Principles of Aquaponic System Design

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In this workshop we will…

- Create a basic conceptual design for an aquaponic farm
- Incorporate principles of daily feed rate into system design
- Layout fish tanks, filtration, hydroponic and aeration systems
- Review water flow and decoupling
- Determine plant and fish production metrics

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2

So many considerations…

Business and Environmental Considerations

- Climate Zone Designation
- Local labor
- Permitted fish species
- Outlet for fish
- Locally accepted crops
- Market pricing for desired crops
- Proximity to markets
- Competitive analysis
- Distribution methods, channels
- Public access, tours, classes
- Security
- Food safety regulations
- Licensing, wholesale, processing
- Insurances
- Business plan (whole other document)
  - Financial
  - Marketing
  - Operations
  - Human Resources

Site Conditions

- Fresh water source
- Water quality test, flow rate, reliability, refresh rate
- Electrical service, reliability
- Propane or natural gas
- Road access
- Equipment delivery method
- Infrastructure
- Locally available construction, plumbing materials
- Sun orientation, obstructions, winter/summer light availability
- Local zoning, permitting and regulatory requirements
- Renewable energy systems
- Grading, fill
- Site drainage, water discharge
- Sanitary sewer
- Utility locates
- Wash station, restrooms
- Site security

 3

3

Assumptions for this Exercise

- We have a business plan!
- We're raising Tilapia
- Water temperature is 72F
- Desired pH range is 6.6 to 7
- No artificial lights except for nursery and microgreen
- Colorado-like climate (hot summers, cold winters)
- Climate controlled greenhouse
- Municipal filtered water
- We're going to grow Romaine, Bibb Lettuce, Green Star, Mustard Greens, Kale

 4

4

Just a few variables that influence plant production, loss rate & profit!

- Startup
- Nutrient Deficiencies
- Operator skills, Management and Training
- Business & Marketing Plan (lack there of)
- Customer & price volatility
- Available light
- Plant species
- Culture time in system
- Pests
- Fish Species, Feeding
- Temperature and Environment
- Quality of Starts
- Product Handling
- Monitoring and control systems
- Food Safety
- Supply Chain
- Water Quality

 5

5

It's All in the Feed…

In any aquaponic system the amount (or number) of plants we can grow is directly related to the amount of nutrient available

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6

It's All in the Feed…

The amount of nutrient available is directly related to the amount of waste the fish produce

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7

It's All in the Feed…

The amount of waste produced is directly related to the amount of feed fed to the fish

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It's All in the Feed…

Therefore, the amount of plants grown is directly related to the amount of feed that enters the system

Dr. Wilson Lennard

 9

9

Designing for Plant Production

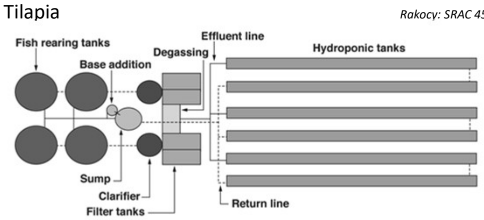
- Number and type of plants you wish to grow
- The area those plants need to grow (or the max area you can provide)
- How much fish feed the plants require for nutrient uptake
- The weight of the fish required to eat the feed
- The volume of water required for the fish based on stocking density

10

Feed to Plant Ratios

- Original research on feed to plant ratios developed by Dr. James Rakocy at UVI
- 60 to 100 grams of feed/m²/per day in the UVI system for Tilapia

Rakocy: SRAC 454



11

Feed to Plant Ratios cont…

- Dr. Wilson Lennard conducted further research and developed models to balance fish feed rates for specific plant species
- Lower fish feed rates were achieved approximately 13 – 20 grams of feed/m²/per day

Lennard: Aquaponic Solutions , Fish to Plant Ratios

12

In our experience

At Flourish Farms we've been consistently running on feed rate ratios between 13 to 20 grams/m²/day

 13

13

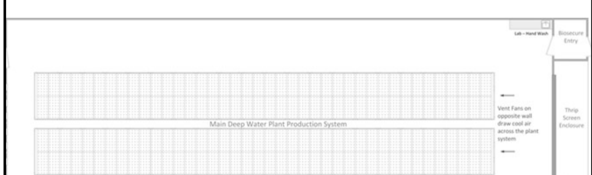
Starting from Scratch

- Look at HVAC Equipment locations – Cooling walls, HAF Fans, Vent fans, Heaters and other equipment in the greenhouse
- Consider concrete for a level floor and easy to maintain washable surface
- 30 x 96' greenhouse = 2,880 sq ft - South Facing (northern hemisphere)

 14

14

Plan out your DWC footprint



- Consider entrance and egress, handwashing, harvesting, circulation space, ADA requirements and distribution among other things.
- Two 8' x 80' DWC troughs = 1,280 sq ft
- Don't build plant growing systems up against the glazing. The air temperature is too volatile. Leave at least 20" for access

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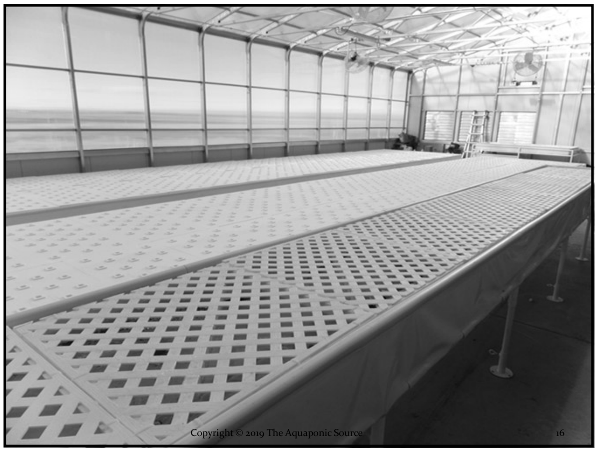


16

Estimate DWC Using the Farm Production and Financial Planning tool

Growasis Ground Level Troughs	2
Trough width (ft)	8
Trough Length (ft)	80
Total Trough Sq ft	1,280
Number of 2x4 Raft Boards	160
Total all Growasis s.f.	1,280
Growout s.f. (excludes 2x2 rafts)	1,280
Total all 2x4 Raft Boards	**160**
Plant density per s.f.	**3.5**
Total plants per culture	4,480
Culture period (weeks)	4.0
Annual Harvests	13.0
Total plants	58,240
Loss rate	10%
Net Plants Annual	**52,416**
Monthly plants	4,368
Weekly plants	1,008

17

Feed & Fish Production

- 1,280 s.f. of DWC = 119 m²
- 119m² * 18g/m² = 2,141 grams of feed per day (4.7 lbs)
- Annual feed input = 1,721 lbs
- Tilapia Feed conversion ratio (FCR) 1.5 lbs of feed to 1lb of body mass (FCR = .66)
- Annual fish production = Annual Feed input x FCR = 1,147 lbs
- Average harvest weight = 1.5lbs
- Total # of harvested fish annually = 770
  - (annual fish production gain 1,147lbs/1.5lbs)

 18

18

Basic feed & fish calculations

- We will have 4 age cohorts in 4 different tanks using the staggered stocking method.
- Assuming a 52 week growth period from fingerling to harvest, we will be performing a full harvest of the adult tank every 13 weeks
- Therefore we will be stocking a new batch of fingerlings every 13 weeks (in the empty adult tank).
  - 52 weeks/4 cohorts = 13 weeks between full harvests
  - Full harvests per year = 4 (52 weeks/13 weeks)
  - Multiple smaller partial harvests may be more realistic
- Weight per harvest = 288 lbs
  - annual weight 1,147 lbs / # of harvests (4)
- Maximum stocking density = .6lbs per gallon
  - Equals density on final day of 12 month cycle
- Water volume for each rearing tank = 480 gallons
  - Weight per final harvest/stocking density
- Stocking Rate of Fish per tank (288 lbs /1.5 lbs) = 193 fish

 19

19

Staggered Stocking

Staggered stocking is the concept of raising different age groups or cohorts of fish in separate tanks. The stagger stocking method allows you to:

- Separate fish by age groups
- Control the specific size and type of feed appropriate for the size and maturity of the fish
- Keep larger fish from dominating feed over smaller fish
- Maintain a predictable rotation and supply of harvestable fish which may be desirable if you have a dedicated market to sell them in to.
- Avoid moving fish from one tank to another which creates stress on the fish and additional labor.

 20

20

Staggered Stocking

Months 1 to 3	Fingerlings	Juveniles	Young Adult	Adult
Months 4 to 6	Juveniles	Young Adult	Adult	Fingerlings
Months 7 to 9	Young Adult	Adult	Fingerlings	Juveniles
Months 10 to 12	Adult	Fingerlings	Juveniles	Young Adult

21

21

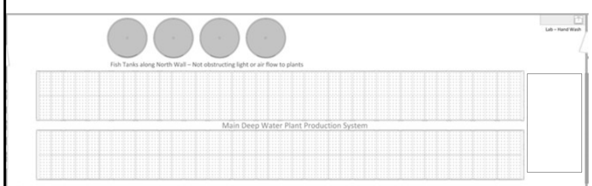
Fish Tank Flow Rates

- The time in which water is fully exchanged in a fish tank is called Hydraulic Retention Time (HRT). One full exchange per hour is equal to a 60 min HRT. An HRT between 30 to 60 minutes is common in aquaculture.
- In our example we are going to target an HRT of 60 minutes for our fish system. The calculation would look as follows: **(4 tanks x 500gal each) = 2,000 gallons ÷ 60 minutes = 33.3 gpm total**.
- The flow rate for each fish tank would therefore be **33.3 gpm ÷ 4 tanks = 8.3 gpm per tank**. This suggests that the pump we select should be able to deliver 33.3 gpm (2,000gph) to the fish tanks. However, this target flow rate also has to factor in the amount of head height and other resistance factors such as plumbing fittings, filters and pipe resistance discussed in the components course.

 22

22

Fish Tanks – Four @ 500 gallons



- Hydraulic Retention Time (HRT) in fish tanks 30 to 60 min
- 500g tank @ 60min HRT = 8.33 gpm or 500 gph (per tank)
- @ 30min HRT = 17gpm or 1,000 gph

 23

23

 24

24

Filtration Review

- **Mechanical Filtration - capture and removal of solid wastes**
  - Settleable solids – float on surface or settle to bottom
    - Drops out of water column within an hour
  - Suspended solids – captured in screens, nets, media, brushes
    - Drops out of water column within two to three hours
  - Dissolved solids – most difficult to separate and capture
    - May remain in water column without clearing
- **Biological Filtration - converts Ammonia to Nitrites and Nitrate**
  - Requires proper surface area for nitrifying bacteria to colonize
  - Requires proper aeration and alkalinity for optimal performance

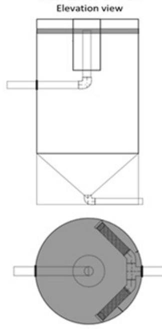
 25

25

Radial Flow Clarifier

- A general rule of thumb for sizing an RFC is to use a hydraulic loading rate of 4.6 gallons per minute per s.f of horizontal surface area of the tank.
- The RFC will experience a total flow rate of 33.3 gpm.
- 33.3gpm ÷ 4.6gpm/s.f. = 7.2 s.f. of RFC surface area.

Cross section of RFC – Elevation view



RFC surface area Top down view

 26

26

RFC Calculations Cont…

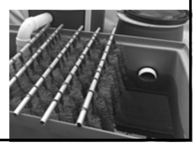
- To determine the diameter of the tank from the surface area use the following calculations:
  - 7.2 s.f. ÷ π(3.14) = 2.3.
  - Take the square root of the previous result: √2.3 = 1.5r. This is the radius
  - Multiply the radius by two: 1.5r x 2 = 3 ft (36 in) diameter.
- The minimum diameter for the tank should therefore be 36”
- In this scenario, tank depth should be roughly equivalent to the depth of the fish tanks at 33”. If the depth of the tank is too shallow, then solids may stay in suspension and not properly settle out of the clarification zone.
- Plumb in a bottom center drain for solids removal.

 27

27

Mineralization Tank

- **This second filtration tank is primarily used for the capture and mineralization of lightweight suspended solids** to prevent them from interfering with the biofilter and plant systems and to further breakdown fish wastes into nutrients for plants.
- Water flows from the RFC into one end of the filter tank and out the opposite end, passing through the filter media on the way.



28

Mineralization Cont…

- We recommend filter brushes 2 feet in length.
  - Brushes are easy to remove and clean
  - Great for filtering finer suspended solids.
- The filter tank in the sample design is 180 gallons (49”L x 33”W x 24”D).
  - Brushes are placed across the width of the tank in several rows.
  - They should span the full depth of the tank.
  - The goal is to force water and suspended solids to pass through the filter brushes.

 29

29

Biofilter Sizing

- About 3% of daily feed ends up as Ammonia-Nitrogen in the water*
- 4.7 lbs of daily feed @ 3% ⇒ 64g TAN
- Volumetric TAN Conversion rate (VTR) is the grams of TAN per volume of media per day converted into nitrate
- Design VTR = 15gTAN/ft^3
  - Assuming granular media (>175 ft^2/ft^3)*
- 64gTAN/15g VTR= 4.3ft^3 of media
- Media @ 50% of container volume≅ 9ft^3 or 64 gallons
- A 64 gallon tank ≅ 2ft diameter x 2.6ft height

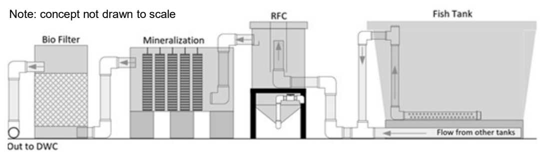
** Timmons, Ebeling Recirculating Aquaculture 3rd Edition*

 30

30

Filtration elevation view

- Fish tank gravity flows into RFC
- Clarified water flows through mineralization
- Filtered water flows up through bio media
- Water flows out to plant beds
- Gradual step down of outflow pipes to allow for gravity flow



 31

31

Filtration Considerations

- Capital cost of equipment
- Available space
- Micron size of filter - This is the smallest particle size that the filter can effectively capture and process.
- Labor - Some filtration systems using separate tanks for mechanical and biological filtration require manual cleaning of filter media. Other filters can automatically backwash filter media which can reduce labor time.
- Work with the filter manufacturer to ensure the filter will support your farm's daily feed rate.
- Understand the flow rate requirements for the filtration equipment. For example, bead filters typically have a maximum operating flow rate. If the flow rate required for your fish system is higher than the filters recommended capacity then the filter may not be able to effectively remove solids.

 32

32

POLYGEYSER® FILTER

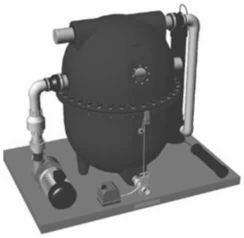
AST BEAD FILTER SOLUTIONS

	Filter Model	DF-3 PG 6000	DF-6 PG 12000
	Bead Media (ft³)	3	6
	Flow Rate (gpm)	30	60
	Total Ammonia Nitrogen mg/L	Bioclarification Aquaculture Capacity for EN Media in lbs feed/day:	
rmwater (15-30° C)	Hardy Growout	1.5	6.0	12.0
	Volume (gallons)		1200	2400
	Growout	1	4.5	9.0
	Volume (gallons)		900	1800
	Fingerling	0.5	2.3	4.5
	Volume (gallons)		900	1800
	Broodstock/Fry	0.3	1.5	3.0
	Volume (gallons)		1200	2400

 33

33

Polygeyser Filter



Automatic Backwashing
Low Maintenance
Mechanical and Biological Filtration in a single unit

 34

34

Sumps - So many uses

- Sump tanks are the lowest point in the system allowing water to gravity feed from tanks or grow beds.
- Pumps move water from the low point back to fish tanks and/or plant beds
- Sumps provide a central point of water exchange between systems
- Can be used for heat exchange
- Automatic top off of fresh water
- Provides a control point for water leveling
- Dosing and mixing of nutrient solutions
- Sensors and Probes
- Place to Decouple Fish and Plant Systems

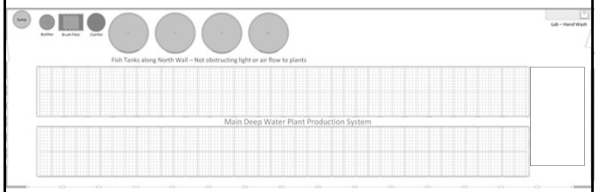
 35

35

 36

36

Filtration and Sump Layout

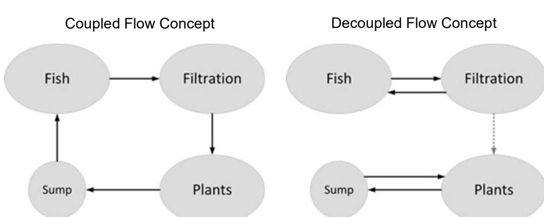


- Three stage filtration system along north wall
- Sump tank in NW corner

 37

37

Coupled and Decoupled Flow



 38

38

Decoupling Benefits

- Fish kills and diseases can happen which can mean loss of nutrients.
- The fish-tank water can be managed at different temperature and pH levels, which helps with disease control and optimization of water quality for the fish.
- Fish water can be periodically discharged from the filtration system into the plant sump but not returned to the fish.
- Nutrients, water temp and pH can be adjusted to optimize for plant growth without affecting the fish system.
- Plants can be run hydroponically, which is good for startup and during low fish feeding levels.

 39

39

Decoupling Continued

- Fish and plant systems can be in separate buildings which can allow the plants to maximize the greenhouse environment and the fish can be in an adjacent "head house".
- Fish production can be maximized beyond the minimum requirements to support plants without overloading the plant system. This is where nutrient rich water can be periodically drawn from the fish system to supply the plant system.
- If more aggressive plant pest and disease control methods are required they can be utilized without adversely affecting the fish when the systems are decoupled.

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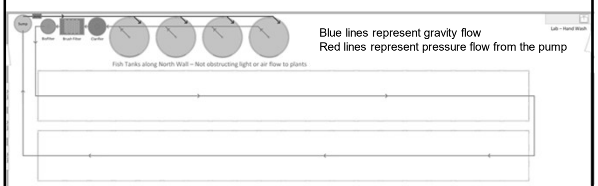
40

Water Flow - Coupled System

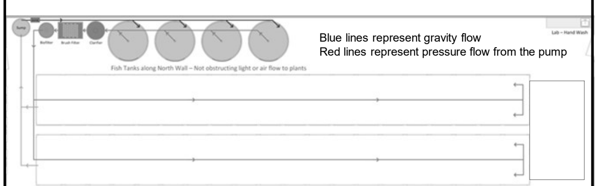


- DWC troughs can be connected in series with a pipe connecting the troughs together at the east end so water flows in the top trough and out the bottom trough and returns to sump

 41

41

Water Flow - Coupled System

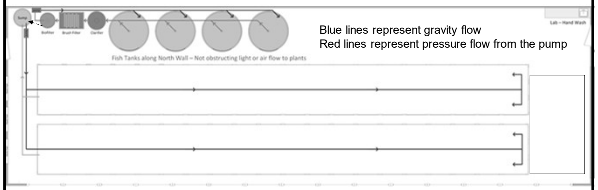


- Flow pattern in DWC shows water piped under the raft boards so inlet and outlet are on the same end of troughs

 42

42

Water Flow - Decoupled System



- A second pump provides pressure flow to DWC troughs with gravity return to sump for recirculation in the plant system only
- Fish water can be drawn off bio filter and added to plant sump
- Water is pumped back to the fish tanks after the bio filter. A second sump could also be installed after the bio filter to allow for base additions and top offs to the fish system

 43

43

Plumbing Recommendations

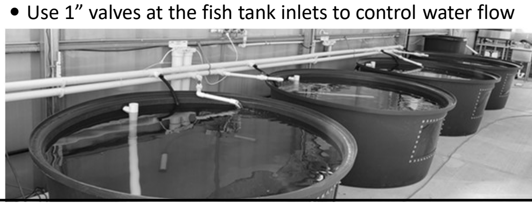
- 2” PVC can be used for the Solids Lift Overflow pipes or center drains in each fish tank
- Each tank should connect to a larger 3” main pipe to handle the total flow of water @ 33 gpm (60 min HRT)
- Continue 3” PVC for gravity flow through the filtration system and out to the DWC troughs
- The DWC troughs should drain to a sump tank recessed at least a foot below grade to allow for a gravity drop
- The recessed sump should be taller than the DWC troughs to prevent overflow in case of a power outage

 44

44

Plumbing continued

- Flow from main pump back to fish tanks can be through a 2” main pipe.
- Flow to each fish tank can reduce from the 2” main line to 1” to increase velocity.
- Use 1” valves at the fish tank inlets to control water flow



45

Nursery and Transplant Systems

Multideck nursery systems save on space and maximize production

The elevated transplanting trough is perfect for waste high transplanting of seedlings from the nursery and transplants to the growout rafts

The nursery and transplant systems are sized and designed to match the production sequence of the DWC so a steady rotation of seedlings, transplants and harvestable plants are continually being produced

Stage 1 - Seedlings start in Nursery

↓

Stage 2 - Seedlings are transplanted in elevated trough

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Stage 3 – Seedlings are transplanted in DWC growout rafts

 46

46

Growasis Vertical Nursery

- 2 x 4' floor space
- LED Lighting for each level
- 16 plug trays per nursery systems
- 128 plugs per tray = 2,048 seedlings per system
- Dedicated nutrient reservoir with timed pump, aerator and heaters

 47

47

Nursery Sizing

- Estimated weekly plants from DWC on a 4 week culture time before loss rate = 1,120
- 18 total trays in rotation – Seeding 9 trays per week
- Requires two vertical nursery systems (16 plug trays each)
- Extra space can be used for microgreens (up to 14 trays)

Seedling Trays	
Number of plugs per tray	128
Weekly transplants	1,120
Weekly trays	**8.8**
Flat loss rate/overseed	5%
Weekly nursery trays to seed	**9.2**
Weeks in nursery	2.0
Total Seedling Trays (rounded up)	**18**
Annual Trays	478

 48

48

Microgreen Production

- Average seed to harvest time ≅ 2 weeks.
- Assuming space for 14 additional microgreen flats = 7 flats per week
- Low maintenance, high margin crop

 49

49

Transplanting Rafts

- Allows for better space utilization in DWC growout troughs
- A 2x2 Lattice Raft holds ≈ 104 seedlings = 4 Beaver boards (32 sf)
- Keeps seedlings from becoming "root bound" in the nursery
- Elevated troughs allows for transplanting at waist height

Transplant rafts	
Total trough sq ft	1,280
number of rafts	160
number of raft groups (4 rafts per group)	40
groups harvested per week	10
Number of 2x2 transplant rafts each week	10
Number of weeks in transplanting trough	2
Total number of 2x2 transplanting rafts	20

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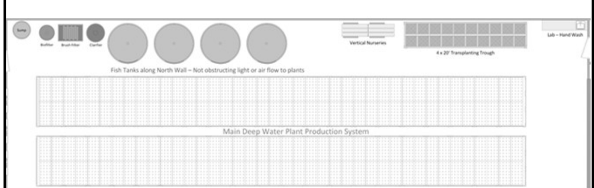
50

Nursery and Transplanting



- 4' x 20' elevated transplanting trough = (20) 2x2 transplanting rafts
- Corresponds with full rotation of plants from seed to harvest. Assumes 2 weeks in nursery, 2 weeks in transplanting trough and 4 weeks in DWC growout.
- Vertical nurseries situated along north wall to prevent shading of lower troughs

 51

51

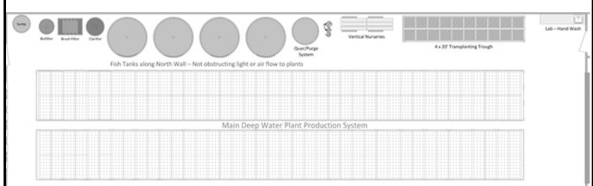
Purge and Quarantine System

- 200 Gallon Tank
- Endurance 2000 Filter
- Optional Chiller
- Heater
- Dedicated Water Top Off
- Not connected to hydroponic system
- The recommended stocking rate of fingerlings per tank is 193. However, it is a good practice to adjust this up by about 10% to factor in for potential mortality.

 52

52

Purge and Quarantine Layout



- Adjacent to main growout tanks for easy access and shared aeration line
- System is not connected to the production aquaponic system
- Water chemistry, temperature, salinity etc. are independently managed and optimized for purge or quarantine.

 53

53

Aeration design simplified

Fish System Aeration

1. Daily Feed = 4.7lbs
2. Rule of thumb = 3 CFM per lb of feed
3. 4.7lbs x 3 CFM = 14 CFM needed for fish system
4. Add 20% safety factor = 16 CFM

DWC Plant Aeration

1. 80 Airstones in DWC system (every 4')
2. 0.15 CFM rating per airstone (check mfg specs)
3. 80 x .15 = 12 CFMs needed for plant system
4. Add 20% safety factor = 14.4 CFM

Note: increase CFM by 4% for every 1,000 ft elevation above sea level

 54

54

Matching the air pump

Example below uses Alita Linear Air Pumps.

Fish System Aeration

- 16 CFM @ 30” water depth = (2) AL-200

Plant System Aeration

- 14.4 CFM @ 10” water depth = (2) AL-150

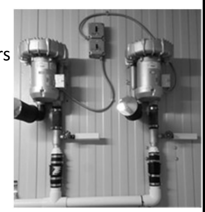
Transplanting Trough

- 1.5 CFM @ 10” water depth = (1) AL- 25

Model	CFM @ 10"	CFM @ 20"	CFM @ 30"
AL 6	0.7	0.6	0.42
AL 15	0.9	0.8	0.72
AL 25	1.5		
AL 40	2.5	2.4	2.2
AL 60	3.4	3.2	2.8
AL 80	4	3.8	3.5
AL 100	5.8	5.6	5.3
AL 120	6.2	6	5.9
AL 150	7.2	7	6.9
AL 200	8.3	8.1	8

55

Regenerative Blowers



Example uses Sweetwater Regenerative Blowers

Total CFM Required = 32 with an average pressure depth of 20”

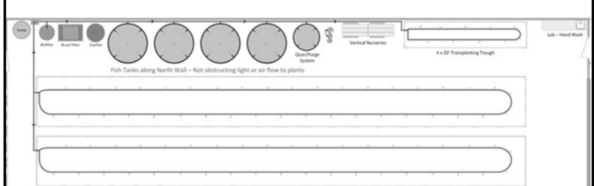
Use 2” main pipe and reduce down at tanks and troughs

Blower Specifications (at Sea Level, 68°F, 60 Hz)

Model Number	Cfm Free Air @ Inches Water 20"	30"	40"	50"	Max Duty	Hp	Phase	No. Filters	Running Watts Input @ Inches Water	Max Starting Watts	Voltage
S11A ❶ ❷	13	3	—	—	34"	1/8	1	1	198/20"	900	115/230
S21 ❶ ❷	27	19	7	—	43"	1/3	1	1	377/30"	1,800	115/230
S31 ❶ ❷	34	28	21	16	56"	1/2	1	1	471/30"	2,000	115/230
S313 ❶	34	28	21	16	56"	1/2	3	1	410/30"	4,000	230/460
S41 ❶ ❷	70	65	53	36	58"	1	1	1	971/40"	4,000	115/230
S43 ❷	70	65	53	36	58"	1	3	1	860/40"	5,000	230/460

56

Aeration Plan



- Airstones every 4’ in DWC troughs for oxygen delivery and agitation of water for plant roots
- 4 large airstones in each fish tank for transfer of dissolved oxygen
- Airstones in biofilter for oxygen delivery to aerobic nitrifying bacteria
- Create an air distribution ring in your DWC trough for uniform pressure
- Air pumps/blowers run 24/7 and should be on backup power

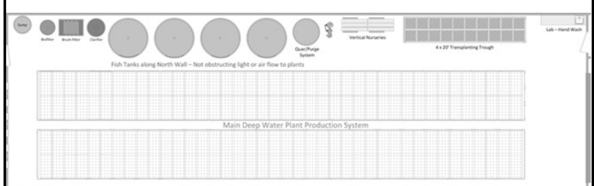
57

58

58

30 x 96 Flourish Aquaponics Farm

- Four 500 gallon tanks
- Purge and Quarantine
- Aeration System
- 2 Vertical Nursery Systems
- Two 8’ x 80’ DWC Troughs
- 4’ x 20’ Elevated Transplanting Trough



- 52,000 Annual Plants – 1,000 heads weekly
- 1,147 lbs of annual fish

59

59

30 x 96 Equipment Energy

Components	Usage	On Backup	volts	amps	watts per unit	total watts
AAPA7.8L Air Pump	Air pump for Endurance Filter charge contro	y	120	0.0	3	3
Sweetwater S31 Blower	Aeration for farm system	y	120	3.8	451	451
Danner HD-4800	Primary pump for Farm	Y	120	2.1	250	250
Danner MD 2400	Fish pump (decoupled only)	y	120	1.5	175	175
AA 550 GPH Water Pump	Pump for nursery (on timer)	y	120	0.3	33	33
AAPA7.8L Air Pump	Ar pump for nursery reservoir	y	120	0.0	3	3
Bluelab Guardian Connect	pH, Temp, EC Monitor	n	120	0.0	5	5
	Total power consumption (watts/kwh)					920

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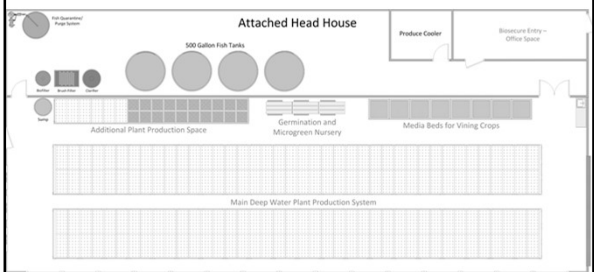
North Head House Concept



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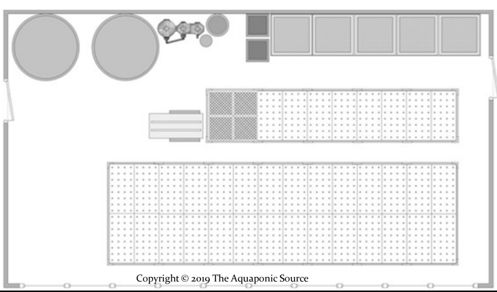
23 x 40 Flourish Farm

- Two 200 gallon tanks
- Endurance 2000 Filter
- Dual Sump
- 5 Media beds
- 8' x 28' Growasis Ground or Elevated DWC
- 4' x 20' Growasis Elevated

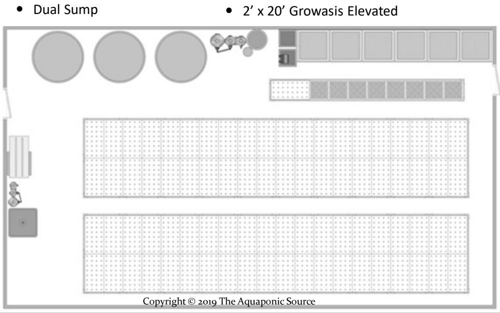


 62

62

30 x 52 Flourish Farm

- Three 300 gallon tanks
- Endurance 4000 Filter
- Dual Sump
- 6 Media beds
- Two 8' x 40' Growasis Ground or Elevated DWC
- 2' x 20' Growasis Elevated



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63