POSEIDON WATER

Appendix L
CFD Modeling of
Flow Augmentation System

Renewal of NPDES CA0109223
Carlsbad Desalination Project

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SUBJECT: CARLSBAD DESALINATION PLANT CONTACT TIME IN DISCHARGE POND DURING STAND-ALONE OPERATIONS

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Introduction

Poseidon Water (Poseidon) is interested in determining the duration of exposure to elevated salinity for organisms entrained in the pumped dilution flow under stand-alone operations of the Carlsbad Desalination Plant (CDP). Specifically, the duration of exposure in the discharge pond portion of the discharge system is of interest. Alden conducted numeric modeling with computation fluid dynamics to estimate exposure durations for entrained organisms in the discharge pond. This was accomplished by releasing neutrally-buoyant, passive particles into a CFD model of the pond that was previous completed. The passive particles follow the established flow pattern in the pond and an exposure duration can be calculated based on when the particles leave the system (exit via the culverts to the outfall channel). The passive particles are used as a surrogate for eggs and larvae that have no swimming ability. It is important to note, however, that at the CDP a portion of the entrained organisms will likely be large enough to mount a swimming response, so these results are considered conservative.

Two water levels were investigated for this study: mean high water (MHW) and mean sea level (MSL). The model details, setup, and results of the study are presented below.

Model Setup

The numeric modeling software selected for this study was FLOW-3D, developed by Flow Science Inc., Santa Fe, New Mexico. The software solves the Reynolds-averaged Navier-Stokes equations to predict steady-state and transient flow fields in the model domain and includes the various models for the creation, transport and dissipation of turbulent kinetic energy. Flow-3D uses a Fractional Area/Volume Obstacle Representation (FAVOR) method (Hirt and Sicilian, 1985) for the modeling of solid objects, such as the discharge tunnel.

For this study, an existing model of the preliminary layout of the discharge system under stand-alone operations was used. Any changes to the system in how the brine and dilution streams combine and enter the discharge tunnel should have minimal effects on the flow field in the pond and thus contact time in the discharge pond.

The CFD model domain consisted of approximately 100 ft of the brine and dilution pipelines and the separate vaults they enter, the discharge tunnel (note, upstream from the dilution vault, the tunnel will be blocked off when stand-alone operation begins), the full pond bathymetry based on original design drawings provided by Poseidon, 100 ft of a two-sided culvert under the road, and the full length (350 ft) of the jetty channel based on an estimated channel geometry derived from aerial imagery and design drawings. The full model domain is illustrated in Figure 1.

The upstream boundary conditions for the brine and dilution pipes were specified as 60 MGD with a salinity of 67 ppt and 171 MGD with a salinity of 33.5 ppt, respectively. As noted above, the existing discharge tunnel was blocked off upstream of the vaults, thus no boundary condition was needed. Two downstream boundary conditions in the form of water level elevations were investigated: MHW (2.32 ft) and MSL (0.41 ft).

To trace the potential flow path entrained organisms would take, neutrally-buoyant, passive marker particles were injected into the model as a block spanning the full width and height of the discharge tunnel directly under the brine vault. A total of 393 particles were injected into in the model for tracking. Marker particles do not affect the fluid dynamics, they simply move based on the velocity field.

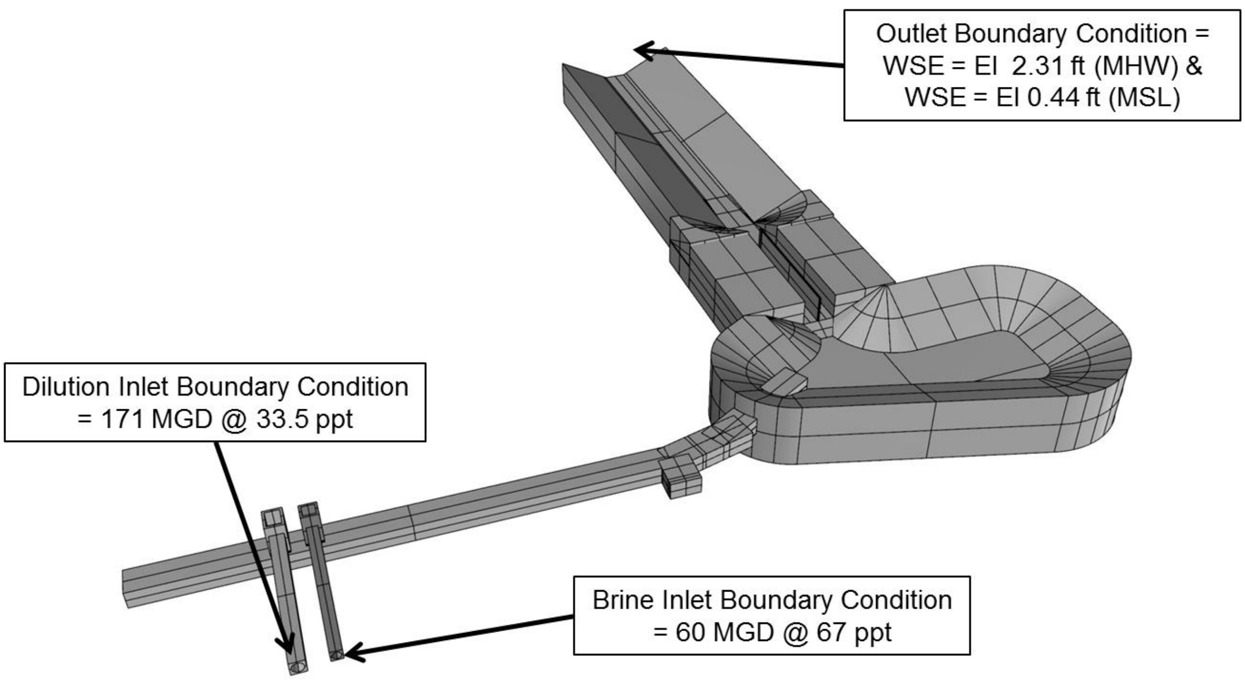

Figure 1: Model Domain with Boundary Conditions

Results

For this study, the exposure start and end points that were of interest were from when the particles first started exiting the discharge tunnel to the time they left the pond (i.e., exit via the culverts). Given that the particles were released in a block in the discharge tunnel beneath the brine vault, the particles have spread out over some distance by the time they reach the end of the discharge tunnel. The contact time for this investigation started when the first particles left the discharge tunnel rather than when all particles had exited.

The flow pattern in the pond does not result in a direct path from the discharge tunnel to the culvert or pond exit. The flow field sets up with two counter-current recirculating eddies (one clockwise, one counter-clockwise) in the pond with the primary recirculation passing in close proximity to the culvert exit. Due to the flow dynamics, some particles did pass directly from the exit of the discharge tunnel to the pond exit while others entered the recirculating eddies of the pond.

Figure 2 provides a representative snapshot of the flow field in the pond (given as flow streamlines) for the MHW condition. Note that this flow field will change slightly from time step to time step but the presented time step is considered typical of the flow field in the pond. Figure 3 provides a representative snapshot of the flow field in the pond (given as flow streamlines) for the MSL condition. Note that this flow field is similar to that seen at MHW in that it has two recirculations; however, the size and exact paths of those recirculations are slightly different. These differences in flow patterns cause differences in the exposure duration between the two conditions (MHW and MSL).

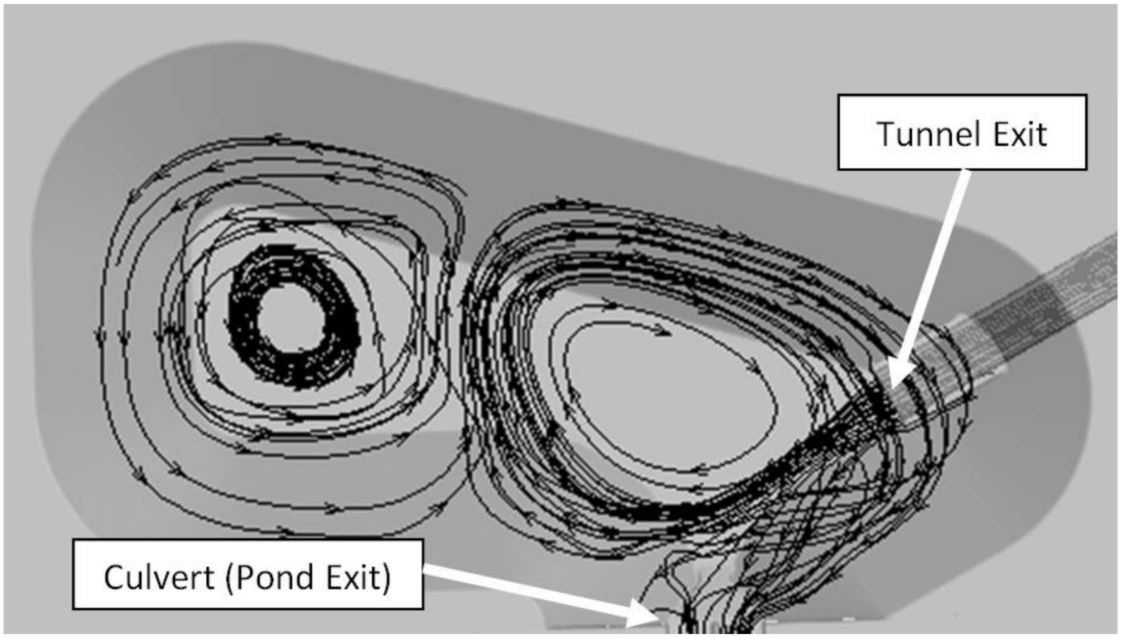

Figure 2: MHW Pond Recirculations Given as Flow Streamlines.

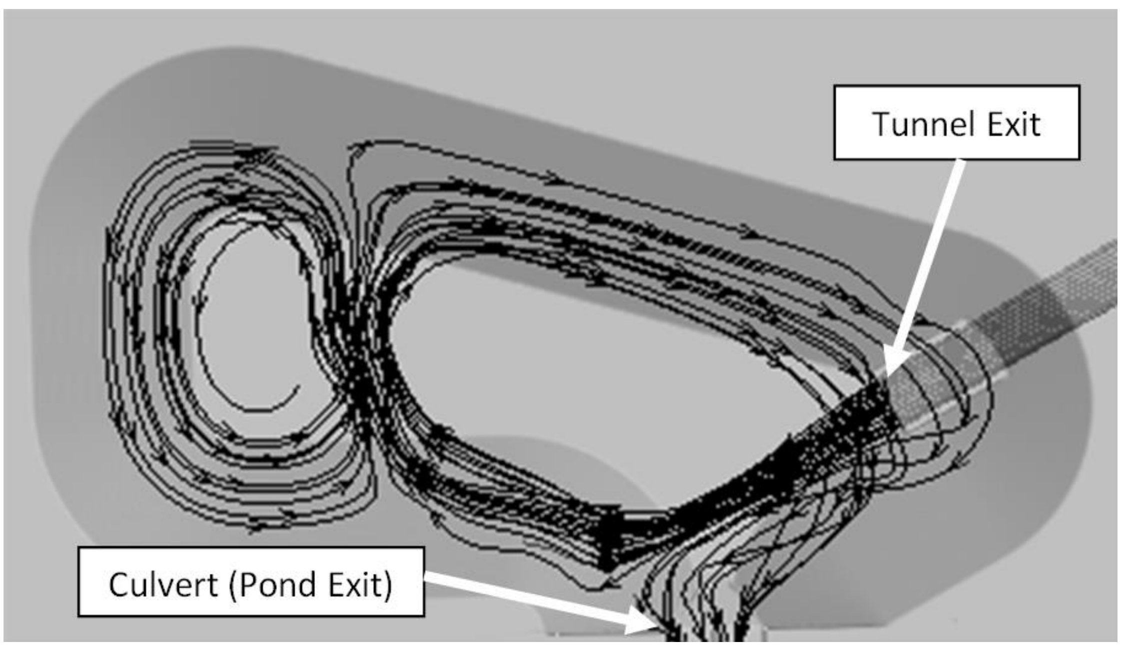

Figure 3: MSL Pond Recirculations Given as Flow Streamlines.

Particles followed different paths through the pond resulting in different contact times (under both water level conditions). To capture the variable exposure times associated with the individual particle tracks, a cumulative distribution plot was developed to capture the range in the results as seen in Figure 4. The plot presents the percentage of the 393 particles that were injected into the model that have left the pond (via the culvert) over time for both MHW and MSL conditions.

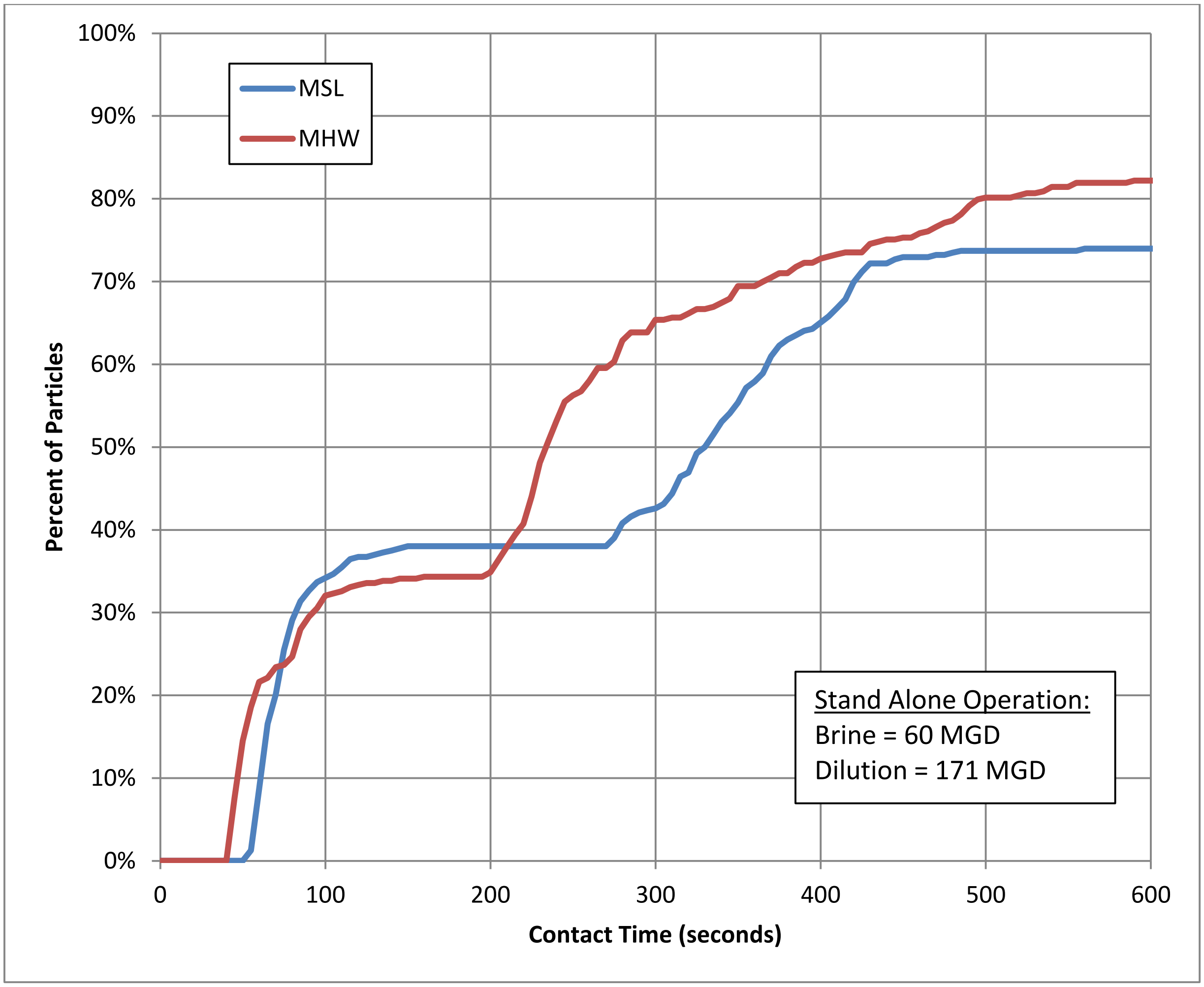

Figure 4: Contact Time in the Discharge Pond for MHW and MSL Results

Particles exit the pond earlier under MHW than under MSL. This is due to the flow streamlines under MHW taking particles closer to the culvert exit from the pond than under the MSL condition, resulting in the particles reaching the pond exit faster. Figure 4 then shows a flat spot in both sets of results with no additional particles leaving the pond as the remaining particles make their way around the recirculation or into the secondary recirculation. Note that this flat spot is longer for the MSL results since the primary recirculation is wider when comparing the flow fields in Figure 2 and Figure 3 and thus takes longer to get around.

In the 200-300 second range, we see an uptick in the particles that are leaving the pond for both conditions. This indicates that the particles have made their way around the recirculation again and some are close enough to find the culvert entrance (exit to the pond). In the 400-500 second range, particles exiting the pond begin to taper off under both water level conditions as the majority of the particles have exited the pond and the remaining particles are distributed across both recirculations providing infrequent opportunities to exit. The model was ran for a total of 600 seconds; time constraints precluded running the model until all particles had exited the pond.

Conclusions

Half of the particles (50%) have left the pond for the MSL condition by 330 seconds (5.5 min) compared to 235 seconds (3.9 min) for the MHW condition. The difference in exposure duration relates to the larger primary recirculation seen in the MSL results and the additional time it takes for particles to travel the flow path through the recirculations.

Seventy percent (70%) of the particles for MSL and MHW have left the pond by 420 seconds (7 min) and 365 seconds (6.1 min), respectively. The remaining particles are well distributed throughout the pond at the 600 sec mark.

Note, that these results are based on a single snapshot of the flow field for each condition. There exist small variabilities in the flow field of the pond. This variability may lead to streamlines passing closer to the pond exit or further away which would result in a change in the results; however, we do not feel the difference would result in substantial changes to the exposure times presented above. Also note that the water level is never static for the discharge system in the field as water level varies by tidal stage. In the model, however, water level was static.

References

Hirt, C.W., Sicilian, J.M. "A Porosity Technique for the Definition of Obstacles in Rectangular Cell Meshes". Flow Science, Inc. New Mexico. August 1985.