AquaFarm

Aquaculture and Aquatics Simulation Software

for Facility Design and Management Planning

Douglas H. Ernst, Ph.D. · AquaFarm Software LLC

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Software use – What AquaFarm does

- AquaFarm is simulation software for aquatic and aquaculture systems and facilities.
- AquaFarm is used to specify, simulate, evaluate, and develop aquaculture systems and facilities.
- AquaFarm can be used for aquaculture feasibility studies, facility design, management planning, research, and education.



Software description – How AquaFarm works

- AquaFarm is built on the knowledge base and quantitative methods of aquatic and aquaculture sciences and engineering.
- AquaFarm uses computer modeling and simulation to test and analyze user-specified aquaculture systems and facilities.
- AquaFarm provides structured aquaculture expertise and intensive calculation processing.
- Facility simulation data are presented in data tables and graphs, management logs, facility resource budgets, and economic enterprise budgets.

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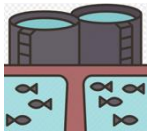
AquaFarm software use

- AquaFarm can be used for aquaculture feasibility studies, facility design, management planning, research, and education.



Aquatic animal and aquatic process modeling

- Calibrate and test models for aquatic animal metabolism, feeding, and growth.
- Simulate biomass support for single culture units (metabolic respirometry).
- Calibrate and test models for physical, chemical, and biological unit-processes.



Aquaculture facility design and management

Test and evaluate:

- Facility location, design specifications, and management strategies.
- Aquaculture production objectives, resource consumption, waste production and reuse, environmental impact, and permitting variables.
- Facility enterprise budget and economic performance.



Aquaculture education

- Use simulation of aquatic and aquaculture systems as a virtual laboratory.
- Perform experiments and observe performance of aquatic animals and systems.



Share and communicate aquaculture projects

- Collaborate and share projects with other AquaFarm users.
- Use working facility and system models to communicate specifications and performance for aquaculture processes, design, and management.

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AquaFarm

AquaFarm Application

Supported Systems, Species & Practices

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AquaFarm can be applied to a wide variety of aquaculture facility types and designs.

- Static aquaculture systems (SAS)
  Static water bodies contained in ponds and tanks. Includes solar-algae aquaculture ponds.

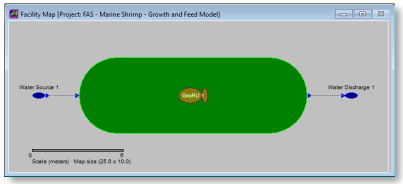
- Flow-through aquaculture systems (FAS)
  Flowing water systems, using single water use and serial reuse with optional water reuse treatment. Water recirculation is not used. Includes open-water net pens.

- Recirculating aquaculture systems (RAS)
  A specified portion of production water is treated and returned upstream, for multiple water passes through animal culture systems.

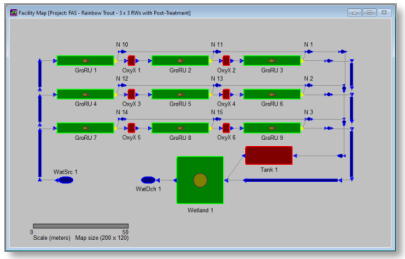
- Clear water systems and Biofloc water systems (brown and/or green water with microalgae).

- Integrated multitrophic aquaculture (IMTA)
  Multiple aquatic species (polyculture) and macroalgae or aquaponic plant production.

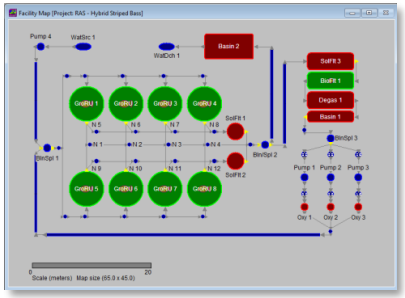
- Aquatic systems with no aquaculture, used for simulation testing of specified physical, chemical, and biological unit-process.



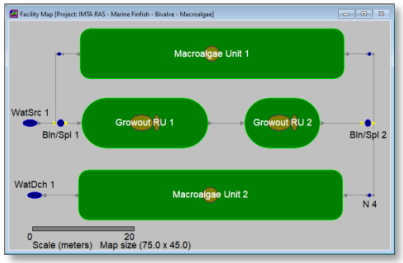
SAS



FAS



RAS



IMTA

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AquaFarm can be applied to a wide variety of aquatic animals and aquaculture practices.



Aquatic animals

- Finfish, crustaceans, mollusks, and other invertebrates
- Generically referred to in AquaFarm as “fish” and ”aquatic animals”

Aquatic animal life-stages

- Broodstock maturation and spawning
- Egg incubation (e.g. salmonids)
- Larval, nursery, and growout rearing



Aquatic animal biology

- Typical population attrition due to mortality and resulting survival rates
- Water quality criteria, environmental stress, and acute mortality
- Oxygen consumption and metabolite excretion rates
- Feeding rates over culture periods rates (natural and/or prepared feeds)
- Growth rates over culture periods (exponential, linear, & asymptotic growth stanzas)
- Development rates for broodstock maturation and egg incubation



Aquaculture management strategies and practices

- Extensive to intensive aquaculture production practices
- Low to high population and biomass density management
- Seasonal and continuous aquaculture production
- Use of transfers, splitting, and combining for aquaculture production lots
- Water flow rates and biomass support, as required by water quality criteria

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AquaFarm

AquaFarm Software

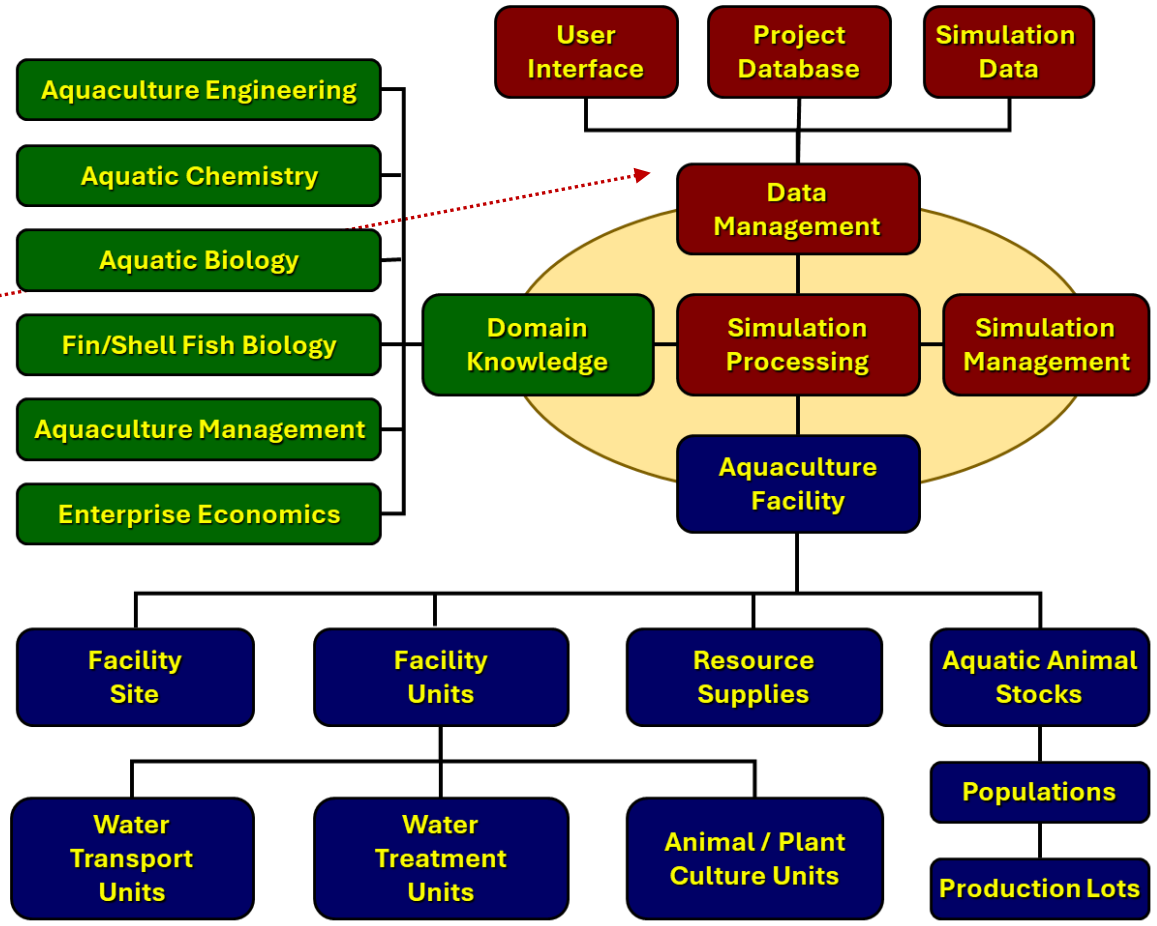
Architecture · Interface · Construction

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Software architecture

- AquaFarm software consists of three main components, each with multiple sub-components.
- This organization is also used for the AquaFarm User Interface and User Manual.

1. Methods of aquaculture science & engineering
2. Simulation and data management procedures
3. Physical and biological facility components



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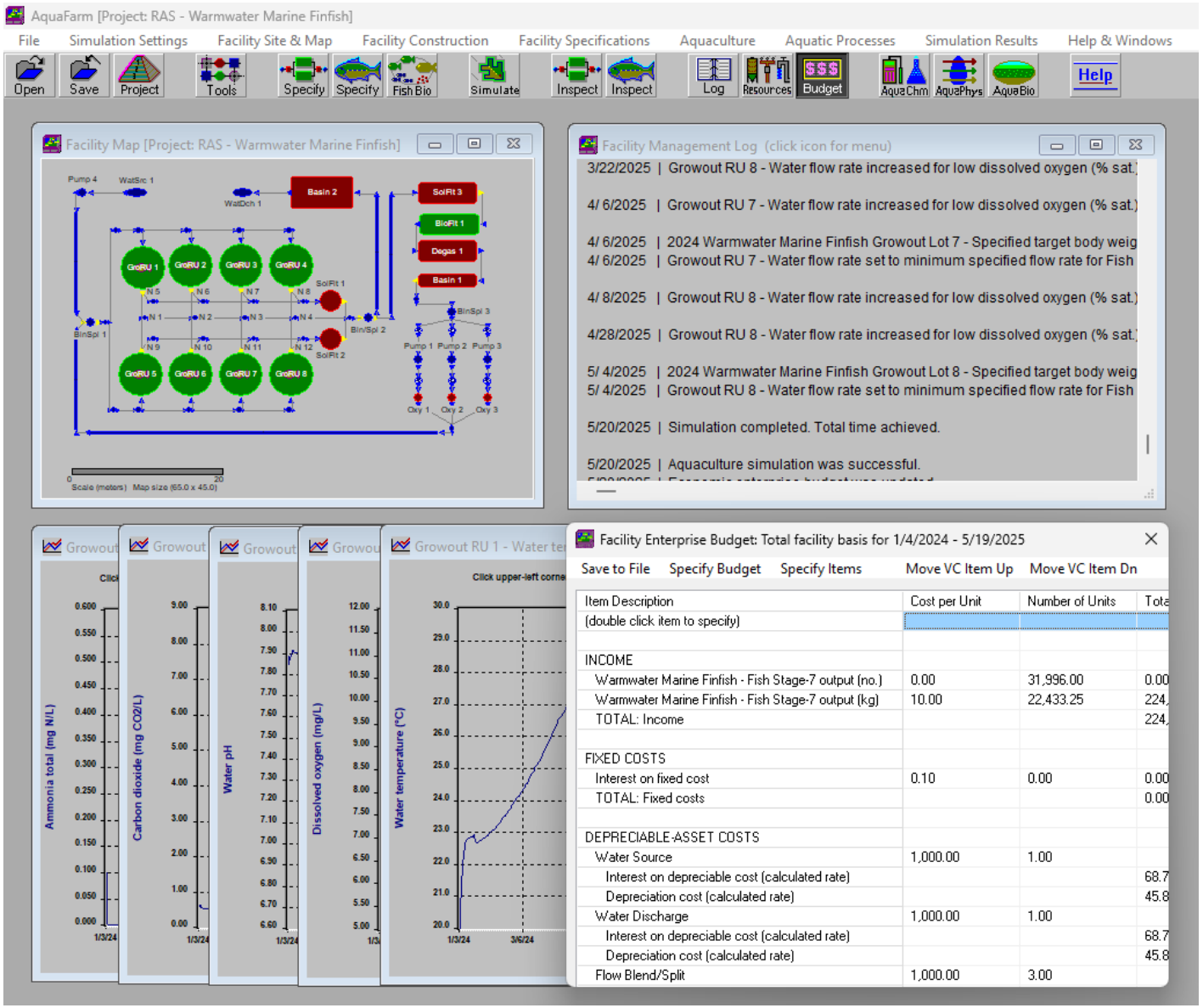
AquaFarm

Main menu

- File
- Simulation settings
- Facility Site & Map
- Facility Construction
- Facility Specifications
- Aquaculture
- Aquatic Processes
- Simulation Results
- Help & Windows

Example interface windows

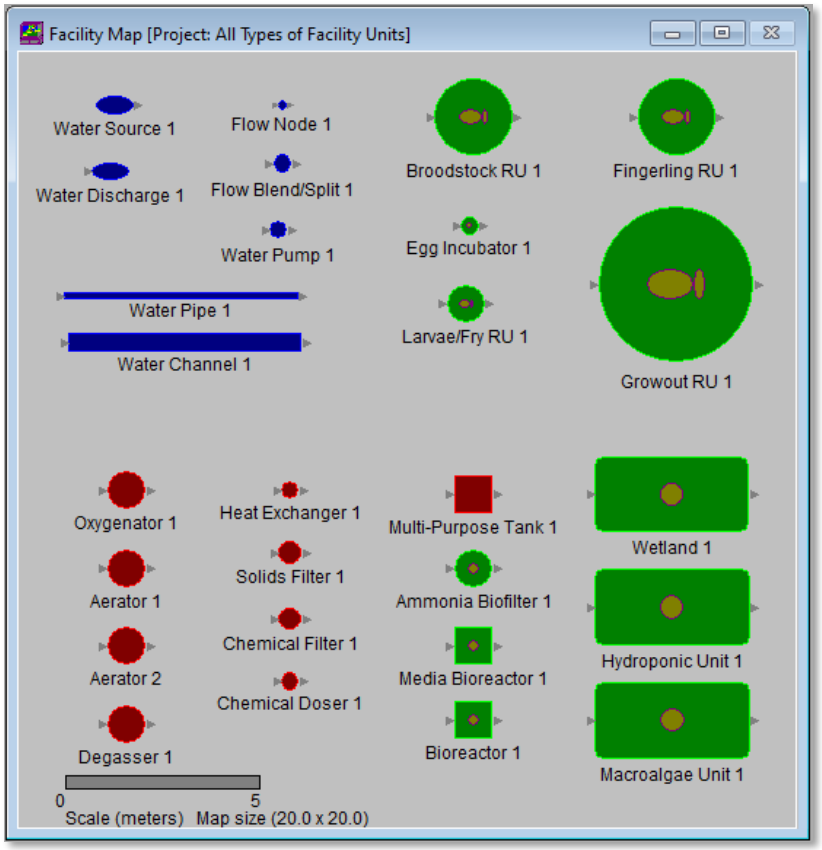
- Facility Map
- Management Log
- Simulation-generated data shown in tables and graphs
- Resource and economic budgets



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Facility Units

- Various types of Facility Units are installed and connected on the Facility Map to build aquatic and aquaculture systems.
- Facility Units are color coded on the Facility Map based on type. Blue for water transport. Red for physical & chemical processes. Green for aquatic animals & biological processes.



Types of Facility Units

Water Transport Units

- Water sources (facility influent water flow & quality)
- Water discharges (facility effluent water flow & quality)
- Water channels, pipes, & nodes (elbows, tees, crosses)
- Water flow blenders & splitters (specialized flow control)
- Water pumps (centrifugal and airlift)

Water Treatment Units

- Multi-purpose basins and tanks for water treatment
- Water heaters and chillers
- Gas exchangers and pure-oxygen contactors
- Chemical suppliers and filters
- Particulate solid filters
- Ammonia nitrification biofilters
- Nitrate denitrification biofilters
- Hydroponic plant production (aquaponics)
- Marine macroalgae production

Fish Rearing Units

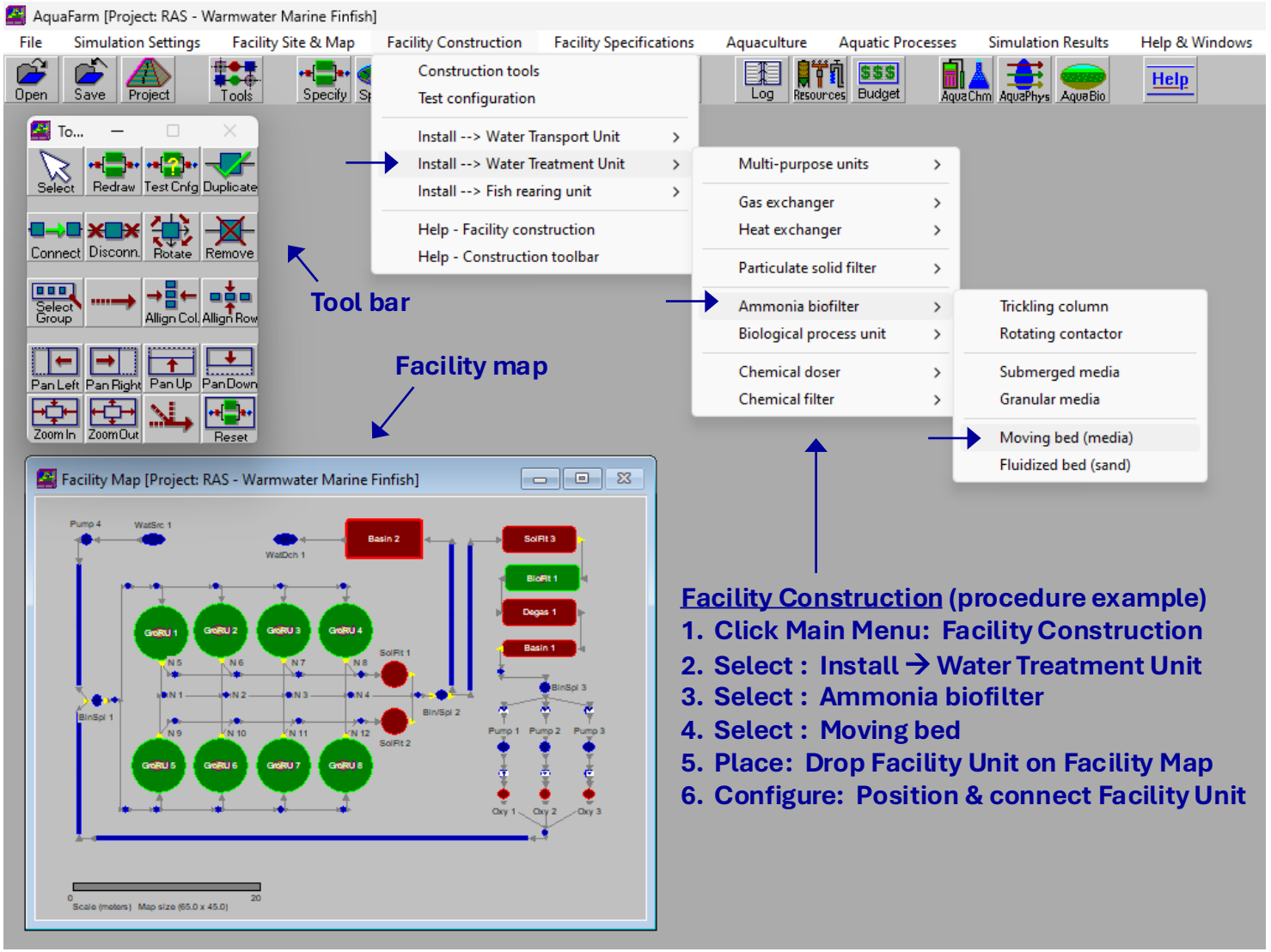
- Fish culture tanks and ponds
- Broodstock holding and maturation
- Egg incubation and hatching
- Larval, nursery, and growout rearing

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Facility Units are installed and connected on the Facility Map

AquaFarm interface screen

Example installation for ammonia biofilter



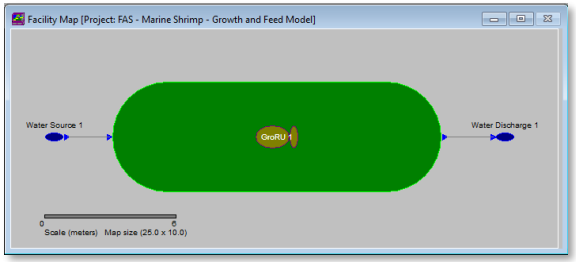
Facility Construction (procedure example)

1. **Click Main Menu: Facility Construction**
2. **Select : Install → Water Treatment Unit**
3. **Select : Ammonia biofilter**
4. **Select : Moving bed**
5. **Place: Drop Facility Unit on Facility Map**
6. **Configure: Position & connect Facility Unit**

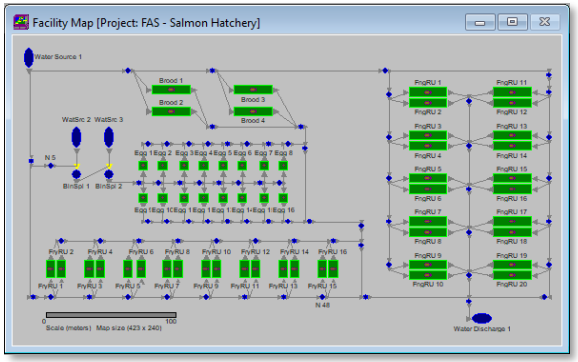
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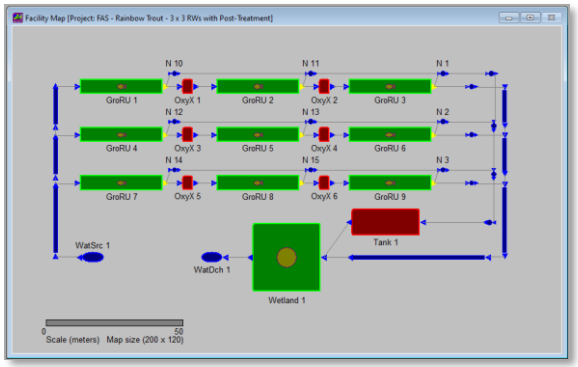
Marine Shrimp Growth & Feed Model



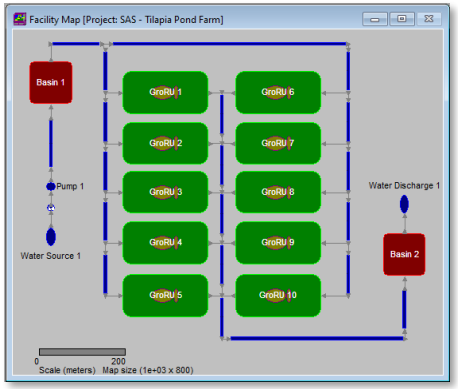
Salmon Hatchery



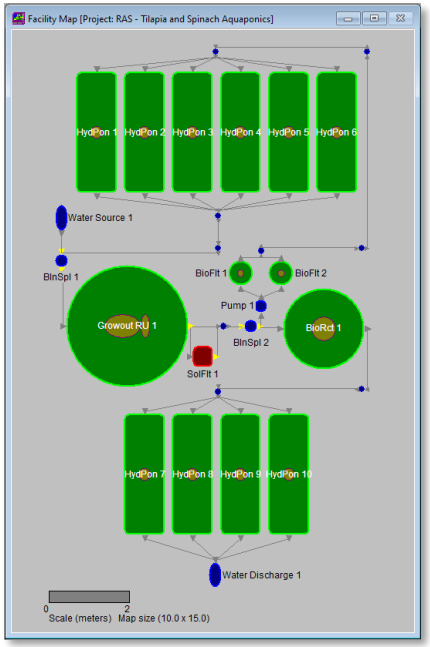
Rainbow Trout - 3 x 3 RWs



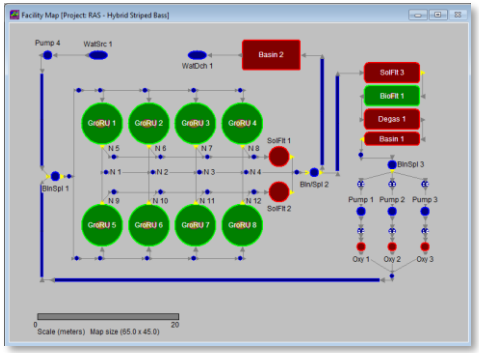
Tilapia Pond Farm



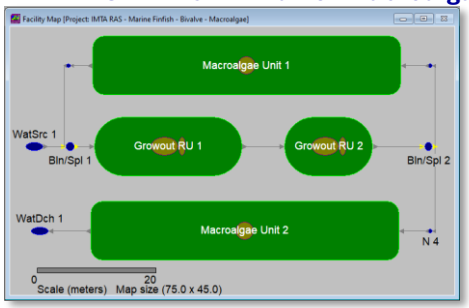
IMTA RAS - Tilapia & Spinach Aquaponics



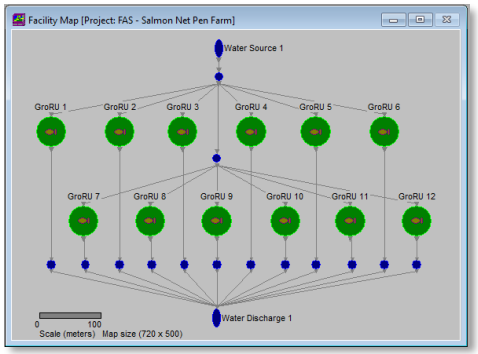
RAS - Warmwater Marine Finfish



IMTA RAS - Finfish - Bivalve - Macroalgae



Net Pen Salmon Farm



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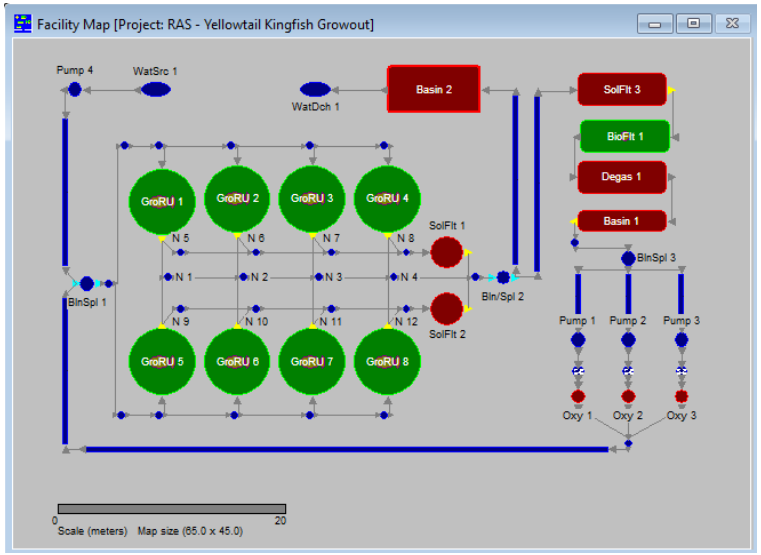
Facility site specifications

- Facility (1) location (latitude and elevation), (2) ambient climate, (3) housing and controlled climate (if used).

Facility system specifications

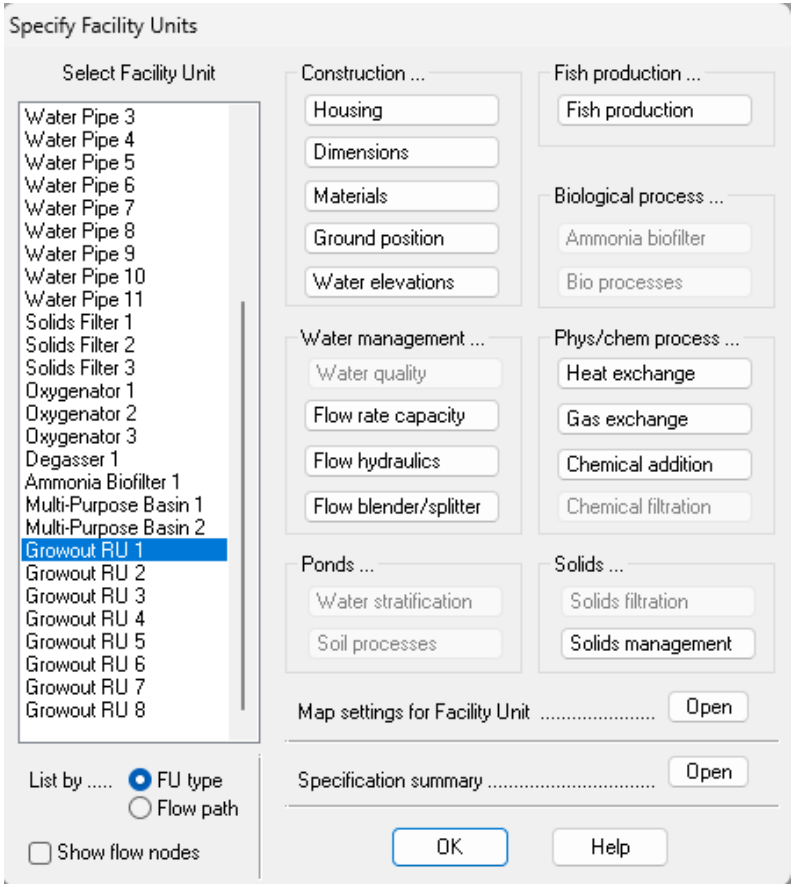
- Facility Units are listed and selected in left pane.
- Specification buttons in right pane are enabled based on type of selected Facility Unit.
- "Fish" is used as a generic term for aquatic animals.
- Specifications:
  - Facility source water capacity and quality.
  - Facility Unit housing, dimensions, materials, hydraulics, and aquatic processes.

Facility used for example interface screen



Example interface screen for Facility Unit specifications

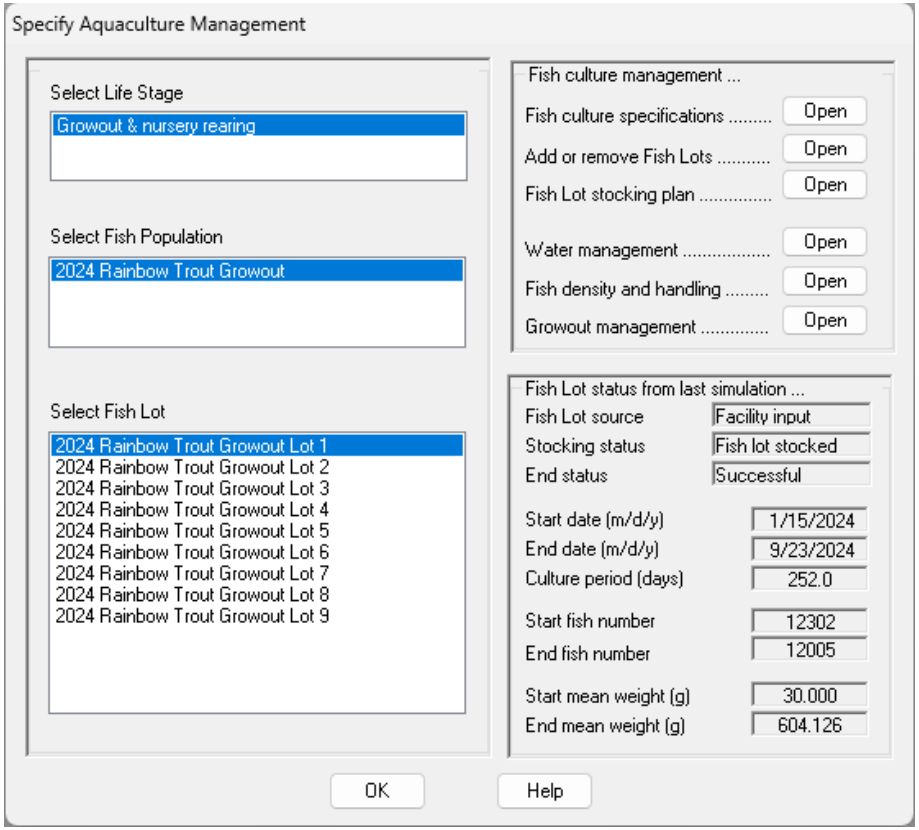
Facility Units are the building blocks for aquatic and aquaculture systems.



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Example interface screen for aquaculture specifications

- Aquatic animals are listed in left pane and organized by (1) life stage, (2) population (year class), and (3) production lot.
- Buttons in right pane are used to open specification screens.
- "Fish" is used as a generic term for aquatic animals.



Specify aquaculture objectives

- Stocking schedules (calendar dates)
- Target fish transfer or harvest schedules (calendar dates)
- Target fish population numbers
- Culture period lengths, or target ending fish development or body size (e.g. target growout mean body weight)
- Target aquaculture production per week, month, or year

Specify aquaculture management strategies and practices

- Seasonal or continuous aquaculture production
- Annual production cycles

- Extensive to intensive aquaculture production practices
- Stocking density criteria (fish number & biomass)
- Fish Lot handling: Lot transfers, dividing, and combining

- Number fish production lots per fish population year class
- Stocked and fallow periods for fish rearing units
- Cyclical use of fish rearing units. Time interval for stocking events (weekly, monthly, seasonally, annually).

- Fish rearing-unit water flow rates, biomass support, and water quality criteria (dissolved oxygen and metabolites).
- Additional management variables for life stages: (1) Broodstock maturation & spawning, (2) Egg incubation, (3) Larval rearing, nursery rearing, and growout

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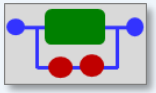
Aquaculture Facility Simulation

Simulation Models & Procedures

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Facility Simulation Model

Specifications for facility design, aquatic processes, and aquaculture management are combined to create facility ecosystem and simulation models.



System processes

- Facility climate and housing
- Facility Units linked by water flow
- Heat & mass transfer by water flow and unit processes



Aquatic chemistry

- Physical properties of water
- Dissolved gases (N2, O2, CO2)
- Acid-base water chemistry



Aquatic animal biology

- Oxygen consumption and metabolite excretion
- Feeding rates for natural and prepared feeds
- Growth rates over culture periods



Physical processes

- Water flow mechanics and budgets
- Passive and active heat transfer
- Water thermal stratification
- Passive and active gas transfer
- Particulate solid sedimentation and filtration
- Pond soil processes



Aquatic biology

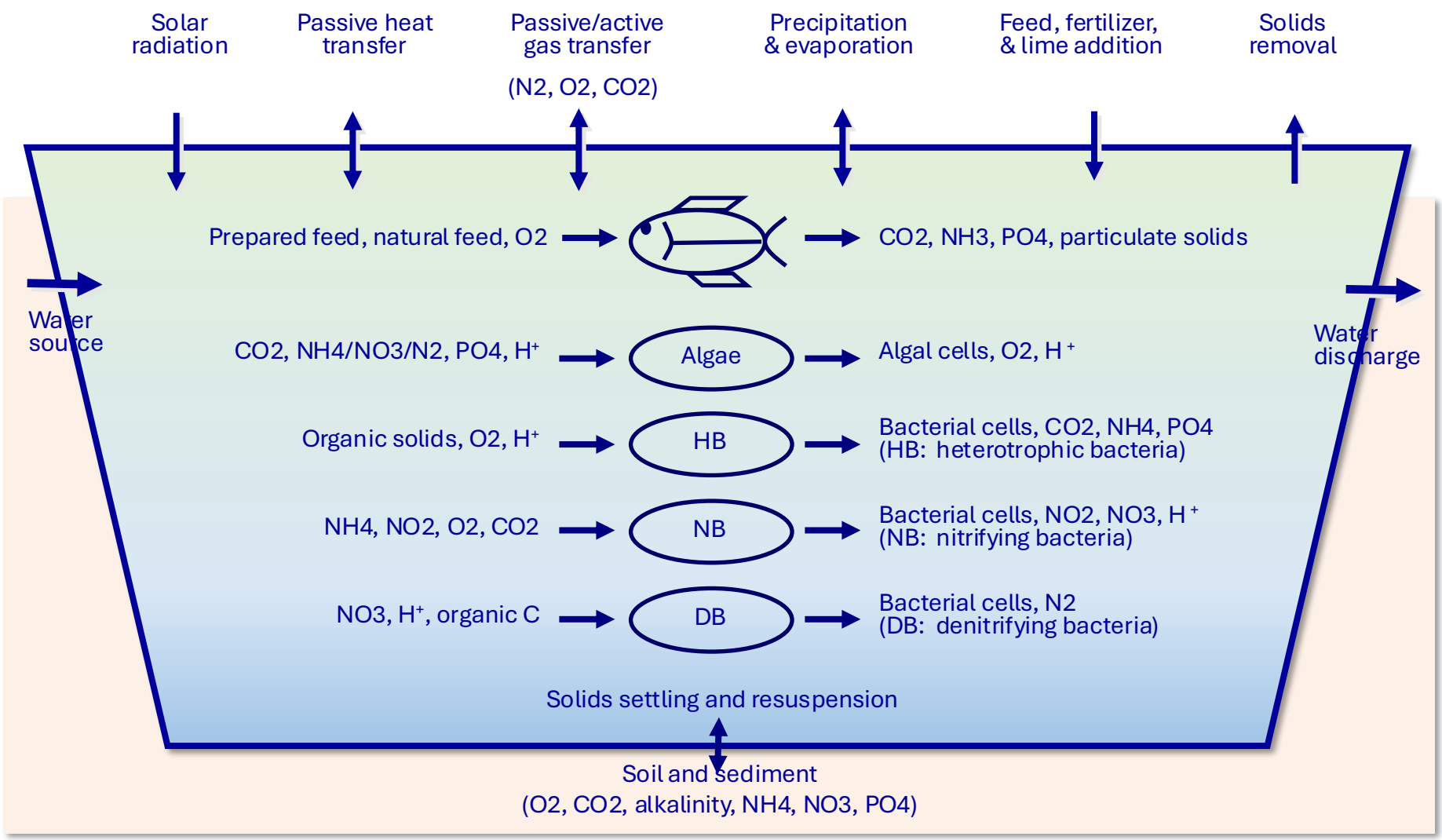
- Bacterial processes, including heterotrophic, nitrifying, and denitrifying bacteria
- Microalgal and macroalgal processes



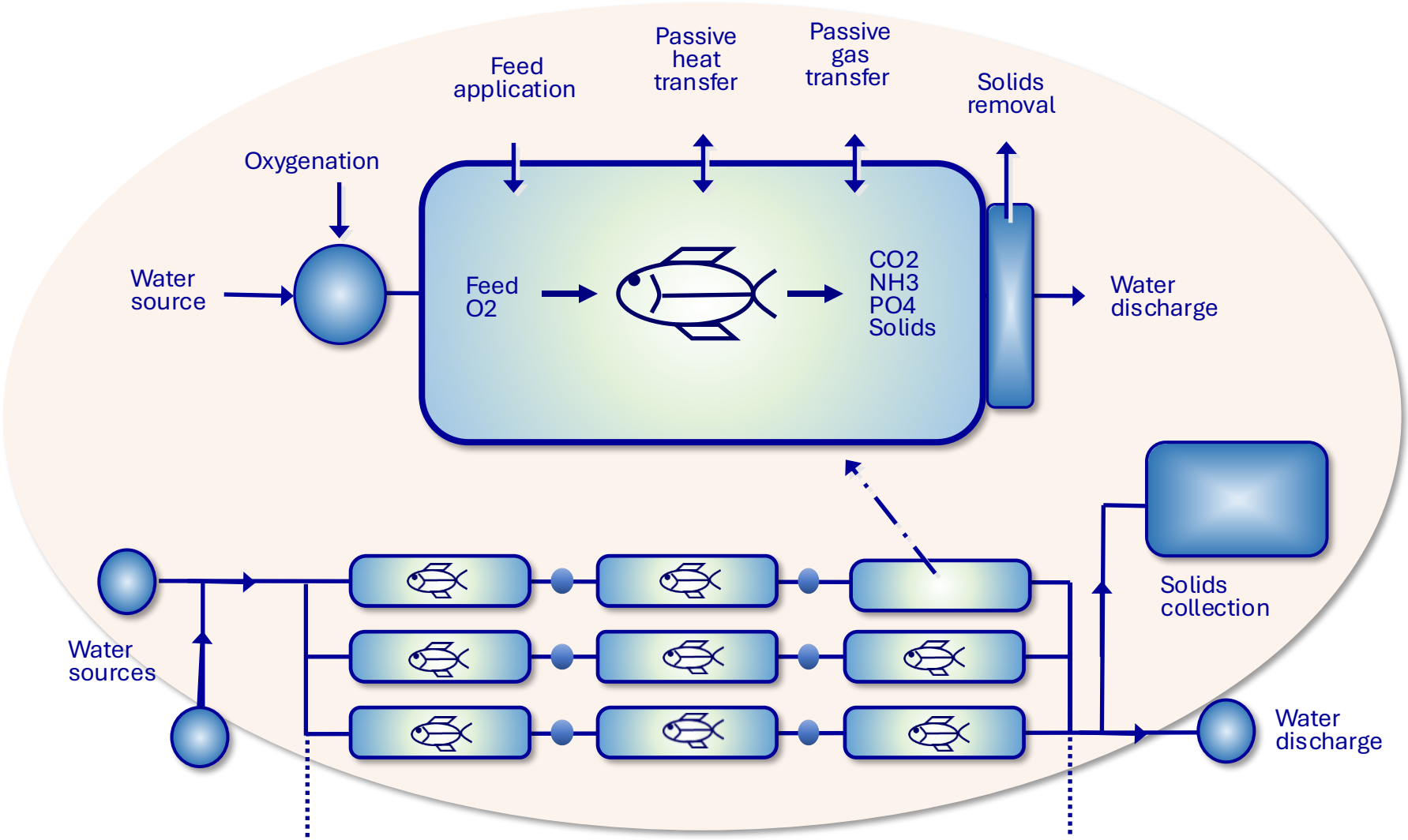
Aquaculture management

- Biomass stocking, culture schedules, transfers, and harvests
- Feed application

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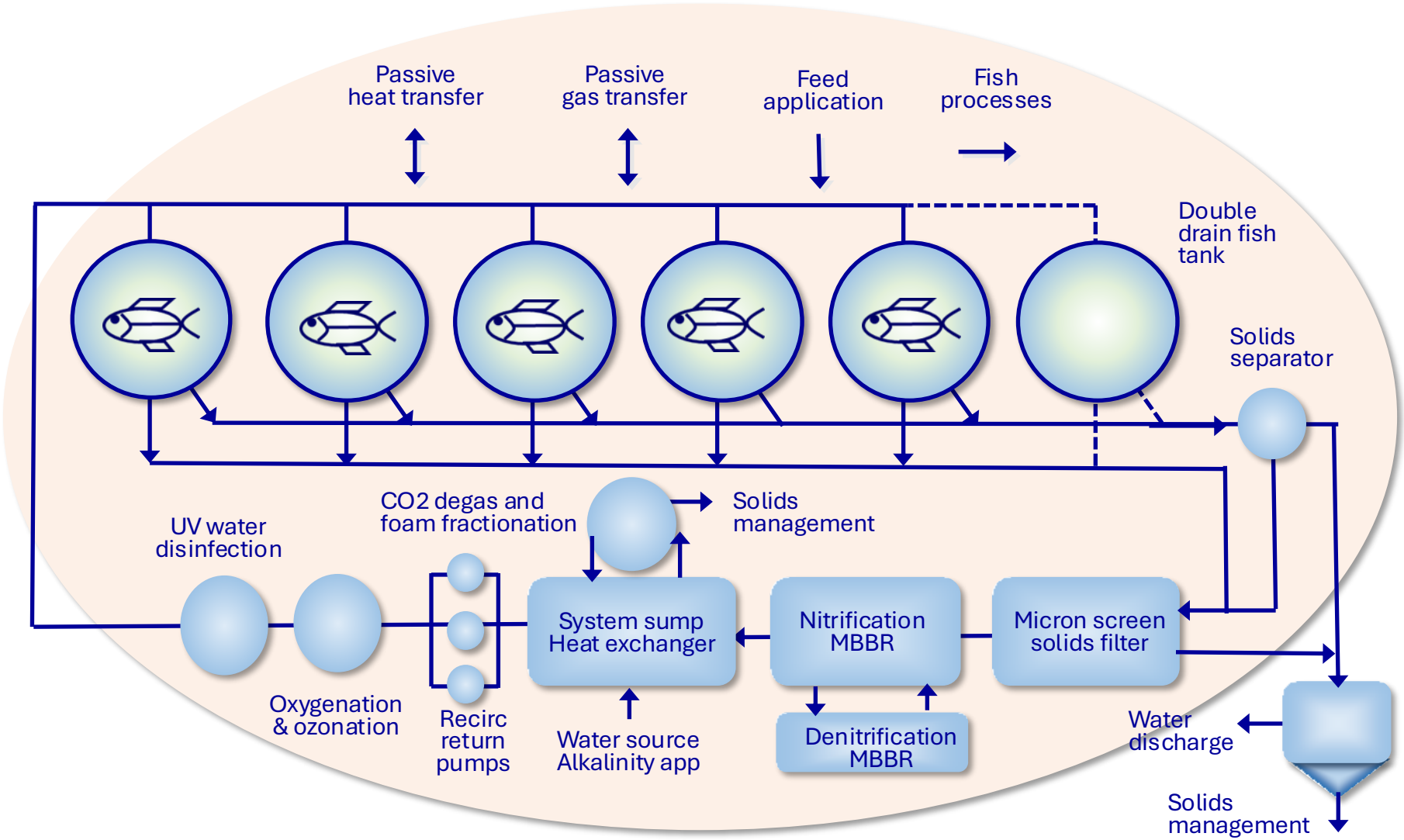


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Example Facility Ecosystem and Simulation Model



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Aquaculture Project Development

Staged, Iterative Facility Development

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Facility Simulation Model

Specifications for facility design and management are combined to create facility ecosystem and simulation models.

- Facility system processes
- Physical processes
- Aquatic chemistry
- Aquatic biology
- Aquatic animal biology
- Aquaculture management

This can get complicated …

To address this complexity, AquaFarm provides:

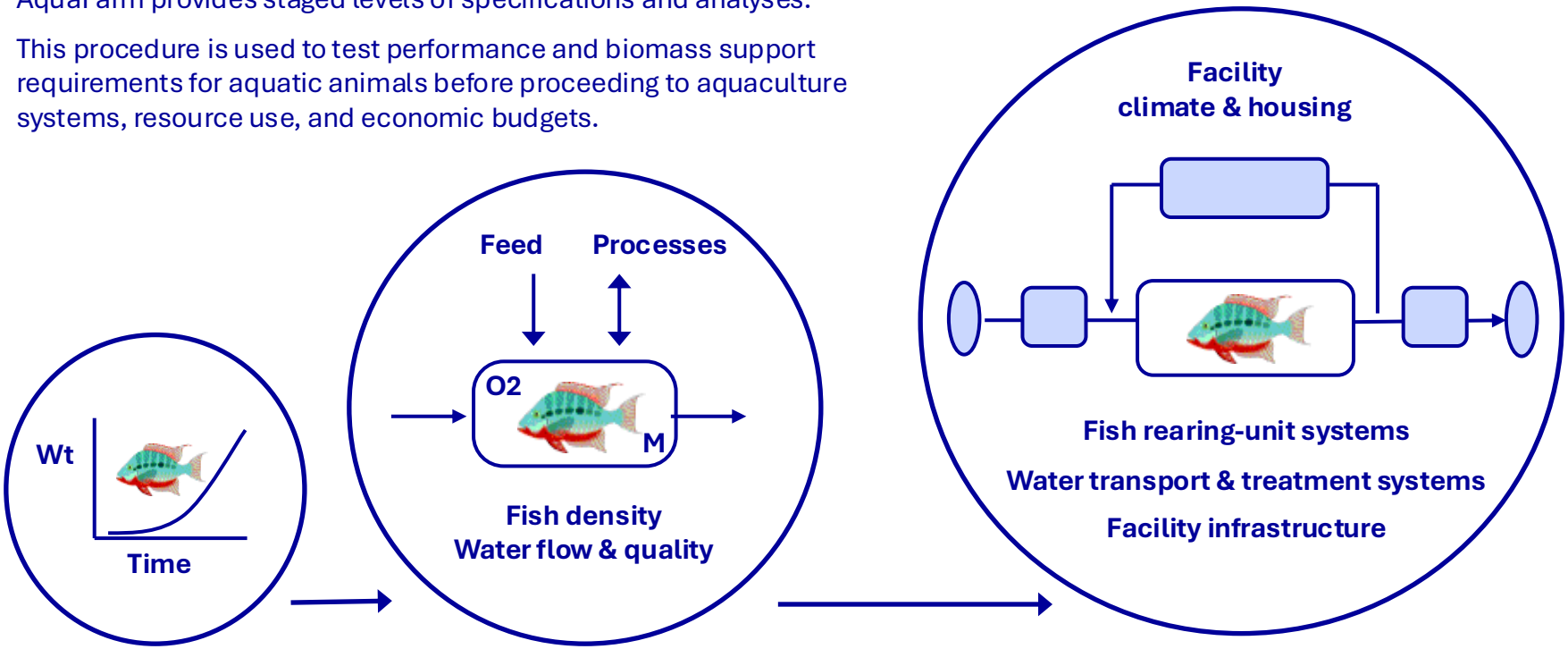
1. Staged levels of specifications and analyses
2. Iterative testing & refinement per analysis stage.

This staged, iterative approach is used to organize and guide complicated facility design projects.

- Start simple
- Use staged project development
- Use iterative refinements per stage

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- To facilitate aquaculture facility specification and development, AquaFarm provides staged levels of specifications and analyses.
- This procedure is used to test performance and biomass support requirements for aquatic animals before proceeding to aquaculture systems, resource use, and economic budgets.



Animal performance

- Facility environment & water temperatures
- Aquatic animal growth & feeding
- Aquatic animal suitability for aquaculture production

Biomass support

- Fish Rearing Unit sizing and modeling
- Fish stocking density and required metabolic support
- Water flow rates, oxygen supply, and metabolite removal .

System design

- Facility systems
- Aquaculture management schedules and production
- Resource use for water, energy, feed, materials, and labor
- Enterprise economics

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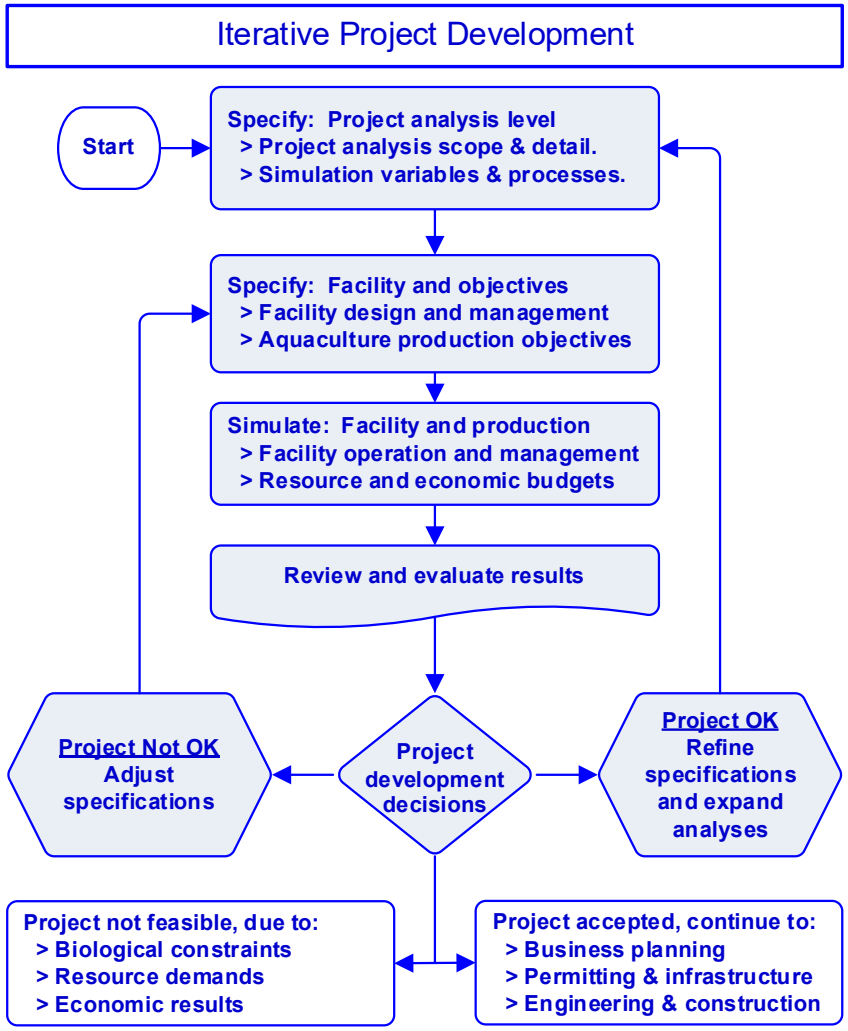
Project staging for specifications and analyses is guided by use of a user-selected Project Analysis Level.

Project Analysis Level	Objective	Processes and Variables Included in Simulation *Specify simulation settings as groups and individually. All settings are optional. Successive levels of analysis include prior levels.*
I	Basic feasibility testing	○ Facility: Climate and photoperiod, water temperature, and water salinity. Include now or later: Water hydraulics and budgets, passive and active heat transfer, and resource and economic budgets. ○ Aquatic animals: Survival, growth and development, feeding with prepared and natural feeds. Management of fish rearing volumes, biomass densities, and water flow rates.
II	Preliminary biomass support	○ Facility: Oxygen mass transfer by water flow, and passive & active air-water gas transfer. ○ Aquatic animals: Oxygen consumption and related water quality management.
III	Comprehensive biomass support	○ Facility: Additional water quality variables and mass transfer by water flow, passive and active processes, and bacterial processes. Water quality: Alkalinity, pH, dissolved CO2, total carbonates, dissolved N2, total gas pressure, total and unionized ammonia, NO3, PO4, and particulate solids. Optional compounds: Dissolved ozone/TRO, Organic C for denitrification, Generic compounds. ○ Aquatic animals: Metabolite excretion and related water quality management.
IV	Green water systems	○ Facility: Microalgae primary productivity. Macroalgae production. Photosynthetically active radiation. Dissolved inorganic C, N, P. Phytoplankton density and water turbidity.

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Iterative specifications and analyses

- AquaFarm supports iterative analyses for each stage of aquaculture facility development.
- This is made workable by (1) the use of intensive calculation processing, as provided by computer simulation, and (2) facilitated review of simulation-generated data in tables, graphs, and management logs.
- Iterative analyses per facility development stage:
  1. Specifications
  2. Testing by simulation
  3. Performance review
  4. Improved & amended specifications
- Aquaculture production objectives may not be achieved or satisfactory for various reasons, as determined by simulation results.
- It is best to consider practical and biological feasibility before proceeding to details of resource demand and economic performance.



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Aquaculture facility simulation model

- **Facility Unit systems**: Facility Units are linked by water flow and related advective heat and mass transfer.
- **Facility Unit processes**: Water bodies contain physical, chemical, and biological unit-processes.
  - Zero-order, first-order, and saturation kinetics
  - Physical and chemical equilibria
  - Biological metabolic stoichiometry
  - Aquatic animal metabolism, feeding, and growth
- **Facility Unit state variables**:
  - Climate (outdoor and housed)
  - Water flow rates
  - Water quality variables
  - Settled and filtered particulate solids
  - Fish biomass and feed loading
  - Other biological components (e.g. bacteria & algae)
- **Facility Unit differential equations**:

Compound mass balances

$$dC_e/dt = Q_i C_i /V - Q_e C_e /V + K_{Lac} (C_s - C_e) + K_{rc} C_e + M_c$$

Water heat-energy balances

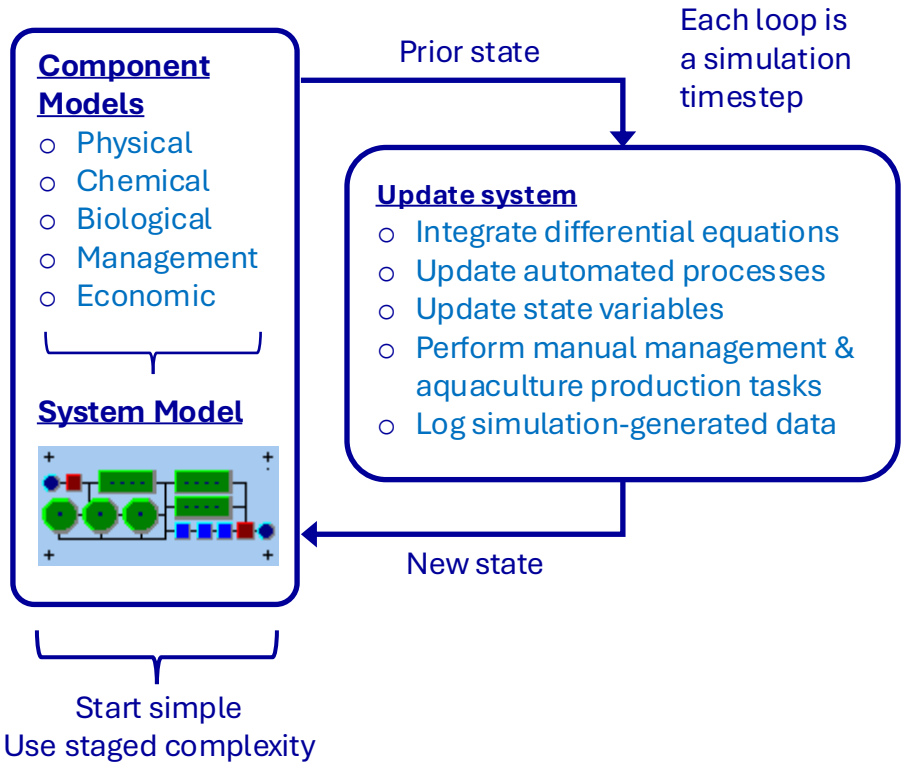
$$dH/dt = Q_i r_i HC_i T_i WJ /V - Q_e r_e HC_e T_e WJ /V + f_{net}$$

Water mechanical-energy balances

$$P_1/g + U_1^2/2g + Z_1 + HA - HL_t = P_2/g + U_2^2/2g + Z_2$$

Aquaculture facility simulation procedure

- At AquaFarm menu, Click 'Simulate'.
- System state variables are updated over a series of Simulation Timesteps (timestep size: 1 min to 1 day).
- At each timestep, analytical and numerical integration of simultaneous differential equations is completed.



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AquaFarm

Reviewing Simulation Results

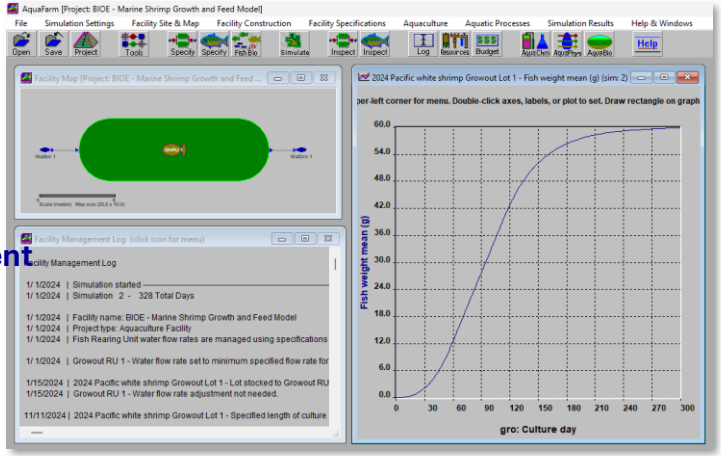
Data · Graphs · Logs · Budgets

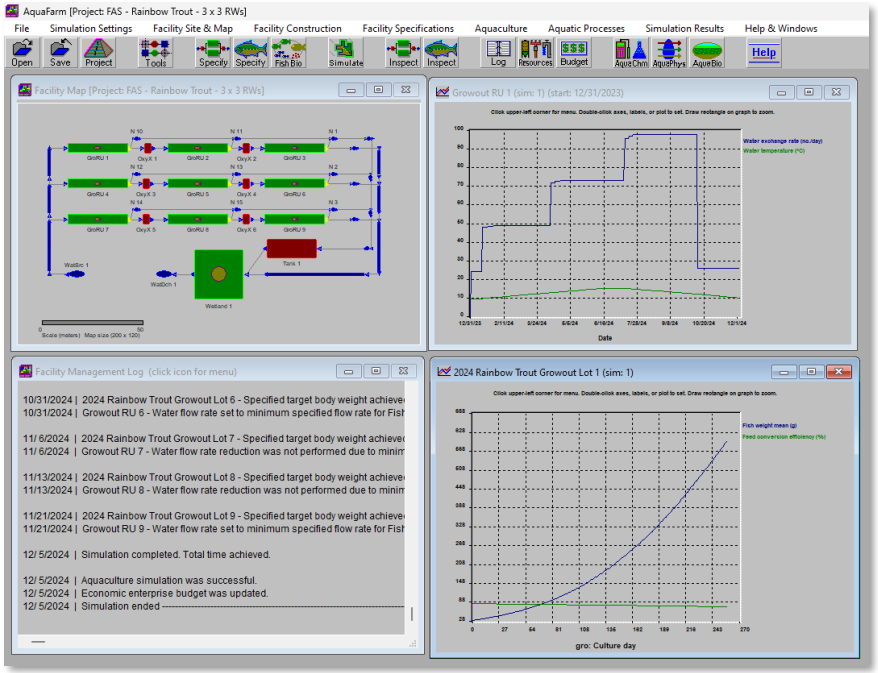
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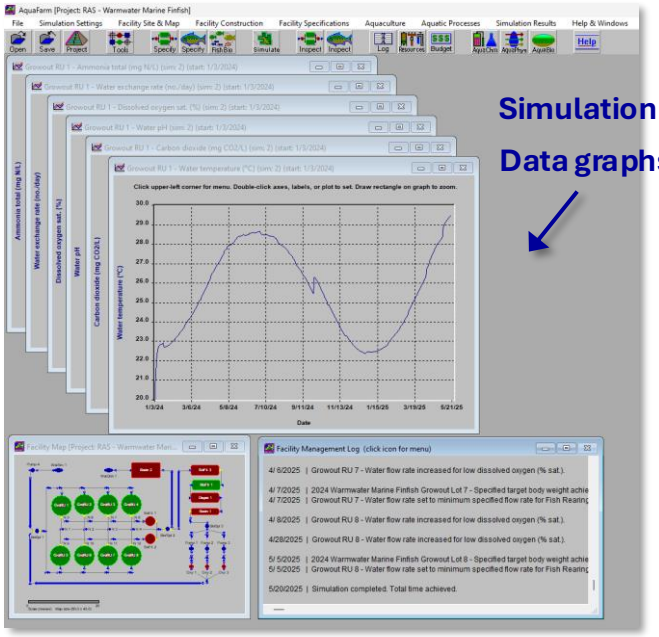
Three Example Facilities are Shown

Facility Map

Management Log







Simulation generated datasets

Data graphs

Data tables

Growout RU 1 (sim: 3) (start: 12/30/2023)

Save to file...

Date (mm/dd/yyyy)	Julian day.time	Water temperature (°C)	Dissolved oxygen sat. (%)	Water pH	Carbon dioxide (mg CO2/L)	Ammonia total (mg N/L)	Susp total solids (mg dw/L)
2/1/2024	397.000	10.2746	82.3748	7.70964	2.51661	0.175682	0.841143
2/2/2024	398.000	10.3094	81.7851	7.69981	2.57346	0.181256	0.868056
2/3/2024	399.000	10.3443	81.1810	7.68996	2.63177	0.186961	0.895592
2/4/2024	400.000	10.3794	80.5621	7.68008	2.69154	0.192798	0.923756
2/5/2024	401.000	10.4146	79.9283	7.67020	2.75278	0.198769	0.952556
2/6/2024	402.000	10.4498	79.2793	7.66029	2.81554	0.204876	0.982005
2/7/2024	403.000	10.6056	89.1042	7.83174	1.87471	0.110683	0.718259
2/8/2024	404.000	10.6406	88.6441	7.82276	1.91320	0.114953	0.748894
2/9/2024	405.000	10.6752	88.3004	7.81550	1.94456	0.118141	0.771640
2/10/2024	406.000	10.7100	87.9490	7.80821	1.97661	0.121397	0.794864
2/11/2024	407.000	10.7448	87.5896	7.80086	2.00944	0.124724	0.818587
2/12/2024	408.000	10.7797	87.2219	7.79346	2.04307	0.128124	0.842818
2/13/2024	409.000	10.8146	86.8458	7.78601	2.07751	0.131597	0.867562
2/14/2024	410.000	10.8497	86.4610	7.77851	2.11280	0.135148	0.892844

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Resource budgets

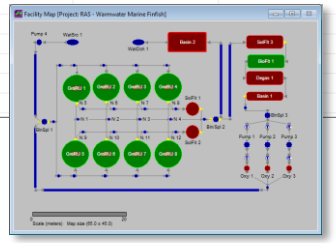
- Resources consumed and produced
- Resource name, units, time of use, total quantity, and rates
- Example consumed resources: Water, energy, aquatic animal stockers and feed, pure oxygen, and chemicals.
- Example produced resources: Aquatic animals, macroalgae, and plants.

Facility resources

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Resource and units	Total time of use (days)	Total quantity (units)	Mean rate (units/day)	Maximum rate (units/day)
Water: Facility source (m3)	501.994	18276.5	36.4078	87.8766
Water: Facility discharge (m3)	501.994	18276.5	36.4078	87.8766
Water: Facility Unit fill (m3)	1.00000	612.547	612.547	612.547
Water: Loss replacement (m3)	501.952	143.191	0.285269	0.665940
Water: Solids transfer (m3)	369.652	338.430	0.915537	25.4407
Energy: Water pumping (kWhr)	498.037	102795	206.401	514.478
Energy: HVAC (kWhr)	159.001	15611.4	98.1848	246.710
Energy: Water aeration (kWhr)	497.995	71718.0	144.013	144.000
Energy: Water filters/biorx (kWhr)	501.994	6024.50	12.0011	12.0000
Oxygenation: Gas supply (kg)	497.953	13252.1	26.6131	64.8542
Air flow: Aeration / airlift (m3)	497.995	1.44877E+08	290921	290880
Solids filter compnts: Moving screen	1.00000	1.00000	1.00000	1.00000
Solids filter compnts: Clarifier	1.00000	2.00000	2.00000	2.00000
Biofilter media: Moving bed (m3)	1.00000	47.5708	47.5708	47.5708
Chem app: Sodium carbonate (kg)	497.037	4345.56	8.74293	35.6490
Chem app: Ozone gas (kg)	497.953	697.475	1.40068	3.41338
Chem app: Generic compound 1 (kg)	497.953	1979.25	3.97478	6.74880
Solids: Removed & transferred (kg dw)	16.3333	8436.47	516.519	1231.37
Warmwater Marine Finfish - Feed: Growout 3 (kg)	230.301	1117.93	4.85420	8.77049
Warmwater Marine Finfish - Feed: Growout 4 (kg)	233.343	2400.55	10.2877	15.6917
Warmwater Marine Finfish - Feed: Growout 5 (kg)	254.012	5144.55	20.2532	37.0178
Warmwater Marine Finfish - Feed: Growout 6 (kg)	284.672	10934.7	38.4115	65.2055
Warmwater Marine Finfish - Feed: Growout 7 (kg)	262.344	10445.5	39.8161	62.6479
Culture stock input and output	Total units			
Warmwater Marine Finfish - Fish Stage-3 input (no.)	35560.0			
Warmwater Marine Finfish - Fish Stage-3 input (kg)	1066.80			
Warmwater Marine Finfish - Fish Stage-7 output (no.)	32010.0			
Warmwater Marine Finfish - Fish Stage-7 output (kg)	22443.2			

Example facility used here



Economic enterprise budgets

- Economic budgets include simulation-generated resources and user-specified budget items
- Economic budget itemization:
  - Fixed, depreciable asset, and variable costs
  - Production revenue
  - Net return

Facility Enterprise Budget: Total facility basis for 1/4/2024 - 5/19/2025

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Item Description	Cost per Unit	Number of Units	Total Cost
(double click item to specify)			
INCOME			
Warmwater Marine Finfish - Fish Stage-7 output (no.)	0.00	32,010.00	0.00
Warmwater Marine Finfish - Fish Stage-7 output (kg)	10.00	22,443.18	224,431.84
TOTAL: Income			224,431.84
FIXED COSTS			
Interest on fixed cost	0.10	0.00	0.00
TOTAL: Fixed costs			0.00
DEPRECIABLE-ASSET COSTS			
Water Source	1,000.00	1.00	
Interest on depreciable cost (calculated rate)			68.77
Depreciation cost (calculated rate)			45.84
Water Discharge	1,000.00	1.00	
Interest on depreciable cost (calculated rate)			68.77
Depreciation cost (calculated rate)			45.84
Flow Blend/Split	1,000.00	3.00	
Interest on depreciable cost (calculated rate)			206.30
Depreciation cost (calculated rate)			137.53
Water Pump	1,000.00	4.00	
Interest on depreciable cost (calculated rate)			275.07
Depreciation cost (calculated rate)			183.38
Water Pipe	1,000.00	11.00	
Interest on depreciable cost (calculated rate)			756.44
Depreciation cost (calculated rate)			504.29

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