Aquaponics Feasibility Study

For the Denver County Sheriff's Department

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8/10/2012

COLORADO AQUAPONICS

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1.0 - Introduction

1.1 - Feasibility Study Project Team and Contributors

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Jesse Hull – Co-Founder/Owner, Imagine Aquaponics

Taylor Webb, Architect – Manifold Design Development

Bob Brashears, Architect – Reilly Johnson Architecture

1.2 - Scope of the Feasibility Study

Our intent with this study is to provide a high level overview and analysis of the major components of the project including the opportunities and risks involved with creating a pilot aquaponic food production system on the property. This project has been noted as a pilot project with the intention to investigate and understand future expansion possibilities. As we indicated in the initial proposal for this pilot project, there are 4 major phases.

- Phase I – Feasibility
- Phase II – Design Development
- Phase III – Construction
- Phase IV – Turnover

The budget allocated for the phase I feasibility study is commensurate with the level of detail that this report provides. To that end, a project of this complexity and scope will require a significant effort in the design development phase. Detailed engineering and planning will be required to achieve a successful outcome. The following key points and project goals are included from both the feasibility study proposal and our collective notes from our initial project discovery meetings.

- **Aquaponic facility and support evaluation**—including an evaluation of the building infrastructure, availability of natural light, electrical requirements, HVAC considerations, opportunities for on-site renewable energy, outdoor land application and other infrastructure requirements.
- **Aquaponic production SWOT analysis**—including analysis of Strengths, Weaknesses, Opportunities, Threats and Risks.
- **Fish and plant production estimates** – including an overview of candidates for plant species and fish species, weekly, monthly and annual production capacities, and potential to supplement current food production and costs.
- **Aquaponic concept development and financial evaluation**—including development of a production and waste management concept plan, preliminary capital cost estimates, operating cost estimates, and concept drawings for the system
- **Industry skills training and education** – including an initial human resources overview for systems construction, operations and opportunities for education

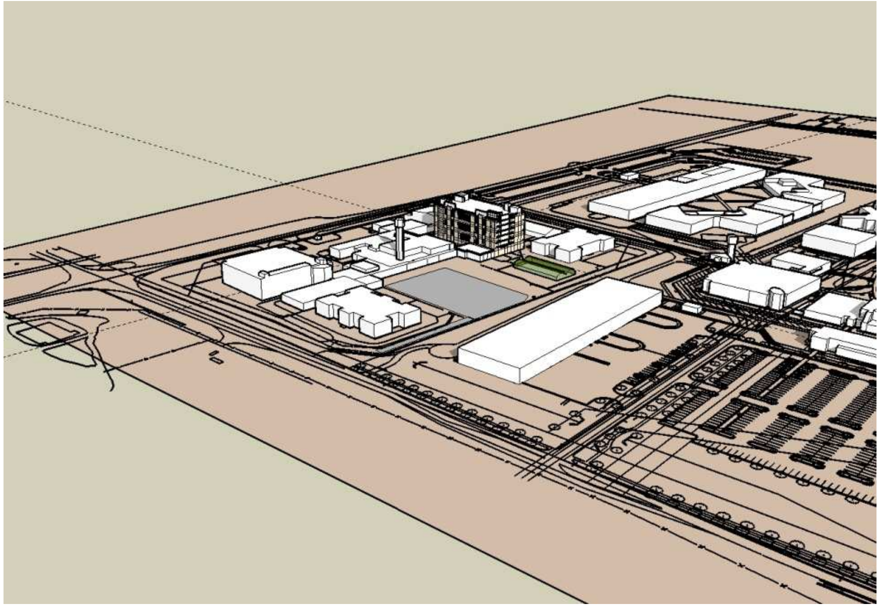
1.3 - Project Goals

- Repurpose the Palmer building as a full production aquaponics system to provide food for the staff and inmate population
- Develop a pilot system as a model for future expansion towards a multi-acre system
- Produce enough food to offset monthly purchasing costs, moving towards a model whereby the jail could be self sufficient relative to its food production and consumption
- Utilize inmate labor to construct and operate the system and create green industry job skills
- Utilize the existing kitchen and storage capacity for fish and plant processing and storage
- Highlight the potential for on-site renewable energy
- Minimize waste and utilize potential waste streams in value added ways
- Integrate outdoor spaces for crop production using aquaponic wastewater
- Consider other products to create revenue in addition to fish and plants
- Create ongoing educational and partnership opportunities

1.4 - Future Goals

It is the intention that this initial aquaponics system proposed for the Palmer building will be a pilot system. The long term goal, as expressed by the Sheriff’s office, is to utilize adjacent acreage surrounding the jail campus for the purposes of food production. The Palmer building could be expanded as a central hub for aquaculture supplying the adjacent greenhouses with nutrient rich fish effluent or serve as a model for future greenhouse and food production systems development.

Figure 1 - DCJ Site View West of Havana



1.5 - Executive Summary of Findings

We spent the first several weeks looking at ways in which to utilize the Palmer building in some capacity to grow fish and plants. Several different scenarios were explored, exhausted, and even revisited. After thoroughly reviewing all of the scenarios along with analyzing the significant risks posed by repurposing the building into an aquaponics operation, we came to the conclusion that it was not practical to invest in repurposing the building for this new use. We felt it was important, however, to include much of that research and analysis in the report because it is largely that investigative work that resulted in our final recommendation.

Building & System Recommendation – We are recommending the complete removal of the Palmer Building down to the concrete slab floor. Installation of a pre-fabricated industry standard greenhouse is advised to create the proper environmental conditions for the fish and plants. The greenhouse allows for the most cost effective and practical solution for the main building structure. The aquaponic system will grow a wide variety of plants tailored to help meet the current consumption demand of the county jail. The fish and plant systems will be connected in a recirculating loop but will also have the capability of being run independently. The system will grow head and romaine lettuce, herbs and fruiting plants along with Tilapia or Hybrid Striped Bass.

Capital Cost Summary – Costs identified in this preliminary feasibility analysis are summarized in the following table. A more accurate and detailed capital budget will be developed during the design development phase.

Table 1 - Capital Summary

Capital Summary	
Phase II - Design Dev	$ 103,500
Phase III - Construction	$ 151,000
Phase IV - Turnover	$ 31,800
Building Demo	$ 60,000
Greenhouse	$ 169,900
Aquaponics System	$ 114,474
Contingency 15%	$ 94,601
Working Capital	$ 6,222
Total startup capital	$ 731,498

Produce Production vs. Current Consumption - Based upon the conceptual system design including crop spacing, crop placement, typical yields and many other factors, we have estimated produce yields within the system and compared them to current consumption to illustrate the overall impact that the aquaponics system could have on current food purchasing costs. This table shows the percentage of production compared to current consumption, the estimated value of that production (using your current cost values) and the total annual value of the proposed production.

Table 2 - Production vs. Consumption

Item	Grown in	$/head/lb/cs	Est. prod/mth	units	% of current	Value/mth	Annual	units	Value/Year
Celery	Media	$16.95	1.9	cases	16%	$31.73	22.5	cases	$380.76
Cucumbers	Media	$0.37	22.3	lbs	50%	$8.36	267.8	lbs	$100.29
Bell Peppers	Media	$0.55	20.6	lbs	28%	$11.43	247.7	lbs	$137.21
Broccoli	Media	$0.86	30.0	lbs	19%	$25.75	360.0	lbs	$309.00
Zucchini	Media	$1.50	26.4	lbs	44%	$39.53	316.8	lbs	$474.41
Whole Tomatoes	Media	$0.74	48.8	lbs	30%	$36.20	585.0	lbs	$434.36
Cherry Tomatoes	Media	$14.15	4.2	cases	53%	$59.43	50.4	lbs	$713.16
Cilantro	Media	$1.00	1.2	bunch	60%	$1.20	14.4	lbs	$14.40
Head Lettuce	DWC	$0.70	138.7	cases	116%	$2,336.53	1664.0	cases	$28,038.40
Romaine Lettuce	DWC	$0.83	138.7	cases	117%	$2,756.69	1664.0	cases	$33,080.32
Total Value						**$5,306.86**			**$63,682.32**

Given these projections, the system is estimated to produce approximately $64,000 worth of produce annually. This number could go up or down depending on a variety of factors. The column noted as "% of Current" represents the estimated volume that the system will produce each month compared to the current monthly consumption of that same item. Again, these production numbers will vary depending on a variety of factors such as the environmental conditions, pest management, human resources, and production management to name a few.

Fish Production Value - The annual production of Hybrid Striped Bass (HSB) or Tilapia is projected at 7,189lbs per year or about 600 lbs per month. With a price per lb estimate of $3.00, the following table illustrates the anticipated value of the fish production in the aquaponics system. Year 1 values are significantly lower due to the introduction of the fish and their nine month grow out period.

Table 3 - Fish Production Value

Item Description	esc	Year 1	Year 2	Year 3	Year 4	Year 5
Tilapia/HSB	3%	$ 5,412.5	$ 21,650.0	$22,299.5	$22,968.5	$ 23,657.5

Combined annual production value of fish and plants (year 2) = $ 85,332

Total annual expenses including depreciation of assets (year 2) = $ 67,412

Annual avg. profit/loss = $ 17,920

While it is important to weigh the financial metrics associated with the project, it is equally important to consider the many “intangible” benefits that are possible.

The Denver County Jail has the unique opportunity to…

- Produce food locally and reduce thousands of food miles therefore decreasing carbon emissions
- Grow the freshest possible food on site
- Provide a healthy food choices for the staff and inmates
- Utilize wasted space in a productive and positive way
- Pioneer a model for sustainable agriculture in the corrections industry and beyond
- Create green industry job skills for inmates
- Create a work incentive program for inmates
- Provide therapeutic benefits associated with plant and animal husbandry
- Support local businesses
- Create ongoing educational and partnership opportunities

2.0 - Aquaponics Overview

Aquaponics bio-integrates aquaculture (growing fish) and hydroponics (growing plants in a soil-less media). The recirculating system brings together the best aspects of each system while minimizing waste, reducing demands on natural resources and providing a means for local, sustainable food production.

2.1 – Aquaculture

Farming of aquatic species such as fish, crustaceans and mollusks is big business. Global aquaculture production increased from less than 1 million tons in 1950 to 52.5 million tons in 2008, and over the past few decades, aquaculture has grown faster than any other form of food production. Last year, one third of the total world harvest of aquatic species was from aquaculture, around 45 million tons. Unfortunately, some of the aquaculture methods have come under fire. Aquatic species produce a large amount of different nitrogen compounds. In some fish farms the nitrogen rich wastewater is dumped into local streams and rivers. As these waste products flow through the natural water systems, they wreak havoc, causing algae blooms, which deplete the water of much needed oxygen, and often times kill many of the natural inhabitants. As well, fish farms in other countries have been allowed to decimate mangrove swamps, marshes or other wetland areas to produce large quantities of fish while in turn destroying the local ecosystems. Aquaponics can help to alleviate these negative impacts in some very unique ways.

2.2 - Hydroponics

Growing of plants in a soil-less media has increased in popularity since the 1970s for both the hobbyist and the commercial grower alike. Hydroponic media can be a nutrient rich water solution, expanded clay, perlite and/or many other inert materials. Growing plants hydroponically has proven to be very effective for most plant species and is significantly increasing its presence in many markets including food and medicine production. Hydroponics in controlled environments is often preferred over traditional soil–based growing methods because the exact nutrient content of the solution can be monitored and adjusted depending on the life cycle of the plants being grown. It also allows growing options in areas that have poor soil or water quality, land access or environmental issues. Hydroponics shows exceptional growth rates and production output for most crops, including lettuce, tomatoes and herbs. As with aquaculture, hydroponics has some features that are not necessarily sustainable. The majority of the nutrient solutions, sometimes referred to as "nutes" are water soluble synthetic or chemical compounds. They are costly and must be added on a continuous basis to maintain proper growing conditions. When a growing cycle is over, the nutrient solution needs to be removed and replaced producing a waste stream that cannot be easily disposed.

2.3 - Aquaponics

Aquaponics developed over 2000 years ago, in countries like China, Mexico and Peru where fish troughs flowed into rice paddies or farm fields. This method of food production proved remarkably efficient. Although the methods have changed, aquaponics today offers some very promising possibilities for sustainable food production using the principles found in ancient civilizations as well as nature. In the simplest form, aquaponics works as follows:

- Fish eat and then produce ammonia
- Water from a fish tank is pumped through a filter or directly into a media filled growbed
- Naturally occurring beneficial bacteria in the filter convert the ammonia to nitrites and nitrates
- The warm, oxygenated water is pumped to the plant roots which absorb the nutrients
- The clean water is recirculated back to the fish tank and the cycle is repeated

Aquaponics is a unique, synergistic growing technique in which fish and plants are grown together. The fish waste feeds the plants using organic hydroponic techniques. The plants, in turn, clean and filter the water that returns to the fish environment**.** Aquaponic gardening needs less than 10% of the water used by traditional soil based growing methods and can sustainably produce food that is 100% organic, with no worries about pesticides or mercury.

Aquaponics is an integrated and balanced system
using the by-product of one species to grow another

Aquaponics takes the good from both aquaculture and hydroponics, and corrects the negatives. Due to its organic nature, all inputs into the system must be organic. Because of the many benefits of aquaponics, it is becoming an increasingly popular alternative to soil gardening, hydroponics and traditional farming. Aquaponics food production means significantly less energy is used and less waste created when compared to fertilizer manufacturing and the use of heavy farm equipment dependent upon oil and gas. Future sustainable food production methods are going to be essential to providing food for an ever increasing world population with fewer natural resources, water, soil and land. Aquaponics systems offer extensive growing capabilities since they can incorporate various intensive and vertical growing methods in a relatively small footprint, close to the consumer.

Key Benefits of Aquaponics

- No fertilizer, pesticides or herbicides
- Fresh, chemical free food
- Opportunity for local food production to reduce food transportation miles
- Uses a fraction of the water, about 10% compared to traditional agriculture
- No soil-borne diseases (E-coli, Salmonella), no tilling, no weeds
- Reduced concerns of fish contamination or species depletion
- Greater crop yields, faster production
- No waste byproducts, all waste can be naturally reused
- Works in draught, places with poor soil quality or challenging climates
- Enhances the local economy and provides green job opportunities

3.0 - Scenario Planning

3.1 - Approach

This is a complex project with many layers, deliverables, and phases. The relationships and dependencies between each must be understood in order for the client to make the most appropriate decision. In the following sections we will highlight two main design scenarios we focused on in the study utilizing the key decision criteria described here.

3.2 - Key Decision Criteria

For the purposes of making some practical comparisons between scenarios, we are using some important decision criteria that each scenario should be measured against. Each criterion will be summarized and given a value of low, medium or high. These are presented in no particular order.

Integration potential with future expansion in mind– Will this system easily scale into the larger plan or will it require a significant overhaul which could bring into question the validity of building something that does not have much longevity and could be replaced in a short period of time?

Capital costs – How significant are the upfront costs? Do they allow the customer to meet their budget goals and thus enter into the project or is too cost prohibitive to undertake?

Building modifications & improvements – How much work must be done to repurpose the building and is it worth it?

Operating costs – How significant are the anticipated operating costs? While not every cost area can be fully and accurately assessed in this preliminary stage, we can anticipate in a general sense which scenarios will likely perform better than others.

Complexity – Is the proposed scenario simple in nature or highly complex which could lead to challenges with functionality, operations, training, and reliability?

Ability to meet short term food production goals – How well does the given scenario address the desired food production goals?

Environmental impact – How well does the proposed scenario deal with wastewater, food waste, and energy among other things?

Renewable energy potential – How easily can the proposed scenario utilize or adapt to renewable energy systems and technologies?

Practicality – What is the overall practicality of the proposed scenario?

4.0 - Scenario 1, The Palmer Building Concept

Our initial approach to the feasibility study had us looking at ways in which we could make the existing Palmer building work for the growing of fish and plants. Our first impressions of the strengths and weaknesses of the Palmer building with respect to the operation of a commercial aquaponics system are noted below. Following this we have provided a general overview of the proposed system concept followed by a more thorough examination of some of the concerns noted in the challenges and risks section. Finally, a summary of how this concept performs against the key decision criteria described previously is included at the end of this section.

4.1 - Opportunities and Strengths

1. The building is 60’ wide and 120’ long and has a 4” concrete floor throughout which will be adequate for supporting the loads of the fish and hydroponic tanks. More detail on this can be found in the water section of the document
2. The building interior and exterior appear to be in good shape and structurally sound
3. The majority of the building has an open floor plan providing a good opportunity to utilize floor space without significant amounts of interior demolition
4. The N/S building orientation allows for positioning of the plant systems and fish systems in desirable locations
5. Main entranceway vestibule provides for a higher level of bio-security than a single door entrance into the facility
6. Existing floor drains are convenient for cleaning and in the case of any water discharge that might take place in the building

4.2 - Challenges and Risks

1. **Lighting** - The repurposing of the building to a fish and plant production environment will require adequate light levels for the growth of the plants. The light required to grow the plants effectively can come from either natural sunlight, artificial light or some combination of both. The introduction of natural light will require the replacement of the existing roof panels to a suitable glazing that will allow enough light penetration to promote photosynthesis within the plants.
    a. Replacing the roof panels to allow the availability of natural light will…
        i. Result in additional capital costs
        ii. Impact the building’s existing heating and cooling systems likely requiring reengineering of these systems to achieve optimal temperature conditions
        iii. Impact the building’s snow loading capacity
    b. Installing artificial lighting will…
        i. Result in additional capital and operating costs
        ii. Dissipate heat which will impact the building’s existing HVAC systems
        iii. Require ongoing replacement and maintenance

2. **Condensation** - Aquaculture systems in enclosed environments such as this can create excess moisture due to evaporation and condensation which can compromise the integrity of building materials and create the potential for biological hazards such as mold.

4.3 - General concept

Following our preliminary assessment of the building we moved forward with some conceptual design planning while also taking a closer look at some of the areas that presented the most risk to the project.

4.3.1 - Demolition Plan

- Remove central control desk
- Remove central lavatory with urinals on back wall
- Remove central janitors closet
- Remove urinals
- Remove toilets in latrine area
- Possible modification of shower area required
- Remove drop ceiling panels from grid
- Remove dormitory cots
- Remove TV's and other accessories in ceiling grid and on walls

Figure 2 - Existing Building Plan

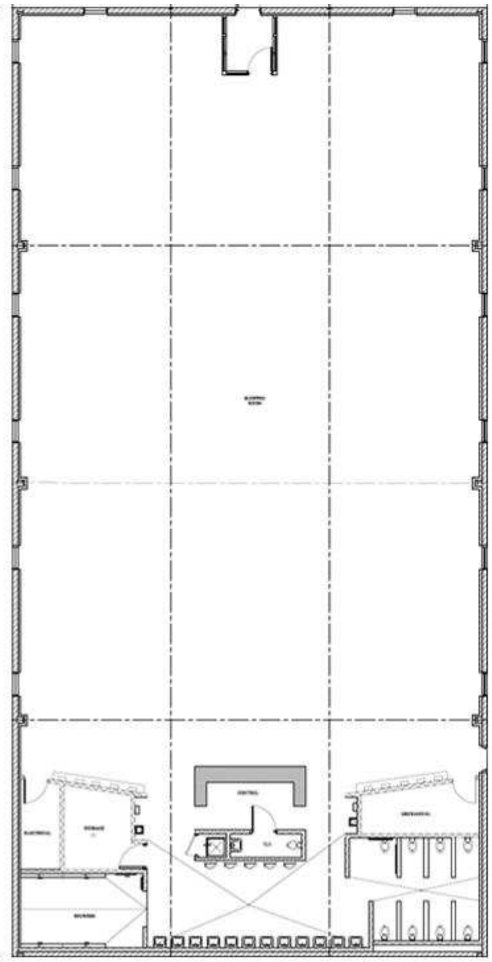
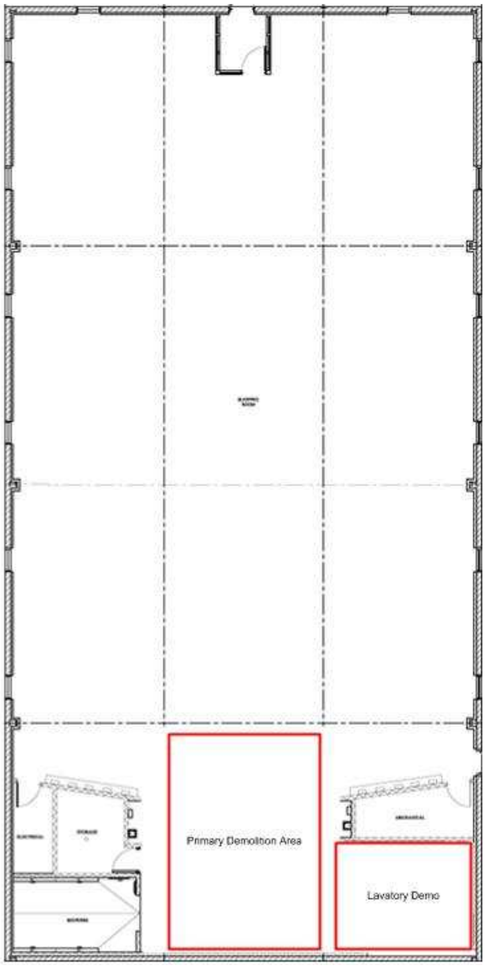


Figure 3 - Demolition Plan



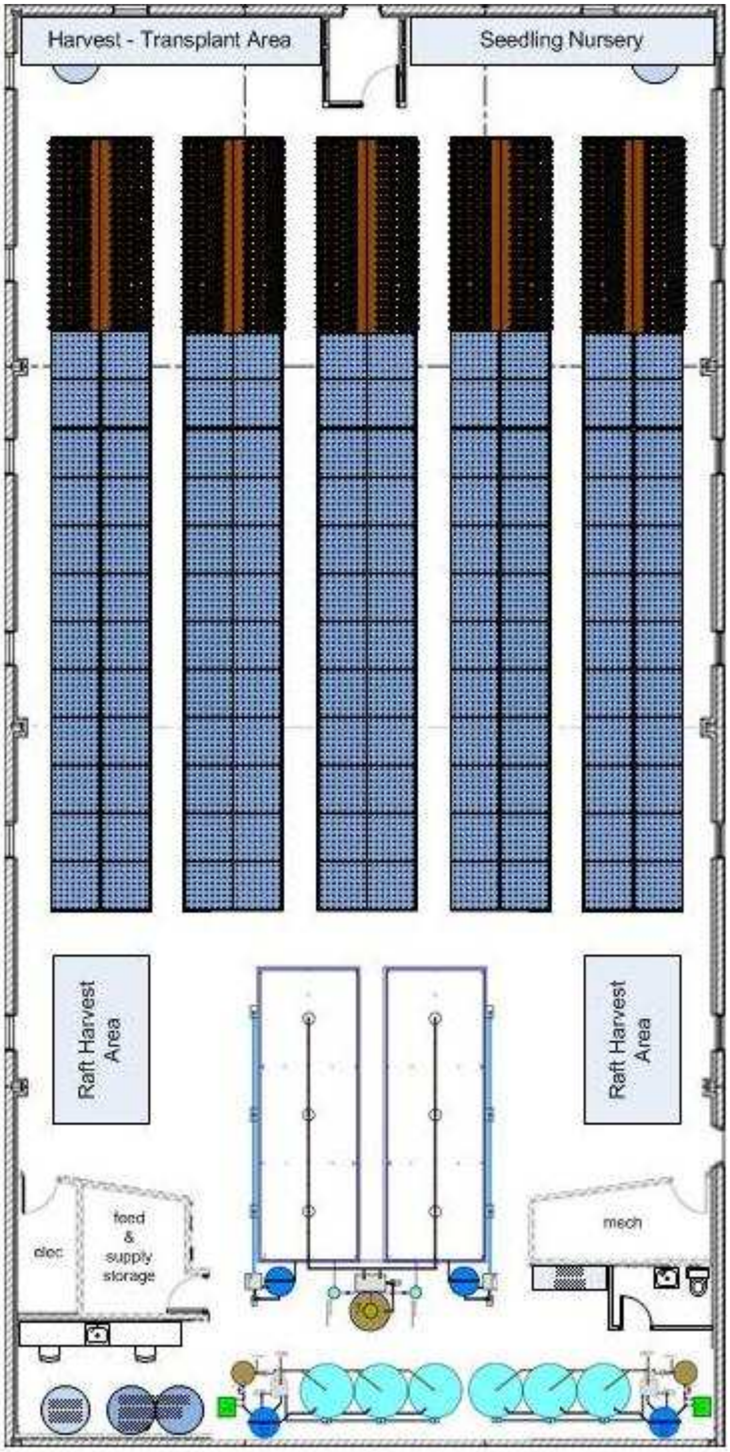
4.3.2 - Aquaponic System Layout

Our concept plan for an aquaponics system in the Palmer Building can be seen in Figure 3. The details of the system will be described in the Aquaponics System Overview Section found later in this document. The purpose of this illustration is to show how the proposed system integrates into the existing building following the interior demolition plan.

In this drawing the main fish tanks for grow out of the fish population are the two rectangular raceways on the south end of the building centrally located in the area previously occupied by the control desk and janitors closet. There are also six additional circular tanks against the south wall for the raising of fingerlings and for fresh water, quarantine and purging as needed. These systems are connected to the plant system which is composed of five 8'x64' hybrid media and deep water culture growing beds. Additional space was provided for harvesting, a nursery, desk space, storage and general circulation.

With a basic system concept plan in place we were now able to take a more accurate look at what the options might be for artificial or natural lighting of the plant areas which was one of our major concern points identified in the risk analysis.

Figure 4 - Palmer Building System Concept



4.4 - Challenges and Risks: Point #1 - Lighting

Understanding that lighting the building would likely present some challenges we engaged veteran aquaponic and hydroponic lighting engineer, Jesse Hull, from Imagine Aquaponics in Milwaukee, WI to look at several important factors related to artificial lighting in this enclosed building.

- Recommended fixtures and ballasts
- Recommended layout of fixtures
- Upfront purchasing costs
- Energy consumption and operating costs
- Annual repair and replacement costs
- Heat dissipation

4.4.1 - Lighting Scenario 1 – Combined T5 and HID fixtures

The white rectangular boxes located over the blue rafts (lettuce/leafy greens) represent the layout of the T5 fixtures. T5 fixtures are popular grow lights because of their relatively low heat dissipation and energy consumption. High Intensity Discharge (HIDs) Lamps can provide a wider coverage area and higher light intensity but consume more power. The white boxes over the brown areas (tomatoes and cucumbers) represent the HID light locations.

Figure 5 – Top View of Combined T5 and HID Lighting Plan – Additional BTUs = 394,000

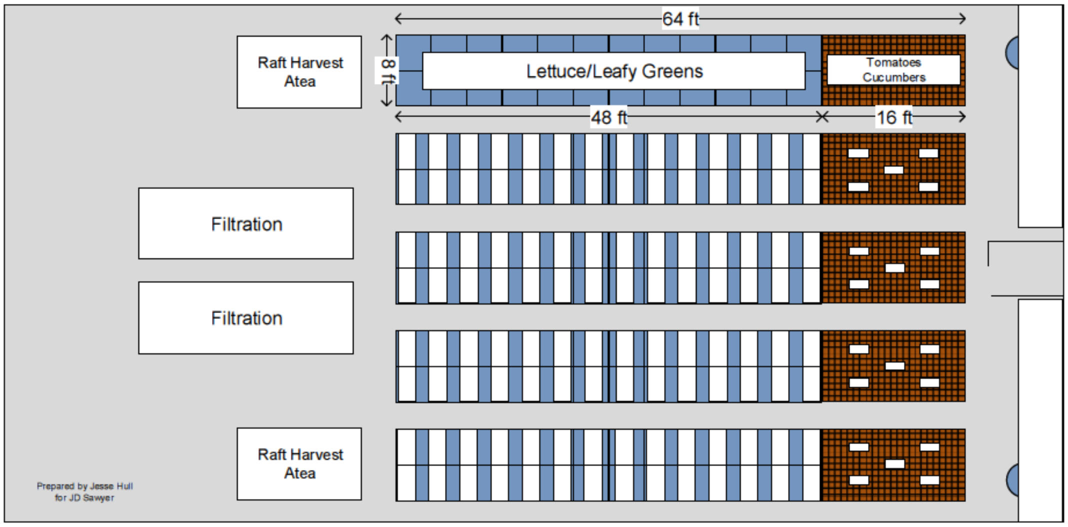
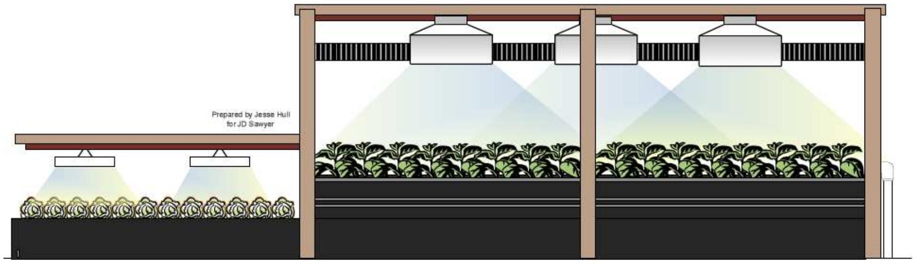


Figure 6 - Side elevation of T5 - HID Plan



Summary of anticipated costs for lighting scenario 1

Table 4 - Upfront Costs for Fixtures

Fixture	unit $	units	total
T5HO Lamp w/ Bulbs	$ 280	140	$ 39,200
HID Lamp w/ ballast & bulb	$ 330	25	$ 8,250
Linear Light Mover	$ 420	10	$ 4,200
Control Center (Timers, Contactors, etc)	$ 2,200	1	$ 2,200
Total Initial Cost			$ 53,850

Table 5 - Bulb Replacement Costs

Bulb Replacement Costs	unit $	units	total	term (yrs)	annual
T5HO Bulbs	$ 6.00	1120	$ 6,720.00	3	$2,240.00
HID Bulbs	$ 25.00	20	$ 500.00	1	$ 500.00
Total Annual Replacement Costs					$2,740.00

Table 6 - Anticipated Usage and Operating Costs

Fixture	units	watts	kwh	op hrs	total kwh	$/kwh	daily	monthly	annual
T5HO Lamp w/ Bulbs	140	432	60.5	16	967.7	0.10	$ 97	$ 2,903	$ 34,836
HID Lamp w/ ballast & bulb	25	1000	25.0	16	400.0	0.10	$ 40	$ 1,200	$ 14,400
Total Operating Costs							$ 137	$ 4,160	$ 49,920

Table 7 - Total Cost of Ownership

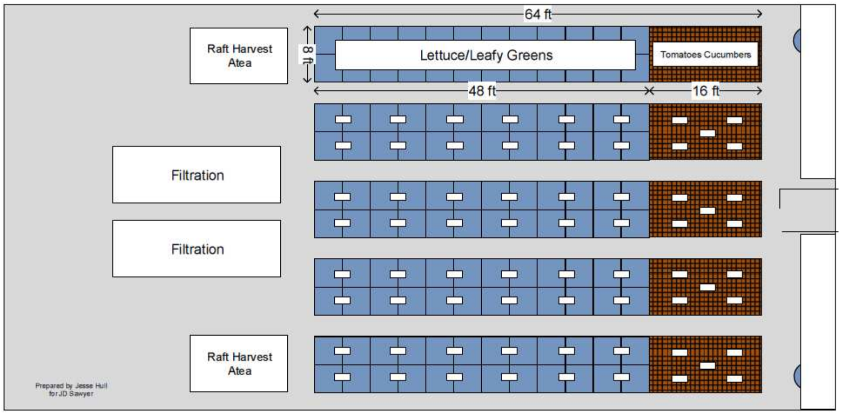
Total Annual Cost of Ownership	
Depreciation 10 yr	$ 5,385
Operations	$ 49,920
Total Annual Cost of Ownership	$ 55,305

Heat Dissipation – The net increase on the buildings thermal load given the above lighting configuration is approximately 394,000 btu.

4.4.2 - Lighting Scenario 2 – HID lamps throughout

In this scenario, HID lighting was proposed for both the lettuce and tomato production areas.

Figure 7 - Top view of HID Lighting Plan – Additional BTUs = 521,000



Summary of anticipated costs for lighting scenario 2

Table 8 - Upfront Costs for Fixtures

Fixture	unit $	units	total
HID Lamp w/ ballast & bulb	$ 330	85	$ 28,050
Linear Light Mover	$ 420	15	$ 6,300
Control Center (Timers, Contactors, etc)	$ 2,200	1	$ 2,200
Total Initial Cost			$ 36,550

Table 9 - Bulb Replacement Costs

Bulb Replacement Costs	unit $	units	total	term (yrs)	annual
HID Bulbs	$ 25.00	80	$ 2,000.00	1	$2,000.00
Total Annual Replacement Costs					$2,000.00

Table 10 - Anticipated Usage and Operating Costs

Fixture	units	watts	kwh	op hrs	total kwh	$/kwh	daily	monthly	annual
HID Lamp w/ ballast & bulb	85	1000	85.0	16	1360.0	0.10	$ 136	$ 4,080	$ 48,960
Total Operating Costs							$ 136	$ 4,080	$ 48,960

Table 11 - Total Cost of Ownership

Total Annual Cost of Ownership	
Depreciation 10 yr	$ 3,655
Operations	$ 48,960
Total Annual Cost of Ownership	$ 52,615

Heat Dissipation – The net increase on the buildings thermal load given the above lighting configuration in lighting scenario 2 is approximately 521,000 Btu.

Lighting summary – It became exceedingly obvious that an artificial lighting solution would not be at all practical on a number of levels. The operating costs for the lights alone doubled the cost of operations for the entire production facility while also adding significant upfront costs to the project. The impact on the buildings existing mechanical systems would also be extraordinary and require significant capital costs in equipment upgrades and construction. Energy requirements to cool the building would significantly increase in order to attempt to maintain reasonable temperatures for the fish and plants. Jesse Hull offered some creative solutions for partially capturing waste heat from the lights such as circulating water through the lighting system and then the fish system to help passively heat the fish tanks. Despite these ideas the complexity of this solution would be high, would add additional costs and the overall net benefit would be difficult to predict without a more detailed analysis.

4.4.3 - Replacement Roof Scenario

Following the lighting study we felt it would be prudent to investigate the possibility of replacing the roof of the Palmer building with a translucent greenhouse covering to allow natural light to penetrate the building. This was an idea that came up in early conversations about the project so we wanted to be sure to investigate this possibility. We engaged Taylor Webb, from Manifold Design Development in Denver to provide three dimensional drawings of the building with a focus on various sun angles at both the winter and summer solstice to see the amount of coverage and shadowing the building would create.

Figure 8 - Winter Views at 9am, noon, and 3pm respectively

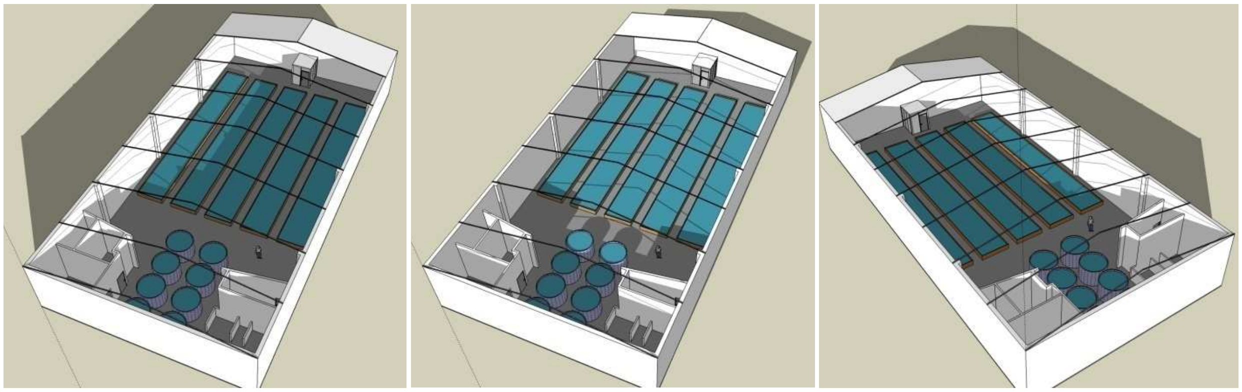
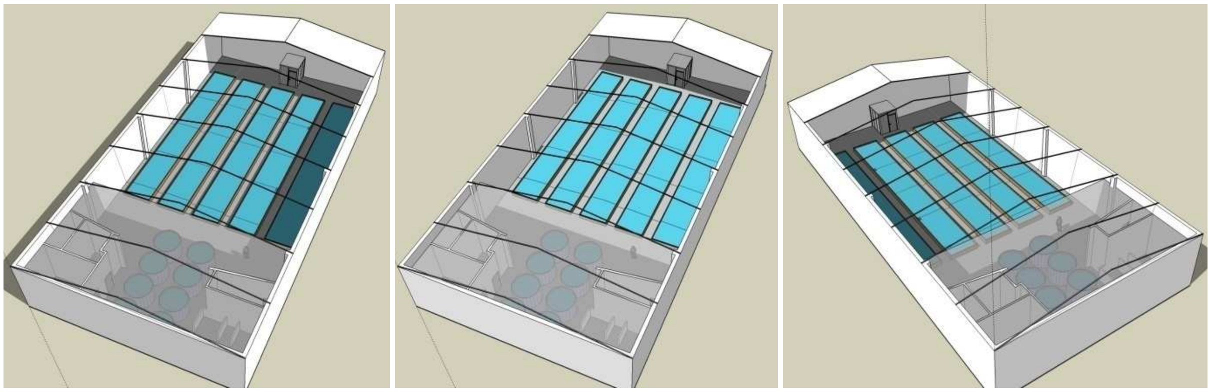
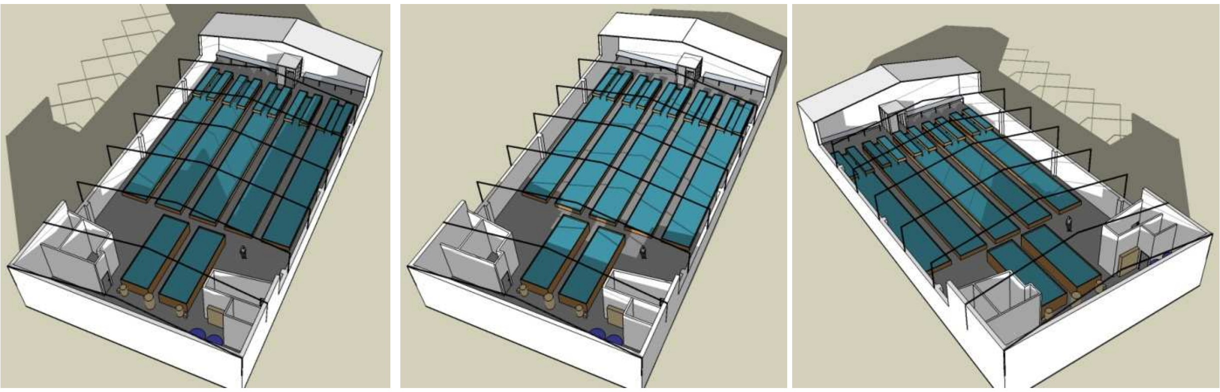


Figure 9 - Summer Views at 9am, noon, and 3pm respectively



Due to excessive shadowing from the side walls we also looked at the effect of glazing the east and west sidewalls coming down 8’ from the top of the wall.

Figure 10 - Winter Views at 9am, noon, and 3pm respectively



Replacement Roof Summary - Even with the best intentions of wanting to use natural light to our advantage, it was clear due to shading and lower light levels in the winter months that an artificial lighting solution would still have to exist in order to provide optimal lighting for the plants on a year round basis. We also concluded that without replacing panels and analyzing the light levels with a PAR light meter we would not be able to effectively determine the PAR light levels at the surface of the plants (PAR stands for photosynthetically active radiation and is a measurement of the wave range that photosynthetic organisms such as plants use in the process of photosynthesis which is how plants convert sun energy into chemical energy). Further complicating the solution was the added cost of replacing the roof, the impacts of the additional heat load in the building and the uncertainty of being able to properly seal the new greenhouse panels to the existing structural frame which was not designed for standard greenhouse glazing.

4.5 - Challenges and Risks: Point #2 – Condensation and Interior Finishes

One of the primary concerns for indoor fish systems located in areas that experience cold winters is the effect of moisture on the integrity and durability of the structure that surrounds the system. Almost by definition, fish systems produce high amounts of moisture that necessarily must be controlled either actively or passively. Indeed, aeration and pumping systems encourage this process.

As water vapor exits a fish system and enters the surrounding atmosphere, it quickly raises the relative humidity in the space. All inside surfaces and equipment necessarily are exposed to this humidity.

During winter, non-insulated roofs and exterior walls quickly reach temperatures at or near outside temperature. When moisture comes in contact with these cold surfaces, moisture condenses and runs down these walls or falls as rain from roofs and ceilings.

Even when these surfaces are insulated, they are still prone to condensation if they are not covered with an adequate vapor barrier. Without a vapor barrier or in the face of failed vapor barrier, moisture will easily move behind the barrier and come in contact with cold wall and roof surfaces. The insulation becomes saturated with water, and mold quickly begins to grow. Obviously, this is a situation that must be avoided at all cost.

We have found the best way to avoid this situation is to apply spray-on polyurethane foam to all existing wall and ceiling surfaces. This material is commonly used, commonly available, relatively inexpensive to purchase and apply, and serves as both insulation and a very effective vapor barrier. Utilities such as electrical outlets and conduit and piping can be affixed to the inside surface of the cured polyurethane, and no other preparation or maintenance is required. The application is permanent and utilitarian in appearance.

4.6 - Key Criteria Summary of Scenario 1 – The Palmer Building Concept

Integration potential with future expansion in mind – **Result**: **Low**
The long-term expansion plan calls for greenhouses on adjacent property for the growing of the produce required for consumption by the inmates and staff. Surplus production could be sold at markets or restaurants, provided to food banks or whatever use is deemed most appropriate. The intention of this pilot project is to help understand the validity of that plan on a smaller scale before making significant investments in property acquisition, site development, future greenhouses etc. We feel that modifying the Palmer building and trying to grow under artificial lights does not represent a practical solution and therefore would not create a model for controlled environment agriculture that would be sustainable or reproducible.

Capital Costs – **Result**: **High**
This scenario requires that the building either be outfitted with artificial lighting or a translucent glazed roof, or some combination of both. With the additional heat load from artificial lights and natural sunlight penetration, the building’s mechanical systems will require upgrading. Significant capital costs would result with replacing the roof, selective demolition and the interior vapor barrier treatments. The

existing electrical service will also require upgrades to handle either of the two lighting scenarios that were developed. We did not go down the path of assessing all of the capital costs required to modify the building in more detail due to the fact that the lighting system itself proved to be impractical and unsustainable.

Building Modifications – **Result**: **High**
Some interior demolition is necessary to make room for the aquaculture portion of the system. In this scenario, the drop ceiling would need to be removed and walls would be treated with a spray-on vapor barrier to insulate and prevent moisture damage as discussed previously. HVAC systems would need to be upgraded given the additional heat load as noted above and electrical systems would also require upgrades. In addition, much of the HVAC ductwork that is in the plenum space would also impact the availability of natural light to the plants. We met with MKK Engineering and Reilly Johnson Architecture to review this scenario and other scenarios related to using the Palmer building. Again, it was realized and confirmed without the need for a much deeper cost analysis that we were not on a course that would be cost effective or produce anything of value for the Jail.

Operating Costs – **Result**: **High**
Running an artificial lighting system will have a serious impact on monthly operating costs and the overall ROI from the system. For example, the monthly cost for all of the head lettuce consumed on site equals $4,400. With the current system we anticipate being able to meet the current demand (detailed later in the study). However, when the annual total cost of ownership and operations of the lighting system is divided out monthly, the resulting value is over $4,600 in expenses a month. Therefore the lights alone negate any chance for the system to create a return on investment and that does not include any of the other anticipated operating costs to support and maintain the system and environment.

Complexity – **Result**: **High**
Given the scenario we have been describing there are many layers of complexity as it relates to modifying the building, installing lighting systems and trusses along with interior improvements that would need to take place. Maintaining the proper environmental conditions for the fish, and more specifically the plants, in the existing building will require a more sophisticated level of automation and control equipment that will add to the overall expense of the project.

Ability to meet short term food production goals – **Result**: **High**
The aquaponic system design itself can meet close to 100% of the total head lettuce demand and a portion of the other produce requirements. This analysis is detailed later in this document. For the purposes of directly answering this criteria point the answer is, yes. However, the issue at hand is whether or not we can meet the demand in an economically sustainable way and that answer is no.

Environmental impact – **Result**: **High**
The system can store and reuse solid waste to a certain degree within the main aquaponics system itself. In addition, solids can be used in compost and other soil-based growing applications or in an outdoor greenhouse. It is likely the case that not all of the solid waste could be reused without partnering with the neighboring Urban Farm. In regards to energy, the artificial lighting system is going

to put a significant burden on the energy demand and cooling systems which are both reliant on electricity and fossil fuels.

Renewable energy potential – **Result**: **Low**
The potential exists to redirect waste heat from the lights back into the water to help provide a source of heat. The high electrical demand from the artificial lights would be too high for any practical solar PV application. The potential to glaze the roof and allow natural sunlight to penetrate could be helpful but it is unclear at this time what the effective PAR light intensity will be at the plant level without actually replacing roof panels and engaging in further experimentation. We also believe that lights would still have to be run as a supplement to the available natural light.

Practicality – **Result: Low**
There is a great deal of concern amongst the project team about the practicality of growing produce consistently, economically, and sustainably in an enclosed building based upon the cost and energy demands of the required lighting system and the costs and potential impact to the building by modifying the roof. The aquaponics system design itself is generally considered practical in terms of its theoretical productivity, use of floor space, and conservation of water among other things.

Scenario 1 Conclusion & Recommendation – It should be noted that several other variations of using the Palmer building were analyzed utilizing the same decision criteria. These options are included in the appendix for reference. We do not recommend pursuing any option that involves utilizing the Palmer building with a requirement for artificial lighting.

Supporting Letter from Jesse Hull, Imagine Aquaponics LLC

Three options were being considered toward incorporating an artificial lighting system into the Palmer building for the Denver County Jail Project. The first was a system completely reliant on artificial lights for photosynthesis. The second involved replacing the roof of the building with polycarbonate panels to allow for natural sunlight to enter. The third scenario investigated the partial or complete tear down of the wall(s) when it was discovered that the height of those walls would not allow sufficient sunlight to enter even if the roof was replaced.

Schematics, initial cost (purchasing the lights and components), and operating cost (wattage consumed) information was provided in order to assess the feasibility of the first option. Heat load (btu) output was also provided for each option to assess HVAC requirements. Negotiations were made with industry contacts concerning the potential purchase of lighting equipment, including automated light movers and control center components. Heavy discounts were therefore applied to the purchase prices listed. Two separate options were laid out, one involving the use of high intensity discharge (HID) lamps throughout the facility, and another involving the use of HID and high output T5 fluorescent lamps. Both options included the use of automated light movers to reduce the amount of lighting required, as well as to provide documented health benefits to the crop.

With initial purchase costs ranging from $38,550 to $53,850 and heat load outputs of 394,000 to 521,000 btu, it was concluded that artificial lighting would not be appropriate for a facility of this size and configuration in creating a return on the investment. Sun angle data revealed that even with the roof and partial walls replaced with greenhouse panels, adequate natural light levels could not be maintained in the growing environment to lessen the need for artificial lights. With doubts expressed early on as to whether the building could be completely or partially reliant on artificial lighting, I support the recommendation to replace the Palmer building with a greenhouse of sufficient size and scope to prove the concept.

Jesse Hull
Imagine Aquaponics, LLC

5.0 - Scenario 2, The Greenhouse Concept

It became apparent through the course of the study that the repurposing of the Palmer Building was not going to meet the goals of the project and would create more costs and drain on resources than if we did nothing at all. This result did not necessarily come as a surprise either, but we felt it was of critical importance to demonstrate that fact early on and provide supporting data. Admittedly we were also not under the assumption that removing and replacing the building was in the realm of possibility for the Sheriff's department. However, following an onsite meeting with consultants from Reilly Johnson Architecture and MKK Consulting Engineers we spoke to Chief Diggins about our findings and expressed our concerns about repurposing the building. The possibility of taking the entire building down to its structural framework and installing a greenhouse glazing all the way around was discussed as well as the possibility of taking the building down all together and installing a new pre-fabricated greenhouse on the remaining concrete slab. Chief Diggins agreed that we should take a closer look at these concepts to see if they proved more viable. We therefore had two new options to investigate; one to convert the building to a greenhouse using its existing framework or a second option of installing a brand new greenhouse in place of the Palmer building.

5.1 - Option 1 – Converting the building into a greenhouse using the existing building frame

5.1.1 - Opportunities and Strengths

Structure – The building appears to be structurally sound although a more formal review should be performed in the design development phase if this option is pursued. No new structure would have to be created and attached to the supporting slab below.

Building height - The building height affords the opportunity to take advantage of more vertical growing applications which could potentially lead to increased production levels.

5.1.2 - Challenges and Risks

Selective Demolition of the building – FCI Constructors was able to provide an initial quote for selective demo of the building. Selective demolition projects often cost more than complete demolition jobs because of the added overhead, time and resources required to properly work around and maintain the integrity of the components left behind.

Table 12 - Selective Demolition Quote

Item	Cost
GC's: 1 month	$12,996
Demo	$73,431
Dump Fees	$7,000
Contingency (5%)	$5,321
Soft Costs / O&P (10%)	$9,874
Total Estimate:	**$108,622**

Sun penetration – The spacing of the existing framework was never designed with light penetration in mind, it was designed to support the weight of the building materials and roof in an enclosed structure. Based upon what we know from the building plans about the structure of the building we can foresee areas in which portions of the building frame could create long shadows in the plant environment.

Appearance – It is difficult to predict what the outer appearance of the building will ultimately be with the new double layer polycarbonate panels installed against the existing building frame. This can result in something that is unsightly compared to a predesigned structure. Since it is an unknown item at this time it is being noted here as a potential risk point.

Vendor Support – The fact that this is a non-standard greenhouse will mean that much of the equipment that is designed for greenhouses such as fans and vent walls will have to be customized to work in the existing framework. In addition, there is concern although not validated yet, that utilizing greenhouse panels in a non-standard application may result in a lack of warranty or vendor support if we experience difficulties. In general, we would not likely have the support of a greenhouse manufacturing company behind us if we are attempting a retrofit project. Again, this has not been confirmed this is simply an educated assumption based upon past experience working with equipment manufacturers on large construction projects.

Building Leaks – Being that this is a non-standard application of greenhouse glazing, it is a shared concern among the team that the building may not seal properly. This is an important element to effectively heating and cooling greenhouses. There is a great deal of supporting data in the controlled environment agriculture industry regarding the negative impacts on heating and cooling systems due to air leaks in greenhouses. This can be a difficult problem to manage and track due to the high building profile and could result in increased heating and cooling costs along with potential increases in ongoing maintenance costs.

Material Costs – The larger surface area of the existing building frame will require more material to cover it resulting in higher upfront costs. Additional customization of mechanical equipment and modifications to the frame in order to support the new panels is expected to be significant. Detailed costs have not been explored in this area and can be if it is decided that this option should be examined further in the design development phase.

Labor – While we don’t have a labor estimate on this scenario we anticipate this number to be higher than the installation cost for a standard kit greenhouse. A non-standard installation will result in more upfront planning and additional installation time because construction efficiencies would not be fully understood in a custom application. The additional height of the greenhouse frame will require lifts and workers to be performing at more dangerous heights between 17’ and 22’ above the finished floor. An onsite assessment, including removal of some wall sections would be required to achieve an accurate estimate for the project. This can be performed in the design development phase if so desired.

Not a reproducible model – As we have touched on before, it’s important that we create a system that will help yield functionally relevant data and provide a model for future development opportunities. This adaptation of the existing building does not represent a reproducible model for future installations.

5.2 - Option 2, Install a new greenhouse on the existing slab

Preliminary cost estimates for a new greenhouse system were provided by American Clayworks, a Colorado based greenhouse equipment and supply company. The materials estimate for the Nexus Teton Greenhouse provided below includes fully engineered stamped drawings, the entire building structural frame work, plastic or polycarbonate covering, all vent fans, heating systems, cooling walls and horizontal air flow fans (described later). We have also included in the estimate, operable side wall vents allowing for passive cooling in the summer months in addition to the evaporative cooling wall. A bug screening enclosure should also be included to help manage pests.

Table 13 - New Greenhouse Construction Cost Estimate

Item	Units	Total
Nexus Teton Greenhouse (pictured)	7,200 s.f.	$167,400
Labor Estimate	7,200 s.f.	$ 43,200
Total		**$ 210,600**

5.2.1 - Opportunities and Strengths

Demolition of Palmer Building – The complete demolition of the Palmer building has been estimated by FCI Inc. at $60,000. This is listed as an opportunity for comparative purposes against the more expensive selective demolition at $108,000 required in the option 1 plan.

Environment – Installing a pre-fabricated greenhouse insures that we are working with a building that will provide desirable light levels and environmental conditions suitable for plant growing. All of the required heating and cooling systems as noted above are included with the structure and are designed specifically for greenhouse applications.

Reproducible Model – Installing an established greenhouse allows for additional versions of the same building to be installed in the long term plan on the adjacent property. This affords several advantages such as maintaining the uniformity of building appearances across both the present and future site. It allows for the ability to collect data on operating costs, production and maintenance in the pilot phase which will yield a higher degree of accuracy and reliability in planning for future expansion. Uniformity of buildings and systems will allow for higher consistency in operations

5.2.2 - Challenges and Risks

Heating and Cooling - A greenhouse tends to need more heating at night than a more highly insulated structure. Conversely, controlling summer heat temperatures can be challenging and a variety of cooling systems may need to be employed. A more detailed description of the greenhouse heating and cooling systems is described in the following overview.

Picture 1 – Nexus Teton Greenhouse

Building Security – A typical greenhouse enclosure will have plastic sheeting or polycarbonate paneling for walls and roofing. This material is significantly lighter and could be more easily penetrated or damaged than a traditional stud frame exterior wall. This is a potential risk point that the county jail officials will have to assess.

Foundation Support – The gutter connect component of the two greenhouses requires support columns down the middle of the concrete floor which was not designed to support the weight of a building. A detailed investigation of the existing concrete slab would need to be completed by a qualified foundation or soils engineer in the design development phase. It may result in having to provide additional foundational support in the middle of the floor via caissons or some other element under the gutter support columns.

5.3 - The Greenhouse Environment

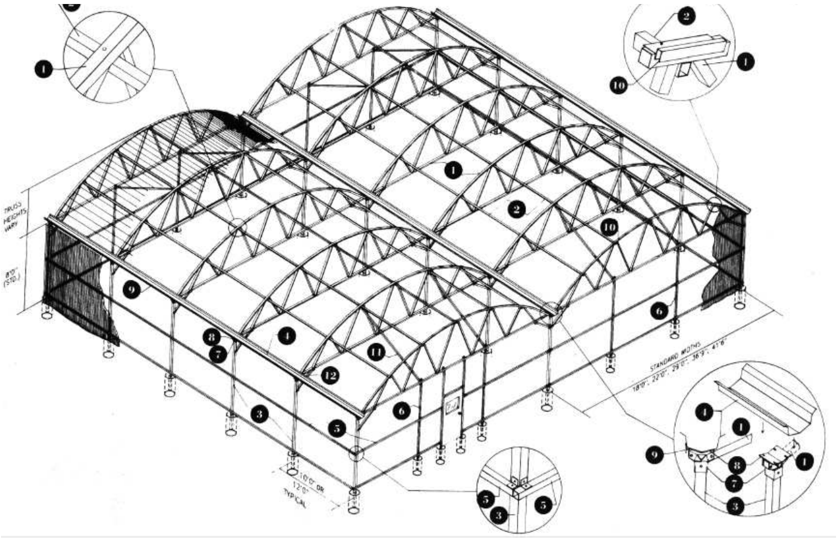


Figure 11 - Nexus Gutter Connect Greenhouse

Description - The low profile Quonset roof design of the Nexus Teton offers a cost effective, energy efficient growing environment. The clear span trusses maximize growing space, using minimum roof covering and can be gutter connected for ease of expansion. The Teton is most often covered with double poly but is adaptable to a variety of coverings. Designed for easy conversion, different rigid coverings can be added later with minimal changes to the structural members. Nexus Teton trusses are factory welded using galvanized steel to offer consistency in dimension and ease of site construction. With one piece trusses, we ship fewer parts and your greenhouse goes together much faster. Therefore, you get big savings during construction. Widespan trusses give you additional crop space and minimize shadowing. They can also be manufactured and shipped in two-piece sections to minimize transportation costs. With our gutter design, you can easily direct roof water to a retention pond or cistern. Baked-on white enamel adds corrosion resistance to the topside of the pre-galvanized "walk-in" gutter system. Options available include partition walls to create separate climate zones and single or double vent systems with aluminum extrusions which can be installed on gable ends, sidewalls, or within the roof. The Teton can be designed for either sub-arctic or tropical environments. The house allows for expansion in either direction. It is designed with a straight bottom chord but is available with a high clearance truss option. This permits the addition of overhead and oversized doors without having to change to a higher sidewall height.

Heating and Cooling Systems - Air temperature in the greenhouse will be maintained through a variety of systems. One of the most important and least costly methods of maintaining proper environmental temperatures is through the storing of water as thermal mass which is detailed later in this study. This will dramatically reduce reliance on heating and cooling systems that require energy from the grid. However, thermal mass alone will not be enough to handle the rapid variations in air temperature that take place in our climate.

Another important factor is simply maintaining a leak free structure. One of the primary reasons we are recommending a new greenhouse system is to ensure that we don't have difficulty with leaks that were identified as a risk if we were to retrofit a structure not originally designed to be a greenhouse. Air leaks and gaps can be extremely detrimental towards a building's ability to properly maintain temperature thus increasing overall energy waste and cost.

The heating, cooling and control systems (with the exception of the shade cloth) described in this section are all included in the greenhouse kit system we have quoted in the capital budget.

Evaporative Cooling – Most greenhouses employ a system of pads along one wall of the greenhouse where water saturates a porous material and is continuously recirculated through the pad. The pad is adjacent to open air vents to the outside of the building. Large ventilation fans located on the wall opposite of the evaporative cooling pad draw outside air across the cool wet pad to help provide a source of cool air for the greenhouse. This is a relatively effective and efficient way of cooling the building.

Picture 2 - Evaporative Cooling Wall

In our design we have chosen to locate the cooling pad on the south end of the building for a few reasons:

- We want the plants to have the coolest air possible. Growing plants in a greenhouse in the middle of the summer can be extremely challenging so you want the plants to be as close to the cool pad wall as possible. In general the coolest area of the greenhouse will always be closest to the pad wall and the warmest area will be closest to the ventilation fans. In this design the plants located on the south end will be closest to the pad wall and the fish will be in the warmer end of the building. This is also good because we want the fish to be warm without having to provide additional supplemental heat. Lettuce demands cooler temperatures and plants such as tomatoes like warmer temperatures so these plants are located in the correct locations in the greenhouse environment. These planting locations are illustrated in the upcoming section on the aquaponics system design.
- Prevailing winds in Colorado blow from the south to the north which means that the vented pad wall will be subject to natural wind flow from the south. This means that the ventilation fans will not have to work as hard to draw cool air across the building if that air is being helped by the natural wind flow.

- Our harvesting area is located along the south wall. There will be regular weekly harvests and lettuce in particular should be harvested in cool temperatures before being transported to the cold storage facility. The harvesting location is therefore located on the south end of the building against the pad wall.

Vent Fans – In order for the evaporative cooling wall to be effective, large ventilation fans will be installed along the north wall of the greenhouse to draw the cool air across the greenhouse. These fans are designed to move large volumes of air and the central control system will turn them on and off as needed.

Passive ventilation – In addition to the evaporative cooling wall, sidewall and roof top ridge vents can be installed in the greenhouse to be opened and closed as needed. Opening the side walls will allow passive ventilation and cooling in the summer months and convection air flow up through the top of the greenhouse ridge vent where hot air gets trapped and needs to be released.

Shade Cloth – In cases of extreme heat and solar radiation, installing a reflective shade cloth to help reduce heat stress on the plants can help with the buildings overall cooling systems. A reflective shade cloth installed on the outside of the building will reflect a percentage of solar radiation from penetrating the building and causing excessive heat gain. The right shade cloth can be chosen to allow for enough PAR light to penetrate to still be able to maintain plant growth without the added heat.

Heating Systems – It can’t be emphasized enough that the capacity to maintain warm water as thermal mass will help the overall heating plan for the building substantially. It is much more efficient to heat water than air. However, the only drawback to water acting as thermal mass is that it can’t react quickly to wide temperature swings. Therefore, it is important to have systems that can maintain the proper air temperature for the plants especially. A series of natural gas or hot water driven air heaters designed for greenhouses can be installed. The heaters are mounted in the ceiling grid and will blow warm air across the greenhouse to maintain proper air temperatures.

Picture 3 - Modine Space Heater

Picture 4 - HAF Fan

Air Movement – A series of smaller fans called horizontal air flow (HAF) fans will be installed throughout the greenhouse. The HAF fans are designed to circulate air and help reduce heating costs by creating a uniform temperature throughout the building.

Control systems – A central control system will be installed which will manage all associated HVAC equipment through thermostats and is fully programmable and customizable. A central control system will be able to turn on fans, heaters, pumps and open vents automatically and therefore be able to maintain proper temperatures throughout the environment and ultimately help reduce costs. Details and specifications on the control system will be worked out in the design development phase when we engage our local greenhouse engineering company.

Pest Control – The vent walls and other openings should be screened to help prevent the entrance of pests which can wreak havoc on crops grown in controlled environment settings such as greenhouses. In order to maintain efficient air flow and performance of the ventilation fans, an extension of the building structure needs to be included for the pest screening.

5.4 - Key Criteria Summary of Option 2 – Install a new greenhouse on the existing slab

Integration potential with future expansion in mind – **Result: High**
As described in the opportunities and strengths section, utilizing a pre-fabricated industry standard greenhouse in the pilot phase will provide for an easily reproducible model for future expansion.

Capital Costs – **Result: Medium**
In the previous scenario where we were considering retrofitting the existing building, we noted that it would be difficult to assess what all of the capital costs might be in retrofitting the building frame into a greenhouse in this early stage of feasibility. Conditions and costs would not be fully understood until well into design development and the selective demolition phase, which in and of itself, presents risk related to unforeseen conditions and additional development work that would be required. However, in this scenario, we can approach the next phase of development with a good understanding of the costs of the full demolition and the new greenhouse thus helping to minimize the risk of the project budget getting out of control.

Building Modifications – **Result: Low**
With the full building demo and conversion to a greenhouse we would need to establish a new location for incoming electrical, water and heat service. We may want to establish new floor drains but it is too early to tell on that and we would like to avoid that if possible. Otherwise, there are minimal modifications since we are completely removing the building and starting with a new structure. We would also keep the existing concrete slab intact for the future greenhouse. An area that requires further exploration is whether or not we will need to create an outbuilding for mechanical and electrical services. It has also been noted that a bathroom may need to be included inside the greenhouse. These points will be further examined in the design development phase.

Operating Costs – **Result: Medium**

While not every cost area can be fully and accurately assessed in this preliminary stage, we can anticipate in a general sense which scenarios will likely perform better than others. We know that without the inclusion of artificial lighting that our operating costs will be significantly reduced in either option where natural light will be used. The greenhouse will be outfitted with environmental controls to help manage energy systems and minimize waste. Further inclusion of thermal mass and other renewable energy options will be explored to aid in the reduction of overall operating costs. Greenhouses can be more challenging to heat and cool due to lower thermal resistance with glazing (r-value) compared to an insulated hard wall building. The resulting financial section will focus specifically on this scenario and provides an estimate of operating costs.

Complexity – Result: Low

We strongly believe that starting clean with a new greenhouse designed for growing plants and where all of the building systems are fully integrated will make for a much simpler construction process as well as an easier environment to manage overall. With the greenhouse we will not have to worry about adding the additional thermal barrier discussed in the first scenario either which minimizes complexity, costs and additional building modifications.

Ability to meet short term food production goals – Result: High

The greenhouse will afford us the best possible growing environment for year round production.

Environmental impact – **Result: Low**

Our overall energy footprint will be considerably lower when not using artificial lighting as described in scenario 1. The building's energy systems will be managed by a greenhouse environmental controller designed to maximize efficiencies through automation of HVAC systems using programmable controls, sensors and thermostats. We will also have the ability to use the sun's natural energy for growing plants, heating the water and the air.

Renewable energy potential – Result: High

Greenhouses provide many opportunities for us to utilize renewable energy systems. Of course, the sun is our best asset here. Inclusion of solar panels for both electrical power and solar heat can be included with the greenhouse. Storage of large volumes of water as thermal mass heated by the sun will provide a great source of passive radiant heat which will further reduce reliance on fossil fuel sources. Options for renewable energy systems will be further explored and detailed in the design development phase to reduce the overall energy footprint.

Practicality – Result: High

We feel there are significant benefits to moving forward with a greenhouse over modifying the existing building to be something other than its intended use. While adaptive reuse projects can be attractive on the surface, they are often more expensive, more complex, and both predicting and achieving a successful outcome is much more difficult. In this case we believe that installing a building designed to grow plants is the most practical option for both the pilot phase as well as the long term expansion goals.

5.5 - Comparison of Scenario 1 and 2 across Key Criteria

While it could be argued that we’re beating a dead horse here, it’s important to circle back and illustrate the two main scenarios side by side for comparative purposes.

Table 14 - Comparison of Scenarios

Key Criteria	Scenario 1 Palmer Building	Scenario 2 - Greenhouse
Integration potential with future expansion in mind	Low	High
Capital Cost	High	Medium
Building Modifications	High	Low
Operating costs	High	Medium
Complexity	High	Low
Ability to meet short term food production goals	High	High
Environmental Impact	High	Low
Renewable energy potential	Low	High
Practicality	Low	High

6.0 - The Aquaponic System

In this section we will cover the major components and benefits of the proposed system design. As a reminder, this is still a conceptual design which can be adjusted as we go through the detailed design development stage. This section is organized under the following major categories with several subcomponents in each.

6.1 - System Overview
6.2 - The Aquaculture Component
6.3 - The Hydroponic Component
6.4 - The Fish
6.5 - The Water

6.1 - System Overview

6.1.1 - Key Design Requirements

- Utilize available building space to its fullest potential for the growth of both fish and plants in the aquaponics system
- Grow produce that is currently consumed by the jail population such that we can offset average monthly purchasing costs through onsite production
- Fish will be stocked at conservative stocking densities so as to ensure a more balanced environment and healthier fish. Overstocking can make fish more susceptible to disease, malnutrition and decreased water quality
- Keep operating costs as low as possible
- Minimize and reuse waste streams as effectively and efficiently as possible
- Utilize adjacent outdoor spaces in conjunction with the indoor growing system
- Ensure the appropriate balance of fish and plants in the system
- Ensure a regular rotation of fish and plants for consistent production
- As an initial pilot system, we are trying to keep the costs as reasonable as possible while also making sure that we develop a system and an environment that has a high probability of success

6.1.2 - Design Highlights

A few important design features are highlighted below. Each will be expanded upon further within this document.

System integration and independence - The system is configured to be either fully recirculating meaning that the fish and plant systems are hydraulically connected, but the system can also be run as two independent loops such that both the fish and plant environments can be effectively disconnected from each other. This is achievable because the fish environment will have its own life support system designed to provide all of the mechanical and biological filtration and maintain the overall desired water quality for the fish (details in next section). That means that the fish system could operate independently without fish health being in jeopardy due to high levels of ammonia or nitrites not being properly removed. In turn, the plant system can maintain its own water recirculation by using independent sump tanks and a recirculating pump. Organic nutrient levels can be maintained for the plants should the systems be disconnected for a longer period.

System independence is advantageous for a number of reasons:

- If the fish required a treatment program, such as an elevation of the salinity level in their water, this treatment could happen independently of the plant system. Plants do not tolerate salt very well and both systems could continue to operate until the salt was taken down to a safe enough level for reintroduction to the plant system
- If you needed to apply a pest application to the plants with an organically approved pest control solution, you could take the fish system offline
- If there was any concern about possible contamination both systems could be separated
- Expansion of the fish production environment may be desired as future phases of the plan develop. The plant system could be disconnected and dismantled to make space for additional fish tanks without significantly impacting the existing fish environment

Multiple growing methods – The system employs a hybrid design utilizing both deep water culture and media based growing methods in the same system allowing for a greater diversity in crop production and increased retention of nutrients resulting in less waste and higher yields. In addition to those growing methods we are also planning on growing tomatoes in hydroponic bag culture whereby we harvest solids from the aquaculture system and remix them into a dense nutrient solution ideal for tomatoes. The tomato bags will not be part of the overall recirculating system but will receive nutrients in a direct or “dead end” method. Again, this allows us to utilize as much of the solid fish waste as possible, decreasing waste streams and growing more plants in the same space.

Passive & Active Heating – While additional design and development of this integration would need to be performed in the next phase, the addition of black storage tanks along the north wall in between the fans will allow for the passive storing of heat through thermal mass. The addition of hot water solar panels can also be utilized to heat the water in these storage tanks. Heated water in the storage tanks can be connected as a supplemental hot water storage tank to a hydraulic radiant heat loop to provide passive solar heat to the fish and deep water culture tanks. Additionally, the central steam plant should be hooked up to provide a second stage backup heat source in the case of cloudy periods or extreme cold.

Use of Floor Space – The goal in most any controlled environment agriculture production operation is to maximize available space for the growing of plants and thus achieve the highest possible revenue per square foot. One of our primary goals with this project is to achieve the highest possible production and thus offset current monthly costs as much as possible. The conceptual design provides a great deal of growing space while also being cognizant of other functional operations and circulation space required within the greenhouse space.

Orientation of systems – The layout of the concrete slab is north to south at 60’ wide on the N/S and 120’ on the E/W. The system maintains the elevated growing beds and tallest plants along the north end so as to not block light from plants in the lower water basins. The fish tanks are located along the north wall behind the elevated plant beds which will provide some natural shading. The plants will also receive the coolest air being located closest to the evaporative cooling wall on the south side of the building. Therefore the warmer air will be on the north end where the plants such as tomatoes desiring warmer temperatures are located. In addition, the fish tanks are in the warmer northern section which will help reduce tank heating costs.

Effluent Waste Reuse – As described earlier, fish solids and effluent will be stored and reused in a variety of ways including the growth of additional tomato plants hydroponically in the greenhouse. Sludge waste from the fish can also be remixed and utilized for fertilizer in land applications such as soil based crops, composting, lawn care, or sold as fertilizer to other farmers in the area such as the Urban Farm across the street.

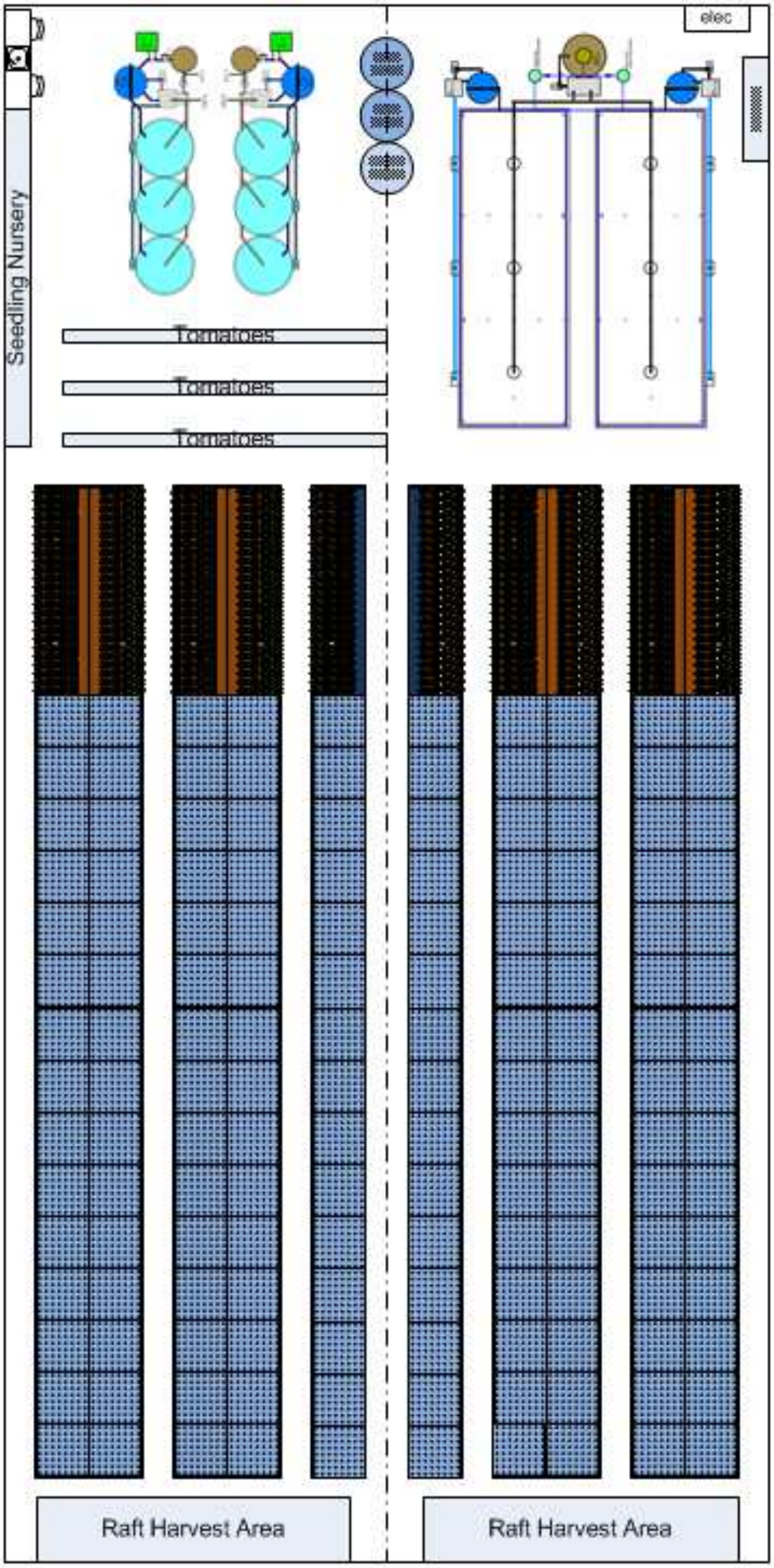
6.1.3 - Concept Overview

The building is oriented from North to South. The two large rectangular tanks in the NE corner (upper right) represent the grow out tanks and filtration system for the fish. The six circular tanks in light blue in the NW corner represent the fingerling system along with storage, quarantine and purge tanks. The three tanks in the north center of the building are for fresh water and effluent storage. The dotted line going down the center represents where the two greenhouse bays will connect via a gutter and column system. This is not a hard wall so the floor space is open beneath this dotted line with the exception of column supports every 10'.

A desk and seedling nursery area is located in the NW corner and tomato rows are located just to the south of the fingerling systems.

The remaining space south of the fish tanks and tomato runs is the primary plant production system. The northern most areas in dark brown represent the media beds which will be filled with a gravel substrate. The remaining dotted blue sections that run to the south end of the building are the deep water culture beds for the lettuce production portion of the system. The southernmost end of the building provides space for removing rafts and harvesting plants.

Figure 12 - Aquaponic System Conceptual Design



6.2 - The Aquaculture Component

6.2.1 - System Description

This system's design is based on several key concepts. First, the stocking and harvest densities are modest, to maximize the probability of an early success. Later, as management and operators of this system become more experienced, with culturing fish and monitoring and managing the water quality, feeding, and overall aquaculture system environment, the densities can be increased. In this design, increasing the annual culture and production of fish from 150% to 167% of the initial fish production goals could be possible with these same basic fingerling and grow-out systems. This is possible because this production level is quite small, and the system components, such as the bead filters for mechanical filtration of solids as well as biological filtration of nitrogenous wastes, shall be operated at a conservative, "low end" of their design loading range, simply because smaller sized units may not be available, or smaller size units, if available leave little "room" for increased production capacity.

Second, multiple cohorts (age groups) of fish are grown out in the life support system water volume. This saves on capital and operational costs of the life-support equipment.

Third, a single cohort is used for each of the fingerling/juvenile tanks, which are then stocked into the grow-out system. The grow-out system is designed to accept 3 cohorts of fish from the fingerling tank and then the grow-out is harvested every four weeks (or smaller harvests every 2 weeks for more "sorting" options) rather than weekly. This allows more flexibility for the fish farmer/operator in dealing with mixed growth rates and trying to obtain a more uniform fish size at harvest. This requires additional sorting of fish at harvest in the mixed-cell raceways, but it also allows for increased product management, oversight and overall system efficiency.

And fourth, using a mixed-cell raceway for final grow out allows for rapid and efficient grading of market size fish and low installation costs compared to fiberglass tanks.

The rectangular raceway design has several advantages over cylindrical tanks.

- Better use of floor space in a single rectangular design over three separate cylindrical tanks
- Easier harvesting of fish in rectangular systems where a grader can be moved from one end of the tank to the other in order to harvest the larger adult fish
- Counter rotating water flow will concentrate solids to the center drain of each square chamber where water can be sent directly to the bead filter.

Figure 13 - Mixed Cell Raceway layout and flow pattern (Ebeling et al., 2005)

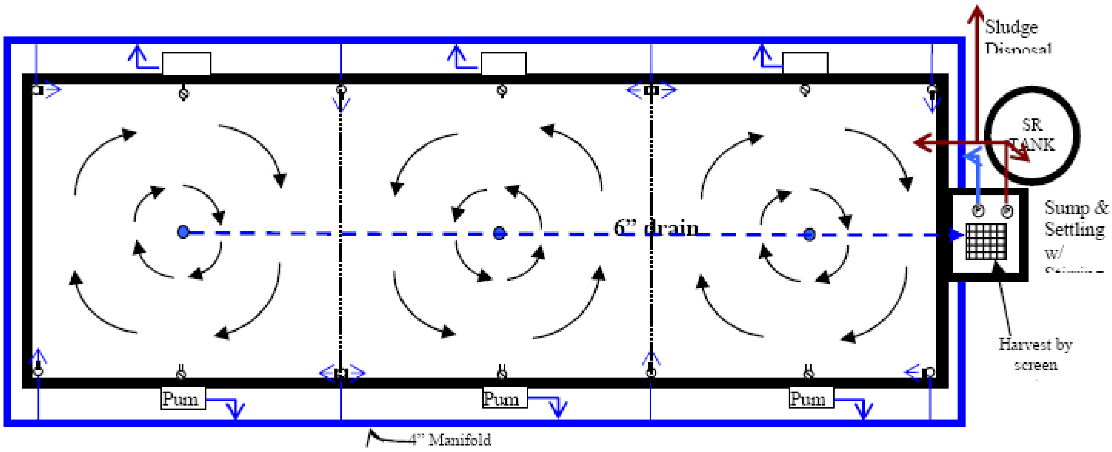


Figure 14 – Bead Filter

6.2.2 - Filtration

There are two types of filtration that operate in a re-circulating aquaculture system (RAS). The first is filtration of solids, also called mechanical filtration. This takes place primarily within the filter bed of the bead filters recommended for these systems. Both settleable solids of a larger size, and suspended solids of a smaller size are controlled with this method of mechanical filtration.

Bead Filters are generally classified as "expandable granular bio-filters" or EGB's. They are distinguished by the use of plastic buoyant granular media. Water from the aquatic system passes through the packed bed of plastic beads. The beads capture the solids, while simultaneously providing a large surface area (400 ft2 /ft3) for the attachment of nitrifying bacteria which remove dissolved nitrogenous wastes. Bead Filters are often referred to as "Bio-clarifiers for their ability to perform both bio-filtration and clarification in a single unit. Bead filters are excellent clarification units capable of maintaining display-quality water at high waste loading rates. Studies have shown that acclimated Bead Filters capture 100% of particles > 50 microns and 48% of particles in the 5-10 micron range per pass through the filter. Each pass-through filters more solids.

The second type of "filtration" is conversion of ammonia (NH_3^-) and nitrite (NO_2^-), to nitrate (NO_3^-). This is also known as "bio-filtration" because it operates biologically by the metabolic activity of beneficial nitrifying bacteria (as well as other natural, beneficial bacteria which can assimilate nitrogen as they need it, converting it into harmless protein). These beneficial microorganisms are present virtually everywhere in nature, in aquatic environments. They will establish themselves naturally in a few weeks time on surfaces of bio-filtration media in the moving bed bioreactor (MBBR) components of the fingerling and grow out systems. They will be present on virtually every surface in the system, such as pipes and in the aquaponic basins, and even in the water column itself. The bead filter is incredibly versatile in that it can even serve as a “bio-clarifying” filter, performing both mechanical and biological filtration, at a suitable solids loading rate.

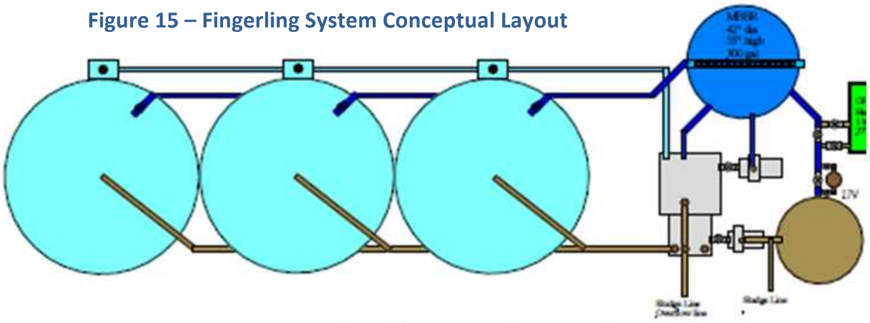
Ammonia and nitrite are relatively toxic to fish if allowed to accumulate within a “closed” system such as an aquarium, for example, whereas nitrate is relatively non-toxic to fish. All three of these forms of inorganic nitrogen are produced in an RAS, and the aquaponic component of this system serves to remove all three forms of these by products, thus acting as a large and very beneficial “biofilter” as well. The aquaculture systems are designed to be able to operate as recirculation aquaculture systems (RAS) “on their own”, that is, without the presence of the aquaponic plant system. Therefore, the option is available to simply close off valves to isolate the two major components of the integrated system – the aquaculture component has sufficient mechanical and biological filtration to operate independently of the aquaponic component of this system, if necessary

A key engineering design value for any RAS is the maximum daily feed rate, in kilograms per day, or pounds per day, for each production stage. These maximum rates are used to determine the size and flow rates of the solids capture (mechanical) filters, as well as the biological filters. The fingerling/juvenile system will have a three cubic foot propeller washed bead filter for solids (mechanical) filtration, and an MBBR bio-filter with about 19 cubic feet of bio-filter media primarily for nitrification and control of nitrogenous wastes. The grow-out system will have a 10 cubic foot propeller washed bead filter for solids (mechanical) filtration, and two MBBR bio-filters with a total of about 64 cubic feet of bio-filter media for nitrification.

6.2.3 - System Flow

The fingerling/juvenile system will have two water pumps as part of that RAS. One pump will deliver about 30 gpm to the 3 cubic foot bead filter from the bottom drains of the round fiberglass tanks. The second pump will deliver about 30 gpm to the MBBR. The total water volume in the 3 fingerling tanks will be about 750 gallons, therefore the combined flow rate of 60 gpm will represent an internal hydraulic retention time (HRT) of about 12.5 minutes, which is very good for the young growing fish. Therefore, continuous “treatment” or filtration of the culture water delivers the entire culture water volume through the mechanical and biological filtration components once every 12.5 minutes.

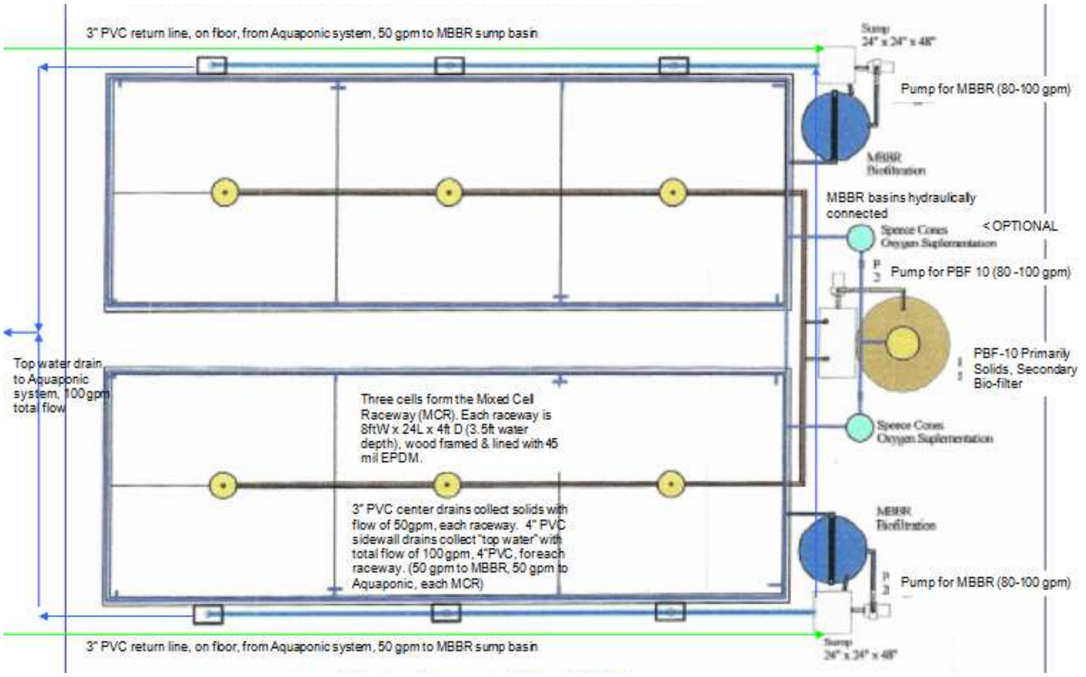
Figure 15 – Fingerling System Conceptual Layout



The water, and therefore the nutrients, in the fingerling system will be a low percentage, about 10% or less, compared to the water volume and nutrients available in the grow out system, for the plants in the aquaponic component to use. However, it will be useful to take advantage of the “treatment” capacity of the aquaponic system with respect to the fingerling system and the culture water within the fingerling system. Therefore, the water within the fingerling system could be slowly and continuously “siphoned” into the aquaponic system, and returned at the same rate, such that the 750 gallons of culture water in the fingerling system is exchanged at least once or twice a day. Such a slow, continuous flow rate would represent about 1 gpm 24 hours a day. Alternatively, “batches” of water volume can be pumped every half hour, for example, reciprocating flow to and from the fingerling system and the aquaponic system, to accomplish the same result of exchanging the fingerling water volume with the aquaponic system at a rate of 1500 gallons per day or more.

The grow-out system will have three water pumps as part of that RAS. One pump will deliver about 80 to 100 gpm to the 10 cubic foot bead filter from the bottom drains of both mixed cell raceways (MCRs). The other two pumps will deliver a total of about 160 to 200 gpm to the two MBBR biological filters. The total water volume in the 2 MCR grow-out tanks will be about 10,000 gallons, therefore the combined flow rate of 240 to 300 gpm will represent an internal hydraulic retention time (HRT) of about 34 to 42 minutes, which is very good for the grow out stage of fish up until harvest. Therefore, continuous “treatment” or filtration of the culture water delivers the entire culture water volume through the mechanical and biological filtration components once every 34 to 42 minutes. In addition to this internal HRT re-circulating within the filtration system of the grow-out aquaculture system, approximately 80 to 100 gpm from the grow out system will be delivered to the aquaponic system and returned continuously to the grow out system through the sump basins used to deliver “top water” from the aquaculture system to the two MBBR biological filters.

Figure 16 - Overall Design Layout for Mixed Cell Raceway - Aquaculture Growout



6.2.4 - Wastewater discharge

Propeller-washed bead filters offer an effective method of back-washing the filter. While the water flow is interrupted or bypassed, high speed embedded propellers agitate and expand the bead media in a blender-like fashion. This process releases captured solids and debris from the bead bed. Waste matter settles into the internal settling cone of the filter where it is removed in a concentrated form. Following sludge removal, water flow is restored to the filter, and the filter resumes normal operation with a clean bead bed. The propeller-washed bead filter employs the most aggressive method of backwashing available, allowing them to mitigate extremely high waste loads without caking or channeling. Back-wash water loss rates are as low as 1% of those experienced by typical sand filters.

For the 10 cubic foot bead filter in the grow out system, typical back wash volumes will range from 10 to 30 gallons water loss, approximately every 1 to 3 days, depending on solids loading rates and internal mineralization of solids into nutrients available for the plants in the aquaponic component of the system. The 3 cubic foot bead filter in the fingerling system will have a typical back wash discharge volume of 5 to 10 gallons of water loss, again approximately every 1 to 3 days, or even longer, depending on solids loading rates and decomposition of solids in the bead filter bed between back wash cycles.

6.2.5 - Effluent Storage

Storage of solids discharged from the bead filter will take place onsite and the solids can be reused in a variety of ways. A solids storage tank has been included in the plans to allow for capture of solid waste and reuse from the bead filter. Solids can be remixed as a nutrient dense solution for the growing of bag culture hydroponic tomatoes, for use as a lawn fertilizer or for growing root based crops such as carrots or potatoes in soil culture. The tank will be a conical bottom tank to allow for easy discharge and removal of the remixed effluent.

6.2.6 – Aeration

Aeration will be supplied with a single regenerative blower with sufficient delivered air volume capacity, expressed as cubic feet per minute (cfm) to serve the needs of 1) oxygen demand by the fish, plants, and microorganisms in the biofilter and in the water, 2) gas exchange (CO_2 stripping), and 3) an aid in designed water circulation within the mixed cell raceways (MCRs). Lack of adequate aeration will result in fish stress and death along with poor overall performance from all of the living organisms within the system that are dependent on dissolved oxygen in the water to survive. Therefore, a redundant aeration system is recommended along with available backup power to maintain oxygen levels in the event of a power outage.

6.3 - The Hydroponic Component

We are proposing to use a combination of growing methods in the system design in order to provide a larger diversity of plants that can be grown in this environment. We are also not reliant on one particular method of growing the plants. Research, experiments and commercial growers in the past few years have shown promising results in systems where multiple growing methods, crops and filtration techniques are utilized. We believe that creating a hybridized system will afford for a much stronger and more resilient system over the long haul creating a greater chance of success in your crop production.

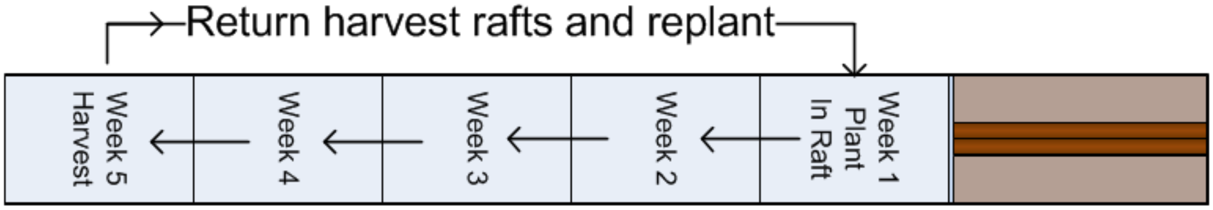
6.3.1 - Deep Water Culture

Picture 5 - DWC System at Flourish Farms in Arvada, CO

Also known as a raft system, plants are grown in polystyrene sheets (rafts) over a 12 to 18” deep water trough which is highly aerated for continuous oxygen supply to the plant roots. Plants are harvested by removing raft sheets from the water basin and plants like lettuce, bok choi, kale to name a few can be harvested live with their roots in tact which is becoming a popular way for markets to provide living plants to their consumers. Living lettuce, for example, often can fetch a higher market value if sold with the roots intact. The large volume of water used in the raft system can also provide additional thermal mass capacity to your overall heating and cooling requirements for the greenhouse (discussed later). Raft systems are the most common type of commercial aquaponic growing system and have a well documented track record.

One of the primary advantages of a raft system is the ability to effectively “conveyor” the production of plants. In other words, the raft sheets which float on top of the water can be moved up and down the water trough as needed for harvesting and planting. The most effective way is to establish a weekly rotation of planting and harvesting such that you are harvesting your mature growth plants in the same location each time. Your youngest growth plants will be introduced on one end of the raft trough and will slowly be pushed down to the harvest end as the mature plants are harvested and the rafts are removed from the system. Once all of the rafts ready for harvest are harvested, all of the rafts will be pushed down the trough and the rafts that were just removed for harvest will be replanted with the newest plants and be put back into the trough at the week 1 location.

Figure 17 - Weekly rotation of rafts in deep water culture



Nutrient rich water in the hydroponic troughs can be maintained at ideal temperatures and water quality for the plant roots to be able to absorb nutrients and contribute to the overall growth of the plant. By maintaining warm temperatures in the water, plants such as lettuce can often tolerate colder air temperatures simply by maintaining warmth at the root zone. This arrangement can help to lower overall energy costs by not having to heat the air as much as you might have to when using traditional agriculture methods.

6.3.2 - Plant Production in DWC

Plant density is determined by looking at the total square footage available in the raft beds and multiplying by the number of rafts in the system to arrive at the total raft square footage. Plant density has been established at 4 plants per square foot for head and romaine lettuce production. This is a tight spacing but not uncommon in commercial aquaponics and is an important variable towards maximizing production and profitability. Planting density can change from species to species and can be adjusted for tighter spacing in the earlier growth stages and wider spacing at maturity. For the purposes of this analysis we are maintaining a standard spacing of 6"

Table 15 - Raft Production

Raft Production		
Raft width	8	ft
Raft Length	60	ft
Max sq ft one tank	480	ft2
Number of rafts	5	
Raft s.f.	2,400	ft2
Plant density per s.f.	4	
Total plants per culture	9,600	
Culture period (weeks)	5	wks
Number of harvests annual	10	
Total plants	99,840	
Loss rate	20%	
Net Plants Annual	79,872	

Planting density multiplied by the total square footage will yield the total plants per culture. The culture period is another critical variable to overall productivity and represents the time from transplant into the system to harvest. This does not include time spent in the seedling nursery and early germination. To be conservative and realistic we have included a culture period of 5 weeks based upon our own experience. Four week culture periods are not uncommon but are realized only under ideal conditions with experienced operators. We felt in this case that it was important to provide a more realistic estimate of growth for planning purposes

Loss Rate - The total annual plant production is the plants per culture multiplied times the number of harvests. The loss rate is a number applied to total plant production to account for average losses in production due to factors such as pests, temperature, product mishandling, substandard growth etc. A twenty percent loss rate is common in the industry and provides another area of variable control (or lack thereof) in production. A system will not ever achieve 100% production and should not be forecasted as such. Therefore the value "Net Plants Annual" is the result of the 20% loss rate applied to the total plant production.

Current Consumption – Current consumption of head and romaine lettuce at the Denver County Jail can be seen in the table below. A combined total of 239 cases of lettuce is purchased and consumed each month. Both lettuce varieties also represent the two largest produce costs each month. A deep water culture system is ideally suited for growing these types of crops.

Table 156 - Current consumption of Head and Romaine Lettuce

Item	Each	Weight		Monthly	Weight		Annual	Weight
Head Lettuce	$16.85	24	ct	$2,022.00	120	cs	$24,264.00	1440cases
Romaine Lettuce	$19.88	24	ct	$2,382.00	119	cs	$28,584.00	1428cases

Table 17 - Head and Romaine Lettuce by the Case

Head and Romaine Lettuce			
Monthly heads		6,656	heads
Monthly cases (24ct)		**277**	**cases**
Current Monthly volume		239	cases
Production %		116%	
Head Lettuce	$	16.85	24ct
Romaine Lettuce	$	19.88	24ct
Average price per case	$	18.37	
Monthly total value	$	4,408	
Total Annual Cases		3,328	

Head and Romaine Cases - Annual heads are divided by 12 to determine an estimate for total monthly heads which when divided by a 24 count case will produce the total number of cases to be expected each month from the system. The table then compares that expected output to the current consumption of combined head and romaine cases in table 16 to determine the overall production % as it relates to consumption. Pricing for head and romaine lettuce are included and an average price per case was determined for the sake of evaluating overall head lettuce production.

Conclusion – The deep water culture portion of the aquaponics system can theoretically meet all of the current head and romaine lettuce demand each month with capacity to actually reduce the output to meet 100% production thus providing remaining space for the growth of additional plant species.

6.3.3 - Media Based Plant Beds

To further diversify the available plants, we are intending to add a series of media beds whereby plants will grow in an inert rock or clay substrate. The media bed depth will be approximately 12" deep and water from the fish tanks will constantly flood the media beds and drain into the adjacent deep water culture beds described previously. Media beds can provide additional biological filtration and oxygenation of the water which is important for the system.

Picture 6 - Aquaponic Media Beds at the GrowHaus

In addition, many plants simply perform better in media beds such as tomatoes, cucumbers, and peppers because they have larger root structures and require a more stable medium to secure to. Many of these plants can also be easily trellised so they can continue to grow well above the surface of the media bed. This is difficult to do in deep water culture because of the movable nature of the raft sheets.

Media Bed Placement – Due to the raised beds and the fact that many of the crops growing in the media beds will be much taller and even require trellising, the media beds have been placed along the north end of the DWC troughs so as to not block light from other plants. The elevated plants will provide some shading for the fish tanks and will make for a more comfortable environment for the workers. These beds will be fed water directly from the main grow out tanks. Water will flood and drain from the beds continuously using simple automatic siphons. You can see in the middle two beds that the dark area represents water from the large deep water troughs that are open directly beneath the media beds. These 4’ wide troughs have been divided to fit around the center support columns shown as the dotted line.

Figure 18 - Expanded view of media beds

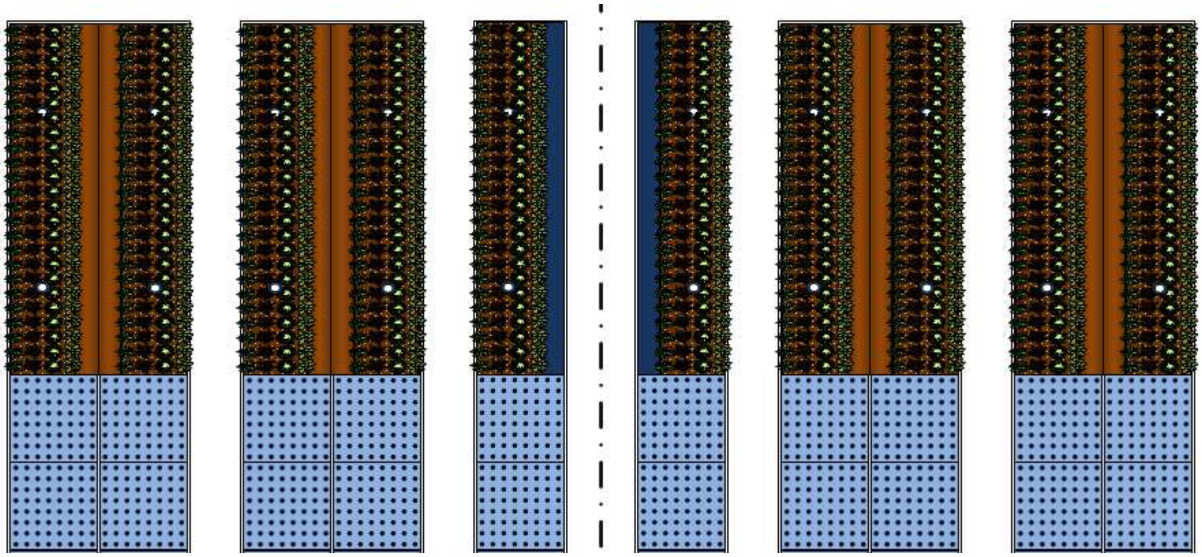
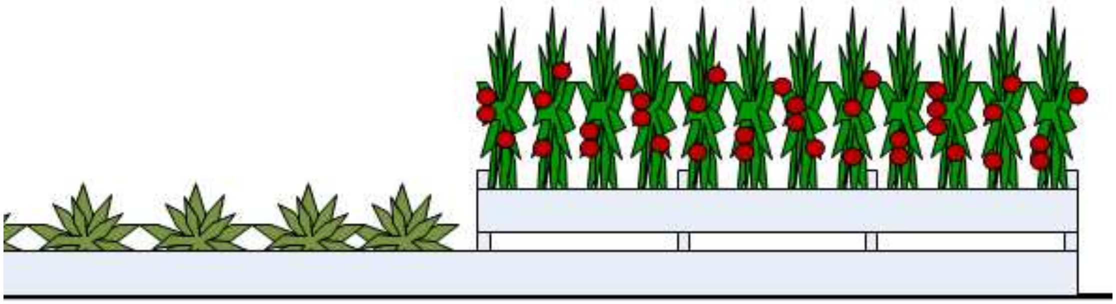


Figure 19 – Side elevation of media beds suspended over the raft trough



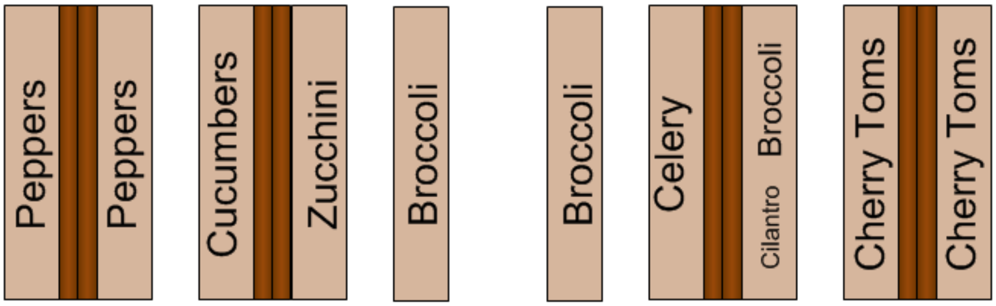
Current Consumption – The table below shows the jail’s current consumption of various types of produce that are ideally suited for growth in the media beds.

Table 168 - Current Consumption

Item	Each	Weight		Monthly	Weight		Annual	Weight
Celery	$16.95	48	ct	$203.40	12	cs	$2,440.80	144cs
Cucumbers	$16.85	45	lbs	$16.85	45	lbs	$202.20	12cs
Bell Peppers	$13.85	25	lbs	$41.55	75	lbs	$498.60	900lbs
Broccoli	$15.45	18	lbs	$139.05	162	lbs	$1,668.60	1,944lbs
Zucchini	$29.95	20	lbs	$89.85	60	lbs	$1,078.20	720lbs
Cherry Tomatoes	$14.15	1	case	$113.20	8	cs	$1,358.40	96cases

Proposed planting layout for the media beds – Based upon the current produce consumption a planting layout for produce best suited to be grown in the media beds is shown in the following illustration.

Figure 20 - Media bed planting layout



With the available planting space in the media beds shown in the media bed planting layout drawing, we have estimated production of various different crops currently consumed in the prison system. Similar to the DWC production estimates, there are a number of variables that will influence production rates. The growth and yield estimates including annual number of harvests are relatively conservative in order to provide a more practical view of actual production. Good management practices, environmental controls, available sunlight and proper nutrient delivery among other things will help to improve yields. These production estimates are tied directly to the produce sales table in the financial section using the current costs per unit volume from the produce consumption table.

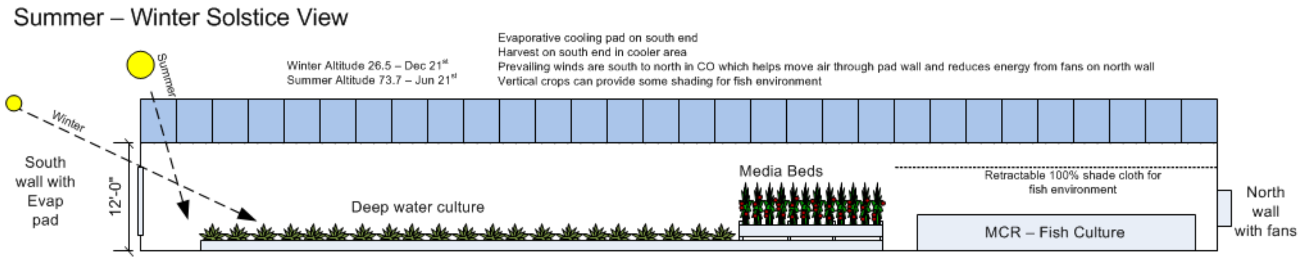
Table 19 - Crop production estimates in media beds

Broccoli			**Cherry Tomatoes**			**Celery**		
length	20	ft	length	16	ft	length	16	ft
width	3	ft	width	3	ft	width	3	ft
bed s.f.	60	s.f.	bed s.f.	48	s.f.	bed s.f.	48	s.f.
number of beds	2		number of beds	2		number of beds	1	
Total s.f.	120	s.f.	Total s.f.	96	s.f.	Total s.f.	48	s.f.
Bed depth	1	ft	Bed depth	1	ft	Bed depth	1	ft
Plant spacing	12	in	Plant spacing	18	in	Plant spacing	10	in
Total Plants	120		Total Plants	43		Total Plants	69	
lbs per s.f. avg yield	0.5	lbs	lbs per s.f. avg yield	1.75	lbs	lbs per s.f. avg yield	0.78	lbs
lbs per harvest	60	lbs	lbs per harvest	168	lbs	lbs per harvest	37	lbs
number of harvests	6		number of harvests	6		number of harvests	6	
annual lbs	360	lbs	annual lbs	1008	lbs	annual lbs	225	lbs
monthly lbs	**30**	**lbs**	**monthly lbs**	**84**	**lbs**	**monthly lbs**	**18.72**	**lbs**
Cucumbers			**Zucchini**			**Bell Peppers**		
length	16	ft	length	16	ft	length	16	ft
width	3	ft	width	3	ft	width	3	ft
bed s.f.	48	s.f.	bed s.f.	48	s.f.	bed s.f.	48	s.f.
number of beds	1		number of beds	1		number of beds	2	
Total s.f.	**48**	**s.f.**	**Total s.f.**	**48**	**s.f.**	**Total s.f.**	**96**	**s.f.**
Bed depth	1	ft	Bed depth	1	ft	Bed depth	1	ft
Plant spacing	15	in	Plant spacing	24	in	Plant spacing	15	in
Total Plants	**31**		**Total Plants**	**12**		**Total Plants**	**61**	
lbs per s.f. avg yield	0.93	lbs	lbs per s.f. avg yield	1.1	lbs	lbs per s.f. avg yield	0.4	lbs
lbs per harvest	44.64	lbs	lbs per harvest	52.8	lbs	lbs per harvest	41.3	lbs
number of harvests	6		number of harvests	6		number of harvests	6.0	
annual lbs	267.84		annual lbs	316.8		annual lbs	247.7	
monthly lbs	**22.32**	**lbs**	**monthly lbs**	**26.4**	**lbs**	**monthly lbs**	**20.6**	**lbs**

6.3.4 - DWC and Media beds combined

A view of the overall system from the side shows the layout of the deep water culture beds along the southern most end of the building followed by the elevated media beds. The tomato rows are not shown in this drawing but are located to the north of the media beds before the fingerling tanks which are also not shown. Opportunities exist to add even more vertical plant production directly over the main grow out tanks to help shade the tanks and provide additional plant production. For the time being a retractable shade cloth is illustrated over the fish tanks. Based upon the sun angles and building orientation this layout of the plant systems provides the most light exposure with taller plants located on the northern end of the building so as to not block light from the lowest plants in the system.

Figure 21 - Side Elevation showing sun angles



6.3.5 - Combined Produce Production

Based upon the conceptual system design including crop spacing, crop placement, typical yields and many other factors, we have estimated produce yields within the system and compared them to current consumption to illustrate the overall impact that the aquaponics system could have on the jail's current food consumption. This table shows the percentage of production, against your current consumption for both the media and DWC systems.

Figure 2 - Three Dimensional Perspective

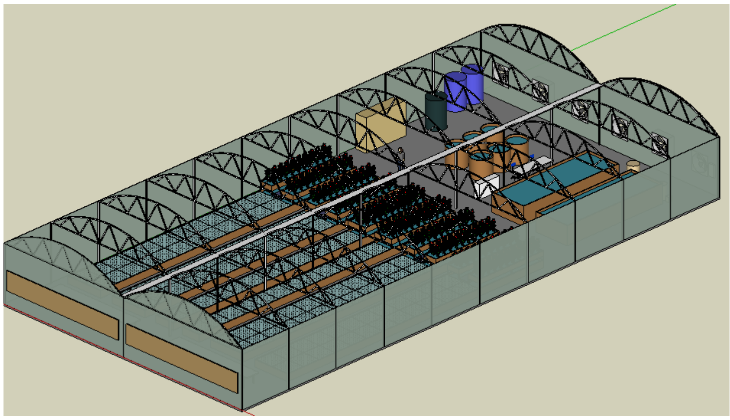


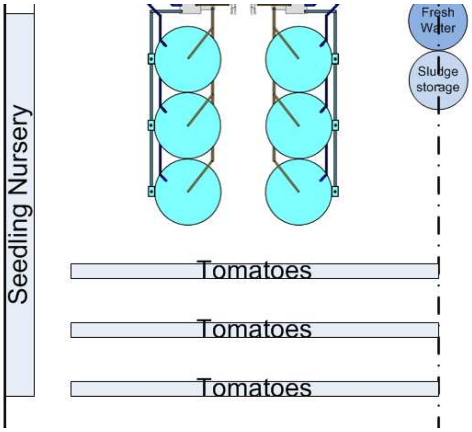
Table 20 - Production vs. Current Consumption

Item	Grown in	Est. prod/mth	units	% of current	Annual	
Celery	Media	1.9	cases	16%	22.5	cases
Cucumbers	Media	22.3	lbs	50%	267.8	lbs
Bell Peppers	Media	20.6	lbs	28%	247.7	lbs
Broccoli	Media	30.0	lbs	19%	360.0	lbs
Zucchini	Media	26.4	lbs	44%	316.8	lbs
Whole Tomatoes	Media	48.8	lbs	30%	585.0	lbs
Cherry Tomatoes	Media	4.2	cases	53%	50.4	lbs
Cilantro	DWC	1.2	bunch	60%	14.4	lbs
Head Lettuce	DWC	138.7	cases	116%	1664.0	cases
Romaine Lettuce	DWC	138.7	cases	117%	1664.0	cases

6.3.6 - Hydroponic Tomato Culture

Additional growth can be achieved through the reuse of solids collected from the bead filter and re-mineralized into a nutrient dense solution to grow tomatoes. The tomatoes would be grown in coconut coir bags in rows directly on the floor of the greenhouse in a gutter system. This is an excellent way to reuse the sludge by product as a fertilizer solution for additional plant growth. This helps us minimize waste and create a value added product in return. The sludge storage tank is located nearby the tomato runs and will be able to provide nutrients directly to the adjacent tomato beds. Approximately 75 ft of tomato runs are shown in the drawing conservatively producing between 50 and 75 lbs a month.

Figure 23 - Proposed Tomato Rows



6.4 - The Fish

6.4.1 - Species selection

There are three primary categories of fishes to choose from as we develop species recommendations for this project; coldwater, coolwater, and warmwater fishes. For the purposes of this study and given the requirements and constraints of this project, we will consider only coolwater and warmwater species as candidates for selection.

Coolwater fishes survive in a range of temperatures of 32-84 degrees. However, they perform best in terms of growth and feed conversion in a temperature range of 70-75 degrees. There are numerous fishes to consider in this category, but relatively few enjoy a high culturability score and are also highly desirable as food fishes. Those species include yellow perch, hybrid striped bass, white sturgeon, and walleye. Of these four species, only hybrid striped bass offer readily available juvenile fish on a year-round basis and at reasonable prices.

As the name implies, warmwater fishes survive in a range of temperatures that is higher—32-95 degrees or more, but perform best in the temperature range of 80-86 degrees. Candidate food fishes within this group include catfish, largemouth bass, tilapia, bluegill, and others. If we once again consider cost and availability of juvenile fish on the open marketplace, tilapia and catfish rise to the top of the list.

Because energy costs (more specifically, minimizing energy costs) are an important factor in a decision regarding species, coolwater species tend to have an advantage. Additionally, we must also consider the compatibility of temperature optima when we couple the production of fish with the production of plants. The majority of the plants we intend to produce prefer cooler temperatures; more in the range offered by coolwater fishes.

Of the three top candidates (tilapia, catfish, and hybrid striped bass), hybrid striped bass appear to offer the best combination of culturability, desirability, availability, affordability, and compatibility with plants. We therefore recommend the production of hybrid striped bass within the fish production system, with the caveat that tilapia also may play a key role within the fish production space. Potentially, tilapia could be cultured during warmer times of the year, or when hybrid striped bass fingerlings are less available or too expensive. Additionally, this would provide the Denver County Jail with some menu variety throughout the year.

6.4.2 - Fingerling Sourcing

Hybrid striped bass fingerlings (i.e., juvenile fish) are readily available throughout the year from Keo Fish Farm in Arkansas. This company has been in business for many years and produces high-quality fish. They routinely transport their fish across the continental U.S., and can "piggyback" our shipments with other fish destined for Colorado and other nearby customers. This will allow us to share shipping costs and minimize overall cost per fish. These fish also can be readily air shipped when piggyback options do not exist, or we can transport the fish ourselves in a truck retrofitted for fish hauling.

If tilapia is chosen for production within the system, fingerlings are available from Colorado Correctional Industries in Canon City. Again, they are available on a year-round basis. Additionally, this source supplies only male fish, which is ideal for our purposes. Males grow to a larger size and the lack of females will prevent unwanted spawning.

If catfish are chosen for production, fingerlings are available from numerous sources in the southeastern U.S. States such as Arkansas, Mississippi, Louisiana, and Alabama contain dozens of catfish hatcheries from which we can purchase juvenile fish.

6.4.3 - Initial system start-up and production sequencing

We intend to use the so-called stagger-stocking method as we begin to introduce fish to the production systems. This is a method of timing and introduction of fish that maximizes the available space within the systems and also allows for more frequent and regular harvesting, as compared to the batch method which underutilizes space and requires the operators to accept larger numbers of market-sized fish much less frequently.

According to the current fish production concept, we will have at our disposal three 250-gal round tanks for new fish entering the system (three other 250-gal round tanks will be used for quarantine, purging, and storage) and a much larger mixed-cell raceway system. Rather than stocking all of the three tanks initially, we plan to stock tanks consecutively with fingerlings at 1-month intervals.

When the first batch of fingerlings has completed their scheduled grow-out time in the round tanks (3 months), they will be transferred to an empty cell of the mixed-cell raceway system, where they will finish their grow-out for another 6 months. This will free a round tank to again accept fingerlings.

In a similar fashion, more fingerlings will arrive every month as round tanks become available. The mixed-cell raceway will fill with fish and will be harvested on the same schedule as new fish arrive, or probably more often (every 2 weeks) as some fish will tend to grow faster than others and can be removed from the system using size-grading harvesters. This stagger-stocking process will continue indefinitely as fish are harvested and processed.

6.4.4 - Stocking densities

Fish will be stocked into both the round tanks and mixed-cell raceways in numbers that will not exceed densities at harvest of 40 kg/m^3 (0.33 pounds/gal). By all accounts this is a safe density under normal operating conditions.

6.4.5 - Production

Two Main Aquaculture Production Units: (1) Fingerlings or Juveniles, (2) Grow-out to Harvest Size

The projected yearly aquaculture production goal is 7,189 lbs/yr of tilapia, or hybrid striped bass, consisting of harvesting 553 lbs of fish at a target (market) size of 750 g (1.5 lb) average weight, once every four weeks. The Aquaculture Bio-Plan (for tilapia or hybrid striped bass) is based on a 36 week grow-out period. The first 12 weeks will grow fingerlings from about 4.5 grams to about 70 grams in the Fingerling or Juvenile production system. Then fish are transferred to the grow-out production system, where they will grow from 70 grams to about 750 grams.

Healthy fingerlings, or juveniles, with an average weight of approximately 4 to 5 grams, will be acquired from a commercial fish hatchery every 4 weeks. Although fish disease should be extremely rare from these controlled-environment hatcheries, as a further precaution, newly arrived fingerlings will be temporarily quarantined, typically for no more than one week. Incoming fingerlings will be quarantined in a designated tank connected to a separate re-circulating aquatic life support system (LSS). This LSS shall be separate from the fingerling/juvenile recirculation aquaculture system (RAS) designated for production and growth of the fingerlings. The LSS that includes the quarantine tank will have an ultraviolet (UV) light sterilizer in the recirculation loop. The quarantined fish will be transferred to the fingerling RAS system after they have been observed and “stored” for a few days.

The fingerling culture stage is 12 weeks. Approximately 390 to 400 tilapia or hybrid striped bass fingerlings (approximately 4.5 grams average) are purchased every four weeks, with an acceptable cull and mortality loss of approximately 5% during the fingerling stage from arrival until transfer to the grow-out stage. During or after quarantine any needed culling will be performed to provide both a uniform size and growth rate as possible from the start of the aquaculture production cycle.

The fingerling production systems consist of three round fiberglass tanks with approximately 250 gallons water volume, sharing a common life support system (LSS), in which the fingerlings are grown out for 12 weeks, (~4.5 g to ~70 g). Each of the fingerling tanks holds a single cohort, or age/size group. These are harvested every twelve weeks for stocking into one of the two the mixed-cell raceways. At the time of maximum fish size in a given fingerling tank, the fish biomass density should not exceed 0.25 lbs/gallon in that tank.

The final grow-out takes place in two mixed-cell raceways (MCRs) over 24 weeks, to grow the fish from 70 g to a harvest size of 750 g, or about 1.5 lbs. The MCRs share a common LSS. Each MCR holds three cohorts (size/age classes) of fish that are stocked every eight weeks. A group of fish from a raceway is graded or sorted using a slow moving grading bar device in which smaller fish can pass through the vertical bars, while harvest size fish are "herded" into a more confined volume to both sort or grade the fish and to facilitate harvesting. This takes place every four weeks, alternating from the first raceway to the second raceway, such that there will be an 8 week cycle from which a given raceway will be harvested from.

One of the primary advantages of the mixed-cell raceway is the ease with which a grader bar can be moved slowly through the raceway with minimal disturbance of the fish. The harvested tilapia or hybrid striped bass are then moved into a purging tank, which shall be part of the same system that the fingerlings are temporarily quarantined in as they arrive in the facility.

The harvested fish are "purged" in this system because they are not given feed for one week, or more. After purging, they are then transferred out and sent to the DCJ kitchen for preparation, or, they may be sold on a designated "market day" of the week, until all fish from a given cohort are sold.

6.4.6 - Recirculation Aquaculture Systems Design Summary

Table 21 - Fish Production Table

Production Stage	Size grams/lbs	Maximum Fish Density kg/m^3 (lbs/gallon) in a single tank or a "mixed cell"	Tanks, Number and Dimensions	Total Culture Volume (in gallons)	Approx. Maximum Biomass, Total Culture Volume (lbs)	Approx. Maximum Feed Rate (lbs/day)
Fingerling System	4.3g – 70g (~0.15 lbs)	30 kg/m^3 (0.25 lbs/gal)	3 round tanks, 52"dia x 36"D	750 gallons	95 lbs	2.9 lbs
Grow-out System	70g – 750g (~1.5 lbs)	40 (0.33)	2 rectangular mixed cell raceways (MCRs), 8'W x 24'L x 3.5'D	10,053 gallons	2039 lbs	30.6 lbs

6.4.7 - Feed Rates and Growth Rates

Feed rates vary as a function of fish size. Young fish (in the range we expect to buy—5-10 g), can consume 6-8 percent of their body weight per day or more. However, older fish more close to harvest size of 750 g (1.65 pounds) consume much less on a percentage basis—often 1-2 percent of their body weight per day.

Despite their lower per-unit consumption, larger fish of course consume more feed on an absolute basis. By far, the most feed will be consumed and the fastest absolute growth will be realized when fish reach the mixed-cell raceway.

Initially, we expect feed conversion ratios (FCR; weight of feed required to produce a unit of fish) to be in the range of 1.7-1.5 for the entire production system. However, again, young fish tend to be more efficient than older fish, and their FCR is likely to be significantly lower—in the range of 1.2-1.3 or even lower. FCR for older fish could drift above 1.8, depending on culture conditions, but this is unlikely and we will manage the system to minimize FCR.

Based on an annual fish production rate of 3,270 kg (7,200 pounds) and FCR of 1.5-1.7, we can expect fish to consume 4,905-5,560 kg (10,800-12,240 pounds) of feed per year.

6.4.8 - Harvesting and Grading

As mentioned above, harvesting of fish is likely to occur at least once every 2 weeks. All fish do not grow at the same rate. As a result, some fish will reach harvest weight sooner than others. In this situation, harvesting is best accomplished using a size grading device that retains large fish and allows smaller fish to pass through. A size grader with metal bars precisely spaced to retain fish at harvest weight will be used to periodically remove market-ready fish from the mixed-cell raceways. As mixed cells are completely emptied over a 1-month period, they can be refilled with fish ready to graduate from the three smaller round tanks.

6.5 - Water

6.5.1 - Water quality

Regardless of fish species, the production system water quality must be managed within relatively strict ranges. Table 18 shows a sampling of items we will measure and monitor during fish production. Water quality will be maintained in the systems using a series of filters to remove solids and convert toxic waste products such as ammonia into non-toxic nitrate. Additionally, in a configuration where some fish wastewater moves directly from the fish tanks and raceways to the plant systems (i.e., fully integrated fish and plant system), the plants will supply significant and substantial filtration capacity as well.

Table 17 - Water Quality Parameters

Component	Hybrid striped bass
Optimal temperature (F)	72-76
O_2 (ppm, at opt. temp. and 5,280 ft. elevation)	5.7-7.1
O_2 saturation (%)	80-100
pH	6.8-7.6
Total ammonia-N (ppm)	<0.5
Nitrite-N (ppm)	<0.05
TDS (ppm)	50-1,000
Hardness (ppm)	50-700
Total alkalinity (ppm)	50-700
Calcium (ppm)	>20
Magnesium (ppm)	>15
Sodium (ppm)	<100
Potassium (ppm)	<75
Chloride (ppm)	>20
Sulfate (ppm)	<100
Copper (ppb)	<15
Zinc (ppb)	<40
Iron (ppm)	<1.5

6.5.2 - Ventilation and carbon dioxide and oxygen production

One of the wonderful advantages of raising fish and plants within the same structure is the ability of these two groups of organisms to complement each other in terms of their raw materials and waste products. Fish systems produce as waste products ammonia, phosphates, nitrites, nitrates, carbon dioxide, solid wastes, and other trace chemicals which are carried away in a matrix of water. It just so happens that plants use all of these substances as raw materials, and produce oxygen as a waste product.

Ideally with respect to gases, there would be a perfect balance between the carbon dioxide produced by the fish and the carbon dioxide requirements of the plants, and the oxygen produced by the plants and the oxygen requirements of the fish. This is, however, never the case. The production status of both the fish and plants is much too dynamic and fluid to ever reach that ideal. Indeed, in structures where only fish are raised, carbon dioxide production is often overlooked, and can accumulate to level that actually adversely affect the fish production process when the space is inadequately ventilated with fresh air. As a result, we must assume that we will add or compensate for at least the majority of the needs of the systems with regard to oxygen and carbon dioxide. Obviously, if we choose a production configuration that completely separates and isolates the fish and plants from each other, we cannot count on complementary use as raw materials of gaseous waste products.

We plan to incorporate into the final system design a battery of regenerative blowers to provide high-volume, low-pressure outside air to the building and systems. The blowers will supply air to the aeration systems within the fish tanks and mixed-cell raceways, as well as the aquaponic plants systems. As air passes through the aeration systems and through water and into the surrounding spaces, it will create pressure within the room that forces air to the outside, in effect acting as an air exchanger. This turnover of air in the building will be significant, and will be an important aspect as we move forward with a design for ventilation within the structure.

Blowers not only provide air and ventilation to a space, but they also add heat. Blowers compress air as they move it into aeration systems and into a building, and can raise the air temperature by as much as 20-30 degrees F.

While we reserve ventilation and heat engineering for the formal design process, we understand the contributions that fish, plants, and blowers make to the air quality of the interior spaces of the structure and its suitability for people.

6.5.3 - Water volume specifications

Total system water volume which combines the water in the fish tanks, storage tanks and deep water culture system is anticipated at 31,286 gallons.

Table 23 - Water Volume Parameters

Fish Systems	**11,553**	**Gal**
Growout	10,053	Gal
Fingerling Systems	1,500	Gal
Fresh Water Storage	**1,733**	Gal
Hydroponic Tank Volume	**18,000**	Gal
Total System Volume	**31,286**	**Gal**
Ratio of Hydroponic to Fish tank	1.56	:1

6.5.4 - Water weight and floor loads

The heaviest potential floor loading will take place underneath the mixed cell raceway grow out system. A typical slab on grade can accept 400 to 600 lbs per s.f. depending on the quality of the subbase material and condition of the floor. The table below demonstrates that we are well under the loading tolerances. These assumptions were reviewed and validated by S.A. Miro.

Table 24 - MCR water weight per s.f.

Mixed Cell Raceway Volume Calculations		
Width	8	ft
Length	24	ft
Water level Height	3.5	ft
Cubic Ft	672	ft3
Converted to Gallons	5,027	gal
Number of Raceways	2	
Total Gallons	10,053	gal
Single MCR weight by water	42,725.76	lbs
Water weight per s.f.	**222.53**	**per s.f.**

6.5.5 - Thermal Mass

Stored water is the best source of thermal mass which is a valuable resource for passive heating and cooling. Water can be used to accumulate and store heat during the day and then passively radiate that heat at night when air temperatures are dropping. In essence, the water helps to stabilize and reduce the daily temperature variations that can be one of the drawbacks of traditional greenhouses particularly in northern climates. One of the great benefits of aquaponics is the large amount of water that is inherent in the system which contributes a great deal towards achieving the desired amount of thermal mass in a greenhouse.

Table 25 - Thermal Mass Water Requirement

Thermal Mass		
Gallons per s.f. of south glazing	3	gal
Roof Glazing	6,656	sf
Required Water	19,968	gal
Sidewall glazing	4,320	s.f.
Required Water	12,960	gal
Total required water	32,928	gal
Total System water	31,286	gal
Balance of water required	1,642	gal
Water Wall Bags - Growers Supply		
Gallons per lay flat s.f.	7.5	gal
lay flat width	6.5	ft
lay flat length	34	ft
total s.f.	221	s.f.
Total gallons	1,658	gal

The calculations in the table below demonstrate the number of gallons required to support the estimated surface area of glazing present in the proposed greenhouse structure. Additional water wall bags can be added against the northern wall to help meet the balance of water required for thermal mass. The anticipated volume of water in the aquaponic system at 31,286 gallons almost entirely meets the minimum thermal mass requirements per the table below. Some additional water barrels can be added to make up the remaining 1,642 gallons.

6.5.6 - Fresh Water Storage

Approximately 1,700 gallons of fresh dechlorinated water should be available at all times. This volume represents about 15% of the total fish culture volume. In the event that a partial water change is required due to excessive ammonia or nitrite levels, the freshwater storage would be available to add to the fish tanks. Regular top offs of the water will be required due to water loss through evaporation and transpiration.

6.5.7 - De-Chlorination

An activated carbon filtration system is required to remove chlorines and chloramines present in the city water supply and these are highly toxic to fish. We have worked with a local water filtration company to specify the appropriate size filtration system based upon our expected storage capacity and flow rate. The system specifications are based on Culligan International model HFxN-242R-FRP configured as a Single/Water Meter. The purpose of the Culligan International Series HF xN-NC single/Water Meter automatic carbon filter will be to remove tastes and odors, reduce organics and/or remove chlorine from a known water supply, when the system is operated at 20.0 gpm and in accordance with the operating instructions. The systems performance is rated at a design flow rate of 20.0 gpm with a rated pressure drop of 2.7 psi, and will be capable of a peak flow rate of 31.0 gpm for sustained periods of 90 minutes with a pressure drop of 5.0 psi.

6.5.8 - Water Heating

Based upon the water temperature parameters described previously for Hybrid Stripped Bass, we will need to provide a source of heat for the water. One of the primary reasons for recommending Hybrid Striped Bass is there wide tolerance range for temperature. As a cool water species we can anticipate running lower temperatures throughout the system and thus saving on energy costs versus going with a warm water species requiring more heat energy. With the large volume of water and water's excellent ability to maintain heat through thermal mass, we expect relatively low heating requirements. The jail's existing steam loop will provide an excellent source of readily available heat which we can utilize through a heat exchange system to provide a reliable source of heat. However, we would also like to explore the option of providing a solar hot water system as a primary heat source using renewable energy from the sun. We have several experts available to design a system in the design development stage of this project. Our primary goal here would be to utilize the sun's energy whenever possible and then fall back on the steam loop when renewable energy was not readily available.

6.6 - System Monitoring and Safeguards

Central control systems can be configured with alerts for system operators in the event of outages or temperature extremes among other variables for the greenhouse environment. The aquaponics system can also be included in this control system or it can maintain its own separate system to monitor power, oxygen, water flow rates and levels among other things. A control system budget has been included in the overall capital plan.

6.6.1 - Backup power

It will be essential to maintain an onsite source of backup power. An uninterruptable power supply is probably not necessary as long as power can be transferred to a generator in under a minute. The most important piece of equipment to maintain in operation will be the regenerative air blower which provides dissolved oxygen to the fish. Fish left without oxygen for more than a few hours can die either immediately or soon thereafter from resulting damage to gills and respiratory systems. Water pumps would be important to have but not as critical as the air blower. The system will be designed to maintain water levels with minimal overflow if any in the event of a pump outage. Most other electrical equipment can remain off for short periods so as to not oversize the generator. Inclusion of the greenhouse electrical systems on any pre-existing backup power source on the jail campus would be ideal. The energy consumption table found in the financial analysis section can be used for the sizing of the backup power systems by an electrical engineer.

6.7 - Square footage summary of major components

Table 26 - Square Footage Summary

General Space Program Plan	**Gutter Connected Teton Greenhouse (29x120x2)**	**6,960**	**sf**
Program Item	**Description**	**Occupied s.f.**	**% Building**
Deep Water Culture Troughs	Primary production space for head lettuce varieties	2,400	34.5%
Media Beds	Production space for fruiting crops/other species	480	6.9%
Mixed Cell Raceway for grow out	Main grow out tanks for fish	682	9.8%
Fingerling production systems	tanks for early stage fish prior to grow out	336	4.8%
Tomato rows	rows for hydroponic tomato production	250	3.6%
Harvest - Transplant work areas	work areas for harvesting produce	240	3.4%
Seedling Nursery	space for seedling growth trays before transplant	78	1.1%
Fresh water and sludge storage	location for tanks to store fresh water and sludge discharge	60	0.9%
Feed & Supply Storage	Fish feed and other supply storage	78	1.1%
Office - Work area	desk space for recording keeping, testing, manager, sink	24	0.3%
Total		4,628	66%
Remaining Circulation Space		2,332	34%

7.0 - Financial Overview

In this section we will review the results of the financial feasibility analysis. It's important to note that some of these numbers will likely change as we progress through the next phase of design development. The goal of the financial overview is to paint a picture of the overall financial performance of the aquaponics system, the greenhouse operation as a whole and the resulting value of the food production. This includes an understanding of the anticipated upfront and ongoing operating costs, the potential savings that could result with internal food production versus purchasing from outside sources and to ultimately understand whether or not this is a good investment for the Sheriff's office. Finally, this analysis looks only at the pilot system in phase 1 and does not take into account the future plans to expand the growing environment into adjacent acreage.

The financial overview section is organized as follows:

- **7.1 - Project Capital Summary & Depreciation**
- **7.2 - Capital Budget Detail**
- **7.3 - Current Produce Consumption & Costs**
- **7.4 - Produce Production vs. Current Consumption**
- **7.5 - Sensitivity & Break Even Analysis of Case Lettuce**
- **7.6 - Cost to Produce vs. Cost to Purchase**
- **7.7 - Fish Production**
- **7.8 - Occupancy - Energy**
- **7.9 - 5 year financial plan**
- **7.10 - Return on Investment**
- **7.11 - Executive Summary Cash flow**

7.1 - Capital & Depreciation Summary

Capital costs are summarized in the table below. Phases II, III and IV represent budget estimates for consulting, architectural, construction and management turnover services as noted in the initial project proposal. The initial feasibility study provides an overview of major cost areas and should still be considered an early estimate for planning purposes. The succeeding design development phase will allow for considerably more detail and accuracy in the capital budget projection. This could mean that costs could go up or down as the final design and costs are fully accounted for.

Table 18 - Capital Summary

Capital Summary	
Phase II - Design Dev	$ 103,500
Phase III - Construction	$ 151,000
Phase IV - Turnover	$ 31,800
Building Demo	$ 60,000
Greenhouse	$ 169,900
Aquaponics System	$ 114,474
Contingency 15%	$ 94,601
Working Capital	$ 6,222
Total startup capital	$ 731,498

Assumptions

- Complete building demolition was quoted by FCI Constructors
- Greenhouse construction is quoted at $17 psf on 7,200 s.f using the existing concrete slab
- Greenhouse cost psf includes all mechanical systems, glazing, fans, cooling walls and environmental controls
- 15% contingency included for unforeseen conditions
- An additional allowance for tying into the existing steam loop was included in the greenhouse costs

Design Development – Costs are detailed in the capital detail section, but these generally include consultant, engineering and architectural estimates for the next phase. Once the scope is agreed upon for services we can provide a more accurate fee proposal for design development. Additional expertise may also be required in areas such as solar PV and solar thermal systems should we wish to pursue a detailed design for those options.

Working Capital – The following table shows the number of months that this system upon startup will be operating at a loss as well as the anticipated month in which the loss will be covered. In this case, the operation produces its first month of positive returns in month 5 and covers the first four months of losses by month 10. Working capital is shown as $6,222 by the end of month 4.

Table 28 - Monthly Cash Flow

Month 1	Month 2	Month 3	Month 4	Month 5	Month 6	Month 7	Month 8	Month 9	Month 10
$ (2,741)	$ (1,375)	$ (1,436)	$ (670)	$ 13	$ 565	$ 1,126	$ 1,517	$ 1,338	$ 3,619
Cumulative surplus/deficit			$ (6,222)	$ (6,209)	$ (5,644)	$ (4,518)	$ (3,001)	$ (1,663)	$ 1,956

Depreciation Assumptions

- Buildings, equipment and construction are on straight line depreciation subtracting a 20% salvage value over 20 years
- A 3% escalator for inflation is added each year
- A more detailed line by line depreciation analysis can be performed in the design development phase if necessary

- Design Development, Building Demolition and Turnover Services were not included in the depreciation schedule

Table 29 - Depreciation

Item Description	Price	Salvage %	Value	Net value	years	esc	Year 1	Year 2	Year 3
Construction	$ 151,000	20%	$ 30,200	$ 120,800	20	3%	$ 6,040.0	$ 6,221.2	$ 6,407.8
Greenhouse Systems	$ 169,900	20%	$ 33,980	$ 135,920	20	3%	$ 6,796.0	$ 6,999.9	$ 7,209.9
Aquaponic System	$ 114,474	20%	$ 22,895	$ 91,580	20	3%	$ 4,579.0	$ 4,716.3	$ 4,857.8
Sum Total	$ 435,374		$ 87,075	$ 348,300			$ 17,415	$ 17,937	$ 18,476

7.2 - Capital Budget Detail

Table 30 - Capital Detail

Category/item	Units	Unit cost	Total	Rollup	Notes
Soft Costs				**$ 286,300.00**	
Phase II - Design Development				**$ 103,500.00**	
FTAI	150	$ 150.00	$ 22,500.00		Detailed design and planning services
CA	175	$ 120.00	$ 21,000.00		Design planning, project oversight, coordination
Reilly Johnson	1	$ 30,000.00	$ 30,000.00		Oversight of engineers, contractors (needs more scope dev)
MKK Engineering	1	$ 30,000.00	$ 30,000.00		Mech systems planning, engineering, estimating (scope dev)
Foundation Engineer	1	$ 15,000.00	$ 15,000.00		allowance - per Nexus for building support engineering
Phase III - Construction				**$ 151,000.00**	
FTAI	50	$ 150.00	$ 7,500.00		Construction oversight, QA
Aquaponics System Build	1	$ 46,800.00	$ 46,800.00		Aquaponics System Construction
Greenhouse Installation	7,200	$ 6.00	$ 43,200.00		Nexus Installer Quote
RJA - Construction Admin	100	$ 120.00	$ 12,000.00		allowance - DD phase for more accuracy
Electrical	1	$ 20,000.00	$ 20,000.00		allowance - DD phase for more accuracy
Mechanical	1	$ 20,000.00	$ 20,000.00		allowance - DD phase for more accuracy
Permits	1	$ 1,500.00	$ 1,500.00		allowance - DD phase for more accuracy
Phase IV - Startup, Turnover				**$ 31,800.00**	
FTAI	20	$ 150.00	$ 3,000.00		Operations turnover
CA	240	$ 120.00	$ 28,800.00		System startup and operations turnover (needs scope)
Building Modifications & Improvements				**$ 60,000.00**	
Demolition				**$ 60,000.00**	
Full Building Demolition	1	$ 60,000.00	$ 60,000.00		FCI Constructors initial quote
Greenhouse				**$ 169,900.00**	
General				**$ 169,900.00**	
Two Teton gutter connected @ 30'x120' each	7,200	$ 17.00	$ 122,400.00		includes all HVAC, HAF, Glazing
Electrical allowance for panel relocate	1	$ 5,000.00	$ 5,000.00		allowance - DD phase for more accuracy

Hook up to steam plant	1	$ 10,000.00	$ 10,000.00		allowance - DD phase for more accuracy
Radiant heat loop - Heat exchanger	1	$ 6,000.00	$ 6,000.00		allowance - DD phase for more accuracy
Optional Passive Solar System	1	$ 10,000.00	$ 10,000.00		allowance - DD phase for more accuracy
Outbuilding for mech/bath/storage/ misc	400	$ 20.00	$ 8,000.00		allowance - DD phase for more accuracy
Restroom, sink	1	$ 3,500.00	$ 3,500.00		allowance - DD phase for more accuracy
Security cameras	5	$ 1,000.00	$ 5,000.00		allowance - DD phase for more accuracy
Aquaponics System				**$ 114,474.43**	
Fingerling System				**$ 25,000.00**	
Fingerling system 3 tank unit	2	$ 12,500.00	$ 25,000.00		Aquaculture Systems Technologies
Mixed Cell Raceway System				**$ 27,800.00**	
MCR Growout System	1	$ 27,800.00	$ 27,800.00		Aquaculture Systems Technologies
Fresh Water and Effluent Storage				**$ 8,450.00**	
1000 gallon fresh water storage tank	2	$ 1,100.00	$ 2,200.00		Poly tank
Tank supports	2	$ 750.00	$ 1,500.00		Poly tank
500 gallon effluent storage tank	1	$ 750.00	$ 750.00		Poly tank
De-chlorination system	1	$ 4,000.00	$ 4,000.00		Culligan or Aquatic Eco
Hydroponic Systems				**$ 22,000.00**	
DWC beds	1	$ 12,000.00	$ 12,000.00		Styrofoam boards, lumber, hardware, liner
Media Beds	1	$ 10,000.00	$ 10,000.00		Lumber, liner, media
Plumbing and Irrigation				**$ 8,500.00**	
Misc plumbing equipment - supplies	1	$ 8,500.00	$ 8,500.00		allowance - DD phase for more accuracy
Aeration				**$ 2,500.00**	
Redundant Blower array	2	$ 1,250.00	$ 2,500.00		
Misc Fixtures and Equipment				**$ 8,174.43**	
Nursery Area Tables	1	$ 1,500.00	$ 1,500.00		
Nursery Lighting	6	$ 250.00	$ 1,500.00		may not be required. TBD
Plant Startup Supplies	1	$ 2,674.43	$ 2,674.43		net pots, seeding media, flats etc
Desk, Office Equip	1	$ 500.00	$ 500.00		
DO Meter/ Test Equipment	1	$ 2,000.00	$ 2,000.00		
Emergency Monitoring and Alerting				**$ 12,050.00**	
Continuous monitoring DO, Temp	1	$ 6,400.00	$ 6,400.00		Aquaculture Systems Technologies
Alarm phone dialer system	1	$ 1,050.00	$ 1,050.00		Aquaculture Systems Technologies
Emergency oxygen on power failure system	1	$ 1,100.00	$ 1,100.00		Aquaculture Systems Technologies
Backup Generator	1	$ 3,500.00	$ 3,500.00		TBD - could me a lot more depending on sizing

7.3 - Current Produce Consumption and Costs

The following table was provided by the Sheriff's office kitchen staff. Items highlighted in grey are ones we feel that we can produce in the aquaponics greenhouse environment and the items not highlighted are ones that are better suited for soil based production and future project phases using adjacent acreage.

Table 31 - Produce Extended Cost

Item	Each	Weight		Monthly	Weight		Annual	Weight
Celery	$16.95	48	ct	$203.40	12	cs	$2,440.80	144cs
Cucumbers	$16.85	45	lbs	$16.85	45	lbs	$202.20	12cs
Bell Peppers	$13.85	25	lbs	$41.55	75	lbs	$498.60	900lbs
Broccoli	$15.45	18	lbs	$139.05	162	lbs	$1,668.60	1,944lbs
Zucchini	$29.95	20	lbs	$89.85	60	lbs	$1,078.20	720lbs
Cherry Tomatoes	$14.15	1	case	$113.20	8	cs	$1,358.40	96cases
Whole Tomatoes	$14.85	20	lbs	$118.80	160	lbs	$1,425.60	1,920lbs
Cilantro	$1.00	1	bunch	$2.00	2	bunch	$24.00	24bunch
Head Lettuce	$16.85	24	ct	$2,022.00	120	cs	$24,264.00	1440cases
Romaine Lettuce	$19.88	24	ct	$2,382.00	119	cs	$28,584.00	1428cases
Carrots Whole	$11.00	25	lbs	$1,320.00	3,000	lbs	$15,840.00	36,000lbs
Fresh Spinach	$6.95	5	lbs	$27.80	30	lbs	$333.60	60lbs
Mushrooms	$18.95	10	lbs	$94.75	50	lbs	$1,137.00	600lbs
Red Onions	$12.15	50	lbs	$12.15	50	lbs	$145.80	600lbs
Yellow Onions	$12.15	50	lbs	$486.00	972	lbs	$5,832.00	11,664lbs
Whole Potatoes	$29.95	100	lbs	$1,755.00	5,800	lbs	21,060.00	69,600lbs
Green Cabbage	$15.15	50	lbs	$272.70	900	lbs	$3,272.40	10,800lbs
Fresh Garlic	$12.90	5	lbs	$38.70	15	lbs	$464.40	180lbs
TOTAL				**$9,135.80**			**$109,629.60**	

7.4 - Produce Production vs. Current Consumption

Based upon the conceptual system design including crop spacing, crop placement, typical yields and many other factors, we have estimated produce yields within the system and compared them to current consumption to illustrate the overall impact that the aquaponics system could have on current food purchasing costs. This table shows the percentage of production, the estimated value of that production using your current cost values and the total annual value of the proposed production.

Table 32 - Production vs. Consumption

Item	Grown in	$/head/lb/cs	Est. prod/mth	units	% of current	Monthly	Annual		Total value
Celery	Media	$16.95	1.9	cases	16%	$31.73	22.5	cases	$380.76
Cucumbers	Media	$0.37	22.3	lbs	50%	$8.36	267.8	lbs	$100.29
Bell Peppers	Media	$0.55	20.6	lbs	28%	$11.43	247.7	lbs	$137.21
Broccoli	Media	$0.86	30.0	lbs	19%	$25.75	360.0	lbs	$309.00
Zucchini	Media	$1.50	26.4	lbs	44%	$39.53	316.8	lbs	$474.41
Whole Tomatoes	Media	$0.74	48.8	lbs	30%	$36.20	585.0	lbs	$434.36
Cherry Tomatoes	Media	$14.15	4.2	cases	53%	$59.43	50.4	lbs	$713.16
Cilantro	DWC	$1.00	1.2	bunch	60%	$1.20	14.4	lbs	$14.40
Head Lettuce	DWC	$0.70	138.7	cases	116%	$2,336.53	1664.0	cases	$28,038.40
Romaine Lettuce	DWC	$0.83	138.7	cases	117%	$2,756.69	1664.0	cases	$33,080.32
Total Value						**$5,306.86**			**$63,682.32**

7.5 - Sensitivity & Break Even Analysis of Case Lettuce

For the purposes of this analysis we chose to focus on head and romaine lettuce cases since the total value of these annual expenses represents the largest portion of the projected output and total production value from the system.

The next two tables show how the operation would perform as a standalone business producing cases of head lettuce. The analysis looks at the current average price per case and shows the impact of price fluctuations in the market as a percentage deviation from the current price you are paying according to the produce cost table. Included in the sensitivity analysis is a look at break even volumes and break even pricing. Annual fixed costs are taken from the 5 yr plan worksheet and total variable costs are divided by production units to determine variable cost per unit. Break even volume illustrates the number of cases that the operation needs to produce in order to break even and cover costs. The margin of safety subtracts the total projected output of cases by the break even volume to determine the surplus cases and margin %. Finally, an alternative way of looking at breakeven is to determine the minimum breakeven price per case you would have to sell the total production volume for.

Table 33 - Sensitivity without Depreciation

Price Per Case Analysis	-10%	Current Avg	10%	20%
Price per case	$16.53	**$18.37**	$20.20	$22.04
Gross revenue annual cases	$55,007	$61,119	$67,231	$73,342
Break Even Cases				
Projected Output volume =	3,328	3,328	3,328	3,328
Annual fixed costs (a) = fixed costs	$27,361	$27,361	$27,361	$27,361
Variable costs/unit (b) =	$5.71	$5.71	$5.71	$5.71
Estimated market value/unit (c) =	$16.53	$18.37	$20.20	$22.04
Break-even volume (a) / (c – b) =	**2,530**	**2,163**	**1,889**	**1,676**
Margin of Safety	798	1,165	1,439	1,652
Margin of Safety %	24%	35%	43%	50%
Breakeven price	$13.94	$13.94	$13.94	$13.94

Table 34 - Sensitivity with Depreciation

Price Per Case Analysis	-10%	Current Avg	10%	20%
Price per case	$16.53	**$18.37**	$20.20	$22.04
Gross revenue annual cases	$3,328	$3,328	$3,328	$3,328
Break Even Cases				
Projected Output volume =	3,328	3,328	3,328	3,328
Annual fixed costs (a) = fixed costs	$44,776	$44,776	$44,776	$44,776
Variable costs/unit (b) =	$5.71	$5.71	$5.71	$5.71
Estimated market value/unit (c) =	$16.53	$18.37	$20.20	$22.04
Break-even volume (a) / (c – b) =	4,140	3,539	3,091	2,743
Margin of Safety	(812)	(211)	237	585
Margin of Safety %	-24%	-6%	7%	18%
Breakeven price	$19.17	$19.17	$19.17	$19.17

7.6 - Cost to Produce vs. Cost to Purchase

The next two tables illustrate your current annual consumption volume of head and romaine lettuce which is 2,868 cases. The goal in this analysis is to illustrate what your current cost per case is versus the cost to internally produce that same case. Since we have established a variable cost per case value from the previous tables, we can apply that number towards the same volume of cases that you are currently purchasing on an annual basis. This will yield a cost per case for internal production assuming the same amount of cases are produced as would have been purchased. The bottom line of the net savings shows the difference in cost between purchasing the case and producing it on site.

If the price to purchase a case of lettuce goes up in the market place and assuming your cost of production stays the same then there is increased value in producing your own cases on site as seen by the positive net savings results in the 10% and 20% price increase columns. When calculating in depreciation, the price to produce a case does not result in a net savings until at least a 20% market price increase is experienced.

Table 35 - Cost to Produce vs. Cost to Purchase (no depreciation)

Price Per Case Analysis	-10%	Current Avg	10%	20%
What you are paying per case	**$16.53**	**$18.37**	**$ 20.20**	**$ 22.04**
Current annual consumption volume	2,868	2,868	2,868	2,868
Total annual expenses	$ 47,404	$ 52,671	$ 57,938	$ 63,205
Break Even				
Annual fixed costs (a) = fixed costs	$ 27,361	$ 27,361	$ 27,361	$ 27,361
Variable costs/unit (b) =	$ 5.71	$ 5.71	$ 5.71	$ 5.71
Estimated market value/unit (c) =	$ 16.53	$ 18.37	$ 20.20	$ 22.04
Break-even volume (a) / (c – b) =	**2,530**	**2,163**	**1,889**	**1,676**
Margin of Safety	338	705	979	1,192
Margin of Safety %	12%	25%	34%	42%
Cost to produce the same case	**$ 15.25**	**$ 15.25**	**$ 15.25**	**$ 15.25**
Net savings	**$1.27**	**$3.11**	**$4.95**	**$6.78**

Table 36 - Cost to Produce vs. Cost to Purchase (with depreciation)

Price Per Case Analysis	-10%	Current Avg	10%	20%
What you are paying per case	**$16.53**	**$18.37**	**$ 20.20**	**$ 22.04**
Current annual consumption volume	2,868	2,868	2,868	2,868
Total annual expenses	$ 47,404	$ 52,671	$ 57,938	$ 63,205
Break Even				
Annual fixed costs (a) = fixed costs	$ 44,776	$ 44,776	$ 44,776	$ 44,776
Variable costs/unit (b) =	$ 5.71	$ 5.71	$ 5.71	$ 5.71
Estimated market value/unit (c) =	$ 16.53	$ 18.37	$ 20.20	$ 22.04
Break-even volume (a) / (c – b) =	**4,140**	**3,539**	**3,091**	**2,743**
Margin of Safety	-1,272	-671	-223	125
Margin of Safety %	-44%	-23%	-8%	4%
Cost to produce the same case	**$ 21.33**	**$ 21.33**	**$ 21.33**	**$ 21.33**
Net savings	($4.80)	($2.96)	($1.12)	$0.71

7.7 - Fish Production and Costs

The annual production of Hybrid Striped Bass or Tilapia is projected at 7,189lbs per year or about 600 lbs per month. With a price per lb estimate of $3.00, the following table illustrates the anticipated value of the fish production in the aquaponics system.

Table 37 – Annual Value of Fish Production

Item Description	Esc	Year 1	Year 2	Year 3	Year 4	Year 5
Tilapia/HSB	3%	$ 5,412.5	$ 21,650.0	$22,299.5	$22,968.5	$ 23,657.5

Assumptions

- We are assuming the first fingerling stocking to be on Jan 1st 2013. With a 36 week grow out period, the first monthly harvest of 600 lbs would take place in October. Therefore the year 1 numbers are significantly lower than the following years which will see a full 12 months of harvests.

Fish Expenses - The major direct expenses associated with fish are the purchasing and shipping of fingerlings as well as the feed.

Table 38 - Summary of Major Fish Expenses

Item	esc	Year 1	Year 2	Year 3	Year 4	Year 5
Fingerlings + Shipping	3%	$ 5,105.6	$ 5,105.6	$ 5,258.7	$ 5,416.5	$ 5,579.0
Feed	3%	$ 4,497.5	$ 8,442.0	$ 8,695.3	$ 8,956.1	$ 9,224.8
Misc Supplies	3%	$ 420.0	$ 420.0	$ 432.6	$ 445.6	$ 458.9
Sum Total		$ 10,023.1	$13,967.6	$14,386.6	$ 14,818.2	$ 15,262.7

Assumptions

- Assumes the purchase of 5 gram hybrid striped bass fingerlings from Keo Fish Farms in Arkansas. In state suppliers offer Tilapia as an alternate option which may reduce shipping costs, but Tilapia also require higher water temperatures as well adding to the cost of heating the system. A final decision on the selected species can be made later on in the process.
- 40 lb feed bags are priced at $28 a bag.