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Hydraulic Model Study of the American River Pumping Station, Phase II Redesign

U.S. Department of the Interior
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14. ABSTRACT
Prior to construction of the Auburn Dam cofferdam on the American River, Placer County Water Authority (PCWA) was pumping their water allotment from the river near the construction site for the dam. Unfortunately, the dam was never completed leaving only the 257-ft-high cofferdam across the river with a diversion tunnel. PCWA has contracted with Arctic Slope Technical Services to design a new river screening and pumping station adjacent to the partially removed Auburn cofferdam.

This report discusses the results from a hydraulic model of the proposed bottom screen for the American River pumping Station in California. The study provided information on the flow conditions for the existing channel design and identified potential changes in channel geometry at key locations that would improve flow conditions, channel stability, and movement of course bed material through the constructed reach.

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Mission Statements

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The mission of the Bureau of Reclamation is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public.

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I would also like to acknowledge the work of Mr. George Slovensky from ASTS who provided the designs, drawings, and flow information for the model construction and changes throughout the study.

Peer review was provided by Brent W. Mefford of the Water Resources Research Laboratory.

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Executive Summary

This section summarizes the results from the report "Hydraulic Model Study of the American River Pumping Station, Phase II Redesign". The model study was conducted for Reclamation's Mid Pacific Regional Office while a redesign of the project was being finalized by Arctic Slope Technical Services (ASTS). The initial objective of the model study was to evaluate flood flow conditions within the reach from the diversion tunnel entrance to downstream of the proposed screened pump intake diversion for the Placer County Water Agency (PCWA). The model study initially focused on evaluating flow conditions associated with widening the river channel adjacent to the cofferdam with particular attention to stability of the Auburn cofferdam remnant. The model was initially constructed based on a preliminary river centerline with the phase I Auburn cofferdam remnant partially removed to widen the river channel to about 140 ft with the cofferdam slope laid back to 3:1. Initial investigations included documenting the upstream river channel flow conditions including the necessary diversion tunnel fill and upstream river channel flow velocities. Alternative A2 based upon the April 2005 draft specifications for the pumping plant screened intake was then installed in the model and tested. The geometry for the pumping plant intake and main river channel was then investigated based upon the June 2005 Concept C specifications and recomputed hydrologic event frequencies.

The model study resulted in recommendations on; 1) proposed channel widening adjacent to the cofferdam; 2) diversion tunnel fill geometry; 3) initial screened pumping station intake geometry and adjacent channel improvements; and 4) modified screened pumping station intake geometry and adjacent channel improvements with revised flood flows. A summary of major study recommendations follows.

1. Proposed channel widening adjacent to the cofferdam:
    a. Model tests of the 10 year and 50 year floods showed that the 140 ft wide channel with a 3:1 cofferdam slope provided a smooth transition from the upstream river to the reach containing the PCWA pumping plant intake structure.
        i. Figure 6 shows the upstream extent of the cofferdam and the diversion tunnel fill cover material redirect the main river flow toward the opposite bank. Downstream from Sta. 106+00 the flow is concentrated to the outside of the right hand bend as it approaches the pump intake structure.
        ii. Figures 7-10 give the results of extensive 2D baseline velocity measurements gathered to document initial flow conditions for comparison as diversion tunnel fill geometries were investigated.

2. Diversion tunnel fill geometry investigations:

    a. The recommended tunnel fill geometry will improve redirecting the flow away from the cofferdam and reduce fill quantities and placement issues. The final tunnel fill geometry is shown on figures 12 and 13.

        i. Flow conditions at the toe of the fill indicate the diversion tunnel fill would need to be well-keyed and protected.

    b. Observations and velocities showed that the upstream portion of the cofferdam must be protected through about Sta. 106+00. Velocities near the toe of the cofferdam reached 11 ft/s for the flow rate of 72,000 ft^3/s (table 2 and figures 15-17) and up to 18 ft/s for the flow rate of 160,000 ft^3/s (table 3 and figures 22-24).

    c. Sand, simulating coarse bed material in the prototype traveled along the right side of the invert under the 10-year event as shown on figure 18. The invert material itself did not move under this flow rate.

    d. Sand fed into the model under the 50-year event traveled more near the center of the invert as shown on figure 25. Invert material downstream from Sta. 101+00 was eroded from the model indicating a high potential for bed scour in this area.

    e. Riprap sized material on the cofferdam slope did not erode during the tests except near the fixed toe under the 160,000 ft^3/s flow rate.

3. Initial screened pumping station intake geometry and adjacent channel improvements with the recommended diversion tunnel fill geometry:

    a. Dye investigations indicated that the sediment vanes and basins would be effective in diverting and/or capturing material to exclude the majority of material from traveling into the intake channel, figures 28.

    b. Under the 1.5-year event, flow passed over the divider berm between the main channel and the intake. The access road adjacent to the pump intake structure was also flooded.

    c. Supercritical flow occurred across the screened pumping station intake structure under all flow rates. The location of the wave front varied with flow rate but was present over a portion of the screen at all times. Various flow conditions over the screened intake are shown on figures 30, 32, and 35.

    d. The screened pumping station intake channel, and right bank including the access roads were submerged to varying degrees for all flow rates tested above the 1.5-year event, figures 30, 32, and 35.

    e. The main channel area also experienced supercritical flow throughout the reach for all flows tested, figures 29, 31, and 35.

    f. The sediment vanes reduced sediment movement into the intake channel. Bed load material introduced in the model under the flow rates of 72,000 and 160,000 ft^3/s largely deposited upstream from the first sediment vane or was deflected toward the main channel control crest, figure 33. A portion of the bed load material passed into the sediment basins, but was then transported to the left toward the main channel.

g. Bed material smaller than about 2 inch gravel (prototype), scoured from the upstream river channel during operation of the 10-year event of 72,000 ft^3/s.

h. Upstream of the intake structure, the entire mobile bed scoured during tests of the 50-year event of 160,000 ft^3/s, figure 36. Most of this material was diverted by the sediment vanes into the main channel, with the finer, 2 in prototype size material, depositing on the cofferdam slope. The majority of the bed load material moved through the model via the main channel, thus bypassing the intake channel, figure 37.

4. Final Layout - Modified screened pumping station intake geometry and adjacent channel improvements, figure 38, with the final diversion tunnel fill geometry with lower revised flood flow estimates:

   a. Improvements to the divider berm and raising the elevation of the invert of the screened intake structure and adjacent access roads and walls resulted in separate main and intake flow channel and dry site access under the 1.5-year event of 11,900 ft^3/s, figures 41 and 42.

   b. Dye investigations indicated that the sediment vanes and basins remained effective when the vanes were raised 4 ft above the channel invert to El. 495, rather than basins formed by excavation to El. 487, figure 43.

   c. Supercritical flow occurred across the screened pumping station intake structure under all flow rates. Cross waves occurred over the screened intake due to the short expansion section upstream from the screened area of the design. The location of the wave front varied with flow rate but was present over a portion of the screen at all times. Various flow conditions over the screened intake are shown on figures 41, 45, 49, 56, and 59.

   d. The screened pumping station intake channel, and right bank including the access roads were submerged to varying degrees for all flow rates tested above the 1.5-year event, figures 46, 49, 56, and 59.

   e. Control occurred farther upstream in the main channel with this design. Flow was supercritical through the main channel crests and pools over the full flow range, figures 42, 47, 50, 55, and 58. The flow followed a very similar path to the previous design through the main channel until near the end of the model where the flow released more to the right due to the orientation of the channel geometry.

   f. Observations of bed load movement through the model with this geometry indicated very similar results to the previous design. The flow rate for the revised 10-year event was much smaller; therefore, less material was mobilized. The material that did move was largely diverted by the sediment vanes toward the main channel, figures 51 and 52. The 100-year event corresponded to the previous 50-year event and showed almost identical bed load movement and deposition patterns with scour of the upstream channel occurring and the majority of the material passing through the main channel.

Background

Placer County Water Agency (PCWA) in California is responsible for delivering water for municipal and industrial use and irrigation. Prior to construction of the Auburn Dam cofferdam on the American River, PCWA was pumping their water allotment from the river near the construction site for the dam. Reclamation agreed to supply PCWA water from a temporary pumping plant during dam construction. Construction of the dam was halted following completion of a 257-ft high cofferdam and diversion tunnel. Reclamation has been providing water to PCWA, ever since using the temporary facility. In addition, the diversion tunnel has continued to operate. In 1986 the cofferdam was allowed to overtop and fail during a major flood. The cofferdam failure resulted in millions of tons of cofferdam material being deposited downstream from the original cofferdam site aggrading the river channel by tens of feet. The objectives of the current project are to restore the river channel, close the diversion tunnel, and construct a permanent pumping plant and screened intake structure to serve PCWA customers. The project has undergone several design iterations in an attempt to identify viable solutions. The present hydraulic study focuses on the performance of the excavated river channel and screened pump intake structure under flows and bed load sediment movement during flood events.

PCWA contracted with Arctic Slope Technical Services (ASTS) to design the river channel and screened pump intake described herein. A January 24, 2005 design report by ASTS outlined two concepts for the redesign of the intake screen structure aimed at reducing construction costs associated with a previous design [1].

Both concepts had uncertainties outlined regarding river channel stability, erosion potential of the cofferdam remnant and the ability of the screened pump intake channel to handle bed load sediment. The remaining portion of the cofferdam creates a restriction in the river and has the potential to adversely affect operation of the proposed new design for the PCWA screened intake structure for the pumping station. The Coanda screened intake geometry and early river channel design were modeled at Colorado State University [2, 3]. Reclamation's Technical Service Center Water Resources Research Laboratory was contracted by our Mid Pacific Regional Office to investigate the overall flow conditions in the river and identify potential improvements.

Objective

The objective of this study is to provide information on the flow conditions for the existing channel design and identify potential changes in channel geometry at key locations that would improve flow conditions, channel stability, and movement of course bed material through the constructed reach of the Placer Valley Water Authority pumping plant intake structure.

Model Description

The model was constructed to a Froude scale of 1:36. This scale was selected to maximize the extent of the model while still achieving the discharge for the 50-year flood event of 160,000 ft^3/s. Sediment was scaled only by size and good agreement should be attained between 1 mm and larger size prototype and model material. This model scale was appropriate, because only movement of course bed material was to be investigated. The model included about 2500 ft of the American River from approximate centerline stationing of 117+50 upstream to station 92+50 based upon layouts received from ASTS [4].

The model topography was constructed as fixed contours with movable material placed over the hard topography where necessary. In addition, material was fed into the model to investigate movement of prototype course bed material during large flood events. Figure 1 shows the model extents with a 4 ft by 8 ft grid overlay and a photo of model construction. Little river bathymetry data was available upstream of the diversion tunnel, therefore this reach was constructed using above water contours and an invert estimated to be at El. 985. Figure 2 shows more detail of the model contours. Rock contours and excavations already made in the field were modeled along the right bank, looking downstream, between Stas. 110+00 to 106+00. The upstream portion of the river channel to the diversion tunnel was modeled as fixed through Sta. 108+00, except for investigations of fill geometries for the diversion tunnel entrance. The diversion tunnel entrance will be plugged with fill material after completion of the pumping plant intake construction in the river downstream.

During a site visit, the team agreed that the cofferdam remnant as left following Phase One of the project greatly constricted the river cross sectional area and posed channel stability concerns. The river geometry and the high computed theoretical velocities in the constriction lead the team to recommend investigating increasing the channel width and laying back the cofferdam slope to 3:1. ASTS performed a cost comparison and HEC-RAS study and determined that there would be a benefit in further removal of the cofferdam to widen the channel and lay back the cofferdam slope [5]. Therefore, the river channel adjacent to the cofferdam was modeled with a width of about 140 ft (width varied) and a cofferdam slope of 3:1 beginning at Sta. 108+00 just downstream from the current diversion tunnel intake and continuing past the screened pump intake area. The cofferdam was modeled with riprap-sized rock on the 3:1 slope from the floor of the model to El. 540 where the 2:1 slope was constructed using fixed contours above the water level.

The pumping station intake structure was initially modeled as shown on figures 2 and 3. The pumping station intake structure was added between Stas. 102+00 and 94+00 to ASTS April draft specification drawings [4], after initial work in the upstream river section was completed, including determining recommended diversion tunnel fill geometry. The pumping station intake and adjacent main channel areas were constructed of plywood to model field concrete, and of plywood templates and rock where rock or grouted rock will be used in the field.

Flow into the model was measured using the laboratory Venturi metering system. Water flowed into the model through two slotted pipes. A baffle arrangement upstream of the river topography was used to provide a good flow distribution into the river section. Spot velocities were measured at the upstream end of the river channel to ensure that the flow velocities entering the model were fairly uniform across the section, thus providing quality results for the study. The model tailwater was controlled to elevations provided by ASTS at the end of the river model near Sta. 92+50 using vertical slats.

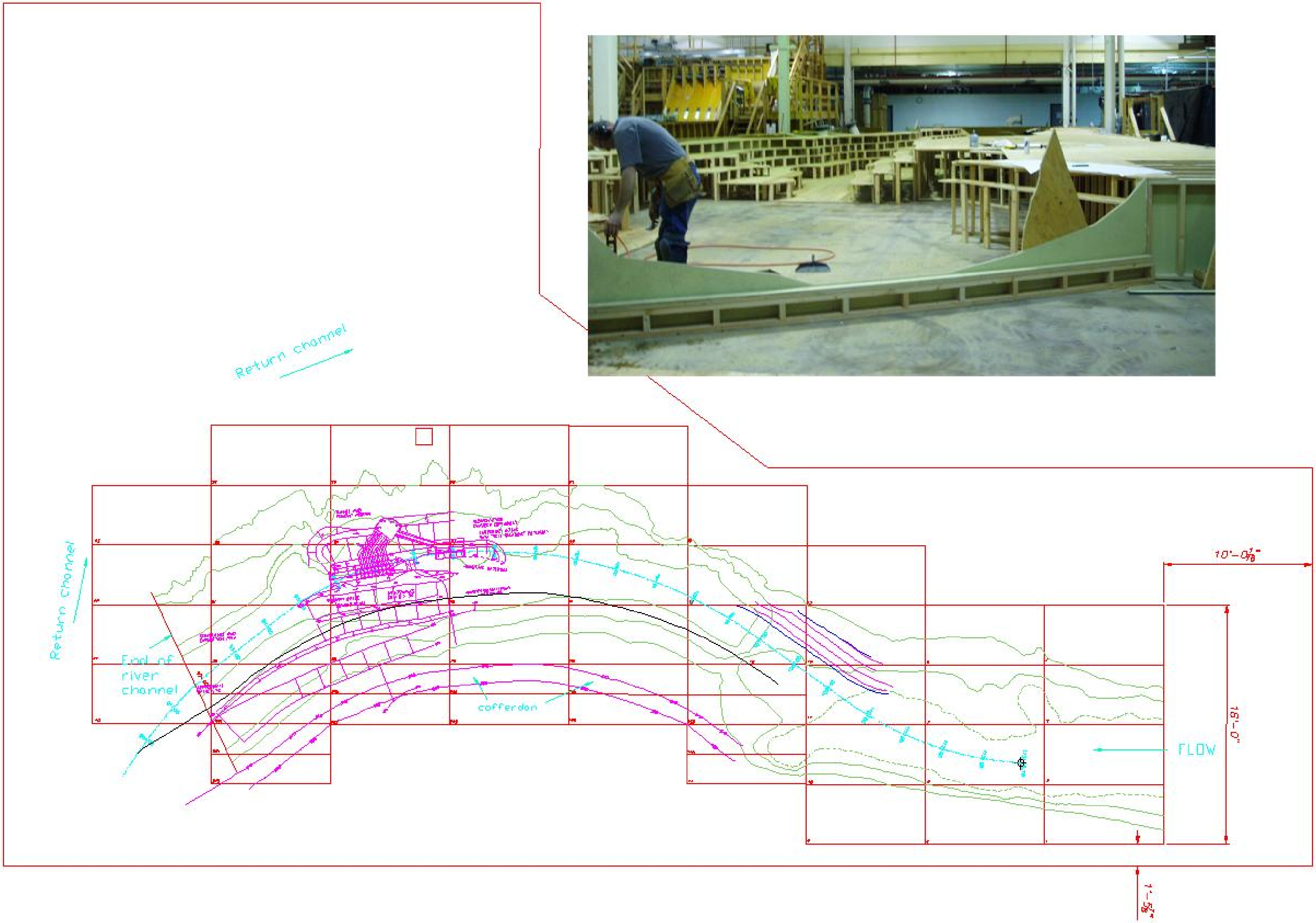


Figure 1. - Plan view of the model layout with 4 ft by 8 ft contour grid system. Construction of contours is shown in the upper right. Flow is from left to right. See figure 2 for detailed design features.

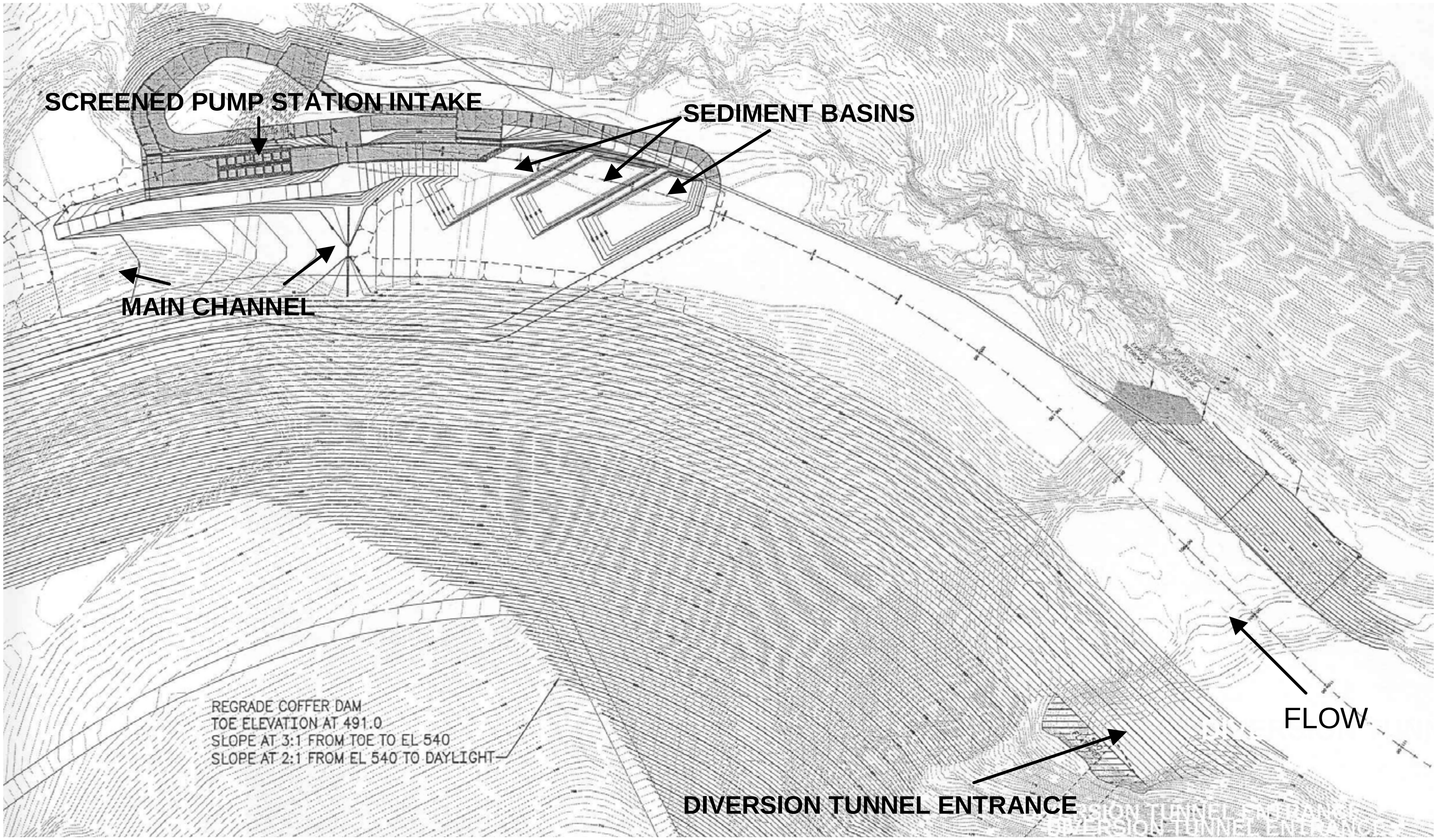


Figure 2. - Plan view of the PCWA American River project showing the diversion tunnel entrance location underneath projected fill, cofferdam, and initial pumping station design.

Figure 3. - Overall view of the 1:36 scale hydraulic model of the American River model showing the upstream river section through the diversion tunnel cofferdam area, the screened intake area, and adjacent main channel. Flow entered the model at the top of the photo.

Test Plan

Initial shakedown runs included setting the baffle structure upstream from the river section to obtain a nearly uniform flow regime as possible entering the river section. Dye and velocities were used to check the flow direction and velocity entering the model at about Sta. 114+00. Part of this process was also to determine the best instrumentation to use for measuring velocity in the model. Both a floating ADCP StreamPro by Nortek for measuring velocity profiles in shallow channels and 2D Flow Tracker ADV by Sontek for measuring two-dimensional point velocities were investigated. After these investigations, it was determined that the point velocities provided better information and; therefore, the ADV was used throughout the remainder of the studies.

Comparisons of model depths and velocities with HEC-RAS runs made by ASTS were made at the most upstream and downstream stations in the physical model. In general, the physical model yielded slightly greater depths and lower velocities than predicted by the HEC-RAS model for like flows.

The hydraulic conditions were evaluated for the 1.5-yr event of 12,300 ft^3/s, 5-yr event of 45,000 ft^3/s, 10-yr event of 72,000 ft^3/s, and the 50-yr event of 160,000 ft^3/s. The model was also operated at the yearly average flow of 1,100 ft^3/s for visual observation.

The hydraulic evaluation included:

- Documenting flow conditions for the existing design.
- Determining modifications to the channel geometry that could improve flow conditions approaching and within the constructed river reach during high flows.
    - The investigation focused mainly on the areas of the rock fill for the diversion tunnel plug and the cofferdam.
- Determining the movement pattern of course bed materials through the constructed channel during high flows.

Flow conditions were documented by visual observations of dye tracings using still and video footage and/or by measuring flow velocities at locations of specific interest.

Cofferdam toe scour and bed material movement patterns were evaluated by comparing run time and post flow differences of moveable bed material for channel modifications under similar flows.

The model study was conducted from March through August 2005 in conjunction with final design. Initial work was completed in May, followed by evaluation of revised designs for the screened pumping station intake and main channel [6] in August.

Investigations

Data from the model was presented to ASTS to answer concerns regarding, channel flow conditions, the assessment of flow on cofferdam erosion, movement patterns of course bed material, and exposure of intake screens to movement of large bed material during significant flood events. Data from the model may also assist ASTS in determining the necessity of or alignment of the proposed upstream RCC cutoff wall.

The model study was conducted by separating the investigations into the upstream river channel through the cofferdam area, and then installing and investigating the screened pumping station intake area. During the initial upstream river investigations, the pump intake geometry was not modeled because the design was not entirely finished and the upstream flow conditions could be investigated independently. The intake reach in the model, between Stas. 102+00 to 94+00, was initially modeled with the approximate existing topography.

Investigations of the upstream river channel included baseline observations and velocity measurements for the 10-year event of 72,000 ft^3/s. Next, the geometry of the diversion tunnel fill geometry was investigated and documented with dye tracings, measurement of bottom velocities, and sediment patterns for the 10- and 50-year events.

The screened pumping station intake and main channel areas across the river were investigated after the upstream river studies had been completed. These investigations included the initial geometries and a later modification of both channels. Flow conditions were documented for the each geometry from the 1.5-year to the 50-year events. Sediment patterns were evaluated for the initial geometries for the 10-year (72,000 ft^3/s) and 50-year (160,000 ft^3/s) flows.

Near the end of the study, flood flow return periods were revised downward. The new flows were used during evaluation of the final pumping station and main channel modifications. The flow conditions for all discharges and the sediment deposition pattern for the new 10-year event were documented for the same return periods as previously tested. In addition, the 100-year event (164,000 ft^3/s) was evaluated, as it was very close to the initial 50-year event.

Upstream River Investigations Stas. 114 to 104

An earth cofferdam across the river and diversion tunnel are being used to divert the river around the new screened pumping station intake during construction. Figure 4 shows the diversion dam, the diversion tunnel area on the right looking upstream, and the toe of the current remaining cofferdam running parallel to the river, during a May 2005 high flow event.

Figure 4. – These figures are looking upstream at the American River section upstream from the proposed pumping station intake in the river during a high flow event in May 2005. The existing cofferdam remnant in the river forms the diversion dam. The diversion tunnel entrance area is out-of-sight to the right behind the cofferdam. The toe of the current 2:1 sloping cofferdam has been protected with riprap. Notice the large bend in the river upstream from the cofferdam toe and the narrow river section formed by the 2:1 sloping cofferdam.

The existing diversion tunnel will be closed and fill added to transition the river flows around the cofferdam slope to the pumping station site downstream.

Figure 4 clearly show how the flow following Phase I construction must turn around the remaining cofferdam slope to enter the screened pumping station area downstream. It also shows the narrow river section formed by the remaining cofferdam excavated on a 2:1 slope that must carry flow to the pumping station intake upon project completion. Riprap has been placed partially up the slope from the toe. Rock is exposed on the right bank but the cofferdam material is highly erodible and of concern for the final design. It was a similar inspection that led to the decision to widen the river channel invert and lay the cofferdam slope back on a 3:1 slope to reduce attack on the remaining cofferdam slope.

Baseline Upstream River Documentation

The first investigations in the model looked at the proposed fill placement over the closed diversion tunnel, figure 5. The diversion dam shown in figure 4 was removed to simulate the final river geometry. Baseline upstream river channel investigations were carried out for the 10-year flow event of 72,000 ft^3/s. Observations with dye tracings, velocity data, still photographs, and video were used to investigate the flow patterns through the upstream river section. Flow conditions were documented from where the flow entered the model (Sta. 114), through the diversion tunnel area, and past the cofferdam to about Sta. 104+00. Data obtained from the baseline evaluation was used to determine if the fill provided acceptable approach flow to the downstream cofferdam**.** The 3:1 sloping cofferdam begins at Sta. 108+00 along the downstream white line with the toe of the 3:1 slope shown in orange in figure 5.

Figure 5. - Original diversion tunnel fill geometry. The fill area is outlined in white paint. The toe of the 3:1 cofferdam slope at El. 491 is shown in orange paint.

The river upstream from the diversion tunnel is aligned relatively straight. Downstream, the river must curve around the sloping toe of the cofferdam. Figure 6 shows that the cofferdam remnant creates a long sweeping bend. The tunnel fill and upstream extent of the cofferdam turn the flow toward the right bank. Once the flow passes Sta. 106+00 it is generally realigned with the bend and concentrated more to the right side of the river channel.

Figure 6. - Overall view (looking downstream) of the American River model operating under the 10-year event of 72,000 ft^3/s with the initial

To develop baseline information, extensive velocity data were gathered at 0.6 and 0.8 tenths depth from the water surface from the upstream Sta. 112+00 to the downstream Sta. 104+00. Velocity data were taken near the bottom to the left of centerline, looking downstream, because of the interest in the velocities near the cofferdam. Velocity data were gathered on 200 ft station intervals and on 18 ft intervals across the river section, including up the sloping banks where depth allowed.

Observations of the flow conditions were made by injecting dye at three upstream locations, Stas. 112+00, 110+00 and 109+00 with the tracings documented at the toe of the left bank with the invert, at about 18 ft, and 36 ft across the invert from the left bank.

Table 1 and figure 7 show the velocity data gathered in the river with the initial tunnel fill geometry. Table 1 provides the specific values for the velocities. Figure 7 is a plan view of the velocity vectors for each location where data were gathered at six-tenths depth representing the average velocity throughout the depth.

Figures 8-10 show the velocities measured at 0.6 and 0.8 (near the bottom of the river channel) of the depth plotted across each station where data were gathered from upstream of the diversion tunnel area at Sta. 112+00 to Sta. 104+00 downstream. Zero on the x-axis is the centerline of the river station according to the layout provided by ASTS. Negative values are left of the centerline towards the cofferdam. Positive numbers are to the right of river centerline where the bank is much steeper. The views across the sections show that the velocity is fairly uniform across the sections with the velocities decreasing up the cofferdam slope. In addition, the bottom velocities are lower than the average velocities, particularly up the cofferdam slope. In general, the average bottom velocities are about 1 ft/s less then the velocities measured at six-tenths depth in the main channel area. Note, at Sta.109+00 the left side near boundary velocity is aligned into the cofferdam bank. The impingement of flow in this area was supported by the appearance of a surface wake extending downstream from the bank.

Table 1. - Measured velocities in prototype values for the 10-yr event with the original diversion tunnel fill geometry. Stationing is larger upstream (Sta. 112+00) and decreasing downstream.

Distance		Measurement	Station 112			Station 110+00			Station 109+00			Station 108+00			Station 106+00			Station 104+00		
Across	Description	Depth	V_x	V_y	Total Velocity	V_x	V_y	Total Velocity	V_x	V_y	Total Velocity	V_x	V_y	Total Velocity	V_x	V_y	Total Velocity	V_x	V_y	Total Velocity
Station (ft)	(looking d/s)	Location	(ft/s)	(ft/s)	Magnitude (ft/s)	(ft/s)	(ft/s)	Magnitude (ft/s)	(ft/s)	(ft/s)	Magnitude (ft/s)	(ft/s)	(ft/s)	Magnitude (ft/s)	(ft/s)	(ft/s)	Magnitude (ft/s)	(ft/s)	(ft/s)	Magnitude (ft/s)
126	to right bank	0.60	9.17	4.33	10.14	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
108	to right bank	0.60	10.90	2.92	11.29	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
90	to right bank	0.60	13.79	1.57	13.88	5.71	1.17	5.82	--	--	--	--	--	--	--	--	--	--	--	--
72	to right bank	0.60	14.59	3.05	14.91	6.15	1.67	6.37	--	--	--	7.62	-0.17	7.62	11.62	1.49	11.71	--	--	--
54	to right bank	0.60	13.65	0.43	13.66	11.69	2.31	11.92	9.35	1.36	9.45	9.44	0.28	9.44	14.05	0.14	14.05	13.07	0.95	13.11
36	to right bank	0.60	14.26	1.95	14.39	13.96	2.65	14.21	9.76	0.90	9.80	11.94	0.48	11.95	15.06	1.72	15.16	15.10	0.97	15.13
18	to right bank	0.60	14.51	1.82	14.63	14.77	2.95	15.06	14.27	0.92	14.30	13.67	0.81	13.70	16.91	1.27	16.96	16.61	0.67	16.62
0	Centerline	0.60	14.59	0.46	14.59	14.15	3.77	14.64	14.46	1.96	14.59	15.08	0.62	15.10	17.17	1.58	17.24	17.92	0.79	17.94
-18	to left bank	0.60	14.30	1.09	14.35	13.37	2.29	13.57	13.51	0.89	13.54	14.61	0.76	14.63	17.36	0.28	17.36	16.91	0.38	16.91
-18	to left bank	0.80	13.70	0.39	13.71	11.90	4.67	12.78	12.30	2.32	12.52	13.75	0.25	13.75	13.37	0.53	13.38	11.87	2.92	12.23
-36	to left bank	0.60	14.14	1.24	14.20	13.39	3.23	13.78	12.51	1.15	12.56	13.26	0.48	13.27	17.48	0.09	17.48	15.91	0.96	15.93
-36	to left bank	0.80	13.89	1.34	13.95	12.36	4.16	13.04	12.05	1.17	12.10	12.23	0.88	12.26	15.20	1.10	15.24	13.13	2.52	13.37
-54	to left bank	0.60	13.24	1.39	13.31	13.45	2.02	13.60	12.82	0.79	12.84	13.15	0.53	13.16	18.74	0.06	18.74	16.10	0.81	16.12
-54	to left bank	0.80	12.16	1.61	12.27	12.34	2.96	12.69	11.82	1.25	11.89	12.31	0.25	12.31	16.33	1.51	16.40	15.23	0.99	15.27
-72	to left bank	0.60	--	--	--	13.21	2.60	13.46	13.06	1.79	13.18	13.19	0.65	13.21	19.33	0.52	19.33	18.44	0.92	18.47
-72	to left bank	0.80	--	--	--	0.61	0.46	0.76	12.11	1.06	12.16	12.08	1.05	12.12	17.36	0.14	17.36	15.17	2.16	15.33
-90	to left bank	0.60	--	--	--	10.11	0.33	10.12	12.52	1.90	12.66	12.52	0.41	12.53	16.40	0.09	16.40	17.93	1.02	17.96
-90	to left bank	0.80	--	--	--	0.22	0.07	0.23	11.11	1.24	11.17	11.51	1.08	11.56	15.64	1.69	15.73	16.42	2.48	16.61
-108	to left bank	0.60	--	--	--	-0.26	0.43	0.50	10.45	2.22	10.68	12.44	0.62	12.46	10.97	0.04	10.97	10.57	1.16	10.64
-108	to left bank	0.80	--	--	--	0.01	0.02	0.02	6.50	1.66	6.71	9.81	0.91	9.85	-6.44	1.17	6.54	9.85	1.11	9.91
-126	to left bank	0.60	--	--	--	--	--	--	6.96	1.51	7.12	9.23	0.75	9.26	8.38	0.67	8.40	5.99	1.49	6.18
-126	to left bank	0.80	--	--	--	--	--	--	3.01	1.48	3.35	7.31	0.83	7.35	0.48	0.12	0.49	1.81	0.29	1.83
-144	to left bank	0.60	--	--	--	--	--	--	0.27	1.33	1.36	4.22	1.03	4.34	--	--	--	0.52	0.02	0.52
-144	to left bank	0.80	--	--	--	--	--	--	-0.47	0.33	0.58	5.20	1.34	5.37	--	--	--	-0.02	0.01	0.02
-162	to left bank	0.60	--	--	--	--	--	--	-0.01	0.01	0.02	-	-	-	--	--	--	--	--	--

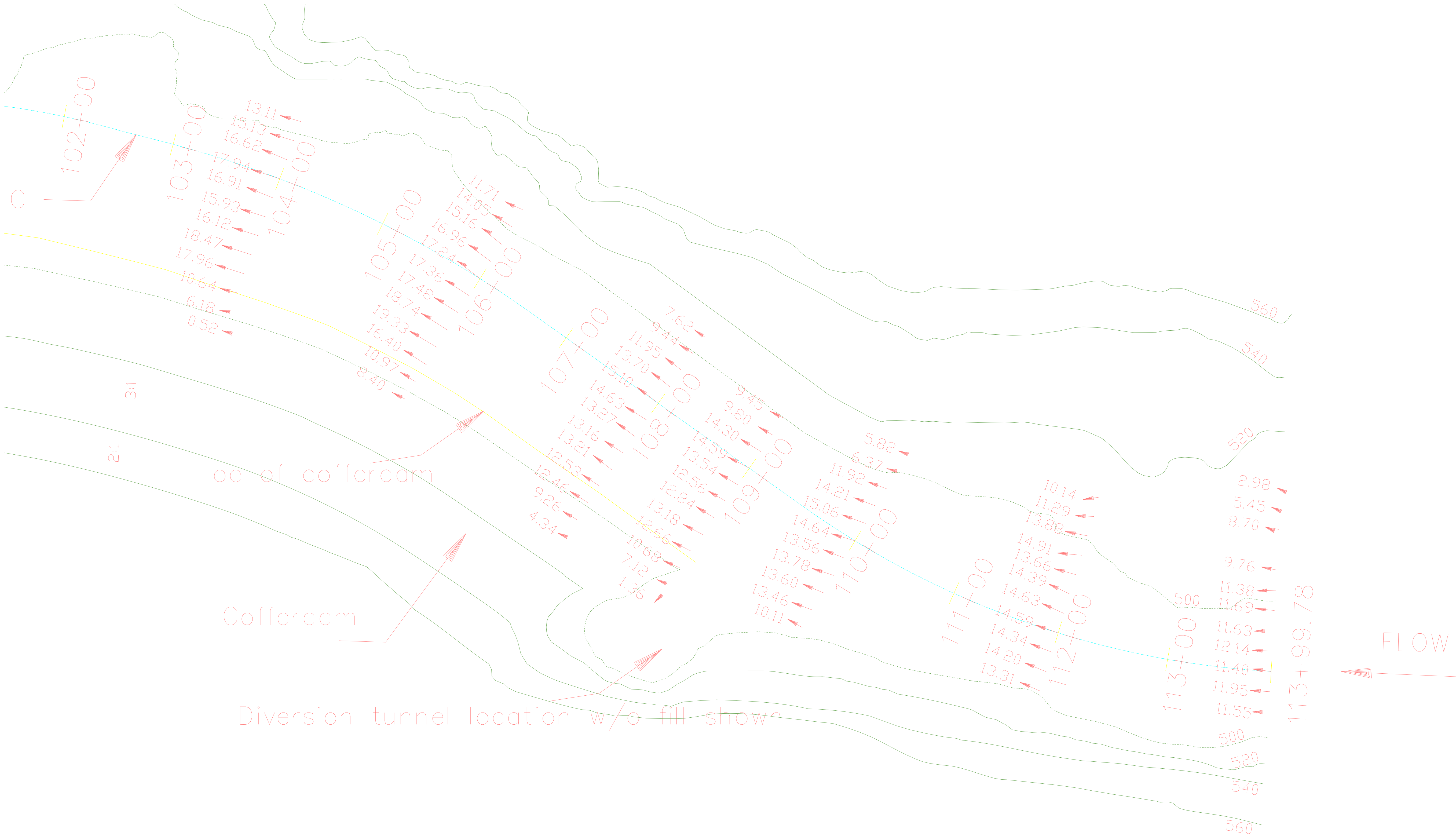
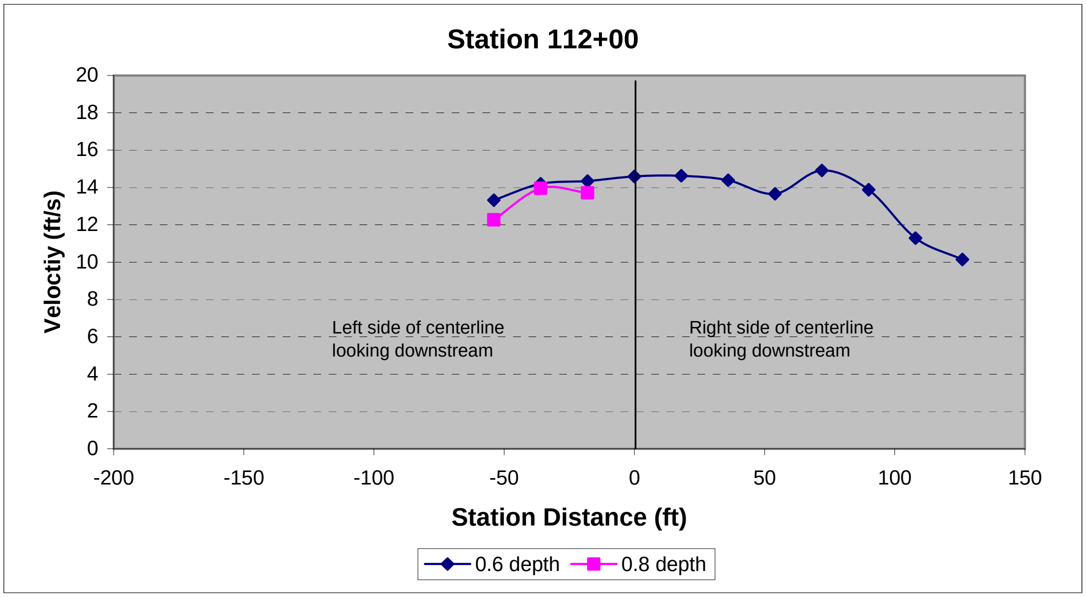


Figure 7 - Average prototype velocity vectors showing direction and magnitudes at 0.6 flow depth for the original diversion tunnel fill geometry.



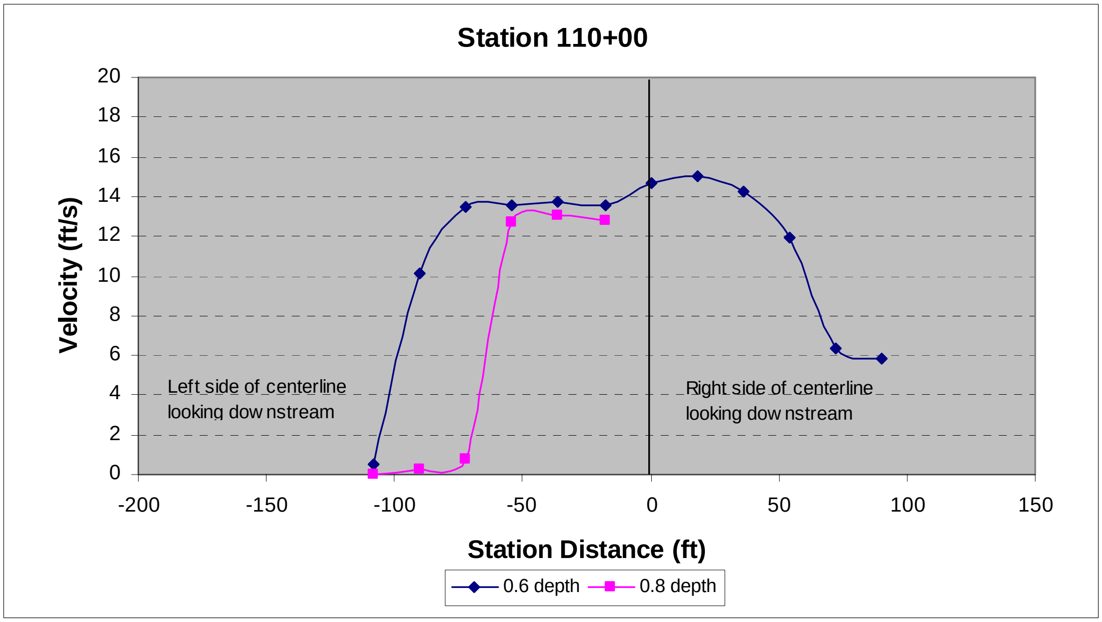
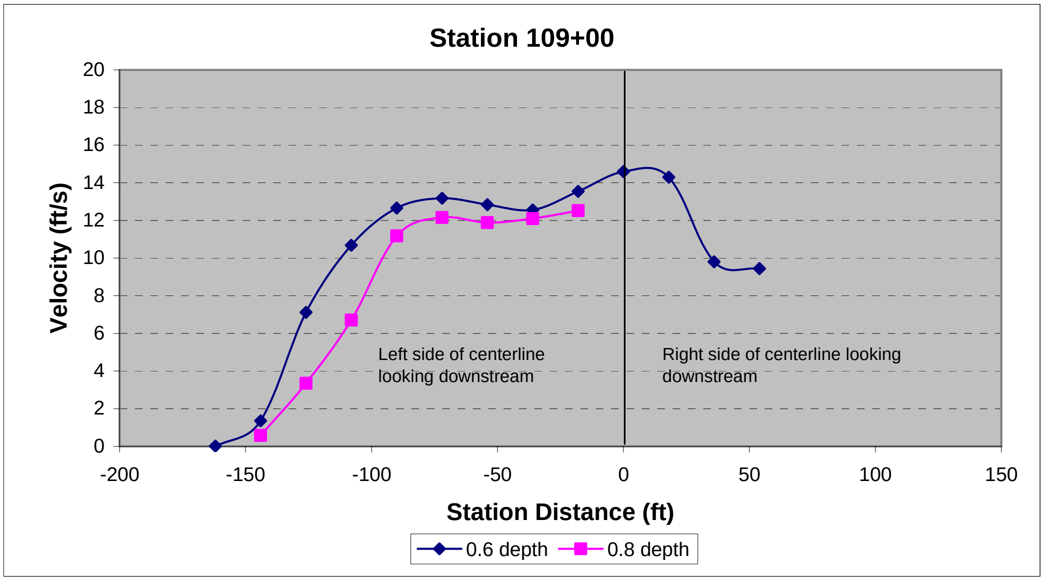


Figure 8. – Velocity cross sections for Stas. 112+00 and 110+00 for the 10-yr event for the initial diversion tunnel fill geometry.



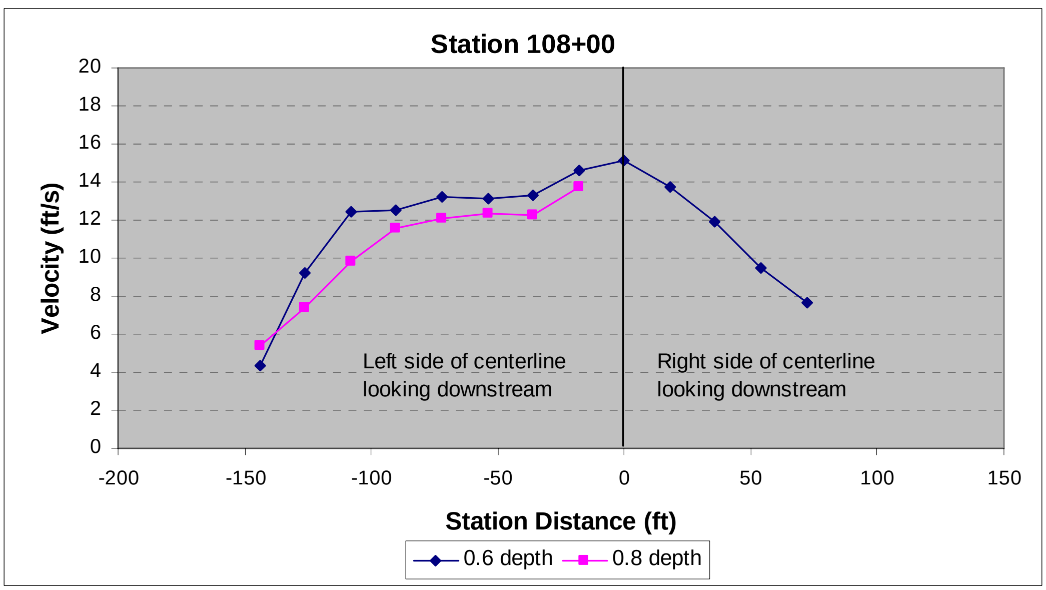
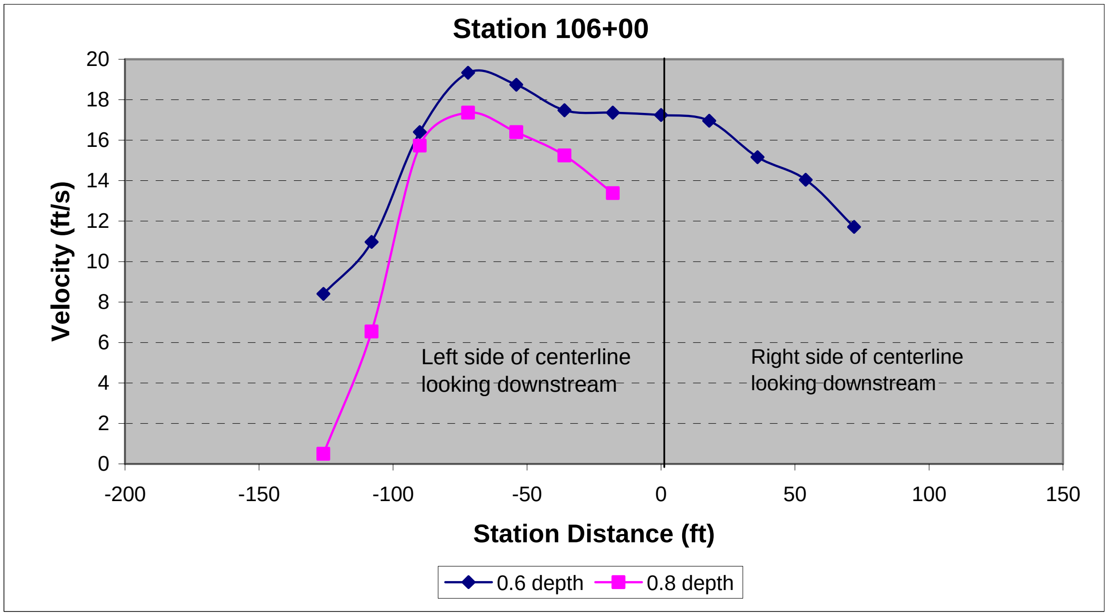


Figure 9. - Velocity cross sections for Stas. 109+00 and 108+00 for the 10-yr event for the initial tunnel fill geometry.



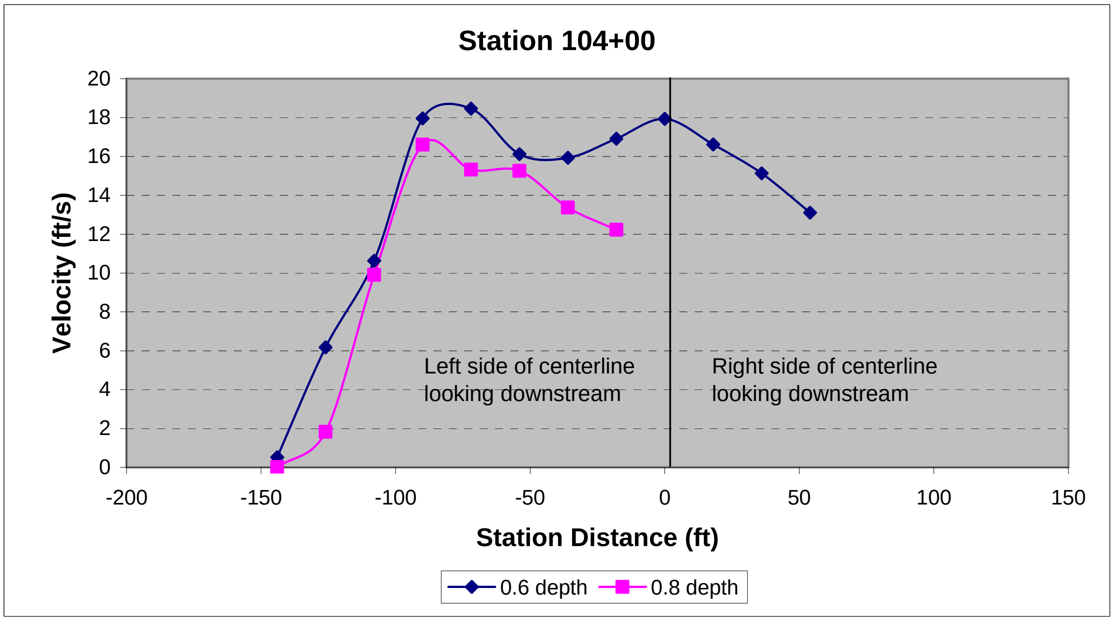


Figure 10. - Velocity cross sections for the 10-yr event for Stas. 106+00 and 104+00 for the initial fill geometry.

Diversion Tunnel Fill Investigations

Several configurations of fill in the diversion tunnel area were investigated under the 10-year event of 72,000 ft^3/s to determine the final geometry of the fill. The goal of the fill was to reduce attack on the beginning of the cofferdam slope as much as possible by redirecting the flow. Investigations proceeded by progressively adding more fill to either steepen the slope by the diversion tunnel entrance or to add fill upstream to redirect the flow earlier.

The following order was used to investigate the fill geometry options:

- Original basic fill,
- Fill added upstream to Sta. 112+00 keeping the slope at the tunnel area about 3:1,
- More fill added to diversion tunnel area to steepen the slope to about a 2:1 slope with fill extending to Sta. 112+00,
- Insert a temporary angled wall into the fill over the tunnel entrance to divert flow from the cofferdam area with fill extending to Sta. 112+00,
- Removed extended upstream fill back to near Sta. 110+00 and removed fill material at tunnel area to match with cofferdam slope and toe. (final design)

Figure 11 shows the fill added to Sta. 112+00 along the left bank upstream from the tunnel entrance. During changes to the fill volumes and geometry spot checks of the velocity were made and compared with the values from the initial velocity mapping. The velocity measurements along with flow visualization techniques and constructability led to the determination of the final fill geometry. While the

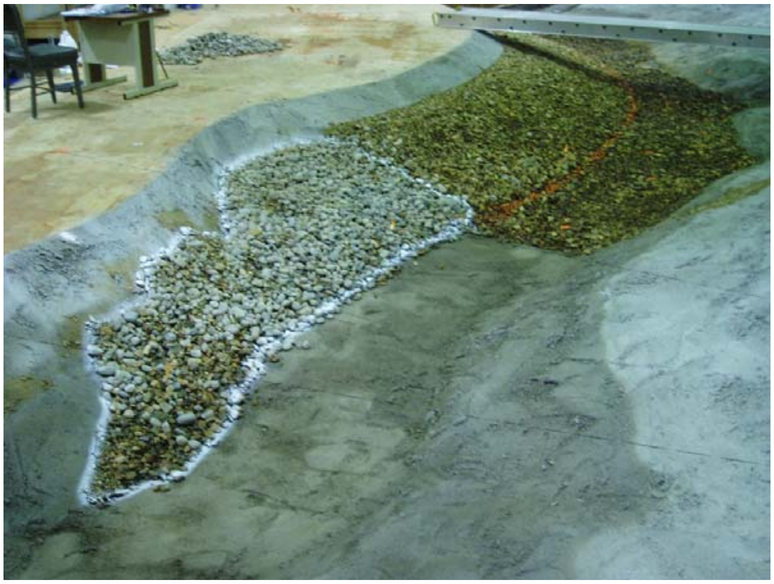


Figure 11. - Fill extended upstream from the diversion tunnel to about Sta. 112+00.

options that added fill aided in redirecting the flow from the cofferdam slope and toe, they also reduced the flow area in the channel and generally increased the flow velocities at stations 108+00, 106+00, and 104+00.

The design team met during this time and determined that the flow conditions observed in the model were acceptable provided the cofferdam was protected with suitable riprap material. Therefore, only small changes to the baseline fill geometry were made to improve flow conditions. The final geometry was selected following dye tracings, measurement of bottom velocities, and sediment transport observations under the 10-and 50-year events.

Final Diversion Tunnel Fill Geometry

The final geometry of the fill over the diversion tunnel is shown on figures 12 and 13. The fill for the diversion tunnel area extended about 176 ft upstream from Sta. 108+00 and the beginning of the remaining cofferdam. The toe of the fill follows the general line of the cofferdam toe upstream to about Sta. 109+44.5 then breaks back to match the steeper slope of the topography at about Sta. 109+76. The slope of the fill varied from 3:1 where it met the cofferdam slope and steepened to about 1.7:1 to meet the topography at the upstream end. The model floor was at prototype El. 485 in this area and the toe of the fill is shown at that elevation. The fill extended up to El. 540 or the top of the cofferdam 3:1 slope.

Figure 12. - Final diversion tunnel fill geometry outlined in white and extending to the toe of the cofferdam. The slope of the fill varies from about 1.7:1 at the upstream end to match the existing topography to 3:1 at the downstream end to match the cofferdam slope.

Compared to the baseline condition, the recommended fill geometry has a slightly steeper slope and the fill extends to the toe of the cofferdam slope at Sta. 108+00.

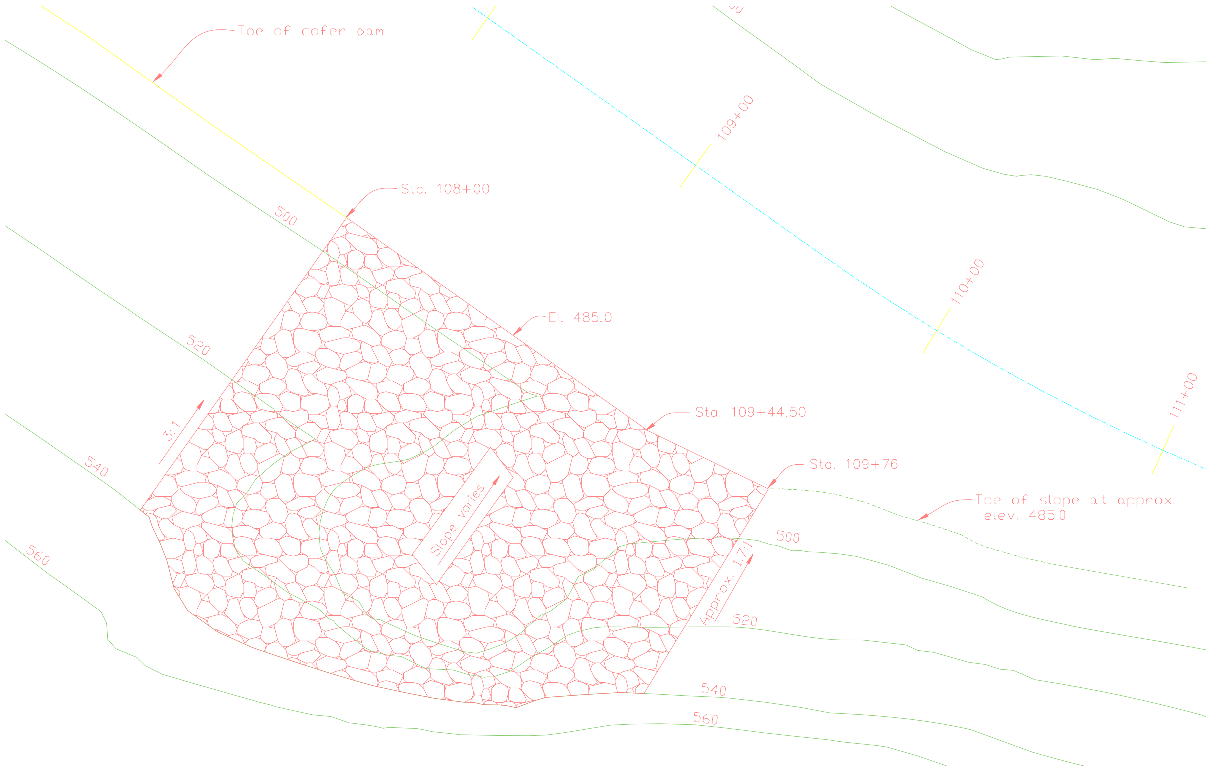


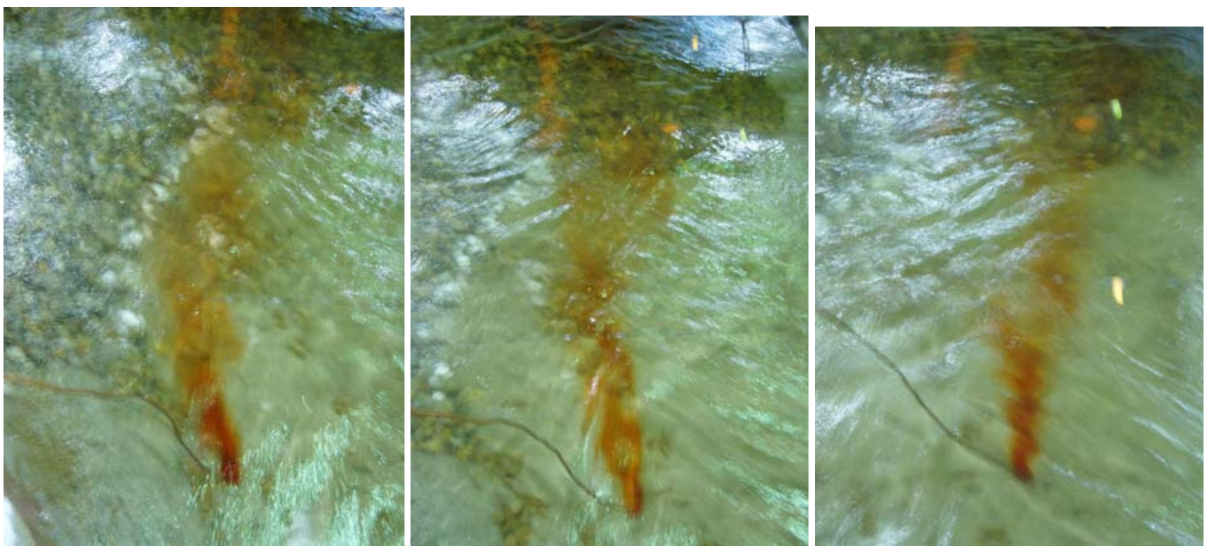
Figure 13. - Recommended fill geometry for the diversion tunnel area upstream from the cofferdam.

Final Tunnel Fill Geometry – 10-year Event Velocities

Figure 14 shows the dye tracings for the final fill geometry in consecutive order from upstream to downstream and from the toe along the left bank across the invert toward the right bank under the 10-year event of 72,000 ft^3/s. Dye was released as close as possible to each station and at the toe of the left bank, about 18 ft and 36 ft out from the left bank across the channel. Dye was injected near the bottom of the river invert in all cases. (The white paint that extends upstream in figure 14 is from previous fill investigations.)

The dye tracings showed that the plume is much more concentrated at the upstream stations and disperses as it travels closer to the cofferdam, indicating that the velocity is reduced. In addition, the plume seems to begin following the cofferdam curvature at Sta. 109 about 100 ft upstream from the beginning of the 3:1 cofferdam slope.

Dye tracing for the 10-year event at Sta. 112+00 for the final diversion tunnel fill geometry.



Dye tracing for the 10-year event at Sta. 110+00 for the final diversion tunnel fill geometry.

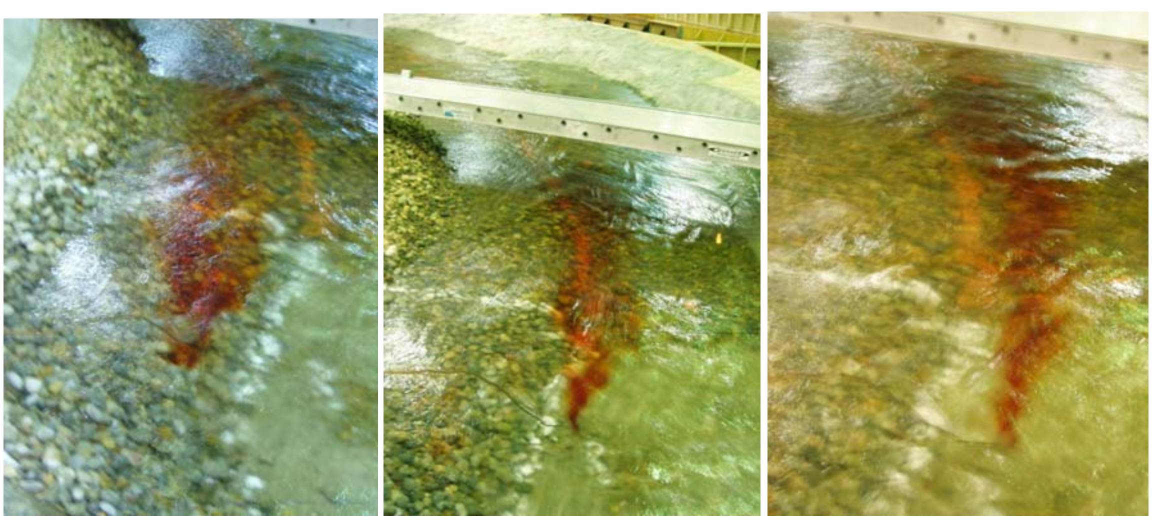


Figure 14. Dye tracing for the 10 yr event at Sta. 109+00 for the final diversion tunnel fill geometry. Photos are at the toe of the left bank, 18 and 36 ft out from the bank across the channel to the right.

Velocities were gathered near the invert of the stations near the fill and through the upstream cofferdam section at Stas. 109+00, 108+00, 106+00 and 104+00. Velocities were taken at eight-tenths depth because scour or erosion of the river bottom or cofferdam toe was of interest. Table 2 shows the velocities near the bottom of the channel for the final upstream fill configuration under the flow of 72,000 ft^3/s. Figure 15 shows a plan view of the velocity vectors and magnitudes from the data in table 2. Figures 16 and 17 show the velocities across the river stations for the previous baseline configuration and the final fill geometry for comparison. Zero on the x-axis is the centerline of the river station. Negative distances are left of the centerline going towards the cofferdam. The velocity vectors show improved flow conditions at Sta. 109+00.

Measured velocities and dye tracings showed that the diversion tunnel fill would need to be well-keyed and protected. The flow surface and velocity vectors indicated that the flow would attack the fill area, but quickly orient to the river channel and bend of the cofferdam. Visually, it seemed that the flow at near the water surface consistently separated from the cofferdam slope near Sta. 106+00. On Figure 14, the center photo for Sta. 109 shows the wavy flow pattern just upstream from the walkway that would be near Sta. 106+00.

Table 2. - Bottom velocities for the final fill geometry gathered for the 10-year event of 72,000 ft^3/s.

Distance		Station 109			Station 108			Station 106			Station 104		
Across	Description	Vx	Vy	Total Velocity	Vx	Vy	Total Velocity	Vx	Vy	Total Velocity	Vx	Vy	Total Velocity
Station (ft)	(looking d/s)	(ft/s)	(ft/s)	Magnitude (ft/s)	(ft/s)	(ft/s)	Magnitude (ft/s)	(ft/s)	(ft/s)	Magnitude (ft/s)	(ft/s)	(ft/s)	Magnitude (ft/s)
36	to right bank	12.60	0.78	12.62	12.96	-2.46	13.19	13.20	-0.30	13.20	12.24	1.08	12.29
0	centerline	13.68	0.60	13.69	14.58	-1.62	14.67	15.66	-0.18	15.66	14.16	1.98	14.30
-36	to left bank	11.04	-0.42	11.05	12.24	-1.68	12.35	15.12	0.06	15.12	13.02	1.74	13.14
-72	to left bank	10.80	0.30	10.80	12.24	-0.96	12.28	7.74	0.90	7.79	17.10	0.36	17.10
-90	to left bank	10.14	0.36	10.15	11.10	-0.18	11.10	7.80	1.80	8.00	15.42	1.92	15.54
-108	to left bank	9.12	1.14	9.19	0.24	0.12	0.27	0.96	0.06	0.96	0.06	0.00	0.06
-126	to left bank	3.30	0.90	3.42	--	--	--	--	--	--	0.00	0.00	0.00

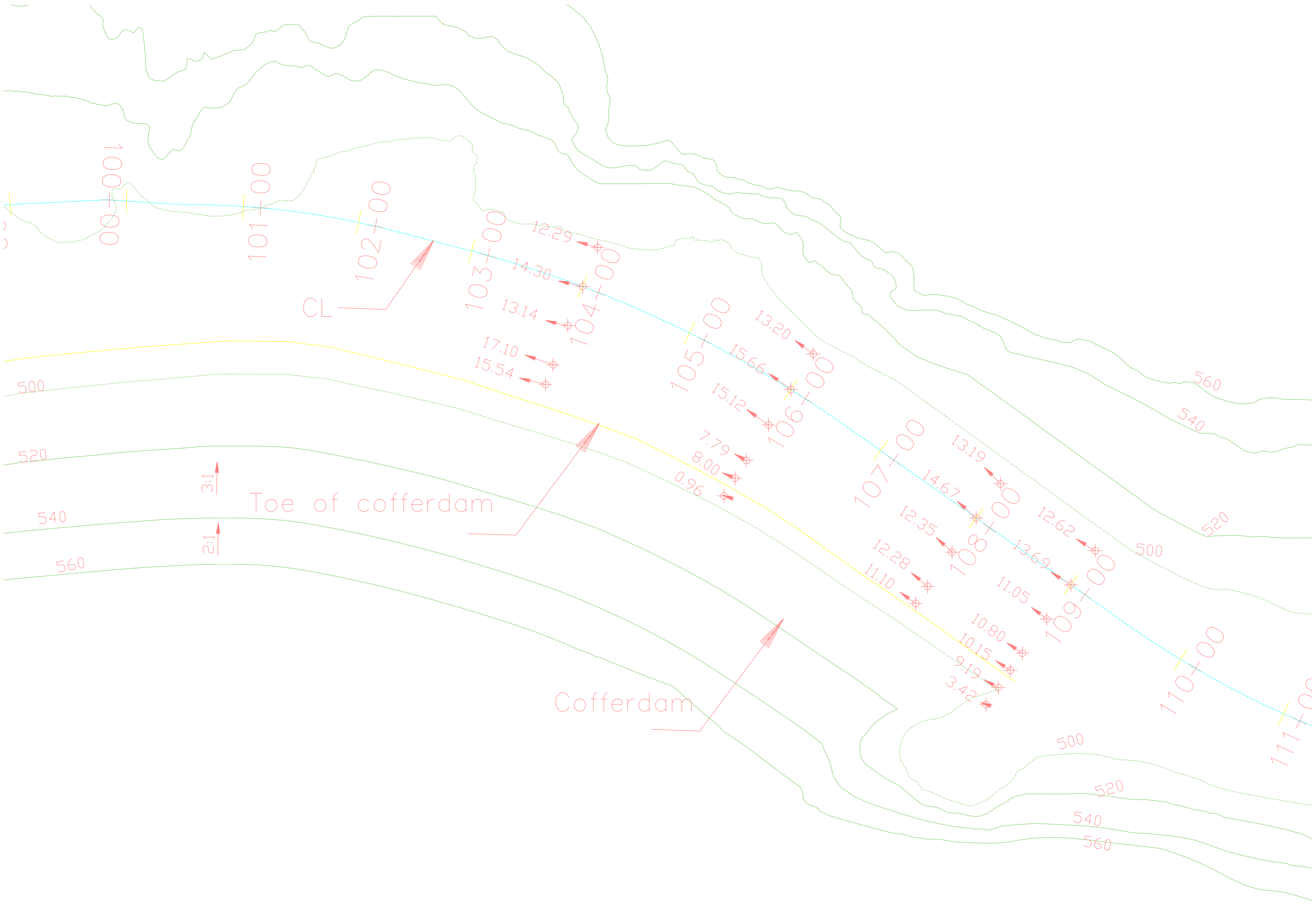
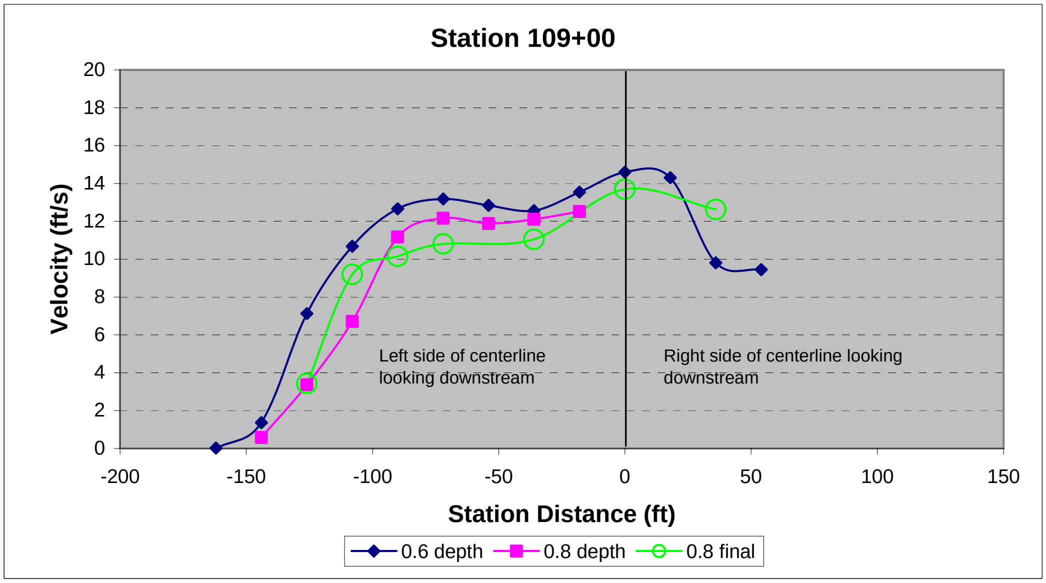


Figure 15. - Plan view of the bottom velocity vectors with magnitudes for the 10-year event of 72,000 ft^3/s with the final tunnel fill geometry.



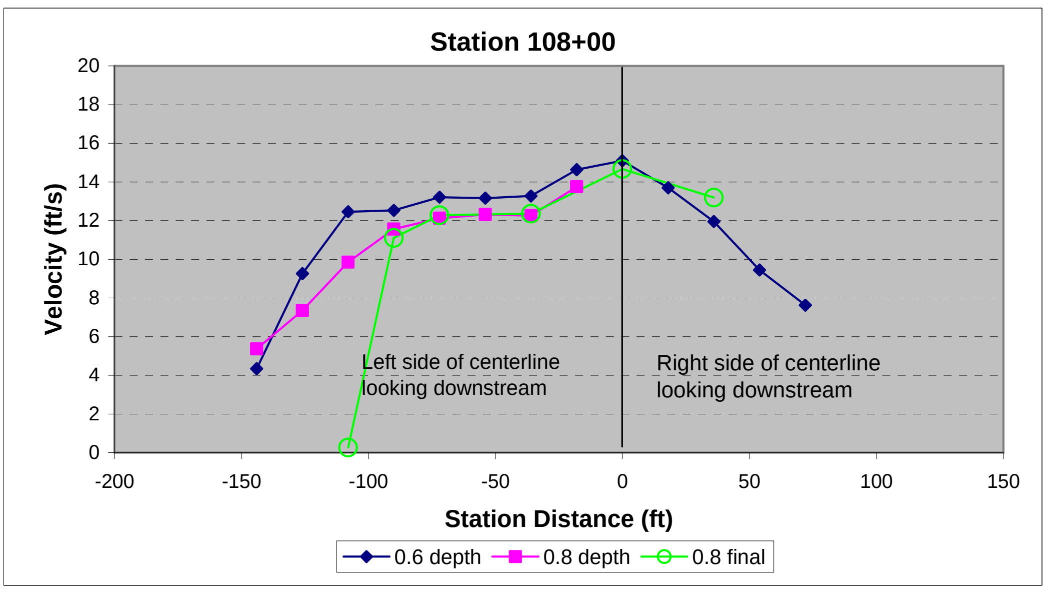
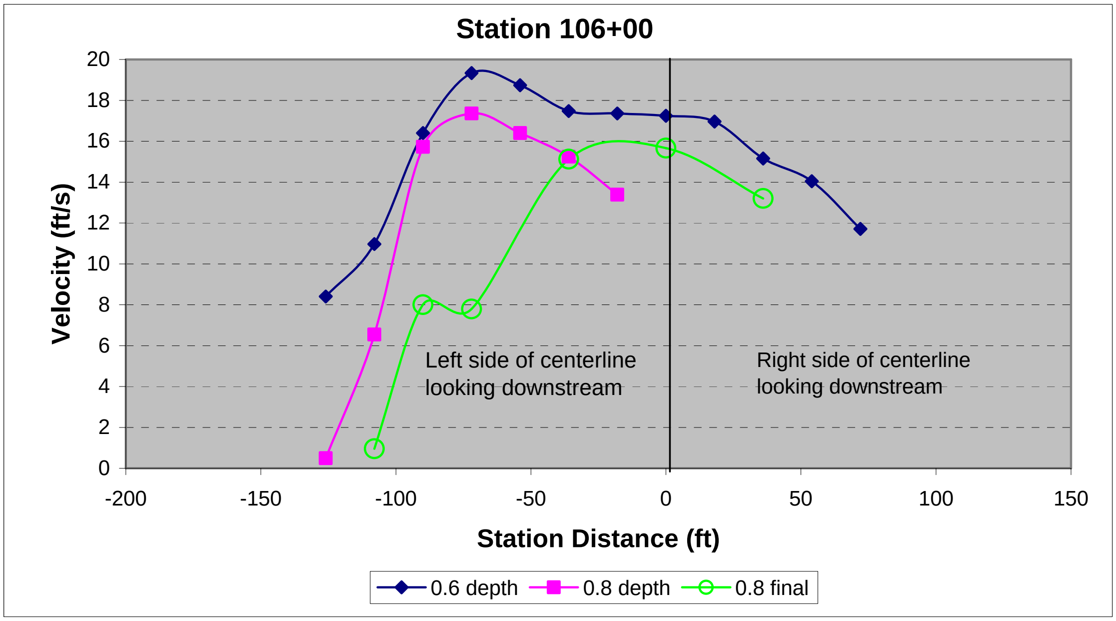


Figure 16. - Bottom velocity cross sections for Stas. 109+00 and 108+00 for the final diversion tunnel fill geometry for the 10-yr event of 72, 000 ft^3/s.



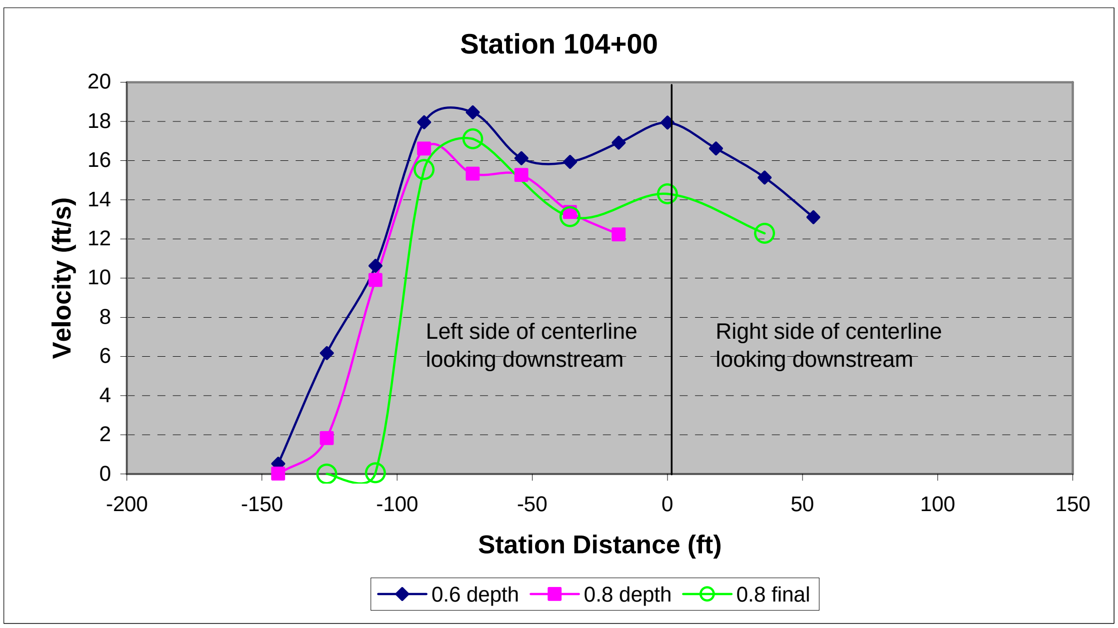


Figure 17. - Bottom velocity cross sections for Stas. 106+00 and 104+00 for the final fill geometry for the 10-year event of 72,000 ft^3/s.

Final Tunnel Fill Geometry - 10-year Event Sediment Patterns

The river section upstream from Sta. 108+00 was modeled as a fixed bed at El. 485. Prototype 2- to 4- foot size gravel material, the same as used on the cofferdam slope, was placed on the invert from Sta. 108+00 downstream to the end of the model at about Sta. 92+50.

Sand was added by shovel at regular intervals at about Sta. 114+00 in the upstream river during operation of the 10-year event of 72,000 ft^3/s and allowed to travel downstream for about 4 hours. The sand in the model represented bed load movement in the prototype of about 2-2.25 inch gravel. The movement of the sand would help define the flow patterns through the river upstream from the intake and constructed river structures. The invert bed material remained in place under this flow rate and the movement of sand could be documented.

Figure 18 shows the overall deposition pattern after operation with the final tunnel fill geometry. The material traveled downstream along the invert scouring along the toe of the tunnel fill. The material formed a dune diagonally across the river from left to right where the material entered the rock invert at Sta. 108 to the right side of the channel, figure 19. The higher velocity flow then stays along the right side of the channel until the rock outcropping at about Sta. 104+00 forced some of the flow to travel back across the river towards the cofferdam. Figure 20 shows the result of the higher velocity flow along the river centerline with deposition along the toe of the cofferdam (outlined in orange paint) at about Sta. 102.

Figure 18. - Overall view of the sediment deposition with the final tunnel fill geometry after passing 72,000 ft^3/s prior to installing the screened pumping plant intake downstream.

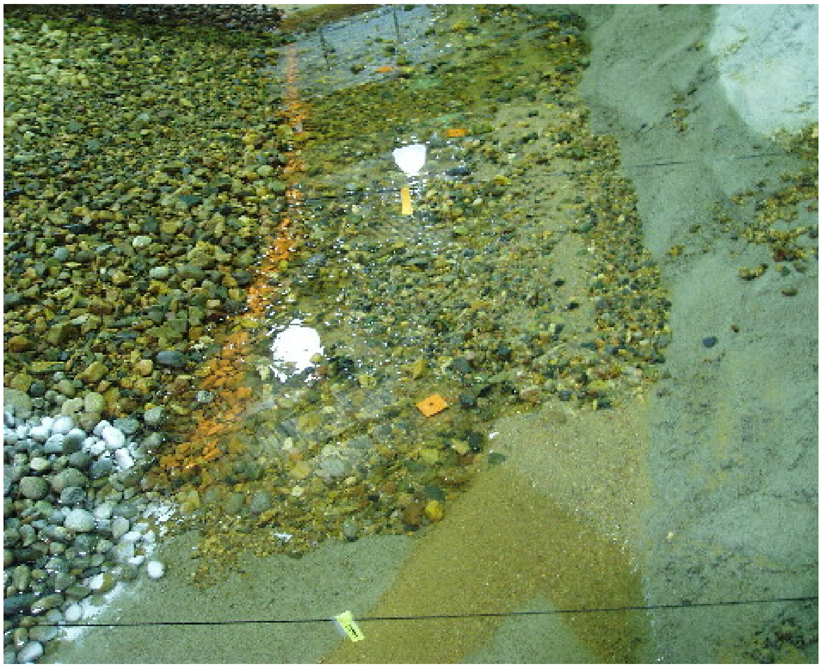


Figure 19. - Initial results of sediment testing after installing the final fill geometry after testing at 72,000 ft^3/s.

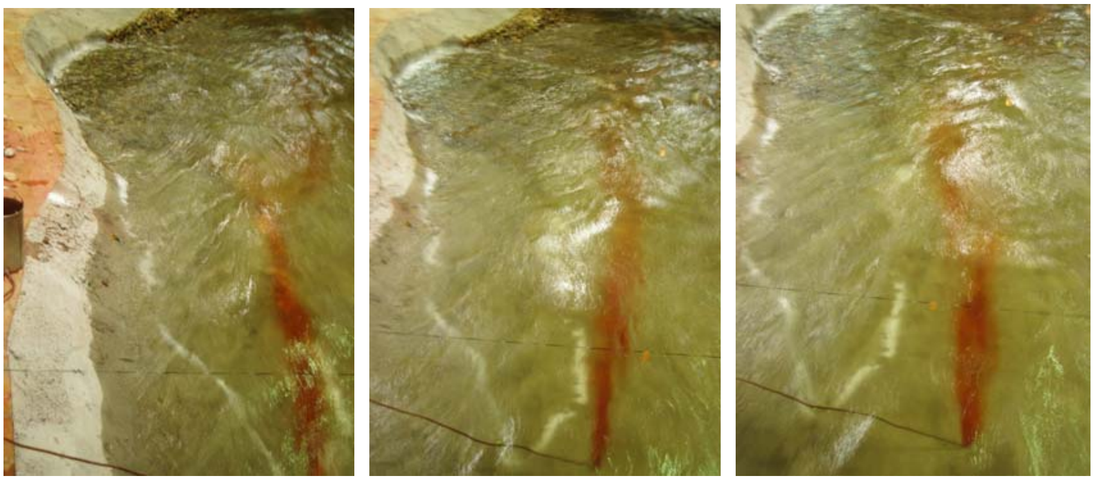
Figure 20. - Close up view of the sediment deposition at about Sta. 102+00 after the 72,000 ft^3/s event.

Final Tunnel Fill Geometry – 50-year Event Velocities

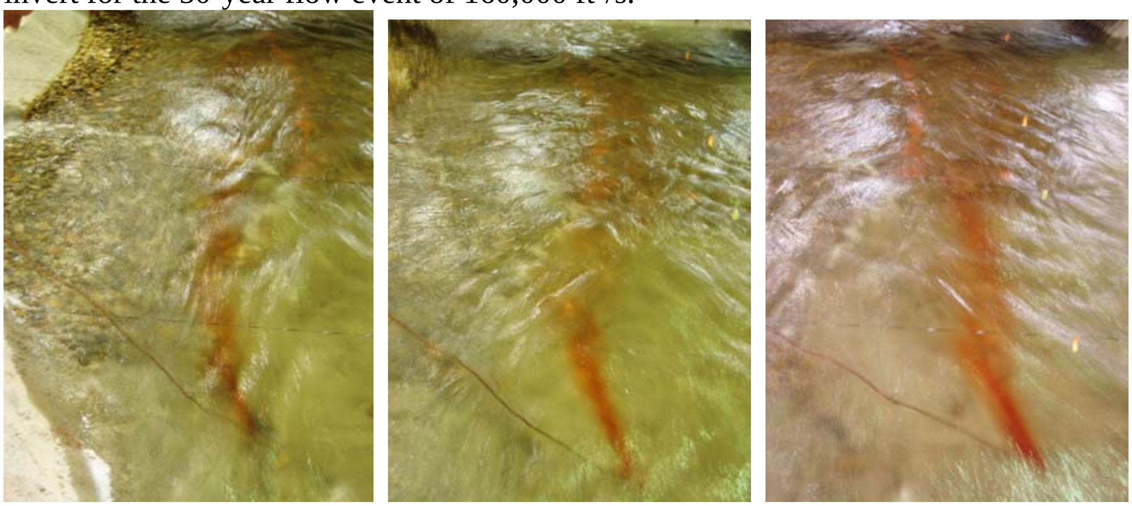
The same dye and velocity data were gathered for the 50-year event of 160,000 ft^3/s as for the 10-year event. The dye tracings are shown on figure 21, with the dye injected at the bottom of the river channel. The tracings were again from upstream to downstream along the left bank across the invert toward the right bank. The results for this higher flow rate were very similar to those from the smaller flow of 72,000 ft^3/s. The same trends were observed, except the higher velocities did not allow the plume to be tracked as far downstream. The dye spread more quickly as the fill and cofferdam areas were approached, indicating less velocity than in the upstream channel.

The velocities were gathered near the bottom to provide information regarding erosion potential of the river channel and the riprap that will be placed on the cofferdam slope. Table 3 shows the velocities near the bottom of the channel for the final upstream fill configuration under the flow of 160,000 ft^3/s. Figure 22 shows a plan view of the velocity magnitudes and vectors for the 50-year event. Figures 23 and 24 show a comparison of the velocities across the river stations for both the 10 and 50-year events. It can be seen that the higher flow produces generally higher velocities as expected, but velocity trends are very similar. The only difference seems to be generally higher proportional velocities near the cofferdam than across the river channel.

Observation of the flow during the 50-year event confirmed the diversion tunnel fill was acceptable for this higher flow. Similar to the 10-year event, measured velocities and dye tracings showed that the diversion tunnel fill would need to be well-keyed and protected. The flow surface and velocity vectors indicated that the flow would attack the fill area, but quickly orient to the river channel and bend of the cofferdam. Again, the flow at the surface seemed to separate from the cofferdam slope flowing toward the center of the channel at about Sta. 106+00.



Dye tracings for the final fill geometry at Sta. 112+00 from the left bank toe across the invert for the 50-year flow event of 160,000 ft^3/s.



Dye tracings for the final fill geometry at Sta. 110+00 from the left bank toe across the invert for the 50-year flow event of 160,000 ft^3/s.

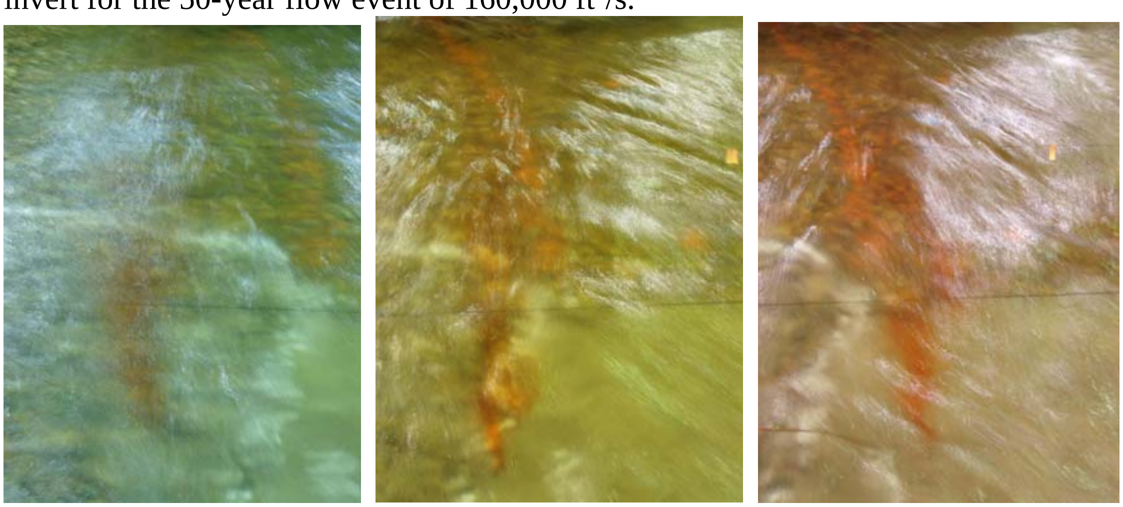


Figure 21. - Dye tracings for the final fill geometry at Sta. 109+00 from the left bank toe across the invert towards the right bank for the 50-year flow event of 160,000 ft^3/s.

Table 3. - Bottom velocities for the 50-year event of 160,000 ft^3/s with the final fill geometry.

Distance		Station 109			Station 108			Station 106			Station 104		
Across	Description	Vx	Vy	Total Velocity	Vx	Vy	Total Velocity	Vx	Vy	Total Velocity	Vx	Vy	Total Velocity
Station (ft)	(looking d/s)	(ft/s)	(ft/s)	Magnitude (ft/s)	(ft/s)	(ft/s)	Magnitude (ft/s)	(ft/s)	(ft/s)	Magnitude (ft/s)	(ft/s)	(ft/s)	Magnitude (ft/s)
36	to right bank	17.46	3.42	17.79	18.66	-3.78	19.04	19.14	-4.26	19.61	20.16	0.72	20.17
0	centerline	19.74	0.78	19.76	21.06	-2.10	21.16	18.06	-1.38	18.11	20.28	-4.2	20.71
-36	to left bank	18.42	1.56	18.49	19.50	1.56	19.56	20.10	-1.98	20.20	17.22	1.44	17.28
-72	to left bank	16.32	-0.72	16.34	18.30	-2.64	18.49	16.50	-0.78	16.52	22.98	1.44	23.03
-90	to left bank	16.20	0.24	16.20	18.12	-3.66	18.49	17.34	0.60	17.35	19.2	2.64	19.38
-108	to left bank	15.66	0.78	15.68	16.08	-0.36	16.08	16.50	-0.30	16.50	15.06	-0.72	15.08
-126	to left bank	9.06	2.58	9.42	16.98	-0.72	17.00	16.44	-0.24	16.44	13.98	2.82	14.26
-144	to left bank	--	--	--	--	--	--	4.14	-0.24	4.15	10.56	2.76	10.91

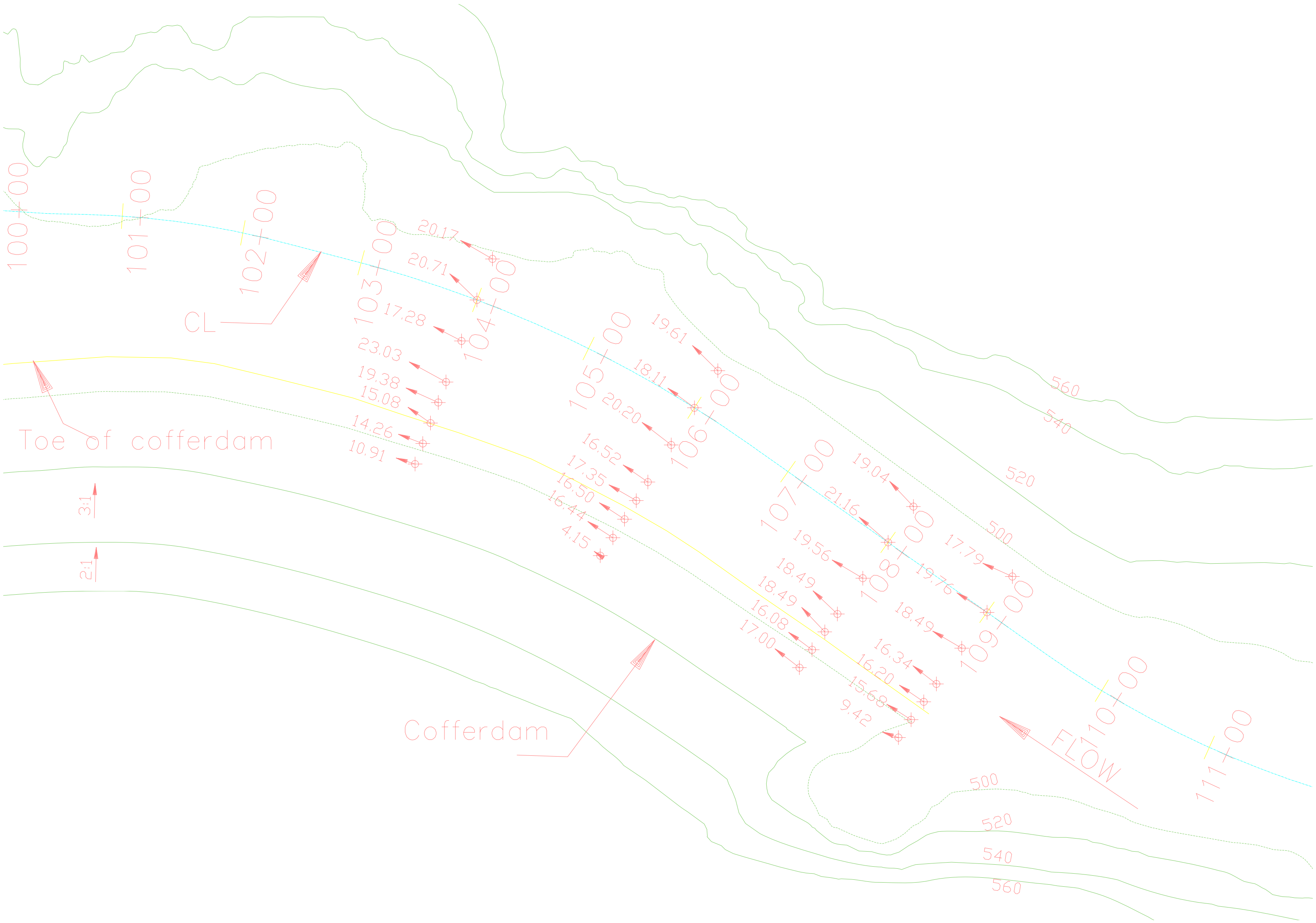
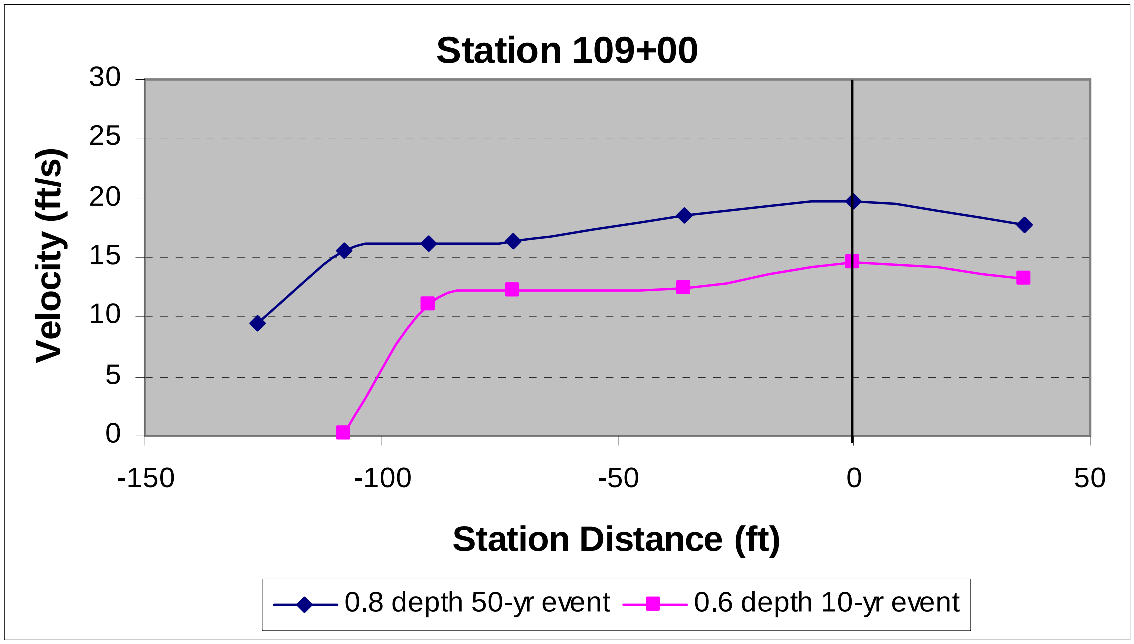


Figure 22. - Plan view of the bottom velocity vectors and magnitudes for the final tunnel fill geometry for the 50-yr event of 160,000 ft^3/s.



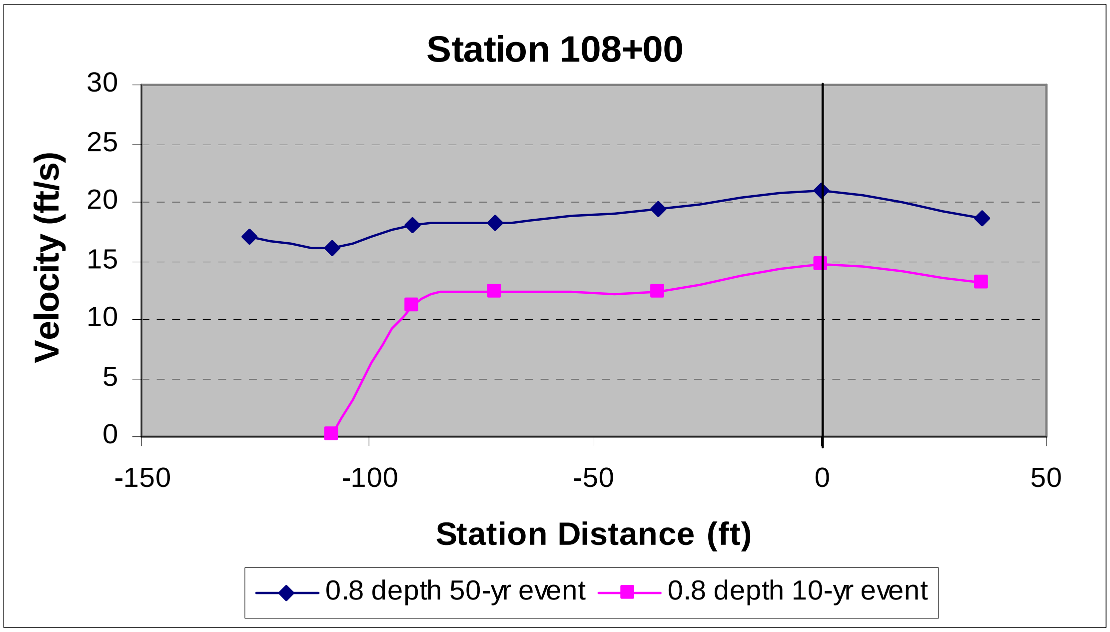
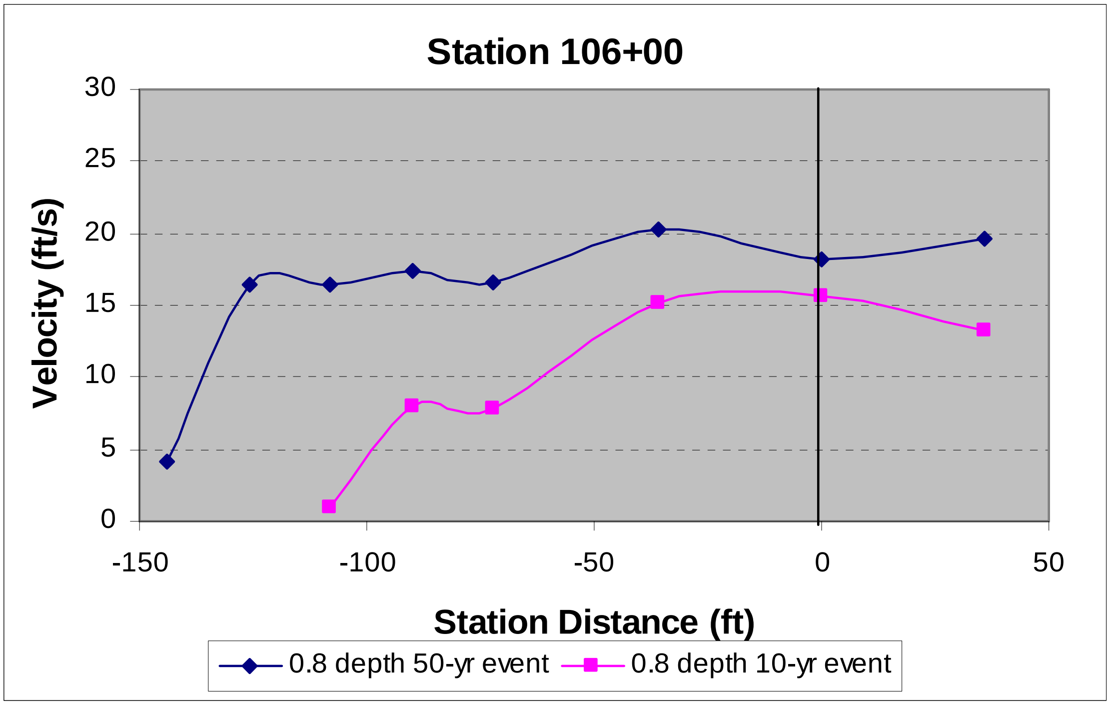


Figure 23. - Bottom, velocity cross section comparisons for Stas. 109+00 and 108+00 for the 50 and 10-yr events and the final fill geometry.



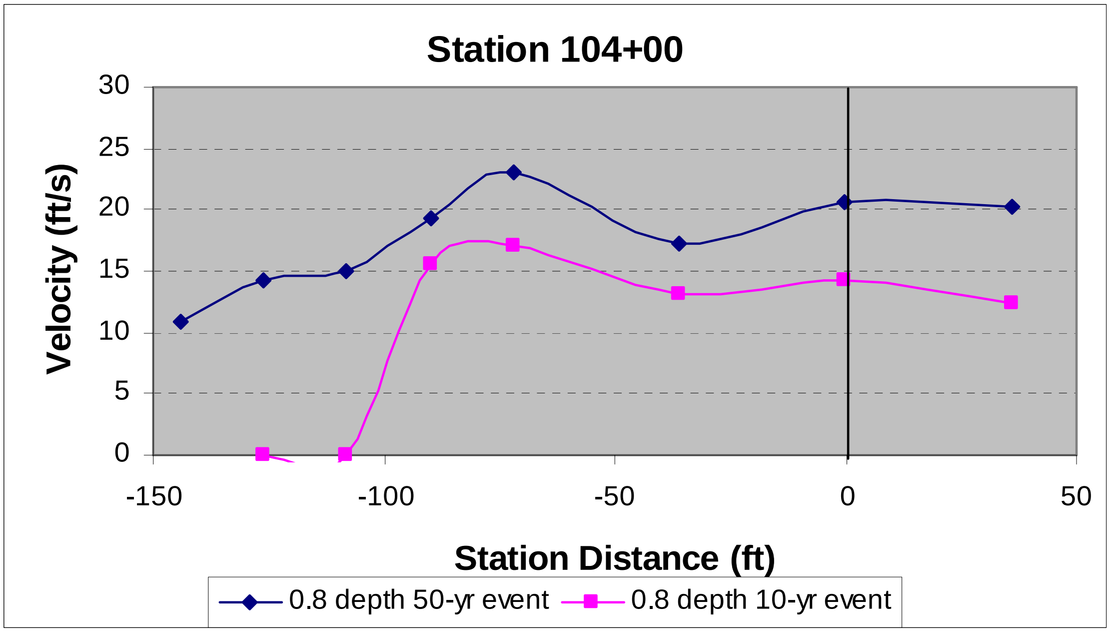


Figure 24. – Bottom velocity cross section comparisons for Stas. 106+00 and 104+00 for the 50 and 10-yr events and the final fill geometry.

Final Tunnel Fill Geometry - 50-year Event Sediment Patterns

Upon completion of the flow observations, sediment travel was investigated again under the same model configuration with the 50-year event flow rate of 160,000 ft^3/s. Five-gallon buckets of sand, representing 2-2.25 inch bed load material in the prototype, were gradually poured into the model at about Sta. 114+00. The sand quickly moved downstream, mostly along the centerline or slightly left of centerline to just upstream from Sta. 108+00, figure 25. The sand formed a berm at this location that then entered the cofferdam area along the centerline of the invert. From the centerline the material then moved left toward the cofferdam toe as it traveled downstream. This pattern was intensified as the sand moved downstream to the topography protrusion at about Sta. 102 where the sand was pushed far left and up on the cofferdam as the flow was redirected by the topography, figure 26. Material appeared to pass through the center of the river channel more than occurred under the 10-year flow.

The rock on the invert of the model between, Stas. 108+00 and 101+00, was not disturbed by the flow; however, the rock on the river invert below the rock outcrop at about Sta. 101+00 downstream was entirely removed, exposing the floor of the model at El. 582.75 and the toe of the cofferdam.

Figure 25. - Overall view of the sediment deposition after the 160,000 ft^3/s event prior to intake installation.

Figure 26. - Close up of the sediment deposition at Sta. 102+00 after the 160,000 ft^3/s event prior to installation of the intake.

Initial Pumping Station Intake and Main Channel Investigations

The river reach between Stas. 100+00 and 94+00 contains the intake structure, intake entrance and exit channels and a bypass channel along the left bank referred to as the main channel, see figure 2. A longitudinal berm separates the channels for river flows less than about 12,000 ft^3/s. The intake structure and main channel were investigated after completion of modeling investigations of the upstream river channel, diversion tunnel fill, and cofferdam. The design objective for the pumping station intake structure is withdrawal of 225 ft^3/s while passing the majority of the flow, sediment, and gravel through the main river. In addition, the main channel area must be designed to allow passage of kayakers and boaters. The intake structure was built in the model from drawings received the end of April, 2005 from ASTS [4].

Figure 27 shows the intake area including three sediment basins with diagonal guide vanes, the intake channel and bottom screen (far right side of the channel), and the main channel separated from the intake by a dividing berm outlined in white. The sediment basins were lined with rock set at invert El. 487. The crest of each vane was fixed at El. 491. The intake was modeled as a structural channel with bottom intake screens. Flow was passed through the model screens to a sump and discharge pipe. The intake structure was modeled in plywood with the elevation of the channel at the maintenance gate and upstream end of the screen at El. 493. The downstream dissipation channel and kayak pool at El. 487 was included below the intake channel. The berm downstream from the dissipation pool was modeled at El. 490. The divider berm between the intake structure and the main channel was formed with longitudinal templates that formed the wall of the intake structure and the left side of the top of the dividing berm. The templates were then filled with rock to grade. The top of the divider berm at El.

Figure 27. - Overall views of the intake structure with the sediment basins and main channel installed in the model.

501.5 was adjacent to the maintenance gate and sloped both in the upstream and downstream directions following the wall heights for the intake structure. The main channel included an upstream control section at Sta. 98+35 with the crest at El. 495. Several plywood templates with rock between formed the main kayak channel and remaining slopes in the area. Even though this rock will be grouted in the prototype, the rock was not grouted in the model. It was felt that this would allow some idea of potential areas of concern for erosion. The right bank topography was formed of concrete with the access roads entering the intake area modeled with plywood. A 1/3 sand and 2/3 pea gravel mixture replaced the larger rock over the fixed river channel invert upstream from the intake area between Sta. 102+00 to Sta. 108+00. The prototype sizes for this invert material ranged from 2 in for the sand to 0.75 to 1.125 ft for the pea gravel.

Flows representing the 1.5, 5, 10, and 50-year events were investigated. Tailboards were inserted in the model during initial start up each day to pond the water and prevent artificial movement of material during filling to the required discharge. Flow and material movement observations were then made for each discharge starting with the 1.5-year event and increasing to the 50-year event. For reference, the sediment basins will be referred to as 1, 2, and 3 from upstream to downstream.

1.5-year Flow Event

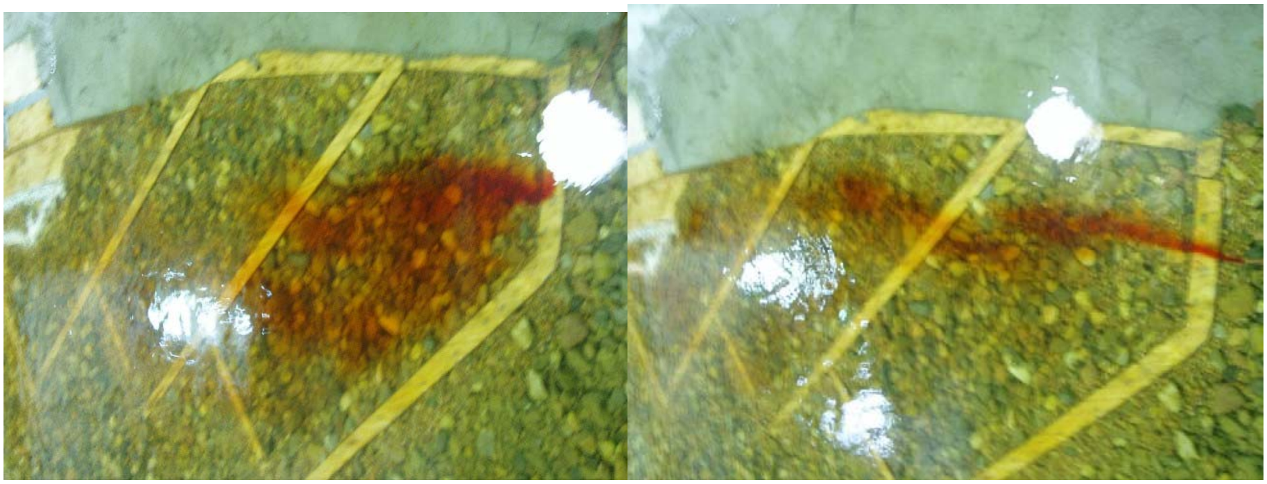
The first test was conducted under the discharge of 12,300 ft^3/s associated with the 1.5-year event. Under this discharge, the topography at the end of the model controlled the tailwater to a level about 1.5 ft higher than predicted by the HEC-RAS information at Sta. 94+00.

Dye was used to investigate the flow patterns through the upstream sediment basins, figure 28. Dye injected at the top of the vanes at El. 491 dove down into the basins, dispersed, and diverted to the left. In general, dye injected up into the flow depth and near the surface went downstream following the bend in the river and the flow streamlines through the intake. Dispersion and cross channel movement of the dye near the bottom was most pronounced in basin number l. Bottom dye showed less travel to the left in the downstream basins. These tracings indicated that bed load should deposit in or be diverted toward the main channel by the sediment basins during small flow events.

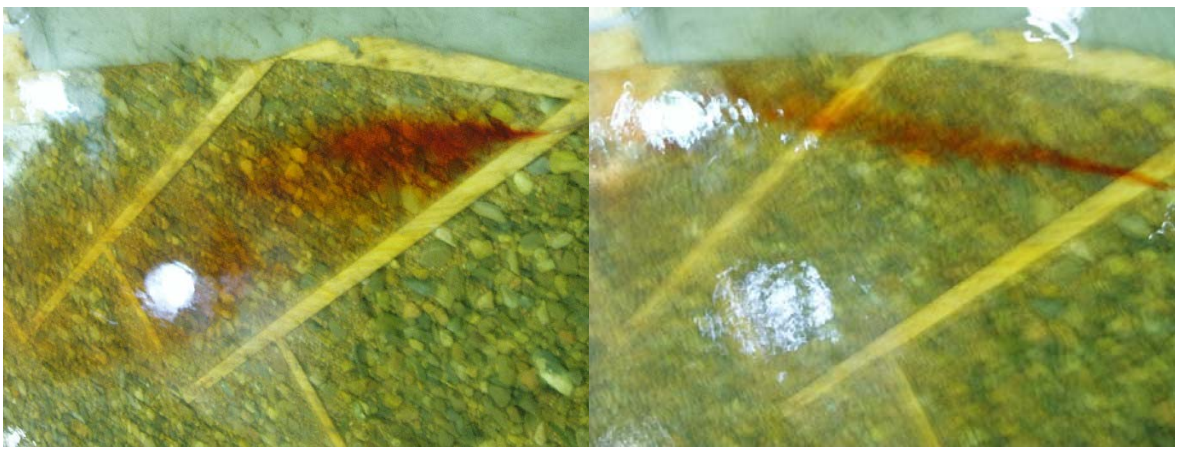
The center dividing berm was submerged by the flow depth over the flat portion at El. 501.5. Downstream from the flat section the flow split and the berm was dry for a distance of about 24 ft. Flow that crossed the divider berm and entered the intake channel caused a standing wave in the channel at the location of the maintenance gate. This could be prevented by raising the wall and berm from the flat section adjacent to the wall upstream to the location of the 495 elevation. The raise would be a distance of about 65 ft along the intake wall.

A supercritical standing wave formed immediately upstream from the screen in the intake channel. The wave extended downstream over the intake screen. Flow exiting the intake channel into the downstream dissipation pool formed a large slow moving eddy in the cove near the right bank. There was some flow up onto the road on the right bank at the end of the intake channel for this tailwater and flow rate.

There was a good concentration of flow in the main channel adjacent to the intake. Flow separated off the upstream end of the flat section of the divider wall and the cofferdam slope about 70 ft upstream from the control section in the main channel. The flow in the main channel existed parallel to the divider berm and headed downstream. No material was observed to have moved throughout the entire area of the intake or the main channel.



Dye tracings for the 1.5-year event from the most upstream sediment basin (#1). Left photo with dye injected near the bottom and right photo near the surface.



Dye tracings for the 1.5-year event from the second sediment basin (#2). Left photo with dye injected near the bottom and right photo near the surface.

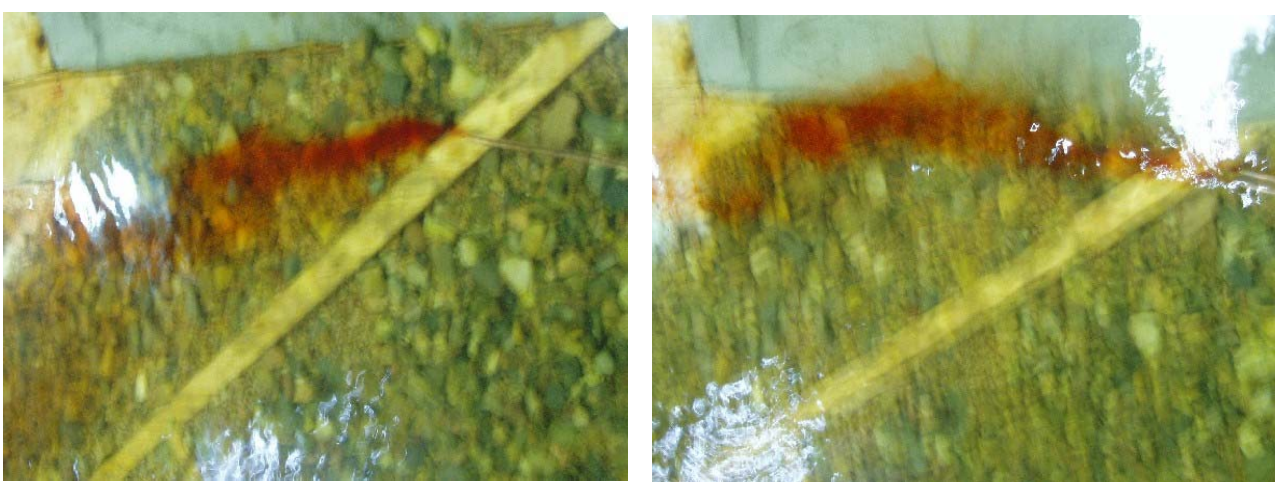


Figure 28. - Dye tracings for the 1.5-year event from the sediment basin closest to the intake (#3). Left photo with dye injected near the bottom and right photo near the surface.

5-year Flow Event

Figure 29 shows the overall flow condition for the initial intake and main channel geometries operating under the 5-yr event of 45,000 ft^3/s. The tailwater was set to El. 511.78 at Sta. 94+00 to match the HEC-RAS model results. Dye tracings showed similar flow patterns to the 1.5-year flow event. Flow conditions upstream from the intake show the angled sediment basins to be effective in redirecting the bottom flow away from the intake. The influence of the bend in the river is seen with the flow up in the water column staying near the right side of the channel and entering the intake area.

Figure 30 shows flow passing over the divider berm into the intake channel and the formation of a standing wave just upstream from the intake screen.

Again, there was no observed movement of material upstream from the intake area.

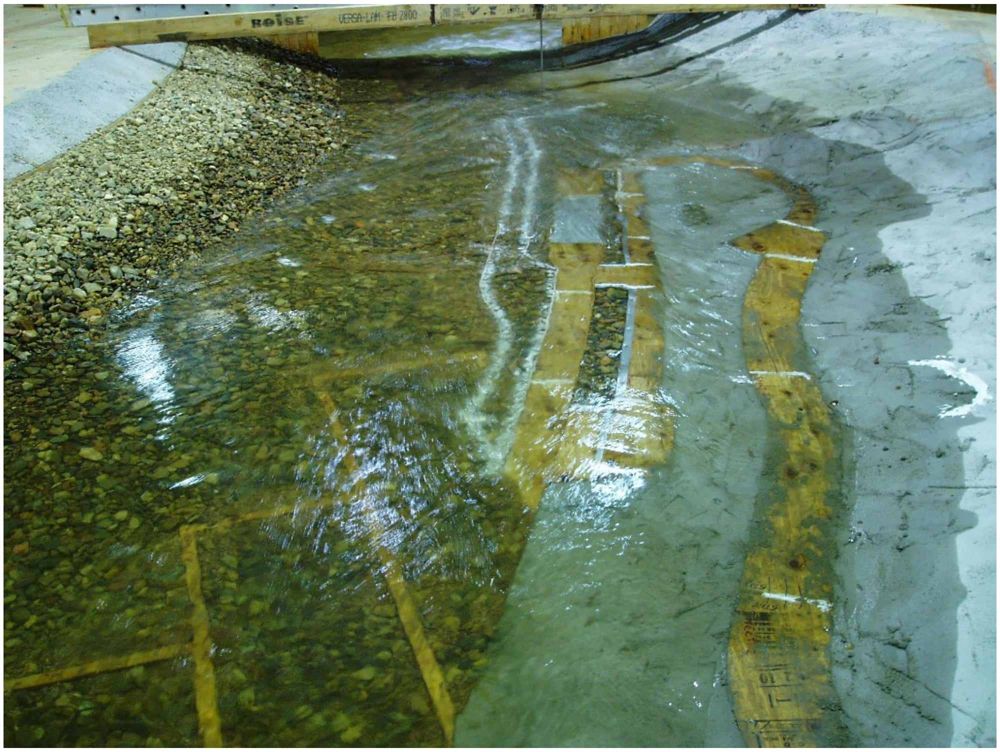


Figure 29. - Flow through the initial intake and main channel geometry for the 5-yr event of 45,000 ft^3/s.

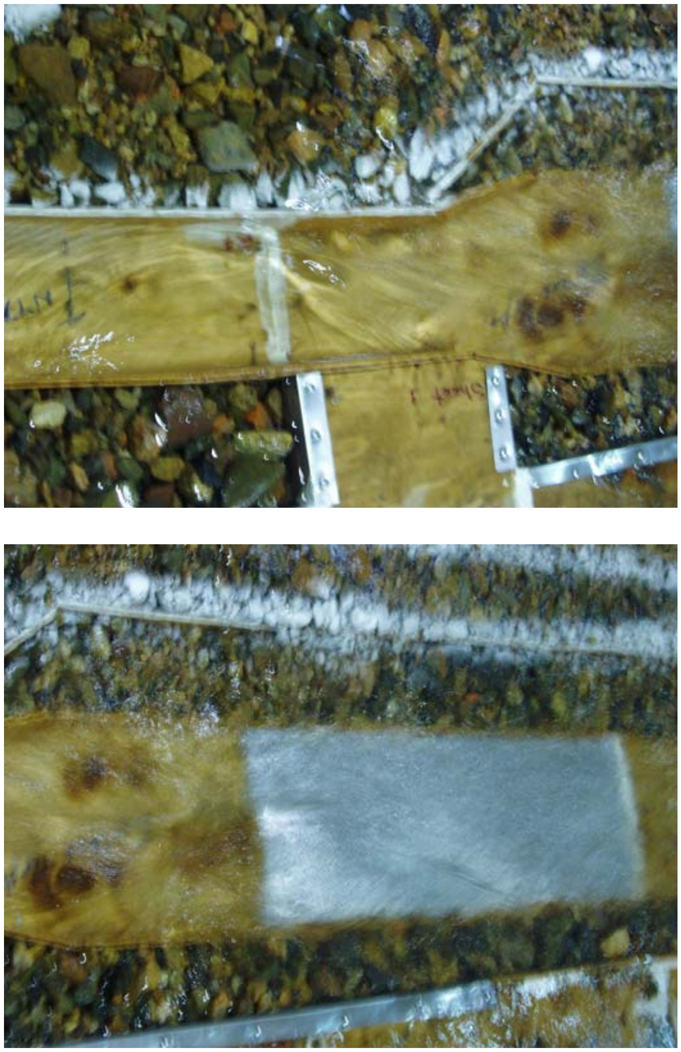


Figure 30. - Close up of the intake channel upstream of and on the screened intake for the 5 yr event of 45,000 ft^3/s.

10-year Flow Event

Figure 31 shows the overall flow conditions for the initial pumping station intake and main channel areas for the 10-year event of 72,000 ft^3/s. The tailwater was set to El. 517.36 at Sta. 94+00 to match that of the HEC-RAS model. The flow conditions continued to be similar to the smaller flows with more submergence of the intake and divider berm and higher velocities overall in the channel. Dye tracings indicated that flow near the bottom was redirected to the main channel on the left by the two upstream vanes. Flows off the bottom and near the surface still followed the bend and entered the intake area or flowed over the right bank topography and access roads from the two upstream vanes. Higher overall velocities in the channel; however, made the third basin or the one closest to the intake channel less effective, with even some dye near the bottom entering the intake.

Figure 31. - Overall view of the initial intake and main channel design operating under the 10-year flow event of 72,000 ft^3/s. Notice that the upper access road is submerged and there is a poorly formed hydraulic jump over the topography adjacent to the screened intake.

Flow converged over the screen from both the main channel and the right bank. Figure 32 shows two views of flow over the intake area. Supercritical flow occurs over the screened intake area with a wave forming over the screen In addition, flow over the right bank forms a jump over the low spot in the topography on the bank (figure 32, bottom photo) then releases downstream over the end of the intake area and into the dissipation pool. The flow exited from the intake and dissipation pool then met with the main channel flow and flowed toward the left of the channel centerline to the end of the model. A recirculating eddy still existed in the pool to the right downstream from the access road cut.

Sediment movement and deposition patterns were investigated for this flow event because this frequency event had been determined as a critical flow event for design purposes. Sand, representing about 2-2.25-in size prototype gravel, was fed into the model at the upstream Sta. 114+00. The model was then operated for most of the day with the final deposition pattern shown on figures 33 and 34.

Figure 33 shows that the sediment traveled along the outside of the bend through the upstream channel forming large dunes that migrated downstream over time. The right photo in figure 33 shows that a large amount of sand was diverted by the orientation of the basins toward the adjacent main channel on the left. A large amount of this material deposited near the toe of the cofferdam upstream from the control section. In addition, the sand traveled over the first vane into the basin, collected and was traveling to the left. Figure 34 shows the view across the intake and main channel showing some movement of ungrouted rock from the berm and the deposition of some sediment into main channel.

There was no apparent movement of the invert material while operating, however; upon completion of the test and draining of the model, it appeared that the fine sand in the invert had been swept from the model as suspended bed load.

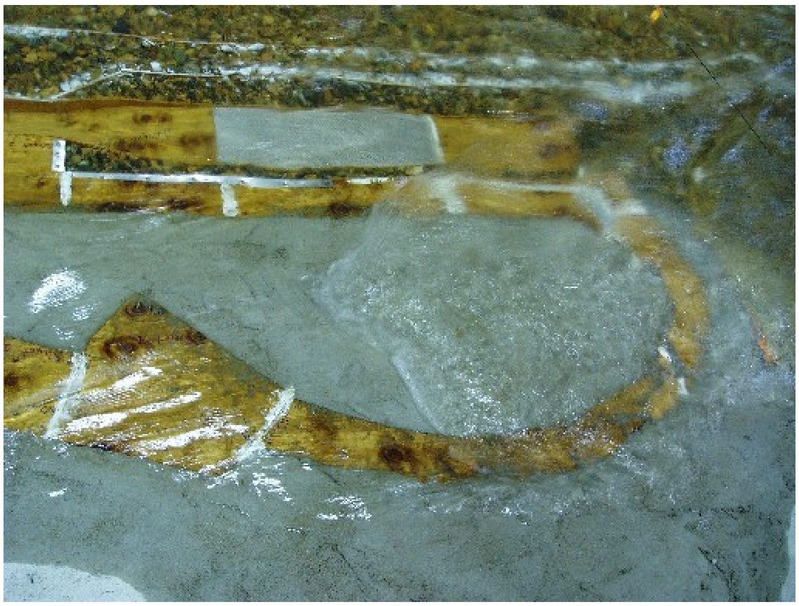


Figure 32. - The top photo shows the 10-year event of 72,000 ft^3/s flowing through the initial intake and main channel. A wave forms over the screened intake. The bottom photo shows the formation of a hydraulic jump over the topography on the right bank.

Figure 33. - Sediment deposition pattern after running the model at the 10-year event for most of a day. The left photo shows the upstream portion of the river from about Sta. 108 to about the first sediment basin in the background. The right photo is a close up view of the sediment basins with the screened intake channel entrance shown at the top. Note that the upstream sediment basin is mostly filled and the material has been pushed to the left toward the main channel.

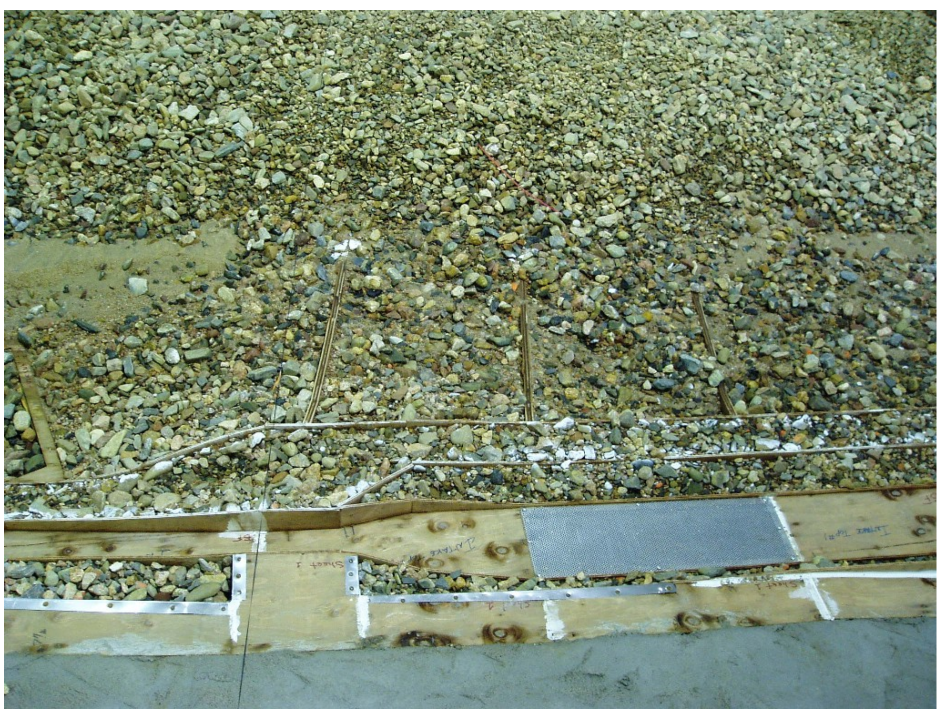


Figure 34. – View looking across the intake structure into the main channel showing the deposition pattern after operation under the 10-year event of 72,000 ft^3/s.

50-year Flow Event

Finally, the model was operated for the 50-yr event of 160,000 ft^3/s with the initial screened pumping station intake and main channel geometry. The tailwater was set to El. 531.7 at Sta. 94+00 to match that of the HEC-RAS model. Figure 35 shows the river channel with the intake and main channel areas fully submerged.

Figure 35. - Flow conditions in the initial screened pumping station intake and adjacent main channel operating under the 50-year flood event of 160,000 ft^3/s.

During filling the material on the upstream invert began moving, even with a surcharge of tailwater. Once the flow and appropriate depth were obtained, material in the upstream river channel invert quickly began moving downstream. Dye tracings indicated that the sediment basins would trap sediment and divert flow near the bottom of the river while flow higher in the water column would travel downstream.

Figures 36 and 37 show the result of movement of the upstream invert material and feeding sand into the model for a period of about 4 hours while the material moved. Figure 36 shows erosion of the upstream invert with a dune formed just upstream from the first sediment vane. It also shows the effectiveness of the vanes in diverting bed load material from in front of the intake and sending it to deposit in the main channel and along the toe of the cofferdam.

Figure 36. - Erosion and deposition of the bed material in the model upstream and adjacent to the sediment vanes after the passage of the 50-year flow of 160,000 ft^3/s.

Figure 37 shows the result of deposition in the main channel area. Primarily, the fine-grained sand added to the model relatively quickly moved downstream entirely through the system. Some deposited up high on the cofferdam slope. Most of the material, particularly that deposited at the downstream end of the model, is the slightly larger material washed from the upstream channel invert.

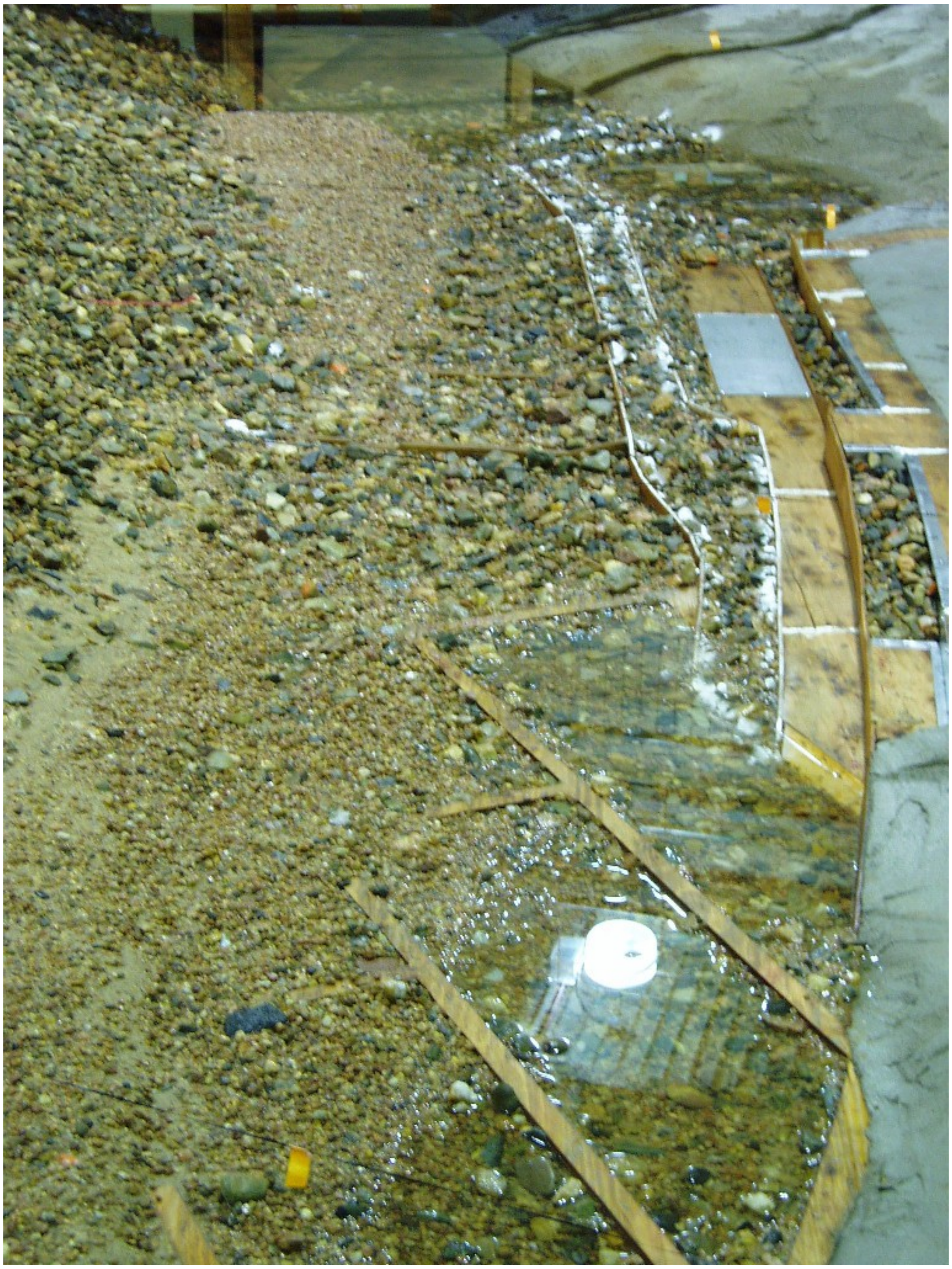


Figure 37. - Overall view of the sediment basins, intake area and adjacent main channel after operating under the 50-year event of 160,000 ft^3/s.

Flow Conditions for the Modified Intake and Main Channel

The model was modified in July 2005 to match the geometry of the specifications provided at the June 27, 2005 Review C meetings [6]. The screened pumping station intake channel and the main channel were both modified according to the plan view of the ACAD drawing provided by ASTS shown on figure 38. The model was modified by:

- Extending the intake channel entrance upstream to the location of the initial third or most downstream sediment vane at about Sta. 100+50. The intake channel remained at El. 491, but the curvature was slightly changed to match the new river centerline alignment provided.
- Raising the two remaining sediment vanes in front of the intake to El. 495 so that the settling basins and surrounding upstream channel invert were the same at El. 491. This reduced excavation and produced a 4 ft differential between the top of the vanes and the inverts of the intake channel entrance and the upstream channel.
- Raising the invert of the intake screens by 1 ft to El. 494 at the upstream end of the screens. The slope of the screened invert remained the same at 1.5 percent.
- Widening the intake screen section by 5 ft to a total of 29 ft to allow a full screen width of 8 ft at a 1 ft lower elevation through the middle of the two screen banks. The center lowered portion was designed to allow passage of bed load through the system.
- Raising the maximum height of the divider berm between the intake and main channel by 3.5 ft to El. 505.
- Adding a series of crests and pools in the main channel to allow for recreational kayaking. The kayak area could only be grossly estimated because of the model scale.
- Moving the toe of the cofferdam out toward the river channel centerline and providing for a kayaker take out between the main channel control section at about Sta. 99+18 upstream to Sta. 101+50.

The model is shown in the dry with the modifications made on figure 39. The model topography on the bank above the intake structure was not reconstructed to expedite the schedule. This meant that the right bank access roads became inundated by the tailwater sooner than will in the prototype under small flows. The templates used to construct the main channel topography are shown at Stas. 99+18, 98+45, 97+43, 96+36, and 94+64 on figures 38 and 39 and represented locations very near to the crests or controls for the first four pools. The pools were modeled by making small depressions below the template crests.

The flow hydrology was also revised at the time of the Review C meetings in June 2005. Table 3 shows the return periods with the previous and new flows to be tested. In general, for the smaller return periods, the flows remained similar, and for the higher return periods, the new flows were significantly smaller. The previous 50-year event is now essentially the 100-year event. The representative tailwater elevations are also shown for Sta. 94+00 as provided by ASTS from HEC-RAS modeling.

Table 3. - Return periods with the previous and new hydrology and tailwater information.

Return Period	Previous Discharge (ft^3/s)	Previous Tailwater (ft)	New Final Discharge (ft^3/s)	Final Tailwater at Sta. 94+00 (ft)
1.5 year	12,300	499.96	11,900	499.71
5 year	45,000	511.78	42,000	510.33
10 year	72,000	517.36	63,000	515.78
50 year	160,000	531.70	128,000	526.13
100 year	??	??	164,000	531.03

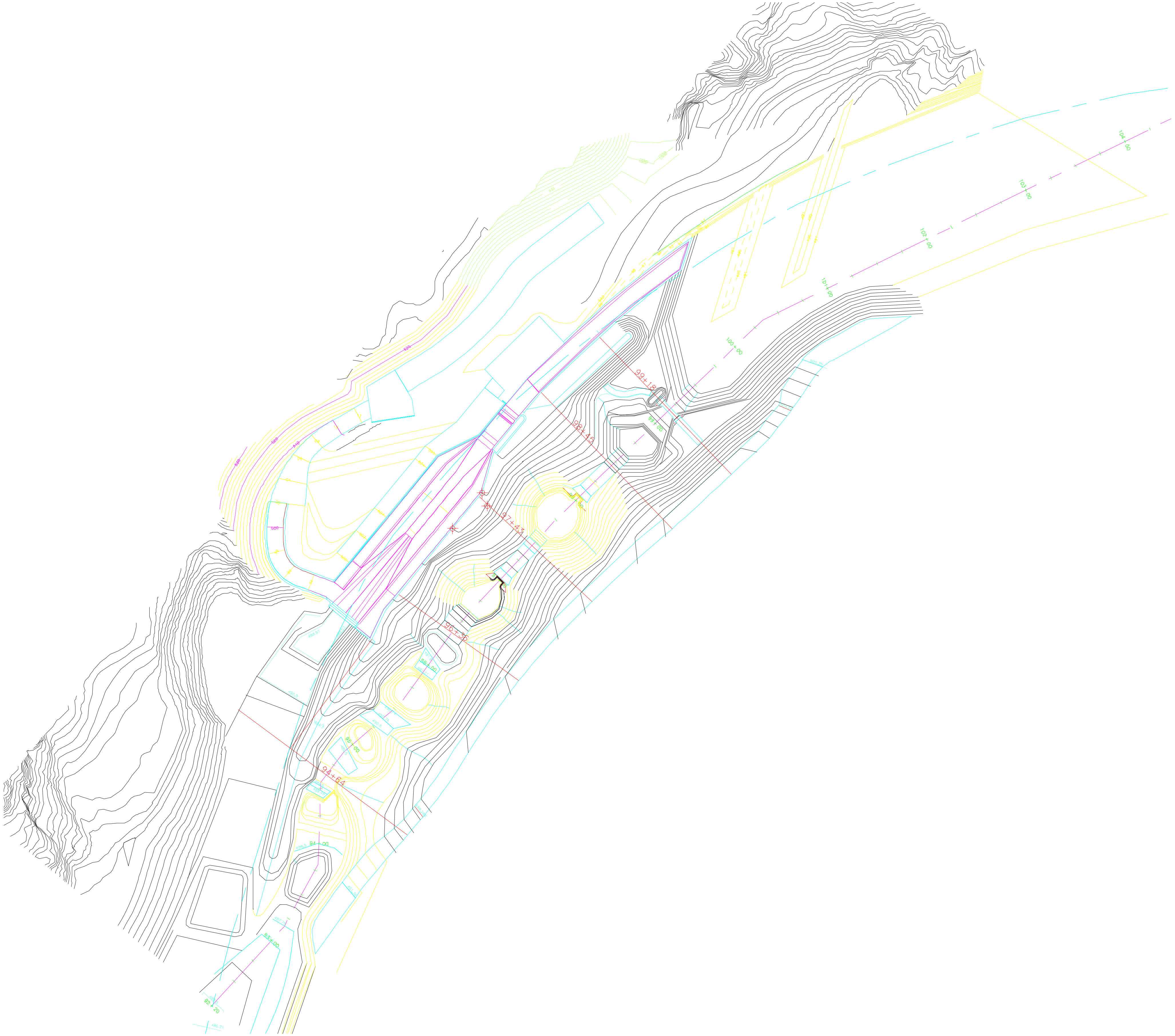


Figure 38. - Plan view of the intake and main channel geometries as of the June 2005 Review C specifications. The entrance to the screened area was lengthened and the screened area was widened. The main channel area was constructed of templates (shown in red) and included the crest control locations for the kayak pools and adjacent topography. The right bank topography and the location and elevation of the structures and access roads were not changed in the model.

Figure 39. - Overall view of the final screened intake channel and main channel modifications per the June 2005 specifications. The location of the emergency intake structure and access roads were not changed in the model. The entrance to the screened area was lengthened and the screened area was widened. The main channel area was constructed of templates (painted orange in the photo) and included the crest control locations for the kayak pools and adjacent topography.

The following sections describe the flow conditions through both the screened pumping plant intake channel and the main river channel for the same return periods with the new flow rates shown in table 3. The screen section is indicated in the model by red lines drawn on the surface of the plywood. Sand, representing 2-2.25 inch prototype bed material, was fed into the model for the 10-year event at the same upstream location, about Sta. 114+00, as in the previous tests. Material movement and deposition patterns for the 10-year event will be discussed.

1.5-year Flow Event

The new 1.5-year event was 400 ft^3/s less than the previous flow rate for the same return period. Many of the modifications made to the intake and main channel divider berm were made to improve the low flow performance of the screened intake reported from the previous testing.

The flow conditions to note at the 1.5-year event were the flow in the intake over the screen and if flow occurred over the access roads. Operation under the flow of 11,900 ft^3/s showed that the upstream portion of the extended intake channel was submerged. The rounded riprap feature adjacent to the structure in the main channel splits some of the flow directing a portion into the intake channel. Flow enters the intake channel along the left and right walls until about Sta. 98+45 when the wall height of the upstream intake channel exceeded the upstream flow depth for this discharge. With the previous hydrology and channel designs, flow came over the berm dividing the intake from the main channel. The current divider berm design successfully separated the flow between the main channel and the screened intake area. An overall view of the model operating under the 1.5-year event of 11,900 ft^3/s is shown on figure 40.

Figure 40. - Overall view of the intake structure and main channel passing the final 1.5 year event flow rate of 11,900 ft^3/s.

The flow in the intake channel went through critical depth at the location where the channel widened and spread to the width of the section. Cross waves formed at the end of the expansion and met over the screened area about two-thirds of the way down the screen area with supercritical flow over the length of the area, figure 41. The width of the channel and the tailwater also influenced the formation of a wave over the screened area.

An attempt was made to force the wave downstream of the screened area by narrowing the channel. Temporary boards were placed from the end of the upstream channel to narrow width through the screen area. The most effective way to improve the flow conditions was to make the expansion longer to end at the beginning of the screen section. By extending the expansion, the cross waves were moved downstream from the screen area before they met in the channel. This was only a temporary adjustment in the model and was not evaluated for the other flow rates, but it is projected that the change would perform at least as well as the modeled geometry.

Discussions with the designers during viewing of the model revealed that they had already made a longer transition section from the upstream channel to the screened area. This should help with formation of cross waves, but was not included in the final modeling.

Figure 41. - Close up of the flow through the approach channel to the screen area and the wave over the screen area during operation under 11,900 ft^3/s.

In addition, because the access roads and topography on the right bank were not modified, the tailwater inundated the road along the right side of the intake channel, but did not flow over the wall into the intake. Water would not be on the access road given the proposed tailwater level and road elevation of 505.

As mentioned, the model scale was not large enough to provide much detail regarding the crests and pools designed for kayaking in the main channel. The crest of the control section into the main channel was entirely submerged under the flow from the 1.5 year event, except for the rounded riprap knob between the main channel and the intake channel. The flow then concentrated through then crest section formed by the template at Sta. 98+45 and came together forming a wave in the pool below the crest. Figure 42 shows the standing waves extended downstream following the center of the main channel, figure 42.

Figure 42. - View of the main channel kayak pools and the adjacent intake channel under the 1.5-year flow event of 11,900 ft^3/s.

5-year Flow Event

The new flow rate of 42,000 ft^3/s is 3,000 ft^3/s less than the previous 5-year event. The tailwater was controlled by the topography downstream from the intake and resulted in a tailwater ½ ft higher than estimated by HEC-RAS.

Dye was injected into the model upstream of the new design for the two sediment vanes and settling basins. The dye tracings looked very similar to the previous design for the two vanes and basins remaining. The dye dispersed when injected near the bottom and flowed downstream following the flow streamlines on the outside of the bend near through the flow depth to the surface. The flow characteristics upstream and downstream of the first vane are shown on figure 43. When dye was injected upstream of the entrance to the intake, the performance was somewhat better than in the previous design. The dye near the bottom dispersed left somewhat which did not occur before. The projection of the vanes higher into the flow is probably the reason for this improvement.

During viewing of the model, the designers discussed options for sloping of the top of the vanes from right to left and possibly changing the initial height of the vanes. Also discussed was the shape of the face slopes from the vanes to the invert of the river or the settling basins. Any of these options should work and may be adopted if economical.

Dye injected on the bottom (left) and top (right) upstream from the first vane under the 5 year flow event for the current design.

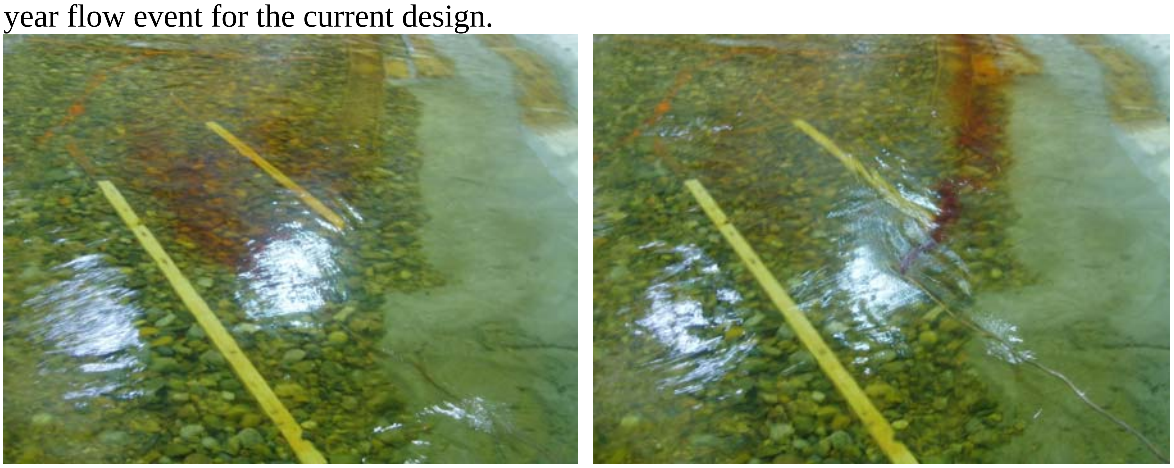


Figure 43. - Dye injected on the bottom (left) and top (right) between the upstream and downstream vanes for the 5-year flow event of 11,900 ft^3/s for the current design.

The entire intake structure was submerged by the depth of the flow in the river upstream, figure 44. Water flowed over the access roads beginning at the bottom of the curve at about El. 514, but the location of the intake vault on the bank was dry. Water over the access roads flowed down the right bank and into the intake structure. Water in the main channel flowed parallel to the intake channel and then flowed over the divider berm into the area of the expanded screen width.

Figure 44. -- Overall view of the intake structure and access road area for the 5-year event of 42,000 ft^3/s. Note the screened intake area is entirely submerged with flow entering from both the main channel and from the right bank, although the access roads are not entirely submerged.

Figure 45 shows a large standing wave was located over the upper portion of the screen area with supercritical flow throughout the remaining downstream screen area. Flow over the upper topography also flowed along the road adjacent to the screened intake area and formed a wave at the downstream end of the structure where the flow from over the topography and that exiting the intake met. Flow recirculated over the flatter topography below the intake vault and access road up to about El. 504 as shown in figure 46.

Figure 45. - Close up of the current screened intake operating under the 5-year event showing flow entering both sides of the expanded section upstream from the screen. A wave is formed over the screen where the flows met.

Figure 46. - Downstream end of the intake operating under the 5-year event with a wave shown on the right side of the structure where flow over the topography met flow exiting the structure. Flow recirculated over the topography in the bottom of the photograph.

Figures 44 and 47 show flow in the main channel over the crests and pools formed for the kayak reach of the current design. In general, the wave front had moved further downstream than the location under the 5-year event. The flow concentrated in the center of the channel and plunged over the third crest at about Sta. 97+43, into the pool below. Waves continued downstream as the flow followed the center of the main channel.

Figure 47. - Flow through the main channel (looking across the channel from the right bank) showing where the flow concentrated and the wave front was formed between Stas. 97+43 and 96+36.

10-year Flow Event

The tailwater was set to El. 515.78 at Sta. 94+00 for the 10-year flow event of 63,000 ft^3/s. The new 10-year event was 9,000 ft^3/s lower than that previously tested. The upstream water surface was measured at El. 521.43 ft. at Sta. 114+00. Flow conditions for this event were similar to those for the previous flow rate and design, just less submergence and velocity, although figure 48 shows there was still submergence of the access roads, intake area, and main channel.

Figure 48. - Overall view of the final intake and main channel geometry operating under the 10 year event of 63,000 ft^3/s. Notice all the structures, main channel pools, and access roads are fully submerged.

The access road conveyed water down the bank through the intake vault area where a hydraulic jump formed over the topography. Flow continued to recirculate over the curved portion of the lower access road. Water from the bank entered the screened intake further downstream than for the 5-year event. A standing wave formed over the screen but slightly further downstream with the higher discharge. A rooster tail developed on the left side of the wave over the screen caused by flow entering from the main channel, figure 49. The wave at the end of the structure was less pronounced and the flow remained supercritical with the greater flow volume sweeping the flow further downstream.

Figure 49. - Flow over the topography to the right of the intake and over the screened area of the intake for the current geometry under the 10-year event. Notice the pronounced wave over the screen with the rooster tail on the left side. Also, note the hydraulic jump and recirculation of flow over the lower portion of the topography and the lower access road.

Flow through the main channel is also shown in figure 50 with the flow supercritical through all sections parallel to the intake channel. Flow in the main channel separated from the cofferdam beginning between Stas. 98+45 and 97+43. The flow concentrated in the low spots in the channel downstream of Sta. 96+36 and followed the right side of the main channel. A large wave formed past the end of the intake structure to the left of the flow exiting the intake structure.

Figure 50. - Flow through the main channel showing the wave near the end of the channel while operating under the 10-year event of 63,000 ft^3/s for the current design.

The sediment tests showed that the upstream vanes and settling basins were more effective at diverting bed load traveling towards the intake than the previous design. The sediment had previously filled a portion of both basins downstream from the first two vanes. With the berms at El. 495, about 4 feet above the invert of the bed, the first or most upstream vane diverted a large portion of the bed load toward the main channel.

Most of the sediment that traveled over the vane entered the settling basin about 69 ft from the right end of the vane, figure 51, and traveled along the bottom of the basin toward the main channel. The point of topography upstream from the first vane directed the flow and sediment. The vane must be anchored to the rock with minimal excavation or shaping needed in the lea of the rock point.

Even though an entire cubic yard of material was fed into the model, no material passed over the second vane and into the settling basin as it had in the previous design. In addition, the flat surface formed into the cofferdam for a kayak take out area collected sand as seen in the upper left corner of figure 51.

During a visit to the model, the design team from ASTS mentioned they wanted to slope the top of the sediment vanes from right to left, looking downstream. This was not studied in the model, but certainly would be acceptable if the design team chose to include that feature based upon their experience. In addition, the upstream and downstream faces of the vanes are sloped with grouted riprap. If another shape is desired by the design team, and deemed more economical, then reshaping could also be performed.

Figure 51. - Deposition pattern at the sediment vanes, upstream of the main channel control section and over the kayak take out area, for the current design after the 10-year event of 63,000 ft^3s.

The main channel after the sediment testing is shown on figure 52. Sediment primarily entered the channel to the left of the centerline of the control section where a trail of deposition occurred. Sediment deposited upstream from the control, in the main pool downstream, and in the area to the left of the main pool. Material then passed through the next crest section primarily through the centerline of the channel and deposited in the pool.

The deposition pattern further downstream at the end of the main channel after the 10-year event is shown in figure 53. At the end of the main channel, sediment deposited to the left of the channel centerline. The centerline of the channel was swept clear by the combined flows from the main and intake channels.

Figure 52. - Sediment deposition in the current main channel design after testing the 10-year event. Note the sediment primarily entered the channel to the left of the centerline, deposited in the main pool and traveled

Figure 53. - Final sediment deposition pattern at the downstream end of the main channel after testing the 10-year event of 63,000 ft^3/s. Note that sediment deposited to the left of the main channel near the end of the model by Sta. 94+00.

50-year Flow Event

The tailwater was set to El. 526.13 at Sta. 94+00 for the 50-year flow event of 128,000 ft^3/s. This was 32,000 ft^3/s lower than that previously tested. The upstream water surface was measured at El. 531.12 ft. at Sta. 114+00. Flow conditions for this event were similar to those for the 10-year event flow rate, but with more submergence of the structures and higher velocities, figure 54.

Figure 54. - Overall view of the model operating under the new 50-yr event of 128,000 ft^3/s showing the diversion tunnel fill area, and the general flow conditions in the river.

Figure 54 shows a portion of the upstream river channel through the diversion tunnel fill area. Flow still appeared to separate from the cofferdam at about Sta. 106+00 and swing toward the outside of the bend where the intake channel was located. Fines in the invert beginning at Sta. 108+00 began moving slightly under this flow event.

Figure 55 shows the submergence of the intake area with supercritical flow through the entire river section. Figure 56 shows a close up view of the flow sweeping over the right bank access road area and the wave pattern over the screened intake area.

Figure 55. - The intake and main channel area operating under the 50-year event of 128,000 ft^3/s showing the submergence of the structures.

Figure 56. - Side view of the main channel, screened intake area and right bank with the roadway submerged under the flow of 128,000 ft^3/s representing the 50-year event.

100-year Flow Event

The 100-year event flow rate of 164,000 ft^3/s was almost identical to the previous 50-year event of 160,000 ft^3/s. Basically, the return period doubled for this higher flow event. Figures 57-59 show that the flow conditions that occurred were almost identical to those discussed under the 50-year event from the previous intake and main channel geometry. Material from the invert at Sta. 108+00 eroded to the fixed floor of the model and the erosion was migrating downstream.

Figure 57. - Overall view of the river from the diversion tunnel location through the main channel and intake for the new 100-year event of 164,000 ft^3/s.

Flow over the bank submerged all the access roads and supercritical flow existed over the bank and intake. Flow in the main channel was also supercritical with waves extending to the end of the model. Material was removed by the flow from the end of the model upstream to about Sta. 93+00.

Figure 58. - View of the intake area and right bank with standing waves over the submerged intake and bank under the 100-year event of 164,000 ft^3/s. The adjacent main channel was also fully submerged with standing waves at the downstream end of the channel.

Figure 59. - The right bank and intake area submerged by the 100-year event with supercritical flow and standing waves occurring.

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