SWRCB Compliance Document

AquaSweep™ Technology

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Operational Basis of AquaSweep™ Technology

C-Water's AquaSweep™ technology is based on the principle of inertial separation (i.e. controlled entrapment-boundary layer.) In layman's terms, inertia can be thought of as an object's "amount of resistance to a change in velocity." AquaSweep™ successfully reduces the IM&E rate of aquatic organisms by utilizing velocity gradients to separate objects of different mass (i.e. inertial separation.) **Refer to Figure 1 below.**

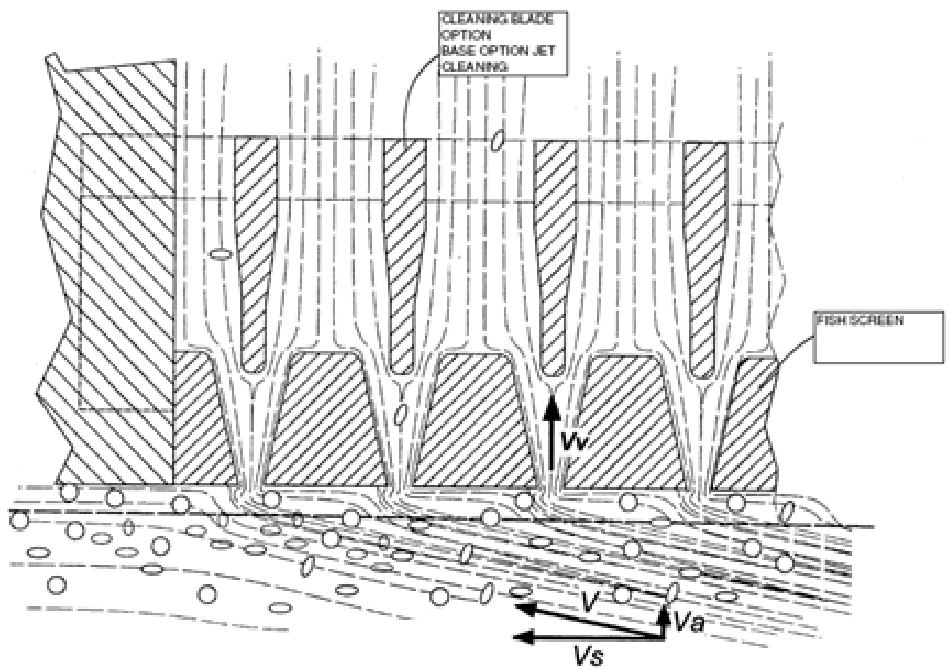

Figure 1: AquaSweep™ and Inertial Separation

The AquaSweep™ Separator (**Refer to Figure 2 below**) is a double-wall steel or concrete structure that will be pre-fabricated offsite and trucked, railed, and/or barged into place, either in whole or in sections depending on the ultimate size of the separator, which is determined by the plant-specific intake volume. **Refer to Table #1 in the Appendix.**

The hollow wall of the separator will be filled with concrete at the site, thereby gradually sinking it in place in front of the existing intake pump house. The amount of source water body bed preparation required will be site-specific. The separator will then be mated to the existing cooling water intake structure (i.e. CWIS) via an intake interface module.

The AquaSweep™ Separator consists of the following modules:

- Trash rack
- Inlet flume
- Deep well
- AquaSweep™ grid
- Intake interface
- Circulators
- Outlet flume

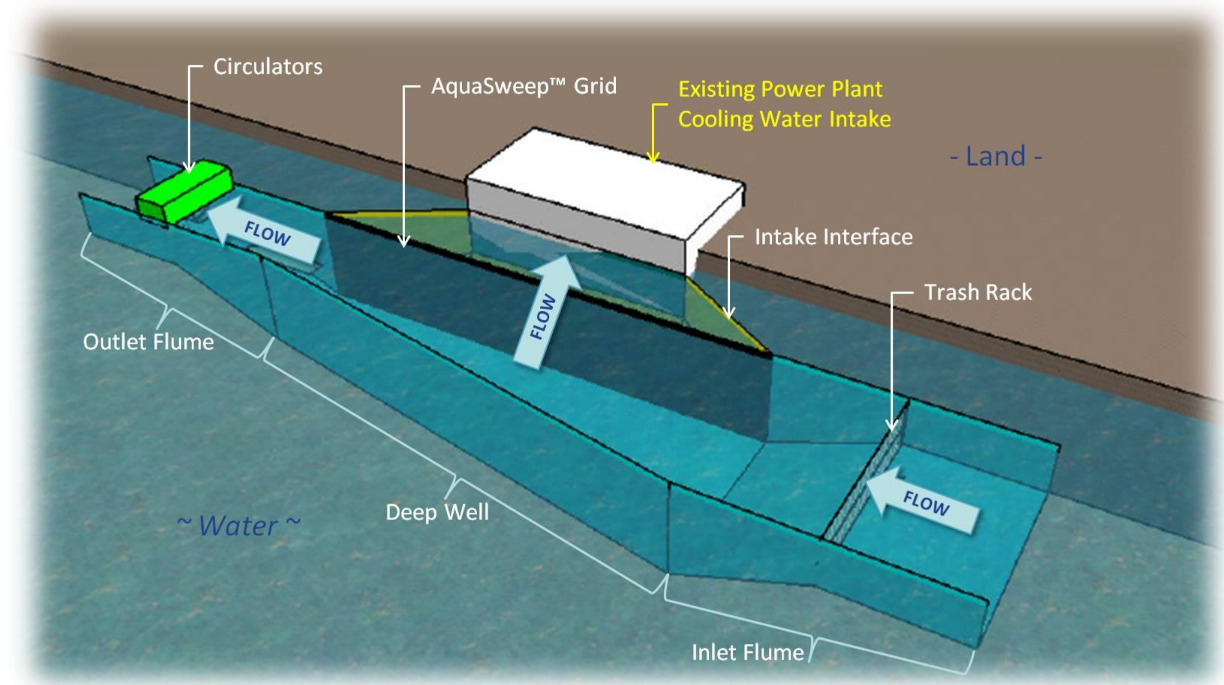

Figure 2: AquaSweep™ Separator

The key to efficient inertial separation is to maintain a large ratio of sweep-to-approach flow velocities (i.e. assisted sweeping flow.) **Refer to Figure 1 above.** This ratio is achieved and maintained by the use of low rpm, fish-friendly circulators. Effectively, the source water body flow is split into an intake flow and a sweeping flow. The inertial separation which ensues, efficiently and effectively prevents the smallest of aquatic life forms from being pulled into the existing cooling water intake structure, and ensures their safe movement through the separator and delivery back to the source water body.

The two factors that must be controlled to ensure effective inertial separation are:

1) Sweeping flow velocity
2) Angle of approach of the sweeping flow to the grid

The sweeping flow velocity is controlled initially by the deep well, which slows the velocity, as well as the slow-speed circulators, which adjust the dynamic head and maintain the flow ratio.

Control of the sweeping flow velocity is critical as this velocity controls the angle of approach to the grid. The angle of approach determines the effectiveness of AquaSweep™ at reducing and controlling entrainment. (Note: As the sweeping flow velocity increases, the angle of approach decreases.) **See Figure 3 below.**

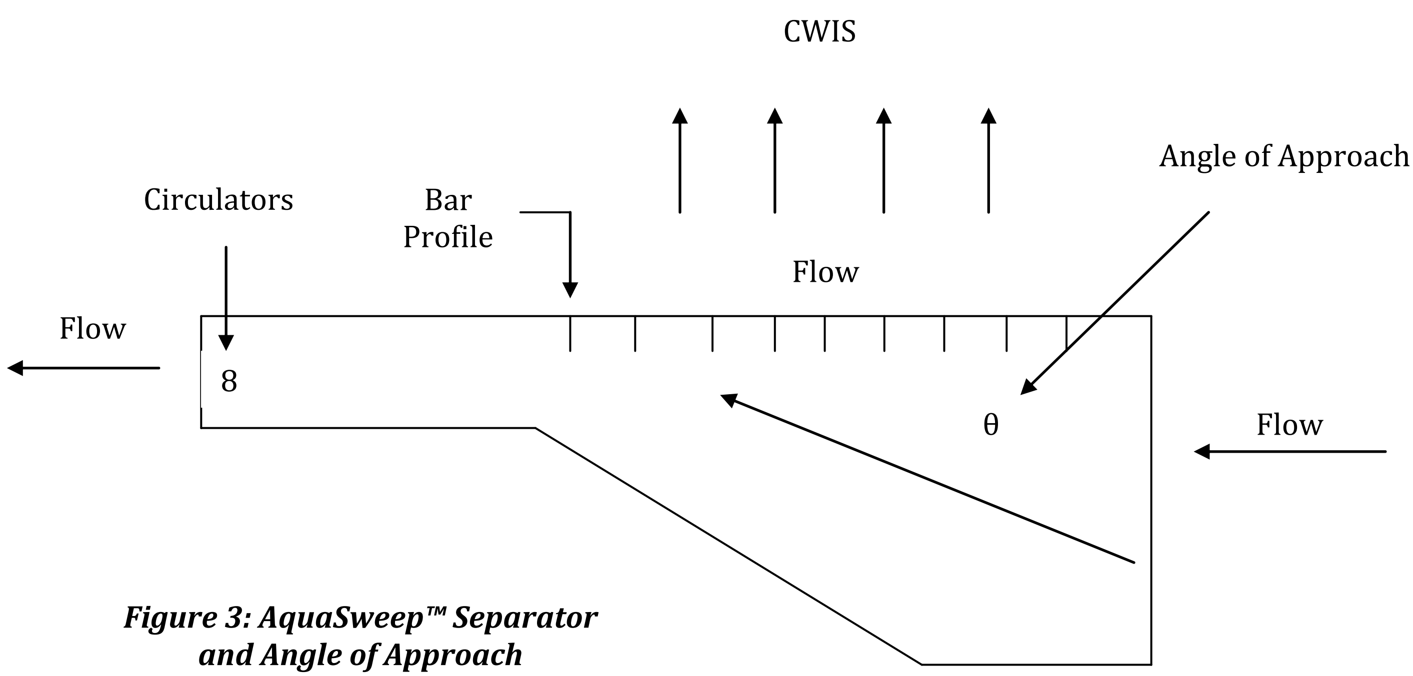

Figure 3: AquaSweep™ Separator and Angle of Approach

As discussed above, in addition to the slow-speed circulators, the other key component of AquaSweep™ that induces inertial separation is the grid module. **Refer to Figure 4 below.**

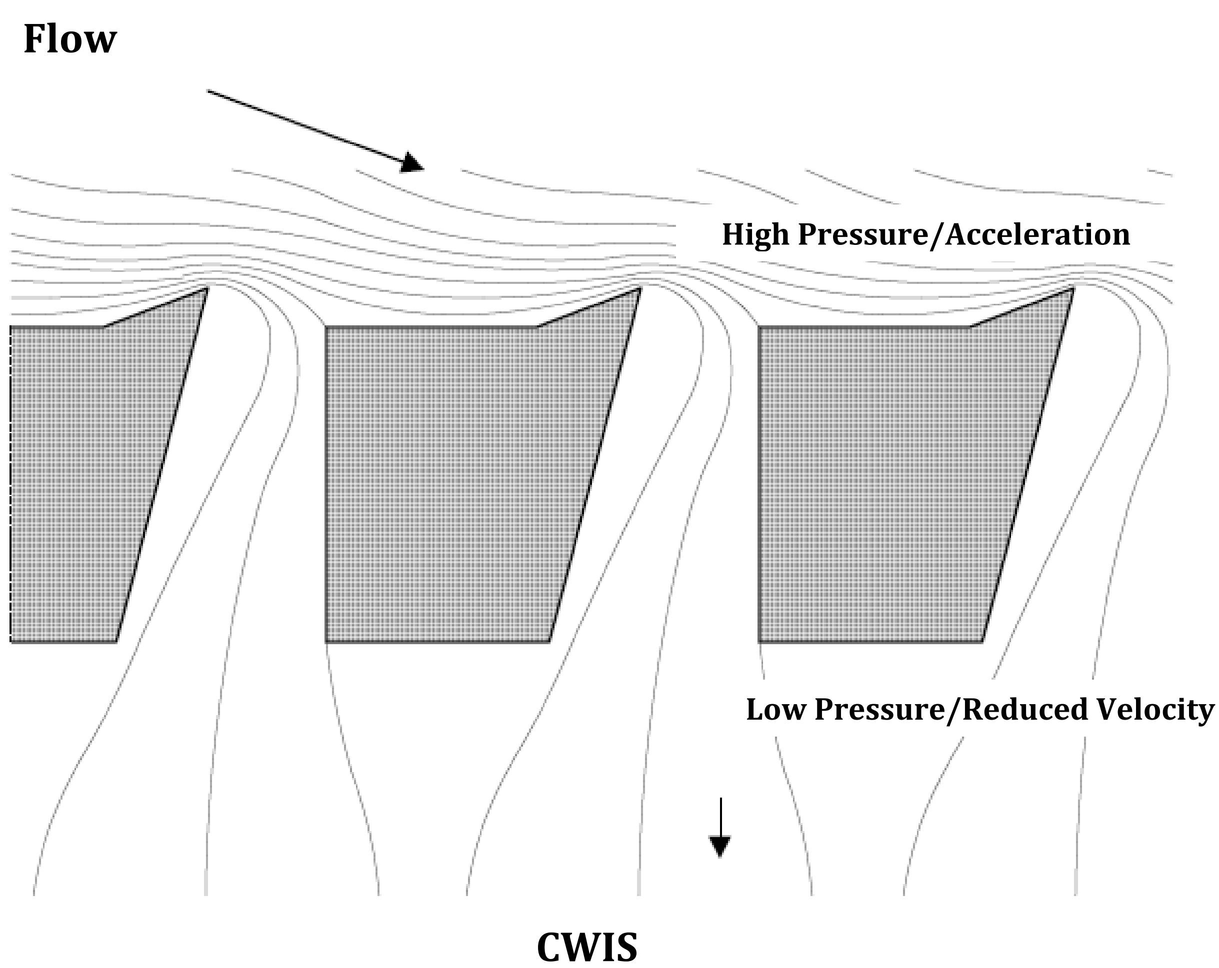

Figure 4: AquaSweep™ Grid

The AquaSweep™ grid is comprised of vertically aligned bars, of a specific geometric profile, with a fixed distance (i.e. gap) between the bars. The individual bar profile is optimized to maximize inertial separation. By maintaining a large ratio of sweep-to-approach flow velocities, an area of acceleration is created on the sweeping flow side (i.e. sweeping the aquatic life past the intake structure) and an area of deceleration is created on the intake side (i.e. aquatic organism-free water into the intake.)

It is key to note that since AquaSweep™ operates on the principle of inertial separation, **the grid does not operate as a classic mesh screen** (i.e. whereby the size of the screen is the limiting factor controlling impingement and entrainment of aquatic life), and the gap between the individual bars is larger than the smallest aquatic life (i.e. fish egg of .8mm in size.)

In summary, the operational basis of AquaSweep™ is founded on a principle that has been successfully proven in other industries (oil and gas, chemical, refinery, pharmaceutical, life science, water treatment, etc): the principle of inertial separation. By inducing velocity gradients and maintaining a large ratio of sweep-to-approach flow velocities, AquaSweep™ is able to capitalize on differences in the mass of objects (i.e. aquatic organisms) in the source water body, sweep these aquatic life forms safely past the cooling water intake structure, deliver them back to the source water body, and, thereby, successfully reduce IM&E levels.

Benefits of AquaSweep™

AquaSweep™ features innovative techniques for inertial separation of larvae and fish eggs, and features significantly improved sweeping-flow efficiency, and thus provides a high rate of IM&E reduction. In addition, it provides a relatively low cost option for 316(b) compliance, simple prefabricated construction, and fast installation that requires only a short outage.

AquaSweep™ is:

- Based on the proven filtration principle of inertial separation
- Consumes only a small amount of water versus closed-loop cooling systems
- Constructed off-site, thereby reducing environmental impact at the project site

AquaSweep™ can:

- Achieve the 90% IM&E reduction target without modifying the existing OTC of the plant, thereby maintaining the plant's operating efficiency

- Provide a viable alternative to closed-loop cooling systems that would necessitate complex and costly new cooling tower additions to the plant.
- Allow utilities to maintain a high level of heat transfer efficiency, typical for OTC systems (< 0.5% parasitic & efficiency loss)
- Reduce the down-time for installation and commissioning versus other alternative cooling water intake structure technologies
- Potentially provide the most cost effective solution among all 316(b) compliance technologies while achieving mandated IM&E reductions.

Path to Commercialization

C-Water, in conjunction with partner CH2M Hill, is implementing a fast-track strategy to accelerate the research and development of AquaSweep™. **See Figure 5 below**.

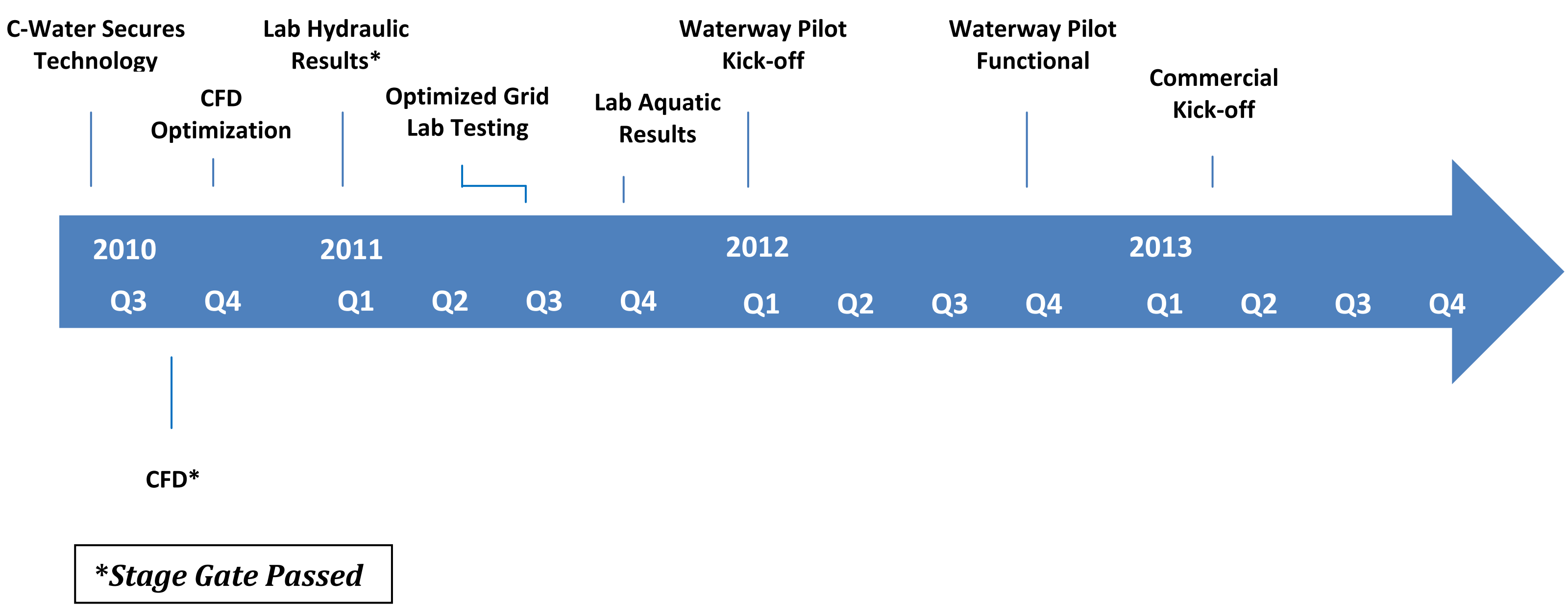

Figure 5: Commercialization Timeline

In conjunction with our strategic partner CH2M Hill, the on-going sequence for the development and commercialization of our 316(b)-compliance technology, AquaSweep™, is as follows:

- Performance of computational fluid dynamic (i.e. CFD) modeling: CFD is one of the branches of fluid mechanics that uses numerical methods and algorithms to analyze and solve problems that involve fluid flows, and to simulate the interaction of liquids and gases with surfaces defined by boundary conditions. The AquaSweep ™ CFD modeling is being performed by the Advanced Hydraulics Group of the CH2M Hill offices in Corvallis, Oregon. **CFD stage gate passed Q1 2011.**

- Prototype design, construction, and hydraulic testing: This work will be performed by Alden Laboratories who specialize in fluid flow engineering and physical flow modeling. The expected outcomes of prototype development and hydraulic testing include:

    - Fabrication of up to three 1:1 scale models of the hydraulic inertial separator, which is representative of the real-world product, so as to ensure representative testing of the performance of the inertial separation.

    - Construct a small scale hydraulic test rig and to test the performance of the inertial separator grid. The function of the hydraulic test is to recreate the real world (micro and macro) velocities and flow conditions.

    - Conduct test runs following test protocols.

    - Conduct performance test runs for the purposes of verifying impingement mortality and entrainment reduction efficiency.

The primary goal of the prototype hydraulic testing is to quantitatively "prove-out" the performance, reliability, and results (i.e. 80% - 95% reduction in impingement from uncontrolled levels and 60% - 90% reduction in entrainment from uncontrolled levels) of the AquaSweep™. **The initial hydraulic lab testing was passed Q1 2011.**

Lab prototype testing of an optimized grid is expected to complete Q3 2011.

Lab prototype testing of the optimized grid, using actual aquatic life, is expected to complete Q4 2011.

- Pilot unit testing: Once the aquatic life prototype test results have been reviewed and confirmed, site selection will occur at an end-user facility, and a pilot unit barge will be utilized, drawing a pre-determined side-stream flow from the in-place OTC system. The objectives of the pilot unit include:

  a. Proving-out of the AquaSweep™ under real-world operating conditions
  b. Foster familiarity with the AquaSweep™ for utility operational personnel
  c. Allow for a seamless transition to a full-scale commercial system.

  The waterway pilot is expected to commence Q1 2012 and complete Q4 2012.

  Concurrently, while pilot testing is being performed, a financial model/analysis and an engineering feasibility study will be performed regarding a full-scale system.

- A full-scale commercial system kick-off is expected for Q1 2013.

Computational Fluid Dynamics Modeling

The CFD model currently being used to analyze the AquaSweep™ technology was developed for the simulation of the flow of water and suspended particles near and around the grid module. This flow model describes the physics, on a small enough scale, comparable to the size of the boundary layer and the size of aquatic species, that it is capable to accurately calculate the forces acting on fish eggs or larvae floating close to the hydrodynamic bar profiles. During the course of CFD modeling, particular attention was given to the local curvatures of streamlines in the sweeping-flow boundary layer that determines the inertial separation forces.

The expected outcomes of CFD modeling include:

- Specify the physical screen geometry (i.e. bar profile) of the AquaSweep™ grid.
- Determine the functional range of the gap spacing between the hydrodynamic profile bars.

- Specify entry flow geometry (i.e. approach angle) for the physical hydraulic model.
- Understand the influence of flow velocity and turbulence on the operational profile of the AquaSweep™ Separator.
- Specify and guide the testing protocol of the laboratory prototype testing.

The CFD modeling is being performed by the Advanced Hydraulics Group of the CH2M Hill offices in Corvallis, Oregon.

The fluid domain around the grid bar row was generated in SolidWorks CAD software. The geometry of the grid consisted of (4) vertically aligned bars, spaced evenly, to form a gap between them for pass-through flow of water. **Refer to Figure 6 below, whereby the grid size defining the resolution and accuracy of the fluid flow model is expressed as a function of the screen gap x.**
Although the expected flow pattern is substantially two dimensional, a true 3D representation of the flow-space was incorporated in the model by adding a depth of 10 times the bar-width to the flow-continuum.

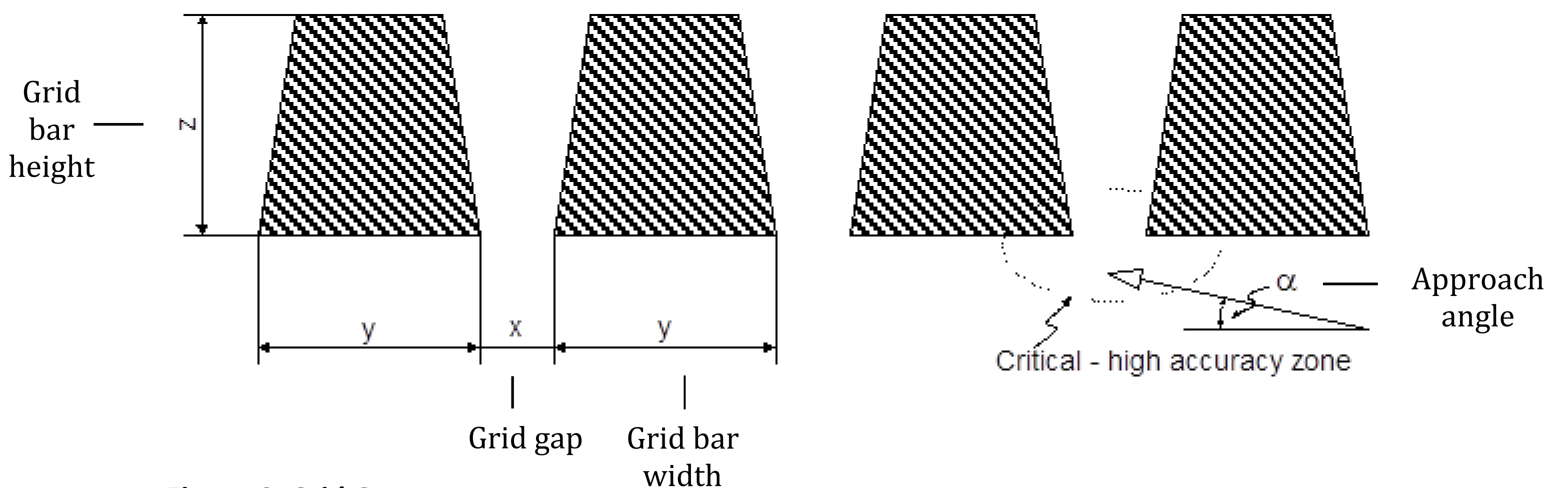

Figure 6: Grid Geometry

Boundary conditions, fluid properties and other flow variables were defined to represent the physical characteristics of the phenomenon.

A high density grid was generated to define the space around and in between the row of profiled grid bars. The nodes and edges of the mesh form the finite volume elements of the flow-space continuum that are at the core of the numerical calculation method. **Refer to Figure 7 below.**

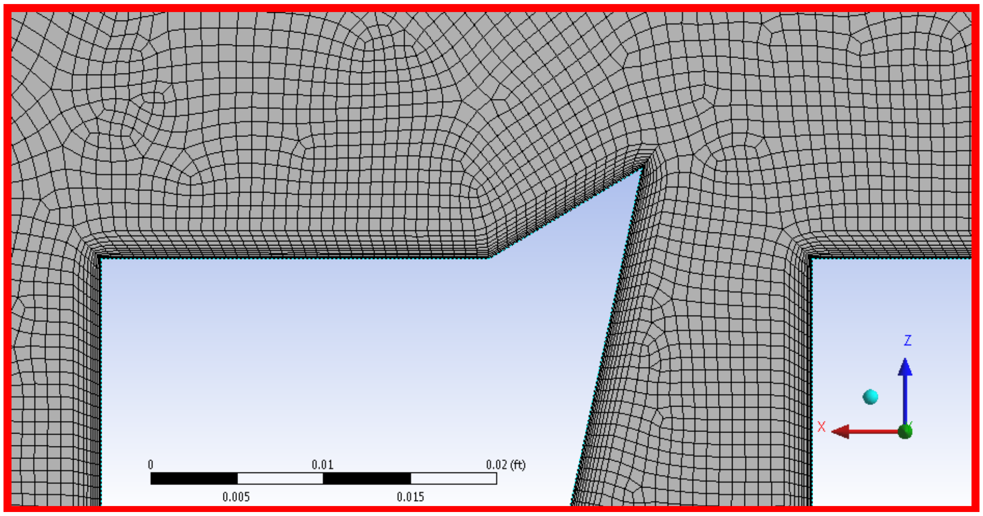

Figure 7: High density grid/mesh

Several iterative runs of the CFD calculations were executed to ensure that the flow patterns, pressure and velocity profiles and streamlines were realistic and the model was robust.

Following the satisfactory fluid-flow simulation, a particle transport model was developed to simulate the two-phase flow of fish eggs or larvae floating in the water. One millimeter diameter spheres were defined as solid particles suspended in and carried by the water.

Within the particle transport model, the total flow of particle phase was modeled by tracking the trajectories of a number of individual particles through the continuum of fluid. The model was first tested by simulating extreme particle densities, where the trajectories are predictable. When the computational results with air bubble and steel pellet densities matched the predicted and expected patterns, simulation runs were completed with particle densities slightly above and below that of the surrounding water. The intent of these runs was to simulate the neutral buoyancy of living organisms.

The CFD runs showed excellent results with the design screen gap size of 3mm or 3x the diameter of the suspended particle. 100% separation efficiency was achieved with none of the particles passing through the gaps. This result meant that the small particles were separated from the pass-through streamlines with a trajectory over an opening that is significantly larger than the actual particle size. **See figure 8 below.**

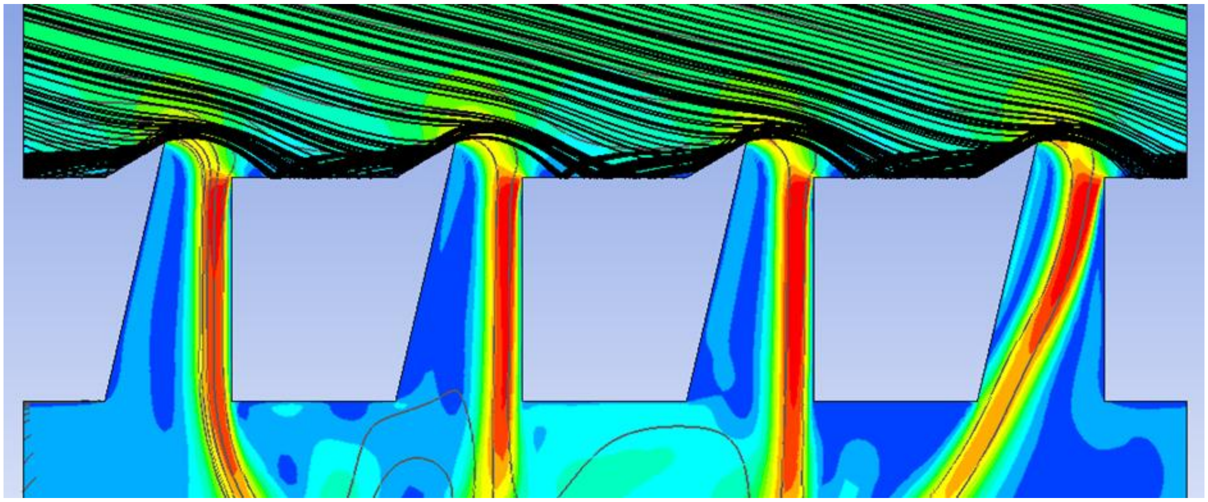

Figure 8: Shows (100) particle paths out of (1000) for the aquatic particle transport simulation at 3mm gaps with particle diameters at 1mm. During the transient simulation, over 3.0 seconds, the particles were shown to pass over several domains, equivalent to dozens of bar screen gaps.

The next phase of the CFD modeling of the grid was gap size optimization. A larger gap size, with acceptable separation efficiency, would result in a smaller grid and, consequently, a lower overall equipment cost. A 4.5 millimeter gap size (4.5 times of the diameter of the particle) was selected for the increased gap. **See Figure 9 below.**

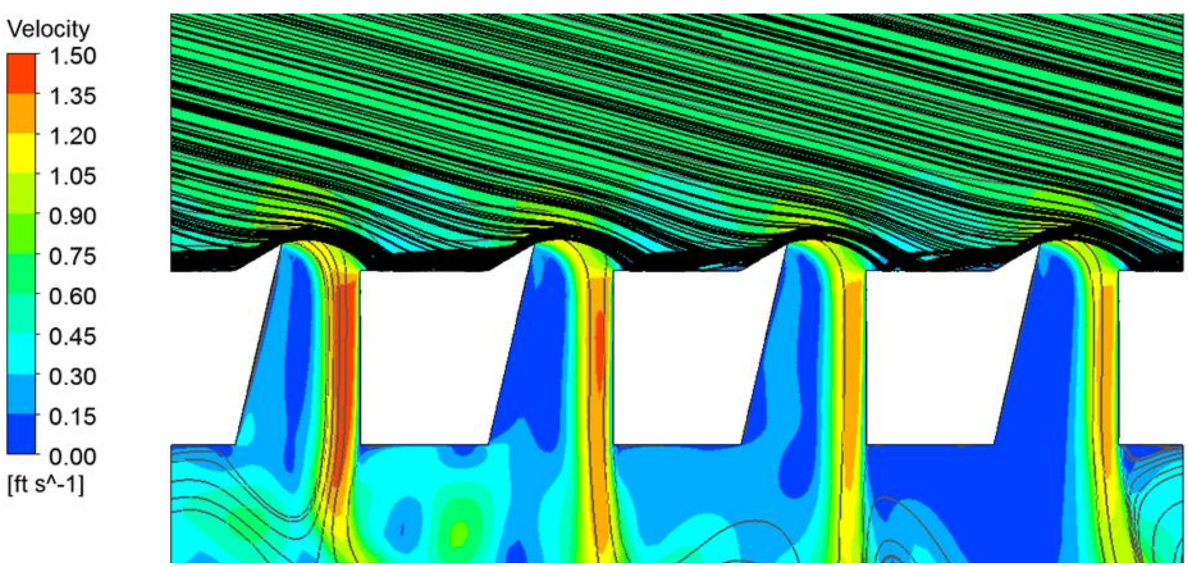

Figure 9: Shows (100) particle tracks out of (1000) for the aquatic particle transport simulation at 4.5mm gaps with particle diameters of 1mm. No particles were pulled through the grid during the 3 second transient simulation duration.

Validation of the initial CFD model with results from the physical hydraulic testing conducted at Alden Laboratories is on-going, and when completed, will allow for sensitivity analysis in order to further define and identify optimal bar profiles, approach angles, gap size, approach and pass-through velocities, and, ultimately, to utilize CFD modeling to design commercial applications.

Lab Prototype Testing

C-Water retained Alden Labs, a nationally-recognized fluids flow engineering and environmental laboratory, to construct a small scale hydraulic test rig (**Refer to Fig. 10 below**) and to test the performance of the inertial separator grid. The function of the hydraulic test was to recreate real world velocities (i.e. micro and macro) and flow conditions.

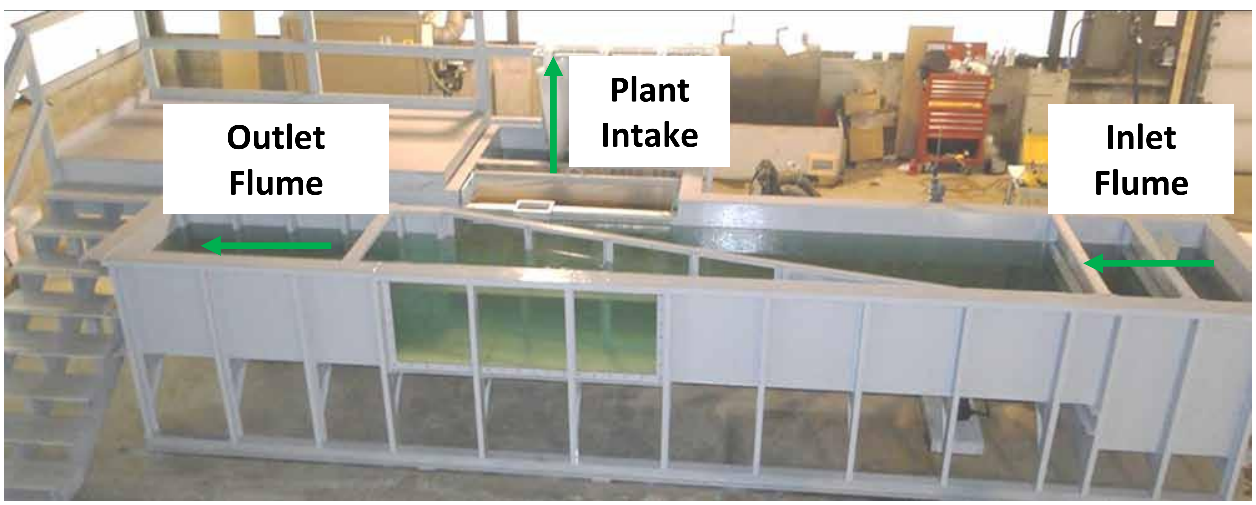

Figure 10: AquaSweep™ Hydraulic Test Rig

The initial test conducted by Alden to validate the efficacy of the inertial separator unit was a dye test. **See Figure 11 below.** Inlet water was dyed and pulled (i.e. creating an assisted sweeping flow) through the flume and across the grid. **This stage gate was successfully passed as the fluid flow correlated with the CFD prediction.**

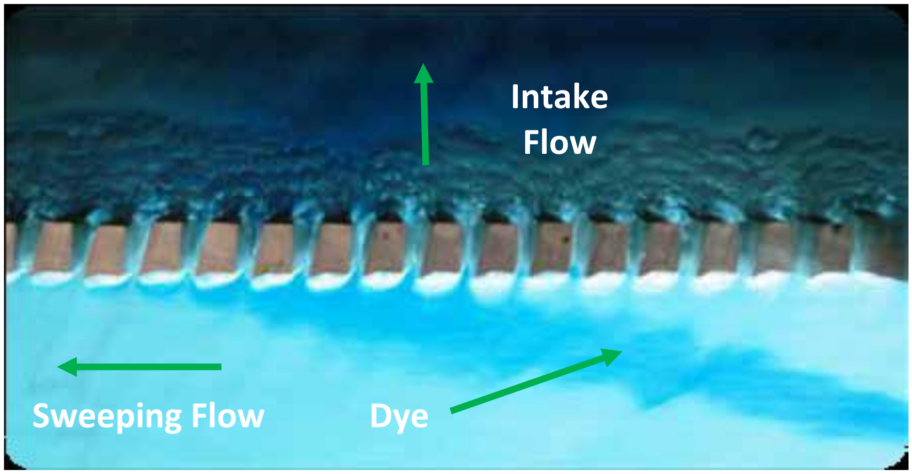

Figure 11: Dye Test

The next hydraulic test performed was to utilize neutrally-buoyant beads, 6 mm in size, to observe impingement on the grid (with 3.0 mm gap spacing.) **This stage gate was successfully passed as none of the beads were impinged and all passed through the outlet flume.**

The final hydraulic test performed was to utilize neutrally-buoyant beads, 2 mm in size, to observe entrainment through the grid (with 3.0 mm gap spacing.) **See Figure 12 below.** As with the two prior hydraulic tests, **this stage gate was successfully passed, as no beads were entrained and 100% grid efficiency was demonstrated.**

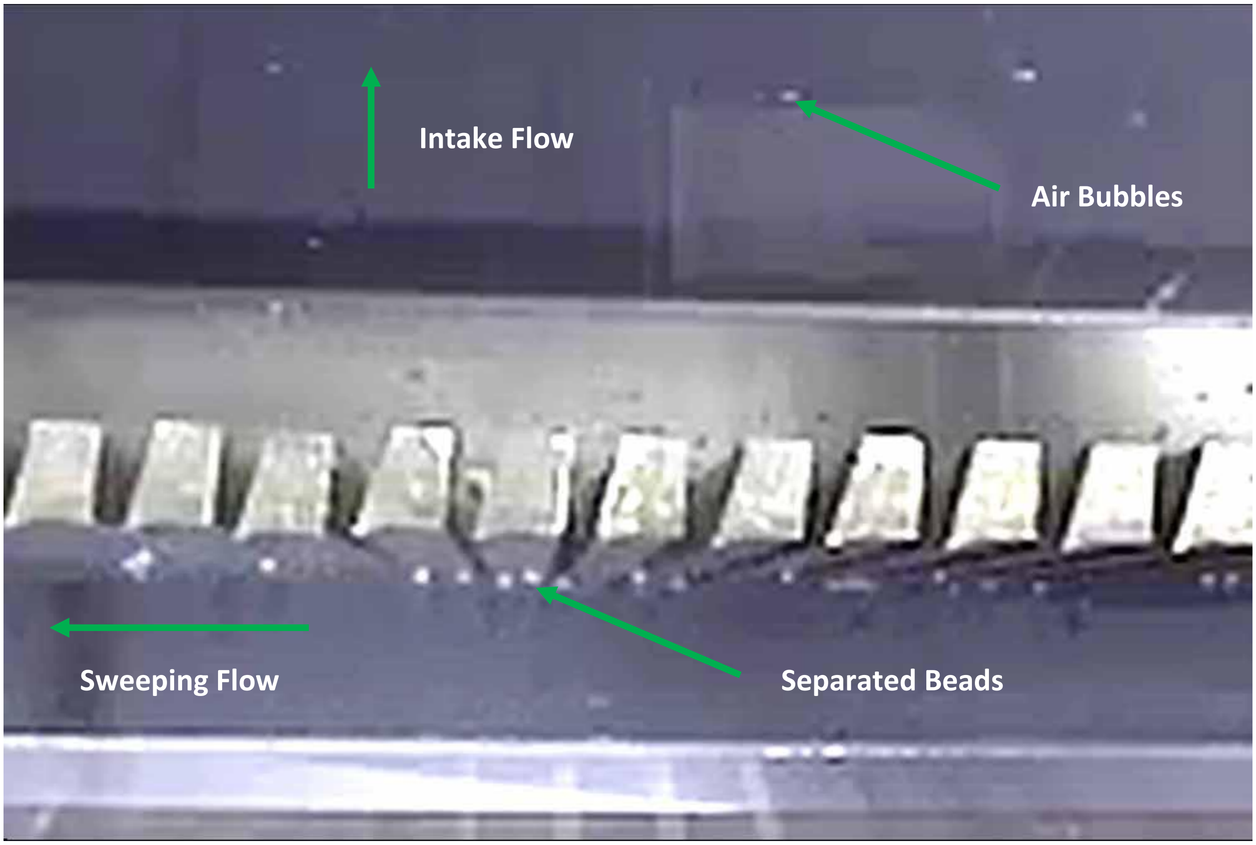

Figure 12: 2 mm bead entrainment test

The upcoming lab prototype test sequence includes:

1) CFD optimization (i.e. 100% correlation between physical model results and CFD predictions) by the Advanced Hydraulic Group of CH2M Hill.
2) Grid optimization (i.e. bar profiles, gap spacing, approach angle, velocities, etc.) utilizing CFD modeling.
3) Manufacture of optimized grid
4) Hydraulic testing of optimized grid by Alden Laboratories, using neutrally-buoyant beads (ranging from 0.5mm to 0.8mm in size) to document entrainment tendencies.

The anticipated completion of this testing sequence is Q2 2011.

5) Aquatic life (i.e. fish eggs, larvae, and juvenile fish) testing of optimized grid by Alden Laboratories.

The anticipated completion of this testing is Q3 2011.

Additional testing by Alden Laboratories will include:

- Seaweed and debris impact
- Grid cleaning protocol and system
- Impact to aquatic life by slow-speed circulators

Waterway Pilot Testing

After successful completion of aquatic life testing of the optimized grid, a waterway pilot unit will be tested to demonstrate field efficacy and O&M of the AquaSweep™ system.

Anticipated sequencing will include:

- Pilot-site landscaping (in-progress)
- Waterway pilot kick-off **(Q1 2012)**
- Waterway pilot completion **(Q4 2012)**

Concurrently performance of a financial model/analysis and an engineering feasibility study will be performed regarding a full-scale system during the pilot waterway study.

Commercial Unit

The kick-off for the initial full-scale system is anticipated to be Q1 2013.

APPENDIX

Table 1: AquaSweep™ Preliminary Structure Sizes

Intake Water Volume (mgpd)	Length (feet)	Width (feet)	Depth (feet)
< 50	< 75	< 15	< 10
50 - 500	75 - 230	15 - 40	10 - 25
500 – 1,800	230 – 500	40 - 100	25 - 55