Sustainable Solutions in Developing Communities

By

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Abstract

Sustainable solutions should be a goal for any long-term project, especially in the context of a developing community. Primary considerations in the evaluation of sustainability include the need, resources, and support. The precise needs that the project fulfills must be known and considered throughout the project's design. Resources must not only be preserved through the project but should also work toward functioning alongside natural processes. The community must also support an undertaking; otherwise there will be a lack of commitment towards witnessing the success of the project.

It is difficult to parameterize a developing community because there are so many variables involved with assessing a community's level of development. Economic measures alone fail to sufficiently answer the question of whether the economic life of a community enhances the lives of people.

Catholic social teaching calls for individuals to work towards justice and the common good while immersing oneself in the truth of God's Word. With the projected population surge, especially in developing communities, engineers are going to be increasingly important in ensuring that all people obtain the resources and standard of living worthy of their dignity.

The Engineers Without Borders Carroll College Student Chapter's work in Mexico at Santa Maria has taught many lessons concerning sustainability and has demonstrated the importance of such factors as community need, resources, and support in the evaluation of overall sustainability. The sustainability of additional projects such as adjustable eyeglasses and compressed earth block construction can then be evaluated using this sustainability criteria.

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Introduction

Beginning this composition of "Sustainable Solutions in Developing Communities" requires first that these terms be defined and explained. It becomes much more difficult to define as one looks further into what makes a solution "sustainable" or a community "developing". There are many different interpretations and opinions on the requirements for these adjectives and I will be presenting these interpretations as well as my own based on my own experiences.

Sustainable Solutions

The term "sustainable" is widely used without really being explained or clearly defined. The "Merriam-Webster is America's foremost publisher of language-related reference works" [1] and it defines "sustainable" as utilizing a resource while neither depleting nor permanently damaging it [2]. This definition emphasizes the ability for the solution to be maintained without damaging the source of the solution.

The University of Colorado-Boulder has developed a program at the Mortenson Center in Engineering for Developing Communities that seeks to teach new engineers about working in a developing world context. Similar to the Merriam-Webster definition, the founder of this program, Bernard Amadei, envisioned this program to create "a major paradigm shift from control of nature to participation with nature" [3] by creating "an awareness of ecosystems, ecosystems services, and the preservation and restoration of natural capital" [3]. This goal of working alongside natural processes also emphasizes the resource side of sustainability. The University of Colorado program also highlights the need for sustainable development in their core values, which state that "we believe in

supporting sustainable projects that are symbiotic with the environment, society, and culture and build capacity for people to solve their own problems" [4] and are able to contribute to the ability of communities to develop solutions and consequently suspend the cycle of poverty [4]. This explanation emphasizes the human element of sustainability whereby it must satisfy the needs of people. The ability for a solution to satisfy a need is essential for a project to be sustainable because it is only then that a community will "buy into" a project whereby they will feel committed for it to be a success.

Developing Communities

When one attempts to define a developing community, one finds that there are many variables one must consider to compare the material quality of life of different communities. There are many economic measures but none of these prove to be sound indicators in every situation. Jonathan E. Sanford attempts to parameterize a developing community in his book *Developing Countries: Definition, Concepts, and Comparisons*. He explains that per capita income is the most common approach for determining level of development but it is not intended to present a definitive result because it fails to account for many other factors [5]. Per capita income or income per person refers to the gross national product (GNP) divided by the country's population [6]. The World Bank attempts to define "developing economies" using a similar method but uses gross national income (GNI) per capita as its main criteria. Gross national income or GNI is determined by adding the value contributed by all the resident producers as well as product taxes and dividing this by the mid-year population [7]. The World Bank however, recognizes that the GNI does not necessarily reflect the development of a country [8]. The United States Conference of Catholic Bishops in their pastoral letter "Economic Justice for All"

explains that "we have many partial ways to measure and debate the health of our economy: Gross National Product, per capita income, stock market prices, and so forth. The Christian vision being more concerned of the wellbeing of individuals as opposed to the overall health of the economy looks beyond all these economic measures and asks, 'Does economic life enhance or threaten our life together as a community?'" [9].

Perhaps the best way to assess the quality of life of a community would be to live within the community to "get a feel for" the extent to which the needs of people are being satisfied. Engineers Without Borders (EWB) is an international, non-profit, humanitarian organization dedicated to improving the lives of people around the world by implementing sustainable engineering solutions. Groups representing EWB must follow the organization's procedure which includes making assessment trips prior to implementation trips. Implementation trips involve sending groups with the purpose of establishing the actual project as designed while assessment trips involve gathering information of the people in addition to the region such as through survey data. These assessment trips become very important in order to be able to assess a community's needs and be able to prioritize these needs. This requires individuals to immerse themselves in the community and to understand their way of life. Dr. Bernard Amadei identified strategies that may assist groups with identifying these needs such as to distribute disposable cameras to people in the community and then collect them once they have finished taking pictures [10]. Upon developing and investigating these pictures, one may determine things that are important to the people. Another method which was utilized by the Carroll College Engineers Without Borders Student Chapter to assess the needs of Santa Maria del Mexicano was a survey of the residents of the orphanage that asked what

projects they would like to see at their community. Upon collecting these surveys from the children we quickly realized that many of them simply listed dreams that we would be unable to address, such as constructing a gym or pool or paving their road, but others surprised us and allowed us to obtain a new insight of their needs. Dr. Bernard Amadei suggested that sometimes it is the outliers in a survey where one obtains the best information because these represent the most knowledgeable people [10].

Evaluating Sustainability

The Carroll College Engineers Without Borders' work at Santa Maria del Mexicano contains many lessons in sustainability. This group has been working on projects at this community for six years and has encountered many issues worthy of examination. This examination has inspired a series of sustainability factors that can be used to evaluate a project's capacity to be sustainable. Adjustable eyeglasses and compressed earth block construction are worthy candidates of this sustainability analysis.

Why and How

Why work so hard to help people?

Working towards assisting others through sustainable projects involves personal sacrifices to ensure the needs of others are being satisfied. This altruism is the motivation behind enduring these sacrifices and thus is worthy of investigation. Various religions view this charity as a virtue and in particular the Catholic Church has strong opinions on the necessity of working towards social justice for the common good of society.

Catholic Social Justice Teachings

Social justice refers to addressing the social structure that results in needs of others, and has been part of the official teachings of the Roman Catholic Church since 1891 with Pope Leo XIII encyclical *Rerum novarum*, which teaches the obligation to work toward social justice and the common good throughout the world [12]. This belief is based on teachings of "the dignity of the human person, the unity of the human family, the universally beneficial purpose of the goods of the earth, the need to pursue the international common good, as well as the common good of each nation, and the imperative of distributive justice" [11]. Some the most noteworthy of these teachings have appeared in Papal encyclicals. In 2009 Pope Benedict XVI released the encyclical *Caritas in Veritate* meaning "Charity in Truth" in which he discusses the need to work towards justice and the common good and to immerse this charity in the truth of God's Word.

There are many themes that emerge throughout Catholic Social Teaching including rights and responsibilities and the option for the poor and vulnerable [13]. Every person has a right to human dignity and therefore every person has a responsibility to work toward upholding this right for others [13]. Related to this responsibility, the option for the poor and vulnerable teaches of the necessity to give precedence to the poorest and most vulnerable members of society [13]. These themes are important ideas to consider in the study of charity and social justice which help clarify the importance of dedicating oneself to the service of others.

Charity refers to the practice of performing acts that assist others in their time of need [12] and is "at the heart of the Church's social doctrine" [14] and iterated by Jesus

when he speaks of the need to "Love your neighbor as yourself" [15]. In his encyclical "Charity in Truth," Pope Benedict does not simply promote practicing works of charity but also speaks of the necessity to couple this charity with truth because only in truth can charity be authentically lived [14]. With truth, charity is no longer confined to emotionalism by incorporating a relational and social content [14]. By incorporating God in the world through charity is not simply beneficial but essential in building a good society and complete human development [14]. By failing to join charity with truth grounds people in earthly activities and forces them to separate their earthly and religious lives as if they could not be joined [16].

Pope Benedict XVI also explains that to love others with charity requires dedicating oneself towards working for justice and the common good. This charity requires not only a sense of the common good but also of justice [14]. The common good involves the good of each group in society while justice seeks to recognize and uphold the rights of individuals [14] and address social structures that are sinful [12]. Pope Benedict XVI recalls Pope Paul VI's encyclical *Populorum Progressio* as he develops this understanding of justice by recognizing that when the Church proclaims, celebrates, and performs works of charity she is promoting human development in every dimension which necessarily needs God to order to appreciate this divine image in others [14]. Then in Pope Paul VI's apostolic exhortation "Evangelii Nuntiandi" he explains that this recognition of the divine image pays testimony, through works of charity, to Christ's love who is concerned with the whole person [14].

The Need

In 1986 the United States Conference of Catholic Bishops composed the pastoral letter "Economic Justice for All" in which they discuss how Americans in particular can apply their Catholic faith to their economic life. It calls for people not to focus solely on personal gain but to look outside of themselves to recognize the moral content and human consequences that are inherent in economic decisions [11].

In order to recognize the urgency with which society must change to protect the dignity of the human person, one must first understand "how disadvantaged large numbers of people and nations are in this interdependent world" [11] as a result of "human decisions and human institutions" [11]. Facts that represent the significance of these disadvantaged people are represented below.

- Half of the world's population resides in countries where the annual per capita income is $400 or less [11].
    - Out of the people in these countries, at least 800 million people are in absolute poverty and fifteen out of every one hundred children die before the age of five [11].
- Over three billion people have to live on less than $2.50 a day and at least 80% of people in the world live on less than $10 a day [17].
- There is enough food grown in the world to ensure that each person obtains a sufficient diet but despite this there are nearly half a billion people who are chronically hungry [11].
- Of the world's population, there is an estimated 20% that lack clean water, 40% that lack adequate sanitation, and 20% that lack adequate housing [18].

These problems cannot be expected to get better or even remain stable without dramatic changes as "the world is becoming a place in which human populations are more crowded, more consuming, more polluting, more connected, and in many ways less diverse than at any time in history" [3]. These populations are expected to explode with almost two billion additional people being expected within the next two decades with 95% of this anticipated growth taking place in developing or under-developed countries [18]. This population growth is expected to impact these countries but also the future prosperity and stability of the rest of the world by creating problems including greater poverty, deficits due to infrastructure investment, land and housing shortages, environmental concerns, disease, and economic dependence on one's government [18].

Many developing countries are unable to improve their situation due to the massive debt in which they find themselves. This debt now approaches $1 trillion, which is more than one-third of these counties' combined GNP [19]. To simply service this debt without even reducing the principal would require that on average the first twenty percent of export earnings be directed toward servicing the debt [19]. Foreign aid is not sufficient to relieve this debt because for every dollar in aid received by these developing countries is met by over twenty-five dollars in debt repayment expenses [17]. A series of events led to this debt in which developing communities now find themselves. Many of these developing countries initially needed these loans when grain prices tripled after the Soviet Union had purchased the entire United States grain surplus in 1972 and after the Organization of Petroleum Exporting Countries (OPEC) had increased the price of oil by eightfold between 1973 and 1979 [19]. These loans had been pushed on developing countries after OPEC had deposited most of the profits from raising oil prices in

commercial banks in the North and these loans would allow OPEC to obtain more interest on these deposits [19]. Many of these countries were then forced to refinance their loans at rising interest rates after oil prices doubled again in 1979. A global recession in 1979 then caused the prices of export commodities in these countries to fall which thus made it increasingly more difficult to repay these debts [19]. In 1994, the Bretton Woods Conference established a global system of finance, trade, and development which made it difficult for debtor countries to manage their debt effectively due to their inability to obtain the International Monetary Fund's approval for creditworthiness [19].

Shortcomings of society become clear when one recognizes the needs that society is responsible to fulfill for all people. A just society is responsible to ensure that all people are able to participate in economic life in order to provide for their material needs, use their talents, and contribute to society [11]. This participation ensures the protection of human rights which, as outlined by Pope John XXIII, are "a right to life, food, clothing, shelter, rest, medical care, education, and employment" [11]. It is for these reasons that the ability of people to sustain themselves economically becomes so important because it lays the foundation for securing other basic human rights. Rather than feeling themselves as being part of and contributing to this global economic life, many developing countries recognize their dependence on industrialized countries due to how the international system appears to subordinate them [11]. This recognition of dependence results from an understanding that the price of their imports and exports, their interest rates, and their external aid is determined by the industrialized world [17]. This lack of influence on the global market is also revealed by developing countries

relative lack of exports as low income countries which comprise 2.4 billion people account for only 2.4% of the world's exports [17]. To overcome these shortcomings, society has a responsibility to the poor and vulnerable and ensuring that the greatest needs obtain the greatest response [11].

Recognizing the significant needs of so many people inspires a call to action to secure justice within our world. An effective approach is through sustainable solutions in these developing communities. While unable to turn towards one's government for assistance due to massive deficits in these countries, empowering people to solve their own problems becomes increasingly important.

How to Work Towards Justice

With such great problems throughout the world, people who feel inspired to assist in this relief may feel uncertain as to the best process in working toward global social justice. Governments have a responsibility in safeguarding human rights and protecting human dignity for all and can thus be an effective avenue through which people can work towards justice [19]. This preferential option for the poor will involve sacrifice because to be in the greatest national interest, standard foreign policy analysis is typically based on power but the poor are not powerful [19]. Government aid has typically been taking the "form of grants, low-interest/long-term loans, commodities, and technical assistance" [19].

Rather than simply providing aid to developing communities, investment can potentially be more constructive because funds are then directed with a specific purpose by providing needed capital for technology and managerial expertise [19]. Issues to consider when investing in a community include ensuring that it does not contribute to

dependency, “sustain or worsen inequities in a developing country”, helps or maintains “oppressive elites in power”, or increases “food dependency by encouraging cash cropping for export at the expense of local needs” [19]. Farmers in particular are especially worthy of recognition as candidates for investment as evidenced by most authorities agreeing that it is the small farmer is the key to development in these poor, food-deficit countries [19]. Problems these farmers face include the lack of a market for these agricultural products since the bulk of the population in these areas are in poverty and a lack of agricultural inputs such as land due to the poverty of the farmers themselves [19].

What Do Engineers Do

Before discussing responsibilities that engineers have, the role of engineers must be established. A famous explanation that emphasizes the responsibility of the engineer states that “an engineer is someone who uses math and the sciences to mess with the world – by designing and making things that people will buy and use; and once you mess with the world, you are responsible for the mess you’ve made” [20]. According to Dr. John Scharf, an engineering professor at Carroll College, the ultimate goal of the engineer is to make people happy, healthy, and comfortable and engineers are necessary because for example if people were to simply drink the water that nature gives us then it would make them sick [21]. Bernard Amadei, an engineering professor at the University of Colorado Boulder and founder of Engineers Without Borders said that the priority for engineers should be “creating a sustainable world that provides a safe, secure, healthy, productive, and sustainable life for all peoples” [22].

What Do Engineers Need To Do

With the expected population explosion occurring in large urban areas of developing communities, [3] engineers will become more important in satisfying demand for "energy, food, land, water, transportation, materials, waste disposal, earth moving, health care, environmental cleanup, and infrastructure" [18]. In order to improve the situation of developing communities despite expected population growth, the next generation of engineers must be willing to look beyond the one billion wealthiest people that are being engineered for and focus on the rest of the world in order to "contribute to the relief of the unnecessary hunger, exploitation, injustice, and pain (physical and psychological) of those who are trying to survive at the end of each day on our planet" [18]. This requires them to couple charity with truth in order to see the divine face in these people and heed the words of Jesus when he taught that "For I was hungry and you gave me food, I was thirsty and you gave me drink… as often as you did it for one of my least brothers, you did it for me" [23]. These engineers must not only be able to see this divine face and understand the necessity of providing for those with the greatest need but also have the awareness of the needs of the developing world and the expertise to address the upcoming endemic issues in these developing communities [18].

Carroll College Engineers Without Borders and Santa Maria del Mexicano

The orphanage of Santa Maria del Mexicano provides an excellent example of a developing community in need and the assistance they have been able to obtain through engineering solutions. To invest in this community requires a sense of social justice to

make sacrifices with the sole motivation of helping others in need. It provides an example of an avenue taken by a group in working towards global social justice and lessons learned in this approach.

Sustainability and Engineers Without Borders

Engineers Without Borders is a humanitarian organization that seeks to provide sustainable engineering solutions to developing communities. Through their work at Santa Maria del Mexicano, the Engineers Without Borders Student Chapter has learned many lessons regarding designing and implementing sustainable projects.

Background of Santa Maria del Mexicano

Santa Maria del Mexicano is a Catholic orphanage a few miles outside of the town of Colon in Queretaro, Mexico. Santa Maria was originally founded in the 1800s as a monastery by the Franciscan monks who were responsible for constructing most of the complex including two dams which create two reservoirs close to the community.

Following the reform war in Mexico, there were a series of reform laws and the Ley Lerdo of June 25, 1856 transferred the Church's property into individual ownership which included this monastery [24]. These dams required regular maintenance to avoid the buildup of silt and loss of holding capacity in the reservoir. After this property had been confiscated, the flushing mechanisms in the dams were not being maintained so silt began quickly building up behind each. In addition, the area receives its rain in short periods of time and then goes for long periods without rain, making this lost reservoir capacity very important. The land was eventually given back to the Catholic Church and converted into the Catholic orphanage of Santa Maria del Mexicano which is now directed by the Catholic order, Society of Our Lady of the Most Holy Trinity (SOLT).

Squatting refers to "the practice of occupying unused properties or land without having a legal title" [25]. According to Mexican law, if a squatter is able to occupy an area for five years peacefully, they acquire the land they occupied. There have been several occasions of squatters occupying Santa Maria's land and have acquired this land through this squatter law, especially during the time when the Mexican government confiscated this land. These sections of land taken by the squatters were not given back to the Church.

Water Reuse Project

The Project

Santa Maria del Mexicano represents the first community where the Engineers Without Borders Carroll College Student Chapter began doing engineering service work. The first trips to the site were assessment trips whereby the needs of the community were identified and the most pressing problems determined. The Engineers Without Borders group decided that the most critical need was for a sanitation system. Santa Maria's previous system allowed the wastes to flow through open channels which allowed various animals to enter these channels and this created especially unsanitary conditions as the children would interact with the animals afterwards. The sewage water would then flow untreated into a nearby river. The Mexican government had also told the orphanage that they would no longer be able to allow their wastes to flow into the river because it was contaminating the river. The orphanage also has trouble with funding and maintaining an adequate and sustainable food supply for the children.

A project was then designed and implemented called the Water Reuse System. This system began by installing a 2,100-foot (640-meter) pipeline that would redirect the

community's wastewater away from the river and away from the community to a detention pond. The system was designed for an estimated 4,000 gallons of wastewater per day. In addition to this pipeline carrying the wastewater, another freshwater line from one of the reservoirs was utilized for this project.

The wastewater then flows into a lagoon where it is treated by natural processes. This lagoon consists of a bottom layer of sludge deposits which support anaerobic organisms, a top layer near the surface of dissolved oxygen from algal respiration and atmospheric reaeration, and an intermediate layer that is aerobic near the top and anaerobic at the bottom. It is lined with bentonite clay to prevent the wastewater from seeping into the ground. The outflow pipe from the lagoon is located in the top layer where the wastewater has been treated. The detention time for the lagoon before waste is able to reach the outflow pipe is about thirty-one days. A freshwater line would also be utilized during periods of low flow to maintain a surface level high enough for outflow into the tilapia tanks.

The outflow pipe sends water into one of four, seven-foot diameter, 1,300 gallon (5,000 liter) plastic tanks. Each of these tanks has the capacity for a total of 500 mature tilapia fish. It is expected that it will take about six to nine months for the fish to grow to their harvest size of 300 to 500 grams. The ideal temperature for these fish is between 27°C (80.6°F) and 32°C (89.6°F) with minimal growth below 20°C (68°F) and the fish will die below 10°C (50°F). These fish will eat unwanted nutrients that remain in the wastewater and have a natural resistance against bioaccumulating these wastes. It is this ability that allows them to be safely harvested even after consuming these wastes. These fish are also very hardy, grow quickly, and will not only feed off the decomposed organic

matter in the wastewater but also the plant life and especially the algae that flourishes in the lagoon. In addition to these food sources, fish foods and supplements may be necessary to ensure their growth and survival. A freshwater line was also installed at each of the tanks in order to provide sanitary water for the fish prior to harvesting them and to be used when the amount of ammonia, nitrates, nitrites, or other contaminant is too high or the amount of dissolved oxygen is too low because the freshwater contains a high concentration of dissolved oxygen. This freshwater line would also be used to clean the tanks and equipment when needed. Each tank is also equipped with a Solaer Lake Bed Aerator solar aeration system located next to the tanks to contribute to the amount of dissolved oxygen in the water and assists with mixing of waste. Being solar-powered eliminates energy costs as well as the cost of electrical cable to the tanks. The pipes through which freshwater and wastewater flow into and out of the tanks are controlled with valves. Both the lagoon and the area with the tilapia tanks were enclosed with chain-link fencing which would keep children as well as animals from getting too close to the wastewater.

Once the tank valves are opened, the wastewater is sent through 91.5 meters (300 feet) of a 160 mm (6-inch) PVC gated pipeline. This pipeline runs north of the tanks and into an open field where it could be used to either grow crops or simply discharge water. These gates along the pipeline can be open and closed in order to evenly distribute the water over the field or in a single desired location. This wastewater is safe to discharge on the ground after having been treated in the lagoon. The tilapia fish assist in this treatment process but are not necessary in order to discharge on the ground.

Issues

There continue to be issues involved with this project even after implementation despite studying and attempting to develop solutions to these problems. One problem is that algae in the lagoon seem to grow cyclically. At some times of the year, the lagoon appears green due to this alga but other times it appears brown when this alga is not flourishing. This alga is important because it helps to treat the wastewater and provides a food source for the fish. To solve this problem, an aerator has been installed in the lagoon which would contribute to the amount of dissolved oxygen in the water and thus increase alga growth. This has shown to be an adequate solution and the lagoon appears to be green with alga growth throughout the year.

The issue of the fish dying continues be a significant problem. There have been many attempts which have increased the success rate but none has enabled a successful harvest. The first attempt to plant fingerlings resulted in all the fish dying in a single day. We believe the primary reason for this was because the tanks were only filled with wastewater when they were planted. Research had suggested that the tilapia fish should be able to withstand this but we then realized that this was true for fully-grown tilapia fish but not young fingerlings. As a solution to this problem we decided to mix wastewater and freshwater in different ratios and test the ammonium nitrate of these ratios until we determine the most wastewater that we could put into the test while still keeping a healthy environment for the fish. Total Ammonium Nitrate is the second most important factor after the amount of dissolved oxygen for the fish's survival. The concentration for total ammonium nitrate is a function of the concentration of ammonium, the pH, and the temperature as shown in the equation below.

$$\text{TAN} = \frac{\text{CA} \times \text{F}}{100} \times (1.2)$$

where $\text{TAN} = \text{Total Ammonium Nitrate (parts per million)}$

$\text{CA} = \text{Concentration of Ammonium}$

$\text{F} = \text{Factor obtained from pH and Temperature table}$

To keep a safe amount of total ammonium nitrate, it should be less than 0.05 parts per million and if it becomes greater than 0.5 parts per million then it could result in gill damage. We determined that with a ratio of wastewater to freshwater of 1:10, we were able to obtain a TAN of 0.05 parts per million. By adjusting the flows into each tank and determining the amount of time for the wastewater and then the freshwater to fill a specific volume, we were able to ensure that there was a 1:10 ratio of wastewater to river water flowing into each tank. Even with this modification, the fish still had trouble surviving in the presence of the wastewater.

Further analysis suggests that the greywater, which is mixed with the wastewater, is too strong and is killing the fish. A solution to this problem has not been formulated yet apart from filling the fish tanks with only freshwater and feeding the fish with purchased fish foods.

Another reason that we believe the tilapia fish did not survive was because they were planted just before winter and, although we do expect them to be able to survive the coldest months in the area, they may be too weak as fingerlings for this. We have now decided to plant these fingerlings in the spring so they have time to mature prior to being exposed to the area's lowest temperatures.

The community has also had some trouble with the tanks being forced out of the ground by forces from the soil. The maintenance staff was informed that this could

happen if the tanks were emptied for an extended period of time but they told us that it had happened after flooding in the area while the tanks were filled. We have not determined a solution to this problem. The wastewater treatment aspect of the project is functioning as designed and has been successful at treating the wastewater and fish are currently growing in the tanks but there has yet to be a successful harvest.

Spices to College

After completing implementation of our water reuse project we began once again looking at the needs of this community in order to start designing our next project. Needs we identified that we would like to address include the lack of funding for scholarships for the children of Santa Maria. Tuition costs to send children to college in Queretaro are about $2,000 annually and, as funds become available, Santa Maria tries to send its children to college. Not only is this important for the children but it can also be a benefit to Santa Maria because many of those who are able to go on to a college or a trade school come back to Santa Maria to help the community that had given them so much. Arturo was a resident of Santa Maria and was sent to college by Santa Maria, where he majored in agriculture with an emphasis in husbandry. He has returned to Santa Maria to give back to the community that supported him and is now their agricultural coordinator for their various agricultural projects including raising sheep, pigs, cows, and rabbits. Santa Maria still has to buy most of the food for its residents but it is a step toward a sustainable food supply for the orphanage. They are getting milk from the cows which they are able to feed the children, and the nuns also use this milk to make cheese and yoghurt for them. The rabbits are very good at converting feed to meat and they are also able to sell rabbits

in addition to butchering them. When they do butcher them, they are able to use their skins to make gloves. In addition, Santa Maria is also raising sheep and pigs.

To meet these needs, we designed and are implementing a project called Spices to College. It involves installing approximately 5,900 feet (1,800 meters) of piping about a foot underground from two reservoirs to irrigate about eight acres of tilled land. During an assessment trip we surveyed the more distant reservoir to be 54.2 feet (16.5 meters) higher than the highest field and 5,748 feet (1752 meters) away.

Before implementing this project we decided to ensure that the agricultural fields did in fact belong to Santa Maria and not to a squatter. The Mexican government sent a surveyor to the area to perform a survey of Santa Maria's property. We were then able to superimpose this survey data on a map of the area to outline their property. We discovered that these fields did in fact belong to Santa Maria as well as another area that Santa Maria was not aware that they owned.

Headloss refers to the energy losses experienced as water flows through a pipe due to friction. Headlosses can be divided into major and minor losses. Major losses involve energy dissipated due to friction involved with fluid flow and minor losses involve energy dissipated due to pipe valves, bends, fittings, etcetera. To calculate the major losses we applied the pipe length as well as several assumptions to the Hazen-Williams equation, as shown below, to calculate the headloss.

$$h_f = \frac{10.44\ L\ F^{1.85}}{C^{1.85}\ d^{4.87}}$$

where h_f = major loss (feet)

L = length of pipe (feet)

F = flow rate (gallons/minute)

C = Hazen-Williams Roughness Coefficient

d = diameter of pipe (inches)

To irrigate these fields will require a maximum flow rate of about eighty gallons per minute but to maintain a conservative estimate we assumed the flow rate (F) to be one hundred gallons per minute. This would increase the headloss calculated and thus decrease the calculated energy available which would contribute to a conservative estimate. We also assumed a Hazen-William Roughness Coefficient (C) of 150. The one hundred millimeter pipe that we will be installing has an English conversion of 4.28-inches but we used a diameter of four-inches in our calculations which would also increase the headloss and contribute to a conservative estimate. We neglected energy losses due to pipe valves, bends, and fittings which would be insignificant losses in our evaluation.

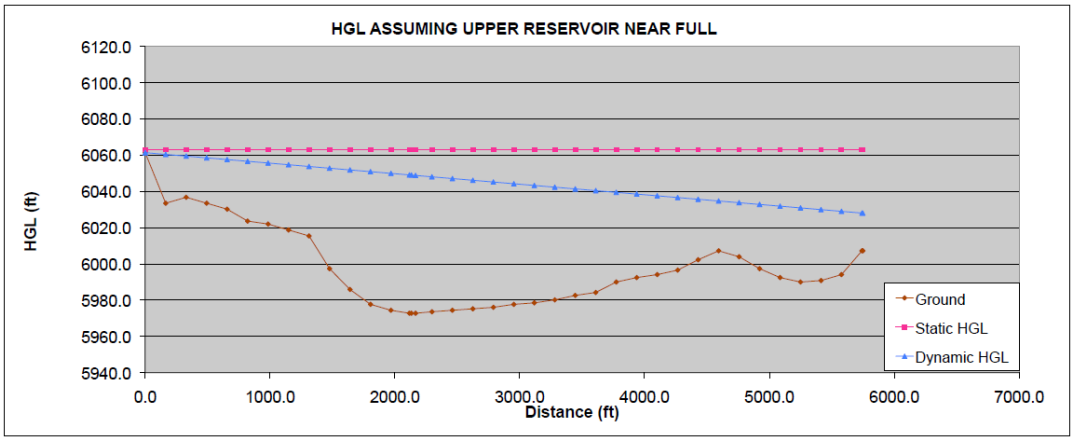
A hydraulic grade line presents a graphical representation of the energy of water flowing through a pipeline. The hydraulic grade line (HGL) data points at fifty-meter intervals can be calculated by subtracting off the major friction loss at each point as shown in the difference equation below.

$$HGL_{n+1} = HGL_n - h_f$$

Water can contain energy in the form of elevation, pressure, and velocity. The initial hydraulic grade line point is represented solely by the reservoir's water surface

elevation as it does not contain any energy in the form of pressure or velocity. Each of these points can be plotted to generate the following hydraulic grade line of water flowing through the pipeline while assuming that the upper reservoir is near full as shown in Figure One below.

Figure One: HGL Assuming Upper Reservoir Near Full



[26]

In the above hydraulic grade line, the ground elevation is plotted in order to demonstrate the amount of hydraulic head available along the pipeline, as this available head is shown by the difference between the hydraulic grade line and the ground. The static hydraulic grade line represents the hydraulic grade line if there was no flow and thus no major losses along the pipeline. The dynamic hydraulic grade line represents the elevation and pressure energy in the pipeline with major losses resulting from a flow rate of one hundred gallons per minute. By subtracting the elevation energy from the hydraulic grade line leaves only the energy due to pressure. The pressure along the pipeline in pounds per square inch can thus be calculated as shown below.

$$HGL = z + \frac{p}{\gamma} \rightarrow p = \gamma(HGL - z)$$

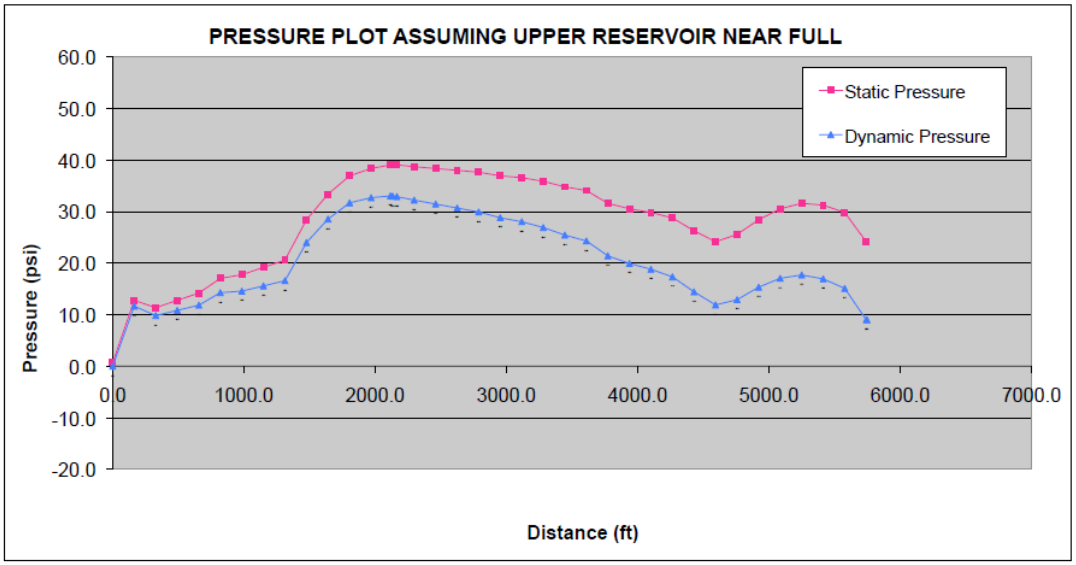
where γ = density of water $\left(62.4\frac{lb}{ft^3}\left(\frac{1ft}{12in}\right)^2 = 0.43\overline{3}\frac{lb}{in^2-ft}\right)$

p = pressure $\left(\frac{pounds}{inch^2}\right)$

z = elevation

The pressure at intervals along the pipeline can thus be calculated and plotted as shown in Figure Two below.

Figure Two: Pressure Plot Assuming Upper Reservoir Near Full



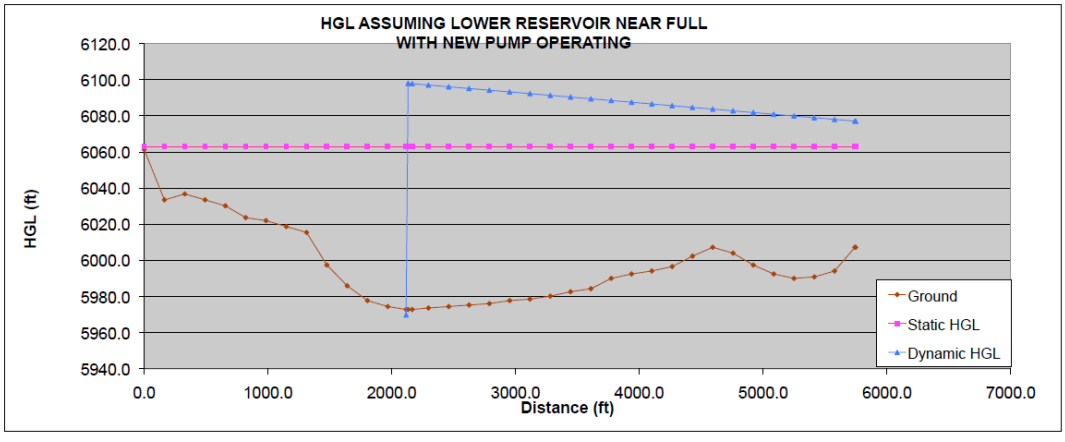
[26]

The plot above demonstrates the pressure available along the pipeline with the static pressure representing the pressure available without a flow and thus without major losses. The dynamic pressure plot incorporates a flow of one hundred gallons per minute and the resulting major losses. The end of this plot demonstrates the pressure available at the highest point in the fields being 9.0 pounds per square inch. This is representative of the highest point in the fields and drip irrigation lines typically require a delivery pressure of approximately ten pounds per square inch. Drip irrigation lines will thus be used in the

highest fields and the fields that are located much lower will have sufficient hydraulic head available for either drip lines or sprinkler irrigation, which requires more pressure to operate.

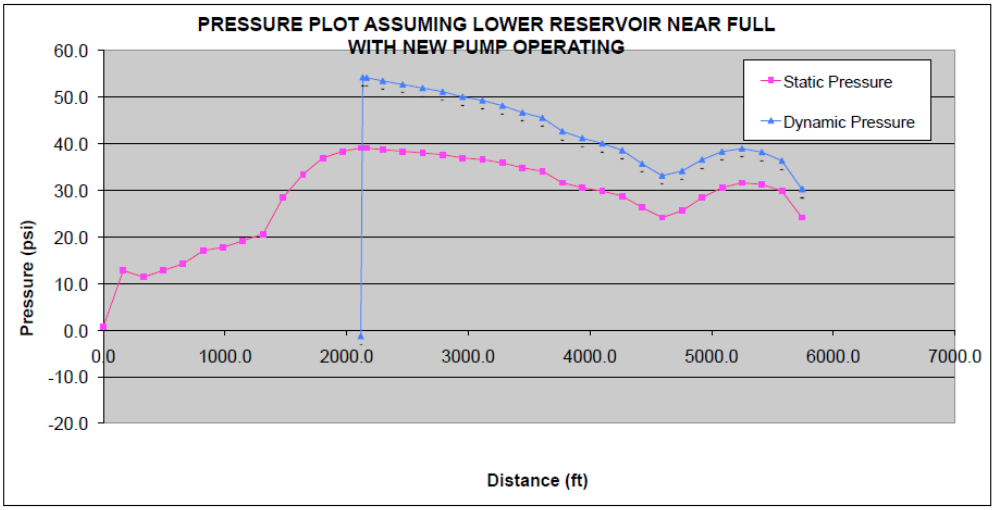
The disadvantage of this reservoir is that it is quickly filling with silt and due to this reduced storage capacity it dries for part of the year. A reservoir of approximately one meter has been placed on the top of the dam, but even that will fill with sediment in approximately twenty years. In order to supplement this line with water during the dry periods we will also be utilizing another reservoir. This reservoir is lower but is fed by a spring in addition to surface runoff and thus does not dry during a period of the year and can thus be used as a reliable backup supply of water. Being lower in elevation, however, this reservoir does not have the capacity to supply water to the fields solely through gravity. A pump will be required, and by using an identical method as described above for the higher reservoir, a hydraulic grade line and pressure plots can be generated as shown in Figure Three and Figure Four below.

Figure Three: HGL Assuming Lower Reservoir Near Full



[26]

Figure Four: Pressure Plot Assuming Lower Reservoir Near Full

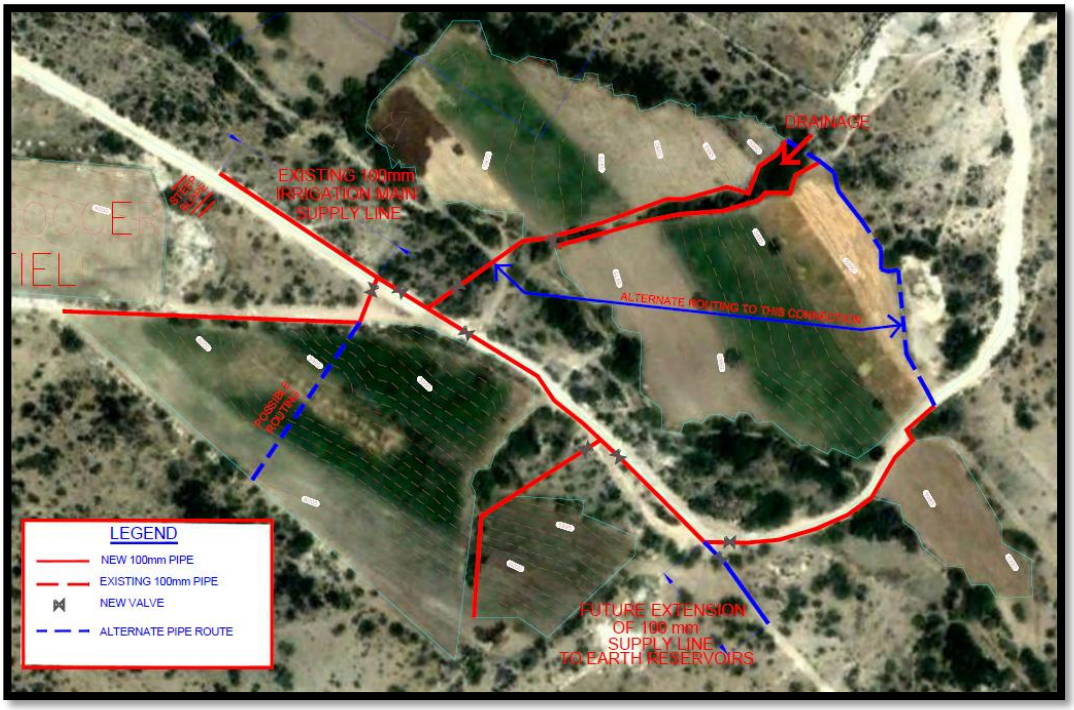


[26]

The jump in the above graphs at a distance of 2132.5 feet is a result of the energy input of 128.2 feet of total dynamic head by the pump. This allows for a pressure of 30.2 feet of hydraulic head at the highest point in the fields allowing for sufficient pressure to operate either drip or sprinkler lines.

A survey was then performed to cross-section the fields in order to design the irrigation system including the header pipe distribution line with valves and risers placed at appropriate locations, and laterals across the field. This design is shown below in Figure Five with alternate routings and the valve placement shown along this line. The valves are placed such that any combination of fields can be irrigated.

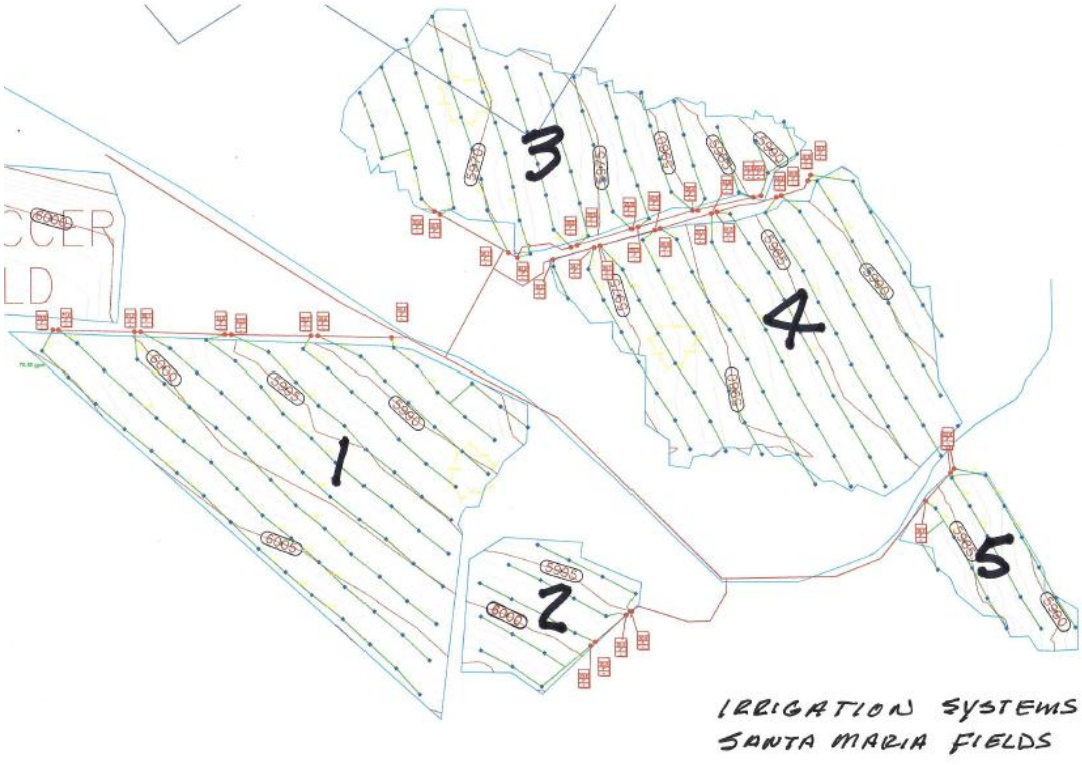
Figure Five: Field Distribution System and Valve Locations



[27]

The laterals that branch from this main line as shown above are placed parallel to the field contours to ensure the water is distributed along the length of the lateral. As shown below, Figure Six depicts this design with the solid line running along the fields representing an elevation contour and the dotted lines representing the laterals. The red boxes represent a riser where two laterals begin.

Figure Six: Field Riser and Lateral Locations



[28]

Reservoir Restoration

The upper reservoir is an important resource for the community especially within the context of the Spices to College project. With the silt flushing system inactive due to the amount that has backed up, a solution must be formulated before the remaining capacity is lost. Solutions have been suggested to preserve this remaining capacity such as to construct a small dam upstream of the current dam which would capture the silt before it is able to travel to the reservoir. The Mexican government has discussed with Santa Maria the possibility of financing this endeavor. After talking about this proposal

with Father Mike Sanchez, a Catholic priest at Santa Maria, the Carroll College Engineers Without Borders group identified several issues with it.

One issue is that it was not a permanent solution and does nothing to restore the previous capacity. Without the ability to flush the silt downstream from this smaller intercept dam, this solution may also create further issues upstream as silt accumulates. It also becomes only a matter of time before the higher reservoir fills with silt. This solution does not guarantee that silt will not still accumulate after its construction as this sediment may also originate from surface runoff directly into the reservoir rather than simply coming from upstream.

Another proposal is the use of a sluice pump that could be used to send both water and sediment over the dam and out from the reservoir. This solution creates issues of additional sediment downstream and lost water from the reservoir. After discussing this solution with Father Sanchez he explained that since the reservoir receives all its rain in a short period of time and water overtops the dam and runs downstream during this wet period, the loss of water due to the pump would not be of concern because this water would be lost over the dam anyway. He was also not concerned about the additional sediment but a more thorough investigation of this has yet to be performed.

We have also discussed the option of excavating down to the de-silting system and opening this so that over time, this silt will gradually be released downstream. A solution along these lines has been promoted by Bill Wiegand, a professional engineer. Previously, attempts were made to open this flushing system from the open, downstream side without excavating the silted side, but due to the immense pressure at this depth of the silted side, a very unsafe situation was created.

Sustainability Factors

When one undertakes a project in a developing community that is meant to be sustainable, one must continuously evaluate it before, during, and after implementation. Leroy Salazar, a professional engineer and founder of Agro Engineering, formulated what he calls the Guiding Principles that instead list qualifications and are designed to indicate whether a project should be considered to be sustainable for the community of Santa Maria del Mexicano in Colon, Queretaro, Mexico. He developed these Guiding Principles based on his experiences of working on projects in developing communities. A series of sustainability factors will be discussed and are based in these guiding principles.

The Guiding Principles developed by Leroy Salazar ask a series of three questions that are meant to address whether a project will be sustainable. The questions are: 1) does the project address a need, 2) does the community have the resources, and 3) is the community committed. He placed particular emphasis on the issue of whether the community is committed. These sustainability factors are based on these guiding principles to the extent that they address the same three aspects of a need, resources, and local support.

To address a particular need is the most fundamental of these factors of sustainability. If a project does not address a legitimate need, then it serves no purpose. To serve a need effectively not only involves evaluating what needs a community has, but also identifying the most pressing needs of the community. For example, at Santa Maria, the issue of wastewater treatment was addressed prior to the irrigation line because the wastewater treatment need was the more pressing need at that time.

Available resources should also be considered in the design of sustainable projects. These resources can be divided into natural, human, technologic, and economic. Natural resources can be critical in the design of many projects. For example, Santa Maria is able to grow animal feed and spices due to their land and water resources. Human resources can be separated into the availability of labor and appropriate expertise. In terms of labor, it must not only be available but the expense involved with that labor should also be evaluated. For example, to raise animal feed by the same methods in the United States and Mexico would demonstrate dramatically different levels of sustainability as labor wages in the United States and Mexico are substantially different. This labor must be coupled with the necessary expertise to understand, maintain, and potentially advance a project. This expertise needs to be capable of being passed within generations of people. Technologic resources must be judged to be appropriate for the community. The community ought to be able to operate, maintain, repair, and potentially replace any crucial device or machine involved with a project. Not only is it critical that the resources to do a project be available, but the financial burden on a community also needs to be evaluated. Economic resources that should be considered include the necessary initial investment, any project maintenance costs, and the revenue it could potentially generate for a community.

The final Sustainability Factor is determining the extent to which a community supports a project. Issues that a community may have in supporting a project involve whether the community believes that there is a significant need that this project addresses, whether the solution justifies the economic resources that the project requires, and that the proposed solution is the best solution. Through our water reuse project we

neglected to investigate whether the Santa Maria supported the fish farming operation. Santa Maria supported the wastewater treatment facility which has been successful but many do not support the fish farming operation. This may be a reason why there has not been a successful harvest as of yet, but perhaps after a successful harvest there will be sufficient support for the project for it to be sustainable. Some however are dedicated to this project and are committed to ensuring its success. Noe is a worker on Santa Maria's maintenance staff and has taken over the maintenance operations for this project. He has researched and studied concepts related to this project and deviated from the original maintenance manual in order to solve problems that arise. His dedication has inspired the Carroll College Engineers Without Borders chapter to continue solving problems related to this fish farming operation.

Examples of Sustainable Projects in Developing Communities

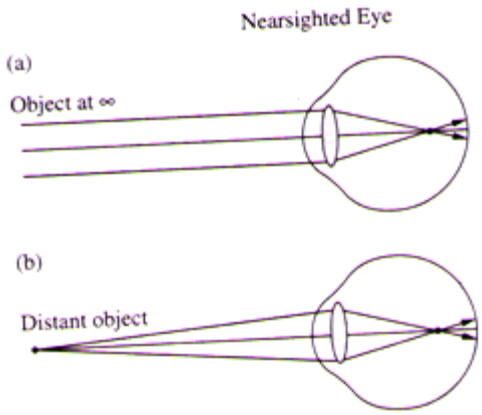
These sustainability factors can be applied to other projects to assess their degree of sustainability. This evaluation should be conducted before, during, and after implementation to ensure that the project remains sustainable.

Adjustable Eyeglasses

There is a great need corrective lens throughout the world. According to 2005 World Health Organization statistics, about one billion people are in need of corrective lenses with 10% of those are amongst school-aged children. [29] This affects the ability of people to "learn, to read and write, function, and even imagine". [29]

Myopia or near-sightedness is the condition whereby rays from objects at a distance "are brought to focus in front of the retina" as shown in Figure Seven below. [24]

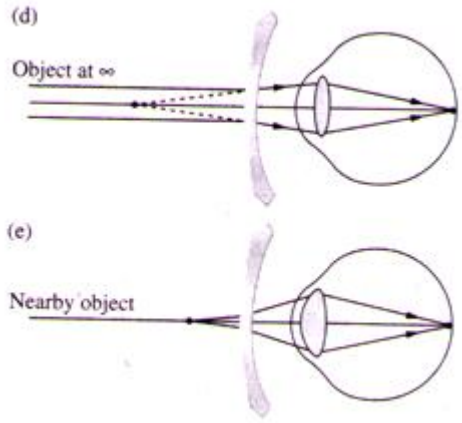
Figure Seven: Unaided Nearsighted Eye



[30]

To correct nearsightedness, a negative lens that diverges the light rays is placed in front of the eye such that its focal point is on the retina as shown in Figure Eight below. [30]

Figure Eight: Nearsighted Eye with Negative Lens



[30]

The focal point describes that point whereby the light rays converge to a point. A negative lens is concave and diverges the light rays. [30] It is "thinner at the center and

tend to advance that portion of the wavefront, causing it to diverge more than it did upon entry". [30] The required focal length of eyeglasses is given by the Gaussian Lens Formula.

$$\frac{1}{f} = \frac{1}{s_0} + \frac{1}{s_i} \qquad [30]$$

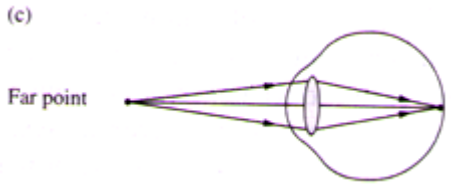
where f = focal length

s_0 = distance of object

s_i = image distance

If the object is far away then $s_0 = \infty$ and thus $f = s_i$. The focal length of a corrective lens should thus be equal to the far point. The far point is the point where the eye is able to clearly see images closer than this as shown in Figure Nine below. [30]

Figure Nine: Far Point of Nearsighted Eye



[30]

The focal length of a diverging lens is located at the point from which the light rays diverge. This focal length is a function of the curvature of the lens as shown in the Lensmaker's Formula below.

$$\frac{1}{f} = (n_l - 1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right) \text{ [30]}$$

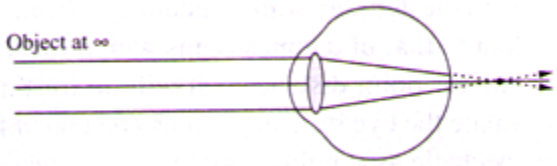
where n_l = the index of refraction of the lens

R_1 = the radius of the side of the lens that the light first encounters

R_2 = the radius of the side of the lens that the light leaves from

Another common condition that requires corrective lenses is hyperopia or farsightedness, which "is a defect that causes the second focal point of the unaccommodated eye to lie behind the retina" as shown in Figure Ten below [30].

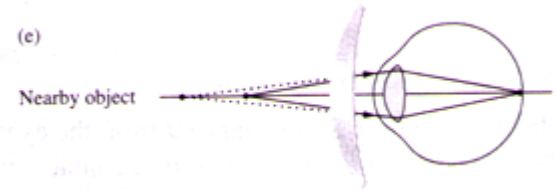
Figure Ten: Unaided Farsighted Eye



[30]

An eye with this condition is limited in seeing closer than its near point. To correct this, a positive lens is placed in front of the eye "to increase the bending of the rays" and "effectively move a close object out beyond the near point where the eye has adequate acuity" as shown in Figure Eleven below. [30]

Figure Eleven: Farsighted Eye with Positive Lens



[30]

The required focal length of the lens can be calculated using the Gaussian Lens Formula as shown above where s_i refers to the near point and s_0 refers to the distance of the object. Curvature of the lens can then be calculated based on this focal length as shown in the Lensmaker's Formula above.

Dr. Joshua Silver, an Oxford physicist and scientist, has been working on a project that he hopes will help solve issues of the lack of sufficient eyeglass services in

the developing world. [29] His idea is to create inexpensive, adjustable prescription eyeglasses that work by adjusting the curvature and thus the magnification of the lenses "by varying the amount of silicon oil between two flexible membranes".[29] This procedure of adjusting the eyeglasses is reasonably simple, requiring only about ten minutes to explain to adults or children. These lenses, however, are limited to the extent that they cannot correct astigmatism or other medical conditions, but they are adequate for over 90% of people in need of visual correction. [29] These glasses currently cost between $5 and $10, but there continues to be pressure to reduce these costs. [29] There have been approximately 10,000 pairs of these adjustable eyeglasses manufactured in China and distributed to developing countries in Africa. [29]

Compressed Earth Block Construction

Compressed Earth Blocks is a building material formed primarily from clay and sand and is thus a "non-toxic and readily available building material". [31] Structures constructed utilizing compressed earth blocks are "aesthetically pleasing, cost and energy efficient, fire and pest resistant, virtually soundproof, durable, and structurally sound. [31] The development of high pressure hydraulic rams allow for blocks to be produced at a rapid rate that ranges from "100 to 800 blocks per hour depending on the machine". [31] These blocks can be stabilized by adding smaller amounts of materials such as Portland cement or hydrated lime, depending on the clay content, to make them water-resistant. [31]

Sustainability Analysis

These projects could potentially represent sustainable projects for a community. The Sustainability Factors that must be considered include the need these projects satisfy, the resources required, and the extent that a community supports the project.

With about one billion people worldwide in need of corrective lenses there is a need in many developing communities for affordable eyeglasses. Manufacturing and distributing conventional eyeglasses requires both technologic and economic resources. Adjusting these alternative eyeglasses does require some instruction, but the operation involved with adjusting them properly is not outside the realm of understanding even for children. Obtaining a prescription for lenses can be expensive and thus not within the budget for many in developing communities, however, these adjustable eyeglasses offer an affordable solution to those in need. Before distributing these adjustable eyeglasses in a community, it is important to determine beforehand if the community would appreciate them. The support for a project such as this may vary between communities or even among people within a community. This project does seem to have the potential to be sustainable and has even been used by the US Agency for International Development (USAID). USAID is the organization that the United States uses to provide economic and humanitarian assistance throughout the world.

There is also a great need throughout the world for affordable housing, with twenty percent of the world's population lacking adequate housing. [18] Constructing housing using compressed earth blocks requires natural, human, technologic, and economic resources. Compressed earth block construction requires land to construct on and availability of acceptable material to form quality blocks. It is however highly labor

intensive and thus is most applicable to regions where ample low-cost labor is available. There are many different manufacturers and models of earth press devices. Selection of the model is based on the fuel, expertise, and extent to which the earth press will be used. These presses may be fueled by diesel, gas, electricity, or manually and thus the availability of each of these resources near the community where blocks will be constructed becomes very important. Due to the variety of styles of presses, some being more complicated than others, the extent to which the members of the community that will be responsible for operating and repairing the device becomes important. In terms of economic resources, these earth block presses also vary widely in price depending on their ability to produce quality blocks quickly. Thus the amount invested in such a device should be based on an estimated number of blocks that will be produced. There must also be a desire for this type of construction in the community. It is very appealing due to its many advantages, but communities may not be open to new forms of construction. Without community support, there will be a lack of dedication in seeing the project become a success, which becomes very important in the sustainability of this method of construction.

Conclusion

There is a natural, inner calling that people seem to have in working toward social justice for other people regardless of their background and origin. According to Catholic teachings of social justice, there is a responsibility everyone has to care for their neighbor and this care should be carried out in light of the truth of the Christian faith. Engineers in particular have a responsibility to assist in addressing the many issues faced by people in

developing communities. This responsibility will become even clearer as the populations of developing communities continue to rise as they are projected to and thus resulting in a decline in their standard of living.

The work of the Carroll College Engineers Without Borders student chapter at Santa Maria del Mexicano contains great lessons in issues surrounding sustainability. Analyzing this work brings up issues of need, resources, and community support. Sustainability is crucial to the success of a long-term solution and should be assessed in the design prior to implementing any project.

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