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HEIFER PROJECT INTERNATIONAL

AQUACULTURE PROJECT

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by

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Abstract

Working from literature, interviews with an aquaponics facility manager, and previously attempted system designs, an integrated aquaculture and hydroponics (aquaponics) system was researched, designed, built and monitored for Heifer Project International (HPI) in Rutland, Massachusetts. This system, with its visual display, was created to provide an educational exhibit for HPI on using an aquaponics approach to providing the world's hungry with an economical food source. In this project we assessed: 1) the problem of world hunger, 2) the design and application of an economical aquaponics system, 3) the establishment of an educational display to describe this effort.

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Executive Summary

World hunger has been a pertinent and ongoing issue in global affairs for decades. Several organizations are dedicated to trying to solve the problem of world hunger using various methods. Heifer Project International (HPI) is one of those organizations, and its efforts are directed toward facilitating self-reliance. This idea of giving families a source of food and a wealth of information rather than short-term relief is the foundation of this project. Our sponsor, Dale Perkins of HPI, requested that we conduct research in order to design and build a system that is relatively self-sufficient to raise fish for food. The objectives of this project were to continue the research that Dale Perkins had begun and provide such a system to HPI along with an educational component that will teach the public about the various benefits of an innovative system such as this.

When this project was given to the team from WPI, it was still in its beginning stages. Another HPI project center in Chicago had addressed a similar issue and developed a design for use in urban areas and this is what sparked Dale Perkin's interest in such a project. A small amount of research had been conducted, the results placed in a folder, and this folder was passed along to us. Based on this preliminary research, a species of fish had already been chosen and initial design ideas were formulated. Construction of a imperfect foundation for a greenhouse had been completed years before, and this was identified as the site for the implementation of the project.

The team scoured literature and the Internet to learn everything possible about tilapia (the selected species of fish), aquaculture and hydroponics. We found a commercial fish farm in Sunderland, MA, where they are operating the same basic system that we were considering, only

on a much larger scale. They were tremendously helpful in answering a lot of questions we had and facilitating our design efforts. We found information regarding the biological specifications of tilapia in order to ensure that the system we would design would suit their specific needs. We also did research on the integration of aquaculture and hydroponics, known as aquaponics, and the benefits of such integration. We researched the different system configurations already in use including recirculating and flow-through designs. Our research allowed us to make recommendations to HPI about what types of systems they could have in place.

Our presentation of recommendations to HPI included the following three designs: 1) a fish tank with a particulate filter and separate aeration such as a domestic fish tank, 2) a recirculating design involving the use of the "three-barrell design" first put forth by the Chicago site, and 3) a recirculating design integrating the use of a hydroponic bed. All three designs were presented with their respective benefits and drawbacks including budgets to the staff at HPI. HPI chose the third option, and we then conducted more research in order to refine the design.

Once the recirculating system type was selected, the WPI team finalized designs for the system and initiated construction of the system components. While the WPI team was on site for construction of the system, HPI began building the greenhouse that would contain the complete system. The WPI team became an integral part of this construction as well once the system components were built, in order to push the project forward.

Once the construction was complete, the system was monitored briefly before fish were added and HPI was tasked with recording temperature data on the system so that it could be analyzed to ensure that life sustaining temperatures could be maintained. After the data was analyzed we determined that the system was sufficient to raise fish.

The fingerlings were procured from Bioshelters Inc. and were transported back to the farm and added into the tank. From this point on, data was collected to determine the performance of the system including temperature and water quality data. Water quality parameters such as dissolved oxygen, dissolved carbon dioxide, pH, ammonia, nitrites, and general hardness were evaluated in order to ascertain any modifications that were needed to ensure that the system could support life. Modifications were made and the system was monitored while running so that any mechanical failures that arose could be analyzed and repaired.

With the fish in place and the system in operation, the focus of the team shifted from engineering a system to creating an educational display. The WPI team brought visitors into the greenhouse to sense an initial reaction to the system and to answer questions. Based on the questions were asked, temporary displays were created. Focus groups were then convened in the greenhouse to help us determine the educational content of the displays, and to offer suggestions on the best manner of presentation to future audiences. The team used these focus groups to determine common questions that were not answered by the temporary visual display. The focus group data was analyzed and a final display set was presented to HPI.

Once the educational display was finished, it was approaching harvest time. The harvest was conducted, the fish were counted and weighed, and the quality of the product was tested. HPI appeared pleased with the results; they had great tasting fish and an impressive system that could be used to teach people what is possible without requiring extensive effort. The WPI team, however, although equally pleased with the quality of the results, was a little dismayed by the quantity.

The data collected on the system was again pondered and set of recommendations was drafted. The list contained such things as minor design modifications, changes in operational guidelines, and different ways of approaching problems that can arise with the operation of the system. These adjustments were designed to enhance system performance and thus increase productivity. Throughout the project, it had become apparent that this year's limited success was not due to a flawed design, but was the result of small details and minor imperfections in the construction and operation of the system.

Presenting final educational display along with this set of recommendations to HPI concluded the project. The final educational display will be placed in with the system upon the inception of next year's crop. Visitors to the site will be able to peruse the exhibit and learn from our endeavors without assistance from HPI staff. If all the recommendations are properly implemented, the next growing season would likely be far more productive than the last. Between the educational benefits of the system and the possible increased yield of fish and vegetables from greenhouse, the project can be considered a success.

INTRODUCTION

Problem Statement

World hunger has been a pertinent and ongoing issue in global affairs for decades. It is a well-known problem in certain underdeveloped countries such as Somalia, Bangladesh, Honduras, and Haiti. 841 million people worldwide suffer from the debilitating effects of malnutrition (Ramonet, 1998). However, hunger is not only related to mass starvation in Third World countries. Developed countries such as the United States also suffer from degrees of poverty and starvation. Due to the media, the American public often sees the vignette of 'starving children in Somalia', and never sees what occurs in their own country. According to World Hunger Year statistics, 3% of all households in the United States show evidence of hunger. Furthermore, approximately 10% of all households, 31 million people, were living on small meals and skipping meals due to poor finances in 1999 (World Hunger Year, 2000).

Hunger is not a crisis simply because the world does not produce enough food; the real challenge is to distribute it more evenly. We as a people now have the experience and technology available to reduce the problem. The total wealth of the world's three richest individuals is greater than the combined gross domestic product of the 48 poorest countries (Ramonet, 1998). The philosophy of unequal distribution, however, does not demean the significance of the situation. It will still take a massive effort to end hunger and malnutrition worldwide. Many institutions have been established to help solve the problem. Examples include Unicef, Children International, CARE, Project Hope, and the Heifer Project International, who are all non-profit organizations solely dedicated to relieving world hunger. On a more local scale, the Mustard Seed in Worcester and the Wachusett Food Pantry in Princeton are both associations that collect non-perishable food items to distribute to families in the Central Massachusetts region.

Heifer Project International, commonly referred to as HPI, is one specific organization committed to solving the problem of world hunger. Heifer Project's endeavors reach the five most inhabited continents in the world, from Russia to Ecuador and from Mozambique to West Virginia, with the world headquarters located in Little Rock, Arkansas (Heifer Project International, 2000). HPI's efforts are directed toward facilitating self-reliance. This includes supplying families with "gift" animals and agricultural tools along with the education to utilize them as a renewable resource. In order for communities to receive aid from Heifer Project, they must promise to continue the giving process by donating the offspring to others so that they may also benefit (Heifer Project International, 2000). This idea of giving families a source of food and a wealth of information rather than short-term relief is the foundation of Heifer Project. Farms have been set up around the world to support this cause, some of which are solely educational facilities.

Overlook Farm in Rutland, Massachusetts is an educational division of Heifer Project International. It raises a variety of animals including: llamas, rabbits, cattle and bees for a total of 13 different species (Heifer Project International, 2000). The coordinators of the farm are investigating the possibility of adding a new animal to their list, fish. In coordination with HPI, we will be researching and developing a method of raising fish in a closed environment as a food source. This habitat will also serve as an educational demonstration on farming fish for food. This demonstration will teach people how fish can be raised simply for an extended period of time and also how to assemble and manage the system in a relatively uncomplicated manner.

Visitors will also discover the value of aquaculture when it is applied as a source of food production.

The design for an aquaculture system will need to take into consideration many factors and limitations. The system itself will be a working model that underprivileged families would conceivably be able to build and use in an effective manner. These families are likely to be poor, so the most economical design is preferred. The costs that need to be considered are not only the costs involved in building the system but also in maintaining of the system. Heating, circulation, filtration and aeration of the water need to be taken care of along with the nutritional demands of the fish themselves.

The educational backgrounds in such disadvantaged families is limited as well, so the design needs to be straightforward enough for a family to be able to build and sustain the system without much trouble. Keeping the design basic will allow people of varying abilities to perform routine maintenance on the system and keep it in operation. This model will also be easily replicated, thus allowing Heifer Project International to pass it on to others in the true spirit of the organization.

The prototype to be built at HPI will provide visitors to Overlook Farm with insights into how people can raise their own food in more economical ways using aquaculture and hydroponics. The system needs to be presented in such a way that it is interesting and informative to the general public. This may involve the use of charts and diagrams to explain the system and how a family can utilize it. This group will provide a model for an integrated aquaculture and hydroponics system that is economical, simple, and educational.

LITERATURE REVIEW

World Hunger

Every 3.6 seconds, someone dies due to hunger-related health problems (The Hunger Site, 2000). If a person does not die due to an outright lack of food, chronic malnutrition can cause various detrimental side effects. Malnutrition affects 800 million people globally, and a stunning 14% of the world population goes to bed hungry every night (The Hunger Site, 2000). Impaired vision, stunted growth and immune deficiencies can result from malnutrition even in mild cases. Severely malnourished people are unable to function at even a basic level (The Hunger Site, 2000). Hunger affects people in almost every country in the world, including the United States. "About 31 million [people] (10.1% of all households) were food insecure (living on small meals and skipping meals) in 1999" (World Hunger Year, 2000). The overwhelming number of people who suffer from the effects of hunger reveals that the problem may arise from numerous sources (see Appendix A).

The reasons for hunger are not always as obvious as a simple lack of food. Other causes of hunger may include an inadequate water supply, scarcity of healthy animals, an insufficient source of viable seeds for crops, lack of education, and uncontrolled population growth (The Hunger Site, 2000). These dilemmas are all major foundations of hunger, however, the most common is poverty. People who live with poverty do not have enough assets to obtain the resources they need to keep from being hungry. The resources that they need exist; however, they are not effectively distributed to the appropriate regions.

The problem of hunger does not arise because of lack of resources or money. The total wealth of the world's three richest individuals is greater than the combined gross domestic product of the 48 poorest countries (Ramonet, 1998). Poor distribution is the basis for most hunger related issues. Most people have enough money to maintain a reasonable standard of living, but still many barely have the necessary means to survive. In the U.S alone, the richest 2.7 million Americans were expected to receive as much net income as the 100 million people with the lowest incomes (The Hunger Site, 2000). This statistic clearly shows that there is indeed a problem concerning the allocation of funds. Also, the U.S. Department of Agriculture has recently shown that 1/3 of all Americans are overweight while others are suffering the effects of malnutrition. Throughout the world, the top 5% of the income bracket has 95% of the total wealth. The problems of hunger and poverty can be solved by the redistribution of a small amount of this wealth (U.S. Department of Agriculture, 1999).

The crisis of world hunger is impending yet solvable. There are many ways in which to provide assistance to disadvantaged people. The donation of food, money, or resources can help. Giving money allows the person to do whatever they deem necessary to help themselves. This may not always be the best solution, because the person may not know how they can most effectively utilize the money. Another option is the donation of a food product. This will provide the person with nutritional sustenance for a short period of time. Donations of food or money are short-term solutions to the problem.

A gift of longer-lasting resources, such as livestock or farming equipment, is an innovative method of providing assistance. The donation of livestock allows people who own the animal to use it in many different ways. They can use it while it is alive to produce milk or offspring. After its death, these people can use the meat of the animal for food and the hides for clothing. These are all acceptable methods of offering relief; however, the most efficient offering is that of education.

Many believe that education is the best method by which to eradicate world hunger. To be effective, education needs to apply to everyone, not just the underprivileged. Education of the hungry can allow them to grow crops more effectively and breed livestock to obtain healthy offspring, but this only resolves half of the problem. Many people are unaware of the severity of the problem and the ease with which it can be solved. A small donation from a substantial amount of people would greatly reduce the overall food debt, and if this donation were in the areas of education or sustainable resources, it would have an even greater effect.

Some people have become aware that world hunger is a rectifiable problem, and have formed organizations to begin combating world hunger. Some of these organizations provide short-term relief while others attempt to achieve more long-term results. One of these groups is Heifer Project International. HPI donates livestock to be utilized as sustainable resources as well as educates the recipients to use the livestock more effectively. Other groups, especially scientific institutions, have also contributed to the efforts against world hunger by devising more high-tech solutions. Each approach has its different benefits and drawbacks, but they are all dedicated to the same goal: eliminating world hunger.

High-Technology Solutions to World Hunger

Scientific organizations around the world have invented methods of improving food items and production using advanced technology. This technology can be applied to both plant products such as fruits and vegetables as well as animal-derived products such as beef and pork to create more desirable appearances, nutritional value, size, and taste. They may also be used to inhibit disease, promote healthy growth, or to mass-produce food in limited space, such as urban areas, using integrated and efficient biomass support systems.

Genetic Engineering

Favorable traits in food products can be selected using genetic engineering. Genetic engineering is the scientific alteration of the structure of genetic material in a living organism. This technology can be employed in a variety of ways to create more desirable characteristics, including selective breeding, gene splicing, and cloning.

Selective breeding can take organisms that naturally have the more appealing features and emphasize them by increasing the relative numbers of the favorable genes in the gene pool. This method can also be used to virtually eliminate unfavorable characteristics by decreasing the relative number of the unwanted alleles. Selective breeding is one of the more economical methods in genetic engineering, and also the most time-honored; farmers have been using selective breeding since the days just after Mendel to produce better crops before the concept of genetic engineering existed. However, selective breeding is also very time consuming. There are other procedures that attain the same goals in a much more timely fashion (Schultes 2001).

Recombinant DNA technology, specifically gene splicing, is another genetic engineering technique through which more favorable qualities can be achieved. Gene splicing is an in vitro technique that involves joining together fragments of DNA from more than one organism. This means that many new characteristics can be given to the organism. Examples include creating a corn plant that naturally secretes a substance that acts as a pesticide, protecting it from harmful insects. The opposite can also be done, making them more appealing to insects that pollinate them. There are numerous possibilities with gene splicing (Schultes 2001).

Cloning is the use of DNA manipulation procedures to produce multiple copies of DNA. This can be used to establish and maintain pure lineages of a cell under laboratory conditions. With gene cloning, partial or complete selections of chosen genotypes can be manipulated. By altering the gametes, or reproductive cells, of an organism in a similar manner, the entire organism can also be cloned. This can be beneficial in creating a species that is specifically good for some agricultural reason, and then making many exact copies of it so that a whole crop is comprised of this species. This idea is generally rejected due to the possibility of disaster. If all the plants are exactly the same, then something that can kill one plant can kill the entire crop.

Selective breeding, gene splicing, and cloning are all examples of genetic engineering. The purpose of all these practices is to create organisms with more desirable traits. This can allow for greater biomass to create more food from one plant or animal. This can also allow for greater nutritional value, such as genetically engineered milk that contains more calcium and vitamins. Genetic engineering is a costly yet effective method for helping to end world hunger and malnutrition.

Chemical Engineering

Chemical engineering can be employed in multiple ways to inhibit disease and promote healthy growth. Chemical fertilizers supply greater quantities of the compounds essential to plant growth in order to encourage greater, more efficient development. Pesticides can inhibit disease and damage to the plants that may be propagated by insect vectors. Another more recent innovation is the use of hormone therapy. For example, in plants, phototropic hormones can be manipulated to alter growth. In animals, one gender often obtains a greater biomass in shorter time than the other. Hormone therapy can be used to cause sex reversal while the animal is very young, thus creating a crop of one gender that will be marketable in a shorter amount of time. Pigs can also be injected with an appetite hormone that causes them to eat more and obtain a greater biomass in a shorter period of time (Hardin 1999). These examples of chemical engineering also help to obtain the goal of a greater mass and value of a food source.

Large Scale Production

Large-scale food production has been around for many years. With new technology, this production can be made much more efficient. The goal of such attempts is to produce as much food as possible using the least space and materials. One example is Bioshelters, Inc. in Amherst, Massachusetts. BSI was founded in 1986 by John Reid as an integrated aquaculture and hydroponics facility. BSI produced 30,000 pounds of Tilapia and 6,080 cases of basil annually in its first facility, which was a recirculating, self-contained modular tank facility. Its new facility was started in 1996 with an initial production of 600,000 pounds of Tilapia and 45,000 cases of produce per annum. The full production capacity of the facility when it is finished will be 1.2 million pounds of tilapia. BSI accomplishes this all in only 60,000 square feet. This high density of fish is sustained using integrated technology. The filtration and aeration systems are integrated using a pure oxygen infusion. All of the electricity and heat used in the bioshelter is produced by a cogeneration system fueled by natural gas. By using radiant slab heating systems, BSI's site is fully integrated to utilize the waste heat and electricity from the cogeneration equipment. BSI also uses hormone therapy for sex reversal to produce all male Tilapia. This facility is a very efficient aquaculture and hydroponics system that produces large amounts of biomass per year using high technology (Reid, 1998).

Controversy Surrounding High Technology Solutions

High technology solutions are not always the most favorable solutions for many different reasons. One very obvious contradiction is that the more technologically advanced methods tend to be the more expensive methods. Other contradictions involve the lifestyles of many people, which cause them to reject this technology. Most religions do not permit the manipulation of genes within an organism or the cloning of that organism. This stems from the belief that one is 'playing God' when these manipulations are carried out. Some people simply prefer to live their lives more naturally and discard technologically enhanced products, including food items. These people often believe that it is healthier to eat only certified organic foods, which are grown without any additional chemicals for fertilizers or pesticides (Hallman 1995).

Other health-oriented concerns also need to be considered. The long-term effects on the consumers of these enhanced products are often still unknown. Some of the advances that have been in circulation for longer periods of time are just now showing their effects. For example, some pesticides such as dichlorodiphenyltrichloroethane (DDT) have been banned due to harmful effects on the environment and on human consumers (Microsoft® Encarta® Online Encyclopedia, 2000). Some have also been proven to promote cancerous cell growth. When using innovations such as hormone therapy, the effects of the remaining hormone in the food item also need to be considered. All these contraindications need to be taken into account when employing high technology solutions (Hallman 1995).

In trying to end world hunger, many different types of people may be involved. To obtain a more global effect, the different lifestyles, education, health concerns and beliefs of different people should be taken into account. A much more universal approach would be obtained if these differences were taken into consideration. These points lead to alternative methods of ending world hunger. Alternative methods need to employ low technology, sustainable methods of raising food rather than the use of expensive, high technology approaches such as those described above used by the agricultural industry. One organization that employs these alternative methods is the Heifer Project International.

Heifer Project International: An Alternative Solution to World Hunger

Heifer Project International is a non-profit organization that offers hungry families around the world a way to become self-reliant. HPI was started in the 1930's when a rural Midwestern farmer known as Dan West realized that short-term relief was only a temporary solution to hunger. West was working in Spain during the Spanish Civil War and spent his days ladling cups of milk to hungry children on both sides of the conflict. He realized that these children and their families did not need a cup of milk to survive; they needed something sustainable. West asked his friends to donate heifers to these families as a form of sustenance. In this way, the families could use the cows as a renewable resource, and when the cow became too old to produce, they could use the meat for food as well. These families would also give the offspring of the cow to another family, thereby continuing the chain of self-reliance (Heifer Project International, 2000). Since then, West's idea has helped families across the globe gain independence.

The first shipment of cows was sent from the U.S. to Spain in 1944 and since then Heifer Project has been a force in the continued effort to eradicate world hunger (Heifer Project International, 2000). Now, in the year 2000, Heifer Project International has helped families in 115 countries around the world. The primary focus of Heifer Project International is to provide a way for hungry families to live healthier lives. HPI accomplishes this in many ways, ranging from donating livestock and crops to educating people to take full advantage of what is available to them.

HPI raises many species of animals including pigs, sheep, llamas, and cows to provide to hungry families. The animals are raised in a purely organic environment, free from chemicals and pesticides to ensure that the most natural of conditions exist (Heifer Project International, 2000). After these animals are large enough to be moved, HPI sends them all over the world for people to utilize. HPI not only sees their gifts as one-time contributions, they also ensure that their donations will be put to good use. The Heifer Project also educates people about how to use the donation to its full potential. This system has been a great success throughout the world, in such places as Peru, Uganda, China, and even in the U.S.

Once a community or family receives livestock, HPI educates these people about how to care for them and their environment correctly. They are taught that everything is interconnected, and to ignore the land on which the animal lives is just as bad as neglecting the animal directly. HPI also teaches about the importance of the environment by showing farmers the most natural way for them to grow and harvest crops. They demonstrate that a balance between man and earth must exist, and if one acquires something from the earth, they should replace it (Heifer Project International, 2000).

The people who have received an animal from HPI also have another responsibility. They are asked to donate some of their animal's female offspring to others. In this way, the donation is not a one-time gift, but a continuation of life. The recipients help improve the lives of other people in the same way that they were helped. Also by doing this, the trend continues and soon, many people have livestock. The line of poverty is broken and the line of prosperity is started. The combination of donation, education and continuation allow HPI to help many more people in a much more efficient manner than simply giving food or supplies alone. A good example of these three virtues at work is a case of farmers in Bolivia.

The people of Bolivia have depended on the wool, meat, and work done by the llama for thousands of years, and recently have had difficulty with inbred llamas. The llama population was thinning due to the amount of inbreeding and the rocky, grassy terrain was crumbling due to overfeeding. The people of Bolivia asked HPI for help and received the best that they could have wanted. HPI not only sent them 35 quality llamas, they also demonstrated how to plant more of the grass the llamas graze on. The people of HPI also taught the Bolivians better bookkeeping skills to keep the llama population under control, so that the same problem doesn't reoccur. This follow-through is what allows Heifer Project International to gain the success that they've had with their donations.

Throughout the world, HPI has had a major effect on the people it has reached out to. HPI has set up three learning centers located in California, Arkansas, and Massachusetts since its induction in 1944. The goal of these learning centers has been to help the public understand the philosophy and practices of HPI throughout the world (Heifer Project International, 2000). Through education that emphasizes experience, the centers' outdoor "living classrooms" acquaint visitors with HPI's mission and the needs of those whom the organization serves. Guests learn about the root causes of hunger and poverty and the way animals and people can make a difference. Every year, thousands of visitors including students, civic organizations, and religious groups learn about sustainable farming and development, and explore solutions to hunger through animal agriculture. HPI's learning centers demonstrate HPI's environmentally sound farming practices and use techniques and resources similar to those employed by the low-income families who receive assistance form HPI. The centers provide tours, programs, special events, recreational facilities and volunteer opportunities for people of all ages.

HPI's International Education Center in Rutland, MA has many opportunities for people to interact in a low-tech environment that demonstrates HPI project sites similar to those in other countries. The center in Rutland is a 270-acre working farm that presents a variety of sustainable agriculture techniques used throughout the world. There are more than a dozen types of animals raised on the farm along with many edible crops, which are consumed on site. They offer tours, learning programs and day camps to educate people on the mission of HPI. The Rutland farm is also in the process of creating a global village on the premises. This global village is an area designed to represent the living conditions in many different areas of the world. There are villages portraying life in Latin America, Asia and the United States. These displays allow people to experience the conditions of the other countries without actually traveling. They can see and understand what needy families around the world require and what they can do to help (Perkins, 2000). This demonstration is an innovative method of enlightening the general public to the problems of hunger and their respective solutions worldwide.

Aquaculture

Aquaculture, also known as fish farming or mariculture, is the breeding of aquatic plants and animals under controlled conditions for recreational, commercial, and scientific purposes (Encyclopedia Britannica, 2000). This includes many different commercial goals such as for food, stocking sport fisheries, producing bait animals, fee fishing, decorative purposes such as home aquaria, and for use by the pharmaceutical and chemical industries.

History of Aquaculture

Aquaculture has been in existence since at least 500 BC. However, only in recent times has it assumed commercial importance, with world production more than doubling between 1970 and 1975 (Fitzsimmons, 2000). The rapid expansion of aquaculture has been related mostly to the production of higher-priced fish consumed as food. Examples are shrimp, crayfish, prawns, trout, salmon, and oysters. However, also increasing is the production of catfish, carp, and tilapia, which are reared in extensive, low-energy systems. For example, catfish farming in the United States has more than quintupled its production since it began to grow in the 1960s (Encyclopedia Britannica 2000).

The growth of world aquaculture has been affected by numerous factors. These factors range from simple differences, including changes in what people prefer to eat; to more significant changes such as rapid population increases, pollution, and advances in culturing technology. Overfishing in oceanic areas has led to limited ocean resources, and aquaculture in barricaded coastal waters has helped to meet the market demand for many types of seafood. The advancement of science and technology in the pharmaceutical and chemical industries has driven aquaculture forward as well, through their research and innovations. The diversity of possible aquaculture environments contributes a great deal of flexibility to the industry. With today's technology, culturing can be accomplished in earth ponds, concrete pools, barricaded coastal waters, or cages suspended in open water (Encyclopedia Britannica, 2000). The choice of the environment in which to culture is dependant upon what is available to the culturist.

System Design

The design chosen by the culturist is dependant on many variables. The species to be cultured is important because different organisms have different requirements. This factor coupled with the geographic location of the system can start to define the system design. For example, if the organism to be cultured is a salt-water species and the geographic location is on a coastline, the culturist might consider barricaded coastal waters as part of the design. Another factor that needs to be considered is the economic capacity of the culturing organization. This may place certain constraints on the system design, including size and complexity. The intended use of the product is another modifying factor. If the product was going to be used for decorative purposes rather than for sport fishing, the culturist may need to modify the system design so that the organism will not harm itself and its aesthetic properties will be preserved. These factors are just some examples of the considerations that the culturist may need to take into account in designing the system.

Fish Enclosure

Seafood can be cultured within open systems such as barricaded coastal waters or closed systems such as tanks or pools. Open systems require a method for separating the cultured organism from the rest of the environment. Suspended cages are often used, especially in rice fields (Rakocy, 1989). Within a closed environment, there are two major categories of fish enclosures that are classified primarily by how they maintain water conditions. These categories are recirculating systems and flow-through systems, which will be discussed in-depth in the next sections.

Circulation System

Culture systems that discard water after use are known as flow-through systems, while those that filter and recycle water are referred to as recirculating systems (Rakocy, 1989). The flow-through systems need a stream or pond to discharge their runoff water and to provide a reliable source of fresh water. The recirculating systems only need to discharge relatively tiny volumes of water, usually in the area of 5 to 10%, in order to remove concentrated animal wastes. However, this design requires more intensive control of water quality. The use of a particulate filter, biofilter, settling tank, or combination thereof is required.

Filtration System

With a recirculating system there must be a means of removing both solid waste and dissolved toxins from the water. Dissolved toxins such as ammonia (NH_3) can be removed using a biofilter, which uses bacteria to change the ammonia to less harmful compounds. There are many effective biofilter designs, but they all operate on the same principle of providing a large surface area for the attachment of the vitrifying bacteria. If the medium is chosen wisely it can assist in maintaining other system parameters; for example, crushed coral or oyster shell will maintain a slightly basic pH. Others can absorb various chemicals, assist mechanical filtration and help maintain dissolved gas levels. There are two types of bacteria involved; they transform the ammonia, excreted from the gills of fish, into nitrite (NO_2), which in turn is then converted to nitrate (NO_3) (Rakocy, 1989). Nitrate is a relatively harmless compound found in all ecosystems. This can be accomplished using more advanced mechanical systems; however, a biofilter is by far the simplest way to remove the toxins from the water. The bacteria in a biofilter may be able to remove aqueous toxins, but cannot remove particulate waste. Another method must be implemented in order to extract the solid wastes.

There are two methods to eliminate solid wastes from the system. One involves the use of a separate tank as a settling tank. This method allows the more dense particles to fall to the bottom of the tank where they can then be removed by draining. The other method involves the use of a particulate filter that will catch all solid wastes larger than the filter rating. This filter will need to be cleaned periodically and replaced when necessary. Another issue to consider when implementing an aquaculture system is the introduction of oxygen into the system. A filter can also integrate aeration into its capabilities when positioned properly.

Aeration

There are many different ways that the water in an aquaculture system can be aerated. For example, Bioshelters Inc. uses a pipe that descends more than 50 feet into the ground in order to elevate the pressure of water to the saturation point of liquid oxygen. At this point, the oxygen is dissolved into the water more efficiently than if it were simply bubbled. The water is then pumped back to the surface fast enough for the dissolved oxygen to remain in solution (Bioshelters, Inc., 2000). More conventional methods would consist of an air pump and airstone, the same design used in household aquariums. This design uses an air pump to push air through some supply tubing into a porous stone, often made of pumice. The pumice forces the air to form tiny bubbles that will help to dissolve oxygen in the water. There is also another even simpler method that uses the position of the filter to the advantage of the system. If the water falls a few inches from the discharge of the filter to the water tank, it is possible to maintain sufficient dissolved oxygen levels to sustain the fish due to the churning of the water and the air at the deposition site. This method may be desirable because precludes the necessity of adding other extra components to a system, such as an air pump, thus increasing efficiency and decreasing cost.

Heating

Many commonly cultured species require temperatures in the area of 80 to 90 degrees for maximum performance. This can be a challenge for culturing areas that lie far from the equator. The use of a separate heater may be to be implemented in order to maintain higher water temperatures. Solar heat is one method that may be considered to help maintain temperature. Solar heat is inexpensive once installed, and environmentally friendly. Solar heat comes in the form of hot water, much hotter than 85 degrees. The water from the solar collector will remain at a temperature of at least 105 degrees Fahrenheit. (Independent Energy, Inc., 1981). Due to the significant temperature difference, a heat exchanger would need to be implemented and it would have to be separated from the organisms for their protection.

Integrated Hydroponics

As an additional benefit to both the fish and the culturist a hydroponic bed can be added to the system. The hydroponic bed may simply consist of a tray on which will plants can grow. The tray only needs to allow water to flow by the plants to provide hydration and nutrition. This will assist the fish by removing fish waste and by providing a food source for the fish. The combination of aquaculture and hydroponics is often referred to as aquaponics. "Fish wastes can be treated with a biofilter and allowed to pass through hydroponic troughs, where the roots of cultivated plants can remove the wastes as fertilizer" (Woods, 2000). Plants grown in attached hydroponic beds can be used as food for people or recycled as food for fish by chopping it up and putting it back in the tank. Several common plant species can thrive in an aquaponic environment, so this integration can become an even more useful part of the food supply for a family in need (see Appendix E).

Tilapia

History

Tilapia is a genus of large white fish native to Africa, specifically to the Nile River. Tilapia has been introduced in many countries around the world. They are disease-resistant, reproduce easily, eat a wide variety of foods and tolerate poor water quality (Bocek, 1994). Worldwide harvest in 1998 surpassed 800,000 metric tons; second only to carp as most widely farmed freshwater fish in the world (Popma *et al*, 1999). These characteristics make tilapia suitable for culture in most developing countries.

Tilapia have been farm raised for decades and is cultivated in warm waters all over the world. Illustrations from Egyptian tombs suggest that Nile tilapia (*T. nilotica*) were cultured more than 3000 years ago (Popma *et al*, 1989). This discovery has led anthropologists to believe that Nile tilapia was first fish species ever cultured. Legend has it that tilapia was the fish Jesus of Nazareth multiplied a thousand fold to feed the masses. This legend gives Tilapia its commonly used name of "St. Peter's fish," a name the FDA does not allow to be marketed (Gofish.com, 1999).

Tilapia was first imported to United States in the 1950's and was used for multiple purposes, none of which were aquaculture. Tilapia was imported for show in aquaria and zoos, used as weed control, and for baitfish. Oriental stores and restaurants displayed the live fish in tanks. The first aquaculture of Tilapia wasn't done in the United States until the late 60's and early 70's. Early farms were found in geothermal areas and warmer regions such as Florida and Alabama. Early markets for the fish included stocking golf course ponds and irrigation ditches. (Fitzsimmons, 2000)

In the United States, tilapia is cultured in the southern and western regions. Three of the most common species cultivated in the U.S. are *Tilapia nilotica*, an emerald-green tilapia known for its high yield and rapid growth; *T. aureus*, a cold-resistant strain; and *T. mossambica*, noted for its reddish skin color, which makes it popular for the live market and display tanks. (Gofish.com, 1999)

Since the 1970's, Tilapia has become a significant segment of many economies and is one of most important domesticated fish today. It is used in hundreds of cuisines and recipes and is known for its mild flavor that many enjoy. Tilapia is accepted in many national dishes and consumption is not restricted by religious observances in most cultures. There are several varieties available, and tilapia can be successfully polycultured with shrimp, catfish, carp and other seafood and will eat a wide range of food. It is estimated that Tilapia will be the single most economically important aquaculture product in the 21st century (Fitszimmons, 1995).

An example of the worldwide importance of tilapia is a case in Honduras. Hurricane Mitch destroyed much of the countries natural resources in October of 1998. Pennyfish, a tilapia hybrid, were brought into the country to help with food and income for the recovering villages. The breeder females of the species produce up to 125,000 offspring per year that can be marketed at one pound in a few short months. A single penny's worth of breeder fish turned into a dollar's worth of fish (Sipe, 1999).

Biological Specifications of Tilapia

Physical characteristics

Tilapia look much like sunfish or crappie, but are identified by an interrupted lateral line that is characteristic of cichlids. They are laterally compressed and have deep bodies with a long dorsal fin. These dorsal fins have very sharp spines that are also found in the pelvic and anal fins. The actual color of the fish depends on the species. *T. niloticus* is known for being emerald green in color, while *T. aureus* is often very light colored or white, and there are also bright red varieties and brown varieties. The males are generally larger than the females, and the average size of adult Tilapia ranges from 1.5 to 2.5 pounds.

Food requirements

The types of food that Tilapia feed on vary greatly. All Tilapia species are herbivorous, although some species will also feed on animal sources. Plant-derived food sources range from microscopic phytoplankton to higher plants such as Chinese water hyacinth. Animal-derived food sources include zooplankton and larval fish. If given the opportunity, some species will eat just about anything from plankton and larval fish to compost such as coffee grinds. In the aquaculture environment commercial feed is most often used rather than live food sources to ensure food quality. The omnivorous species will benefit from a mixture of feed derived from plant and animal sources. Many will eat commercial pet food such as small particle dog or cat food if no other is available (Bardach, 1972). Heavily supplementing the food given to growing fish will account for 30 to 50% of their growth; therefore, it is important to ensure that the fish receive the protein, fatty acids, vitamins and minerals that they require in order to produce a sufficient amount of healthy biomass (Popma *et al*, 1999).

Most species of Tilapia have similar nutritional requirements as other warm-water farmed fish. Most of these types of fish all need the same 10 amino acids to be present in their feed (see Appendix C, table 1). Protein requirements for growing fish can be up to as much as 50% of their nutritional needs, but this amount varies due to the protein quality and fish size. Most commercial food is 26 to 30% crude protein with 0.10 being of animal origin. Digestible energy requirements for tilapia have been noted to resemble that of catfish at about 8.2 to 9.4 kilocalories of digestible energy per gram dietary protein. The fatty acid requirement for tilapia is in the linoleic (n-6) family of fatty acids. The vitamin and mineral needs of tilapia are again closely related to that of most warm-water fish (see Appendix C, table 2). A vitamin and mineral mix similar to that of catfish is added to most commercial tilapia feed (see Appendix C, Figure 5) (Popma *et al*, 1999).

Tilapia do not truly have a feeding pattern, they will feed at any time of the day. A good rule of thumb in the feeding of Tilapia is to give enough food that the larger and more aggressive fish are able to eat and still allow for the smaller fish to get the leftovers. It is very important not to feed too much, as the water quality will decrease drastically within a few days (Robinson *et al*). To avoid over and underfeeding, one must watch the behavior of the fish during this process of feeding. The feed amounts will change as the fish become larger; they will eat dramatically more feed. As when they are young, follow the recommendations above to keep healthy tilapia.

Environmental Requirements

Salinity

All tilapia species are able to survive in brackish water. Nile tilapia (*T. niloticus*) is the least tolerant to salty water. They can withstand a salinity of only 15 parts per thousand (ppt). The blue species of tilapia grow well at a salinity of 20 ppt and the Mozambique Tilapia tolerates full-strength seawater, which is 35 ppt (Swenson). Salinity changes in some species could go from zero ppt to 50 ppt without killing the tilapia. This means you could grow those tilapia in fresh water ponds or in the open sea without killing the fish as long as you moved them gradually from one level to the target level, or about 30 hours per 10 ppt (Sipe, September 21, 2000). Although these species can survive at such high levels of salinity, most reproduction occurs at lower salinity levels. All of these species will be inhibited from spawning if the salinity rises above 10 ppt.

Temperature

Tilapia is native to the warm waters of the Nile River and grows best at higher temperatures. Tilapia species are able to survive in temperatures that range from 52 degrees to 95 degrees Fahrenheit; however, the optimum temperature for the aquaculture of this type of fish is 85 degrees. A close range about this temperature must be maintained in order to have suitable biomass production levels. Growth of tilapia is about three times greater at 84 degrees than at 72 degrees. Tilapia also has a much higher spawning capacity at higher temperatures. After a 16 to

20 day spawning cycle in differing temperatures, half-pound Nile tilapia spawned 600 fry per female in 82 degree water. Conversely, fry recovered from water of 75 degrees averaged at about 250 fry per female.

Low temperature is a serious constraint for commercial producers living too far from the equator. At the temperature of 52 degrees the fish will not eat. 63 degrees is the lowest temperature at which the fish will feed on normal levels. Most diseases caused by stress and handling occur at 65 degrees or lower. Reproduction occurs at a range of 80 to 90 degrees Fahrenheit and will not occur at temperatures less than 68 degrees (Popma *et al*, 1999).

Dissolved Oxygen

Dissolved oxygen concentrations in water also are very important to the sustainability of Tilapia, however, this fish is much more tolerant to low dissolved oxygen levels than other cultured fish. At times of low activity such as during the night, dissolved oxygen levels can drop to 0.3 milligrams per liter. This number is considerably lower than the tolerance levels of other farmed fish, which is 4 to 5 mg/L (Somerset). Tilapia survives best at a nighttime dissolved oxygen level of about 0.7 to 0.8 milligrams per liter. Most tilapia will survive for a few hours with little very little dissolved oxygen in the water, but the general rule for lowest dissolved oxygen levels is no lower than 1 milligram per liter. This staves off disease and aids in growth, metabolism and spawning (Popma *et al*, 1999).

pH Levels

Tilapia can survive in water with pH ranging from 5 to 10 but seem to prefer pH ranging from 6 to 9 (Popma *et al*, 1999). Tilapia species are very hardy and can withstand wide ranges of water quality and temperature as long as there is some time to adjust to changing conditions. They have shown the ability to adjust to pH changes from 4 to 10 and even further with more adjustment time (Sipe, September 21, 2000).

Ammonia

All fish excrete their liquid waste through their gills in the form of ammonia. Tilapia is much less sensitive to high ammonia conditions than other cultured fish. Ammonia found in commercial fishponds is found in two forms: ionized ammonium (NH_4^+) and unionized ammonia (NH_3). The unionized form, NH_3, is highly toxic in small concentrations and should be kept at levels below 0.05 mg/l. "The total amount of NH_3 and NH_4 remain in proportion to one another for a given temperature and pH, and a decrease in one form will be compensated by conversion of the other. The amount of unionized ammonia in the water is directly proportional to the temperature and pH. As the temperature of pH increases, the amount of NH_3 relative to NH_4 also increases" (Helfrich *et al*,). Long-term unionized ammonia in the water can cause large losses in crops, but with increased dissolved oxygen levels, the fish survival rate is greater (Popma *et al*, 1999).

Nitrite

As ammonia, tilapia are much more tolerant to high nitrite levels that would kill many types of farmed fish. Nitrite, to many fish, causes hemoglobin to reduce its oxygen carrying capacity. When the DO high and the chloride levels low in water, tilapias have been shown to survive in nitrite levels of 89 mg/L. However, the recommended nitrite level is approximately 27 mg/L (Popma *et al*, 1999). To solve the deadly effects of nitrite in the tank, add salt at a rate of 1 pound per 120 gallons of water (a chloride to nitrite ratio of 16:1) (Popma *et al*, 1999).

Behavioral Characteristics

Temperament

Tilapia are less aggressive than most carnivorous cichlids but do have the habit of nipping and biting other species or even their own. Many factors affect the temperament of tilapia including gender, temperature, and population density (Popma *et al*, 1999).

Breeding and the Young

In many cases of fish culture, it is very difficult to spawn the fish, whereas with tilapia it is difficult to keep them from breeding. This is one of the reasons that these fish have become such a widely used species for culture. Most Tilapia species are mouth-brooders, which means that they hold the eggs and young in their mouth to protect them from predators.

To spawn tilapia, all that is needed is a pond or tank with a sandy bottom and breeding stock. Stock for the pond should be 25-30 females per 1000 m^2 and about 12-15 males per 1000 m^2. The male of the species will begin digging fairly large holes, about 35 cm in diameter and about 6 cm deep. In these holes a female will deposit 75-250 eggs and then picks them up in her mouth. The male then discharges sperm into the hole, which is again picked up by the female. Fertilization takes place in the female's mouth and hatching occurs in 3 to 5 days. The small fry are kept in the female's mouth until the yolk sac is absorbed. After that period, the fry leave the females mouth to venture for food but will return to the female's mouth for 10 to 15 days if threatened. In this time the female will not eat very much if at all. The young fry will reach breeding maturity after about 2 to 3 months (6 to 10 cm long) and will breed thereafter every 3 to 6 weeks (Popma *et al*, 1999).

Overpopulation and Methods of Control

The problem of overpopulation is one that can change a farmer's entire crop of fish. In many places, the size of the fish is very important. The larger the fish, the more money it will bring to the farmer. If overpopulation does occur, the difference in the size fish caught is staggering. There will be many more fish caught, but they will be of such a size that they will bring far less money than if fewer large fish were farmed.

The removal of fry from a pond or tank is an important way to control overpopulation. When the females are disturbed, they will spit out the fry that then can be removed by draining or by netting the adults. Keeping a mono-sex culture also helps to keep the population of the pond or tank stable; this is done by sexing individual fish (see appendix B). Another well-known way to control tilapia populations is to introduce a predator species that will eat the smaller fry. This use of population control is mostly used in Africa where catfish and largemouth bass are introduced to tilapia ponds (Bardach, 1972).

Diseases

Tilapia is far more resistant to bacterial and viral diseases as many other farmed fish especially at optimum temperature. Some diseases that tilapia fall prey to are: *Lymphocystis*, *columnaris*, whirling disease, and hemorrhagic septicemia, although these diseases do not normally show at temperatures above 68° F.

The most serious illness affecting tilapia is *Ichthyopthirius multifiliis*. "Ich", for short, is a protozoan that kills every fish that it infects. Ich is spread by direct contact with the lesions that form on the fish's body, so quick removal of sick or dead fish is very important to keep as many fish as possible.

Other protozoans such as *Trichodina* and *Epistylis* also can infect many fish in a community that is overpopulated. *Streptococcus inae* is a bacterium that accounts for a large number of losses in recirculculating and intensive flow-through systems (Popma *et al*, 1999).

Growth and Yields

In good water and temperature conditions, tilapia can grow from 1 gram to 1 to 2 ounces in about two months. In a monosex culture, males can grow up to ½ pound (200 grams) in 3 to 4 months (Popma *et al*, 1999).

Educating the Public

The purpose for creating a public exhibit is to teach the masses how and why the subject is important. There are many ways to display a piece of art, an artifact, a science experiment, etc; however there is not clear set of rules to get the message to people. In fact, studies are continually done in many science and art museums across the globe to determine traffic patterns; time spent at different types of displays, and the overall impact the display has on the public. Like many other sciences, the science of teaching the public is an ongoing process that will never be solved completely.

Although there are many ways to design a public display, there are a few simple rules that most follow to achieve the most impact. One of the best and most interesting ways to reach people is to make the display a working model. This entails letting people see the actual workings of the apparatus. The working model also combines the actual view of the apparatus with signs to describe what is happening inside. There should be a picture or description of the apparatus as a whole telling about its ultimate use. Other signs describe individual parts of the apparatus telling how it is important to the system as a whole. These two types of signs should stand out with attractive labels and answers to the most asked questions people may have (Drake *et al*, 2000).

An alternate way to display a project is to simply have a sign that shows the system as a whole and the relationship between parts. This sign and its components should be proportional to the real system, so people are not confused. Also it should be placed as close to the system as possible, allowing people to compare it to the working system to gain good understanding of the system (Drake *et al*, 2000).

Within each of these two possible display setups is a set of techniques widely used to create the wanted design. The signs need to be placed carefully as to allow people to read them easily. Lighting is important so people can easily read them without strain. Coloration of the signs is also very important; it will make people more easily read text on the signs. Light colored backgrounds with dark, preferably black; text works best for reading purposes. Sizing of the text also insures that people will easily be able to read it. If people are not able to look closely at a sign and the text is small, the sign is useless (Drake *et al*, 2000).

The signs and parts of the display that will be exposed to the environment need to be adequately protected so they will last a very long time with little or no maintenance. A photograph of each component within the system also allows people to piece together the system as a whole. Placing these pictures directly on or near their respective parts is the most beneficial, keeping confusion to a minimum (Drake *et al*, e2000).

Although all of these ways to design a display are very good guidelines, there is no concrete way to educate everyone with one display. People are from different backgrounds and have different education levels, so a middle ground must be settled for that will educate the majority of people who will be viewing the system.

Aside from the basic ways to set up a public display, there have been many studies to determine how people learn through displays in museums. Journals such as Science Education and other teaching sources devote time and money to find the best way to educate people. Many studies in art and science museums around the world allow curators and workers to better understand the way in which people learn and the types of displays they will learn most from. Studies range from the time spent at each display to the grasp of the concepts shown at the display. Although studies focus on different aspects of educating the public, each one is like a piece of the puzzle and looking at the big picture is the ultimate goal of everyone involved.

People learn is through a pattern of understanding. They first experience the puzzling system and formulate a question as to the nature of the system; next they examine in detail the system and look at individual parts; next the person discovers and constructs an idea of the system as a whole; and finally a complete idea with deeper understanding of the elements of the system to answer the initial question (Stevens, 1997). This learning is characteristic of both adults and children and allows a display creator to reach people at every level of understanding. It also can lead to mistakes that cause dissatisfaction in the viewers; they may be unable to answer the questions they have about the system.

Studies have determined the types of displays that keep the public's attention therefore increase learning. Displays that are more concrete (people are able to touch, hear, smell, or can feel objects) are able to hold peoples' attention far better than just looking at the display. This interaction between the display and the person viewing it creates an interest to know more.

Therefore, a person who interacts with a display is more likely to take valuable information away from the experience (Boisvert *et al*, 1995).

The most interactive type of display is to have a mediator or a member of the staff available to explain the concepts being displayed and answer any possible questions. A mediator that is present at a display has the ability to attract more people to the display and also is able to keep people at the display for a longer period of time versus all other types of displays studied. By attracting more people and keeping them for a long period of time, a mediator is able to pass along a great deal of information to viewers (Boisvert *et al*, 1995).

Other productive display types found by many studies are large, inviting simple interaction, and are easy to understand. These types of displays have very good attraction power but do not have high holding value; they are not able to keep visitors interested for a long time. The reason for this lack of holding power is thought to be the simplistic nature of the display. This type of display appears to be readily seen and understood by the people viewing it, causing the movement away from the display after a short amount of time. This type of display is not ineffective, just the second best compared to the first type described (Boisvert *et al*, 1995).

Simple displays that invite more interaction and smaller hands-on activities seem to have opposite effects on people viewing the display than the above display type. These types of displays have a very long holding time second only to a mediator. The difficulty in these types of displays is its attractiveness to passers by. These types of displays are usually small boxes or set ups that allow a person high interaction with the theory presented. People are not always interested in smaller types of displays; they are more quickly drawn to the large "budget busters" that usually become a central point. Once a person is attracted to this smaller display, they spend a large amount of time at the display and the possible leaning greatly increases (Boisvert *et al*, 1995).

Small, abstract displays seem to be the least provocative type of display used. These displays usually include a great deal of reading material and attempt to communicate concepts in this way. Unless interesting to the person, the display is often passed by without a second glance. If interested in the subject, the person usually spends a good amount of time at the display and understands its concepts well (Boisvert *et al*, 1995).

The creation of educational displays for the public is indeed not a perfect science. There are various studies and surveys on how people view and understand displays. Although there seem to be general ways to display theories or pictures or principles to get the most learning from them, scientists are far from establishing a set of guidelines or rules to get the most from a display. The public is also very aware of what is new and innovative, so if a guideline were ever created it would soon be obsolete. The best that a display creator can do is creating from the mind, not from a set of rules to create a good display.

METHODOLOGY

Introduction

The objective of this Interactive Qualifying Project is to provide our sponsor, Heifer Project International (HPI), with an exhibit that will increase the overall awareness and knowledge of the general public regarding the use of aquaculture as an alternative and economical food source. Through interaction with HPI and creation of a working demonstration, the group will provide a means to teach people how they can reduce their food deficit using aquaponics.

The deliverables to HPI are a working prototype for an aquaponic system appropriate to the needs of HPI, a manual for running their system and others like it, and various educational displays that will enhance the visitor's understanding of the system. In order to provide these items, aquaculture in general was researched extensively in order to design and build a system that is both efficient and economical. The following is a detailed description of the steps we took to reach the goals above.

Timeline

Here is a chronology of events in the research, design and testing of the system from it inception to its end.

10/2000	Initial meeting with Dale Perkins
10/2000-12/2000	Primary research
12/2000	Initial presentation and recommendations
12/2000-4/2001	Secondary research
1/2001-2/2001	System components construction
2/2001-3/2001	Greenhouse construction
3/2001	System installation
3/2001	Initial testing
4/2001	INTRODUCTION OF FISH
4/2001-11/2001	Observation of system
6/2001	*International Fair, first observations of public reaction
9/2001	*Barn-Raising, use of focus groups for more public reaction
11/2001	HARVESTING OF FISH
11/2001-2/2002	Completion of written project/Manual
2/21/2002	Final presentation, conclusions and recommendations

Initial Meeting with HPI

In order to determine exactly what HPI desired from the team, we first set up a meeting with Dale Perkins, the Farm Steward of Overlook Farm (HPI's farm in Rutland, MA). Mr. Perkins provided us with an excellent starting point. He had a small amount of preliminary research, some of the construction materials on hand, and information about the species of fish that we would be culturing, the fish tanks, and the greenhouse. This information greatly clarified the purpose and direction of the project, and allowed us to commence further research.

Contacts

Proceeding from where Mr. Perkins' research left off, we contacted companies that we found either on the Internet or in Mr. Perkins' documents. Unfortunately, few of the calls that we made to these companies provided useful information. For example, Mr. Perkins had clipped an article about a commercial fish farm in North Grosvenordale, Connecticut, aptly named Connecticut Aquaculture. After many unsuccessful attempts to find a phone number or location of this company, the search was abandoned. We also contacted a Tilapia researcher and enthusiast by the name of Mike Sipe, who is the president and research director of Tilapia Aquaculture International. Mr. Sipe was interested in our project as a marketable idea to make a profit for himself, so we did not pursue this contact. Our most useful contact was one of companies we discovered on the Internet knows as Bioshelters Inc., and they seemed to have an operation much like what we were trying to accomplish. We were able to tour their facility and they actually became the provider of the fingerlings for the project.

Literary Research

We began by searching libraries for books on the topic, and while searching we discovered that there is no great surplus of current material on this subject. There were a few books that were useful, but they dated in the 1970's and the information gained from these sources did not reflect current theories. The majority of the detailed information that was obtained came from the Internet or from contacting people with a certain expertise in one of the aspect areas that this project covers.

Choosing a Specific System Design

Once we completed the initial research, we were able to supply HPI with three basic designs for the system. We traveled there to have a second meeting and present the three designs (see presentation located on included cd). HPI chose one design and then we were able to have a short brainstorming session with the staff of HPI to come up with more ideas for the finalization of the system.

Data Collection

In order to finalize the design of the system, data was collected on the various parameters impacting it. Physical measurements, such as the size of the system, water quality measurements and qualitative measurements on how to best relate the benefits of the system to the public. We then ran the system in its entirety to try to pinpoint areas of concern and correct them.

Physical Measurements

Exact measurements of the greenhouse were necessary to ensure what we designed would fit properly into the building and to determine if there is anything that must be inside before the roof is installed. Temperatures were monitored inside and outside the greenhouse to determine heating and cooling needs of the system. The volume of the tanks was determined in order to ascertain how many fish could be supported. With the number of fish the waste production was estimated and the volume of the biofilter was calculated using ratios found in the literature. Finally, with all of the above data, a three-dimensional model of the greenhouse with all of the components installed was created for both demonstration to HPI and to ensure that we had achieved the desired results with respect to aesthetics and presentability for education.

Water Quality and Temperature

Once the system was constructed there was an additional series of tests that were run to fine tune the system. The water chemistry was monitored to ensure that it could sustain the fish without harming them. We analyzed pH, oxygen, ammonia, chlorine and carbon dioxide levels. Temperature was also closely monitored due to the tropical nature of the fish.

Focus Groups

Interviewing focus groups, a method of collecting qualitative data, can be used to generate a variety of information from a group of people in a research environment including: detecting the potential for problems with a new program, service or product; stimulating new ideas and creative concepts; generating impressions of programs, services or products; and or learning how participants talk about the subject at hand in order to facilitate the researchers to better convey the information at hand to other people (Lewis 1995).

The focus groups were held in the greenhouse during a fair on the farm to determine what people wanted to know about this system, what they didn't understand from what as presented, what they found most interesting and how this information could be best presented to them. This provided us with data on what the general public would benefit from in regards to the information found on and placement of the educational posters that comprised our display. We used this information to design informational signs, one large general diagram of how the system works and decide where in the greenhouse these placards should be placed.

Test Run

Throughout the summer while the system was running, we watched it closely and instructed the volunteers at HPI who were involved with the care and maintenance of the system to contact us if anything should go wrong. A number of things did go wrong and we were able to fix them and keep the system running. We were able to see what was going wrong and learn how to fix it, and we could include this information in the manual that would go along with the system.

Conclusion

The above steps were taken in order to provide our sponsor, Heifer Project International, with a working exhibit of an integrated aquaponics system and a manual to go along with it. We were also able to provide an interesting and informative educational display to be able to inform the general public about more cost-effective methods of producing their own food.

DESIGN AND DEVELOPMENT OF THE SYSTEM

Sources of Primary Information

Initial Meeting with Heifer Project International

In order to determine the exact requirements of HPI, we first met with Dale Perkins, the farm steward at Overlook Farm in Rutland, Massachusetts. Mr. Perkins has worked with project teams from Worcester Polytechnic Institute in the past, and he is grateful to be able to use our knowledge and research to enhance the farm's capabilities. When we arrived, we found Mr. Perkins busy grooming the farm animals. We were pleased to see that our contact with the sponsoring organization was involved at such a level. Mr. Perkins gave us a tour of the farm, which included the Global Village, a demonstration area designed to educate the public about the life and culture of other countries that have benefited from the work of HPI. Our aquaculture presentation is to serve a similar educational purpose and possibly become integrated into the Global Village in the future.

During the tour, Mr. Perkins showed us the area where he would like the display to be located. He informed us that HPI has been in the process of building a greenhouse next to the Global Village, where he was hoping the aquaculture system would be placed. The foundation for the greenhouse was already built and from it we could get the dimensions of the length and width of the greenhouse. These dimensions will effect the overall size constraints of the system.

Mr. Perkins also explained that he had been preparing for this project for some time and had gathered information on the topic. He had already decided that he would like to culture Tilapia and passed that information on to us so that we could focus our research. He also gave use a folder filled with newspaper clippings and other articles pertaining to Tilapia and aquaculture. We were grateful for the head start on our research. Along with this material, Mr. Perkins informed us of a project completed by an HPI site located in Chicago, Illinois that involved designing an aquaculture system for use in urban areas. The developers also wrote a manual entitled "The Urban Aquaculture Manual" which Mr. Perkins obtained and mailed to us. All of the information that we gained from this meeting was extremely helpful, and served to direct the large amount of research ahead of us by revealing the goals of HPI in relation to out project.

The folder given to us by Mr. Perkins held some very useful information. "The Urban Aquaculture Manual" by Jonathan Woods was one of the most important and helpful pieces of information as explained above. This piece of work gave an overview of aquaculture and the benefit/cost ratio. The manual then described three different systems that could be placed into any home. A list of materials along with assembly and maintenance instructions were all included. Types of fish and plants that can be used in these systems were also included. Furthermore, it incorporated a troubleshooting guide if something should happen to the fish or the apparatus being used. This manual was a turning point of the project and gave us a general basis on which to work.

A manual entitled "Water Quality Management in Pond Fish Culture" by R. Dennis Rouse was also helpful to us in providing solutions to problems often found in farmed fish tanks. Although the manual gives a great deal of information on pond problems, many of the solutions could be downscaled to work with a smaller, indoors system. The book even provides equations for solving a problem based on gallons, so that the solutions could be used with great accuracy.

In the packet from Mr. Perkins was an article about Tilapia written by a Tilapia researcher and enthusiast named Mike Sipe. There were also several articles on tilapia written by him on various colleges' web sites. Mr. Sipe claimed to have developed some of the different species of tilapia using careful selective breeding. He is the president and research director of

Tilapia Aquaculture International, located in Florida. We contacted him through email and told him about our goals, that we were doing this as part of a college project, and that it was being sponsored by a nonprofit organization and asked if he had any suggestions or ideas. He replied to our email by suggesting that he could design a system for us as long as we gave him the appropriate citations in the paper and allowed him to have all the rights to the design and marketability of the system and the project. With group consensus on the matter we met with Professor Elmes, the four of us agreed that it this was not the type of help we were looking for and that it would not be beneficial to continue communications with him, so we thanked him for the offer and discontinued our contact with him. A more helpful contact was one of companies we discovered on the Internet knows as Bioshelters Inc., and they seemed to have an operation much like what we were trying to accomplish.

The Internet

The Internet was very useful to us in learning the life history of tilapia and what the cost of certain systems would be. There were many sources of information and pictures of tilapia and their life history. One source in particular named "Tilapia-Life History and Biology" gave us the most useful and accurate information. It gave us all of the biology, history, and quality requirements for these fish. Another article entitled "General Principles of Fish Health Management" was a great source of information on the treatment of ill fish.

Bioshelters, Inc.

While searching on the Internet, we found a company located in Amherst, MA that is a commercial tilapia fish farm named Bioshelters Inc. When we contacted them we learned that they gave monthly educational tours, and we signed up for the next available tour. Upon arrival at Bioshelters, we met with the Vice President, Tracy Highteller. On our tour of the location, she told us the many things that one needs to consider in running a fish farm. Tracy explained to us that the system at Bioshelters Inc. is a recirculating system. The water used was filtered for solid waste, harmful wastes, injected with liquid oxygen, and pumped through hydroponic basil that was being grown on the level above the fish tanks. The water was then returned to the fish tanks very clean and oxidized. The system that was in effect at Bioshelters filtered millions of gallons of water a day and over 99% of it stayed in the system.

The solid waste was removed from the system by a huge rotating drum filter and placed out behind the facilities and to decompose. Once the waste had decomposed to a desired level, the manure was used to fertilize the basil. The liquid waste was filtered using beneficial bacteria in a sand based biofilter that absorbed harmful ammonia and nitrates in the system.

Tracy showed us the many tanks they use in farming, each with different size fish. We were showed the area in which the fish were born as the company breeds their own tilapia. Then we went upstairs to the area that housed the hydroponic and organic basil. The basil was set into soil and placed in pots that allowed their roots to dip into a trough that the water flows through. Water is sent up to the plants every 15 minutes with 5 minute duration. The basil plants were not sprayed with pesticides; beneficial insects such as ladybugs were used to keep the pests from invading the crops. The basil was harvested once it reached maturity and was sold to local markets; Tracy informed us that they could not grow enough of the basil to keep up with the demand for it. We left Bioshelters with three basil plants and two tilapia fingerlings to raise. This tour showed us that this type of aquaponics system was not only feasible but also profitable.

Libraries

Searching the library was a futile and time-consuming chore. Traveling to four libraries, we found only very limited sources of information that were all out of date. Many of the books were published in the late 70's and did not have the proper guidelines set up for us. Although all of these books were outdated, two books helped in the general knowledge of farmed fish and the system they are placed in. "Aquaculture Engineering" gave many of the suitable and problematic water quality issues found in many aquaculture systems. "Fish Nutrition" told us of the many nutritional requirements of Tilapia.

Conclusions and Basic System Design Factors

All of our research thus far led us to the following conclusions and recommendations for a basic system design that will best benefit the purpose of Heifer Project International:

In order to begin designing the system, we considered the fish species to be involved. Heifer Project had already decided on Tilapia for the fish species prior to our team's involvement, so that was one variable we did not need to address.

The next step was to choose the enclosure system in which to culture the fish. HPI was interested in utilizing a small greenhouse as the location for the aquaculture project. This detail combined with the climate at HPI precluded the use of outdoor pond culture. Instead, tanks would be used. Heifer Project already had in their possession two (2) 1000 liter plastic cubes that would be utilized as the tanks.

A recirculating rather than a flow-through water system would be utilized because it requires neither large sources of water nor the processing of large amounts of wastewater. It does require slightly more maintenance due to the requirement of sustained water quality. This amount of effort however, is minimal compared to the treatment that wastewater would need to undergo in order to make it environmentally sound for a flow-through system.

Due to the fact that the fish wastes were not simply being washed through and deposited outside of the tank, there needed to be other methods to remove them. A biofilter would be necessary to process the wastes in the water. Bacteria in the biofilter would convert ammonia (poisonous) to nitrite and then to nitrate (harmless). A biofilter by itself would not be able to exonerate all of the fish waste, however. Another method would be necessary to get rid of solid fish waste in the system. A particulate filter is one option that could be used in conjunction with the biofilter to remove waste. A settling tank is another option that could be used to cause the solid wastes to settle and allow a person to drain off the wastes when necessary.

We were very interested in implementing hydroponics into the system due to the various rewards that the integrated hydroponics would provide. Plants could absorb fish waste in solution and use the nutrients as fertilizer. Integrating plants into the system would provide rewards such as vegetables and flowers, while also providing part of the waste removal for the fish. In an integrated hydroponics system, there would be a hydroponic bed where the water from the outlet of the biofilter would flow in order to provide nutrients and water to vegetables and other plants that require a more complex root structure.

With regard to the plant species to be raised, there would be negligible variance in the effects on the process between the different plants on the list of suitable hydroponic species (see Appendix E). Due to this flexibility, the species selection was left to Heifer Project so that they could maximize their gain from this system.

All systems would require a method to circulate the water and a method to introduce oxygen. Circulation and aeration are generally related to each other and the two systems often depend on each other. The two could be accomplished by simply using a water pump to circulate the water and an air pump to introduce oxygen. However, both the aeration and the circulation could be accomplished by either one of these pumps. The air pump could be used to decrease the pressure under a column of water and raise the water, thus beginning circulation and aerating the water at the same time. A water pump could pump the water to a sufficient height above the height of the tank and allow the water to fall back into the tank that will also capture a sufficient amount of oxygen. Any of these designs is acceptable.

Another important factor in aquaculture is maintaining a system temperature. HPI was interested in using a solar heating system donated to them that they wanted implemented into this project. This would provide a source of hot water in this system during the day. The collector also has an electrical backup, which would ensure that sufficient hot water is supplied during periods of low sunlight to guarantee the temperature will not drop low enough to injure the fish.

With these factors considered, we came up with three separate designs to present to Heifer Project International and obtain feedback from them regarding each.

Presentation of Possible System Designs to HPI

Upon completion of our preliminary research, we traveled to Overlook Farm in Rutland, MA to present our findings to Dale Perkins and his staff. We offered three possible systems as solutions to the situation at hand (see Appendix G or presentation on included cd). The presentation began with some background information on the project and quickly progressed into the system to be engineered. We described the single tank, triple tank, and the recirculating with hydroponic bed designs. All three were shown with benefits and weaknesses; however, we placed an emphasis on the recirculating design with the hydroponic bed because we felt that this was the best fit to Heifer Project's needs. We also put forward some information on heating the system. Heifer Project requested the incorporation of solar heat so we presented estimated costs of that versus that of implementing electric heat. Once we were through presenting our introductory research we hosted a short question and answer period that turned into a brainstorming session that served to finalize the details of what Heifer Project wanted to receive as a deliverable. This brainstorming was extremely useful because it allowed our team to understand exactly what was required of them as well as quelling any of the less than practical expectations of Heifer Project. The end result of this meeting was an agreement on the use of the recirculating design with the hydroponic bed. We also discussed the use of solar heat and how it would be implemented.

Further Research And Finalization Of The Design

With the knowledge gained at Heifer Project the team returned to the books to conduct secondary research and further refine the smaller details of the system.

Due to more research, we decided that a settling tank would benefit the system. A settling tank would force the integration of periodic draining and filling into the normal operation of the system. This continual water change would help guarantee a fresh water supply for the fish. Second, it would retard the effects of any chemical shock by increasing the total volume of liquid within the system, thereby increasing the survivability of the product. The settling tank, although not specifically designed to do so, will also provide an excellent place to grow floating type hydroponic plants.

In order to cause water flow in the system a pump would need to be placed, as described in the original design. We decided that the optimum placement in the system would be between the settling tank and the biofilter. This would allow us to pump water from a tank without worrying about harming the fish. The rest of the flow in the system was to be performed by natural circulation. The biofilter would run along the center of the hydroponic beds and it would discharge the water from the pump into them. The elevated hydroponic bed would then drop water back into the fish tank. This method of water circulation makes the use of an auxiliary aeration device unnecessary. The water dropping back into the fish tank should capture sufficient amounts of oxygen for the fish.

A heater would also need to be placed in order to keep the tilapia at their optimum temperature, 85 degrees Fahrenheit. We decided the best place for a heater is inside the settling tank, again so that the fish remain out of harm's way. The heater itself has the capability to be very hot, making it foreseeable that the fish could burn themselves on it. Removing it from the actual fish enclosure eliminates that problem. In order to regulate the temperature of the water in the system, the heater would need a thermostatic control so that the water does not become to warm or too cold for the fish.

The design was modified and finalized, water chemistry specifications were researched, and supplies were ordered for construction.

PRELIMINARY DATA COLLECTION AND ANALYSIS

Physical Measurements and Spatial Arrangement

First we measured the greenhouse and each of the fixed components of the system to determine the spatial arrangement of the system and if any part of it needed to be lowered into the greenhouse before its construction was completed.

Greenhouse:	19'2" x 8'8" – inside base
	11'5" – high wall
	5'8" – low wall
Tanks:	47" x 39" x 40" (L x W x H)
	1000 L = ~265 gal
Water heater:	69" x 28" diameter

With this data we generated a 3-D model of what the system would look like once installed using a program called Pro/Engineer, see Figure 1 below (picture can be found on included cd as well).

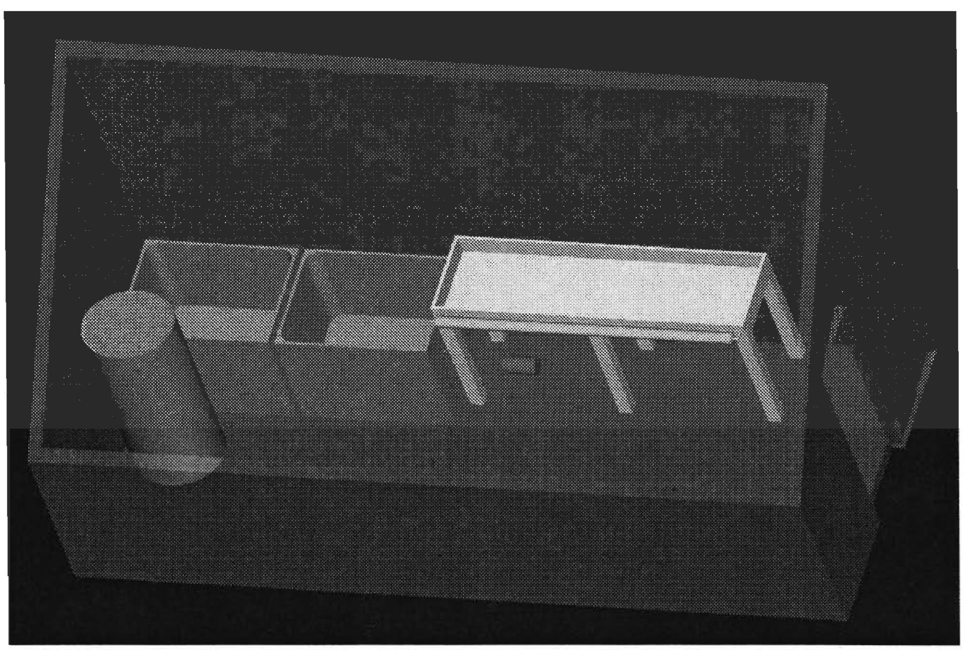


Figure 1: Pro/Engineer Model of System

We determined that the water heater and the tanks would all be more easily installed if they were lowered into the greenhouse while the roof was still open rather than try to fit them through the doorway. We then analyzed the spatial arrangement of the system using the Pro-Engineer® software and moved the tanks and the water heater to where they would be placed in the final design.

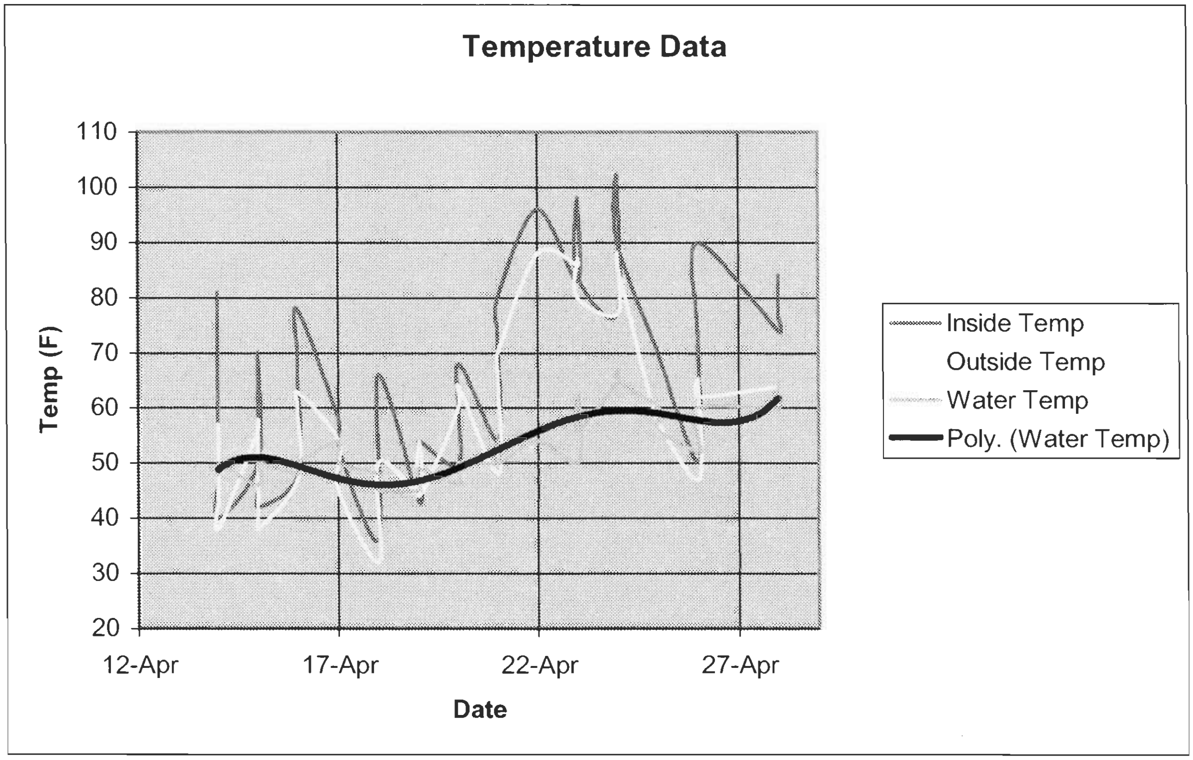
Temperature Measurements

Once the tanks were in place, the fish tank was filled with water and allowed to sit within the greenhouse after it was completed. Temperature data was recorded during two weeks in April for the outside temperature, inside temperature and the water temperature without the water heater running in order to determine the exact heating needs of the system. See data and graph below (Table 1, Figure 2).

Table 1: Initail Temperature Data

Date	Time	Inside Temp (°F)	Outside Temp (°F)	Water Temp (°F)
14-Apr	1330	81	57	50
14-Apr	1700	61	53	48
14-Apr	1830	52	48	50
14-Apr	1915	48	44	50
14-Apr	2300	40	38	50
15-Apr	900	50	56	46
15-Apr	1545	70	58	50
15-Apr	1800	58	50	50
15-Apr	2030	46	40	50
15-Apr	2200	42	38	50
16-Apr	800	48	47	48
16-Apr	1050	68	60	49
16-Apr	1200	78	63	50
17-Apr	1330	58	54	54
17-Apr	1800	53	45	50
18-Apr	830	36	32	48
18-Apr	1300	66	50	45
19-Apr	800	43	45	45
19-Apr	1200	52	54	46
19-Apr	1745	54	44	49
20-Apr	810	50	60	46
20-Apr	1615	68	64	50
21-Apr	845	54	48	50
21-Apr	1130	72	66	54
21-Apr	1600	80	70	50
22-Apr	1200	96	88	54
23-Apr	800	83	86	50
23-Apr	1330	98	87	62
23-Apr	1700	84	80	56
24-Apr	830	77	77	65
24-Apr	1300	102	88	67
24-Apr	1600	90	86	65
25-Apr	1200	70	56	60
25-Apr	1500	70	57	56
26-Apr	730	50	47	52
26-Apr	900	72	65	54
26-Apr	1340	90	62	60
28-Apr	1050	74	64	60
28-Apr	1210	77	64	62
28-Apr	1515	84	60	65

Figure 2: Graph of Initial Temperature Data



We determined that even when temperatures outside the greenhouse rose into the 80's the water temperature remained under 70 degrees, so the need for significant heating was established.

Biomass Calculations

Next we used the formulas and ratios provided in the literature to determine the amount of biomass we could support.

Biomass as related to volume of water:

If there is a suggested biomass ratio .6 lbs/1gallon of water, and we have 1000 liters of water, which equals ~264 gallons of water, then:

$.6/1 = X/264$

$=158$ lbs of biomass supportable.

If each adult fish could weigh a maximum of 1 pound apiece, then a conservative estimate of about 158 fish could be supported. Since the fish are going to be very small upon introduction and subject to a number of stresses, we will introduce more than 158 fish in order to correct for fish mortality. We decided to introduce approximately 200 fish.

Waste Production and Removal Calculations and Biofilter Design

According to our biomass calculations, we then used formulas provided in the literature to determine the amount of waste that the fish would produce, and the corresponding amount to biofilter surface area needed to compensate for this waste.

A. An average value of about 10 grams of ammonia per 100 lbs of fish per day was an estimate given in "Tank Culture" by James E. Rakocy.

Assuming we have our maximum value of 158 lbs of fish, then:

10/100 = X/158

=15 grams per day.

Unfortunately this type of data is highly variable and actual ammonia production depends on quality of feed, feeding rate, fish size and water temperature, among other factors.

B. Ammonia removal rates in a biofilter may range from 0.02 to 0.10 grams/ft^2 of biofilter surface area/day depending on type of media, biofilter design, and the factors that affect vitrification such as dissolved oxygen levels. Required biofilter surface area = total NH_3 production / NH_3 removal rate

Total NH_3 production = 15 g/day

NH_3 removal rate = .05g/ft^2/day

15g /.05g per ft^2 = 300 ft^2 of surface area required on the biofilter.

C. We decided to use crushed coral as our biofilter media, so now we needed to determine the volume of crushed coral we will need. The crushed coral is comprised of approximately 1/8" round particles. This gave us a specific surface area of:

Surface area of a sphere = $4\pi\, r^2$

$= 4\pi\, (1/16)^2$

$=0.0491\ in^2$

Volume of the sphere = $4/3\pi\, r^3$

$=4/3\pi\, (1/16)^3$

$=0.0010\ in^3$

$300\ ft^2$ of surface area needed / surface area of one particle = number of particles

$300\ ft^2 = 43{,}200\ in^2$

$43{,}200\ in^2 / 0.0491\ in^2 = 879{,}800$ particles

879,800 particles with a volume of $0.0010\ in^3$/particle give the needed volume of the biofilter.

879,800 particles * $0.0010\ in^3$

$=879.3\ in^3$ of volume needed

So if we were to use 4" diameter pipe to house the media, then we would need a pipe 70 inches long as a minimum to support our fish.

SECONDARY DATA COLLECTION AND ANALYSIS

Focus Groups

As described in the methodology, focus groups were utilized in order to generate information about how to best convey information to the general public to inform them about the benefits of the system. During a barn-raising at Heifer Project, we asked three groups of 10-12 people to step into the greenhouse to participate in a focus group.

The focus group participants were picked at random out of a group of volunteers that were in the process of raising a new barn. They reflected a wide range of ages and were mostly female. In all of the sessions there were one or two dominant persons that posed most of the questions; the rest of the people would nod in agreement or ask about closely related things to what the "group leader" was asking. The person that assumed control was one of two types: she was a mother in her late forties to early fifties or a female college student. The mothers were asking questions both of curiosity and for what they would want their children to see; the college students were trying to come up with anything that they could to help with the project out of a sense of shared academic stress.

Although these groups seemed very diverse, they were very truthfully representative of our target audience and we are confident that the results will be accurate for the setting of the display. Given that the focus groups were selected from people present on the farm and participating in an important farm event can assure us some homogeneity. These people are all concerned about the endeavors of Heifer Project International, and they all had experience as volunteers at this location.

In order to generate responses from the groups we followed the same procedure with each group. We first introduced the group to the system and gave them a brief and simple explanation of how it works. We then asked them the following questions:

- What do you find most interesting about this system?
- Is there anything that you are having trouble understanding?
- What would help you understand this better if you didn't have a tour guide?
- Where should the signs be placed to be most beneficial?

This study was run three times and all three returned similar results. What the groups found most interesting about the system was how it was integrated using both plants and fish and how the plants and fish complemented each other in the process. They also found it interesting how the waste was removed from the system once it was described to them in detail. This was one of the concepts they had some difficulty with. Without an explanation from us, they had a hard time understanding the purposes and operation of the biofilter and the settling tank. They also seemed confused at first as to what was being produced of the whole thing, whether you got plants or fish or both. They had questions about the fish and what type they were, and about the plants and how they were exactly being grown on the table. All three focus groups were in consensus that if there was no tour guide available, then large colorful signs and explanations would be useful.

Given the information that we generated with the focus groups, we devised captions to be placed on each component and one large diagram to explain the operation of the system as a whole. We attempted to emphasize the areas of the project that the participants found most interesting and to answer the questions that they had. We also tried to describe the processes of waste elimination so that they could better understand them.

We decided that the captions and the large diagram needed to stand out due to the fact that people got interested in the system itself and never really looked around the greenhouse for any descriptions. They need to be relatively large and colorful to attract attention. Since the participants tended to look at each component to figure out what it was, the captions were placed directly on each component. The captions followed a set format from component to component so that they were recognizable as descriptions, and the font was made large enough to attract attention to each of the captions. The large diagram was designed to help inform people without a tour guide of how the system works as a whole given the integration of the aquaculture and the hydroponics. This was made to be very large and colorful to attract attention, and is located on the barn wall above the tanks. This location was chosen because it is the area of most interest, given that it is where the fish are, and it was also the largest area of wall uncovered by plant matter from the hydroponic bed (see Figure 1 on page 74).

The following are the final captions that we developed and the large diagram that we designed based on the data generated from the focus groups.

Fish Tank:

A species of fish live in this tank called Tilapia. A species of cichlid, they are originally from Africa and need warm water to survive. Their water is approximately 85° F at all times. The fish arrived at HPI as babies, about the size of your finger. Once they reach maturity, 6 to 8 months in age, they will be harvested and eaten by the people that raised them.

Settling Tank:

This tank does not contain any fish. It is used to remove the solid fish waste from the fish tank. The waste falls to the bottom of the tank where is decomposes and can be drained and used as fertilizer. Also, the hot water heater heats this tank through a loop of tubing that rests in the tank to keep the water in the system at the correct temperature.

Water Heater:

This water heater was once used in a house. It is now being used to keep the fish at their optimum water temperature. It runs a closed loop through the settling tank to keep the temperature at 85° F. A closed loop means that the water from the heater does not drain directly into the tank, but it is circulated through the clear hose to the right. The heat from the water in the hose warms the water in the settling tank. Eventually, the volunteers here at HPI plan to introduce solar heating units to replace this heater so that the system will become more cost effective and environmentally friendly

Biofilter:

This long tube is filled with coral from Florida. The water flows through this coral to be cleaned. The water cannot be cleaned by chemicals because then you wouldn't be able to eat the fish. The coral holds on its surface bacteria that clean the water naturally. The bacteria break down ammonia in the water that is created by the fish. The ammonia is broken down into nitrates that the plants can use for food. Once the bacteria and the coral are in place, it never needs to be changed.

Hydroponic Bed:

This area is used to place any water-loving plants on. The water constantly runs down the table and back into the fish tank. The plants take all the carbon dioxide and nitrates they need from the water and return small amounts of oxygen back into the water. The plants that are put here should like to be watered all the time. Other plants may not do well if they don't like constant watering. That is why vegetables and annual plants do well in this type of environment. They grow really fast and need all the nutrients they can get, so the hydroponic bed is ideal for them.

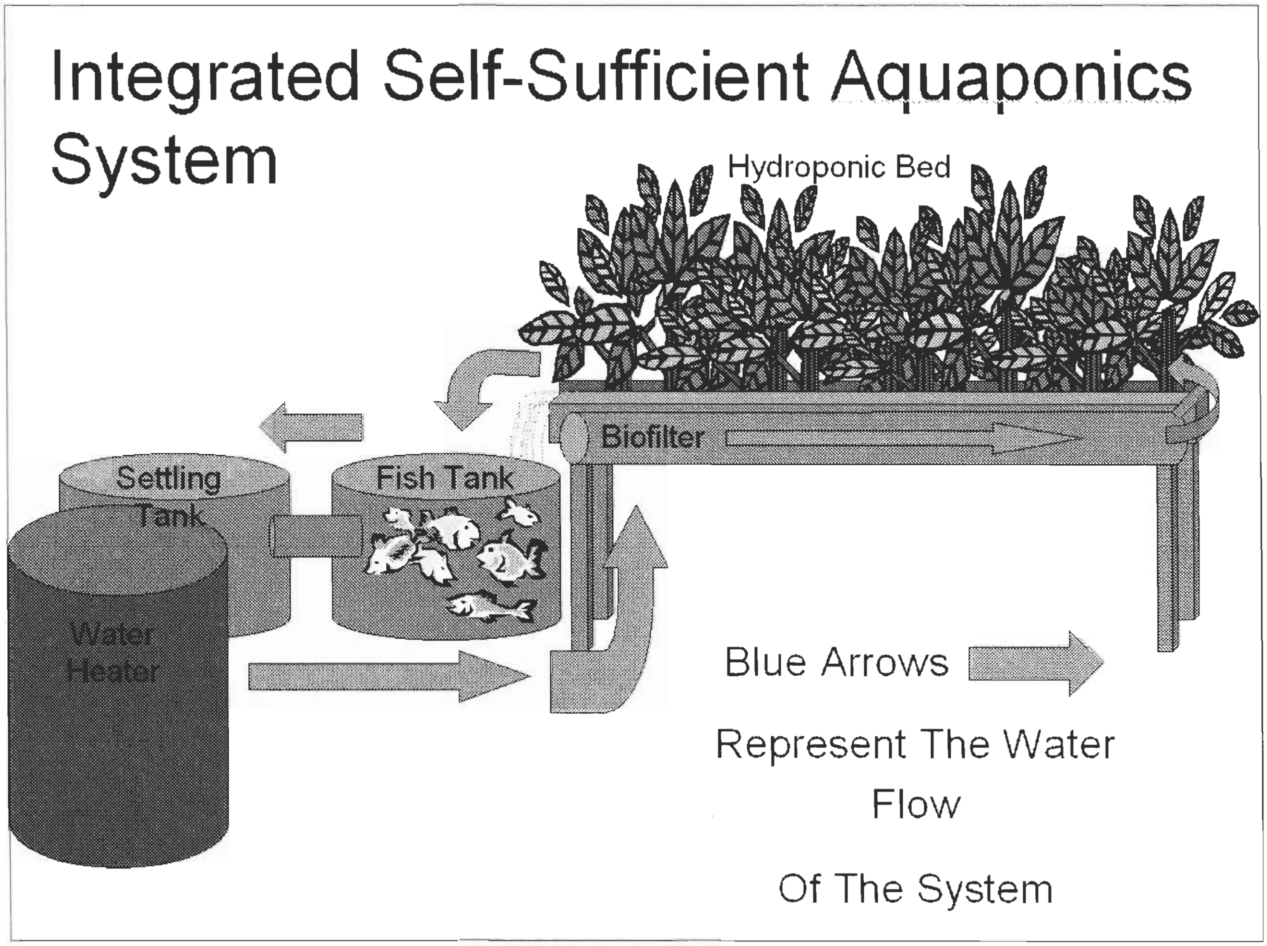


Figure 3: Large Display Located in Greenhouse

Analysis

The temperatures of the outside air, inside air and the water were recorded for a variety of reasons. First, we were interested to be sure that we could get the water warm enough to adequately sustain the fish and keep it warm enough. Next, we were interested to see how stable the water temperature would remain as compared to air temperatures inside and outside the greenhouse, so that we could see what kind of buffer be were working with. Last, we wanted to see how warm the water would get to determine if vents in the greenhouse were necessary. As is visible from the charts below (See Table 2 and Figures 4 and 5), the water rose to about 80 degrees and therefore was fit to sustain the fish. The water temperature also was much less variable than the air temperatures as we expected due to its high specific heat, and we found that even when the outside air temperature dropped or rose significantly we still had a stable water temperature. Our buffer zone was about 20 degrees in either direction, giving us a buffer of about 40 degrees altogether over a 12 hour period. The water itself did rise to over 90 degrees on some occasions; therefore we determined that it was necessary to install vents in the greenhouse.

Temperature Measurements

Table 2: Summary of temperature recordings over a period of 4 months.

The complete data set is located in Appendix H.

Date	Inside Temp	Outside Temp	Water Temp
04/14-04-20	56	50	49
04-21-04/27	79	71	57
04/28-05/04	87	78	72
05/05-05/11	84	71	71
05/12-05/18	76	65	68
05/19-05/25	72	60	78
05/26-06/01	80	67	78
06/02-06/08	82	73	81
06/09-06/15	93	80	87
06/16-06/22	81	76	85
06/23-06/29	92	85	84
06/30-07/05	86	66	84
07/06-07/12	90	77	85
07/13-07/19	86	78	84
07/20-07/27	93	88	88
07/28-08/03	94	84	87
08/04-08/10	95	87	92
08/11-08/15	87	78	85

Figure 4: Average of Temperature over a 4-month period.

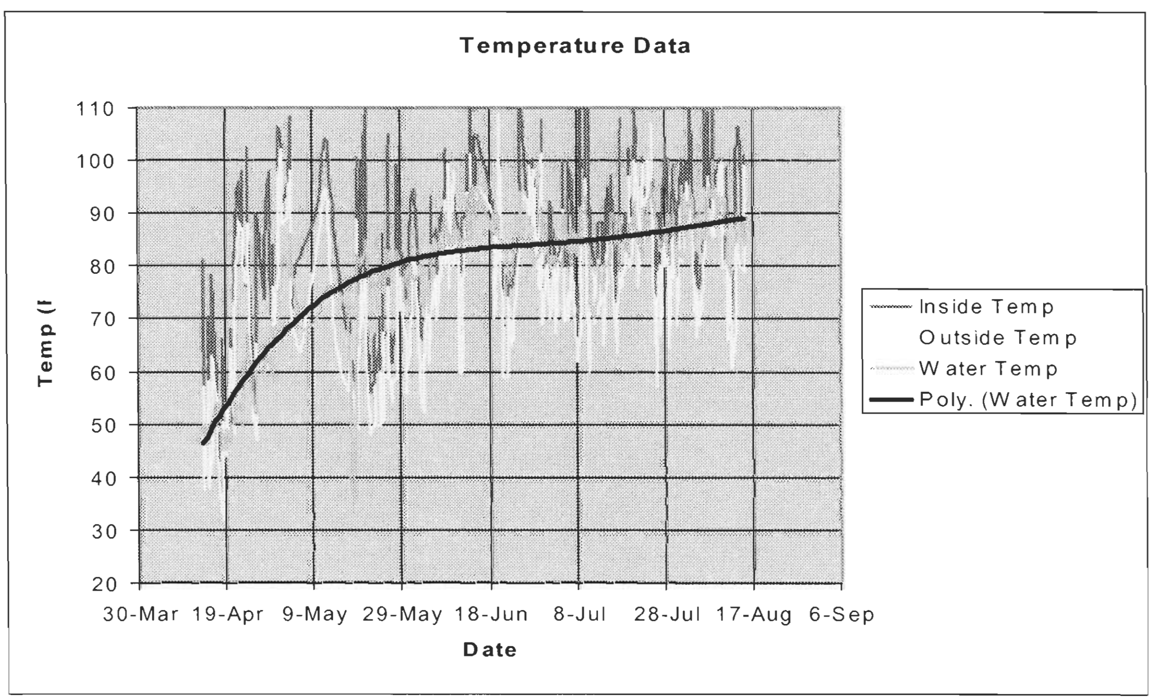
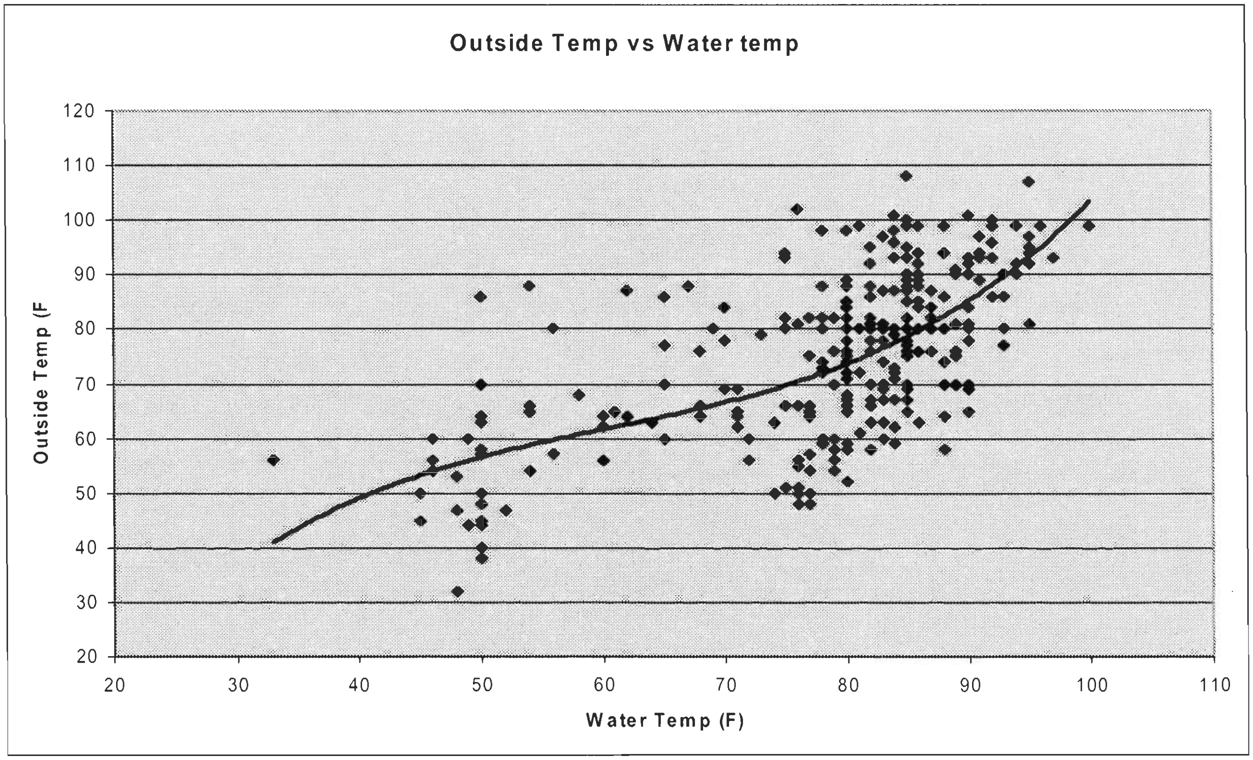


Figure 5: Outside Temperature vs Water Temperature



Water Quality Data

Dissolved Oxygen

The test for dissolved oxygen is important because the fish need enough oxygen in their water to survive and grow healthily. If they do not have enough, the fish will linger at the top of the water and gasp for air. A lack of oxygen hurts aerobic organisms in a number of ways, including decreased metabolic rates and tissue ischemia. If the dissolved oxygen remains too low, the fish will die due to brain and/or cardiac damage. We were concerned about this value given the nature of the system. Any time you have a number of organisms in a closely-packed space you need to worry about oxygen levels, especially in as closed an environment as water. We also wanted to gauge the effectiveness of the water falling into the fish tank from the hydroponic table with regards to oxygenating the water.

We determined by testing for oxygen within the first week the fish were in place that not only was the waterfall not nearly effective enough to keep the water oxygenated, but that we needed a fairly heavy duty air pump to keep the water sustainably oxygen-rich. As is visible in the chart for dissolved oxygen, the levels at first stayed relatively constant, and then dropped fairly dramatically (See Figure 7). The initial lag phase can be attributed to two things. The first recorded measurements of water quality were taken just prior to the addition of the fish, therefore there was no respiration taking place and no oxygen being used. The remainder of the lag phase can be attributed to low metabolic levels in the fish due to a lower water temperature and acclimation of the fish to their new environment. Once the water warmed up a bit and the fish were acclimated, the dissolved oxygen levels dropped and we were in the store looking for a good air pump.

Dissolved Carbon Dioxide

We tested for dissolved carbon dioxide for a number of reasons as well. Carbon dioxide is actually poisonous to aerobic organisms in mid-to-high concentrations. The carbon dioxide measurements told us if respiration was taking place as carbon dioxide is a by-product of respiration, and they also relayed to us the effectiveness of removing carbon dioxide from the water. Two processes removed carbon dioxide from the water. The plants on the hydroponic table and the surface area of the water will both assist in removing excess carbon dioxide. The plants use carbon dioxide in carrying out photosynthesis, and carbon dioxide naturally will evaporate out of water if the surface area to volume ratio is correct. We eventually determined that due to rising carbon dioxide levels it was very important to keeping the hydroponic table fully covered in plants (See Figure 6). It would also help to have a shallower, wider fish tank, but given that the fish tank was a set piece in the system, it was virtually impossible to replace and we needed to compensate for rising carbon dioxide levels in the only way we were able to, which was to keep the hydroponic table full.

Waste Secretions Panel

The waste secretions panel measures two different values, ammonia (NH_3, NH_4^+) and nitrite (NO_2). The presence or absence of these items would relate to us the effectiveness of the biofilter in removing waste from the water. The biofilter contains two types of bacteria, one that converts ammonia to nitrite, and one that converts nitrite to nitrate. We could diagnose if either of these bacteria needed to be supported or reintroduced in the biofilter if either or both of these values appeared to be rising in the presence of fish. These measurements would also confirm that the biofilter itself was the correct size to effectively do the job.

We determined that since the ammonia and nitrite levels remained constant and that they were both very low and in normal range, the biofilter was working properly (See Figure 8).

pH

PH is important to organisms because the biochemical processes that take place within the organisms need a specific ion/charge environment in order to occur. The literature stated that Tilapia prefer a slightly basic pH (just over 7) in order to function at optimum levels. The biofilter media (crushed coral) is made of calcium carbonate, which is a substance that produces a base in water. This media would act as a buffer and keep the water slightly basic in the presence of the fish and we could determine if this method was effective enough the keep the pH stable. The pH fluctuated slightly at the beginning, and then leveled out at approximately 7.2, which is acceptable (See Figure 9).

General Hardness Index

The general hardness index indicates the presence of metal ions in the water. The presence of high counts of metal ions in the water can mean death to fish and most other seafood. We were mainly concerned with this to determine if the water itself coming from the well was suitable and if the system was releasing any metal ions that could potentially be harmful for the fish. Fish tend to store metal ions present in the water in their fat, and therefore the presence of metal ions can also affect the quality of the taste of the fish. We determined that our initial value of 7 was plenty low for the fish, and it only rose to 12 at its highest point. This occurred after introducing the fish and starting the system running as a whole at its inception. It leveled off at about 10, which is acceptable (See Figure 10).

Table 3: Water Quality Data

	O2 (ppm)	CO2	NH3/NH4	NO2	GH	pH
21-May	10	30	0.25	0	7	8
26-May	10	80	0.25	0	12	6.4
27-May	7	84	0.25	0	10	7.2
2-Jun	5	150	0.25	0	10	7.2

Analysis

Figure 6: Dissolved CO_2

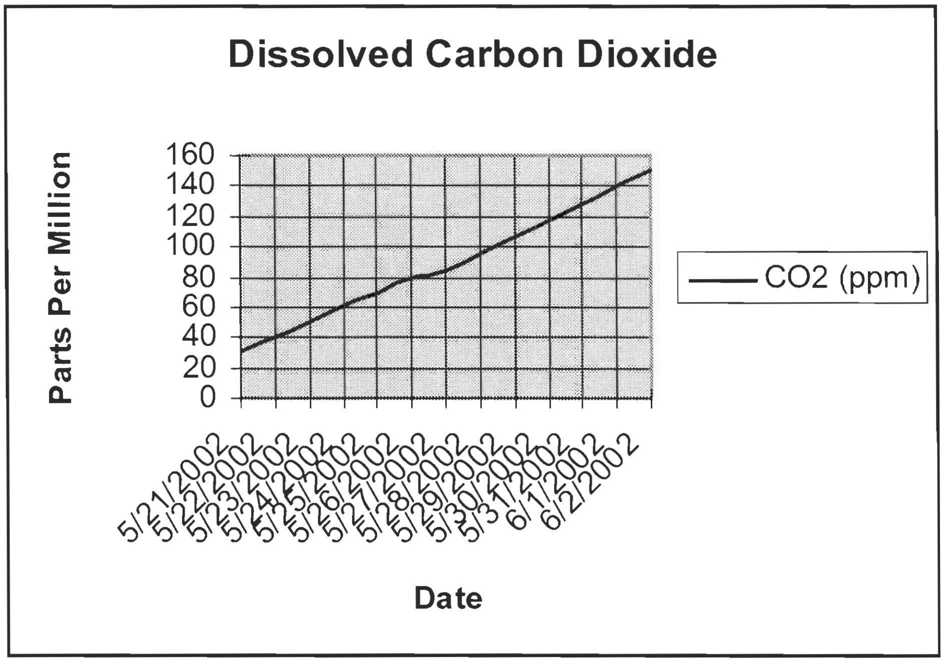


Figure 7: Dissolved O_2

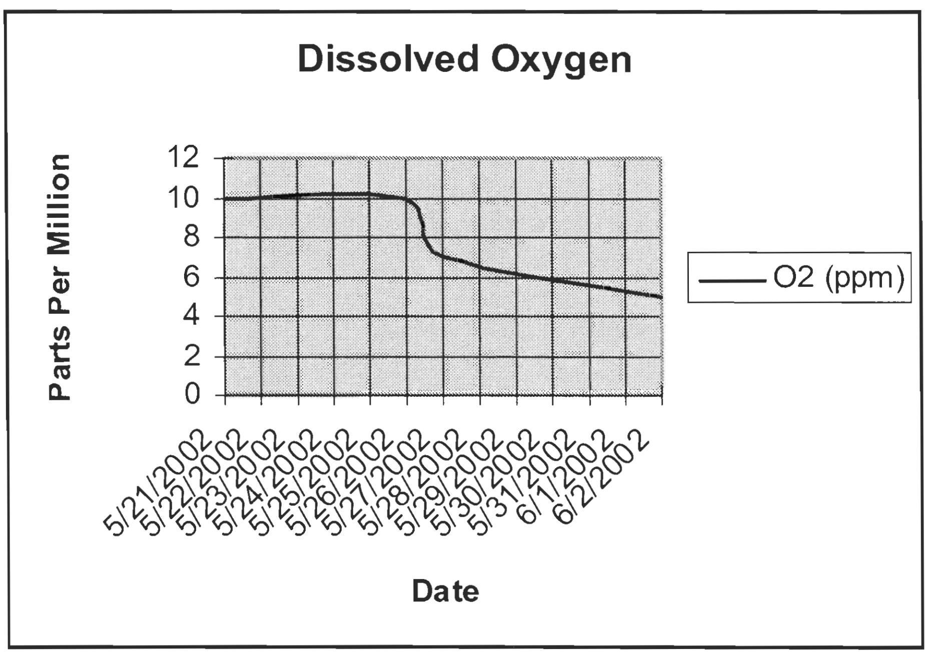


Figure 8: Waste Secretions

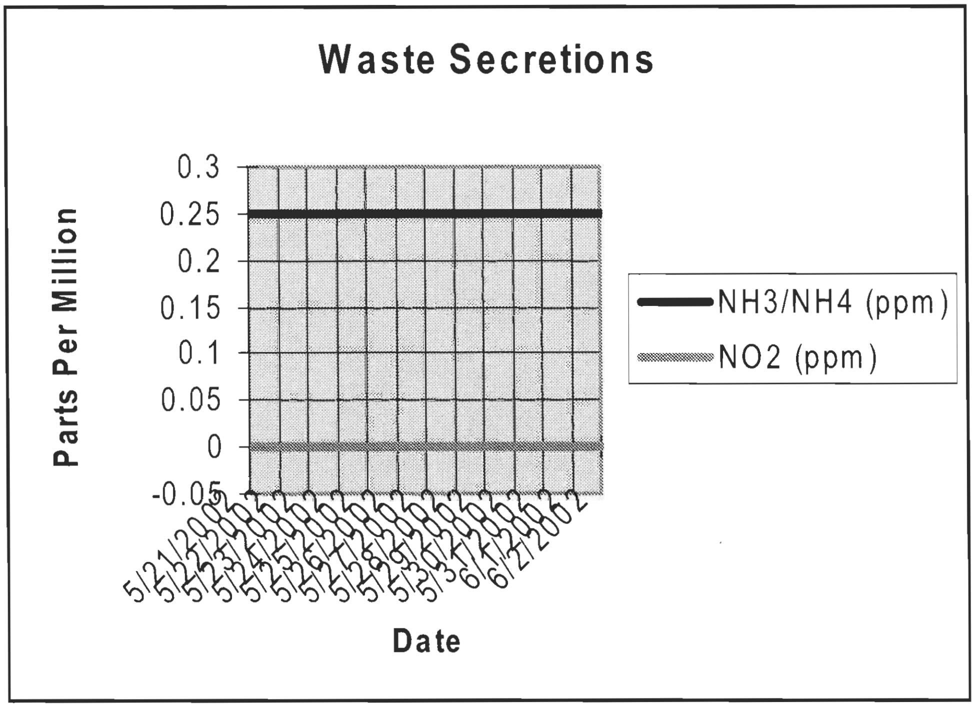


Figure 9: pH

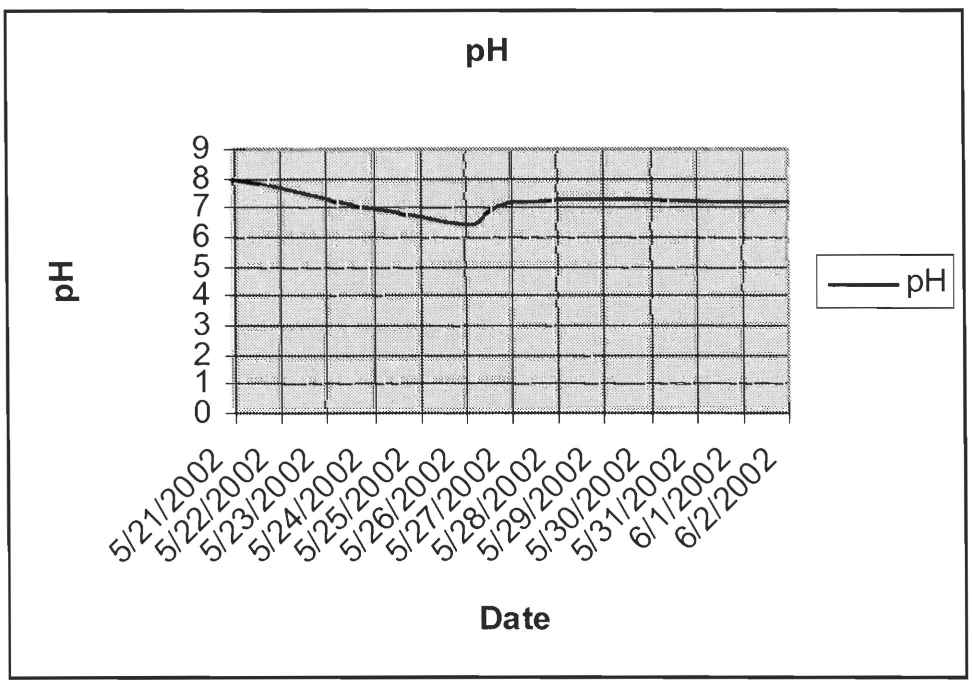
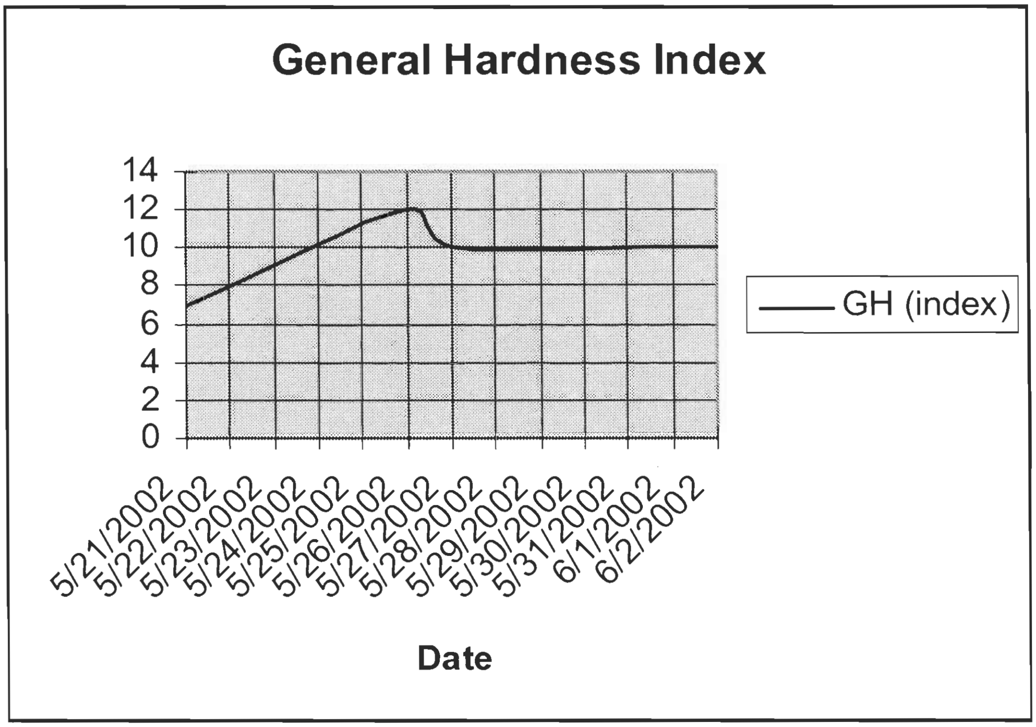


Figure 10: General Hardness Index



FINAL ANALYSIS AND RECOMENDATIONS

Overview

The entire system was in operation for 9 months. In that amount of time, many problems arose and novel solutions were designed to solve these problems. Since the system and all the components were an entirely new design, many failures and issues came up that were unexpected and had to be dealt with immediately for the health of the fish and the plants in our system.

Pump Failure

One of the most frequent, and possibly the most frustrating, design flaw of the system was the water pump. It failed entirely too frequently. Initially, the pump that was purchased for the project was a circulator for a home boiler but it didn't have the necessary discharge pressure to make the system work. We exchanged the pump with a semi-positive displacement pump. Though this pump would have output enough pressure and enough volume it did not have a sufficient duty cycle, and would have burned it self out very quickly. Due to its short life it was exchanged for a 100% duty cycle centrifugal pump. This pump, though slightly more expensive then what we wanted, would be much better suited for the task.

This pump was not without its flaws either. The negative pressure on the inlet of the pump was enough to collapse the inner wall of the tubing that was used as a suction line from the settling tank to the pump. The inside layer of the hose separated from the out layers and the suction of the pump caused the inner layer to completely close causing the water to stop flowing in the system. Since the water was not flowing, the pump was not being lubricated; therefore it overheated and stopped working. All of the lines were replaced with hard opaque pvc pipe which will not collapse and will help reduce the amount of light that is let into the system.

Another cause of pump failure was an effect of the pump overheating and shutting down. Once the pump shut down, air was able to get into the system and cause the pump to get air bound once it restarted. This type of pump is not capable of pumping air and one that would be prohibitively costly. Therefore, the pump that would have otherwise have been working correctly would again overheat and shut down. Another way that air entered the system was through air leaks in the suction line to the pump. The hoses were originally placed with brackets that would support their weight and prevent leaks from developing. As the system was operated and changed to make it operate better, some of these brackets got removed along with some of the valves that were deemed un-necessary. This provided a means for the leaks to develop. These leaks were in locations in the system where system pressure is lower than atmospheric and the leak was due to air into the system instead of water, thus they are not readily identifiable. When the system was replumbed with the hard pipe measures were taken to ensure leaks of this nature would be much less likely to redevelop.

Low Dissolved Oxygen

Dissolved oxygen in the system was an important part of the design and operation of the system. Because oxygen in the water was one of the most important necessities to the fish, we realized that getting oxygen into the system was a vital task. The most important and useful way of getting oxygen into the system was by using air pumps. We placed 3 air pumps in the main fish tank with air stones to get the most dissolved oxygen into the water as possible. However, the placement of the largest and most important air pump caused it to be damaged by water. The pump was located underneath the waterfall and was damaged by water that periodically spilled on to. This caused the pump to stop and left the fish gasping for air. Once the pump was replaced and moved to a different location, the oxygen levels rose again.

The water pump failure, as described above, also led to low oxygen in the system. The design of the system allowed for the water traveling down the hydroponic bed to fall almost a foot back into the main fish tank. The water falling and splashing into the tank would also add air to the water. Since the pump was not working for long periods of time, the fish were not getting enough oxygen to sustain the number of fish in the tank.

Overabundant Algae

Throughout the entire lifetime of the fish and system, algae was a constant problem. Algae grew in the water and attached itself to the sides of the tank, the hoses, the biofilter, and the hydroponic bed. It is a naturally occurring process of the algae to grow like this in warm water and in large amounts of light, as was our system. The algae helped to block pipes and slow the biofilter down. The treatment used to keep algae populations down was simple. Since algae need light to grow, we simply blocked out as much light as possible. The biofilter was covered and the two tanks were painted. In future operations of the system, our suggestion is to paint every hose, pipe, and tank black. We also suggested that a cover be placed on the hydroponic bed to keep even more sunlight from the water.

Water Temperature

On many occasions, the water in the main fish tank reached temperatures above 90° F and sometimes even over 100°F. The water in the tank is supposed to be warm to support the fish, but temperatures that high were detrimental to them. A solution was not reached, mainly building vents in the roof of the greenhouse. It was suggested for the entire time the fish were in the system, and was finally completed by the HPI volunteers in late February.

Low Fish Weight

How much the fish consume and grow is contingent on many factors, including quality of feed, water temperature, and oxygen levels. Unfortunately, the water temperature did not stay as stable at around 85 degrees as we had hoped. As is stated in the literature, fish weight can as much as triple from cultures at 70 degrees to cultures at 85 degrees. Therefore it is important to ensure that all the pumps are operational and that the water heater is functional to keep the water temperature at the right levels. Low fish weight can also be attributed to the size of the food particles, as described below.

Fish Death

The main problem and the result of all of the above problems was fish death. Along with the other reasons above, there are a few other causes for the losses.

Once the fish were placed into the system in April, they started showing signs of fungal infections. Most of the fish showed cloudy eyes and some died. We placed the fish in a salt bath and salted the system water, therefore ending the fungal infections. In the future, we suggested that the fish be given a salt bath before their introduction into the system.

We placed in the tank a "birth control" net to keep the fish from reproducing. The net was placed on the bottom of the tank slightly raised from the bottom of the tank. This net, instead of keeping the fish from mating, actually caused many deaths. The fish would find themselves trapped under the net unable to get out. Without food or enough oxygen, the fish died.

The water in the system was changed frequently, which is a correct step to keeping the fish healthy. However, the water that was placed into the system was extremely cold, usually less than 50°F. The new water was introduced very fast into the system, therefore shocking the fish and causing death. We urged the HPI staff to do water changes slowly to allow the fish to adapt to the new water temperature.

We bought nutritionally complete food for the fish to eat for their growth and health. The food was adequate and floated on top of the water, allowing for less waste. The food pieces were fairly large and while the fish were small, they were not able to eat the food effectively. The fish were not able to completely swallow the food and could not get as much food as they should have. The larger fish were better able to eat the food and therefore grew bigger while the small fish stayed small. In the future, the food should be slightly crushed to allow for fish of all sizes to be able to eat the food easily.

APPENDICES

Appendix A: Hunger Maps

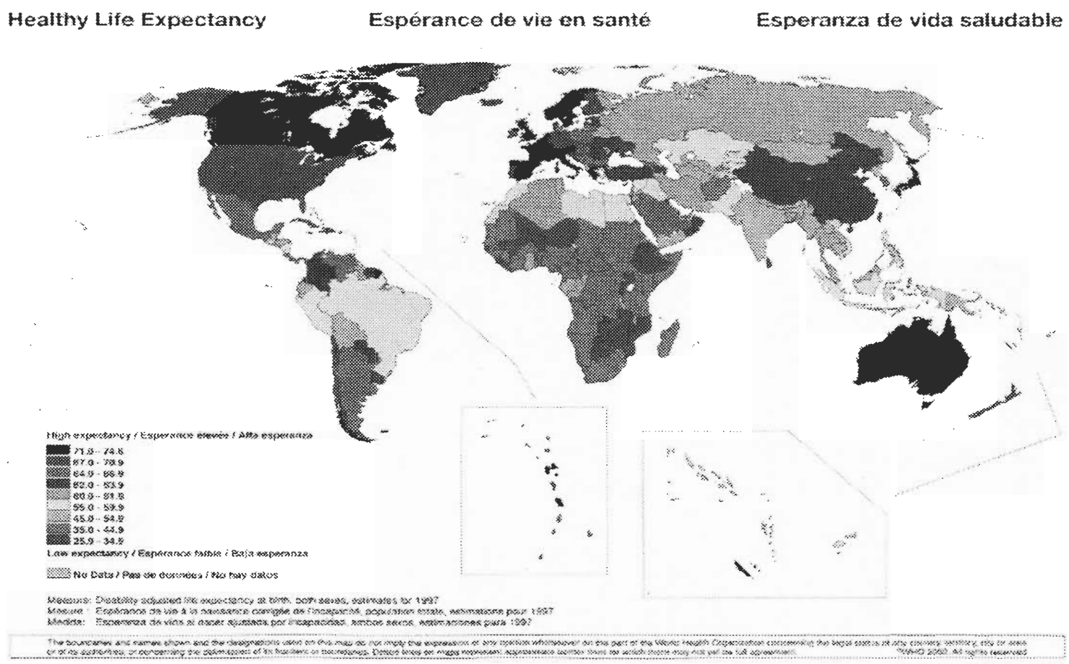


Figure 11: Healthy Life Expectancy

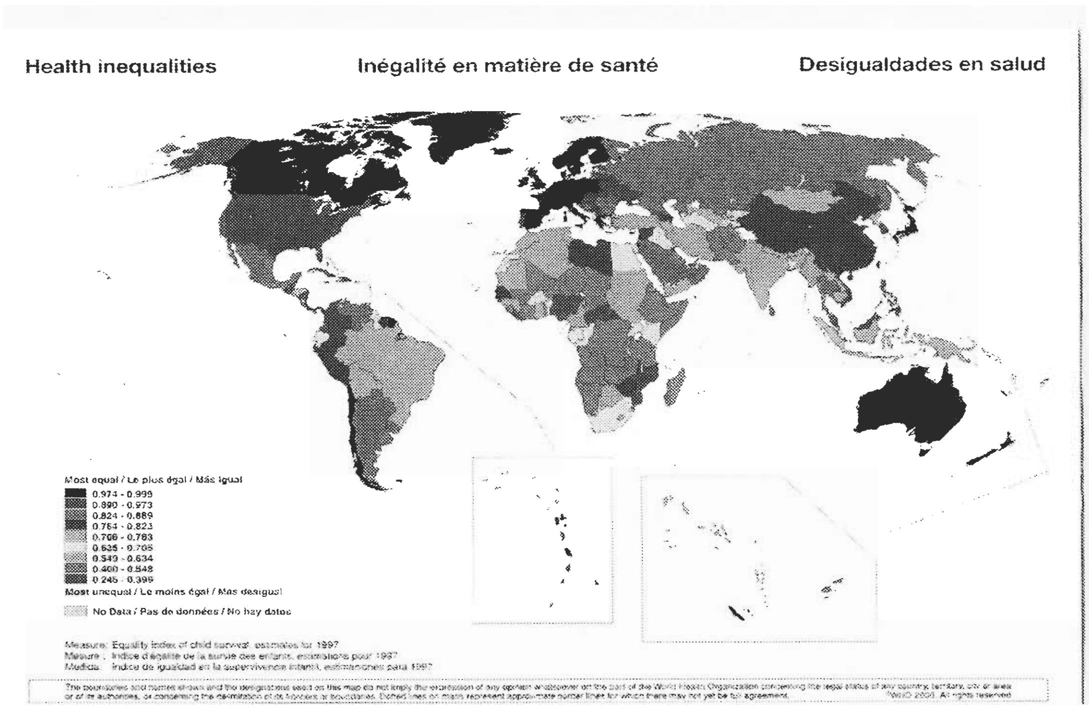


Figure 12: Health Inequalities

Appendix B: Sexing

This close-up shows a female (top) and male (bottom) tilapia together. Note that the female has two openings in the papilla for passage of urine and eggs, while the male has only one opening for urine and sperm passage. (Bocek, 1995).

Appendix C: Nutrition Tables

Vitamin	Requirement
Vitamin A (IU/lb)	450-900
Vitamin D (IU/lb)	110-220
Vitamin E (IU/lb)	23
Vitamin K (ppm)	R
Thiamin (ppm)	1
Riboflavin (ppm)	9
Pyridoxine (ppm)	3
Pantothenic Acid (ppm)	15
Niacin (ppm)	14
Biotin	R
Folic Acid (ppm)	1.5
B12 (ppm)	R
Choline (ppm)	400
Inositol	NR
Ascorbic Acid (ppm)	60

Amino acid	Requirement (% dietary protein)
Arginine	4.3
Histidine	1.5
Isoleucine	2.6
Leucine	3.5
Lysine	5.1
Methionine + cystine	2.3
Phenylalnine + tyrosine	5
Threonine	2
Tryptophan	0.5
Valine	3

* R and NR are required and not required, respectively

Appendix C: (con't)

Vitamin	Amount
Thiamin (ppm)	6
Riboflavin (ppm)	2.3
Pyridoxine (ppm)	5.2
Vitamin B_{12} (ppb)	8.4
Folic acid (ppm)	0.78
Niacin (ppm)	31.1
Pantothenic acid (ppm)	10.1
Vitamin C (ppm)	0
Choline (ppm)	1,760
Vitamin A (IU/lb)	N/A
Vitamin D_3 (IU/lb)	N/A
Vitamin E (ppm)	20
Vitamin K (ppm)	N/A

Appendix D: 4H Display Scorecard

EDUCATIONAL DISPLAY SCORECARD C0879

Examine the display for the qualities listed below. Place a check in each column to indicate placing earned.

Exhibitor Name or Number ______________________

Class ______________ Lot ______________ Ribbon ______________

	Excellent	Good	Fair	No Placing
DESIGN (40 points) Color –pleasing to the eye				
–effectively used				
Lettering –easily read				
–style suitable to message				
Illustration –part of message or just eyecatcher?				
Layout –simple and orderly				
–organization of parts				
–good spacing				
–neatness				
–reflects planning				
ORIGINALITY & CREATIVITY (20 points) Shows imagination				
New idea or innovative way to present familiar one				
EDUCATIONAL VALUE (40 points) One main idea				
Message effectively and accurately presented				
Message elicits viewer response				
Message appropriate for intended audience				
Chart/graph is titled				

COMMENTS ______________________

COOPERATIVE EXTENSION Washington State University

Cooperating agencies: Washington State University, U.S. Department of Agriculture, and Washington counties. Cooperative Extension programs and employment are available to all without discrimination. Reprinted October 1999. Subject code 039. X

Figure 14: Educational Display Scorecard

Appendix E: Plants suitable for use in Hydroponics

Vegetables:

Basil
Mint
Arugula
Chives
Coriander
Ginger
Parsley
Beans
Bok Choy
Broccoli
Cabbage
Chard
Chinese Cabbage
Corn
Cucumber
Eggplant
Kale
Lettuce
Mustard Greens
Peas
Peppers
Radish
Rapini Spinach
Sweet Potato
Tomato
Zucchini

Floating Plants:

Azolla
Bladderwort
Duckweed
Salvinia
Water Hyacinth
Water Lettuce
Indonesian Water Hyacinth

Submerged Plants:

Hydrilla
Elodea

Emergent plants*:

Alligator Weed
Cattail
Lotus
Pickerel Weed
Water Buttercup
Watercress
Water Lily

* Plants that are rooted in underwater soil

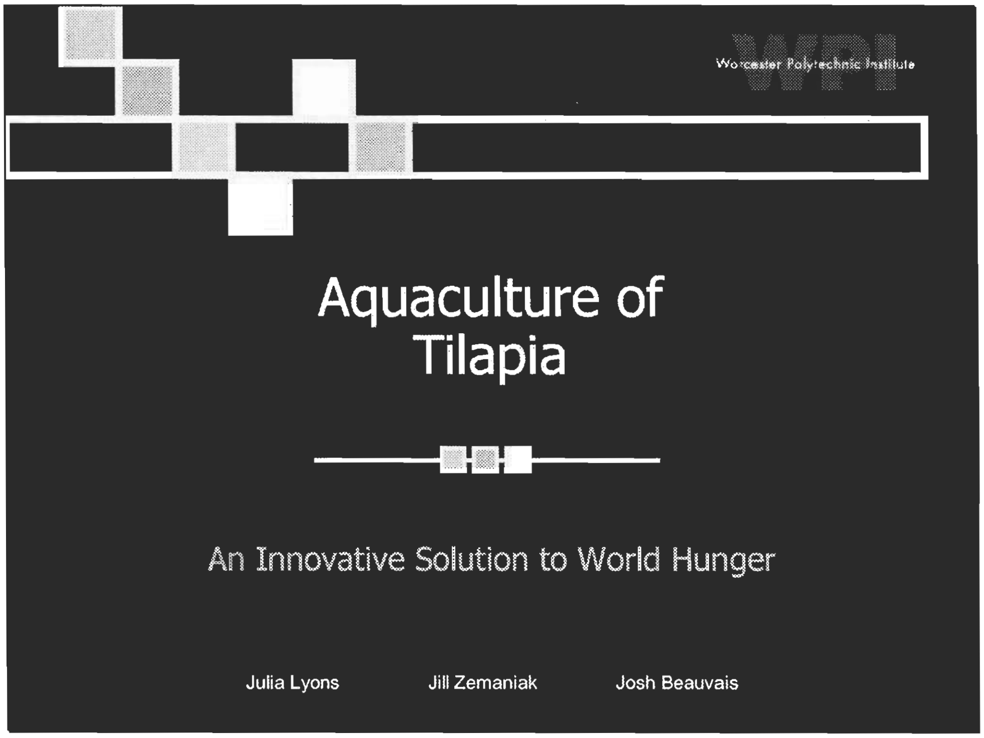
(Woods, 2000)

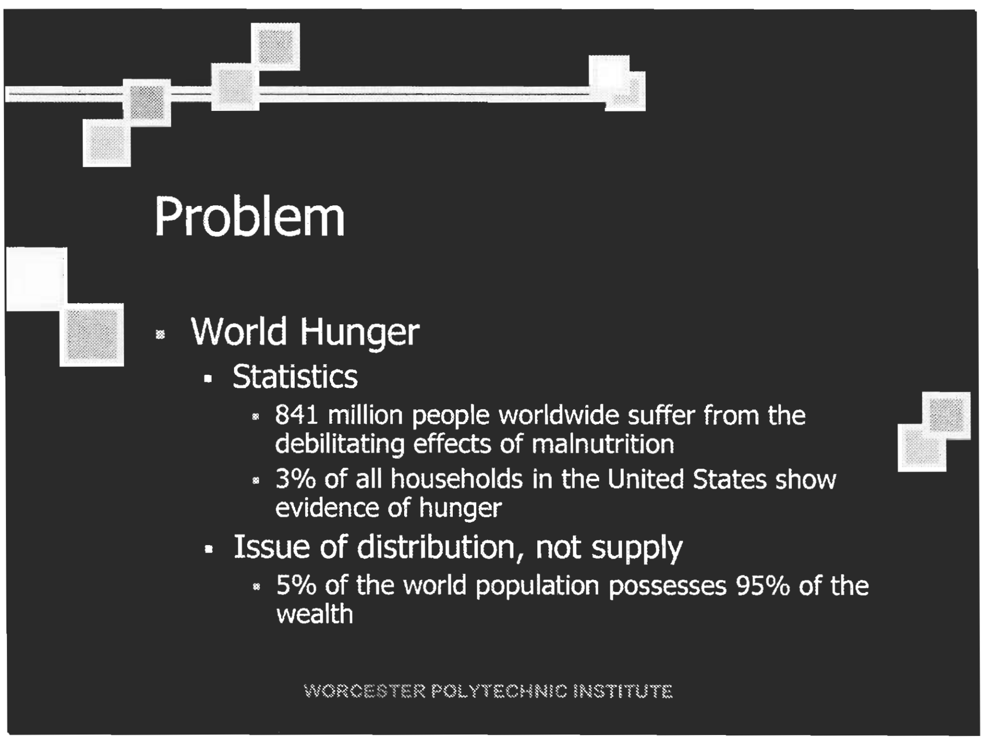
Appendix F: Budget

This table is the projected costs for the system components that will be paid for by HPI.

Supplies	Retailers	Price	Notes
1000L tank (2)	at HPI	$0.00	
250 Tilapia fingerlings	Bioshelters, Inc	<$1.00/ea.	donated?
Water pump (50gph, 20psi)	Hardware store	$60.00	
Hydroponic tray	More research	$75.00	
Oyster shells (100lbs)	www.ebirdseed.com	$65.00	
Biofilter starter kit	Pet store	$10.00	pond water, etc?
Plants and accessories	various retailers	$40.00	
Accessories (misc.)	Various retailers:	$20-$100	
	Total:	**$600.00**	
		$350.00	fish donated
Electric heater (~1500W)	www.aquaticeco.com	$100-$200	
OR Solar heating system	at HPI, needs parts:		
	Piping and insulation, etc.	$200-$500	

Appendix G: Initial Presentation at H.P.I.





Solutions

- Short-Term Relief
  - Monetary Donations
    - Christian Children's Fund
    - Unicef
  - Food/Supplies
    - US Armed Forces
    - The Mustard Seed

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Solutions

- Renewable Food Sources
  - Heifer Project International
  - Independent farmers' gifts
- Education
  - Heifer Project International
  - Peace Corps

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Heifer Project International

- "Not a cup, but a cow" philosophy
  - Teaching families to raise animals as a renewable source of food
- Aquaculture project
  - HPI's latest idea to facilitate the struggle against hunger

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Aquaculture

- The science, art, and business of cultivating marine or freshwater food fish or shellfish, such as oysters, clams, salmon, and trout, under controlled conditions. ~Merriam-Webster
- Species
  - Shellfish
  - Salmon
  - Trout
  - Tilapia

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Aquaculture

- Categories
  - Professional
    - Supplying fish to supermarkets
    - Bioshelters, Inc.
  - Non-Profit
    - State stocking local ponds
    - Peace Corps
    - HPI

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Design Possibilities

- There are three concepts that we are reviewing
  - Tank with particulate filter and separate aeration system
  - Recirculation system with "three barrel design"
  - Recirculation system with hydroponic bed

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Particulate Filter Design

- This involves three separate systems
  - Filtration
    - Pump and filter that must be cleaned daily/weekly
  - Aeration
    - Air pump and stone
  - Heating
    - Use of solar heating system already in HPI's possession

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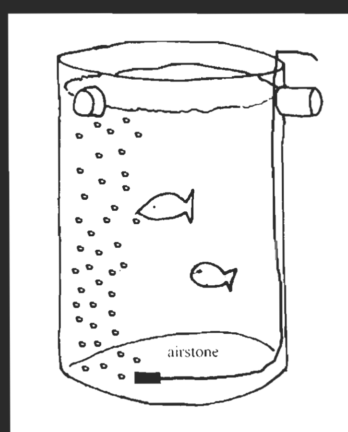

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Budget Summary

Supplies	Retailers	Price	Notes
1000L tank	at HPI	$0.00	
250 Tilapia fingerlings	Bioshelters, Inc	<$1.00/ea.	donated?
5.2 in. ceramic air diffuser (2)	www.petdiscounters.com	$12.94	
Air pump	www.petsmart.com	$56.99	
Submersible filter	www.aquamart.com	$60.00	
Airline tubing	available at any pet store	$5.00	
Accessories (misc.)	Various retailers:	$20-$100	
	Total:	**$497.90**	
		$247.90	fish donated
Electric heater (~1500W)	www.aquaticeco.com	$100-$200	
OR Solar heating system	at HPI, needs parts:	$200-$500	

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Three Barrel Design

- This uses three integrated tanks
  - Filtration
    - Biological filter that fills one of the tanks
    - Hydroponic plants that fill the second tank
  - Aeration
    - Accomplished by the main circulating pump
  - Heating
    - Use of solar heating system already in HPI's possession

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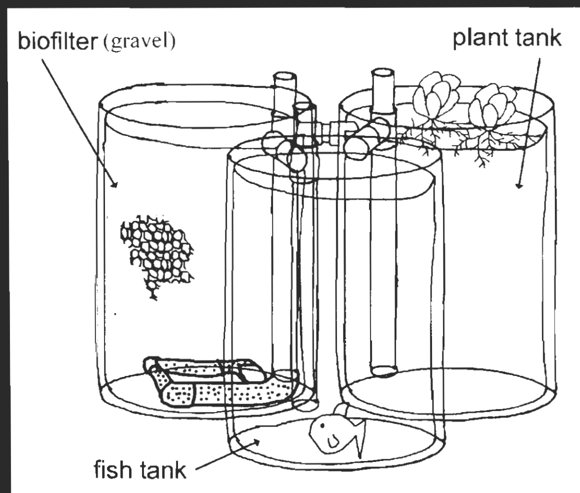

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Budget Summary

Supplies	Retailers	Price	Notes
55 gallon barrels (3)	www.rcbequip.com	$45.00	
30 Tilapia fingerlings	Bioshelters, Inc	<$1.00/ea.	donated?
Air pump	www.petsmart.com	$56.00	
5.2 in ceramic air diffuser (2)	www.petdiscounters.com	$12.94	
Oyster shells (50lbs)	www.ebirdseed.com	$32.50	
Biofilter starter kit	Pet store	$10.00	pond water, etc?
Piping (PVC)	Any plumbing supply	$100.00	
Plants (water lettuce or hyacinth)	Nursery	$10	
Accessories (misc.)	Various retailers:	$20-$100	
	Total:	**$409.40**	
		$379.40	fish donated
Electric heater (~1500W)	www.aquaticeco.com	$100-$200	
OR Solar heating system	at HPI, needs parts:		
	Piping and insulation, etc.	$200-$500	

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Recirculation with Hydroponics

- Single tank design combined with integrated biofilter and hydroponic bed
  - Filtration
    - Hydroponic bed with biological filter in the center
  - Aeration
    - Water falling from the bed back to the fish tank
  - Heating
    - Use of solar heating system already in HPI's possession

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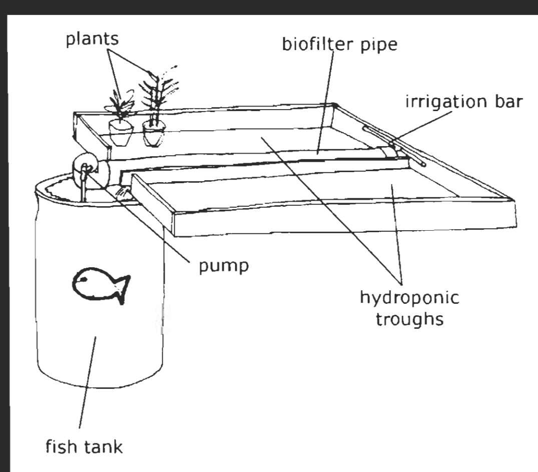

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Budget Summary

Supplies	Retailers	Price	Notes
1000L tank	at HPI	$0.00	
250 Tilapia fingerlings	Bioshelters, Inc	<$1.00/ea.	donated?
Water pump (50gph, 20psi)	Hardware store	$60.00	
Hydroponic tray	More research	$75.00	
Oyster shells (100lbs)	www.ebirdseed.com	$65.00	
Biofilter starter kit	Pet store	$10.00	pond water, etc?
Plants and accessories	various retailers	$40.00	
Accessories (misc.)	Various retailers:	$20-$100	
	Total:	**$600.00**	
		$350.00	fish donated
Electric heater (~1500W)	www.aquaticeco.com	$100-$200	
OR Solar heating system	at HPI, needs parts:		
	Piping and insulation, etc.	$200-$500	

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Our Recommendation:

Recirculation with Hydroponics

- Limitations of the other systems
  - Particulate filter design
    - High maintenance
    - Higher energy consumption
  - 3 Barrel design
    - Only supports up to 60lbs of fish
    - Complex design
    - High construction cost to fish produced ratio

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Our Recommendation:

Recirculation with Hydroponics

- Benefits of this system
  - Plant crops
  - Recycling of fish waste as plant fertilizer
  - Completely organic system
  - Simplification of maintenance and design
  - Minimize harmful discharge to environment
  - Up to 500lbs of fish produced
  - Higher energy efficiency

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Educational Value

- Operational model of aquaculture and hydroponics combination
- Large colorful flow chart for ease of understanding
- Recipes available for many Tilapia dishes

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Projected Timeline

- Dec. 25th Greenhouse completed
- Jan. 19th Building materials and fish ordered
- Feb. 16th Plants planted
- Mar. 2nd Construction of system completed
- Mar. 10th System running
- Mar. 16th Fish arrive
- Mar. 17th Fish in water
- Until May 1st Observation and analysis

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Appendix H: Temperature Data

Date	Time	Inside Temp	Outside Temp	Water Temp
14-Apr	1330	81	57	50
14-Apr	1700	61	53	48
14-Apr	1830	52	48	50
14-Apr	1915	48	44	50
14-Apr	2300	40	38	50
15-Apr	900	50	56	46
15-Apr	1545	70	58	50
15-Apr	1800	58	50	50
15-Apr	2030	46	40	50
15-Apr	2200	42	38	50
16-Apr	800	48	47	48
16-Apr	1050	68	60	49
16-Apr	1200	78	63	50
17-Apr	1330	58	54	54
17-Apr	1800	53	45	50
18-Apr	830	36	32	48
18-Apr	1300	66	50	45
19-Apr	800	43	45	45
19-Apr	1200	52	54	46
19-Apr	1745	54	44	49
20-Apr	810	50	60	46
20-Apr	1615	68	64	50
21-Apr	845	54	48	50
21-Apr	1130	72	66	54
21-Apr	1600	80	70	50
22-Apr	1200	96	88	54
23-Apr	800	83	86	50
23-Apr	1330	98	87	62
23-Apr	1700	84	80	56
24-Apr	830	77	77	65
24-Apr	1300	102	88	67
24-Apr	1600	90	86	65
25-Apr	1200	70	56	60
25-Apr	1500	70	57	56
26-Apr	730	50	47	52
26-Apr	900	72	65	54
26-Apr	1340	90	62	60
28-Apr	1050	74	64	60
28-Apr	1210	77	64	62
28-Apr	1515	84	60	65
29-Apr	1300	98	65	61
29-Apr	1604	82	63	64
30-Apr	800	68	68	58
30-Apr	1600	84	76	68
30-Apr	1900	70	66	68
1-May	800	81	80	69

Date	Time	Inside Temp	Outside Temp	Water Temp
2-May	1150	102	102	76
2-May	1500	100	92	82
2-May	1730	92	88	82
3-May	1730	94	89	80
4-May	1100	104	98	78
4-May	1500	108	94	86
4-May	1630	94	88	80
4-May	2230	72	72	81
5-May	1650	80	66	75
6-May	840	82	64	68
10-May	1630	91	84	70
12-May	225	104	94	75
14-May	1145	86	66	76
17-May	1200	67	56	72
17-May	1540	74	63	74
17-May	1915	60	56	76
18-May	915	62	56	33
19-May	530	56	50	74
19-May	1030	100	88	78
19-May	1300	95	75	80
19-May	1645	79	70	65
19-May	1945	68	58	82
20-May	1100	100	78	80
20-May	1800	77	68	80
21-May	1400	110	78	83
21-May	1600	92	70	85
21-May	1830	75	65	85
22-May	910	60	48	76
22-May	1415	60	50	74
22-May	1815	60	50	77
22-May	2130	56	48	77
23-May	830	58	50	76
23-May	930	60	51	76
23-May	1540	67	57	77
23-May	1930	60	50	77
24-May	845	64	50	76
24-May	1000	70	55	76
24-May	1100	68	54	77
24-May	1300	70	60	78
24-May	1830	60	50	77
25-May	900	65	51	75
25-May	1515	86	67	80
25-May	1830	66	59	80
26-May	840	69	59	78
26-May	1300	105	76	80
26-May	1720	72	63	83
27-May	910	62	54	79
27-May	1800	65	58	79
28-May	830	68	59	80

Date	Time	Inside Temp	Outside Temp	Water Temp
29-May	815	82	80	80
29-May	110	84	72	78
29-May	1300	87	74	78
29-May	1445	91	73	78
29-May	1630	84	74	78
30-May	900	76	66	77
30-May	1330	80	56	79
30-May	1815	74	58	79
31-May	900	78	65	71
31-May	1630	86	66	80
1-Jun	930	94	82	77
2-Jun	1115	68	58	80
3-Jun	930	66	52	80
3-Jun	1900	69	60	72
4-Jun	800	70	75	77
4-Jun	900	71	64	77
4-Jun	1500	70	64	71
4-Jun	1630	68	62	71
5-Jun	845	86	76	79
5-Jun	1400	93	80	82
5-Jun	1630	86	72	84
6-Jun	820	86	78	82
6-Jun	1030	87	74	83
6-Jun	1730	77	70	85
7-Jun	900	89	81	82
7-Jun	1130	88	85	86
7-Jun	1700	88	77	85
8-Jun	925	92	87	83
8-Jun	1130	102	92	86
8-Jun	1700	94	80	90
9-Jun	830	91	87	84
9-Jun	1050	100	99	85
9-Jun	1220	94	78	85
9-Jun	1730	84	76	86
10-Jun	1030	97	98	84
10-Jun	1630	98	84	90
10-Jun	1715	94	80	90
11-Jun	830	87	85	86
11-Jun	850	82	82	85
11-Jun	1730	67	60	83
12-Jun	815	70	60	83
12-Jun	1200	85	70	83
12-Jun	1615	89	76	85
13-Jun	810	90	90	85
13-Jun	1130	101	94	88
13-Jun	1600	100	90	93
14-Jun	800	89	88	85
14-Jun	1200	110	101	90
14-Jun	1445	117	95	95

Date	Time	Inside Temp	Outside Temp	Water Temp
15-Jun	845	95	91	89
15-Jun	1645	105	95	95
19-Jun	845	90	89	86
19-Jun	2210	70	70	90
20-Jun	815	92	90	89
20-Jun	11:30	108	108	85
21-Jun	8:30	72	65	85
21-Jun	1100	76	67	85
21-Jun	1720	69	59	84
22-Jun	810	69	59	84
22-Jun	1745	79	74	80
23-Jun	845	76	65	77
24-Jun	940	81	76	89
25-Jun	825	90	85	85
25-Jun	1510	115	90	94
26-Jun	1000	100	93	84
27-Jun	810	90	90	86
27-Jun	1000	100	99	86
28-Jun	840	91	88	82
28-Jun	1145	100	98	80
29-Jun	800	76	76	82
29-Jun	1310	90	80	82
30-Jun	1000	100	101	84
30-Jun	1400	107	97	91
30-Jun	2000	74	69	90
1-Jul	845	82	80	86
2-Jul	920	78	70	79
2-Jul	1320	92	70	82
3-Jul	820	82	80	80
3-Jul	1200	80	75	80
3-Jul	1630	70	67	82
4-Jul	1630	82	80	81
5-Jul	8302	85	84	80
5-Jul	1200	100	90	89
5-Jul	1710	84	70	90
6-Jul	810	80	75	85
6-Jul	1200	86	73	84
6-Jul	1600	100	70	85
7-Jul	900	90	82	80
7-Jul	1630	96	80	87
8-Jul	900	70	63	82
8-Jul	1345	76	62	84
8-Jul	1600	71	63	86
9-Jul	820	80	71	84
9-Jul	1330	112	90	90
9-Jul	1630	100	89	91
10-Jul	900	99	92	90
10-Jul	1330	113	96	92
10-Jul	1700	81	77	93

Date	Time	Inside Temp	Outside Temp	Water Temp
11-Jul	1430	111	82	75
11-Jul	1645	92	79	73
12-Jul	845	81	78	70
12-Jul	1200	80	69	70
12-Jul	1630	80	69	71
13-Jul	830	82	81	76
13-Jul	1520	85	72	80
13-Jul	1700	88	71	80
14-Jul	830	88	80	75
14-Jul	1910	72	65	80
15-Jul	1015	95	85	80
16-Jul	845	80	86	88
16-Jul	930	95	88	86
16-Jul	1700	97	81	90
17-Jul	930	70	64	88
17-Jul	1150	72	69	85
17-Jul	1645	80	70	88
18-Jul	830	90	82	79
18-Jul	1500	108	81	89
18-Jul	1640	85	76	87
19-Jul	840	88	80	85
19-Jul	1040	82	80	83
19-Jul	1645	90	85	85
20-Jul	805	86	82	82
20-Jul	1145	102	97	83
20-Jul	1710	95	80	88
21-Jul	800	90	87	87
21-Jul	1210	110	100	92
22-Jul	900	87	93	85
22-Jul	1900	77	76	87
23-Jul	945	100	99	81
23-Jul	1645	96	89	91
24-Jul	925	90	95	85
24-Jul	1140	97	100	85
24-Jul	1600	96	93	91
25-Jul	830	96	99	94
25-Jul	1130	107	107	95
25-Jul	1700	104	99	96
26-Jul	920	68	58	88
26-Jul	1630	90	70	89
27-Jul	930	89	80	83
27-Jul	1630	80	67	84
28-Jul	1020	99	87	85
28-Jul	1330	103	80	86
29-Jul	730	92	86	82
29-Jul	1430	100	84	87
29-Jul	600	84	74	88
29-Jul	745	69	65	90
30-Jul	645	99	88	86

Date	Time	Inside Temp	Outside Temp	Water Temp
31-Jul	830	88	82	78
31-Jul	1640	90	80	84
31-Jul	1715	81	69	83
1-Aug	945	100	95	82
1-Aug	1615	92	81	95
2-Aug	915	100	96	84
2-Aug	1750	94	86	92
3-Aug	1020	100	94	91
3-Aug	1420	110	94	95
4-Aug	830	79	67	83
4-Aug	1710	84	75	89
5-Aug	800	76	69	90
6-Aug	810	89	85	85
6-Aug	1450	110	95	95
7-Aug	815	90	89	85
7-Aug	1320	109	97	95
7-Aug	1620	105	92	95
8-Aug	740	88	86	93
8-Aug	1440	122	99	100
8-Aug	1710	102	93	97
9-Aug	810	95	93	92
9-Aug	1730	98	93	90
10-Aug	1040	100	99	92
10-Aug	1710	81	80	93
11-Aug	905	91	80	85
11-Aug	1500	98	82	87
11-Aug	1945	72	66	82
12-Aug	1015	67	80	78
12-Aug	1630	69	61	81
13-Aug	930	81	69	85
13-Aug	1330	99	84	86
14-Aug	1530	106	80	90
15-Aug	815	85	79	84
15-Aug	1130	101	99	88

Appendix I: Manual

Congratulations! You are the proud parents of Tilapia! These fish, if cared for properly, can feed many people with little amount of work. They are very hearty fish and can survive many conditions they may be exposed to. However, there are a few general rules to taking care of your new fish and the system they live in.

Tilapia is a species of fish that originated in Africa. They are extremely hearty and they can withstand water chemistry and temperature changes easily. These characteristics make tilapia one of the most cultured fish in the world. They also have a short maturation period. The time it takes them to reach adulthood usually varies from 6 to 12 months depending on food, temperature, and water conditions. This way, a person growing tilapia can optimally get two harvests every year. This type of growth and development is not seen in many other species of fish, especially not those that grow well in many conditions like Tilapia.

Although Tilapia are vigorous fish, there are a few basic things they need to stay alive and grow well.

Food

All species of Tilapia are plant-eaters. They can eat bugs and insects, but prefer plant material to animal. There are many different types of commercial food sold by feed stores that will suit the needs of your tilapia. It is important to ensure that the fish receive the protein, fatty acids, vitamins and minerals that they require in order to grow successfully. Below is a table of 10 amino acids necessary for the survival of your fish. These amino acids should be ingredients in your food.

Figure 15: Amino Acid Requirements

Amino acid	Requirement (% Dietary Protein)
Arginine	4.3
Histidine	1.5
Isoleucine	2.6
Leucine	3.5
Lysine	5.1
Methionine + cystine	2.3
Phenylalnine + tyrosine	5
Threonine	2
Tryptophan	0.5

There are also important vitamins and minerals to keep in mind when purchasing food. These supplements should also be ingredients in the food you decide to purchase. Most warm-water fish, such as catfish and tilapia need these vitamins in order to survive. Therefore, finding a proper food for your tilapia should not be too difficult.

Figure 16: Vitamin Requirements

Vitamin	Requirement
Vitamin A (IU/lb)	450-900
Vitamin D (IU/lb)	110-220
Vitamin E (IU/lb)	23
Vitamin K (ppm)	R
Thiamin (ppm)	1
Riboflavin (ppm)	9
Pyridoxine (ppm)	3
Pantothenic Acid (ppm)	15
Niacin (ppm)	14
Biotin	R
Folic Acid (ppm)	1.5
B12 (ppm)	R
Choline (ppm)	400
Inositol	NR
Ascorbic Acid (ppm)	60

When feeding your tilapia be aware of their eating patterns. Tilapia normally shouldn't be very picky about food; they should eat any time of the day. However, if you notice that if you feed them in the morning and in the afternoon the food is completely gone, then you need to feed them again. Remember, the point of growing these fish is to harvest them in a short amount of time for food or profit. Therefore feeding them often will reduce the time it takes for them to come to maturity. You need to be careful about feeding them too much also. If food is allowed to decay and rot in the system, bacteria and algae can take it over and make the fish ill. If there is still food in the tank for longer than 24 hours, remove the pellets left floating on the top. This will keep the food from disintegrating and falling to the bottom of the tank. Common sense and keeping a careful eye on your fish will ensure they get all the nutrients they need.

Water

As mentioned before, Tilapia are originally from Africa. This means that they are a warm water fish. Also as mentioned before, they can live in a variety of temperatures. The range for keeping Tilapia alive is anywhere from 52° - 95° F. However, these extreme temperatures cannot be sustained for a long period of time. Even though the fish can live in low temperatures, they will not eat. Tilapia will not feed correctly at 63° F or below. Many stress related diseases also occur in the fish at temperatures of 65° F or below. Conversely, high temperatures breed bacteria very well. Many bacteria are suited to be in a warm environment as they can reproduce very fast in this type of condition. Large amounts of bacteria can cause major problems to fish in the form of disease and stress. High water temperature also makes the oxygen in the water escape faster. Since the fish are breathing the oxygen in the water, it is very important to keep as much of it in the water as possible.

The optimum temperature for Tilapia is around 85° F. At this temperature, the fish will eat well and be healthier as a result. They will also grow the fastest at this temperature. Slight fluctuations are nothing to be concerned about, as long as normally the temperature stays around its optimum.

Oxygen in the water is also a very important component of keeping your fish healthy. Aerator pumps should be working at all times and the flow of water off the hydroponic bed should be strong. These things will prove to be enough to keep oxygen levels up to standard. The normal range for oxygen in the water should be around 4 to 5 parts per million (ppm). You can test the oxygen in the water by using one of the test kits provided.

System

The system in place at Overlook Farm was originally designed by the HPI group in Chicago. WPI students altered and worked with the original design to accommodate for larger tanks, outdoor living, and need for plant space. Although the original system has been working flawlessly for many years now, this new design of the system will still need to be worked out to create a minimally concerned system.

The basics components of the system are as follows:

Fish tank- the tilapia are housed here; the water from the hydroponic bed flows into this tank.

Settling Tank- water flows from the fish tank into the settling tank to remove solid waste. In the settling tank, the waste falls to the bottom and begins to decompose. The settling tank is also the place where the water is heated from the hot water heater.

Hot Water Heater- This heater was once used to heat a home and now heats the fish. It runs a closed loop through the settling tank of hot water to keep the temperature of the system up. The closed loop system is comprised of a long hose that circulates warm water through the water in the settling tank. The water is never transferred into the settling tank; the hose heats up because of the water from the heater and transmits that heat into the settling tank. The water in the hot water heater is substantially higher than the system as much of the heat in the hose is not able to penetrate into the settling tank.

Biofilter- this type of filtration is a much cleaner and easier way to keep the water healthy. Compared to chemical pumps (those that use carbon or other chemicals to rid the water of waste), the biofilter provides two important benefits to the system. Inside the biofilter are pieces of coral. The coral has two functions: first, it provides a home to bacteria that clean the water.

Bacteria stick to the coral and have a place to grow and multiply here. Second, the coral make the water pH more basic. This also helps to keep the water healthy.

Hydroponic Bed- the bed is used to house plants on. The plants placed on the bed should be annuals. Fruits and vegetables work very well on hydroponic beds as they grow very rapidly and need all the water they can get. The plants remove waste produced by the fish and return small amounts of oxygen to the water.

There are a few mechanical pieces to the system also that are integral in keeping the system going. There is a water pump, one normally found in homes, that continually runs. It has a turn off valve that can be used when changing the water or making repairs to the system. There are aerators also working around the clock to supply oxygen to the fish. All of these things need to be kept in working order to keep the system going.

There are also many hoses and pipes that connect the parts of the system. These were designed and chosen based on their function and they should not be replaced or removed without careful consideration and consultation with others. The system can be permanently damaged if a hose or pipe is changed without thinking.

Start-Up Procedure

Read all directions before beginning!

Before you begin:

1. Make sure all fittings are tight.
2. Paint all areas where water can be exposed to sunlight black and let dry. (Do not paint in places where water may come into contact with paint. Use only nontoxic latex paint if possible.
3. Check all seals and reseal if necessary with fish-safe or aquarium grade silicone.
4. Clean inside of fish tank and settling tank.
5. Check that all waterways are patent.
6. Insert new filters (between tanks, intake line).

Ready to Start:

1. Fill tanks to above intake line (see FILL LINE). Water quality on the farm has been tested and no alterations should be needed.
2. Open throttle valve all the way (counterclockwise).
3. Prime pump. Use hose to force water through intake line and into pump.
4. Uncover air escape holes on spray bar.
5. Plug in pump. (At first you may hear noise secondary to air in the lines).
6. Continue priming pump with hose until noise subsides and water begins to spray like a fountain from air escape holes.
7. Remove hose from intake line and allow pump to circulate water on its own. Note any issues with circulation. More air may escape at this point.
8. Cover air escape holes once all air has escaped.
9. Obtain a biofilter starter kit containing bacterial culture (available at most pond and aquarium supply stores). Also obtain VERY SMALL amount of animal dung (one horse clump).
10. Break up dung into powder and place in settling tank.
11. Feed culture directly into intake line. Once all culture has been fed through (approximately 1-2 minutes) shut off pump.
12. Cover tanks and allow system to sit overnight for bacteria to settle in biofilter.
13. Check water levels in water heater and add water if necessary.
14. Plug in and or turn on water heater, and circulators. Thermostats should be set to appropriate temperatures already, don't manipulate.
15. After system has settled overnight, again prime pump with hose as in procedure described above. Turn on pump and allow air to escape.
16. Allow system to run until temperature is adequate for introduction of fish.
17. Once adequate temperature has been obtained, (at least 75 degrees Fahrenheit) plug in and run air pumps. Allow system to circulate water with air pumps for at least 4 hours before introducing fish.

Before you add fish:

1. Place plants on hydroponic bed so that maximum surface area is covered. Use black trash bags to block water from sunlight.
2. Obtain fingerlings. If transporting fingerlings, make sure they have an air supply.
3. Examine fingerlings for signs of disease. Eyes should be clear and open. Fins should be intact and shiny. Gills should be dark pink to red. If eyes are cloudy, bathe fish in salt solution before placing in tank (see troubleshooting). Remove dead fish and dispose.
4. Check temperature of water fingerlings are in and compare to water in fish tank. If remarkably different, (5 degrees or more) slowly add water to fingerlings to even out temperature difference.
5. Once temperatures are within 2-3 degrees, suspend fish in plastic bag or bucket in water of fish tank.
6. Once temperatures are even, fish may be allowed to swim out of bucket or bag into tank.
7. Watch for signs of distress such as gasping, lingering at surface and frantic swimming.
8. Feed fish for the first time. One handful should be plenty.

Shut Down Procedure:

Read all directions before beginning!

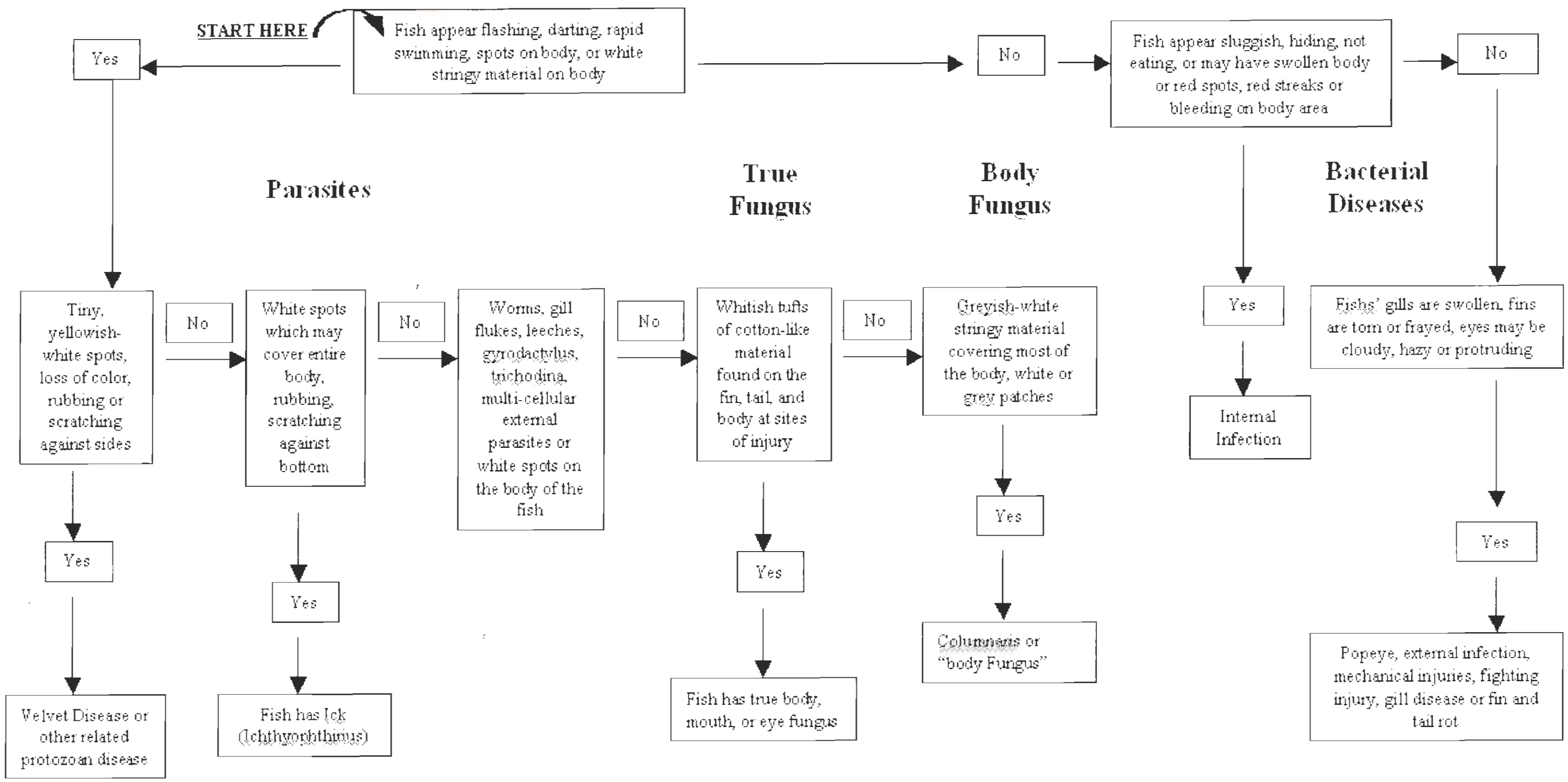
1. Remove fish from tank.
2. Unplug and or switch off air pumps, circulators, and water heater.
3. Remove air pumps from fish tank.
4. Place drain lines over drains.
5. Open drain valves and allow tanks to drain on both tanks and water heater.
6. Clean algae build up and waste from tanks while they are still wet.

Troubleshooting

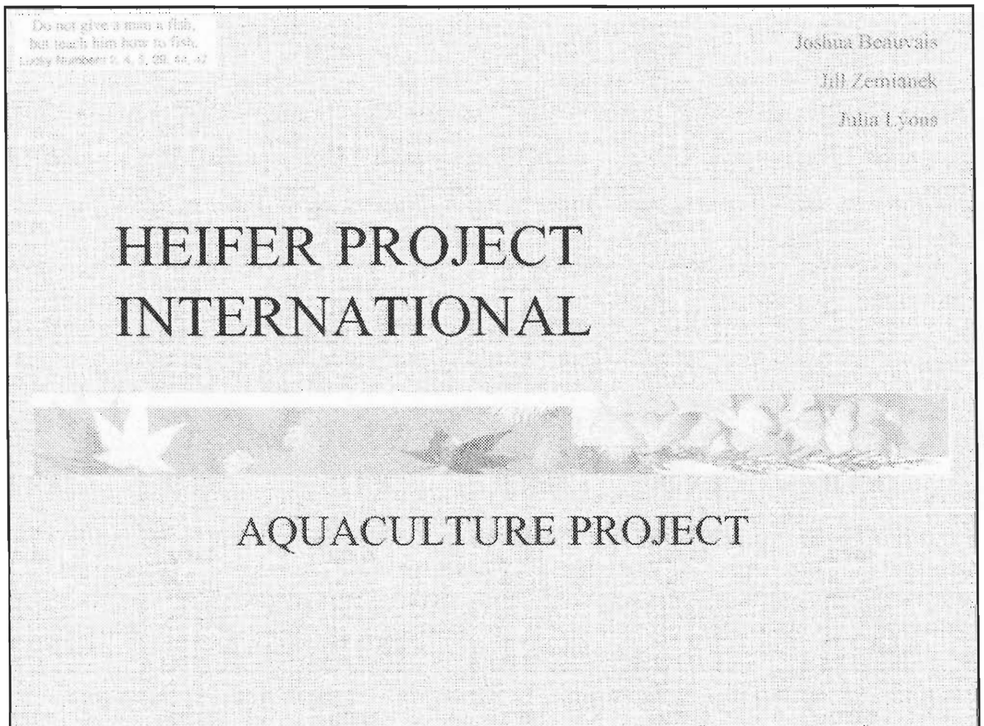
Symptom	Possible Cause	Suggested Solutions
There is no flow in the system	No power to pump	Check that the pump is plugged in. Check breakers in barn to ensure none of them have tripped.
	Isolation valve is shut	Check position of valve next to the pump, should be fully open.
	Pump shutdown on thermal overload	Check system for clogs, pump will restart once it cools down
	Pump not able to keep up with system demands	Consider upgrading the pump
System temperature too low	Heat circulators are turned off	Check that the switches controlling the circulators are turned on.
	Thermostat has been changed	Check that the thermostat is set to the proper temperature and adjust as necessary
	Power to heater or pumps has been turned off	Check breakers in barn to ensure none of them have tripped.
	Low water in the heating loop or water heater	Check the water levels in the standpipes above the water heater.
	No flow in the main system	Follow steps above for no flow
The fish are gasping for air. Fish are crowed at the top Of the tank breathing heavily	Air pumps are not functioning	Check air lines, connections, and clean stones in necessary
	No flow in the main system	Follow steps above for no flow
	Not enough air getting into the water	Consider upgrading air pump
There is a large amount of algae (green stuff) on all components of the system	Too much surface area exposed to the sun	Cover all clear pipes and tops of tanks from the sun, wipe down all areas covered by algae, then change half of the water in the settling tank.

Symptom	**Possible Cause**	**Suggested Solutions**
System temperature too high	The temperature in the greenhouse is too high	Open up vents overhead and door and make sure the hot water heater is not on. Exchange some of the water in the settling tank not to exceed 50% of the settling tank (not total system volume), slowly add new water to the settling tank only
The fish are dying	Disease	See disease flow chart and perform a salt bath and or salt the water
The fish are not eating as they should	The food may be too large to fit in their mouth.	SLIGHTLY crush their food into smaller pieces, but be careful no to make the pieces so small they sink immediately or the fish cannot eat the food
	Disease	See disease flow chart and perform a salt bath and or salt the water
	System temperature is too low	See low temperature section above

Fish Disease Flow Chart



Appendix J: Final Presentation to HPI



10/2000	Initial meeting with Dale Perkins
10/2000-12/2000	Primary Research
12/2000	Initial Presentation
12/2000-4/2001	Secondary Research
1/2001-2/2001	System Components Construction
2/2001-3/2001	Greenhouse Construction
3/2001	System Installation
3/2001	Initial Testing
4/2001	INTRODUCTION OF FISH
4/2001-11/2001	Observation of System
6/2001	International Fair Initial Feedback
9/2001	Barn-Raising Focus Groups
11/2001	HARVESTING OF FISH
11/2001-2/2002	Completion of Written Project/Manual
2/21/2002	Final Presentation

Design

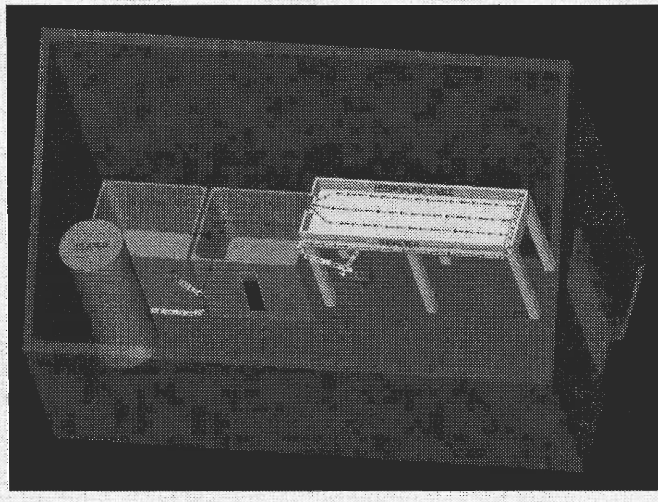
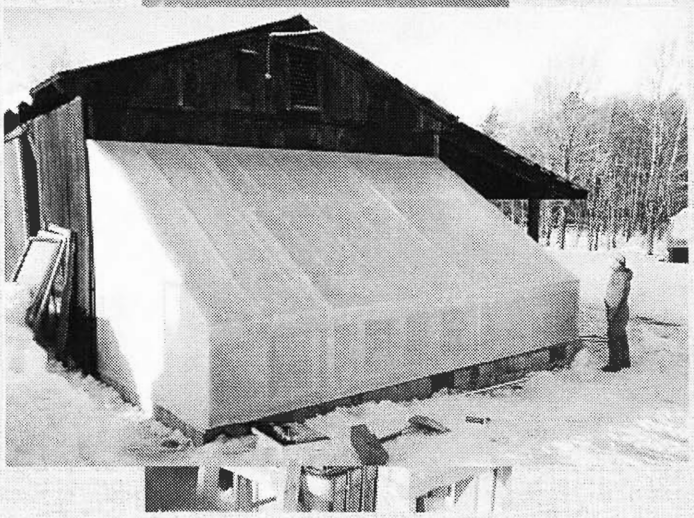
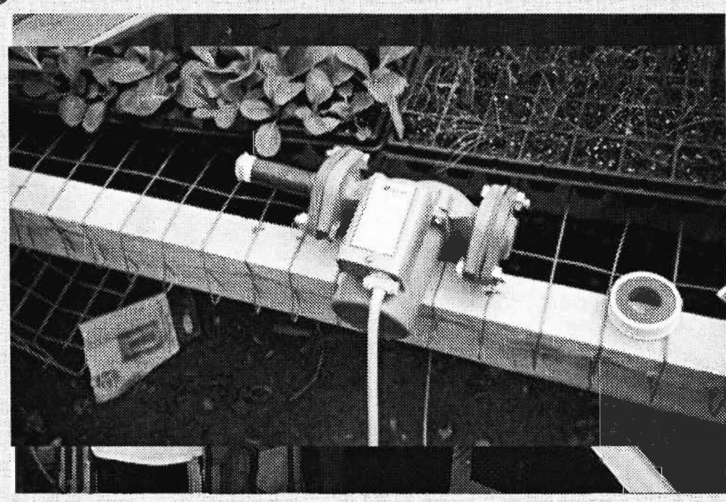


Table Construction

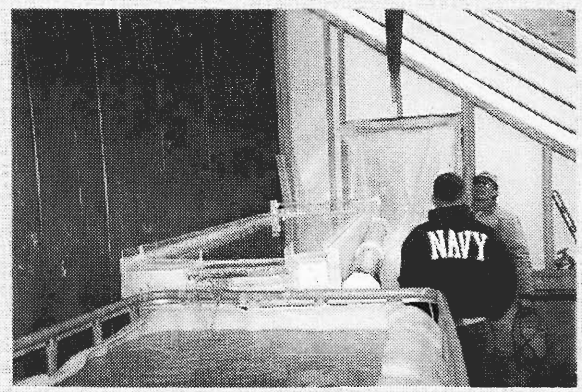
Greenhouse Construction



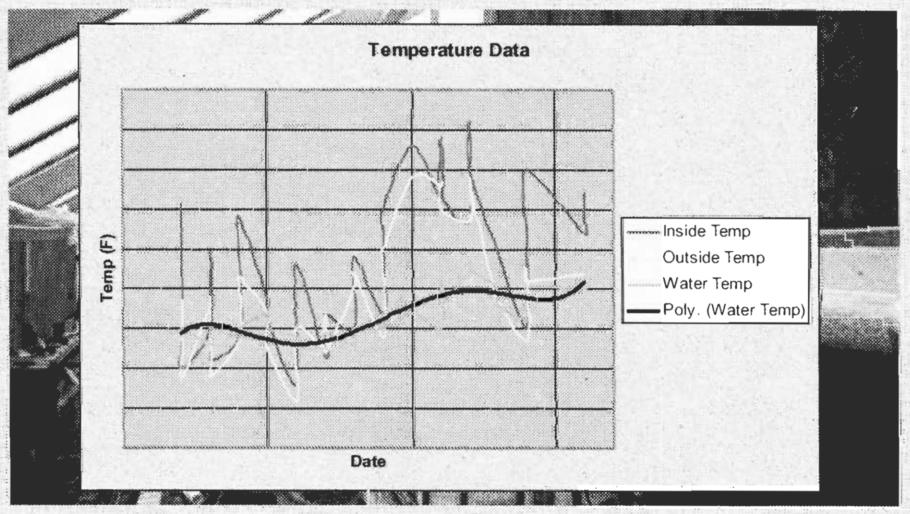
System Installation



System in Action



System Monitoring



The Results

Problems Encountered

- Pump Failure
  - Bad pump
  - Collapsed tubes
  - Air in system
- Low Dissolved Oxygen
  - Air pump malfunction
  - Need stronger air pump
  - Bad circulation – see above

Problems Encountered

- Algal problems
  - Too much sunlight
- Collapsed tubes
  - Air in system
- Too hot
  - No vents in the greenhouse

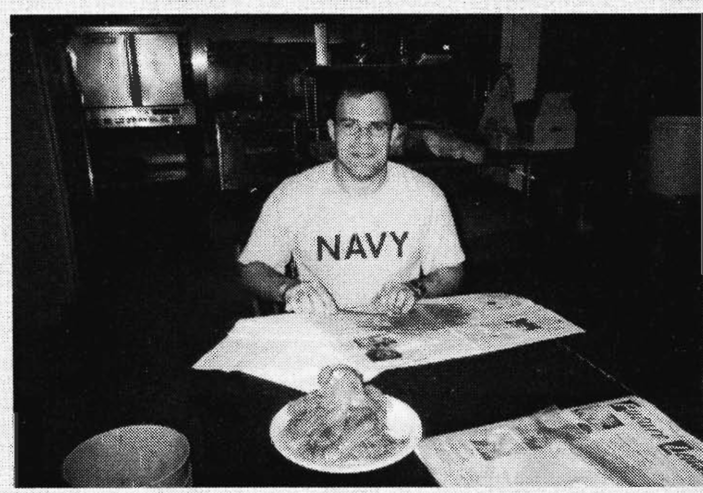
Problems Encountered

- Fish deaths
  - Fungus problem
    - Salt bath
  - Birth control net
    - Fish got stuck
  - System down time
    - System down for longer periods of time due to simple problems, symptom treated, problem not corrected in full
- Other losses of fish
  - Dale's pond (puddle)
  - Jared's snacks
  - HARVEST TIME

Harvesting of the Fish

- How we did it
- Where the fish went
  - Russ Anderson from the Burncoat Horticulture Project
  - Dale's breeding project
  - Dinner
  - Freezer
- Final counts
  - ~80 fish
  - Average weight, 8oz

Harvesting of the Fish



What to do Better Next Time

- All piping should be hard piping on suction end of pump
- All piping should be painted (black preferable)
- Tanks should be covered and painted black as well
- Keep biofilter covered
- Preventative salt baths to fish before introduction
- Install vents
- Fix problems/not symptoms
- Contact ken before fixing anything major

What to do Better Next Time

- Consider water exchange on intervals
  - Half settling tank 1x/month
  - Be careful to introduce water slowly due to temperature
- Use SMALL amount of feces to start biofilter
  - Handful not shovelful!
- Feeding
- While fish are small, break food up into smaller pieces (not powder)

Questions

BIBLIOGRAPHY

American Tilapia Association http://ag.arizona.edu/azaqua/ata.html

Bardach, John. E. Aquaculture: The Farming and Husbandry of Freshwater and Marine Organisms. ©1972 John Wiley & Sons, NY.

Bocek, Alex. Introduction to Tilapia Culture. ©1994 Auburn University, Alabama http://www.ag.auburn.edu/dept/faa/tilap.html

Bocek, Alex. Culture of Hand-Selected Male Tilapia. ©1995 Auburn University, Alabama http://www.ag.auburn.edu/dept/faa/monotil.html

Boisvert, D.L., B.J. Seiz. "The Relationship Between Exhibit Characteristics and Learning-Associated Behaviors in a Science Museum Discovery Place." Science Education. Sept. 1995.

Bowser, Paul R. Dr. Buttner, Joseph K. Dr. General Principles of Fish Health Management. http://www.umassd.edu/specialprograms/nrac/health/medicine.html

Bulger, Ginny. Stewart, Taffy. Raising Fish in Solar Greenhouses. Small Farmers Journal Vol. 4 No. 2.

Drake, Cheryl Jeanne, Ning Gu, Qun Lin, Tzu Wen Wu. "Designing and Installing an Alternative Energy System for Heifer Project International." Interdisciplinary Qualifying Project, WPI. 2000.

"DDT," Microsoft® Encarta® Online Encyclopedia 2000 http://encarta.msn.com ©1997-2000 Microsoft Corporation. All rights reserved.

Encyclopedia Brittanica Online www.brittanica.com

Fitzsimmons, Kevin PhD. Marketing of Tilapia in the USA. ©2000 http://ag.arizona.edu/azaqua/tilapia/Thailand/PowerTilapiaMarket.ppt

Fitzsimmons, Kevin PhD. Tilapia in the 21st Century. ©2000 http://ag.arizona.edu/azaqua/ista/keynote.ppt

Hallman, William K Ph.D. **"**Public Perceptions of Agri-Biotechnology," *Genetic Engineering News*, v.15 n.13 (July 1995).

Halver, John E. Fish Nutrition. ©1972 Academic Press, NY.

Hardin, Ben. "Appetite Hormone Puts Pigs on Faster Growth Track."September 16, 1999. http://www.ars.usda.gov/is/pr/1999/990916.htm

Heifer Project International © 2000. http://www.heifer.org

Helfrich, Louis A., George Libey. Fish Farming in Recirculating Aquaculture Systems. http://www.fw.vt.edu/fisheries/extension/fishfarming/RecirculateAquaSys.html

Lewis, Melinda. "Focus Group Interviews in Qualitative Research," Action Research Electronic Reader. 12 Apr. 1995. http://www.cchs.usyd.edu.au/arow/reader/rlewis.htm

Massie, Barbara. *Create Display That Sells Your Product!* Craft Talk. 1998. http://casa-chia.org/Craft-talk/MBAug98.html

Perkins, Dale. Heifer Project International. Interview 10.3.00.

Popma, Thomas. Masser, Michael. Tilapia Life History and Biology. Southern Regional Aquaculture Center. ©1999 http://ag.ansc.purdue.edu/aquanic/publicat/usda_rac/efs/srac/283fs.pdf

Rakocy, James. Tank Culture of Tilapia. Southern Regional Aquaculture Center. ©1989 http://ag.ansc.purdue.edu/aquanic/publicat/usda_rac/efs/srac/282fs.pdf

Reid, John. Bioshelters, Inc. ©1998. 500 Sunderland Rd. Amherst, MA 01002. Tel. (413) 549-3558.

Robinson, Edwin H., Meng H. Li. "Aquaculture: Catfish" MSUCares, 2001. http://www.msucares.com/aquaculture/catfish/index.html#other

Schultes, Neil P. "Biotechnology in Agriculture." The Connecticut Agricultural Experiment Station, New Haven CT. 2001. http://www.caes.state.ct.us/PlantScienceDay/1999PSD/biotech99.htm

Sipe, Mike. Breeding fat fish that can fly Agriculture Worldwide 17-Feb-00 http://www.agriculture.com/scgi/notebook/nb.cgi?FNC=ArticleList__Aarticle_html___7291___440

Sipe, Mike. Can Pennyfish rescue a Honduran village? Agriculture Worldwide 26-Apr-99 http://www.agriculture.com/scgi/notebook/nb.cgi?FNC=ArticleList__Aother_arts_html___7031___440___7

Sipe, Mike Chocolate fish: Who would want them? Agriculture Worldwide 15-Jul-99 http://www.agriculture.com/scgi/notebook/nb.cgi?FNC=ArticleList__Aarticle_html___7116___440

Sipe, Mike. Color-coded tilapia are 'chicken of the pond' Agriculture Worldwide

12-Jan-99
http://www.agriculture.com/scgi/notebook/nb.cgi?FNC=ArticleList__Aother_arts_html___5358___440___7

Sipe, Mike. The perfect fish (part 1 of 2) Agriculture Worldwide 21-Sep-00
http://www.agriculture.com/scgi/notebook/nb.cgi?FNC=ArticleList__Aarticle_html___7539___440

Sipe, Mike. The perfect fish (part 2 of 2) Agriculture Worldwide 22-Sep-00
http://www.agriculture.com/scgi/notebook/nb.cgi?FNC=ArticleList__Aarticle_html___7541___440

Sipe, Mike. The power of oxygen Agriculture Worldwide 03-Feb-99
http://www.agriculture.com/scgi/notebook/nb.cgi?FNC=ArticleList__Aother_arts_html___5838___440___7

Sipe, Mike. The promise of genetics in aquaculture Agriculture Worldwide 01-Feb-99
http://www.agriculture.com/scgi/notebook/nb.cgi?FNC=ArticleList__Aother_arts_html___5798___440___7

Sipe, Mike. Tilapia in the marketplace Agriculture Worldwide 18-Jan-99
http://www.agriculture.com/scgi/notebook/nb.cgi?FNC=ArticleList__Aother_arts_html___5478___440___7

Soares, Scott. Massachusetts Department of Food and Agriculture Tour of Massachusetts Aquaculture Sites. 4/24/98.

Somerset, Ira J. Understanding Aquaculture. http://idh.vita.org/pubs/docs/aquacult.html

Stevens, R., R. Hall. "Seeing Tornado: How Video Traces Mediate Visitor Understanding of (Natural?) Phenomena in a Science Museum." Science Education. Nov. 1997.

Swenson, Herbert. Why is the Ocean Salty?
http://oceanography.palomar.edu/salty_ocean.htm

The Hunger Site ©2000.
http://www.thehungersite.com/cgi-bin/WebObjects/CTDSites.woa/506/wo/PNKyK0gb7XCVDN2wDp/0.0.17.1.1.3.0.1.0.15.0.CustomContentLinkDisplayComponent.0.0

The Tilapia Story © 1999-2000 Gofish.com, Inc .
http://www.gofish.com/cgi-bin/WebObjects/Gofish.woa/wa/gotoArticle?document_id=1879052229

Tilapia. Harbor Branch Oceanographic Institution.
http://www.hboi.edu/aquaculture/pdfs/Tilapia.pdf

Tilapia Expert System Computer Program Now Available to Farmers.
http://library.kcc.hawaii.edu/praise/hames/

U.S. Department of Agriculture. *Federal Statistics: Exercise and Eating.* Vol. 12. © 1999. http://www.usda.gov/cnpp/FENR/fenrv12n1/fenrv12n1p62.PDF.

Wheaton, F.W. Aquaculture Engineering. ©1977 John Wiley & Sons, Inc. NY.

Washington State University. 4H Educational Display Scorecard. Oct. 1999.
http://cru.cahe.wsu.edu/CEPublications/c0679/c0679.pdf

Woods, Jonathan. The Urban Aquaculture Manual. © 2000.

World Health Organization http://www-nt.who.int/whosis/statistics/whr_statistics/maps.cfm?path=statistics,whr_statistics,whr_maps&language=english

World Hunger Year. *Hunger, Poverty And Homelessness In The U.S.* ©2000.
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