From Textbook to Treatment: Designing and Building a Bench-Scale Drinking Water Treatment System

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Background and Objective

- The Humboldt Bay Municipal Water District draws high-quality source water from the Mad River aquifer via Ranney Collectors, where natural filtration produces high-quality water that is disinfected prior to distribution to the cities of Arcata, Mckinleyville, Eureka, Blue Lake and Manila.
- The main goal is to model a *conventional* drinking water treatment facility as a bench-scale model community education, research purposes, and for future engineering drinking water treatment design courses.
- The model is designed as an educational tool that bridges classroom concepts with hands-on understanding and as a research tool to combat the effects of climate change. For enhanced visibility, the model will be transparent.
- Design considerations include flow control, head loss, and hydraulic efficiency, providing a hands-on application of fluid mechanics concepts

Constraints & Criteria

- Bench-model must be a scaled conventional water treatment plant, often found in larger municipalities. Must meet criteria in Table 1 and Table 2.
- Maintain low costs of materials and student hours due to funding
- Meet the 6 month timeline
- Emphasize turbidity removal as a visible and measurable indicator of treatment effectiveness
- Capacity for a range of 0.1-0.5 gpm flow
- Physical dimensions not exceed 20 sqft

Table 1. (Right) List of criteria and their weights used in the decision making process.

Criteria	Weight
Size	8
Visibility	10
Portability	10
Modular	9
Cleaning	8
Testing	6
Cost	5
Time	10
Total	**66**

Coagulation + Rapid Mixing	Selected Design Parameters
Radial-flow impeller	Provides more turbulence prefered for rapid mixing
Small detention time	Range of 1-7 seconds acceptable for rapid mixing
High velocity gradient	Range of 6000-1000 s^-1 suitable for coagulation
High mixing speed	Motor speed n=201 rpm
Sized down freeboard	Freeboard factor of 0.045m
Flocculation	
Longer detention time	Range of 20-30 minutes or 1,200-1,800 seconds
Decreasing velocity gradient	Range of 30-80 s^-1, suitable for slower mixing
	1st chamber G=80 s^-1, 2nd chamber G=65 s^-1, 3rd chamber G=30 s^-1
Decreasing motor speeds	1st chamber n=28 rpm, 2nd chamber n=24 rpm, 3rd chamber n=14 rpm
Sedimentation	
Length to width ratio	a minimum ratio of 6:1 is acceptable
Length to depth ratio	a minimum ration of 15:1 is acceptable
Inflow velocity	an acceptable range of 0.005 - 0.018 m/s
Reynold's number	a result of less than 20000 is acceptable
Froude's number	a result of 10^-5 and greater is acceptable
Scaling	was scaled down from full size by factors of 10x
Filtration	
Filter type	gravity-driven dual-media filtration
Filter media	anthracite over sand, graded gravel support layer
Anthracite coal, Effective Size (ES)	1.1mm
Depth	0.2m
Fine Sand, ES	0.6mm
Depth	0.15m
Graded Gravel, ES	2-20mm
Depth	0.1m
Flow control	perforated plate, shallow distribution zone
Underdrain	120 mesh stainless steel
Filtration rate	10 m/hr
Total media depth	0.45m

Table 2. (Left and above) Design specifications for each stage, excluding disinfection

System Overview

Common steps in conventional drinking water treatment processes include coagulation, sedimentation, filtration, and disinfection which treat and provide potable water to municipalities. Figure 1 depicts the treatment system.

1. Untreated water, often groundwater or surface water, first enters the coagulation stage which involves adding iron or aluminimum salts, alum, to the water at high mixing speeds. These chemicals, coagulants, are added to neutralize the negative charges on fine particles (i.e. dirt, organic matter).
2. The water then enters the flocculation stage, where the gentle and decreasing mixing allows particles to collide with each other and become heavier in density often called floccs. Organic compounds are removed during this stage.
3. Water then enters a large sedimentation chamber where heavy floccs are allowed to settle to the bottom of the tank by gravity.
4. Following sedimentation, water enters filtration where it is passed through porous media often made of natural materials. This stage removes particulate matter and suspended solids.
5. Finally water is disinfected using chlorine, UV light, or ozone, or a mix of all 3!

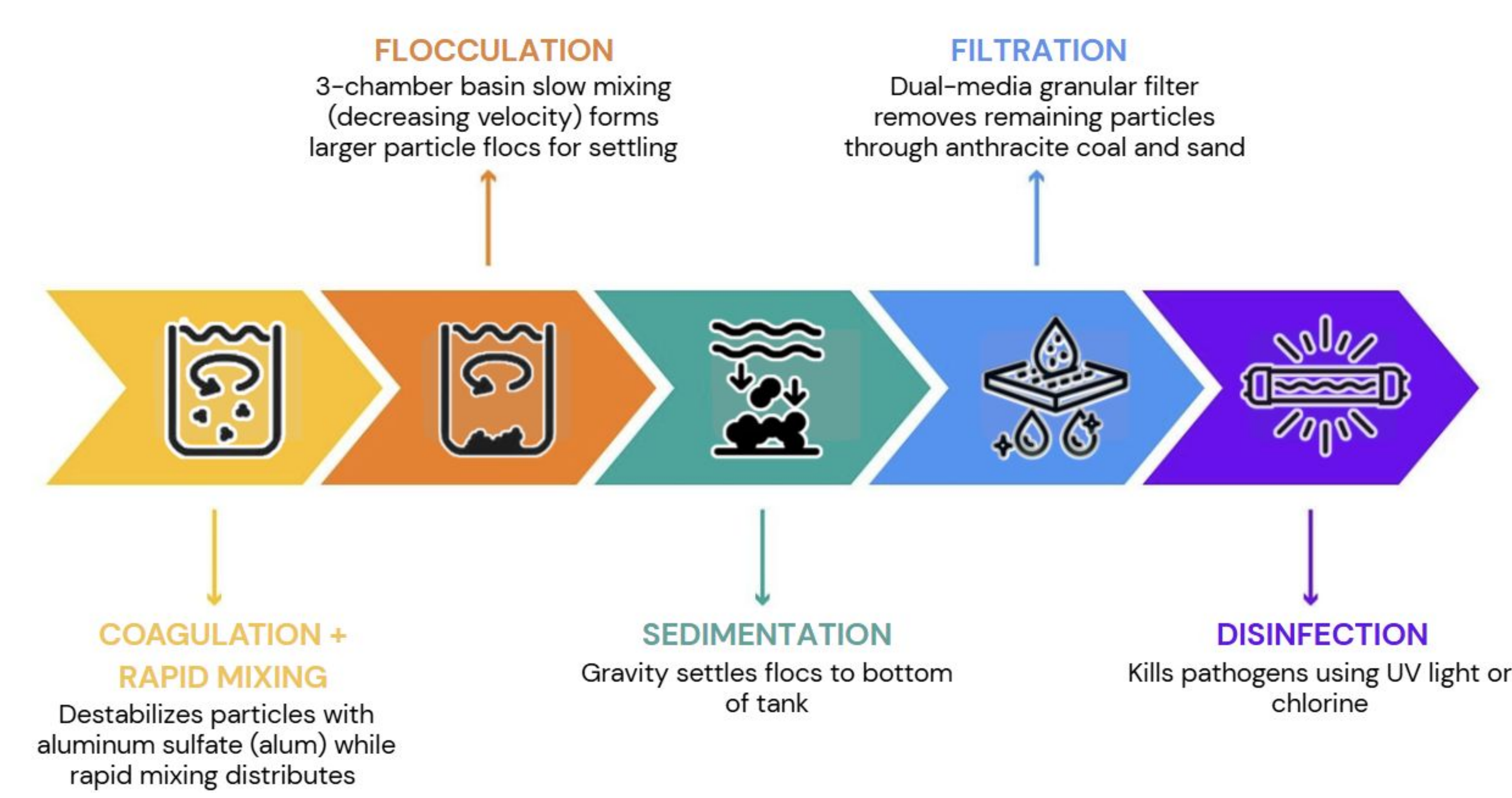

Figure 1. (Above) A physical representation of the chosen drinking water treatment chain, often found in municipalities. Stages include coagulation, flocculation, sedimentation, filtration, and disinfection. Disinfection is currently not designed or constructed.

Hydraulic Design & Flow Control

It is essential to maintain constant flow rate throughout the entirety of the system to ensure system performance. The model is able to handle a range of 0.1-0.5 gpm inflow and successfully transfer constant flow rates down the treatment train using baffles and weirs, barriers across the system used to control flow through fluid mechanic principles. Velocity must also be controlled to ensure proper water treatment. Too high will produce shear and too low will effectively not drive the system. Monitoring filtration bed clogging, flows through pipes and structures, and the overall system capacity are ways to monitor headloss, reduction in energy expressed in height. Persaltic and diaphragm pumps are chosen for this system. A schematic of the first three stages in the water treatment chain is seen in Figure 4.

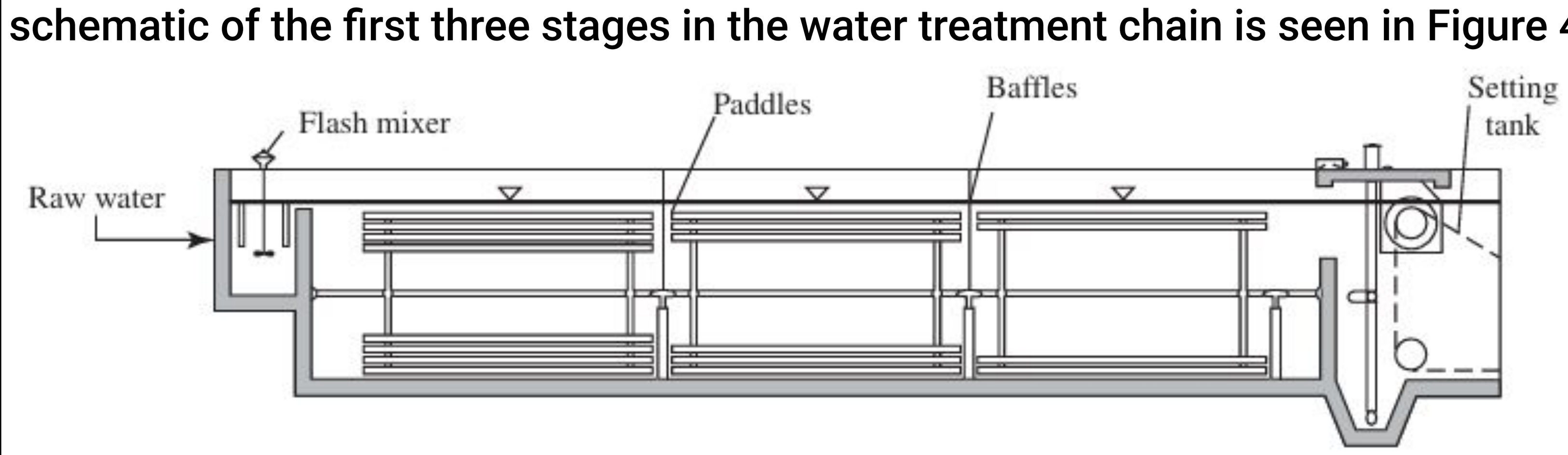

Figure 4. (Above) Textbook schematic showing the flow of the conventional drinking water treatment process for coagulation, flocculation, and sedimentation (Davis, 2010).

Pilot Model Final Design

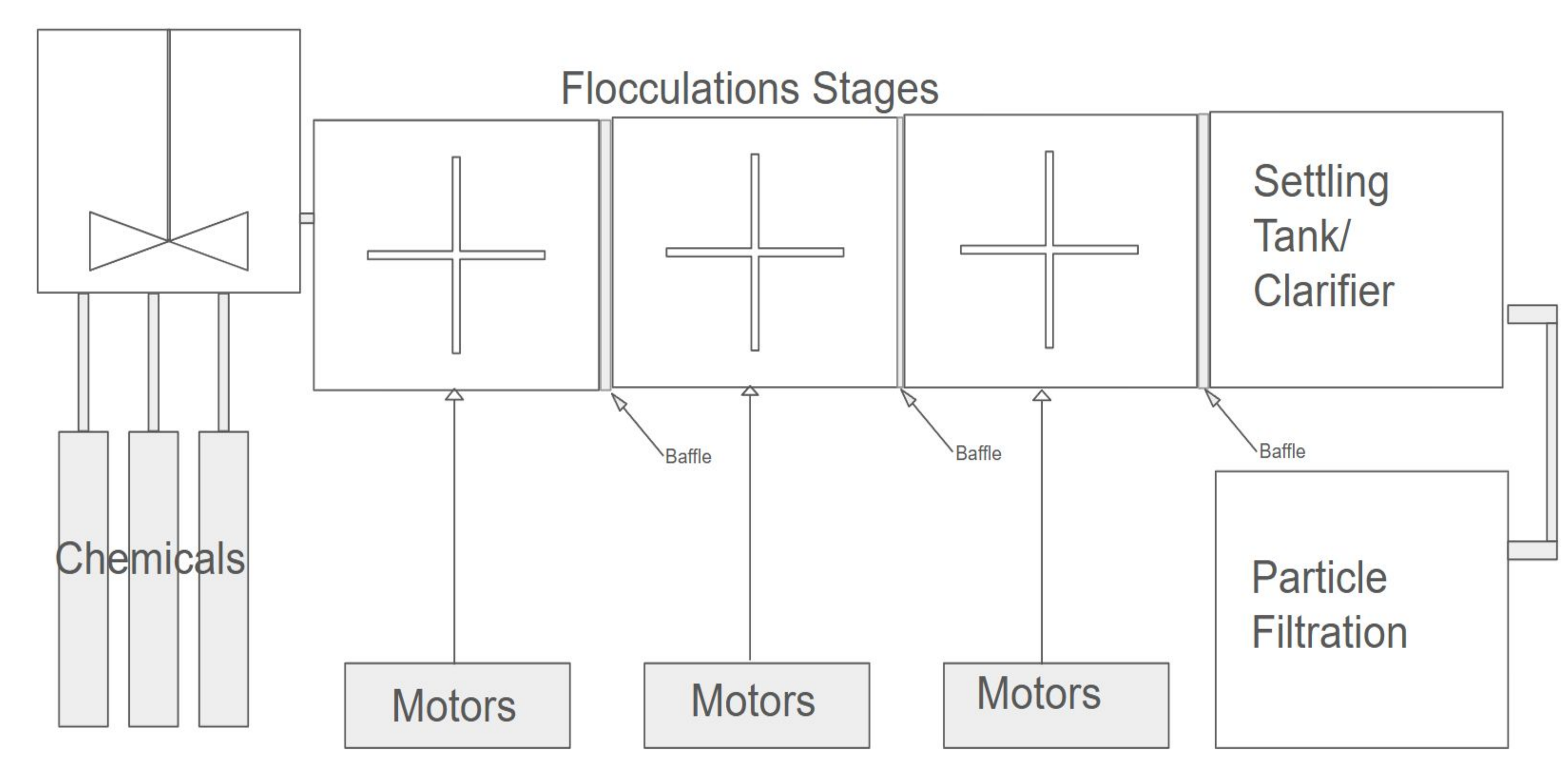

Figure 2. (Above) The chosen design includes the flocculation and coagulation basins with the additions of a sedimentation basin and particle filtration.

Construction & Materials

The physical model is primarily made using clear acrylic sheets for the tanks, metal impellers for mixing, plastic tubing for pumping, and several electronic parts. Figure 3 represents the cost distribution.

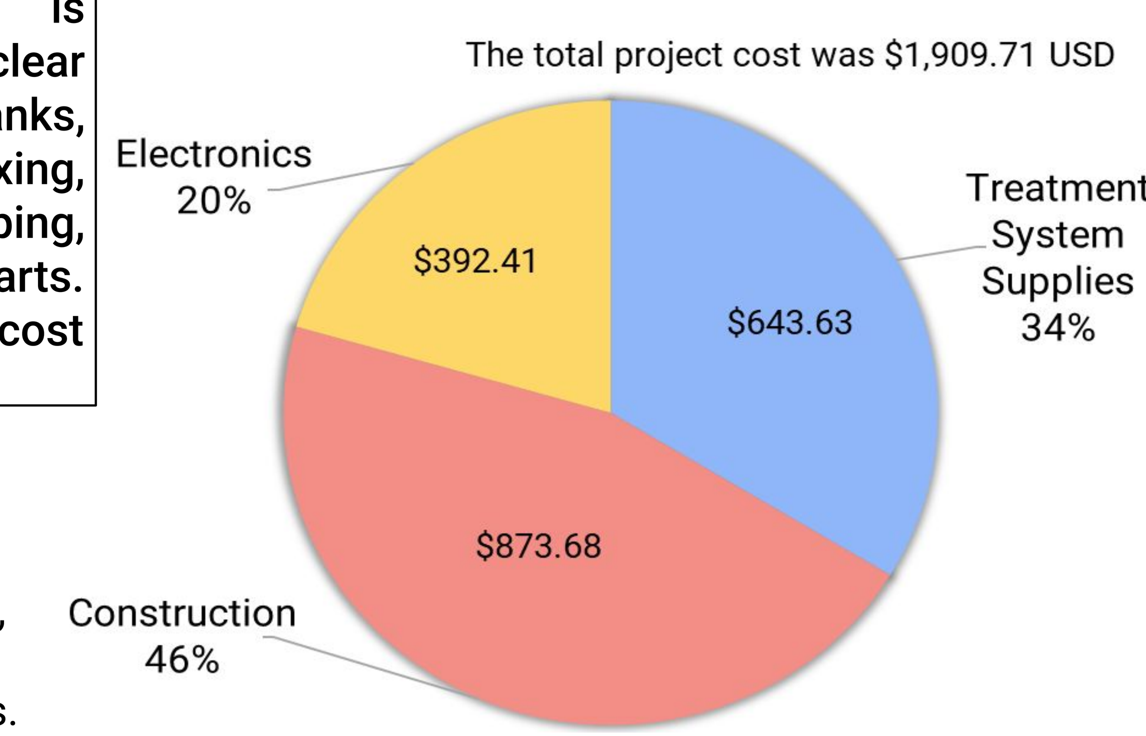

Figure 3. (Right) Pie chart showing project cost distribution for electronics, water treatment supplies, and construction materials.

Limitations & Future Work

Water treatment systems are precise and complicated systems, relying on strict calculations based on fluid mechanic principles, often being difficult to scale down to smaller systems. While we were able to successfully design the treatment plant, building our modular system in a short time frame has proved to be an exciting and challenging process. In the future, we plan to add UV disinfection, chlorination, and improvements to our modular and automated design.

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