Hydroponic System: Design Notes

I've started construction of the system. I have a bill of materials (stuff I need to get), a list of the major sub-assemblies I have to build, and decent starts on the designs for those sub-assemblies.

At the outset of the project, the only major aspect of the project that I hadn't done before is the 3D printing, so I bought a printer, and produced one of each of the types of parts I'll need. I did this construction first, because it represents the major technical risk (stuff I don't know about) and so it makes sense to tackle that first to make sure there aren't any roadblocks that will interfere with the project later on. Better to find out now, if indeed there were.

There weren't any big problems. Lotta little hiccups, but nothing major.

I also did almost all of the ordering of the bill of materials. Some parts have long delivery cycles, so in order to reduce project delays, I placed the orders as soon as I was confident enough in the design to buy the parts.

The following notes are ones I wrote to document my thinking and the materials others created that influenced that thinking as I was designing. These notes are offered up here because someone that's just starting on a project like this might benefit from monitoring my thought process as I went through the early stages of design.

A Few Big Questions

Here are a few big questions that may or will affect the design:

- What are the weaknesses of hydroponics systems?
- What do we lose by using hydroponics .vs. soil culture, and can we mitigate those deficits?
- Should we recirculate the nutrient repeatedly, or discard it after one pass ("drain to waste") through the system?
- Which system topology performs best, horizontal or vertical?

Weaknesses of Hydroponics Systems

The major weaknesses of hydroponics systems appear to be:

> **Timeliness**. If the system doesn't provide nutrients – especially water – on a timely basis, the plants will immediately suffer, and may die. Power interruptions count for a lot.
>
> **More equipment**; more capital investment, and more things to fail.

Hydroponic System: Design Notes

Differences Between Soil .vs. Hydroponics

From the perspective of the plant roots, the key differences between soil culture and hydroponics are set out in the following table.

Aspect	Soil	Hydroponics
Effort to acquire nutrients	More. Have to spend more plant resources to grow extensive root systems, so the branches, leaves and fruit get less resources to grow	Much less. Nutrients are brought to the roots. If the nutrient solution is correct and timely, almost all plant effort goes into growing branches, leaves and fruit
Predators	More. Most soil biota has evolved to swipe nutrients from or actively devour roots	Less. Fewer root predators can live in a liquid habitat. Some, like bacteria and fungus certainly do, though
Stability	More. Soil holds way more nutrients and water than a nutrient film	Less. If the nutrient flow is interrupted, the plants will shortly die.

Conclusion: We must design our system so that nutrient flow is never interrupted.

Drain to Waste .vs. Recirculating

This next table sets out the pros and cons of the two basic types of nutrient flow used in hydroponics systems.

Drain-to-Waste	**Re-circulating**
Pros	
• Crops fed fresh nutrient solution with same EC and pH each irrigation cycle • Many different kinds of growing media could be used • Lower probability of clogged emitters • Water-borne disease transmission less likely • Certain pest control products may be applied effectively as drenches (read labels for more information)	• Nutrient solution and/or water is recycled • Fewer nutrients may be used throughout production • Fertilizer leaching from nutrient solution is minimized • Reduced water use • A variety of hydroponic systems can be recirculating

• Flushing of salt accumulation is straight-forward	
Cons	
• Increased water use • Increased fertilizer use may add production costs • Fertilizer and pesticide leaching may occur more often • Salt accumulation may occur several times throughout production • Limited to certain hydroponic systems	• EC and pH of nutrient solution may fluctuate • Ratios of individual nutrients in solution may fluctuate • Probability of water-borne disease transmission may be high • Flushing of salt accumulation may be labor intensive • Without appropriate action, algae and or biofilms may clog emitters

I’ve decided to use recirculation as my nutrient-flow strategy.

It’s used in many systems at all scales, apparently to great effect, and the downsides of disease and nutrient variability of recirculating systems seems to be fairly well addressed via operational procedures.

Topology: Horizontal .vs. Vertical Orientation

The major advantages of vertical over horizontal topology are:

Ease of access by operators
Better light distribution
Higher density per square foot of floor space

This excellent video provides many insights:

https://www.youtube.com/watch?v=_N7A6BMF2Ik start at 11:22 in the video.

Note also the removable tower idea to get access to top plants. Wow.

I chose the vertical topology option.

Hydroponic System: Design Notes

High-Level Design

The table identifies the main sub-assemblies of the design. For each sub-assembly it includes a brief description its components, materials, and traits.

Sub Assembly	Main components / bill of materials
Frame	The frame consists of three sub-assemblies: The bottom frame; a rectangular box on casters, which supports the nutrient reservoir, the return manifold, and the tower support plates The upright supports, which are vertical members that fit between bottom and the top frame The top frame, which supports the gravity tank, the supply manifold, the plant lights and curtain, and light wiring, and the nutrient supply lines
Nutrient tank	Stores nutrient solution. 10+ gallon vertical-sided food-safe plastic bin with flat sides and bottom and a tight-fitting lid. The tank must be very dark and dense to prevent light from entering the tank. Bulkhead for the outgoing supply and incoming return (drain) pipes. TODO: how are we draining this tank? Need a plan Bulkhead for incoming AC power line for pump Bulkhead for incoming air line for aeration stones Tank lid is removable. Lid has a 1.5” bulkhead on it, with a threaded lid for easy access to test nutrient level, pH, EC, and to top-up nutrient solution. We will use a graduated (marked) dowel as a dip-stick or fill-level gauge
Gravity Tank	This tank holds the nutrient solution, pumped in from the Reservoir, and slowly trickles it down via the supply manifold into the towers. This tank is exactly like the reservoir tank. Bulkhead for incoming nutrient solution is on the side near the top of the bin. Bulkhead for outgoing solution is on the bottom. Bulkhead for supply manifold vent is on the side near the top of the bin.
Supply manifold	Distributes nutrient solution equally and gradually to each of the three towers. Consists of a 1.25” PVC pipe with three Ts, one for each tower. Each tower is served by a 0.5”ID PVC pipe, with a ball-valve to regulate flow

Hydroponic System: Design Notes

Sub Assembly	Main components / bill of materials
	rate independently for each tower. The manifold is vented back tot the gravity tank to insure that no vacuum forms in the manifold and thereby prevents an equal flow of nutrients to all towers The manifold is suspended from the frame with several velcro tapes to facilitate removal and cleaning.
Tower	Consists of: a close-fitting cap through which the supply line fits a diffuser to spread the nutrient flow equally around the cylinder containing the plant roots 8 sets of plant-holder and spacer. Plant holders have either 3 or 4 sockets into which the plant strainer cup is inserted. Bottom collector which routes excess nutrient solution flowing down the bottom of the tower into the return manifold The bottom collector rests on a rotating lazy susan bearing assembly. The bearing assembly is supported by an aluminum sheet and aluminum angle sliding shelf that is laid across the top of the frame base assembly.
Return Manifold	Collects excess nutrient solution from each of the three towers and routes it into the reservoir tank. The return manifold consists of a 1.25” PVC pipe with a T fitting. The tower’s collector outlet fits into the T. The manifold has a cleanout union on one side, and another union at the other end, right before the manifold connects to the Reservoir’s intake bulkhead. The manifold is suspended from the frame with several velcro tapes to facilitate removal and cleaning.
Ventilation	Two 12VDC circulation fans will route air in a racetrack pattern from top-left side to bottom-right side.
Lighting	Light system consists of vertical LED tubes spaced every 10” across the grow zones. Power cables connect each LED tube to a power trunk line which is energized by the 120AC – to 12VDC transformer in the control and power panel The light system also has a reflective curtain around the perimeter of the plant system to reflect light back into the plant zone
Aeration	Aeration system consists of an aquarium air pump that supplies airflow to the two airstones which are submerged in the nutrient supply reservoir. The

Sub Assembly	Main components / bill of materials
	aeration system runs for some (TBD, what?) minutes before the nutrient solution is pumped into the gravity tank
Control and power panel	The control panel is an aluminum sheet metal box which contains: The device controller board and associated relays and LED indicators. The indicators will be mounted on control panel so they are visible from without The power distribution blocks, which support AC and DC power busses and fuse blocks for each powered device One ON-OFF-AUTO switch for each bank of lights, the nutrient pump, and the aeration pump. This enables the operator to manually turn the device on and off, and also put the device on “automatic” so the device controller turns it off and on under program control. Each switch will be accompanied by an indicator light to show the device’s on-off state A power metrics meter, showing real-time incoming AC voltage, amperage, watts, and cumulative watts-used (power as kWh) since reset.

Hydroponic System: Design Notes

Open Design Questions

Question	Current Answer
Rotating towers, or fixed-towers	Rotating towers. We’re going to make it really easy to access all the plants without having to move around much
PVC fittings, or custom 3DP components	Custom 3D components. In addition to getting a product that does its job better, we’re going to learn 3D printing, as well.
Where to start the design	Start with a list of necessary sub-assemblies, and link them together into a system. Show that system from the side and from the top.
Where to start construction	Start with what we don’t already know how to do: print 3D parts. Then do the frame, tanks, plumbing, lighting, ventilation,and tie all together with the electrical and control module.
Where’s this thing going to go? How tall will it be?	(After doing the design, I can answer this). It’s going in the basement, in an area 4’ wide, 7’ long, and 9’ tall
Are we using drain-to-waste or recirculating nutrient strategy?	Recirculating. Looks like it’ll work. It’s more work, but less waste … theoretically. If we don’t like it, we’ll fall back to once and done with a minor modification.
How do you know, in a drain to waste system, if the plants at the bottom of the tower have gotten enough nutrients?	Take out the bottom plant, and see if the roots are wet. Use the amount of nutrients required to wet those roots as the baseline quantity or time of application
what about salt buildup?	Not sure that’s possible to happen in this system. There’s no growing media for salt to accumulate in. We’ll wash out and brush out the plumbing and tanks every 6 months, so, I see this as a non-issue.
When do you have to flush the system. Maybe we need a good hydroponics book.	Change the nutrient solution every 2 weeks, and completely dis-assemble and clean the system about every 6 months.
When do you apply algae treatment	We’ll see. We may not need it if we successfully block out light from the system.
How drain nutrient tank?	There will be a drain pipe, with a valve, under which a bucket can fit. Open the valve, and the tank drains into

Hydroponic System: Design Notes

	the bucket.
What plastic filament to use?	PETG.
How fill, test nutrient solution?	Fill via tank cap. Test via turkey-baster eye-dropper in via tank cap. Use meter to test EC and pH.
How are we going to attach the tower components so that they stay securely connected if/when the tower has to be removed as a unit	Seat them in the lazy-susan ring, which suspends the tower above the return manifold port. We'll tie the tower components together with string through the bolt-holes on the outside of each tower component. We'll unscrew the tower cap, lift it a few inches to get some play, lift the entire tower up to clear the return manifold port, tip the whole tower out and down. Done.
Is the tower diameter sufficient to feed all the (how many?) plants on the grow module?	Looks so if we have just 3 plants per growing module. We'll see as we go.
Will the roots of the lowest plants interfere with drainage?	Maybe. We may have to put extra spacers at the bottom of the tower, or keep very small plants at the bottom that don't have extensive roots
How about cut and come again harvesting technique? Does that improve performance?	Likely will. Also reduces spoilage, since we just pick what we're ready to eat today or next day, leave rest on the plants till we're ready
Harvest a plant, or harvest a salad?	Harvest a salad, per above.
What is the proper spacing between towers for lettuce plants?	I estimate 21" on-center between towers. Allows for about 6" of lateral growth for each plant before it touches the opposing growth from the next tower
Self-vent gravity tank / supply manifold?	Yes. Let's just avoid the restricted / uneven flow issues
Where should we use nutrient-solution diffusers within the grow-tower? Just at the top at point of nutrient-stream entry, or elsewhere in the column	So far, just at the top. During trials we'll see if that's sufficient to effectively cover the entire area of the tower's interior.

Hydroponic System: Design Notes

What remains to be designed?

Ventilation plan
Wiring plan
Control and power system and enclosure
Tower base, lazy susan, drain collector – return manifold interface

What remains to be procured?

Lights
Ventilation fan
Some bulkhead fittings for the tanks. Air and power mainly.
DIN rail components
Plumbing – 3/4” PVC pipe, fittings

Construction Plan

The general construction sequence is:

3D print at least one of each tower part, and make sure nothing’s wrong with the tool-chain, the design, or the materials
Ice down the remaining designs
Build the frame, tower supports, tank supports (reservoir and gravity)
Build the tanks. Bulkheads, fittings, pump, aerator, etc.
Build the supply and return manifolds
Build the light and curtain hanger assembly and install it
Assemble one tower and install it into the manifold system. Test it
Install the plumbing to connect the tanks and manifold subsystems. Test the plumbing
Install the light system and test it
Install the control and power subsystem, and connect the lights, the pump, the ventilation fan, aerator
Install the device controller hardware and test it
Develop the software to manage the system, install and test it

Hydroponic System: Design Notes

Reservoir Construction

Material Moved	Connectors	Connector Location
AC power to pump	Waterproof strain relief bulkhead. Upstream is a power plug that plugs into a one-plug receptacle served by a relay on the controller.	Side and top of bucket. Not on lid
Nutrient outflow to supply manifold	Exterior: bulkhead with quick-connect, ID 0.5 inch or greater Interior: 0.5 ID hose barb, hose connects to pump outflow	Side and top of bucket. Not on lid
Air inflow to aeration stones	Exterior: Female air chuck over threaded 0.25 pipe nipple with nut-and-washer assy on both sides of bucket. Interior: 0.25 NPTF to 0.125 barb to flex air tube to diffuser stones. Upstream is the air pump enclosed within the control assy	Side and top of bucket. Not on lid.
Nutrient inflow from return host	Exterior: bulkhead with quick connect 1” ID Interior: nothing. Dumps directly into nutrient pool, no concern for splashing. Possibly has a 45-degree elbow on it to prevent splashing if that becomes a concern.	

Hydroponic System: Design Notes

Frame Construction

Do I have any square stock that fits snugly within the 1” square tube I’m planning to use as frame material? If so, then I can begin to build frame segments like the two-level base assy, and the top shelf assy, and maybe even the top hanger bars, and leave the issue of uprights-height to a little later when I have the actual parts that will be assembled into a tower unit.

Supply Manifold Construction

I wonder if I should design the supply manifold so that it can be lifted vertically in order to release a tower assy. No. Lift it, and you simultaneously release all towers. Not good. Need one at a time.

In order to lift out a tower, I’d have to have sufficient play in the top-cap and diffuser assy so I could lift the tower high enough as to clear the bottom collector from the return manifold receiver. That would be at least 2 inches, right?

That means the top-cap would need to be very deep – at least 3 inches, in order for the tower to rise the 2” needed to clear the return manifold, and still have plenty of overlap between the bottom of the supply pipe and the bottom of the tower cap, in order to prevent light incursion.

Have to wonder about the clearance around that cap opening and the supply pipe, too. Need some play there in order to tip the tower enough to get it out. If it’s a snug fit, can’t get the tower out. Too loose, got algae. Unless we use a fiber/rubber gasket or washer at the junction between supply pipe and the top-cap.

or...maybe we unscrew the cap so it’s not integral to the tower anymore, raise it up, and take out the tower. Then let the cap slide down the supply pipe, and remove it, too.

Is the supply pipe and related assy to the supply manifold going to be strong and stiff enough to serve as linchpin around which the tower revolves?

How are we bonding the supply manifold to the frame, so that it doesn’t rotate on its longitudinal axis? Or do we want it to rotate on that axis? How to secure it when we want the feed tube to be on same plane as the tower assemblies?

Maybe use multi-turn velcro strips to bond the manifolds, top and bottom, to the frame. It’s OK if they move a little, just not much. Velcro makes it easy to remove the manifold for cleaning. Rest of manifold connections are (might be) quick-connect.

Hydroponic System: Design Notes

Plants To Grow

This is the current list of plants I expect to grow with the new system:

Plant	Commentary
arugula	
kale	Might be better in a different (horizontal) system so we can pick baby kale, or maybe we do the cut and regrow method on this one
romaine	
butterhead lettuce	
cilantro	
basil	Thai and italian
spinach	
watercress	Might not work. May need to supplement nutrient solution with iron chelate

Hydroponic System: Design Notes

Notes Obtained From Others

The following are excerpts of discussions about other systems I gleaned from the various places on the internet.

Water pump: https://www.amazon.com/Hygger-Submersible-Aquarium-Electric-Cleaning/dp/B07TXHPKZZ

“be sure to protect your towers with UV blocking paint if install in greenhouse”.

if you shoot the nute with the 1/4 in tube from back to front, the nute will naturally drop from one plug to the next. Originally I drilled through the caps on top (also useful to reduce evaporation from the system) and shot the nutrient downward. The back to front was an "upgrade" at some point. No nozzles - I'd be worried about clogging and there is plenty of aeration as the nute drops down the pipe. I don't even use an aerator in the nute container.

The reflective background seems to be a positive change - doesn't seem to make a huge difference but there seems to be a difference. The backing seems to also channel some of the air from the fan so there is also additional circulation which is very important. The lights are also an improvement too as they decreased my energy needs by about 30% with the same grow rate. 2 weeks ago I had to replace the irrigation tubing and I made a 90 at the end of the line and came down about a foot and closed with a ball valve for an easy clean out. I think that will help with the calcification that was happening at the end of the line and diminishing the flow into the last towers.

the plugs are 1.5 inches and the towers are tilted slightly forward and so the nute runs down the front of the towers.

The pump is dependent on your head (height to pump nute) - I use a Pondmaster Supreme model 5.

The challenge is keeping the nutrient temp low for outside / greenhouse ops. Reflective, UV-block paint.

The end of the system tends to calcify and so this will keep that junk from plugging up the lines going to the final towers. As for pump, I am using the pondmaster model 5 and I think that should be more than enough for your setup. They have charts for the height of your head so you can check those out to be sure. There may be some initial leaking from when you put in your connectors but they always fix themselves within a couple of days. Finding the balance between too much pressure and just enough is tricky.

I use Grodan plant plugs (1.5 inch) to hold the plants and the nutrient just trickles down the pipe and irrigates each site. The nutrient (watch ChillLed Nutrient on YouTube for recipe) is collected in a pipe on the bottom and runs back to the nutrient container for re-circulation. Use a Pondmaster Supreme Model 5 pump, 30 minutes on and 15 minutes off.

19 lettuce pipes spaced on 8" centers and 3 herb pipes spaces on 12" centers for a total system length of approximately 14'.

vertical distance between lettuce plants: min 8 inches - depends on what you grow.compact butterheads can deal with 8 inches off center. other varieties need more room. My sites are 9 inches off center if I remember correctly.

Aeroponic Tower assy. Free-standing. Wonder if this isn't a better model. Put it on a lazy susan.
https://www.youtube.com/watch?v=JrUF38T7Nl8

Setpoints

- Rel Hum: 45-55%
- Nutrient solution temp: 65-75 degrees F
- Nutrient solution pH: 6.5.

Nutrient Film Technique

Change solution every 2-3 weeks.
Do we need to top-up?

Are we getting enough oxygen?

nutrient feed strategy

pump to gravity feed tank

- Pro: operate if pump fails, stronger pump runs less often
- Con: another tank to clean

pump direct to tower

- Pro: fewer parts
- Con: system fails if pump fails

Hydroponic System: Design Notes

supply tank strategy

tank level – use a manual dipstick inserted via fill port

test sample taken from tank
test tank contents directly

prepare addition in separate vessel
add nutrient concentrates directly to tank

drain
pump inside or outside tank
nutrient solution
- sample to test
- test direct in tank
- fill level
- supplement
  - pre-mix solution
  - mix in-tank with repetitive sample
  - how mix tank to sample

how connect parts:
- to facilitate component removal
- to take components off-line

System Tests Before we Begin Operations

Interior light test using scope. Is light getting inside the tower, and encouraging algae growth, or not?

Nutrient solution flow rate. Is it too fast, or slow enough that the plants derive full benefit from each flow of nutrients?

Even flow across all towers. Don't want one tower hogging all the nutrients

Even flow through the entire height and cross-section of the tower. Is the nutrient solution being evenly distributed within the tower? All roots getting enough?