PNNL-16121

Pacific Northwest National Laboratory
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Forebay Computational Fluid Dynamics Modeling for The Dalles Dam to Support Vortex Suppression Device Studies
Memoradum for Record

C.L. Rakowski
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September 2006

Prepared for the U.S. Army Corps of Engineers
Portland District, Portland, Oregon
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Summary

A computational fluid dynamics (CFD) model (STAR-CD) was used in an investigation into the suppression of a surface vortex that forms in the south-most spilling bay at The Dalles Project. The CFD work complemented studies at the prototype and the reduced-scale physical models. The CFD model was based on a model developed for other work in the forebay but had additional resolution added near the spillway. Vortex suppression devices (VSDs) were to be placed between pier noses and/or in the bulkhead slot of the spillway bays.

The simulations in this study showed that placing VSD structures or a combination of structures to suppress the vortex would still result in near-surface flows that would be entrained in a vortex near the downstream spillwall. These results were supported by physical model and prototype studies. However, there was a consensus of the fish biologists at the physical model that the fish would most likely move north. If the fish went under the VSD, it would immediately exit the forebay through the tainter gate and not be trapped between VSDs or the VSDs and the tainter gate if the VSD's draft was deep enough.

Acknowledgments

Financial support was provided by U.S. Army Corps of Engineers Portland District. This work was funded under the Columbia River Fish Mitigation (CRFM) Program and specifically The Dalles Juvenile Fish Passage Program. This work benefited from the technical support provided by Laurie Ebner, Bob Wertheimer, and Randy Lee of the US Army Corps of Engineers, Portland District.

Abbreviations and Acronyms

BGS	Behavior Guidance System
CENWP	U.S.Army Corps of Engineers, Portland District
CFD	computational fluid dynamics
ERDC	Engineer Research and Development Center
kcfs	thousand cubic feet per second
PNNL	Pacific Northwest National Laboratory
STL	stereolithography
TDA	The Dalles Dam
USACE	U.S. Army Corps of Engineers

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1.0 Introduction

Work is ongoing to improve survival of juvenile salmonids migrating past The Dalles Project. As part of that effort, a spillwall was constructed between spill bays 6 and 7 in 2004. The spillwall confines spill typically to Bays 1-6 which has reduced direct injury of juvenile fish in the stilling basin. The spill between Bays 1-6 is evenly distributed between bays. The equal distribution of spill is necessary for good egress conditions to exist in the stilling basin. As a consequence of the spill pattern and the forebay shape, a strong vortex develops near the pier noses in the forebay and is magnified at the southern most spilling bay, typically Bay 6. The vortex creates a very large surface feature that could be increasing the number of juveniles passing through the southern bays (5 and 6) where survival is not as high as in other bays (1-4).

The next step in improving survival for juvenile salmonids migrating past The Dalles is the investigation of the potential suppression of the vortex. The study used a computational fluid dynamics (CFD) model, the physical models, and field studies to design and test concepts for vortex suppression devices (VSDs). This report documents the CFD model used in the investigation. In 2005, PNNL developed a numerical model of The Dalles forebay to aid the process of siting a Behavior Guidance Structure (BGS). This CFD model was refined in the area of the spillway to be able to evaluate the VSDs.

The original concept was an 8 to 12 ft draft structure in the existing bulkhead slot or on the pier nose. Preliminary evaluations were made in the 1:25 Engineer Research and Development Center (ERDC) physical sectional model (Memorandum to the files from Laurie Ebner dated 7/13/2006). At the physical model, they found that:

1. A VSD in the bulkhead slot was not effective at suppressing the vortex, especially when compared to the device on the pier nose,

2. When the VSD was used to suppress the vortex at 21 kcfs, the discharge through the gate was larger than without the VSD, and

3. The deep VSD draft caused strong oscillations between the VSD and the tainter gate.

CFD runs were used to provide flow fields for the whole forebay rather than just in the vicinity of the spillbay with the structure added. These runs were used to add additional insight into the potential impacts of various VSD configurations.

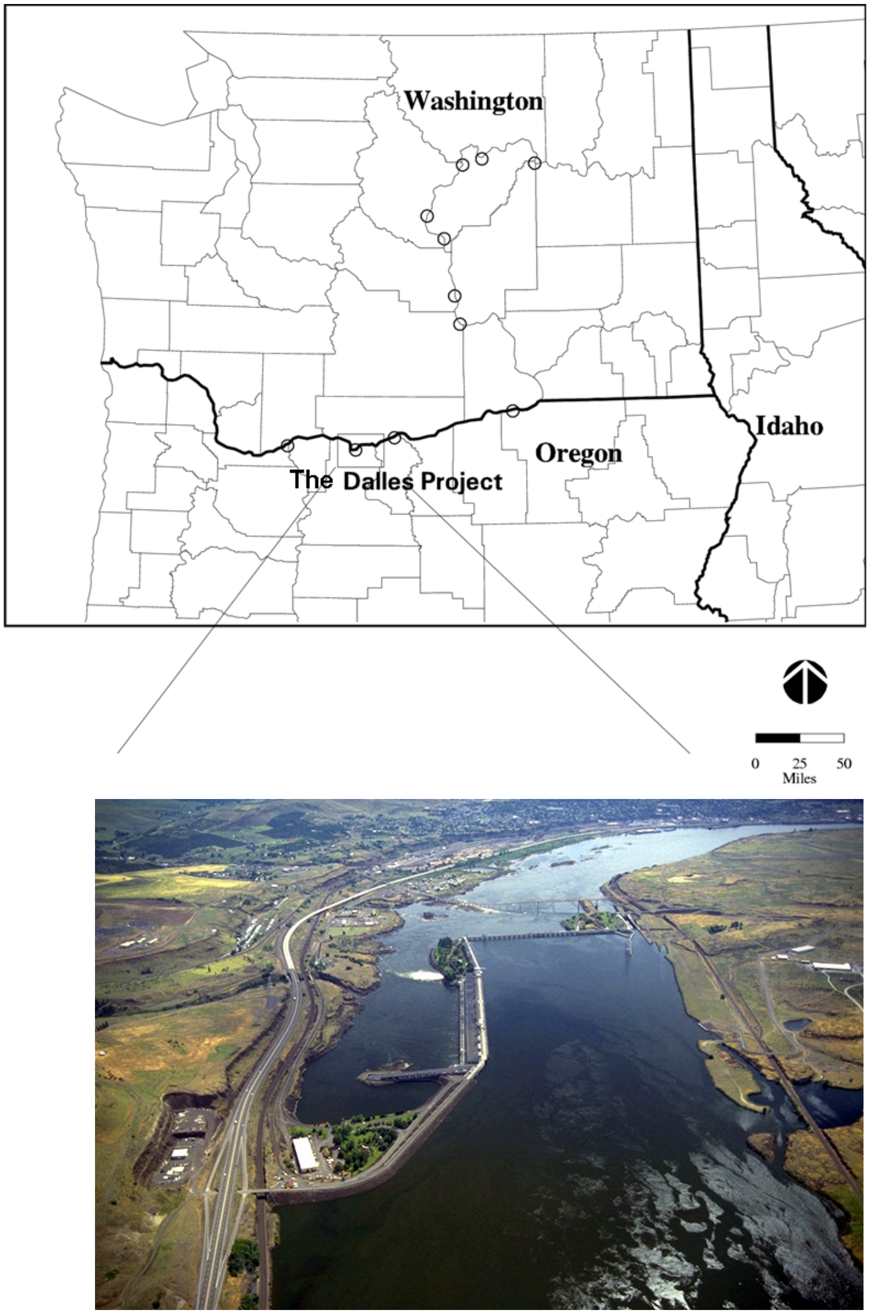


Figure 1.1. Location of The Dalles Project. Looking downstream, the powerhouse is on river left, running parallel to the shoreline; the spillway is across the channel.

2.0 Methods

The computational mesh developed for the length and depth selection process for the BGS was, for the most part, re-used for these simulations. The computational mesh and the underlying data are documented in Rakowski et al. (2006). Whereas the BGS work was most concerned with the details of flow near a BGS structure near the powerhouse, this study was concerned with the details of flow in and near the spillway, especially near Bays 5 - 7. In addition, the ability and flexibility to add walls of multiple depths in the bulkhead slots and at the pier noses of the spillway was required. Consequently, a computational mesh that provided greater resolution in the vicinity of the spilling bays and included the bulkhead slot locations was needed.

All simulations were run in STAR-CD (ADAPCO 2004), a commercial CFD solver, with a standard k-epsilon high Reynolds number turbulence closure. The simulations used a rigid lid with a slip wall at the water surface. Flows were specified as velocities at the powerhouse and spillway boundaries.

2.1 Model Development

A new computational mesh for a single spillway bay was created from STL files created of The Dalles spillway for other work. The computational mesh was created in Gridgen (Pointwise 2003). The gate slots were added to the computational mesh and an extruded layer created on the pier noses to more accurately represent the flow separation of the vortex. This bay was replicated and added to the existing model for spillway Bays 1 to 8, inclusive. Additional refinements were made in STAR-CD for Bays 4 to 7, inclusive, with additional refinement in Bays 5, 6, and 7. The computational mesh from the BGS model was truncated in the powerhouse intakes to reduce the number of cells, and hence run times, without impacting the flow solutions near the spillway.

A preliminary run was used to test computational mesh and for comparison to the prototype. It was deemed critical to assess the impact of using a rigid lid approximation rather than a free surface simulation. The features of interest are the vortices that form on the most south spilling bays.

2.2 Model Runs

All simulations for main part of this study had the same flow conditions: 315 kcfs Total River with 126 kcfs passing through the spillway. The flow splits through the turbines were 37%, 35%, and 28% for Bay A, Bay B, and Bay C, respectively. Each model run had a potential combination of shallow or deep draft structures in the bulkhead slot or at the pier nose in Bay 6 or in Bays 5 and 6. Shallow draft was 4 feet and the deep draft was 13 feet on pier nose and 10 feet at bulkhead slot.

2.2.1 Model Configuration Summary

:

Model 1 - clean forebay
Model 2 - shallow draft structure at the pier noses in bay 6
Model 3 - shallow draft structure at the pier noses and in the bulkhead slot in bay 6
Model 4 - deep draft structure at the pier noses in bay 6
Model 5 - shallow draft structure at the pier noses in bays 5 and 6
Model 5 with added surface weir in Bay 4
Model 6 - shallow draft structure at the pier noses and in the bulkhead slot in bays 5 and 6
Model 7 - deep draft structure at the pier noses in bays 5 and 6
Model 8 - deep draft structure in the bulkhead slot in bays 5 and 6
Model 9 - deep draft structure in the bulkhead slot in bay 6
Model 1 and Model 9 were used early in this study for comparison to a field study. A field test was scheduled to assess the feasibility of adding structures in the bulkhead slot and the impact to the near-surface flows was assessed using oranges. A simulation with a blockage in the bulkhead slot for a total river of 315 kcfs was used for comparison.

Simulations were run and visualizations and model files were provided to CENWP for use during trips to the prototype and ERDC. Particle traces and streamlines were used to assess flow patterns.

2.2.2 Additional Runs by CENWP

CENWP Hydraulic Design ran additional simulations of the structural configurations desired after observations were made at the ERDC reduced-scale physical model. While at the physical model, it was found that a pair of VSDs, with a shallower draft (8 ft) on the pier nose and deeper draft (12 ft) in the bulkhead slot, did not have the issues with the oscillations nor the large head differential between the structures and the tainter gate found in the other VSD configurations. This paired configuration successfully suppressed the vortex in both the 1:25 and 1:80 scale models and in the 1:80 model had good guidance of confetti into other spillway bays. In addition, it was found that adding training flow through Bay 7 (3 ft opening) greatly improved tailrace egress from Bay 6. If spill were added at Bay 7, then a pair of vortex suppress devices would be needed in both Bays 6 and 7 to move juvenile migrants north where spillway survival is better.

Table 2.1. River flow (in kcfs) and VSD structural alternative for CENWP runs.

Total River	Bay 6	Bay 7
135	x	
135	x	x
225	x	
225	x	x
315	x	
315	x	x
990	x	x

3.0 Results and Discussion

The greatest utility of this project was to have simulation results in hand when making trips to The Dalles Project and to the ERDC physical models. The simulation results provided insight on what to look for and what one might expect. In addition, the cross validation of both the physical and numerical models provided greater confidence in both tools.

3.1 Prototype Trip and Preliminary Results

A trip to the prototype was planned by CENWP to assess the feasibility and effectiveness of a VSD structure in the bulkhead slot. Visualizations for the simulation results the clean forebay and for Model 9 (Figures 3.1 and 3.2) were created prior to the trip. Model 9 had a deep draft structure in the bulkhead slot. Those numerical model results, although not for the exact flows as were observed at the prototype, were used to determine if prototype flow patterns for the prototype clean forebay and with a VSD present in the bulkhead slot were similar to the numerical model results. The simulation results showed strong vortices in Bays 5 and 6 for the clean forebay (Figures 3.1 and 3.2) much like had been reported by others (e.g., Deng et al. (2006), see Figure 3.3). The results for the added structure, however, were not as expected. The streamlines in the simulation results showed a large helical recirculation zone behind the structure with a lateral flow component. In the numerical model results, much of the water circulated behind the structure exited the forebay in a vortex near the wall between Bays 6 and 7. Streamlines in Figure 3.2 were seeded at near-surface locations (elevation 156.5 ft) in front of the spill bay. At the prototype, oranges were used to follow flow patterns. The oranges were tossed into the water upstream of the spill bay. The paths followed by oranges in the clean forebay and with the temporary VSD in place were very similar to the simulation results (pers. comm. WA Perkins, JA Serkowski, PNNL).

3.2 Results from Structural Alternatives

For discussion purposes, the simulations can be grouped as follows: pier nose structures (Models 2, 4, and 5), structures in both locations (Models 3, 6, and 7), and bulkhead slot structures (Models 8 and 9). Models 5, 6, 7, and 8 have structures in both Bays 5 and 6. Placing a second set of structures (or pairs of structures) in Bay 5 had little impact on the simulated streamlines near Bay 6. It should be noted that streamlines are not equivalent to the pathways fish would take. Additional professional judgment will be needed from fisheries biologists to judge the potential impact the deflection of flow lines might have on fish behavior.

3.2.1 Clean Forebay

The clean forebay simulations showed that near-surface flow was efficiently entrained into the Bay 6 vortex and that vortices were at Bays 4, 5, and 6 (Figures 3.1 and 3.4). These results are very consistent with what was observed in the physical model for both the sectional (1:25) and full project (1:80) models as well as at the prototype.

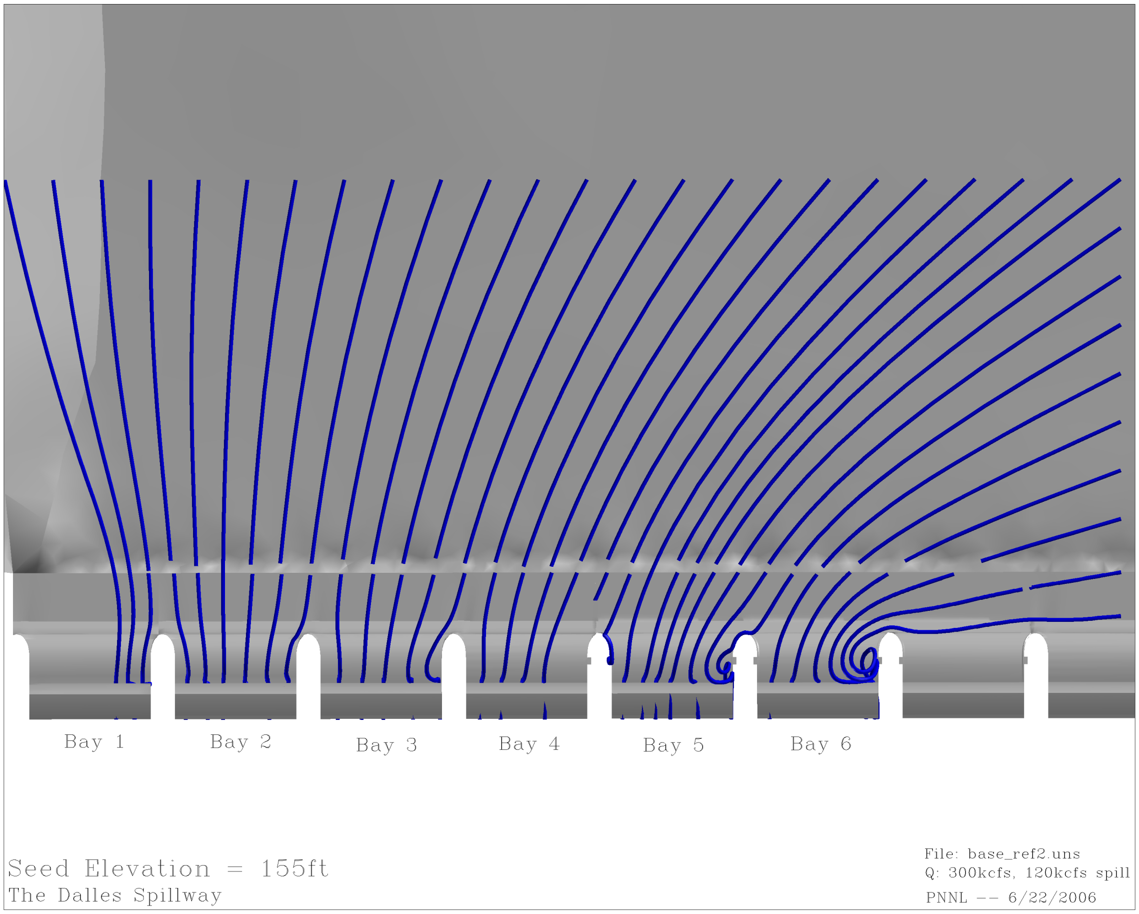


Figure 3.1. Streamlines near Bays 1 to 6 for the clean forebay for a Total River of 300 kcfs. Streamlines were seeded at elevation 155 ft.

3.2.2 Pier Nose Structures

Simulation results for adding structures at the pier noses in Models 2, 4, and 5 (Figures 3.5,3.6, and 3.7) all had similar characteristics. The vortex at the water's surface near the pier nose was suppressed, however a recirculation zone developed behind the structure. The recirculation zone had a large southward component (opposite the lateral flow direction in front of the structure) and the streamlines exited the model in a vortex near the wall between Bays 6 and 7. The deeper the draft of the structure, the deeper the streamlines entrained in the recirculation behind the structure.

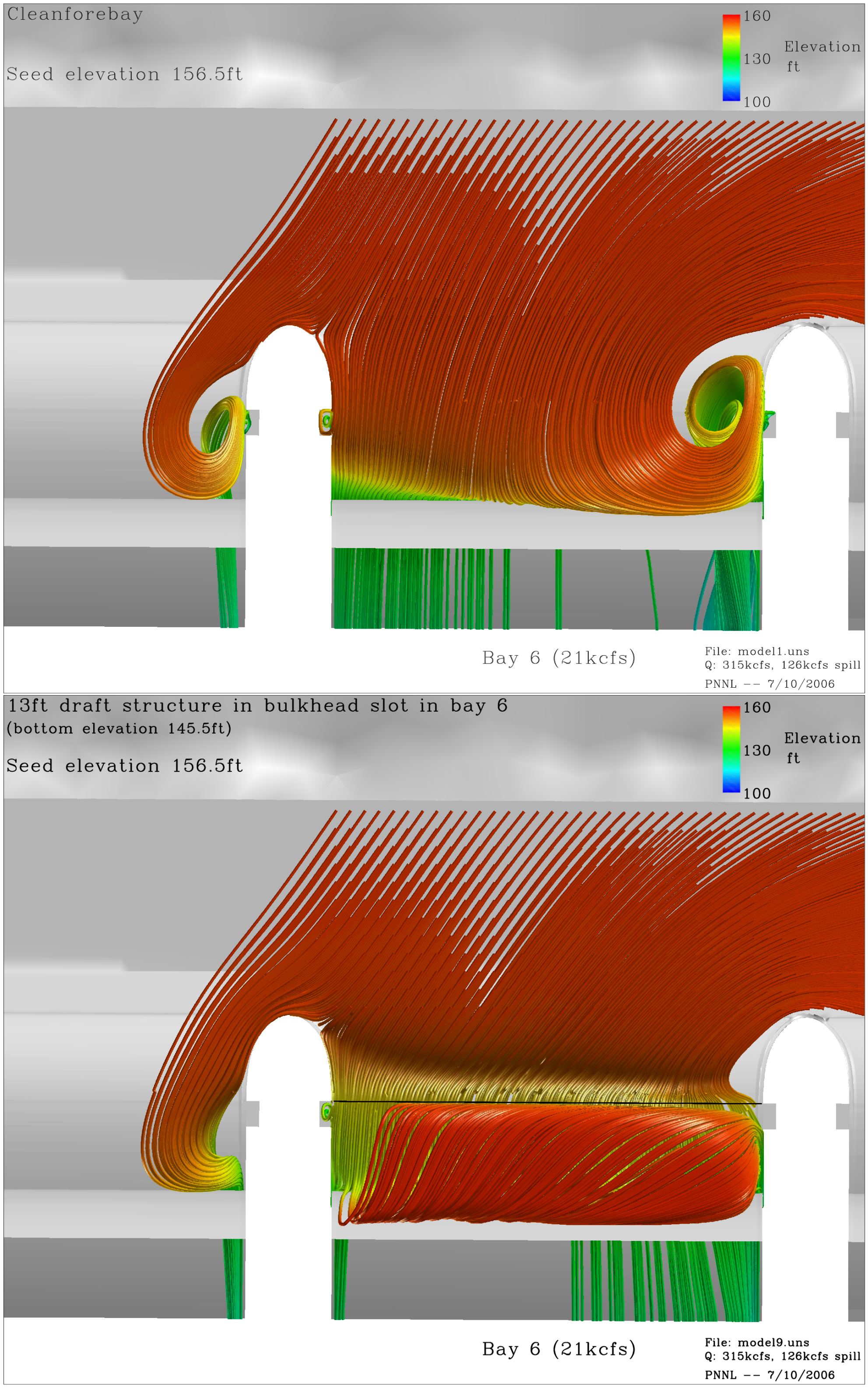


Figure 3.2. Simulation result streamlines near Bay 6 for the clean forebay (top) and for Model 9 (bottom), a deep draft structure in the bulkhead slot of Bay 6. Total River was 315 kcfs, 126 kcfs spill. Streamlines are colored by elevation in the water column.

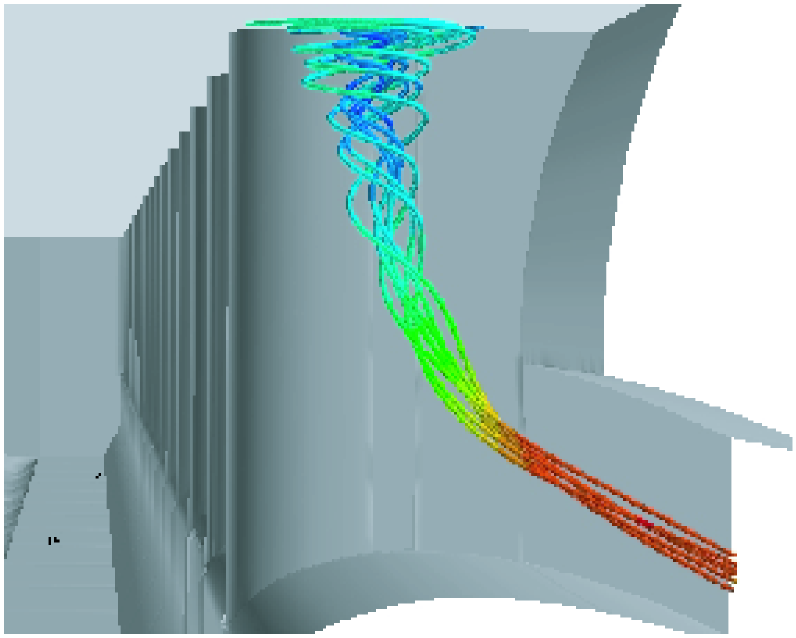
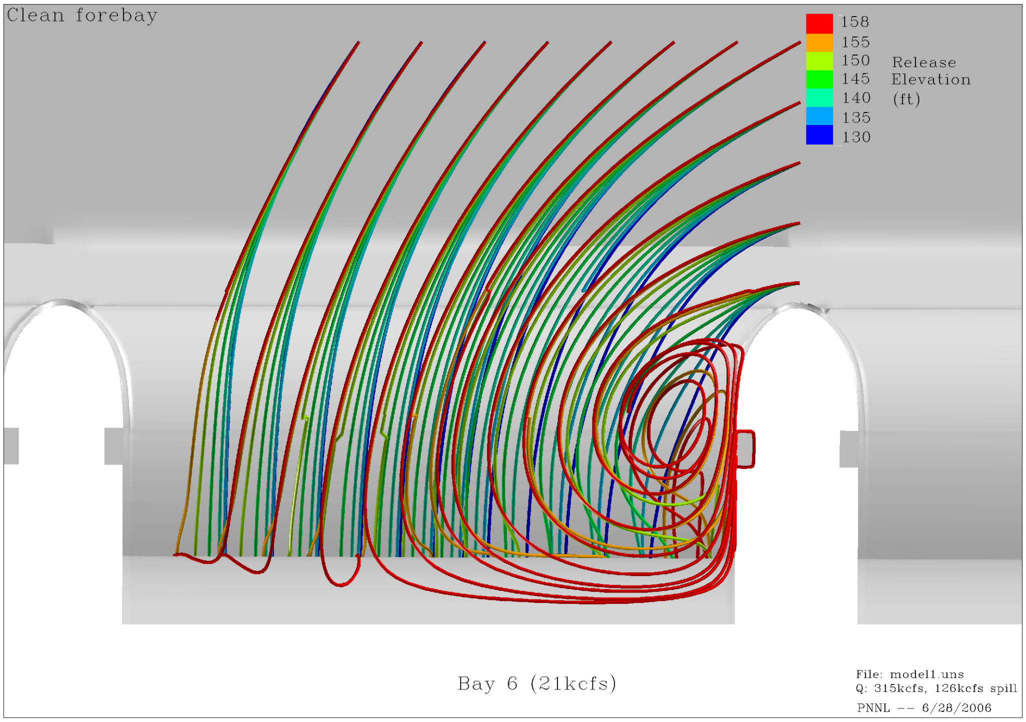


Figure 3.3. Typical vortex structure in the forebay of The Dalles Project near spill Bay 6. The scale of the vortex varies as water swirls downward. Taken from Deng et al. (2006).



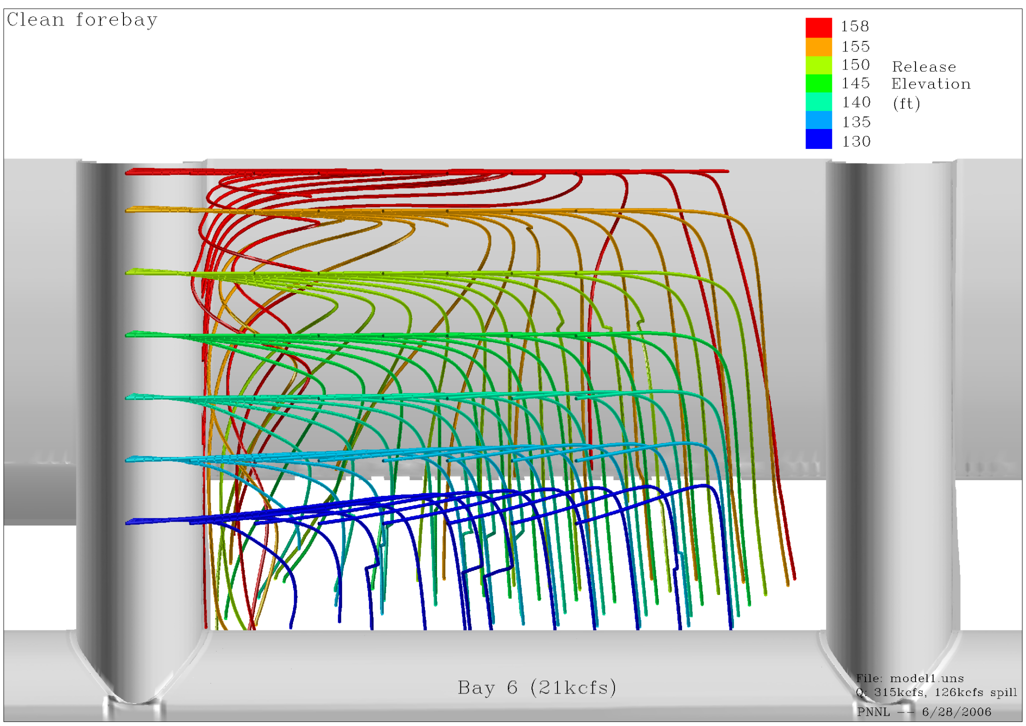
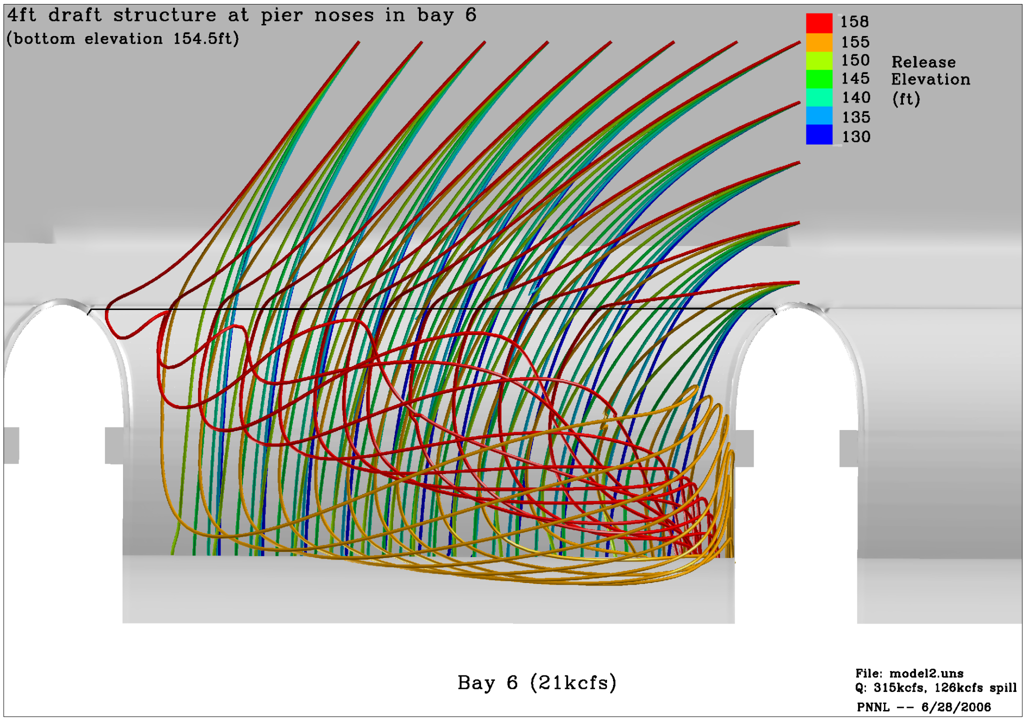


Figure 3.4. Streamlines near Bay 6 for the clean forebay for a Total River of 225 kcfs. Streamlines are colored by release depth. Top figure is plan view, bottom figure is and elevation view looking into Bay 6.



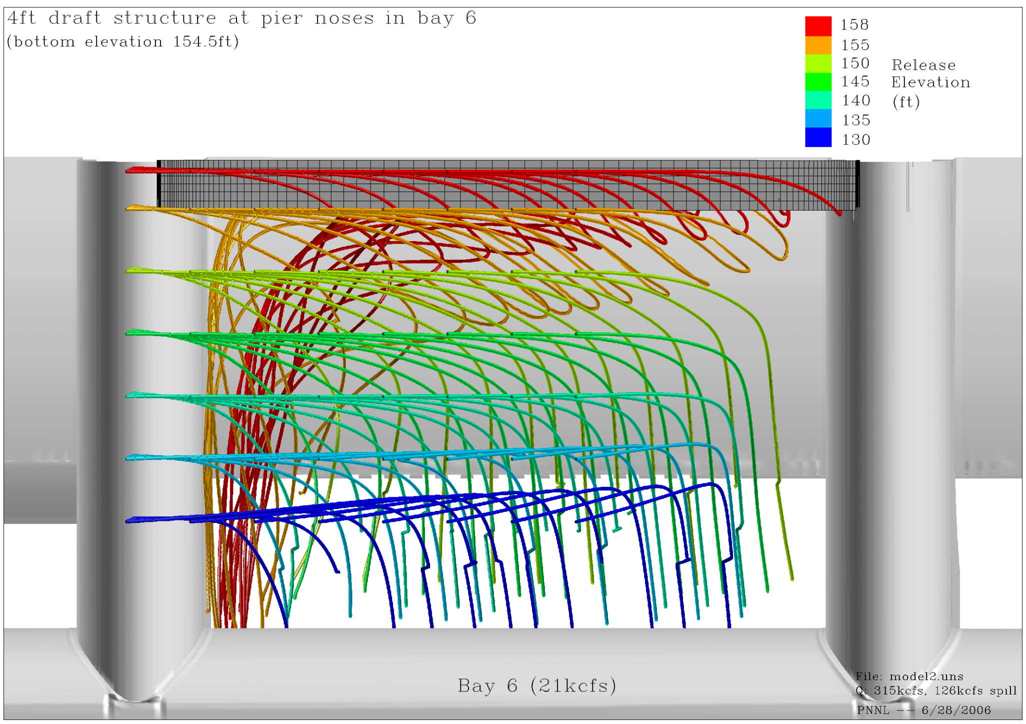


Figure 3.5. Streamlines near Bay 6 for Model 2. VSD is a shallow draft (4 ft) structure at the pier nose in Bay 6. Total River was 225 kcfs. Streamlines are colored by release depth. Top figure is plan view, bottom figure is and elevation view looking into Bay 6.

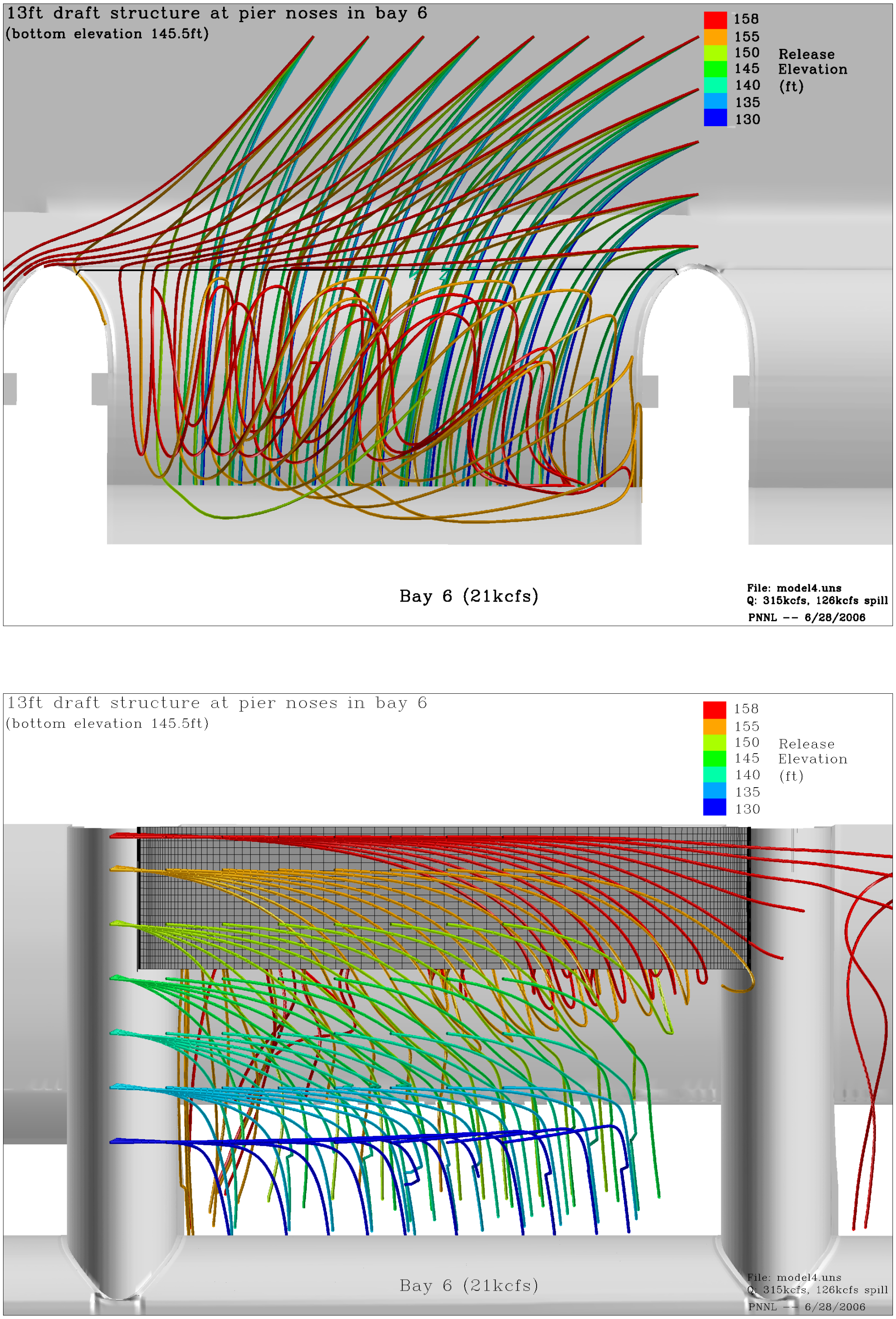


Figure 3.6. Streamlines near Bay 6 for Model 4. VSD is a deep draft (13 ft) structure at the pier nose in Bay 6 for a Total River of 225 kcfs. Streamlines are colored by release depth. Top figure is plan view, bottom figure is and elevation view looking into Bay 6.

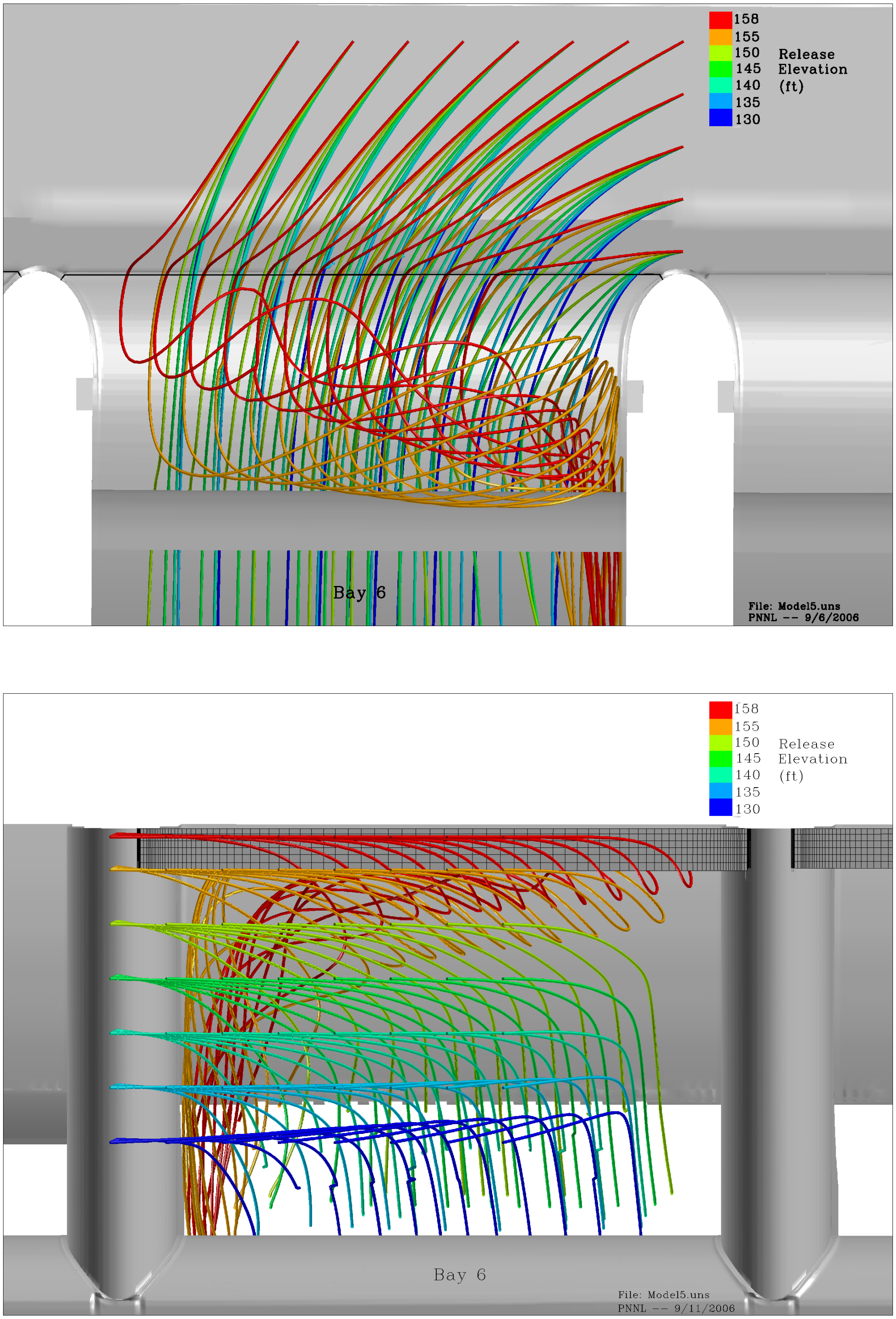
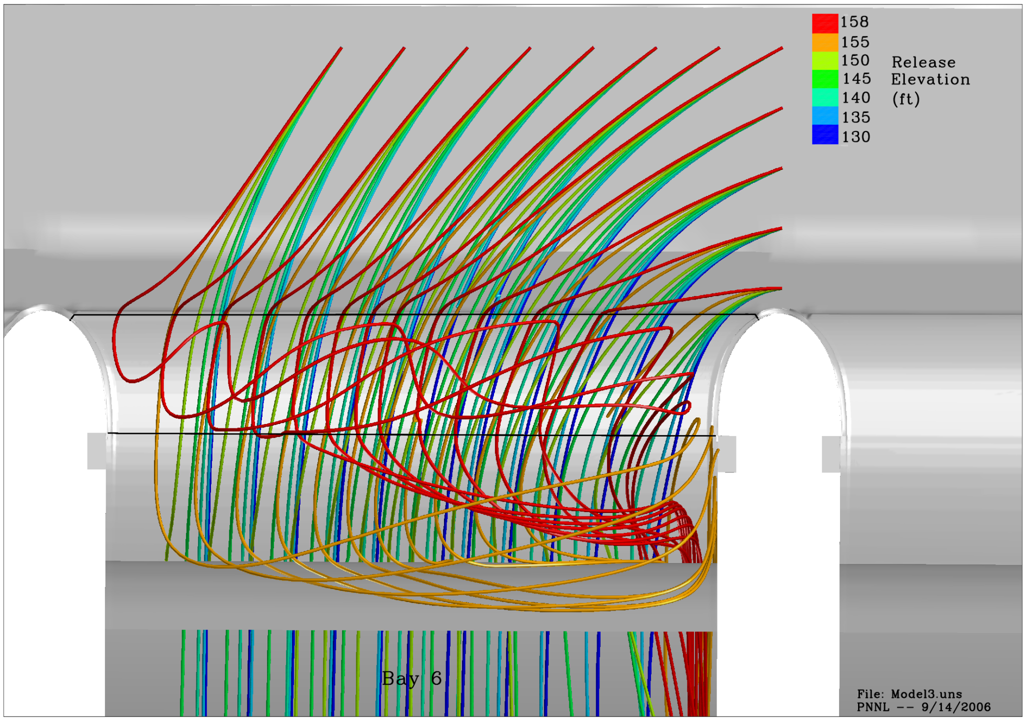


Figure 3.7. Streamlines near Bay 6 for Model 5. VSD is a shallow draft structure at the pier nose in Bays 5 and 6. Total River was 225 kcfs. Streamlines are colored by release depth. Top figure is plan view, bottom figure is and elevation view looking into Bay 6.

3.2.3 Paired Structures at the Pier Nose and Bulkhead Slot

In an attempt to eliminate the recirculation behind a single pier-nose structure, a second structure was added in the bulkhead slot. The results (Figures 3.8, 3.9, and 3.10) all had similar features. For these simulations, there were recirculation zones with a large lateral components behind both structures. The streamlines that entered the recirculation zone behind the structures exited the model domain in a vortex near the wall between Bays 6 and 7. The vortex was suppressed at the surface in front of the structures.



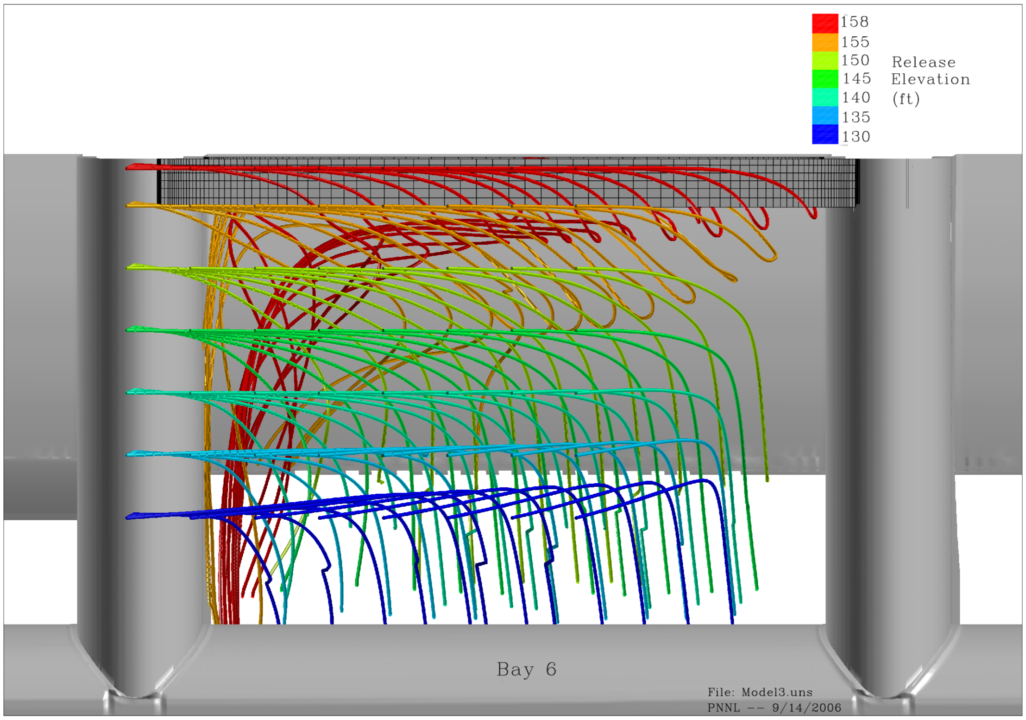


Figure 3.8. Streamlines near Bay 6 for Model 3. VSD is a pair of shallow draft (4 ft) structures at the pier nose and in the bulkhead slot in Bay 6. Total River was 225 kcfs. Streamlines are colored by release depth. Top figure is plan view, bottom figure is and elevation view looking into Bay 6.

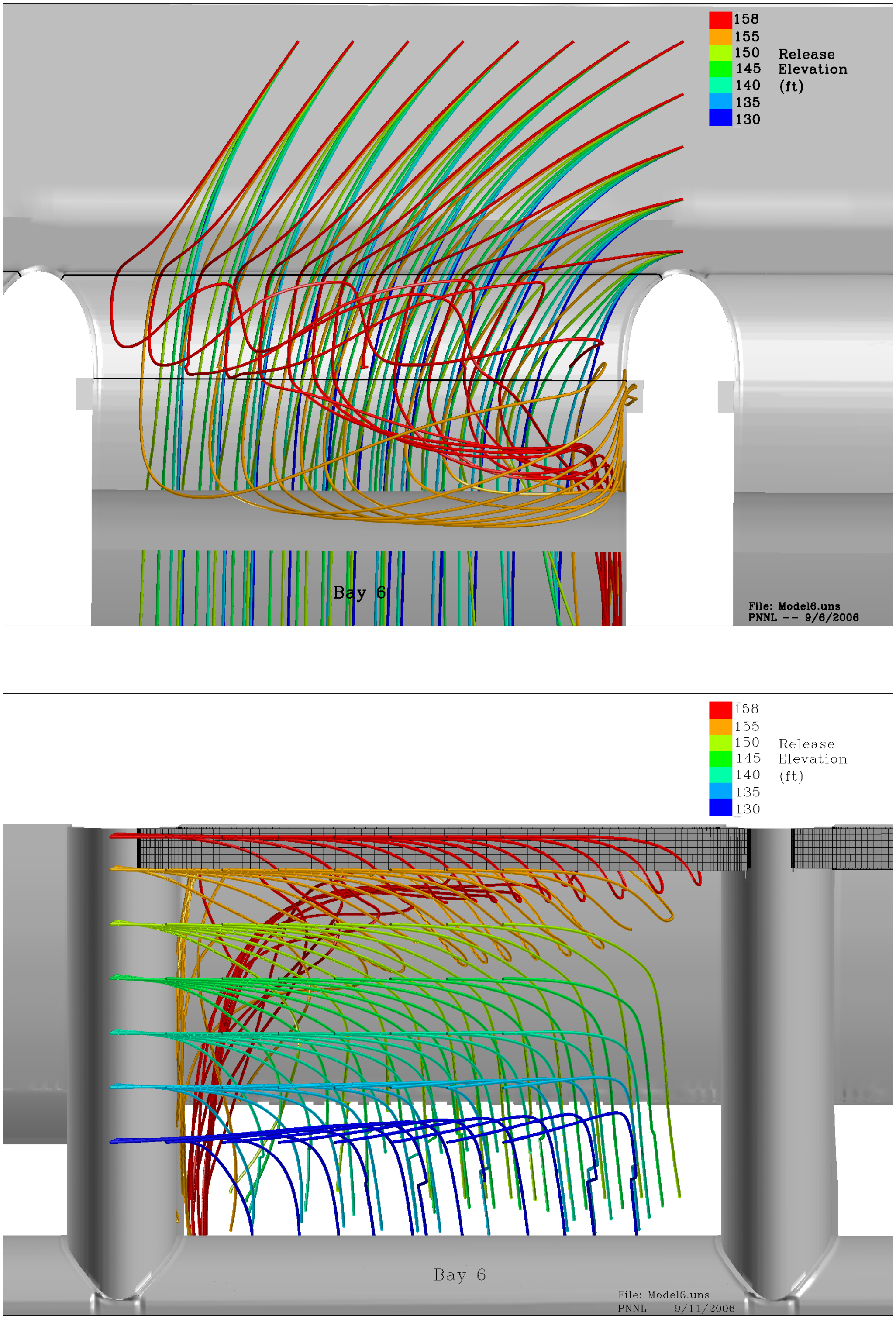


Figure 3.9. Streamlines near Bay 6 for Model 6. VSD is a pair of shallow draft (4 ft) structures at the pier nose and in the bulkhead slot in Bays 5 and 6. Total River was 225 kcfs. Streamlines are colored by release depth. Top figure is plan view, bottom figure is and elevation view looking into Bay 6.

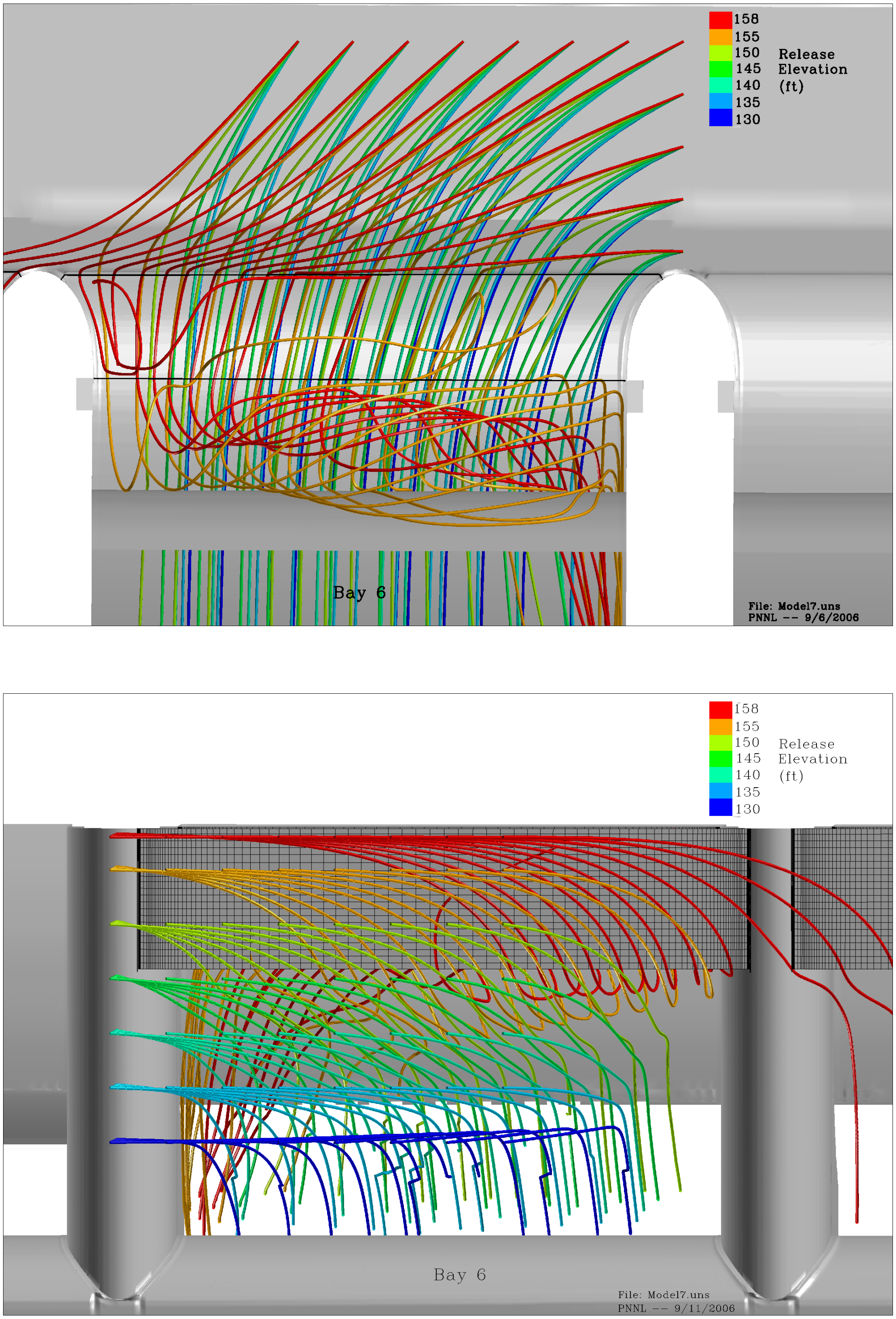


Figure 3.10. Streamlines near Bay 6 for Model 7. VSD is a deep draft (13 ft) structure at the pier nose in Bays 5 and 6. Total River was 225 kcfs. Streamlines are colored by release depth. Top figure is plan view, bottom figure is and elevation view looking into Bay 6.

3.2.4 Bulkhead Slot Structures

Simulation results with structures in the bulkhead slot share flow characteristics with the other structural alternatives, namely a recirculation zone behind the structure. However moving the structure back into the spillway did not completely eliminate the surface vortex near the pier nose (Figures 3.11 and 3.12). This is consistent with observations at the prototype and in the physical model.

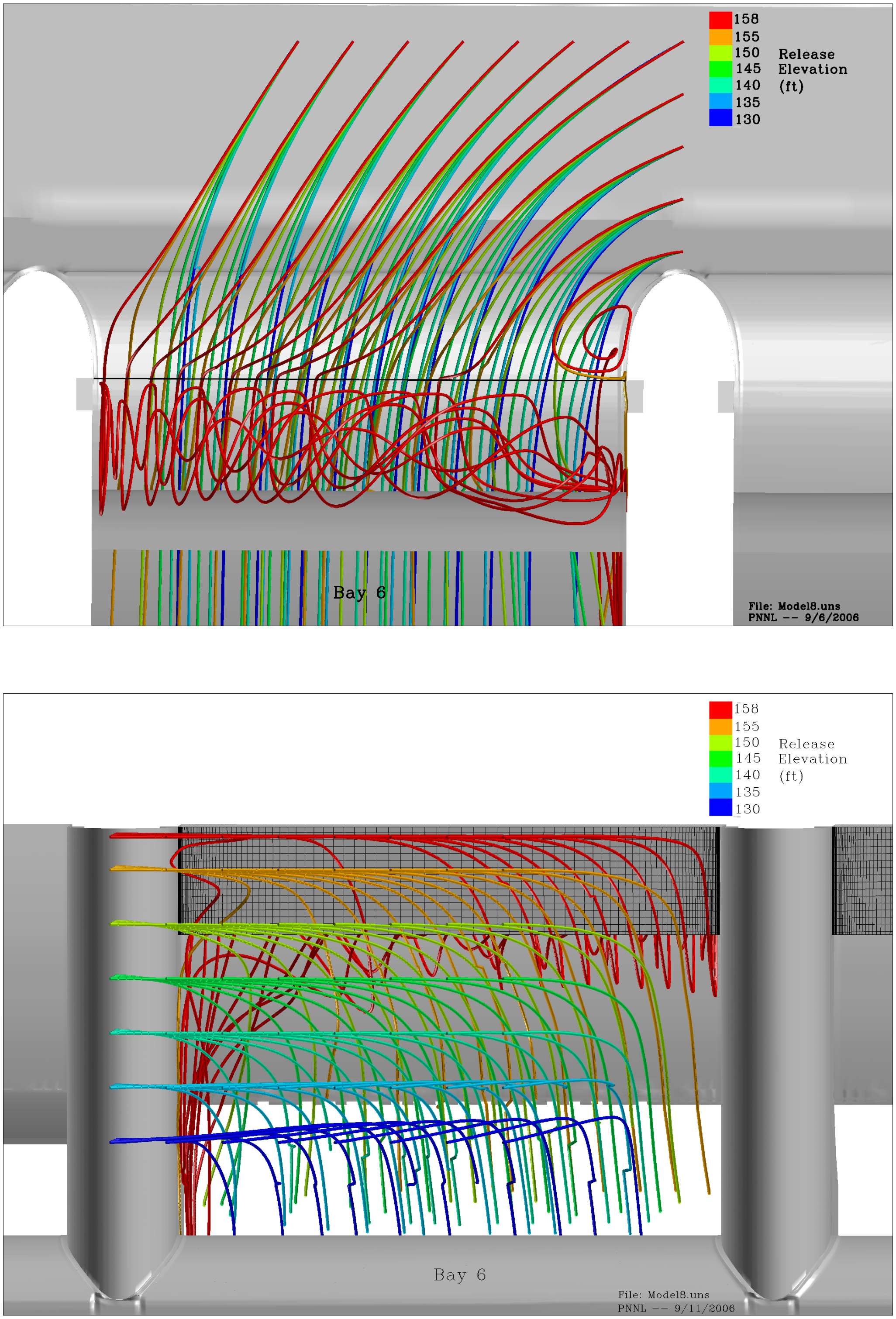


Figure 3.11. Streamlines near Bay 6 for Model 8. VSD is a deep draft (10 ft) structure in the bulkhead slot in Bays 5 and 6. Total River was 225 kcfs. Streamlines are colored by release depth. Top figure is plan view, bottom figure is and elevation view looking into Bay 6.

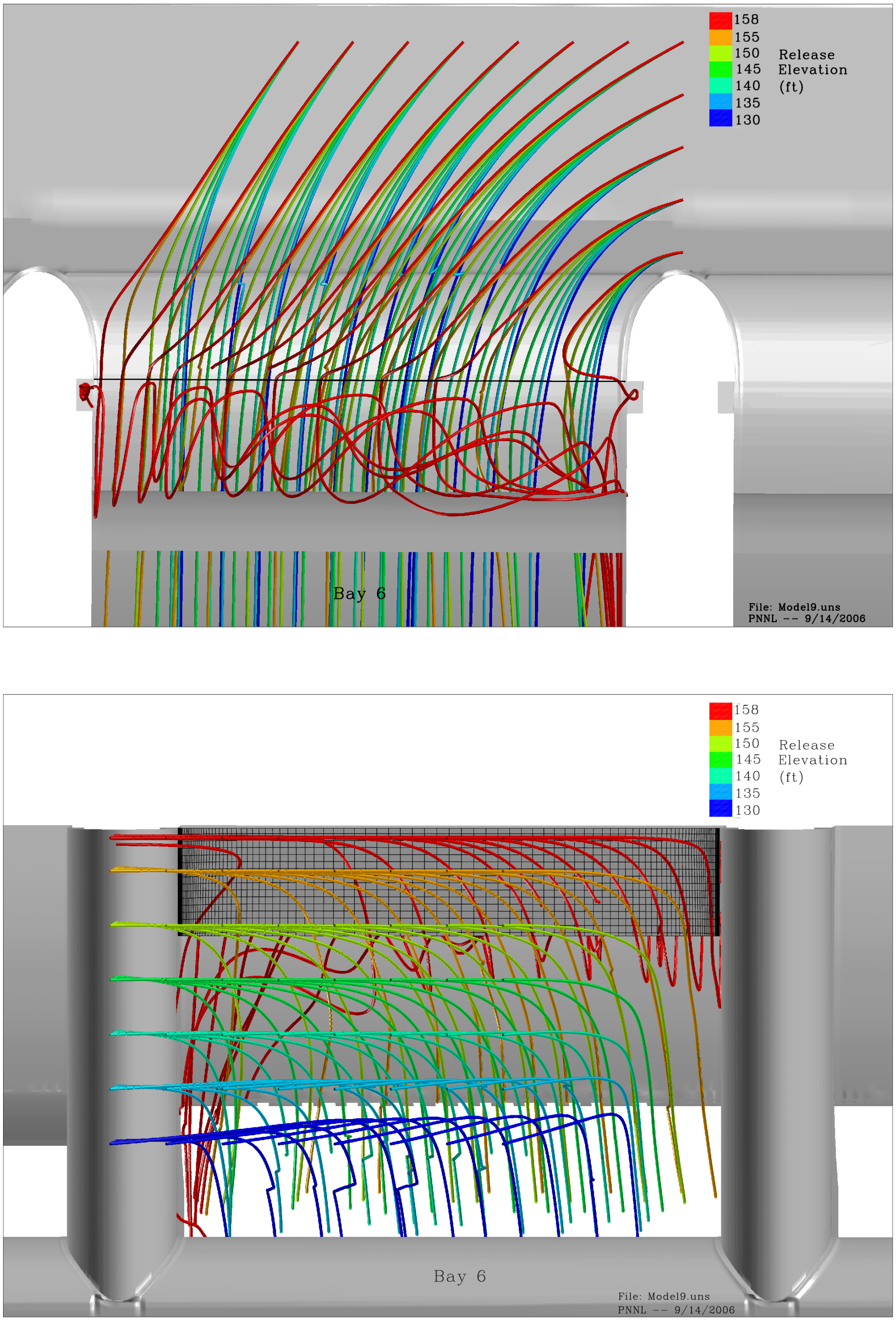


Figure 3.12. Streamlines near Bay 6 for Model 9. VSD is a deep draft (10 ft) structure in the bulkhead slot in Bay 6. Total River was 225 kcfs. Streamlines are colored by release depth. Top figure is plan view, bottom figure is and elevation view looking into Bay 6.

4.0 Conclusions

In summary, the simulations in this study showed that placing VSD structures or a combination of structures to suppress the vortex would still result in near-surface flows that would be entrained in a vortex near the downstream spillwall. These results were supported by physical model and prototype studies. However, there was a consensus of the fish biologists at the physical model that the fish would most likely move north into bays with better survival. If the fish went under the VSD, it would immediately exit the forebay through the tainter gate and not be trapped between VSDs or the VSDs and the tainter gate if the VSD's draft was deep enough.

5.0 References

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