

Modular Aquaponics System for Indoor Growing

Plans and Instructions



Prepared by Western Dakota Technical College through a project made possible by the USDA Specialty Crop Block Grant program.

Introduction

The primary feature of a modular aquaponics system is its customizability, since each unit should be custom built for the space it will go into. What follows is a guide on the structure itself and processes necessary to operating an aquaponics systems. Specialized technical support on crops, fish, electrical components and installation, automation, and water quality is best done individually with our faculty members. If you would like personalized technical support, please email corped@wdt.edu.

Design Philosophy: Modularity and Target Life Source

Through this project, WDTC was focused on creating a modular aquaponics system that is inexpensive to build and customizable to each producer's needs. The resulting design centered on two key principles:

1. **Readily Available Materials:** The team focused on using readily available materials to make the system highly affordable and accessible so interested producers can build a system with limited funds or access to supplies.
2. **Modularity and Portability:** The system was engineered to be easily taken down and moved to suit the temporary area or structure where it will be housed.

Before embarking on design and customization, thought must be given to the target life source of your system.

- **If the system is Plant-Focused:** Identify the target crop and research the specific conditions that produce the best results for that crop. You must then try to mimic that crop's optimal environment with how you automate the system (lights, water flow, and nutrient delivery) with your system. We found that lettuces grew best in raft beds while flood-and-drain is best for berries and microgreens.
- **If the system is Fish-Focused:** You must lean heavily into the importance of the specific surface area (SSA) of your grow media (or biofilter). The SSA is the space where the nitrifying bacteria cling and colonize; these bacteria are the key pieces to making the water safe for large volumes of fish.

Because of this focus and design approach, every aquaponics system can be customized for the producers' needs, including resizing, changing the controls on pumps and lights, and water quality requirements. This is why this guide is a general guide to building the unit and does not include measurements. Each unit should be custom built for the space it will go into.

This system can support both flood-and-drain and deep-water culture techniques for growing. The attached plans include raft beds and media beds.

System Design

Phase 1: Planning and Physical Construction

Step 1: Choose the Space and Identify Components

First, select the final location for your unit. Since the system should be custom-built, the size of your space will dictate the size of your components. Identify the components of the system you wish to include. Our design features:

- **Modified Deep-Water Culture (Raft Beds):** For leafy greens like lettuce.
- **Flood-and-Drain System (Media Beds):** For fruiting crops and microgreens.
- **Fish Tanks and Water Pumps**
- **Electrical Supply and Controls**

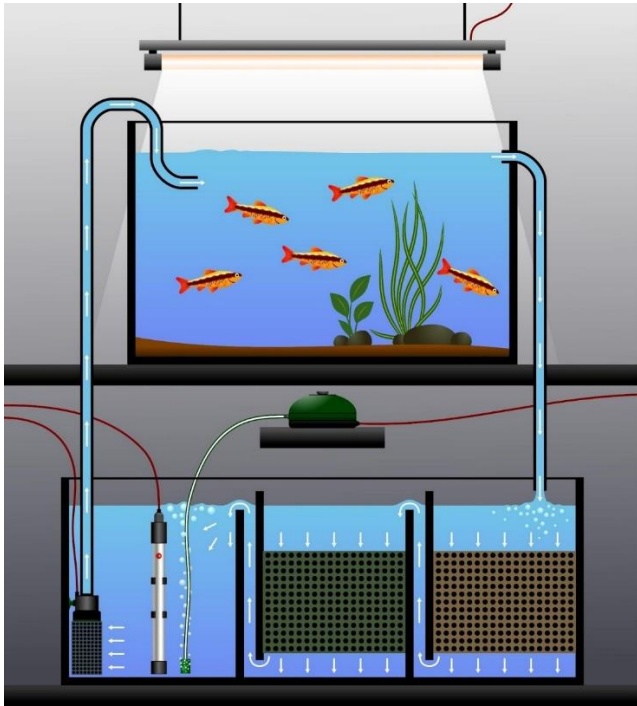


Illustration of fish tank and water pumps

Step 2: Frame Construction

Construct the main support frame for the entire unit. This structure must be sturdy enough to hold the significant weight of water, fish, and grow media/rafts. The system shown below uses Unistrut (a commonly available structural member in the US), pressure-treated boards for the grow bed surround, and electrical conduit for the upper framework to support lighting. Ensure the frame is sized to fit the unit's intended space according to the general drawings.



Media beds (upper) and raft beds (lower) in the aquaponics system

Calculating Structural Load: To determine the necessary strength of your frame, you must calculate the total weight of the water.

- The volume of a rectangular tank or grow bed is calculated as: $\text{Volume} = \text{length} \times \text{Width} \times \text{Depth}$.
- One cubic foot of volume holds approximately 7.48 gallons of water.
- A gallon of water weighs approximately 8.34 pounds.
- For deep-water culture (DWC), it is usually recommended to have 3 liters of water per plant for adequate space and nutrient buffering. This is equivalent to approximately 0.79 gallons per plant.

Step 3: Grow Bed Assembly and Placement

Build or prepare the grow beds according to your customized dimensions. Creativity is highly recommended here to keep the project cost down. We have successfully used 55-gallon drums cut in half, IBC tote tops, and repurposed garbage cans as grow beds. A little creativity and thought can go a long way!

In our trials, the system used was both a deep-water culture bed created with wood and pond liner to fit our lettuce rafts, and the flood-and-drain containers were commercially available.

Install the grow beds onto the supporting frame. This system is designed to support both deep-water culture (raft beds) and flood-and-drain culture (media beds).



A closer view of media and raft beds

Step 4: Fish Tank, Pump Installation, and Efficiency

Place the fish tanks and any necessary reservoirs at the base of the system. Fish tanks need to be sized according to the amount of waste the biofilter can convert. Biological Surface Area (BSA) and Specific Surface Area (SSA) are some of the most important pieces to understand because they provide the environment the nitrifying bacteria need to thrive.



Aquaponics system water tanks



Increasing Biological Surface Area (BSA):

The easiest way to increase the BSA is to increase the volume of grow media in your flood and drain system.

- Standard 3/8 pea gravel has a BSA of approximately 85 square feet per cubic foot.
- Clay media balls are much higher because they are porous and have lots of cavities the bacteria can cling to.
- You can include all the surface area the water touches (tanks, pipes, etc.) in these BSA calculations.

Stocking Rates based on BSA (or grow media SSA):

- Before the system is cycled properly, it is recommended to maintain 100 square feet of BSA per 1 pound of fish.
- As the bacteria colony matures, this can safely go down to 25 square feet per pound of fish, which usually coincides with baby fish growing into maturity.

Water Movement and Efficiency:

- Consideration must be given to minimize the number of pumps needed; the fewer the better. Our first system was designed to operate efficiently with only one water pump (for circulation) and one air pump (for aeration).
- Install the main water pumps that will move the water from the fish tanks up to the highest point of the grow beds.
- In the design of the test system, the team utilized the vertical space above the lettuce rafts (deep-water culture beds) to install the flood-and-drain grow beds. This stacking serves multiple purposes:
 - It utilizes gravity to assist in the water movement from the grow beds back to the fish tanks, minimizing the pump's workload.
 - It takes up less floor space.
 - It provides leak redundancy; should there be an issue with the flood-and-drain system, the water would just drop down to the deep-water culture bed below.

Step 5: Plumbing and Drainage Setup

Install all necessary plumbing for water circulation:

- **Inflow:** Connect the pumps to the grow beds to deliver nutrient-rich water.
- **Outflow/Drainage:** Install drainpipes from the grow beds back to the fish tanks or reservoir. This gravity-driven return includes specialized drainage (e.g., siphons) for flood-and-drain beds.

Using Bell Siphons for Pump Efficiency:

The use of a bell siphon in a flood-and-drain system is highly effective for eliminating the need for a separate pump or electronic timer to drain the grow bed. The only pump required is the single water pump to move the water up to the grow bed. The siphon handles the draining cycle automatically using hydraulic principles.

- The pressure difference caused by the water draining over the internal pipe causes a **vacuum** to form inside the Bell Siphon (BS), pulling water out of the main tank until the pressure equalizes.

(Note: Detailed Bell Siphon installation instructions and material requirements are included in Appendix B)

Step 6: Electrical Supply and Controls

Install the electrical supply box and connect it to the main power source. Wire all components, including the water pumps, grow lights, and any other electrical components, to the control system. Install any required sensors (e.g., temperature, water quality) for monitoring. **NOTE: The electrical supply and control are the most dangerous part of this project. It is highly recommended that all attempts be connected to a Ground Fault Circuit Interrupter (GFCI) protection device.**



Electrical components of the aquaponics system

Step 7: Automation Software Installation

The system was designed to operate independently of human interaction, so the connection of the pumps and lighting were connected directly to the electrical automation piece. While this can be complicated, we have included the step-by-step software installation guide, how to import and load an existing program, and the actual working program used on the trial system. Follow the provided installation guide for the automation software. Calibrate the control system to manage pump cycles and light timing based on your specific crop and fish requirements. For questions about the automation control process, please email corped@wdt.edu

Phase 2: Establishing the Living Ecosystem

Once the physical hardware is complete, the focus shifts to creating the functional biological system.

Step 8: Water Preparation and System Cycling (The Biofilter)

Aquaponics systems rely on a natural bacterial cycle (the biofilter) to convert toxic fish waste (ammonia) into usable plant nutrients (nitrates). This cycle must be established before adding fish and plants.

- **Initial Fill and Check:** Fill the tanks and grow beds with water and run the pumps to check for leaks and ensure proper flow to all sections.
- **Water Quality Baseline:** Check the initial water quality parameters, including pH and temperature.
- **Cycling:** Start the process of cultivating nitrifying bacteria. This can be done fishless (using an external ammonia source) or with fish (once ammonia is introduced).
- **Monitoring:** Regularly test the water for **ammonia**, **nitrite**, and **nitrate** levels until the system is stable. The cycle is complete when ammonia and nitrite levels drop to zero, and nitrates begin to rise.

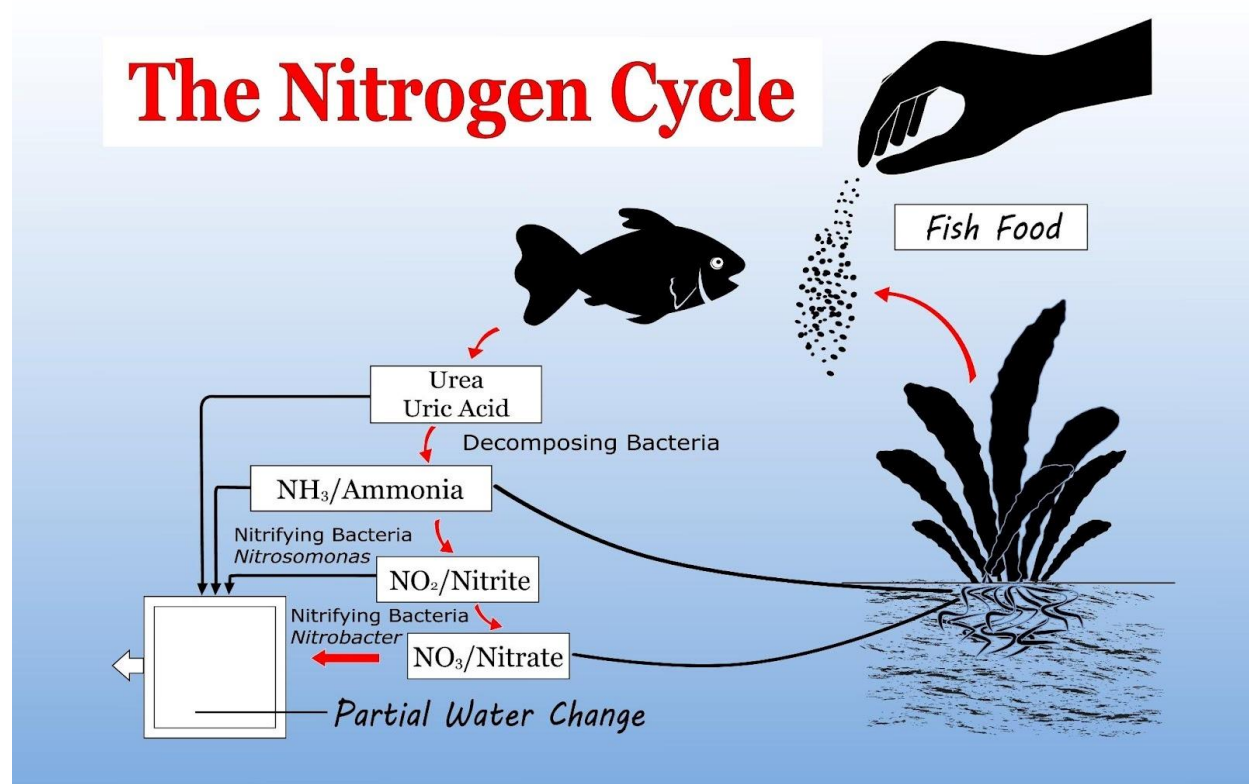


Image depicting The Nitrogen Cycle

Step 9: Introducing Organisms

With the water chemistry stabilized and the biofilter functioning, you can introduce the living components.

- **Stocking Fish:** Introduce the chosen fish species into the tanks. Select a suitable stocking rate to maintain a balanced nutrient level. For beginners, it is recommended to start with a cheap, colorful goldfish species. They are very hardy, can handle some mistakes without dying, and are cheap, making them ideal for commissioning a new system. Furthermore, goldfish are friendly and can live in a wide range of water parameters, so as you switch over to edible species, the goldfish would be fine to just come along for the ride.
- **Planting:** Transplant seedlings or seeds into your grow beds.

Seed Propagation for Aquaponics

It's important to document your seed selection to track what grows best in your system. Successful propagation ensures your plants have a strong start before being introduced to the system water.

Propagation Steps

1. **Select Media:** Choose a clean, inert, and pH-neutral media for germination, such as rockwool, coco coir, or propagation plugs.
2. **Hydrate Media:** Fully saturate your chosen media with clean, fresh water. Once soaked, allow excess water to drain off completely. The media should be moist, not waterlogged.
3. **Sow Seeds:** Place 2-3 seeds into each plug or cube. The seeds should be covered lightly, typically no deeper than twice the size of the seed itself.
4. **Create Humidity Dome:** Place the seeded media in a humidity dome or cover with plastic wrap to create a high-humidity environment. This high humidity is crucial for seed germination.
5. **Provide Warmth/Light:** Place the dome in a warm location. Light is not necessary for germination but can be added once the first sprouts appear.
6. **Monitor and Thin:** Check the seedlings daily. Once two true leaves develop, thin the plants by snipping the smaller or weaker seedlings at the base, leaving only the healthiest plant per plug.
7. **Harden Off (Fertilize):** Once seedlings are robust, they need to be introduced to nutrients. Begin soaking the media in diluted aquaponics water (or very diluted nutrient solution) to transition them away from plain water.
8. **Transplant:** Once the roots begin to show clearly at the bottom of the plug, the seedlings are ready to be placed directly into the deep-water raft holes or the grow media beds.
 - Place rafts with seedlings into the deep-water channels for leafy greens like lettuces.
 - Plant seedlings directly into the media in the flood-and-drain beds for plants like berries and microgreens.

Phase 3: Ongoing Management

Long-term success requires consistent care and monitoring of the integrated ecosystem.

Step 10: Ongoing Management and Maintenance

The system requires daily and weekly routines to keep all three components (fish, plants, and bacteria) healthy.

- **Water Quality Maintenance:** Weekly checks of pH and ammonia are crucial, with nitrate checks performed monthly. Water quality requirements are one of the aspects that can be customized.
- **Fish and Feeding:** Monitor the fish for signs of stress and maintain a proper feeding routine, as the fish feed is the primary source of nutrients for the entire system.
- **Plant Care:** Monitor plants for any signs of nutrient deficiencies or pests. Ensure proper spacing and timely harvesting.

Conclusion

WDTC has created and operated aquaponics systems since 2017, and the college has found that once you get all the pieces in the right place, these systems are surprisingly robust and easy to maintain.

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Appendix A

Aquaponics Parts List

Lumber and Structural

- Lumber
- 2x10s
- 2x6s
- 2x4s
- 3/4" ply wood
- Deep Strut
- Deep Strut feet
- Shallow Strut
- L-Brackets
- 3/4 Emt Maker-pipe fittings (to Build canopy)

Tanks, Beds, and Liners

- 50-gallon media Beds
- 50-gallon Food grade Barrel
- 2 - 330-gallon tanks
- 1 - 100-gallon sump tank
- Rubber Liner

Plumbing & PVC

- PVC Primer
- PVC Glue
- PVC
- Strut straps for PVC
- Penetration Portals w/ Rubber gaskets
- **1-inch PVC:**
 - 90s
 - Ts
 - 45s
 - Valves
 - Reducers
 - End caps
 - Portals
 - Male Female
- **3/4-inch PVC:**
 - 90s
 - Ts
 - 45s
 - Valves
 - Couplings
 - Portal

2-inch PVC:

- 90s
- Male adapters
- Portals

1/4-inch PVC:

- 90s

Electrical & Control Components

- 20x20x6 Cabinet
- 12x12x6 Cabinet
- Micro 850 PLC W/power supply 24vLX
- -12v DC power Supply
- Allen-Bradley Panel view (8"x6")
- 3 motor starters (30)
- 4p Contactor
- Terminal Block's
- Network Switch
- N.O. Floats (Normally Open)
- N.C. Floats (Normally Closed)

Power Supply & Wiring

- Sub panel w/ GFCF protection
- 2P 30A (breaker)
- 20A (breaker)
- 20A (breaker)
- 4 Receptacles (for pump and 2 for Lighting)
- 3-4 square Boxes
- 3-RS covers
- (2) Duplex (receptacles)
- (1) Quad prex (receptacle)
- Conduit
- 1/2 in LBS
- 3/4 in LBS
- 3/4 Ent-straps, connectors, couplings
- 1/2 Ent-straps, connectors, couplings, compression
- LFMC (Liquid-Tight Flexible Metal Conduit)
- Straight connectors
- 90° connectors

- Connector
- Splitter

Lighting

- 7 LED
- 7 LED grow lights
- (3) media bed lights
- (4) Floating Raft lights

Pumps & Air

- 2 Sump Pumps
- 1 Jet pump
- Air Pumps
- Air Hose
- Air Stones-Multi-port

Hardware & Tools

- Staples/staplegun
- Carriage Bolts 4 inch?
- 3/8 Bolts, nuts, washers, lock washers
- Zip ties
- Hinges
- Peck screws
- Wood glue

Consumables & Live Goods

- Floating plant trays
- Fish
- Seeds
- Fish Food
- Water

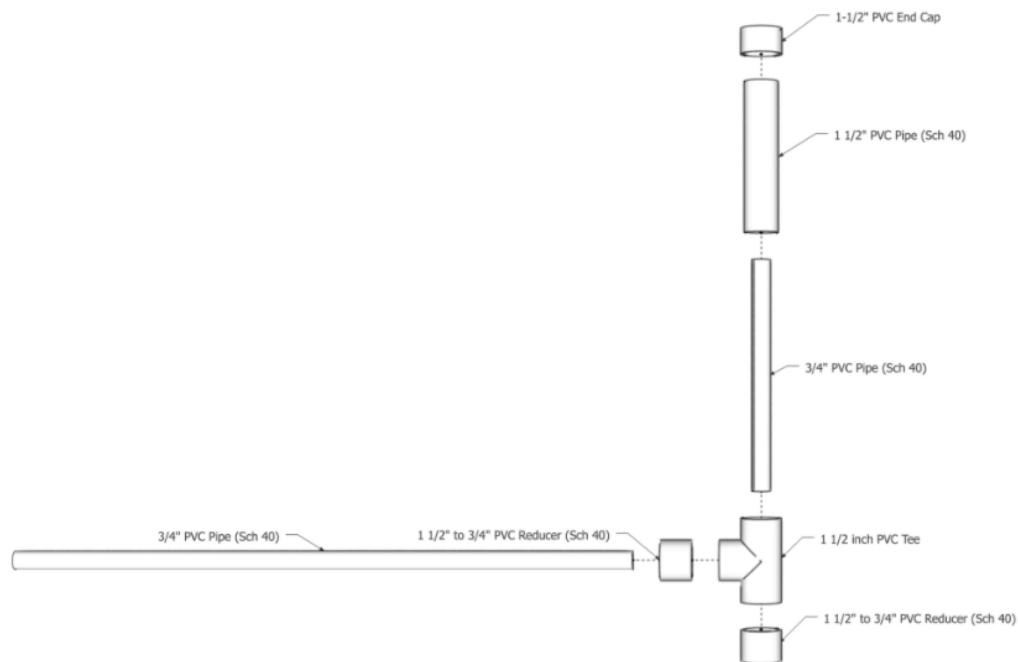
Appendix B

External Bell Siphon

The goal with this lab is to build, install, commission, and troubleshoot an external bell siphon in a flood and drain grow media system.

How it works:

As the water level inside the grow bed raises the water inside the connected bell siphon (BS) raises until it begins to drop over the internal pipe. While the water inside the BS begins to drain out, the water inside the tank continues to increase causing a pressure difference between the tank and the inside of the BS. This pressure difference causes a vacuum to form inside the BS and will pull water out of the main tank until the pressure between the BS and the tank have equalized.



Safety requirements Safety glasses Hand protection (gloves of some kind) Tool requirements Tape measure Drill Assorted drill bits Assorted hole saws Hack saw PVC pipe cutter Pencil	Material Requirements 1x 1 1/2 pvc end cap 1x piece of 1 1/2 inch pvc 1x 1 1/2 pvc T 1x 3/4 bulkhead 1x 3/4 45* pvc connector 1x 3/4 90* pvc connector 2x 1 1/2 to 3/4 pvc reducers 2x 3/4 male adaptors 1x piece of 3/4 pvc 1x tank or equivalent
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1. Measure 13 inches down from the top and 4-ish inches from the side on the skinny end of your tank and mark an x, this will be the center of the hole in our tank
2. Load the right size hole saw for the hole needed for the bulkhead fitting
3. Drill the bulkhead hole on the x you just measured on your tank
4. Insert bulkhead and tighten the nut ensuring a proper seal.
5. Measure the depth of the tank and calculate the proper aquaponic zones
 - A. Dry Zone
 - B. Root Zone
 - C. Solid collection and mineralization zone
6. Calculate and measure the depth you want to be able to drain the water down to
 - A. I like to try to drain as much as possible
 - B. Using 1 male adaptor and the $\frac{3}{4}$ 45° connector build a piece of pipe that is only about $\frac{1}{4}$ to $\frac{1}{2}$ inch above the bottom of the tank
7. On the outside of the bulkhead fitting, insert and tighten a $\frac{3}{4}$ male adaptor
8. Cut a short piece of $\frac{3}{4}$ pvc and install it into the above male adaptor
 - A. This piece should only 2 times the depth of the above pvc male adaptor
9. Insert the 2x 1 $\frac{1}{2}$ inch to $\frac{3}{4}$ reducers into both the center and one end of the 1 $\frac{1}{2}$ pvc T
 - A. the side with the 1 $\frac{1}{2}$ to $\frac{3}{4}$ reducer will now be considered the bottom of the T
10. The reducer on the bottom of the T will now need to have the little stopper piece filed down to the exact diameter of the outside of the $\frac{3}{4}$ pvc
 - A. This must be a tight seal so care must be taken to not remove more material than necessary
11. Once the adaptor has been filed down and fit tested insert a piece of $\frac{3}{4}$ into the center of the T from the top down. This piece will be known as your standpipe.
 - A. This is the piece that determines the depth the water reaches in the tank before the siphon takes over and begins to drain the water.
 - B. Expect to make adjustments
12. The 1 $\frac{1}{2}$ inch pvc will act like a housing over the internal $\frac{3}{4}$ pvc creating a seal to create an internal vacuum to pull the water out of the system
 - A. Measure and cut the 1 $\frac{1}{2}$ pvc long enough to be able to allow space above the internal $\frac{3}{4}$ pvc
 - B. Plan to adjust this so start the measurement a little longer with the expectation that you'll need to cut this down to size
13. One side of the 1 $\frac{1}{2}$ PVC is to be covered with the 1 $\frac{1}{2}$ pvc cap and the other will be inserted into the top side of the 1 $\frac{1}{2}$ inch pvc T
14. Fill the tank with water to test for operation and adjust
 - A. Expect to modify and to add a piece to the siphon to increase flow
 - B. Come up with a solution to measure the output flow from you siphon while no media is present and make note
15. Once a satisfactory flow has been achieved add grow media to the tank and retest operation
 - A. Expect to troubleshoot flow issues created by adding media

- B. remeasure the volume of water you are getting from your siphon and see if any changes have been made

Appendix C

Installation Guide for Automation Software

Part 1: How to Download Connected Components Workbench

Step 1: Create an Account

- Navigate to the official Rockwell Automation website.
- Create a free account (sometimes called a Knowledgebase or PCDC account) before you can access any downloads.

Step 2: Go to Download Center

- Once logged in, find the Product Compatibility and Download Center (PCDC). This is the main hub for all Rockwell software.

Step 3: Find the Software

- In the PCDC search bar, type “Connected Components Workbench”
- Click the search results. You will likely see several versions.

Step 4: Select the Version

- Find the latest version (i.e. v22, v23, etc.)
- Click the download icon (it may look like a small hard drive or arrow)
- On the next screen, you will see a list of files. Choose Standard Edition, which is free. Do not select the Developed Edition unless you have a paid license.

Step 5: Download the Files

- Select the checkbox for the Standard Edition download.
- Click the Downloads button (it may look like a shopping cart)
- You will likely be given two options:
 - Download Manager: This is the recommended method. It will download a small .exe that manages the large download, which is more reliable.
 - Direct Download: This will download the entire package (often 4GB+) as a single .zip or .iso file, or sometimes in multiple parts.
- Accept the End-User License Agreement (EULA) and begin your download.

Part 2: How to Install CCW

Step 1. Prepare the Files:

- If you downloaded a .zip or .iso file, you must first extract the files to a new folder on your computer.
- If you used the Download Manager, it will typically download and extract the files for you to a default folder (often C:\RA).

Step 2: Run the Installer as Administrator

- Open the folder with the installation files.
- Locate the Setup.exe file.
- Right-click Setup.exe and selected “Run as Administrator”. This is critical for industrial software, which needs to install system services and drivers

Step 3: Follow the Installation Wizard

- The installer will launch. This can take a few minutes.
- Select “Install Connected Components Workbench” (or “Customize” if you need to change the installation path).
- Accept the license agreement(s)
- The installer will install CCW along with all necessary components, such as RSLinx Classic or FactoryTalk Linx (which are communication drivers) and ControlFLASH (for firmware updates)

Step 4: Be Patient

The installation process for CCW is very long. It is not uncommon for it to take 30 minutes to an hour, depending on your computer’s speed.

Step 5: Restart Your Computer

Once the installation is complete, restart your computer to ensure all services and drivers are correctly loaded.

Part 3: How to Open an Exported File (Import a .ccwarc File)

This is the most common point of confusion. An “exported file” (which usually has a .ccwarc extension) is a project archive. You **cannot** open it using File>Open. You must Restore or Import it.

Step 1: Launch CCW

Open Connected Components Workbench from your Start Menu.

Step 2: Find the Restore Option:

- On the main Start page, look at the Project section.
- You will see options for New, Open, and Restore.
- Click on Restore.
- (Alternatively, you can often go to the File>Import Projects menu)

Step 3: Select your Archive File

- A dialogue box will open. Browse to the location of your exported file (i.e. MyProject.ccwarc).
- Select the file and click Open

Step 4: Choose a Destination

- The software will then ask you where you want to save the restore project.
- This is important: It is unpacking the archive into a new, regular project folder. Select a location (like your Documents\CCW folder) and give the new project folder a name

Step 5: Open the Restore Project

Once the restore is complete, CCW will either open the project automatically, or you will now be able to open it from the Open menu by navigating to the new folder you just created.

Important Tips

- **Version Compatibility:** You can only restore an archive file if your version of CCW is the *same or newer* than the version that created the file. If you have CCW v21, you cannot open a project made in v22.
- **Administrator Rights:** Always run CCW as an administrator, especially when you plan to go online with a PLC.
- **Communication:** The RSLinx/FactoryTALK Linc software installed with CCW is what allows your computer to find and communicate with the actual PLC hardware (like Micro800 controller).

How to Install Connected Components in Workbench

This video provides a clear visual walkthrough of the installation process, which can be very helpful to follow along with.

<https://www.youtube.com/watch?v=oqe8b6Udv7U&themeRefresh=1>