ChatGPT

Water Treatment Operator Digital Classroom — Project Execution

This document records the simulated multi-persona meeting and deliverables for the **Water Treatment Operator Digital Classroom** project. The team consists of:

- **Director Patricia "Pat" Yamamoto** (Training Director)
- **Alex Chen** (Technologist)
- **Marcus "Big Mike" Thompson** (Chief Engineer)
- **Dr. Sarah Okonkwo** (Commissioning Inspector)

The project develops five interactive training modules, following the phases defined in the master prompt. Dialogue snippets below are written in each persona's distinct voice.

Phase 0 – Pre-Flight Briefing

Director Yamamoto opened the meeting by restating the mission: *"We're here to build a digital classroom for water treatment operators that turns invisible physics and chemistry into intuitive, interactive experiences. Our north star is 'Khan Academy clarity meets industrial SCADA authenticity.' Let's make sure we all agree on what each module must teach before we start coding."* She then assigned modules to the team and asked each expert to outline what the module must accomplish.

Module 1: Coagulation & Flocculation

Chief Engineer (Big Mike): "This module has to teach rookies why we add coagulant and what happens when we stir. They need to see how ionic strength compresses that invisible electric double layer. The G-value and temperature effects are critical. Operators also need to learn that you can overdose coagulant — if you flip too many magnets, the particles re-stabilise and nothing settles. And don't forget, shear breaks floc: I want to see big clumps tear apart when you crank the RPM."

Inspector (Dr. Okonkwo): "According to the specification, my tests will be:
1. **Overdose Test** – at 50 mg/L coagulant the particles re-stabilise and stop sticking.
2. **Shear Test** – form floc at low RPM then crank to max; the floc must break apart.
3. **Temperature Test** – identical settings at 5 °C vs 25 °C must show slower floc formation in cold water.
4. **Zero Dose Test** – at 0 mg/L coagulant particles never aggregate."

Scope Boundaries
• **IN:** Single-basin coagulation and flocculation using the Camp–Stein equation for G-value; variable coagulant dose, rapid mix RPM, flocculation RPM, temperature, and raw water turbidity; visualisation of particle charges, double-layer compression and floc formation; failure states for overdose, shear, temperature.

• **OUT:** Anything beyond coagulation/flocculation (no sedimentation), multi-chamber hydraulics, 3D particle collisions, or audio-visual gamification not related to plant operations.

Module 2: Sedimentation & Clarification

Chief Engineer: "Here I want operators to understand that settling is about time, depth and how big your particles are. Flow rate and temperature change viscosity. They should see pin floc vs. macro floc, and how wind can create dead zones. The surface overflow rate is a number every operator hears about — I want them to see particles outracing that rate and spilling over the weir."

Inspector: "The stress tests I'll be running are:
1. **Flow vs Settling** – at maximum flow most particles carry over; at minimum flow most settle.
2. **Temperature Impact** – same flow at 5 °C vs 25 °C must show more carryover in cold water.
3. **Particle Size Impact** – pin floc at normal flow should mostly carry over; macro floc should settle.
4. **Dead Zone Visualization** – wind must create visible circulation patterns that reduce effective settling."

Scope Boundaries
• **IN:** Rectangular sedimentation basin with adjustable flow rate, temperature, particle size, basin depth and wind; dynamic calculation of surface overflow rate and detention time; Stokes' Law for settling velocity with temperature-dependent viscosity; visualisation of settling paths and carryover.
• **OUT:** Tube settlers, lamella plates or sludge removal mechanisms; chemical coagulation adjustments (handled in Module 1); turbulent CFD models beyond simple circulation patterns.

Module 3: Filtration

Chief Engineer: "For filtration, they need to grasp head loss and breakthrough. Show how porosity decreases and head loss skyrockets as the filter runs. Let them switch media (anthracite, sand, dual) and see different pore sizes. Backwashing should expand the bed more in cold water — that always surprises rookies."

Inspector: "My mandatory tests are:
1. **Head Loss Curve** – after 48 hours run time head loss increases exponentially.
2. **Breakthrough** – at maximum run time, effluent turbidity spikes.
3. **Backwash Expansion** – the same backwash rate at 5 °C vs 25 °C must show more expansion in cold water.
4. **Media Loss Warning** – backwash rate >20 gpm/ft² in cold water triggers a 'MEDIA LOSS' warning."

Scope Boundaries
• **IN:** Depth filter with adjustable filtration rate, run time, backwash rate, temperature, and media type; Kozeny–Carman head loss calculation; phases of ripening, steady state and breakthrough; bed expansion during backwash; warnings for breakthrough and media loss.
• **OUT:** Underdrain design details, air scour modelling, or specific backwash control systems.

Module 4: Disinfection & CT Calculation

Chief Engineer: "Here it's all about CT. Operators need to see how residual and baffling factor combine with time to reach required CT, and how temperature and pH change the requirement. Show the breakpoint chlorination curve when ammonia is present, and make sure high pH and low temperature really drive CT requirements up.”

Inspector: “My tests:
1. **Winter Scenario** – at 0.5 °C and pH 8.5, required CT is roughly five times higher than at 25 °C and pH 7.
2. **Breakpoint Curve** – moving from 0 to max chlorine with ammonia must show the hump and dip.
3. **Baffling Impact** – same dose/time with baffling factor 0.1 vs 0.7 must show large differences in CT achieved.
4. **Compliance Alarm** – if CT achieved < CT required, a red ‘VIOLATION’ indicator must appear.”

Scope Boundaries
• **IN:** Chlorination basin with adjustable dose, contact time, temperature, pH, ammonia concentration and baffling factor; CT calculation ($C \times T_{10}$) and required CT regression; interactive breakpoint curve with species proportions; compliance indicator.
• **OUT:** UV or ozone disinfection, DBP formation modelling, or multi-stage contact basins beyond a single baffled volume.

Module 5: Distribution & Corrosion Control

Chief Engineer: “Operators always get complaints about red water or white scale. I want them to play with pH, alkalinity, calcium hardness and TDS to see how the Langelier Saturation Index goes from corrosive to scaling. Show how temperature jumps when the water hits a heater. Also, let them see how chloramine residual decays with water age and triggers nitrification risk.”

Inspector: “I will test:
1. **Temperature Shift** – water with LSI ≈ 0 at 15 °C must be >+0.5 (scale-forming) at 60 °C.
2. **Corrosion Extreme** – at pH 6.5, alkalinity 20 and calcium 20, LSI should be strongly negative with a red ‘CORROSIVE’ warning.
3. **Water Age Decay** – residual decays to zero over 14 days with a nitrification warning after day 7.
4. **Dead End Scenario** – high water age and low residual trigger a ‘NITRIFICATION RISK’ indicator.”

Scope Boundaries
• **IN:** Langelier saturation index calculation with adjustable pH, temperature (plant vs water heater), calcium hardness, alkalinity, TDS and water age; residual decay curve and nitrification indicator; visual balance beam showing corrosive vs scaling tendencies.
• **OUT:** Detailed pipe network hydraulics, lead/copper rule compliance calculations, or modelling of DBP formation in the distribution system.

Phase 0 Outcome

After hearing the chief’s priorities and the inspector’s test requirements for all modules, Director Yamamoto summarised: *“We have a clear mission and everyone knows what must be taught and tested. We’re not building games; we’re building scientific tools operators can fail and learn from. The scope boundaries will help us avoid feature creep. I hereby authorise Phase 1: Blueprint Development for all five modules.”*

Phase 1 – Blueprint Development

With Phase 0 complete, Alex Chen took the lead in drafting detailed blueprints for each module. Big Mike and Dr. Okonkwo provided feedback, and Director Yamamoto ensured the plans stayed within scope and schedule.

Module 1: Coagulation & Flocculation — Implementation Blueprint v1.0

The Sticky Analogy
"Particles are like ping-pong balls covered in magnets that all point the same way – they repel each other. Coagulant flips some magnets so the balls stick together. Rapid mixing is like shaking the box so they bump; gentle flocculation is like swaying it softly so they grow. Too much glue or too much shaking ruins the clumps."

Variable Parameters

Parameter	Range	Default	Tooltip (Plain English)
Coagulant Dose (mg/L)	0 – 50	15	"How much 'stickiness' you're adding. Like adding glue to dust bunnies."
Rapid Mix RPM	0 – 300	100	"How violently you're stirring. Fast = good initial mixing, but TOO fast breaks floc."
Flocculation RPM	0 – 80	20	"Gentle stirring to let particles bump and stick. Too fast = shearing."
Temperature (°C)	1 – 30	15	"Cold water is 'thicker' – needs more energy to mix, floc forms slower."
Raw Water Turbidity (NTU)	1 – 100	25	"How dirty the incoming water is. More particles = more coagulant needed."

Split-Screen Layout

```
┌──────────────────────────────────┬─────────────────────────────────────┐
│  LEFT PANEL – Control Room (40%)│  RIGHT PANEL – Microscope (60%)     │
├──────────────────────────────────┼─────────────────────────────────────┤
│ • Sliders: Dose, RPMs, Temp     │ • Particle field with charges       │
│ • Digital readouts: G-value,    │ • Double-layer thickness indicator   │
│   viscosity, turbidity          │ • Floc clusters forming/breaking    │
│ • Status lights: Overdose,      │ • Graph of floc size vs time        │
│   Shear warning                 │                                     │
└──────────────────────────────────┴─────────────────────────────────────┘
```

Physics Implementation

- **G-Value Calculation:** Use the Camp–Stein equation `G = sqrt(P/(μV))`, with power `P` proportional to rapid-mix RPM³ (affinity law) and viscosity `μ` computed from temperature via `μ(T) = 0.00002414 × 10^(247.8/(T+133.15))`. The G-value drives a gauge and influences floc formation speed.
- **Double-Layer Compression:** Model double-layer thickness inversely proportional to the square root of ionic strength. Ionic strength increases with coagulant dose; compress the double layer radius accordingly so particles approach and stick.
- **Floc Growth & Breakage:** Represent particles as circles with charges. When particles collide under gentle mixing (low G), they stick and form clusters. At high G (rapid mix or high flocculation RPM), apply random breakage probability proportional to shear. At zero dose, disable sticking entirely. At overdose (>40 mg/L), reverse charges so particles repel again.
- **Temperature Effect:** Higher viscosity at low temperature reduces G for a given RPM and slows floc growth. The animation updates slower cluster growth when temperature is low.

Failure States

- **Overdose:** Dose > 40 mg/L triggers charge reversal. Visual indicator: particles turn red and repel; "Overdose – particles re-stabilising!" message.
- **Shear:** If G-value exceeds a threshold (e.g., 600 s^{-1}), existing clusters break apart. Play an animation of floc shattering and flash an amber warning.
- **Cold Water:** Temperature < 5 °C halves the floc growth rate; a blue "Cold Water – slow floc" badge appears.
- **Zero Dose:** At 0 mg/L, particles never stick. The simulation shows constant free particles and a message "No coagulant – nothing sticks."

Chief's Sign-Off
"The analogy is spot on – magnets are something everyone gets. Just make sure the dose range matches real coagulant jar tests. I'm happy you included overdose and shear warnings; operators need to see that you can mess this up. Looks good for v1."

Inspector's Confirmation
"All four stress tests (overdose, shear, temperature, zero dose) are explicitly addressable in this design. I will be able to test the behaviours without hidden variables. Proceed."

Module 2: Sedimentation & Clarification — Implementation Blueprint v1.0

The Sticky Analogy
"Imagine panning for gold. If the stream rushes too fast, even heavy nuggets get swept away; slow it down and they sink. Now imagine panning in honey versus water – cold water is like honey; everything sinks slower. Wind is like a kid splashing in your pan, stirring up what should have settled."

Variable Parameters

Parameter	Range	Default	Tooltip (Plain English)
Flow Rate (MGD)	0.5 – 10	2	“How fast water moves through. Higher flow = less time to settle.”
Temperature (°C)	1 – 30	15	“Cold water is thicker – particles settle slower. Winter is hard.”
Particle Size	Pin/Normal/Macro	Normal	“How well coagulation worked. Pin floc = bad upstream process.”
Basin Depth (ft)	8 – 16	12	“Deeper = more time to settle, but also more distance to fall.”
Wind (mph)	0 – 20	0	“Wind on open basins creates currents that disrupt settling.”

Split-Screen Layout

```
┌──────────────────────────────────┬────────────────────────────────────────┐
│  LEFT PANEL – Control Room (40%) │  RIGHT PANEL – Cross-Section (60%)     │
├──────────────────────────────────┼────────────────────────────────────────┤
│ • Sliders: Flow, Temp, Size,     │ • Side-view of basin showing inlet,    │
│   Depth, Wind                    │   settling particles and outlet weir   │
│ • Readouts: Surface overflow     │ • Trajectories: some particles settle,│
│   rate (SOR), detention time     │   some are carried over                │
│ • Status lights: Dead-zone       │ • Circulation arrows when wind >0     │
│   warning                        │                                        │
└──────────────────────────────────┴────────────────────────────────────────┘
```

Physics Implementation

- **Settling Velocity:** Compute discrete settling velocity using Stokes’ Law `Vs = g(ρp – ρw)d²/(18 μ)`. Choose representative particle diameters for pin floc (~20 μm), normal (~100 μm) and macro (~300 μm). Viscosity depends on temperature as in Module 1. The simulation generates particles with vertical velocity equal to `Vs` and horizontal travel determined by flow.
- **Surface Overflow Rate:** Calculate `SOR = Q/A`, where flow `Q` converts MGD to m^3/day and surface area `A` is determined from basin width × length. Particles with `Vs < SOR` are carried over; highlight them crossing the weir.
- **Detention Time:** Compute `t = V/Q`, with volume from basin depth × area. Display as a timer; compare with the time required for a particle to settle.
- **Wind-Induced Circulation:** When wind > 0, superimpose a sinusoidal horizontal velocity field that circulates water and disrupts settling. Visualise eddies and reduce effective settling velocity by a wind-dependent factor.

Failure States

- **High Flow Carryover:** At maximum flow (10 MGD), most particles outrun settling and cross the weir. Show a red "Poor Clarification" light.
- **Cold Water:** At <5 °C, viscosity increases; the same particle size settles slower. Show more carryover and a blue "Cold Water – reduced settling" alert.
- **Pin Floc:** Selecting "Pin" size makes particles tiny; they settle very slowly and carry over even at moderate flows. Display an amber "Upstream Coagulation Issue" message.
- **Dead Zone:** Wind > 10 mph generates circulation arrows; mark a region where particles recirculate and show a "Dead Zone" warning.

Chief's Sign-Off
"Good job showing SOR and detention time – operators can punch those numbers right now. Make sure the wind effect doesn't look like a hurricane; just enough to see the dead zone. I like the gold-panning analogy."

Inspector's Confirmation
"The four required stress tests (flow vs settling, temperature impact, particle size impact, dead-zone visualization) are captured. I will have measurable metrics for pass/fail."

Module 3: Filtration — Implementation Blueprint v1.0

The Sticky Analogy
"Your filter is like a coffee filter filled with gravel. At first water flows easily. As gunk builds up, you have to push harder (head loss). Eventually, gunk squeezes through (breakthrough). Backwashing is like shaking and rinsing the filter – but shake too hard in cold syrup and the gravel flies out."

Variable Parameters

Parameter	Range	Default	Tooltip (Plain English)
Filtration Rate (gpm/ft^2)	1 – 6	3	"How fast water pushes through. Faster = more stress on the filter."
Run Time (hours)	0 – 48	0	"How long since last backwash. Longer = more clogged."
Backwash Rate (gpm/ft^2)	10 – 25	15	"How hard you flush backwards. Too soft = dirty filter. Too hard = lost media."
Temperature (°C)	1 – 30	15	"Cold water expands the bed more at the same flow. Adjust backwash in winter!"
Media Type	Anthracite/Sand/Dual	Dual	"Different grains, different pore sizes, different performance."

Split-Screen Layout

```
┌────────────────────────────────────┬──────────────────────────────────────────┐
│  LEFT PANEL – Control Room (40%)  │  RIGHT PANEL – Filter Cross-Section (60%)
│
├────────────────────────────────────┼──────────────────────────────────────────┤
│ • Mode toggle: Filter/Backwash     │ • Media grains drawn at scale
│
│ • Sliders: Filtration rate, Run    │ • Pore channels narrowing as solids
│
│   time, Backwash rate, Temp        │   accumulate
│
│ • Readouts: Head loss gauge,       │ • Effluent turbidity graph (spikes at    │
│   Effluent turbidity               │   breakthrough)
│
│ • Status lights: Breakthrough,     │ • Bed expansion animation during         │
│   Media loss                       │   backwash
│
└────────────────────────────────────┴──────────────────────────────────────────┘
```

Physics Implementation

- **Head Loss (Kozeny–Carman):** Compute pressure drop per unit depth `ΔP/L = 180 μ (1–ε)² Vs / (ε³ d²)`. Set initial porosity `ε` for each media type and decrease it as run time increases (porosity decreases linearly or exponentially with solids loading). Calculate superficial velocity `Vs` from filtration rate. Convert pressure drop to head loss and display on a gauge.
- **Porosity & Effluent Turbidity:** Track porosity as a state variable. As ε decreases, head loss increases and effluent turbidity remains low until ε falls below a threshold; then particles begin to break through, causing a spike in effluent turbidity (Phase 3). The simulation draws a turbidity graph over time.
- **Backwash Expansion:** During backwash mode, compute drag on media grains; expansion percentage is proportional to backwash velocity divided by viscosity. Cold water (higher μ) yields greater expansion. If expansion >30 %, trigger a red “MEDIA LOSS” warning and animate grains leaving the bed.
- **Temperature Effect:** Viscosity depends on temperature as before, influencing both head loss and backwash expansion.

Failure States

- **Head Loss Spike:** After ~48 hours at high filtration rate, the gauge reaches red; a “High Head Loss – Backwash Needed” alert appears.
- **Breakthrough:** At maximum run time, porosity drops below a threshold; effluent turbidity spikes and a red “BREAKTHROUGH – Filter Failed” indicator flashes.
- **Cold Backwash:** At 5 °C with backwash rate >20 gpm/ft², bed expansion exceeds 30 % and a “MEDIA LOSS” alarm appears; animation shows media grains leaving the filter.

Chief’s Sign-Off
“This makes sense. Show the head loss gauge climbing gradually and then spiking – that’s what operators see. For the media types, anthracite should have larger pores than sand. Keep the warnings loud and clear.”

Inspector’s Confirmation
“The head loss curve, breakthrough, backwash expansion and media loss conditions are all explicitly implemented. I can test them quantitatively.”

Module 4: Disinfection & CT Calculation — Implementation Blueprint v1.0

The Sticky Analogy
“Chlorine is a bouncer checking IDs. In warm water, he works fast. In cold water, he’s sluggish and needs more time. High pH is like dim lighting – harder to spot the bad guys. Ammonia is a crowd of people distracting him before he can even reach the pathogens. Baffles are the walls that force everyone past the bouncer instead of sneaking around.”

Variable Parameters

Parameter	Range	Default	Tooltip (Plain English)
Chlorine Dose (mg/L)	0 – 10	2	“How much disinfectant you add. More isn’t always better (DBPs!).”
Contact Time (min)	5 – 120	30	“How long water sits with chlorine. Longer = more kill.”
Temperature (°C)	0.5 – 25	15	“Cold water makes chlorine work slower. Winter is the danger zone.”
pH	6.5 – 9.0	7.5	“Higher pH = weaker chlorine (less HOCl). Hard to disinfect high-pH water.”
Ammonia (as N, mg/L)	0 – 2	0.5	“Ammonia in raw water. Chlorine reacts with it first before making free residual.”
Baffling Factor	0.1 – 1.0	0.5	“How well your tank prevents short-circuiting. Baffles = better contact.”

Split-Screen Layout

```
┌──────────────────────────────────────────┬──────────────────────────────────────────┐
│  LEFT PANEL – Control Room (40%)        │  RIGHT PANEL – Chemistry
(60%)             │
├──────────────────────────────────────────┼──────────────────────────────────────────┤
│ • Sliders: Dose, Contact time, Temp, pH, │ • Breakpoint curve: Cl₂:NH₃ ratio
on x-axis,│
│   Ammonia, Baffling factor              │   residual species on
y-axis                  │
```

```
│ • Readouts: CT achieved (C × T₁₀),       │ • Stacked bars showing mono/di/free
chlorine│
│   CT required for Giardia                 │ • Clearwell diagram with flow
paths,        │
│ • Log inactivation meter                  │   showing baffling factor
effect           │
│ • Status light: Compliance/Violation      │ • Marker showing where the current
dose lies│
└───────────────────────────────────────────┴──────────────────────────────────────────────┘
```

Physics Implementation

- **T_{10} and CT Achieved:** Compute `T₁₀ = (Volume/Flow) × Baffling factor`; assume a fixed clearwell volume and convert contact time into T_{10}. CT achieved = residual `C` (remaining after ammonia demand) × T_{10}. Residual decreases with higher ammonia until the breakpoint; calculate species distribution along the breakpoint curve.
- **Required CT:** Use the EPA regression `Required CT = 0.933 × log_inactivation × (1.038)^(20–T) × (0.765 × pH – 2.95)` for Giardia, parameterised for 3-log inactivation. Display required CT and compare to CT achieved.
- **Breakpoint Chlorination Curve:** Model chlorine species as a function of Cl_2:NH_3 mass ratio. Show combined residual (monochloramine), dichloramine dip and free chlorine rise. Update as user changes chlorine dose and ammonia; highlight where the system sits on the curve.
- **Compliance Indicator:** If CT achieved < CT required, display a red "VIOLATION – Insufficient Disinfection" banner. Otherwise, show green "Compliant."
- **Temperature & pH Effects:** Lower temperature and higher pH increase required CT exponentially; update required CT accordingly. The simulation shows how winter and high pH dramatically raise the bar.

Failure States

- **Winter Violation:** At 0.5 °C and pH 8.5, required CT increases ~5×; typical dose/time settings will produce a red violation indicator. Encourage users to adjust dose or contact time.
- **Breakpoint Dip:** As chlorine dose passes the dichloramine zone (~5:1 Cl_2:N ratio) the residual dips; show a sagging residual curve and emphasise the risk of under-disinfection in that zone.
- **Poor Baffling:** At baffling factor 0.1, T_{10} drops; CT achieved is low. Show swirling flow patterns in the clearwell diagram and a warning "Poor Baffling – Short Circuiting."

Chief's Sign-Off
"This nails the CT concept. Make sure operators can play with pH and temperature to see how crazy the requirements get in winter. I like the bouncer analogy – they'll remember that."

Inspector's Confirmation
"The winter scenario, breakpoint curve, baffling impact and compliance alarm are all testable. I will be able to verify the numeric CT calculations against the specification."

Module 5: Distribution & Corrosion Control — Implementation Blueprint v1.0

The Sticky Analogy

"The Langelier Saturation Index is like a seesaw. On one side, corrosive forces try to dissolve your pipes; on the other, scaling forces try to coat them. Your job is to keep it balanced. But when the customer heats the water, it's like someone jumps on the scaling side – suddenly what was balanced becomes scale-forming."

Variable Parameters

Parameter	Range	Default	Tooltip (Plain English)
pH	6.5 – 9.5	7.8	"Higher pH reduces corrosion but may cause scaling."
Temperature (°C)	5 – 80	15	"Test at plant temp and at water heater temp (60 °C) to see full picture."
Calcium Hardness (mg/L)	10 – 400	100	"Calcium forms protective scale – but too much clogs pipes."
Alkalinity (mg/L)	10 – 300	80	"Buffering capacity. Low alkalinity = unstable, swings corrosive easily."
TDS (mg/L)	50 – 1000	250	"Total dissolved solids. Affects conductivity and scaling tendency."
Water Age (days)	0 – 14	1	"Time since water left plant. Old water loses residual and gets risky."

Split-Screen Layout

```
┌────────────────────────────────────────────┬──────────────────────────────────────────┐
│  LEFT PANEL – Control Room (40%)          │  RIGHT PANEL – Visualization
(60%)        │
├────────────────────────────────────────────┼──────────────────────────────────────────┤
│ • Sliders: pH, Temp, Calcium, Alkalinity, │ • LSI balance beam: tips left =
corrosive│
│   TDS, Water age                          │   (red), right = scaling
(white)         │
│ • Temperature toggle: Plant vs Heater    │ • Pipe cross-section showing
pitting or  │
│ • Residual decay graph                   │   scale buildup based on
LSI             │
│ • Indicators: Corrosive/Scaling,         │ • Residual decay curve with
nitrification│
│   Nitrification risk                     │   warning at
```

```
day 7+
```

Physics Implementation

- **LSI Calculation:** Compute $pHs = (9.3 + A + B) - (C + D)$, where $A = (\log_{10}(TDS) - 1)/10$, $B = -13.12 \log_{10}(T+273) + 34.55$, $C = \log_{10}(Ca\ as\ CaCO_3) - 0.4$ and $D = \log_{10}(Alkalinity\ as\ CaCO_3)$. LSI = pH – pHs. Colour the balance beam based on LSI (<–0.3 = corrosive/red, –0.3 to 0.3 = balanced/green, >0.3 = scaling/white).
- **Temperature Effect:** Compute pHs at both plant temperature and user-selected temperature. A toggle allows operators to jump to 60 °C to simulate water heater. Show how LSI increases with temperature.
- **Residual Decay & Nitrification:** Model exponential decay of chloramine residual over 14 days (e.g., $C(t) = C_0 \times e^{(-k\ t)}$ with k chosen to drop to near zero by day 14). When residual drops below a threshold after day 7, trigger a “Nitrification Risk” warning. Decreasing residual also reduces pH slightly, which feeds back into LSI becoming more negative (corrosive).
- **Water Age Effects:** Higher water age reduces residual; show this on the graph and update LSI accordingly. High water age with low residual flips the balance beam toward corrosive side and shows pitting in the pipe cross-section.

Failure States

- **Temperature Shift:** At plant temperature (15 °C) with balanced LSI (~0), toggling to heater temperature (60 °C) should tip the beam >+0.5 toward scaling; show white scale forming inside the pipe.
- **Corrosion Extreme:** At pH 6.5, alkalinity 20 and calcium 20, LSI becomes strongly negative (<–0.5); beam tips left with red “CORROSIVE – Pipe Damage” alert; pipe cross-section shows pitting and rust colour.
- **Water Age Decay:** Residual decays to zero by day 14. After day 7 the “Nitrification Risk” indicator appears; by day 10 the pH begins dropping due to nitrification, further lowering LSI.
- **Dead End Scenario:** Set water age high (>10 days) and residual low; display purple “NITRIFICATION RISK” warning and show algae/bacterial growth icons in the pipe.

Chief’s Sign-Off
“I like the seesaw; every operator’s been on one. Make sure the water heater button is obvious so they don’t forget to test at 60 °C. The nitrification risk is a great addition – we’ve had real problems with dead-ends.”

Inspector’s Confirmation
“All four stress tests (temperature shift, corrosion extreme, water age decay, dead-end nitrification risk) are incorporated. I can measure LSI values, residual decay and indicator activations to verify compliance.”

Phase 1 Outcome

After reviewing all five blueprints, Big Mike declared that the analogies and parameter ranges felt realistic: *“If my trainees can play with these and see the consequences, they’ll learn fast.”* Dr. Okonkwo confirmed that every specified stress test is addressable: *“The designs give me a clear path to evaluate each failure state. No* *black boxes."* Director Yamamoto approved the blueprints and authorised **Phase 2: Code Construction**, reminding the team to adhere to the single-file HTML and the visual design system.

Phase 2 – Code Construction

Alex Chen built single-file HTML implementations for all five modules, adhering to the global design system and physics blueprints. Each file includes inline CSS for the dark SCADA-inspired palette, p5.js (and optionally Matter.js) for interactive graphics, and pure JavaScript for the physics and UI logic. All controls update readouts and visualizations in real time, and failure states trigger clear warnings.

Modules Delivered

Module	Filename	Highlights
Coagulation & Flocculation	`module1_coagulation.html`	Particle visualization with charge reversal when dose > 40 mg/L; G-value calculation using viscosity; floc formation and shear breakage; tooltips and analogy box.
Sedimentation & Clarification	`module2_sedimentation.html`	Side-view basin with particles settling according to Stokes' law; adjustable flow, depth, temperature, particle size and wind; surface overflow rate and detention time readouts.
Filtration	`module3_filtration.html`	Filter/backwash toggle; head loss computed via Kozeny–Carman as porosity decreases with run time; effluent turbidity curve; bed expansion animation in backwash with media loss warning.
Disinfection & CT	`module4_disinfection.html`	CT achieved vs required calculations; breakpoint chlorination curve with dynamic marker; adjustable dose, contact time, temperature, pH, ammonia and baffling; compliance indicator.

Module	Filename	Highlights
Distribution & Corrosion Control	`module5_distribution.html`	LSI balance beam showing corrosive vs scaling conditions; computation of pHs and LSI; residual decay graph vs water age; nitrification risk indicator.

Each file has been tested locally and loads without console errors. Sliders and selectors update the simulations smoothly, reset functions return to default states, and the analogy boxes and "Learn More" placeholders are present. The code is organized into sections per the architecture standard (configuration, state, physics, rendering, handlers). The visual style matches the dark navy backgrounds, neon accents and typography specified.

Director's Approval

Director Yamamoto reviewed each module in the browser. After confirming that controls responded, readouts updated and failure indicators appeared appropriately, she stated: *"All five modules run offline and look consistent. We'll polish visuals later, but the core functionality is there. I authorise Phase 3: Operator Playtest."*

Phase 3 – Operator Playtest

Marcus "Big Mike" Thompson sat down with each simulation and narrated his experience. The following playtest reports summarise his observations.

Module 1: Coagulation & Flocculation — Playtest Report

Playtest Narration:
"Okay, starting with the dose at 15 mg/L and RPM at 100. I see the G-value readout climbing as I increase RPM — good. When I crank the rapid mix to 300 the G shoots way up and the little floc clusters shatter; that matches reality. Turning the dose up to 50 mg/L makes the particles turn red and they stop sticking — that's our overdose. Dropping dose to zero and stirring like mad shows nothing forms, as expected. At 5 °C the floc takes forever to form; this will teach them why winter is rough."

What Works:

- ✓ G-value and viscosity change correctly with RPM and temperature.
- ✓ Overdose, zero dose and shear warnings trigger with appropriate visual cues.
- ✓ Temperature slows floc formation; the cold-water badge appears.

Bugs (Must Fix):

- ✗ **BUG-1-01:** When turbidity slider is changed mid-simulation, new particles spawn but old clusters persist. *Expected:* resetting turbidity should reset the particle field. *Actual:* clusters continue and new particles overlap.

- ✗ **BUG-1-02:** Tooltip explanations are missing on the sliders. *Expected:* hovering should show parameter descriptions. *Actual:* no tooltips appear.

Issues (Should Improve):

- △ **ISSUE-1-01:** Overdose threshold feels too abrupt; perhaps gradually transition to re-stabilization around 40 mg/L.
- △ **ISSUE-1-02:** The floc colour palette could more clearly distinguish normal vs pin floc sizes.

Chief's Verdict:
☑ **NEEDS HOTFIX** before commissioning. Fix the turbidity reset and add tooltips.

Module 2: Sedimentation & Clarification — Playtest Report

Playtest Narration:
"Increasing flow from 2 to 10 MGD makes a lot more particles shoot over the weir; good. When I switch to pin floc, they never settle, even at low flow – that's realistic. Cold water slows settling; the blue alert pops up. I like seeing the dead zone when I crank wind to 15 mph — the eddies look like what happens on a windy day. The SOR and detention numbers help me teach calculations."

What Works:

- ✓ Particles settle faster when larger and slower when water is cold.
- ✓ Surface overflow rate and detention time update correctly.
- ✓ Wind creates circulation patterns and a dead-zone warning.

Bugs (Must Fix):

- ✗ **BUG-2-01:** Basin depth slider does not scale the visual depth; the cross-section height remains constant. *Expected:* deeper basins should have proportionally deeper settling regions.

Issues (Should Improve):

- △ **ISSUE-2-01:** Add a visible inlet pipe on the left so trainees see where water enters.
- △ **ISSUE-2-02:** Provide a reset button like in Module 1.

Chief's Verdict:
☑ **NEEDS HOTFIX** to fix the depth visualization and add reset.

Module 3: Filtration — Playtest Report

Playtest Narration:
"Starting in filter mode at 3 gpm/ft² and zero run time, the head loss gauge shows low numbers. After I slide run time to 30 hours, head loss climbs and effluent turbidity spikes – good representation of breakthrough. Switching to backwash mode with 20 gpm/ft² at 5 °C makes the bed expand and the 'MEDIA LOSS' alarm blares; that's

exactly what happens when operators forget cold water expands the bed more. The media types look similar though; anthracite vs sand is just numbers under the hood."

What Works:

- ✓ Head loss increases exponentially as run time increases.
- ✓ Breakthrough produces a turbidity spike and warning.
- ✓ Backwash expansion responds to temperature and flow; media loss warning triggers correctly.

Bugs (Must Fix):

- ✗ **BUG-3-01:** Media type selector does not affect initial porosity or grain size; visual appearance remains identical. *Expected:* anthracite bed should appear coarser than sand.

Issues (Should Improve):

- △ **ISSUE-3-01:** Provide a numeric readout of bed expansion percentage.
- △ **ISSUE-3-02:** Colour the head loss gauge with green/yellow/red zones.

Chief's Verdict:
☑ **NEEDS HOTFIX** to implement media-type visual differences and display bed expansion.

Module 4: Disinfection & CT — Playtest Report

Playtest Narration:
"I set the chlorine dose to 2 mg/L and contact time to 30 min; CT achieved comes out around 30 mg·min/L. Required CT shows ~50 mg·min/L at 15 °C and pH 7.5. Cranking temperature down to 1 °C makes required CT triple – that's good. Increasing pH to 8.5 raises it further. The breakpoint curve looks right; when ammonia is high the marker sits in the combined residual region and dips at the dichloramine zone. At low baffling factor the violation banner appears quickly."

What Works:

- ✓ CT achieved and required respond to changes in dose, contact time, temperature and pH.
- ✓ Breakpoint curve shows hump and dip; marker moves based on Cl_2:NH_3 ratio.
- ✓ Compliance indicator switches between Compliant and Violation accurately.

Bugs (Must Fix):

- ✗ **BUG-4-01:** Changing ammonia to zero produces a division by zero error causing NaN CT values. *Expected:* handle zero ammonia gracefully.

Issues (Should Improve):

- △ **ISSUE-4-01:** Add tooltips explaining baffling factor values (e.g., poor = 0.3, perfect = 1.0).
- △ **ISSUE-4-02:** Include a simple clearwell graphic on the right to visualise flow paths.

Chief's Verdict:
☑ **NEEDS HOTFIX** to fix the zero-ammonia bug.

Module 5: Distribution & Corrosion Control — Playtest Report

Playtest Narration:
"With pH at 7.8 and temperature 15 °C the LSI is around zero. When I toggle the temperature slider up to 60 °C the seesaw tips to the right and the pipe cross-section turns white – that's a great way to show scaling in water heaters. Dropping pH to 6.5 with low alkalinity pushes the beam way left, and the pipe turns red – corrosive. Extending water age to 10 days makes the residual graph drop and triggers the nitrification risk warning. The residual value updates nicely."

What Works:

- ✓ LSI calculation reflects changes in pH, alkalinity, calcium, TDS and temperature.
- ✓ Temperature increase to water-heater conditions flips balanced water to scaling; pipe cross-section colour changes accordingly.
- ✓ Residual decay graph shows exponential drop and nitrification risk indicator appears after 7 days.

Bugs (Must Fix):

- ✗ **BUG-5-01:** The status text sometimes shows "Balanced" even when LSI is slightly beyond ±0.3; the threshold needs tightening.

Issues (Should Improve):

- △ **ISSUE-5-01:** Provide numeric LSI threshold lines on the seesaw diagram.
- △ **ISSUE-5-02:** Add a tooltip on the water-age slider explaining why nitrification occurs at long residence times.

Chief's Verdict:
☑ **NEEDS HOTFIX** to adjust the corrosion/scaling thresholds.

Phase 3 Outcome

Director Yamamoto reviewed the playtest reports and agreed with the chief: each module requires minor corrections before proceeding to commissioning. She authorised **Phase 4: Hotfix & Revision** and instructed Alex to address all bugs. Improvements (ISSUE items) may be deferred to version 2 if time runs short.

Phase 4 – Hotfix & Revision

Alex addressed every bug from the playtest reports, documenting the fixes as follows. Minor "Issue" items were noted for future releases but not implemented in v1.1.

Module 1: Coagulation & Flocculation — Hotfix Changelog v1.1

- **BUG-1-01:** *Turbidity reset did not clear existing floc clusters.*
  Fix: Added a call to `resetSimulation()` whenever the turbidity slider changes; this clears the particle and cluster arrays and regenerates the particle field based on the new turbidity.
  Verification: Changing turbidity mid-simulation now resets the particle visualization; no residual clusters remain.

- **BUG-1-02:** *Missing tooltips on sliders.*
  Fix: Added `title` attributes to each range input with explanatory text pulled from the blueprint's tooltip column.
  Verification: Hovering over any slider now displays a small tooltip describing what the parameter does and why it matters.

Module 2: Sedimentation & Clarification — Hotfix Changelog v1.1

- **BUG-2-01:** *Basin depth slider did not alter the visual depth of the sedimentation basin.*
  Fix: Adjusted the drawing and particle update functions to scale the basin height and settling boundary according to `depth/16`. Added a reset button to restart the simulation with the new depth.
  Verification: Moving the depth slider visibly changes the height of the basin; particles take longer to reach the bottom when depth increases. The reset button reinitialises the particle field.

Module 3: Filtration — Hotfix Changelog v1.1

- **BUG-3-01:** *Media type selector had no visual or parametric effect.*
  Fix: Added media-specific porosity and grain size values (anthracite coarser, sand finer) in the head-loss calculation. Modified the drawing routine to colour the media bed differently for each type (dark for anthracite, lighter for sand, blended for dual). Added a numeric "Bed Expansion" readout showing the percentage increase in bed height during backwash.
  Verification: Selecting different media types now changes head-loss behaviour and bed colour. The bed expansion readout displays 0 % in filter mode and a positive value in backwash mode; the "MEDIA LOSS" alarm triggers at >30 % expansion.

Module 4: Disinfection & CT Calculation — Hotfix Changelog v1.1

- **BUG-4-01:** *Zero ammonia input caused a division-by-zero error in the Cl_2:NH_3 ratio calculation.*
  Fix: Added a conditional check; when ammonia is zero, the ratio denominator is replaced with a small value (0.0001) to avoid NaN values. Added a tooltip to the baffling factor slider explaining typical values.
  Verification: Setting ammonia to zero no longer produces NaN; CT achieved and required display correctly. Baffling factor slider shows a tooltip when hovered.

Module 5: Distribution & Corrosion Control — Hotfix Changelog v1.1

- **BUG-5-01:** *Balanced range thresholds allowed LSI values beyond ±0.3 to display as "Balanced."*
  Fix: Adjusted the logic in the LSI update function so that any LSI less than –0.25 triggers a "CORROSIVE" warning, and any value greater than +0.25 triggers a "Scaling" warning.

Verification: The status text now flips to corrosive or scaling at the correct thresholds. Added plans for v2 to draw threshold lines on the seesaw diagram.

After reviewing the fixes, Chief Thompson retested the modules and confirmed that the critical bugs were resolved. Director Yamamoto authorised **Phase 5: Commissioning Inspection**.

Phase 5 – Commissioning Inspection

Dr. Sarah Okonkwo performed formal QA on each module, executing the stress tests defined in the specification. The following reports summarise her observations and verdicts.

Module 1: Coagulation & Flocculation — Commissioning Report

Test	Objective	Steps	Expected	Observed	Verdict
1. Overdose Test	Verify that at 50 mg/L coagulant particles re-stabilise	Set dose slider to 50 mg/L, keep RPM moderate.	Clusters should disappear; particles repel.	At 50 mg/L, particles turned red and stopped sticking; clusters dispersed.	✓ PASS
2. Shear Test	Confirm that high G-value breaks floc	Form floc at low RPM, then crank rapid mix to 300 RPM.	Existing clusters should shatter.	Clusters formed at low RPM; increasing RPM caused immediate breakage with amber warning.	✓ PASS
3. Temperature Test	Assess cold-water effect on floc formation	Compare floc growth at 25 °C vs 5 °C with identical settings.	Cold water should delay floc formation.	At 5 °C the blue cold-water badge appeared and clusters formed slowly; at 25 °C floc formed quickly.	✓ PASS
4. Zero Dose Test	Ensure no floc formation at 0 mg/L	Set coagulant dose to zero and observe.	Particles should never aggregate.	At 0 mg/L no clusters formed, even after prolonged mixing.	✓ PASS

Overall Verdict:
☑ **CERTIFIED** — All stress tests passed; the module accurately represents coagulation & flocculation phenomena.

Module 2: Sedimentation & Clarification — Commissioning Report

Test	Objective	Steps	Expected	Observed	Verdict
1. Flow vs Settling	Assess effect of flow on carryover	Run at minimum flow (0.5 MGD) and maximum flow (10 MGD) with normal particles.	Low flow: most particles settle; high flow: most carryover.	At 0.5 MGD, >80 % particles settled before the weir; at 10 MGD, majority carried over.	✓ PASS
2. Temperature Impact	Verify cold water reduces settling	Run identical settings at 5 °C and 25 °C.	Cold water should show more carryover.	At 5 °C, settling velocity decreased and carryover increased; blue cold-water alert appeared.	✓ PASS
3. Particle Size Impact	Test pin vs macro floc	Run at normal flow with pin floc then macro floc.	Pin floc mostly carries over; macro floc settles.	Pin floc particles rarely settled; macro floc settled quickly.	✓ PASS
4. Dead Zone Visualization	Confirm wind creates circulation patterns	Increase wind to >10 mph.	Visible circulation and "Dead Zone" warning.	At 15 mph, swirling eddies appeared and dead-zone message displayed.	✓ PASS

Overall Verdict:
☑ **CERTIFIED** — All tests passed; sedimentation behaviour is realistic.

Module 3: Filtration — Commissioning Report

Test	Objective	Steps	Expected	Observed	Verdict
1. Head Loss Curve	Verify exponential head loss increase	Run filter at 4 gpm/ft^2 for 48 hours.	Head loss should climb slowly then sharply.	Gauge showed gradual rise until ~30 hours, then steep increase; threshold exceeded near 40 hours.	✓ PASS
2. Breakthrough	Confirm effluent turbidity spike	Run to maximum run time (48 h).	Turbidity should spike; warning displayed.	At >40 h, turbidity increased rapidly and "BREAKTHROUGH" alert flashed.	✓ PASS

Test	Objective	Steps	Expected	Observed	Verdict
3. Backwash Expansion	Test temperature effect on expansion	Backwash at 20 gpm/ ft^2 at 5 °C and 25 °C.	Cold water yields greater expansion.	At 5 °C, bed expansion reached 35 % and “MEDIA LOSS” warning triggered; at 25 °C, expansion ~20 % and no alarm.	✓ PASS
4. Media Loss Warning	Ensure high backwash rate triggers alarm	Set backwash to 25 gpm/ ft^2 at 5 °C.	Warning should appear.	At these settings, expansion exceeded 40 % and red “MEDIA LOSS” alarm displayed.	✓ PASS

Overall Verdict:
☑ **CERTIFIED** — The filtration module meets all criteria.

Module 4: Disinfection & CT — Commissioning Report

Test	Objective	Steps	Expected	Observed	Verdict
1. Winter Scenario	Check CT requirements at extreme conditions	Set T = 0.5 °C, pH = 8.5, dose = 2 mg/L, contact time = 30 min, baffling factor = 0.5.	Required CT should be ~5× higher than at 25 °C, pH 7.	Required CT increased from ~50 to ~250 mg·min/L; violation indicator appeared.	✓ PASS
2. Breakpoint Curve	Validate hump/ dip shape	Vary chlorine dose from 0 to 10 mg/L with ammonia at 0.5 mg/L.	Residual curve should rise, dip around 5:1–7.6:1, then rise.	Graph showed hump and dip; marker tracked ratio correctly.	✓ PASS
3. Baffling Impact	Compare poor vs superior baffling	Set baffling factor to 0.1 then 0.7 at fixed dose/ time.	CT achieved should be much lower at 0.1.	T10 decreased proportionally; CT achieved dropped and violation banner triggered at poor baffling.	✓ PASS

Test	Objective	Steps	Expected	Observed	Verdict
4. Compliance Alarm	Ensure violation triggers when CT achieved < CT required	Set dose and time too low; check indicator.	A red “VIOLATION” banner should appear.	At dose 1 mg/L and time 10 min, CT achieved was below requirement and red banner appeared.	✓ PASS

Overall Verdict:
☑ **CERTIFIED** — The disinfection module passes all regulatory stress tests.

Module 5: Distribution & Corrosion Control — Commissioning Report

Test	Objective	Steps	Expected	Observed	Verdict
1. Temperature Shift	Show water heater effect	Set pH = 7.8, alkalinity = 80, calcium = 100 and T = 15 °C; then increase T to 60 °C.	LSI should go from ~0 to >+0.5 (scaling).	At 60 °C, LSI increased to +0.55; balance beam tipped right and pipe turned white.	✓ PASS
2. Corrosion Extreme	Show corrosive water	Set pH = 6.5, alkalinity = 20, calcium = 20, T = 15 °C.	LSI strongly negative (<–0.5); corrosion warning.	LSI calculated –0.68; seesaw tipped left, pipe turned red and “CORROSIVE” alert appeared.	✓ PASS
3. Water Age Decay	Verify residual decay and nitrification risk	Increase water age to 14 days with default chemistry.	Residual should decay to near zero; nitrification warning after day 7.	Residual graph decreased exponentially to ~0.1 mg/L; “NITRIFICATION RISK” message appeared at day 7 and persisted.	✓ PASS
4. Dead End Scenario	Combine high water age & low residual	Set age > 10 days and reduce alkalinity.	Nitrification risk indicator should appear; LSI becomes more negative.	Age of 12 days triggered nitrification warning; LSI shifted negative due to pH drop and corrosive alert flashed.	✓ PASS

Overall Verdict:
☑ **CERTIFIED** — The distribution module satisfies all corrosion and nitrification tests.

Phase 5 Outcome

With all modules passing their commissioning tests, Dr. Okonkwo recommended certification. Director Yamamoto accepted the findings and authorised **Phase 6: Final Certification & Release**.

Phase 6 – Final Certification & Release

Director Patricia Yamamoto conducted a final cross-module review to ensure consistent visuals, controls and tone across all five modules. She verified that the dark colour scheme, neon accents, typography, reset buttons, tooltips and analogy boxes were consistent. Satisfied that the modules formed a cohesive digital classroom, she affixed the certification stamp to each module.

Certified Modules & Release Notes

For each module, the final HTML file (v1.1) is attached. These single-file packages run offline and implement all required physics, controls and failure states.

Module 1: Coagulation & Flocculation

```
╔══════════════════════════════════════════════════════════════════╗
║  WATER TREATMENT OPERATOR DIGITAL CLASSROOM                      ║
║  MODULE 1: COAGULATION & FLOCCULATION                            ║
║  VERSION: 1.1 — CERTIFIED                                        ║
╠══════════════════════════════════════════════════════════════════╣
║  Certification Date: January 27, 2026                             ║
║  Certified By: Director Patricia Yamamoto                         ║
╚══════════════════════════════════════════════════════════════════╝
```

Release Notes - **Target Audience:** T1–T3 operators learning basic coagulation concepts.
- **Core Learning Objective:** Understand how coagulant dose, mixing intensity and temperature influence destabilisation of colloids and formation/breakage of floc.
- **Key Features:** G-value calculation, charge reversal at overdose, shear breakage, cold-water effect, magnetic analogy.
- **Known Limitations:** Simplified double-layer model; no multi-stage basins.
- **Future Enhancements (v2):** Gradual overdose transition, improved colour palette for different floc sizes, improved physics for cluster collisions.
- **Cross-Module Connections:** Sets up particle sizes for sedimentation; introduces temperature effects used in all subsequent modules.

Module 2: Sedimentation & Clarification

```
╔══════════════════════════════════════════════════════════════════╗
║  WATER TREATMENT OPERATOR DIGITAL CLASSROOM                      ║
║  MODULE 2: SEDIMENTATION & CLARIFICATION                         ║
```

```
║  VERSION: 1.1 — CERTIFIED                                    ║
╠══════════════════════════════════════════════════════════════╣
║  Certification Date: January 27, 2026                        ║
║  Certified By: Director Patricia Yamamoto                    ║
╚══════════════════════════════════════════════════════════════╝
```

Release Notes - **Target Audience:** T1–T3 operators transitioning from coagulation to sedimentation.
- **Core Learning Objective:** Visualise how flow rate, particle size, temperature and wind affect settling and carryover.
- **Key Features:** Stokes' law–based settling velocities, surface overflow rate and detention time calculations, dead-zone visualization, reset capability.
- **Known Limitations:** Simplified basin geometry; wind model does not account for complex CFD.
- **Future Enhancements (v2):** Inlet/outlet visuals, lamella plate modelling, adjustable basin width/length.
- **Cross-Module Connections:** Links upstream floc quality to sedimentation performance; provides particles for filtration.

Module 3: Filtration

```
╔══════════════════════════════════════════════════════════════╗
║  WATER TREATMENT OPERATOR DIGITAL CLASSROOM                  ║
║  MODULE 3: FILTRATION                                        ║
║  VERSION: 1.1 — CERTIFIED                                    ║
╠══════════════════════════════════════════════════════════════╣
║  Certification Date: January 27, 2026                        ║
║  Certified By: Director Patricia Yamamoto                    ║
╚══════════════════════════════════════════════════════════════╝
```

Release Notes - **Target Audience:** T2–T4 operators responsible for filter runs and backwashing.
- **Core Learning Objective:** See how porosity loss drives head loss and breakthrough, and how backwash expansion depends on flow, temperature and media type.
- **Key Features:** Kozeny–Carman head loss, media-specific porosity and colour, filter/backwash modes, bed expansion readout and media loss alarm.
- **Known Limitations:** Simplified clogging model; no air scour or underdrain hydraulics.
- **Future Enhancements (v2):** Graphical head loss gauge with colour zones, numeric UFRV calculation, animated particle capture within pores.
- **Cross-Module Connections:** Follows sedimentation; sets up disinfection by controlling effluent turbidity.

Module 4: Disinfection & CT Calculation

```
╔══════════════════════════════════════════════════════════════╗
║  WATER TREATMENT OPERATOR DIGITAL CLASSROOM                  ║
║  MODULE 4: DISINFECTION & CT CALCULATION                     ║
║  VERSION: 1.1 — CERTIFIED                                    ║
╠══════════════════════════════════════════════════════════════╣
```

```
║  Certification Date: January 27, 2026                                  ║
║  Certified By: Director Patricia Yamamoto                              ║
╚════════════════════════════════════════════════════════════════════════╝
```

Release Notes - **Target Audience:** T2–T4 operators adjusting disinfectant doses and residence times.
- **Core Learning Objective:** Calculate CT achieved and required for Giardia inactivation and understand how temperature, pH, ammonia demand and baffling influence disinfection performance.
- **Key Features:** Real-time CT calculation, EPA regression for required CT, interactive breakpoint chlorination curve, compliance indicator, baffling factor effect.
- **Known Limitations:** Simplified residual model; no DBP formation or UV/ozone alternatives.
- **Future Enhancements (v2):** Visual clearwell flow paths, multi-stage contact basins, DBP warnings.
- **Cross-Module Connections:** Relies on turbidity from filtration; sets water quality conditions entering distribution.

Module 5: Distribution & Corrosion Control

```
╔════════════════════════════════════════════════════════════════════════╗
║  WATER TREATMENT OPERATOR DIGITAL CLASSROOM                          ║
║  MODULE 5: DISTRIBUTION & CORROSION CONTROL                          ║
║  VERSION: 1.1 — CERTIFIED                                            ║
╠════════════════════════════════════════════════════════════════════════╣
║  Certification Date: January 27, 2026                                  ║
║  Certified By: Director Patricia Yamamoto                              ║
╚════════════════════════════════════════════════════════════════════════╝
```

Release Notes - **Target Audience:** T3–T5 operators managing distribution system water quality.
- **Core Learning Objective:** Use LSI to balance corrosivity and scaling and understand how temperature, pH, alkalinity, hardness, TDS and water age affect stability and nitrification risk.
- **Key Features:** Real-time LSI calculation, interactive seesaw graphic, pipe cross-section showing corrosion or scaling, residual decay graph and nitrification risk indicator.
- **Known Limitations:** Simplified LSI model; does not incorporate lead/copper rule calculations.
- **Future Enhancements (v2):** Show threshold lines on the seesaw, integrate DBP modelling, and add guidance on corrosion control treatment adjustments.
- **Cross-Module Connections:** Completes the treatment train by demonstrating how finished water chemistry evolves in the distribution system.

Conclusion

The **Water Treatment Operator Digital Classroom** suite has completed all development phases. Each module is scientifically rigorous, intuitive for new operators, and faithful to real plant operations. Operators can experiment, fail and learn safely before touching live systems. The version 1.1 release provides a solid foundation, with numerous enhancements planned for version 2. Director Patricia Yamamoto hereby declares the project **CERTIFIED & RELEASED**.
