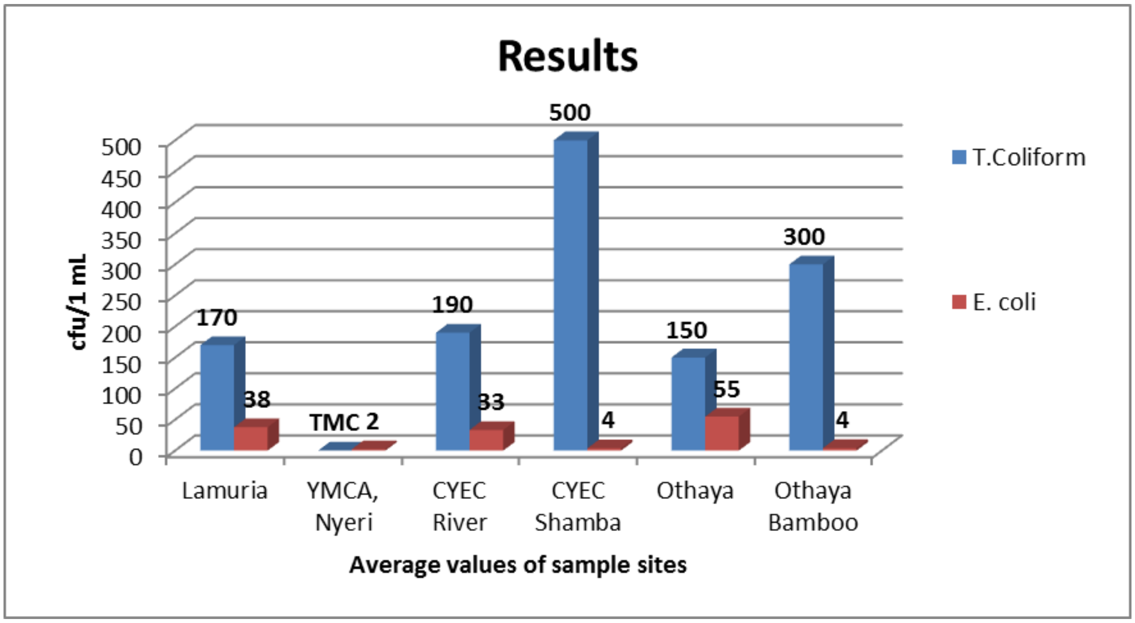

Figure 3-13 Results of bacteria water quality tests showing average values

The test results were consistent with results typically found when testing for inorganic forms of nitrogen in standing or slow-moving bodies of water. The Citizen Science water quality tests can only detect inorganic forms of nitrogen that are readily available for plant uptake. Since all the water bodies tested had active plant growth on site, it is expected that low, and sometimes non-detectable, levels of inorganic nitrogen resulted (Citizen Science Fact Sheet W-4). Due to the rapid movement of the Nitrogen Cycle, using just the water testing strips is not an accurate measure alone of the threat of eutrophication and the levels of inorganic and organic nitrogen in the water sites.

The table below is a water test taken using just the Petrifilm plates of the piped water on site at the CYEC.

Table 3-3 Results of water quality tests taken at CYEC

Drinking Water at CYEC	
	Average Results
Total Coliform	37.5 cfu/1mL
E. coli	0.00 cfu/1 mL

The water piped to the CYEC serves the functions of washing, cooking, and drinking. No detectable levels of *E. coli* and/or total coliform are acceptable for drinking water. Even though the drinking water at the CYEC does exceed this, the resulting levels were significantly lower than the levels detected in the surrounding bodies of water from the other sites tested.

Lessons Learned

The completion of the above research imparted valuable lessons and developed an ability to be creative with available resources, flexible with time constraints, and successful in gaining local knowledge. The challenges described in the following sections highlight the main problems faced and highlights the areas for future students to be better prepared.

Time Restrictions

Below (Figure 4-1) is a photograph taken of a bacterial eye infection that developed after the subject swam in the Thunguma community river. This sample site was a popular place for the youth of the CYEC, as well as any volunteers, including myself, to swim. The ratings from Citizen Science assigned to that site designate the river as being unsafe for non-contact recreational sports.

Figure 3-14 Photograph taken of a bacterial eye infection as a result of swimming in river at Thunguma (June 2011)

The significance behind this image is that by the time results from the Petrifilm plates were conclusive; my time in Kenya was coming to a close. Before leaving for Kenya, I had not completely factored in the time needed to arrange transportation to sample sites, the incubation period required for the colony forming indicators, and the phenomenon referred to as "Kenyan time," the fact that Kenyans tend not to function quite as quickly as Americans. As a result, I was already at the airport when the high amounts of contamination in the sample sites were confirmed. At this point I had no way of sharing my knowledge with the community or developing any strategies for improving the water quality within the area. Thankfully, I have an avenue to educate future volunteers and hopefully work alongside other Kansas State student groups to develop a strategy for the communities facing high levels of contamination in their water supplies.

Validity of Tests

A major concern with the water quality test results was the accuracy of the total coliform and E. coli test results. The following photograph was taken of a finalized Petrifilm plate test used at the river site in Lamuria. The red dots indicate the total coliform colony forming units and the blue dots indicate *E. coli* colony forming units. Lamuria received a rating of poor, not safe for non-contact recreation, based on the results of the plate tests displayed in Figure 4-3.

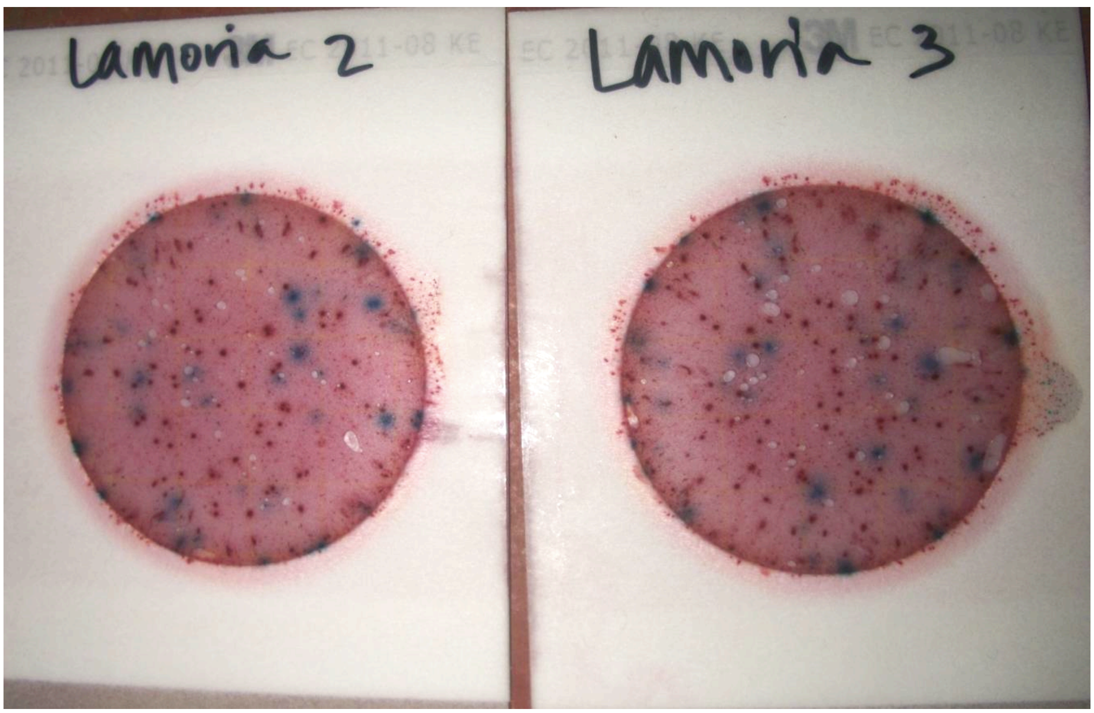

Figure 3-15 Photograph taken of incubated *E. coli*/coliform count plates (June 2011)

The above image is used to demonstrate the success of the plates for bacteria colonization. Safe drinking water would show zero signs of red or blue dot formations. The image of the plates also is important in the lack of orange or brown discoloration present on the plates, which was a primary indicator used to insure test validity. If the plates had been affected by the surrounding environment in any negative way, they would have dried out and indicated a color change, which these plates did not show. The Petrifilm plates have specific temperature requirements for storage, use, and incubation. The facilities in Kenya did not allow for the exact temperature specifications to be met, something I had not considered until arriving on site. However, the Citizen Science fact sheets do describe what a tainted, or contaminated, plate would look like, "plates that show orange or brown discoloration" (Citizen Science and Fact Sheet W-6). None of the plates used for the water quality tests indicated any form of spoiling or contamination. Since most of the risk resided in the pre-testing storage of the plates, I sheltered the plates from the sun and hid them in the coolest, darkest corner of my makeshift laboratory. The Petrifilm plates cannot be exposed to temperatures above 77^{o}F and/or humidity in excess of 50% without potential damage to the performance of the plates. Initially, the Petrifilm plates were stored at temperatures below 46^{o}F until use. However, this was not possible once departing for Kenya since the facilities in Kenya did not allow for refrigeration. According to the test literature, the Petrifilm plates can remain accurate up to one month if stored in a cool, dry place (Citizen Science Fact Sheet W-6). Since the plates did not show any signs of contamination and bacteria did successfully colonize, I was able to deem the results from the water quality testing sites from the Petrifilm plates as being credible. Thanks to creatively working within my given environment and available resources, the most important part of my water quality tests were able to be used despite initial doubt as to their functionality in Kenya.

Community Collaboration

Without having previously visited Kenya, the ability to complete this project would have been significantly more difficult. Staff members at the CYEC worked with me to arrange for transportation to the different sample sites, imparted their knowledge about local agriculture, and educated me on the services provided and future needs of local water resources. Working alongside youth in the YMCA farms revealed not only the resilience of Kenyan agricultural systems, but also the people who work and live off the land. Kenyans have been clearing land by hand and developing adaptive solutions to water to ensure the survival of their crops for generations. Although I came into this project interested primarily in water quality, through interacting with community members the interests and goals of the community became clearer and helped direct my objectives for this project. Solutions do not always come in the form of problems sets solved and designs finalized. Developmental engineering requires adaptive solutions over large time scales. Thus, my objectives to provide a framework for future students to impart effective, sustainable, and locally dictated solutions in Kenya.

Chapter 4 - **Summary and Conclusion**

The engineering profession has made great strides in the last century. Due to the accomplishments of past engineers, there is a greatly improved standard of living for many in the world. However, as evidenced in the water quality tests, there is still much progress to be made. The need to feed, shelter, and provide clean water for an ever-increasing population will be primarily the responsibility of the next generation of engineers. Duderstadt (2008) poses an important question, “are today’s engineers–their profession, their tools, and their education–adequate to address either today’s needs or tomorrow’s grand challenges?” The goals of this study were to show that fundamental changes in engineering curriculum need to include valuable international experience as well as an interdisciplinary and dynamic education focused on provided economical, effective and flexible technologies to the developing world is required. In order for students to be successful, education must be targeted to cover both cultural and technological aspects of designing and especially the externalities associated with international design. It is necessary for engineers to develop a working relationship between people, culture, and the infrastructure that provides basic life necessities.

Personal Reflections

After returning from Kenya, I realized my challenges to providing effective developmental engineering were not yet over. First, I will discuss what the results suggest from the high contamination levels found at my sample sites in Nyeri, followed by my recommendations for future students travelling to the CYEC in Kenya.

Case Study in Nyeri, Kenya

Results from the water quality tests conducted in Kenya indicate that contamination was primarily, if not solely, attributable to contamination by fecal pathogens and not agricultural runoff from fertilized fields. Due to high costs of fertilizer and the lack of education and awareness involving manure and human waste in proximity to surface water, these results were as expected. The low levels of nitrate, nitrite, and ammonia detected were reasonable results for these sites because of the algae and plant growth within the site locations. In order to better gain an understanding of what levels of total nitrogen are present at the water quality testing sites, a total nitrogen analysis from a commercial laboratory could be conducted to provide more information regarding the actual levels of nitrogen (organic and inorganic) present at the sites.

Next Steps

While the water quality testing in Nyeri, Kenya was a study into more than just the levels of water contamination and its potential contributors, it does provide a good basis for future students to continue monitoring water quality in the area. By continuing to work with the individuals at the CYEC, Kansas State students will have contacts in Kenya with which to develop the next steps in addressing the water quality issues of the community. I also recommend students take time to learn more about the community's needs within and surrounding the CYEC. What are current health issues? Is the community wanting or willing to work with students to develop ways to clean the water to make it safer for consumption and use? My case study just touched the surface of water quality issues in the Nyeri community, but due to my relationship and knowledge of the community, future steps can now be taken given the resulting water quality has been measured and seen to be highly contaminated.

Apart from the immediate objective of this project, which is to provide future students with a starting place for developing effective solutions in Kenya, the overarching need to include an international dimension as part of engineering education is also recommended. After my time in Kenya, I was able to realize how establishing relationships with local community members enhanced my potential for providing and learning about appropriate engineered solutions. Conducting research in an international setting has instilled in me the ability to be better prepared for the unexpected, especially for future experiences. The capacity to be flexible and creative with available materials and resources, while also sensitive to local social and cultural cues, are abilities I best learned in country. Without an international research experience included in engineering education, the ability to prepare students to become facilitators of sustainable development is greatly hindered. As the world becomes increasingly interconnected and the pressure to provide food, water, and shelter rises alongside a growing population, engineers, more than ever, must provide sustainable solutions to withstand the future challenges of human development.

Recommendations

What many, well-intentioned engineers fail to realize is the futileness of arriving onsite with set objective in mind for research outcomes. The need for collaborative efforts between Western experts in their fields and local citizens with in-depth knowledge of the area is absolutely necessary for sustainable, successful engineering and for creating improved livelihoods for communities. It is recommended that engineers develop an understanding of the local communities' needs by interacting with community members and instilling a trusting, mutually beneficial relationship. Productive dialogue should be emphasized in order to provide a collaborative approach and maintain a positive working relationship which can mutually benefit both engineers and identified communities. Engineering education should also include the study of a versatile and inter-disciplinary curriculum, with emphasis students' to apply affordable and flexible technologies. The engineering profession has already impacted and improved the lives of many, but the potential for engineered solutions to contribute to many of the contemporary resources issues are substantial and growing. By readdressing current engineering education programs, engineering students will be prepared to contribute in a global, complex and changing world.

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