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Hydraulic Laboratory Technical Memorandum PAP-1176

North Fork Battle Creek Screens and Ladders Hydraulic Evaluation

Eagle Canyon Diversion Dam and North Battle Creek Feeder Diversion Dam, Battle Creek Salmon and Steelhead Restoration Project, California

U.S. Department of the Interior
Bureau of Reclamation
Technical Service Center
Hydraulic Investigations and Laboratory Services Group
Denver, Colorado

August 2019

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Introduction

Background

Pacific Gas and Electric (PG&E) operates 15 dams located along Battle Creek in Tehama County, California as shown in Figure 1. Many of these dams were constructed in the early 1900s and did not originally include fish screens for the diverted water or fish ladders. Part of the Battle Creek salmon and steelhead restoration project was to construct screens and fish ladders at some of the diversions along Battle Creek. This report focuses on two of the diversions; the Eagle Canyon Diversion Dam (ECDD) and the North Battle Creek Feeder Diversion Dam (NBCFDD).

Figure 1. Location map of Battle Creek projects in northern California

Purpose

This technical memorandum describes the post-construction hydraulic evaluation of the fish screens at ECDD and NBCFDD. A Facility Start-Up Testing and Acceptance Plan (referred to as "Hydraulic Evaluation Plan") was drafted by representatives from PG&E, California Fish and Wildlife (CDFW), United States Fish and Wildlife (USFWS), Bureau of Reclamation (USBR) and National Marine Fisheries Services (NMFS) in 2018 to comply with all applicable criteria. The goal of this evaluation is to adjust the fish screen louvers to create uniform approach flow and to document the hydraulic performance. Assuming a favorable result, this hydraulic evaluation will be used to document compliance with federal and state fish screening criteria.

Fisheries Criteria

NMFS Anadromous Salmonid Passage Facility Design (2011) requires that the approach velocity (velocity vector perpendicular to the screen face) not exceed 0.40 ft/sec for on-river screens at a point approximately 3 inches in front of the screen face. This approach velocity criterion is intended to prevent impingement of juvenile salmonids on the screens. The NMFS criteria states the sweeping velocity (velocity vector parallel and adjacent to the screen face) must be greater than the approach velocity and multiple bypass entrances are required if a fish would not be moved to the bypass within 60 seconds. CDFW criteria (2000) for screens in flowing canals match the NMFS criteria. Both agencies recommend approach flow conditions should be uniformly distributed across the screen face to prevent localized areas of higher velocity. Adjustable baffles are commonly used behind the fish screen to fine tune screen panels with non-uniform velocities.

Methodology

Velocity data were collected with a Nortek Vectorino Plus three-dimensional down looking Acoustic Doppler Velocimeter (ADV). Data can be collected in the velocity range of 0.01 to 4 m/s with a sampling rate of up to 200 Hz at a sample volume distance of 0.1 m from the probe. The ADV was oriented such that the x-axis was parallel to the screen face to measure sweeping velocity, the y-axis was perpendicular to the screen velocity to measure approach velocity, and the z-axis was vertically oriented to measure vertical velocity. ADV data were collected 3 inches from the screen face. The ADV was mounted on straight piece of dimensional lumber (2x4) with a spacer between the board and the probe to ensure the center of the sampling volume was 3 inches from the screen face. Figure 2 is a photograph of the ADV probe mounted to the end of the 2x4. To perform the measurements, the board was held stationary with the probe tips collecting data at a fixed elevation for a 30 second recording period at 25 Hz sampling for a total of 750 measurements per location.

Figure 2. Photograph of the Nortek Vectrino Plus ADV probe and mount

A laptop computer was used to store raw velocity measurement data. Nortek velocity data files were viewed and processed with WinADV version 2.031 data processing software. The raw ADV data was filtered to remove velocity spikes, correlation values less than 70 percent and signal to noise ratios below 5.

At each site, when flow depths on the screen were above two feet, five fish screen panels were sampled at four locations, and the remaining screen panels were measured on the centerline at mid-depth as shown in Figure 3. When the flow depth on the screen was less than two feet, a single measurement point was taken at the centerline at mid depth on every panel. Sampling stations were marked on the blanking panel prior to testing, and the measurement depths were marked on the 2x4 to align with a linear conduit above the screen face. The total distance from the WSE to the conduit was measured and added to the three depths (¼, ½ or ¾ of the flow depth) and the sampling volume offset of the probe to place the 2x4 marks. Figure 4 shows how the red tape mark is aligned with the conduit during data collection. Both diversion sites include an automated screen brush cleaner, and all velocity data was recorded with the brush cart a minimum of two screen panels away from the ADV (either upstream or downstream) to reduce the likelihood of flow disturbance created from the brushes.

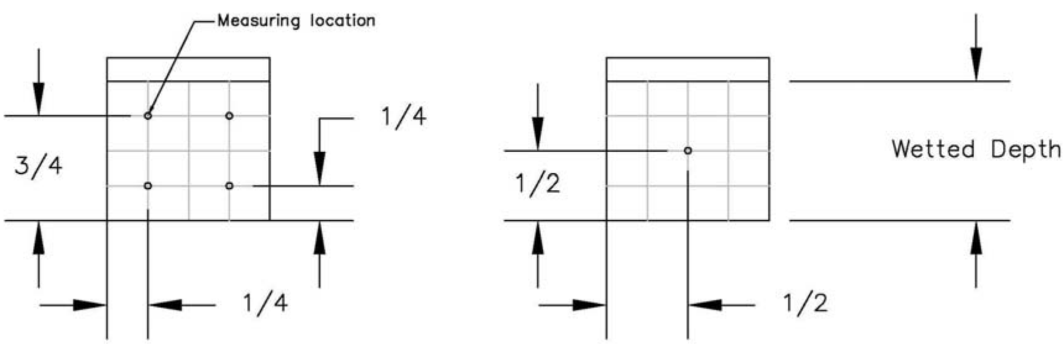


Figure 3. Velocity measurement locations for fish screen panels

Figure 4. Photograph of ADV data being collected at ECDD
showing the red tape mark on the 2x4 that was used to ensure correct measurement depth.

Eagle Canyon Diversion Dam

PG&E owns and operates the Eagle Canyon Diversion Dam (ECDD) on the North Fork of Battle Creek near Manton, California. The modifications to the existing diversion were designed by Department of Water Resources (DWR) and constructed by USBR as part of the Battle Creek Salmon and Steelhead Restoration Project. The structure consists of a flat plate fish screen with an entrance structure and a vertical slot fish ladder. PG&E's maximum diversion is 70 cfs through the canal with an additional 5 cfs for the fish screen bypass for a total river diversion of 75 cfs. A plan view drawing of the structure is shown in Figure 5 and has a photograph of the fish screen.

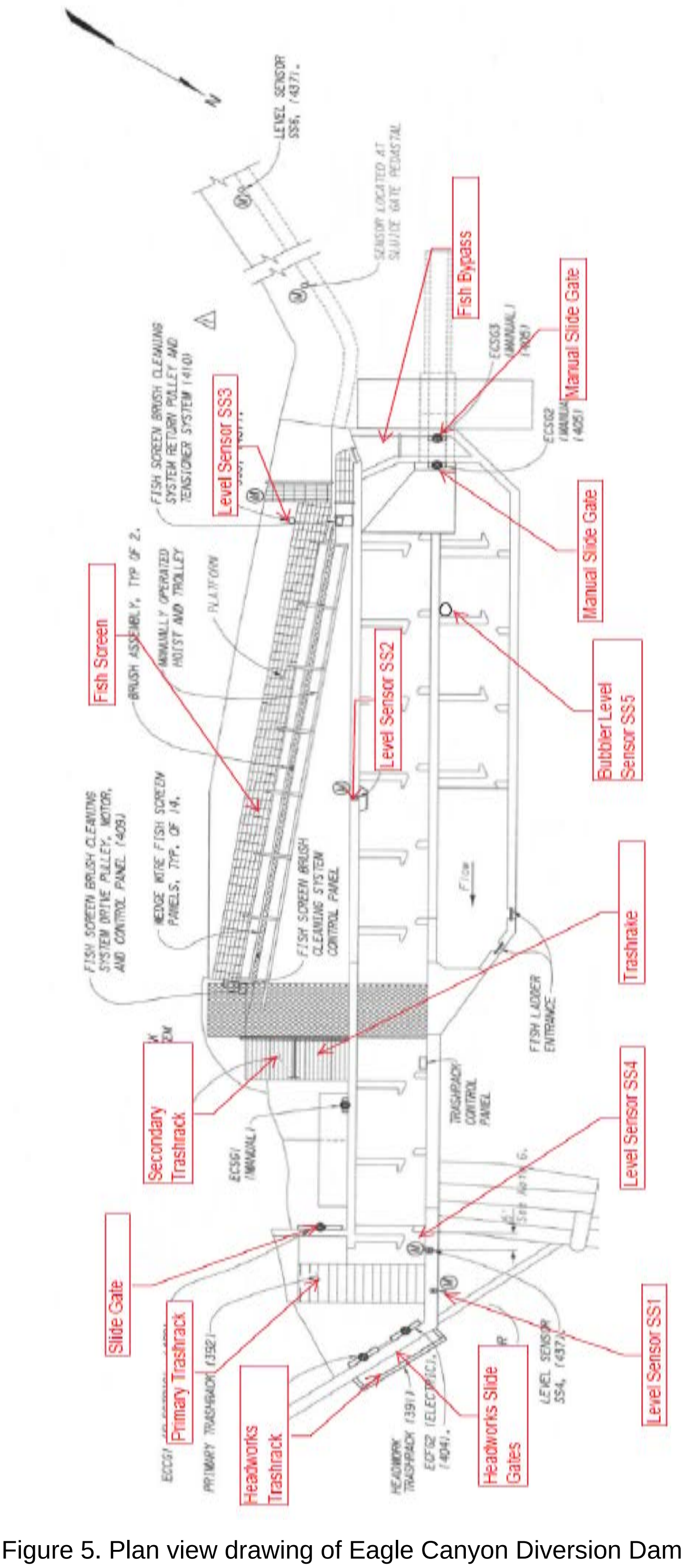


Figure 5. Plan view drawing of Eagle Canyon Diversion Dam, fish screen, and ladder

Figure 6. Photograph of Eagle Canyon Diversion Dam from downstream

Eagle Canyon Diversion fish screen is comprised of 14 screen panels, each 4.5 foot wide x 4.5 foot tall. For consistency, the testing plan used the same velocity locations from the April 2012 fish screen hydraulic evaluation where velocities on screen panels 1, 4, 7, 11, and 14 were measured at four locations, and at the midpoint on all remaining screen panels.

Screen velocities were recorded for both a high canal diversion (90 – 100% of the authorized amount of 70 cfs) and for low canal diversion (per the testing plan of 35 cfs, however during the August 2018 meeting, PG&E stated a more realistic low canal flow value is 10-15 cfs). The hydraulic evaluation was conducted during the weeks of 11 March and 25 March 2019. Team members present during the weeks (not necessarily there every day) consisted of Trang Nguyen (USBR), Jason Foust (USBR), Melissa Shinbein (USBR), Jacob Carter-Gibb (USBR), Jason Wagner (USBR), Lisa Gentry (USBR), Kent Walker (USBR), John Walsh (PG&E), Duncan Drummond (PG&E), Ben Taylor (PG&E), Kevin Colgate (PG&E), Nathan Wunner (PG&E), Jean Castillo (NMFS), Doug Killam (CDFW), Laurie Earley (USFWS), RJ Bottaro (USFWS), Kevin Gilton (Black & Veatch (BV)), and Dewey Smith (BV).

Fish Screen Velocity Results

The fish screen louvers were set to match the final configuration from the 2012 hydraulic evaluation and were observed to create uniform approach flow to the fish screen, therefore no adjustment was required. Throughout the two weeks of testing, seven separate screen velocity ADV datasets were recorded. Figure 7 and Figure 8 show the approach and sweeping velocity at the fish screen panels for both the 64.5 cfs and the 12.0 cfs tests, respectively. Plots for the remaining ADV test data can be found in the Appendix.

As indicated in Table 1, three of the measurements were recorded with stoplogs installed between the fish screen and the canal which created a higher water surface elevation (WSE) for a given canal flow rate. While operation of the facility with stoplogs installed is not currently the preferred operation, trials with stoplogs were investigated to determine the ability to operate the system with a larger canal gate opening to prevent damage to migrating adults that could be swept into the canal gate opening. The higher WSE results in lower sweeping velocities and therefore a longer exposure times that do not meet NMFS criteria for juveniles to pass the screen length compared to measurements without stoplogs. The approach velocities were also lowered when stoplogs were used, however there are no drawbacks to decreasing the approach velocity.

Canal flow rates were measured with a Sontek FlowTracker 2D ADV at the stoplog guide slot between the end of the fish screen and the start of the canal. While this location is not ideal, especially due to a sudden flow contraction from the left side rock wall through the concrete stoplog slot, it is the most uniform area at ECDD to be able to take measurements of flow passing through the fish screen. In addition to direct measurement with the FlowTracker, a continuity calculation was performed to ensure a consistent representation of the canal flow. To calculate the continuity, the approach velocity for each panel is multiplied by the flow area of the panel to obtain a panel discharge. The summation of all the screen panels resulted in the total screened flow calculation by the continuity equation. When comparing the continuity measurements, the discharge for the low and high flow tests were 89% and 95% of the FlowTracker measurements, respectively.

Table 1. ECDD fish screen velocity summary

Date	Canal Flow, cfs*	Flow Depth, ft	Fish Screen Forebay Elevation, ft	Upper Fish Bypass Stoplogs, inch	Average Sweeping Velocity, ft/s	Time to pass screen, seconds	Average Approach Velocity, ft/s
3/28/2019	12	1.42	1426.38	12	1.08	58	0.12
3/28/2019	16.4	1.67	1426.62	18	0.93	68	0.11
3/27/2019	57.6	4	1428.95	42	1.35	47	0.17
3/27/2019	64.5	4.5	1429.2	42	1.39	45	0.22
3/13/2019	6.4	2.8**	1427.82	24	0.52	121	0.04
3/25/2019	50	4.95**	1429.61	48	1.02	62	0.15
3/25/2019	52	5**	1429.7	54	0.93	68	0.12

* Canal flow values are from FlowTracker measurements, which differ slightly from CB43 rating.

**These tests had stoplogs in the canal slot which created higher flow depths.

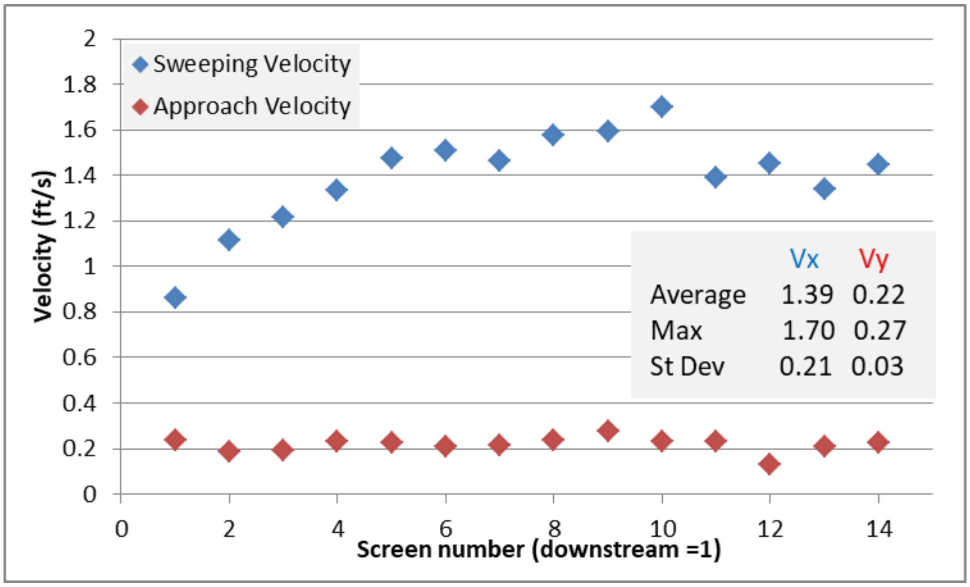


Figure 7. ADV measurements for high flow screen test. Canal discharge of 64.5 cfs

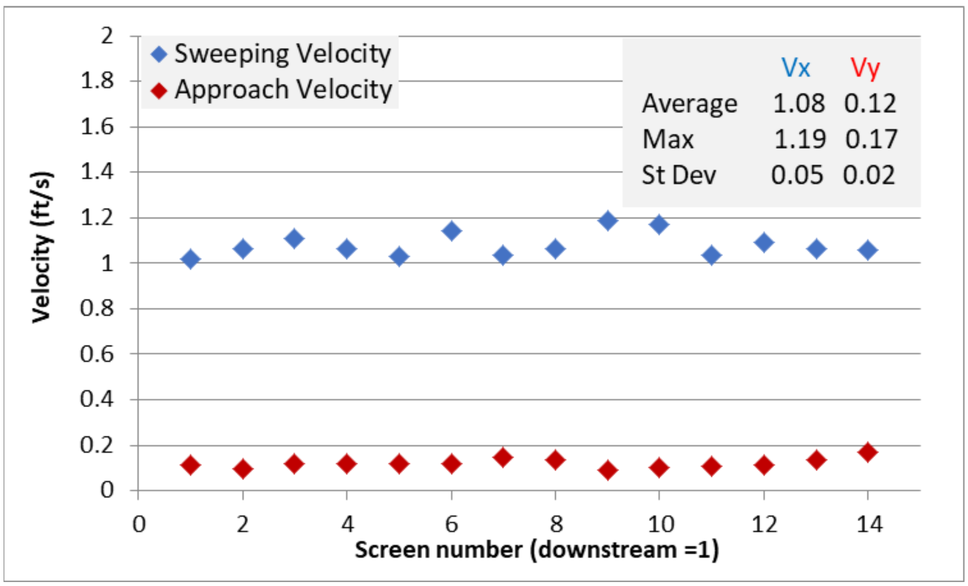


Figure 8. ADV measurements for low flow screen test. Canal discharge of 12.0 cfs

The ECDD fish screen was tested at a high canal flow diversion of 64.5 cfs and at a low canal flow diversion of 12.0 cfs. By testing at the high and low range of operations, the fish screen performance can be assured for the entire range of operation. Tests without stoplogs were observed to have uniform approach flow conditions and resulted in approach velocities, sweeping velocities and exposure time at the fish screen that met all required NMFS criteria for Salmonid exclusion. Test with stoplogs also met a majority of the required NMFS criteria, but the lower sweeping velocities resulted in exposure time that exceeded the NMFS 60 second criteria. Additional tests to document fish screen conditions and canal gate openings with stoplogs installed are planned for September 2019.

SS2 (Fish Screen Forebay Elevation) Sensor

During March 2019 testing when the canal stoplogs were used to increase the WSE along the fish screen forebay, it was observed that the SCADA output for the SS2 sensor would occasionally go into a failure status. This occurred at fish screen forebay elevations above 1429.7 feet on the SCADA panel, which was slightly above the top of the fish screen. With the 18-in.-high blanking panels mounted above the fish screen, an increased WSE on the blanking panel should not damage the facility. However, this higher WSE encroached on the sensor's deadband distance of 12 inches which caused the error. In July 2019 the mounting bracket was modified to raise the sensor by 6.5 inches without the need for rewiring. Figure 9 shows the sensor mount in March and Figure 10 shows the modified mounting from July 2019.

Figure 9. Fish screen forebay WSE (SS2) sensor and mounting bracket showing fish screen blanking panel in the distance. The enclosure for the wiring connections is mounted within the concrete wall to the left of the sensor mount

Figure 10. Fish screen forebay WSE (SS2) sensor and mounting bracket as modified in July 2019. The revised mount raised the sensor by 6.5 inches

Fish Bypass

Members of the testing team evaluated the effectiveness of the fish bypass side plates. They were installed due to past observations of water contacting the top of the concrete fish ladder structure at high flows. The stainless steel side plates were installed in fall of 2018 and can be seen in Figure 11. At all flow rates tested through the bypass system, no water was observed to spread beyond the extent of the side plates, and did not strike adjacent walls, pipes or grating. Based on these observations, the addition of the side plates produced a satisfactory result.

Without a hydraulic control downstream of the fish screen, the WSE in the fish screen forebay at ECDD will change with to the amount of flow diverted into the canal. When the WSE fluctuates, the number of stoplogs in the upper fish screen bypass will also need to change to keep the flow rate through the bypass system within its operational range. The bypass channel at ECDD uses three sets of stoplogs: one roughly five feet downstream of the final fish screen (upper), a second set an additional five feet downstream at the plunge with the side plates (middle), and a third set just before the bypass flow enters the fish ladder (lower). Both the upper and middle bypass stoplogs are 24 inch, and have two 6 inch tall stoplogs and many 12 inch tall stoplogs to allow WSE control in the fish screen forebay.

Testing on 25 March 2019 investigated the impacts to sweeping velocity and approach velocity when using a constant or fixed WSE (El. 1429.6) in the fish screen forebay. While the bypass was designed for flows up to 5 cfs, it was observed that the additional bypass flow created significantly more turbulence but did not appreciably increase the sweeping velocity along the fish screen. For this test, a 48 inch upper stoplog height resulted in an average sweeping velocity of 1.02 feet per second, and a travel time (time required to pass the entire screen length) of 62 seconds. When comparing to a 54 inch upper stoplog height, which was less turbulent, the sweeping velocity decreased to 0.93 feet per second and the travel time increased to 68 seconds. The turbulence between the upper stoplog settings can be seen in Figure 11 where the left image used 6 inches less stoplogs than the right image. Both photographs were taken with a difference between upper and middle stoplog heights of 12 inches (the left image had 48 inches of stoplog in the upper and 36 inches in the middle).

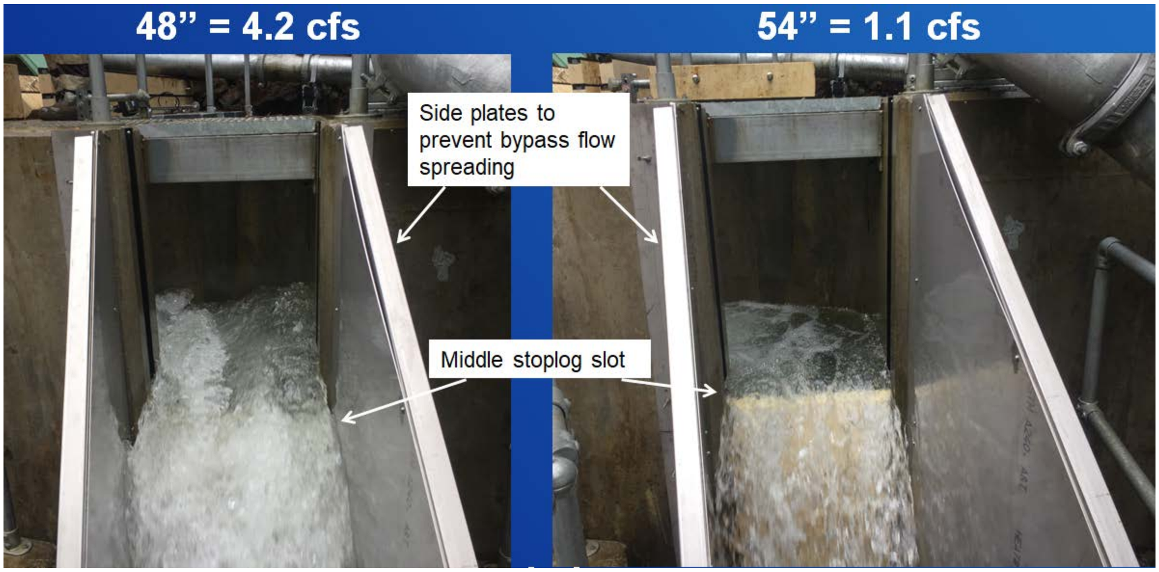


Figure 11. Comparison of fish bypass flow conditions for a constant fish screen forebay elevation of 1429.6 feet. The left image had 48 inches of upper stoplog height and the right image had 54 inches of upper stoplog height. Both images show the bypass flow conditions in the chamber between the upper stoplog and the middle stoplog with the middle stoplogs more visible with the lower flow rate and less turbulence when 54 inches was used.

With limited benefit of higher bypass flows, the recommended height for the upper bypass stoplog are based on a minimum flow depth over the upper stoplog of approximately 3.6 inches and results in flow estimates of 0.95 cfs to 3.7 cfs through the bypass system depending on fish screen forebay WSE. The middle bypass stoplog height should be a minimum of 6 inches below the upper stoplog height with 12 inches acceptable for higher flow rates. The lowest acceptable WSE for the fish screen would be achieved with a bypass setting that consists of 12 inches in the upper stoplog slot and 6 inches in the middle stoplog slot.

Table 2 has the recommended heights for the upper and middle bypass stoplogs for the range of fish screen forebay elevations (corresponds to the SCADA panel “2-UpStr Scrn”).

Table 2. Recommended fish bypass stoplog settings for ECDD

SS2 Fish Screen Forebay Elev, ft	Recommended Upper Bypass Stoplog, inch	Recommended Middle Bypass Stoplog, inch	Estimated Bypass Flow, cfs
1429.5-1430	54	48	0.95-3.7
1429-1429.5	48	42	0.95-3.7
1428.5-1429	42	36	0.95-3.7
1428-1428.5	36	30	0.95-3.7
1427.5-1428	30	24	0.95-3.7
1427-1427.5	24	18	0.95-3.7
1426.5-1427	18	12	0.95-3.7
1426-1426.5	12	6	0.95-3.7

Fish Ladder

Eagle Canyon Diversion Dam has a vertical slot fish ladder with 14 chambers that is combined with the fish screen structure. Because of this hydraulic connection, flows down the ladder will generally increase when the fish screen forebay elevation is high. The only isolation provided is a five foot wide canal gate that was not observed to create much head loss unless the gate was nearly closed. To operate the fish ladder, California DWR provided the following information in the May 2000 technical concepts report:

- The 9-inch sill blocks should be installed in all of the slots in the fish ladder at all times unless operational experimentation shows that the fish ladder operates better without them under specific flow conditions.
- The minimum recommended depth in the pools in the fish ladder is three feet. When the fish screen is in operation the pools downstream of the juvenile bypass return will be a little deeper than the upstream pools because of the extra water added by the bypass.
- During low-flow conditions, if the water depth in the pools at the upstream end of the fish ladder drops below three feet, then the 13-inch sill blocks should be added on top of the 9-inch blocks to maintain pool depth.
- The minimum flow in the fish ladder is approximately 20 cfs.
- When flow into the fish ladder increases (to approximately 30 cfs) the 13-inch sill blocks can be removed.
- The normal operating design depth, as measured on the upstream side of a slot, is five feet. However, depths of between three and seven feet will occur depending on the total flow in the creek and how much water is being diverted into the canal.
- Flow through the fish ladder will be approximately 10 cfs per foot of water depth through the slot.

- The maximum design flow through the fish ladder is 71 cfs. With the 9-inch sill block in place the water depth will be near the top of the slot. Water should not be allowed to overtop the baffle wall adjacent to the slot. At higher flows (60 cfs to 70 cfs) the 9-inch sill blocks may need to be removed to ensure water does not overtop the baffle wall.

- Unstable flow will occur in the fish ladder for a short time if significant changes are made to the headwater or tailwater conditions.

- Water entering the fish ladder in the turning pool from the juvenile fish bypass will slightly backwater up to the upstream weir and cause slightly higher water depths in the downstream pools.

During the two weeks of testing, numerous measurements of pool water level differentials were collected. Since removing the grating above the fish ladder chambers was not practical, a tape measure was used to measure the distance from the WSE to the top of the grating on each side of the fish ladder chamber wall. The difference in this reading is the WSE differential between fish ladder chambers. Between chambers 6 through 10, the metal grating is sloped, therefore readings were estimated by looking through the grating and obtaining measurements from the WSE to the top of the concrete chamber wall.

Testing of the fish ladder pool differentials was performed with the fish ladder entrance bar rack removed to reduce backwatering of the lower fish ladder chambers. For a majority of tests, only the 9 inch sill blocks were installed in the ladder. When operating in this condition, any WSE greater than 1428.5 feet at the upstream ladder (SCADA “4-Upstr Ldr”) resulted in flow depths greater than 3 feet in the ladder pools. **Below an upstream ladder (SS4) elevation of 1428.5 feet, the additional 13 inch sill blocks should be added to the fish ladder to meet the minimum depth requirement**. At either operating condition, the average fish ladder chamber WSE differential was below 1.0 feet as shown in Figure 12. Tabular data for the operating conditions of each of the fish ladder differential tests can be found in the Appendix.

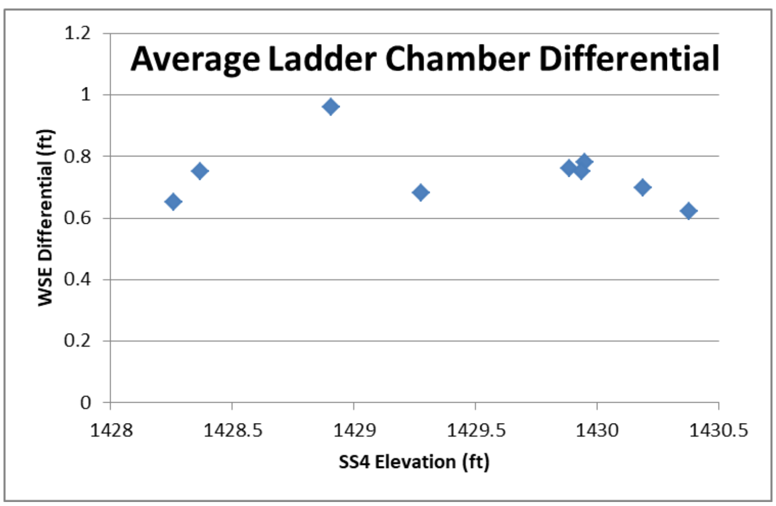


Figure 12. Fish ladder average chamber WSE differential

Canal Flow Measurement

Obtaining an accurate (+/- 5%) canal flow measurement at Eagle Canyon Diversion Dam is difficult due to a lack of steady uniform flow within the structure. After looking at site conditions, the best location to measure flows at the site was the stoplog guides between the screened side of the fish screen and the entrance to the canal as shown in Figure 13. Measurements were taken using a Sontek FlowTracker handheld 2D ADV in the stoplog slot to ensure the probe was oriented correctly into the approach flow. Seven data points were taken without stoplogs to compare the CB43 (canal water level sensor) rating with manual measurements of canal discharge. Figure 14 plots the CB43 rating with the measured data points and shows slight deviation in the middle and upper ranges of expected canal stage. From conversations with PG&E’s hydrographer, this rating was taken at lower canal stages and extrapolated for the higher stages. PG&E is planning on updating the rating in the near future.

Flow measurement was also attempted immediately downstream of the canal stoplog slot using an Acoustic Doppler Current Profiler. Unfortunately, the flow data recorded from the ADCP varied from 28 cfs to 116 cfs for a CB43 stage of 4.96 feet (CB43 = 62.9 cfs, FlowTracker = 52.0 cfs) and was not deemed reliable enough to use to compare to the FlowTracker measurements of PG&E’s CB43 discharge rating.

Figure 13. Photograph of the Eagle Canyon canal stoplog guides. Flows were measured at this location with a FlowTracker 2D ADV. Flow measurements were taken without stoplogs in the slot to compare to the CB43 discharge rating..

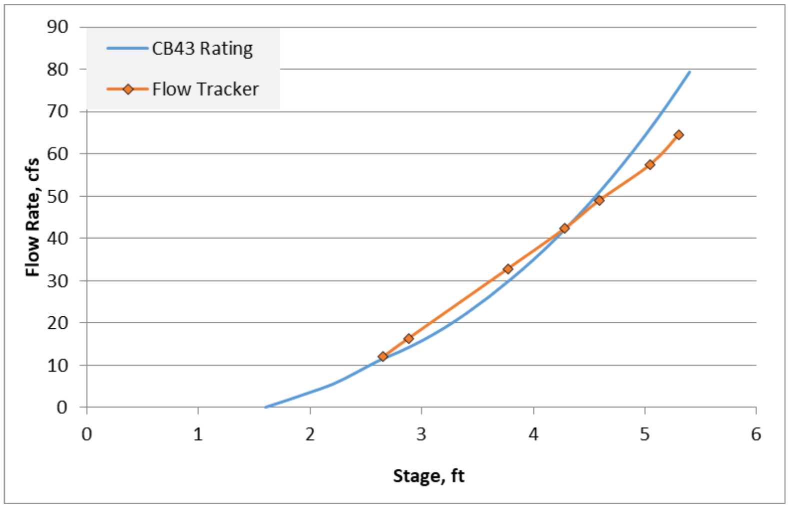


Figure 14. Comparison of FlowTracker flow measurements with CB43 discharge rating

North Battle Creek Feeder Diversion Dam

PG&E owns and operates the North Battle Creek Feeder Diversion Dam (NBCFDD) on the North Fork of Battle Creek near Manton, California. The modifications to the existing diversion were designed by DWR and constructed by USBR as part of the Battle Creek Salmon and Steelhead Restoration Project. The structure consists of a flat plate fish screen with an entrance structure and an in-channel pool and chute style fish ladder. PG&E's maximum diversion rate is 55 cfs through the canal with an additional 7.5 cfs for the fish screen bypass for a total river diversion of 62.5 cfs. Figure 15 is a photograph of the fish screen and Figure 16 is a plan view drawing of the diversion structure..

Figure 15. Photograph of North Battle Creek Feeder Diversion Dam fish screen and ladder from the access bridge above the dam. The concrete structure on the right side of the photo is an abandoned fish ladder.

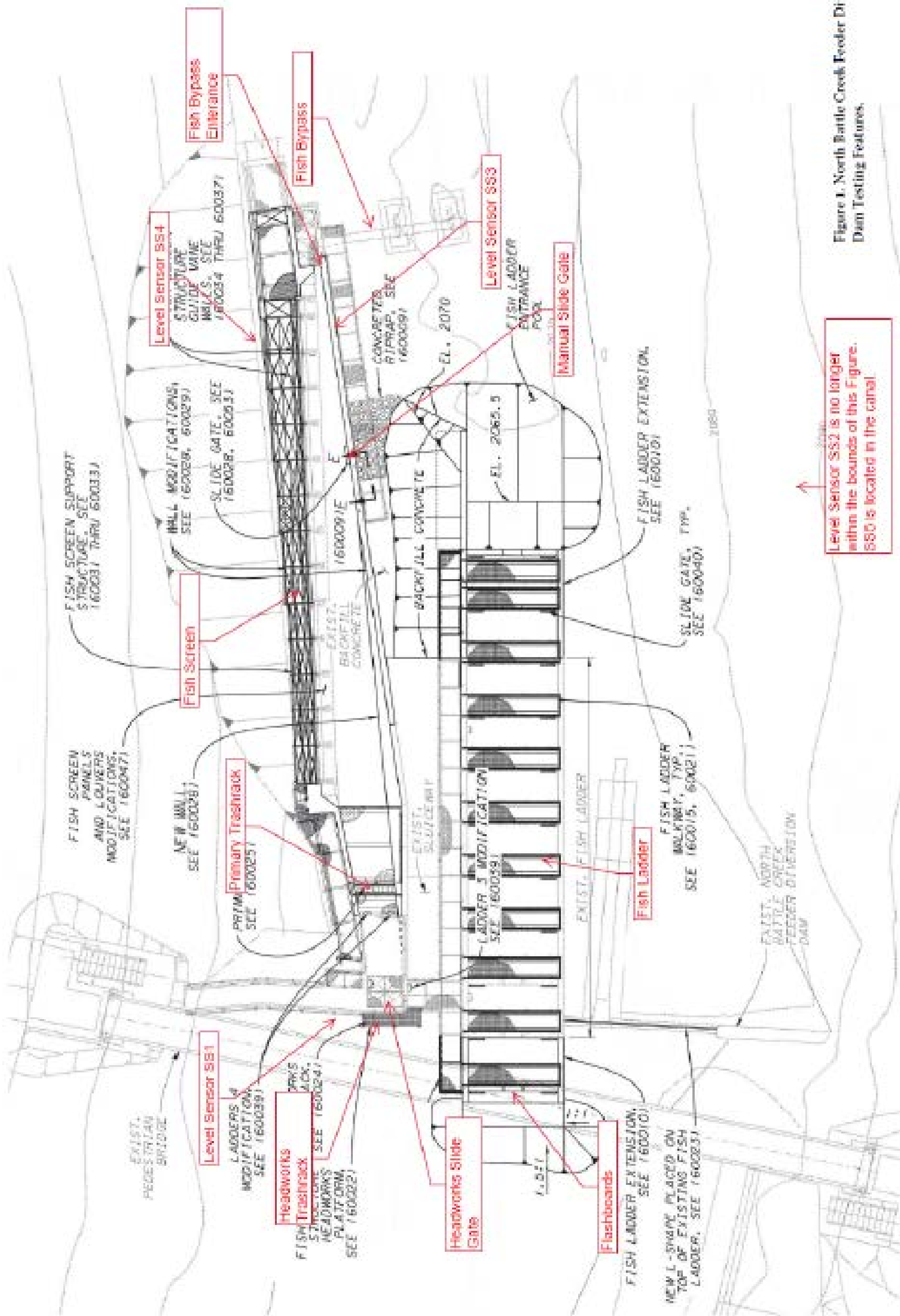


Figure 16. Plan view drawing of North Battle Creek Feeder Diversion Dam

North Battle Creek Feeder Diversion Dam has a fish screen comprised of 27 fish screen panels, each measuring 35 inches by 35 inches. For consistency, the testing plan matched the velocity measurement locations from the August 2011 fish screen hydraulic evaluation. Velocity measurements were made on screens 1, 7, 14, 21 and 27 at four locations, and at the midpoint on all remaining screen panels.

Screen velocities were recorded for both a high canal diversion (90 – 100% of the authorized amount of 55.8 cfs) and for low canal diversion (per the testing plan of 35 cfs, however during the August 2018 meeting, PG&E stated a more realistic low flow is between 10-15 cfs). The low flow hydraulic evaluation was conducted during the weeks of 24 September 2018 and the high flow during the week of 11 March 2019. Team members present during the weeks (not necessarily there every day) consisted of Trang Nguyen (USBR), Jason Foust (USBR), Jeff Kelly (USBR), Melissa Shinbein (USBR), Tracy Vermeyen (USBR), Jacob Carter-Gibb(USBR), Jason Wagner (USBR), Lisa Gentry (USBR), Kent Walker (USBR), John Walsh (PG&E), Duncan Drummond (PG&E), Ben Taylor (PG&E), Kevin Colgate (PG&E), Nathan Wunner (PG&E), Jean Castillo (NMFS), Doug Killam (CDFW), Laurie Earley (USFWS), RJ Bottaro (USFWS), Kevin Gilton (BV), and Dewey Smith (BV).

Fish Screen Velocity Results

Upon arrival to the site for the low flow hydraulic evaluation in September 2018, the fish screen louvers were set to match recommendations from the physical hydraulic model study performed at Reclamation's hydraulics laboratory in Denver Colorado. The physical model testing showed that installing guide vanes behind the fish screen with the addition of three chambers to the fish ladder allowed full diversion flow at the site. Following the initial testing, the louvers were slightly adjusted to create more uniform approach flow through the fish screen.

Throughout the two weeks of testing, three complete sets of screen velocity measurements were recorded. As opposed to ECDD, all the fish screen velocity tests were performed without the use of any stoplogs in the canal.

Table 3 contains a summary of the fish screen velocity tests while Figure 17 and Figure 18 show the approach and sweeping velocity at the fish screen panels for both the high flow and the second low flow test, respectively. Additional data on all tests can be found in the Appendix.

Table 3. NBCFDD fish screen velocity summary

Date	Canal Flow, cfs*	Flow Depth, ft	Fish Screen Forebay Elevation, ft	Fish Bypass Stoplogs, inch	Average Sweeping Velocity, ft/s	Time to pass screen, seconds	Average Approach Velocity, ft/s
9/26/2018	7.4	1	2079.93	12	0.65	122	0.09
9/27/2018	7.4**	1	2079.91	12	0.93	124	0.08
3/12/2019	55.8	3	2082.31	30	1.46	54	0.14

* Canal flow values are from FlowTracker measurements and differ slightly from SS5 rating.

**Canal flow on 9/27 was not directly measured, but was assumed to match 9/26 since screen forebay elevation was within 0.02 feet.

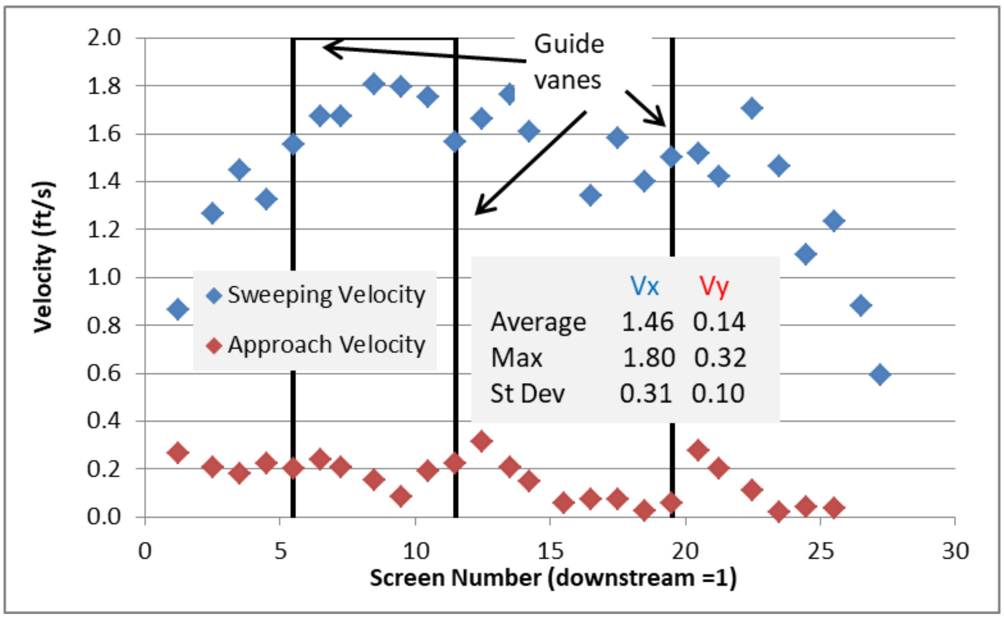


Figure 17. High flow ADV screen test. Canal discharge of 55.8 cfs

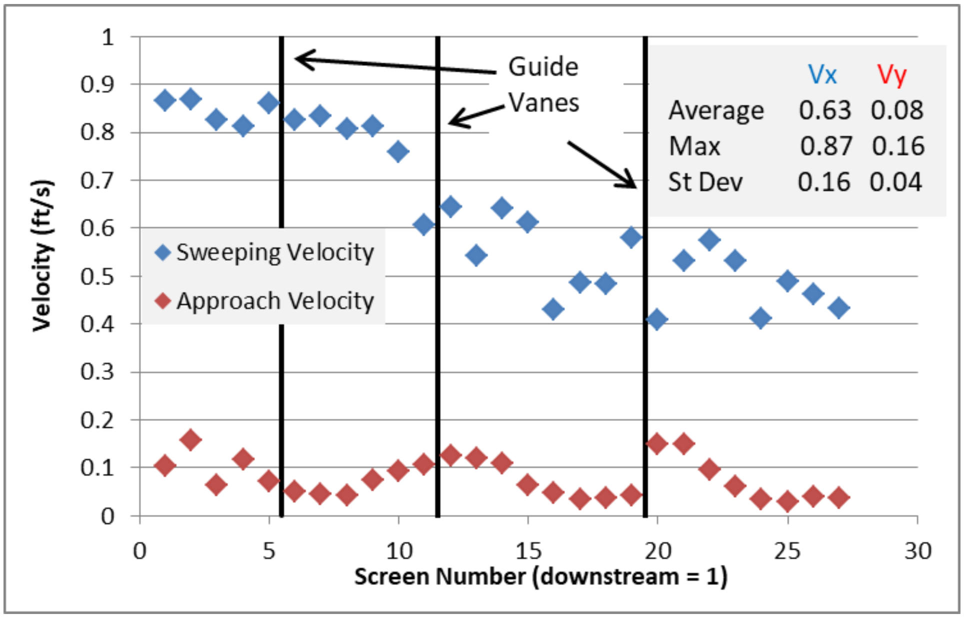


Figure 18. Low flow ADV screen test. Canal discharge of 7.4 cfs

Canal flow rates were measured with a Sontek FlowTracker 2D ADV near the stoplog guide between the end of the fish screen and the start of the canal. While this location is not ideal, as the flow is transitioning from rectangular channel to the semi-circular flume, it is the most uniform area at NBCFDD to make measurements of flow passing through the fish screen. In addition to direct measurement with the FlowTracker, a continuity calculation was performed to ensure a consistent representation of the canal flow. To calculate the continuity, the approach velocity for each screen panel was multiplied by the flow area of the panel to obtain a panel discharge. The summation of all the screen panel discharges resulted in the total screened flow calculation by the continuity equation. When comparing the continuity measurements, the discharge for the low and high flow tests were 83% and 62% of the FlowTracker measurements, respectively.

At NBCFDD, flows were also measured with the FlowTracker upstream from the fish screen after the water passes the headworks diversion using two different methods. The first method used three vertical velocity readings (20%, 60% and 80% of flow depth) at seven stations across the 7.5’ wide channel (measured on 9/25). The second method used the same stations, but used only a single measurement point at 60% depth per station (measured on 9/26). Measurements during the low flow testing week resulted in 11.1 cfs and 11.7 cfs and had good agreement and therefore any future measurements at this location used the single measurement point method. In March 2019, the flow at the headworks was measured just prior to recording the fish screen ADV measurements and resulted in a total diversion flow of 59.4 cfs.

The NBCFDD fish screen was tested at a high canal flow diversion of 55.8 cfs and at a low canal flow diversion of 7.4 cfs. By testing over the range of operations, the fish screen performance can be assured for the entire range of operation. For these tests, the approach flow conditions were uniform and resulted in approach and sweeping velocities at the fish screen that met all required NMFS criteria for Salmonid exclusion. At the low flow canal diversion test, the sweeping velocities were very low and resulted in screen exposure time for passing juvenile fish of 124 seconds, more than double the NMFS exposure criteria. However, for a facility that was designed for 55 cfs, diverting only 7.4 cfs (or 13 percent of its design) resulted in low sweeping velocity values that were unable to be increased with fish bypass adjustment. With approach velocities of roughly $1/5^{th}$ the NMFS criteria, the longer exposure time should not result in injury. At high flows, the exposure time was 54 seconds which meets NMFS criteria.

Fish Bypass

During the low and high flow hydraulic evaluations, flows were passing through the fish screen bypass system at NBCFDD. Flows that pass the weir enter a chamber which contains an embedded HDPE pipe that conveys juvenile fish back to the creek downstream of the fish ladder. Without a hydraulic control downstream from the fish screen, the WSE in the fish screen forebay at NBCFDD will change with to the amount of flow diverted into the canal. When the WSE fluctuates, the height of stoplogs in the fish screen bypass will also need to change to keep the flow rate through the bypass system within its operational range. The stoplogs should be set to maintain a minimum of 0.3 feet (3.6 inches) of flow depth over to top of the stoplogs to ensure sufficient flows through the bypass system. Table 4 has the recommended height settings for fish bypass stoplogs for the range of fish screen forebay (corresponds to the SCADA panel “3-UpStr Screen”) elevations.

Table 4. Recommended fish bypass stoplog settings for NBCFDD

SS3 Fish Screen Forebay Elevation, ft	Recommended Bypass Stoplog Height, inch	Estimated Bypass Flow, cfs
2082-2082.5	54	0.80-3.3
2081.5-2082	42	0.80-3.3
2081-2081.5	36	0.80-3.3
2080.5-2081	30	0.80-3.3
2080-2080.5	24	0.80-3.3
2079.5-2080	18	0.80-3.3
2079-2079.5	12	0.80-3.3
< 2079	6	0.80-3.3

Fish Ladder

North Fork Battle Creek Diversion Dam has a pool and chute style fish ladder with 11 chambers located in the center of the creek channel. Unlike at ECDD, the fish ladder is not connected to the diversion structure; therefore, the fish ladder flow is entirely dependent on the upstream creek WSE. There are stoplog guides on the upper 3 chambers for controlling flows through the ladder, and are paired with orifice gates on each side of the center weir that measure 15 inches high x 12 inches wide within each baffle wall. Flow conditions for this type of ladder improve with additional flow depth and therefore flow depths in the ladder were only investigated during low flow hydraulic evaluation testing.

Since each baffle wall has a pair of orifice gates (left and right of each center weir), the settings were confirmed upon arrival to the site during low flow testing. This ladder was designed to have alternate orifice gates open when moving downstream (i.e. an upstream right orifice open and the next downstream baffle would have the left orifice open). Both of the upstream most orifice gates were closed to reduce the amount of sediment entering the fish ladder. Table 5 has the final settings for the fish ladder orifice gates.

Table 5. Final fish ladder orifice gate settings

	Left Gate	Right Gate
Chamber 1 (Upstream)	Closed	Closed
Chamber 2	Closed	Open
Chamber 3	Open	Closed
Chamber 4	Closed	Open
Chamber 5	Open	Closed
Chamber 6	Closed	Open
Chamber 7	Open	Closed
Chamber 8	Closed	Open
Chamber 9	Open	Closed
Chamber 10	Closed	Open
Chamber 11 (Downstream)	Open	Closed

The first test of the fish ladder chamber WSE differentials used HOBO data loggers to record pressures (correlates to depth of water above the sensor) on each side of the fish ladder baffle. However, due to the top shape of the concrete walls, consistent placement of the HOBO loggers was difficult, and all remaining tests were performed with a level line scribed on the concrete above each baffle wall. Once the line was drawn above each baffle, a measurement from the line to the WSE was taken on each side of the baffle wall as shown in Figure 19. Multiple measurements of the fish ladder pool differentials were taken during the low flow testing week. Results are in Table 6, and confirm that at low flow conditions, the fish ladder meets the NMFS pool differential criteria. Tabular data for the operating conditions of each of the fish ladder WSE differential tests can be found in the Appendix.

Figure 19. Photograph of fish ladder pool differential measurements by level line and tape measure

Table 6. Fish ladder pool WSE differential results during the low flow testing week

Date	Headwater Elevation, ft	Average Ladder Pool Differential, ft
24-Sep	2081.01	0.97*
25-Sep	2081.16	1.04**
26-Sep	2081.12	1.00
27-Sep	2081.29	0.99

*Measurements with HOBO loggers, were not consistent due to weir shape. A level line and manual tape measurements were used following this test

**Orifice gates not set correctly during the first two tests

Canal Flow Measurement

Screened flow entering the diversion canal was measured just upstream from the transition from rectangular channel to semi-circular flume cross section. While this location was not ideal, it was the most suitable location to measure canal flow to confirm measurements during testing and with PG&E's CB31 rating. The recorded flow rate was likely to have the highest uncertainty of any of the hydraulic evaluation flow measurements due to the high velocities and non-uniform converging flow. Measurements were taken using a Sontek FlowTracker 2D ADV in the stoplog guide slot to ensure the probe was oriented correctly into the approach flow. Data points were taken at 0.5 feet stations across the guide slot and measured at 60 percent flow depth without stoplogs to confirm screened flow measurements for the fish screen ADV tests. Table 7 contains the data for the low and high flow tests performed at NBCFDD. On the SCADA panel, the sensor is labeled SS5 – Diversion Canal Level. PG&E has rated the flume at this location and assigned it a name of CB31.

Table 7. NBCFDD canal flow measurements from SS5 stage sensor and CB31 rating

Date	SS5 stage, ft	CB31 Flow, cfs	FlowTracker Flow, cfs
9/24/18	0.76	7.63	7.4
3/11/19	1.39	26.03	27.62
3/12/19	1.11	17.96	55.8

As can be seen in Table 7, the rating for CB31 is very close at low to moderate flows but has significant error as the canal water level increases. This was investigated and the likely cause was the high canal water level encroaching on the deadband distance that the SS5 sensor requires. On March 27, 2019, the sensor was dismounted from its bracket and held roughly 4.5 inches higher at a potential new location to mount the sensor with a revised conduit as shown in Figure 20. Prior to the temporary relocation, the SS5 data on the SCADA panel was observed for five minutes which resulted in four data spikes typically lasting 10-30 seconds where the SS5 output data was significantly lowered. Holding the sensor at the temporary location for another five minute observation period resulted in zero data spikes. The offset distances from the original sensor mount to the WSE were 13.5 inches and 18 inches at the temporary location. In July 2019, the SS5 sensor was mounted 5.5 inches higher to reduce the likelihood of encroaching on the deadband distance as shown in Figure 21. During the sensor work, the canal stage at SS5 was 0.55 feet which resulted in a canal flow rate of less than 7 cfs and PG&E water operations did not allow for raising the canal diversion to test if the relocated sensor removed the faulty data readings from deadband errors.

Figure 20. Photographs of SS5 showing original sensor mount (left image) and temporary relocation (right image) to test sensor deadband errors

Figure 21. Photograph of SS5 in July 2019 after sensor relocation

In addition to the issue with SS5, the canal rating at higher discharges did not agree with the FlowTracker measurements. When setting up the facility for the high flow fish screen ADV test, the canal flows were increased to the maximum safe canal level. Using the canal stage at the "Saxophone" spill located approximately 200 yards downstream, the canal flow from that rating was only 44 cfs. However, a measurement using the FlowTracker at the canal stoplog slot resulted in a screened flow rate of 55.8 cfs. To confirm the diverted flow amount, the FlowTracker was also used upstream of the fish screen which measured 59.4 cfs. The measured fish screen bypass flow at this time was 2.1 cfs which results in two FlowTracker measurements within 3 percent agreement. Duncan Drummond (PG&E Hydrographer) who assisted with these measurements at NBCFDD stated that the canal rating will be updated.

Conclusions

Eagle Canyon Diversion Dam

- Fish screen velocities met NMFS criteria for both high and low canal flows with or without the use of stoplogs between the fish screen and the canal.

- Fish ladder pool differentials for many different elevations in the chamber between the flood gate and the canal gate (SS4 sensor reading) were all below 12 inches and met the NMFS fish ladder criteria for pool differentials.

- During low flow periods, the additional 13-inch-tall fish ladder sill blocks will be required to meet the minimum depth requirement when the upstream ladder (SS4) elevation is below 1428.5 feet.

- Increasing the fish screen bypass flows do not significantly decrease travel time along the fish screen, but do significantly increase turbulence. Therefore, it is recommended to operate the fish screen bypass at lower flow rates as recommended in Table 2.

- The recommended minimum flow depth over the fish screen bypass upper stoplog is 0.3 feet (3.6 inches). Typical operation would be to raise the stoplog height by 6 inches when flow depth over the weir exceeds 0.8 feet (9.6 inches). The middle bypass stoplog height should be set a minimum of 6 inches below the upper stoplog height.

- The lowest WSE that the facility should be operated at corresponds to a middle stoplog height of 6 inches, an upper stoplog height of 12 inches and a fish screen forebay elevation of 1426 feet elevation.

- To simplify adjusting fish bypass stoplog heights, a water resistant system should be developed to account for the number of 12 inch and 6 inch stoplogs placed in both the upper and middle fish bypass stoplog slots.

- The SS2 sensor (fish screen forebay elevation) had periods of failure likely caused by WSE encroachment on the sensor deadband offset. The SS2 sensor should be remounted higher to ensure reliable data at high fish screen forebay WSEs. (Update July 2019, SS2 was mounted 6.5 inches higher).

- The CB43 rating for flow entering the canal deviated from FlowTracker measurements, especially at higher discharges. The rating should be investigated and updated.

North Battle Creek Feeder Diversion Dam

- Fish screen approach and sweeping velocities met NMFS criteria for both high and low canal flows without the use of stoplogs between the fish screen and the canal.

- At low canal flows, the sweeping velocity resulted in exposure times greater than NMFS criteria, but with approach velocities roughly 1/5th of the NMFS criteria a longer exposure time should not result in injury.

- The pool and chute style fish ladder pool differentials at low flow conditions averaged nearly 1.0 feet and met the NMFS criteria for fish ladder pool differentials.

- The recommended minimum flow depth over the fish screen bypass weir is 0.3 feet (3.6 inches). Typical operation would be to install an additional 6-inch-tall weir block when flow depth over the bypass weir exceeds 0.8 feet (9.6 inches) as recommended in Table 4. .

- The SS5 sensor (canal water level) had periods of failure likely caused by WSE encroachment on the sensor deadband offset and should be remounted higher to ensure reliable stage data for the canal. (Update July 2019, SS5 was remounted 5.5 inches higher).

- The CB31 rating for flow entering the canal deviated from FlowTracker measurements, especially at higher discharges. The rating should be investigated and updated following the SS5 sensor remounting.

References

Eagle Canyon Fish Ladder Performance Evaluation (April, 2012)

Eagle Canyon Fish Screen Hydraulic Performance Evaluation (April, 2012)

Eagle Canyon Juvenile Fish Bypass Tuning Experiment Notes (September, 2013)

Hydraulic Laboratory Report HL-2013-04. North Battle Creek Feeder Fish Screen and Fishway Hydraulic Model Study. US Bureau of Reclamation, Denver, CO, 2013

National Marine Fisheries Service (2009). Biological Opinion for the Central Valley Project

National Marine Fisheries Service Southwest Region (1997). Fish Screening Criteria for Anadromous Salmonids.

National Marine Fisheries Service Northwest Region (2011). Anadromous Salmonid Passage Facility Design.

North Battle Creek Feeder Fish Screen Hydraulic Performance Evaluation (August, 2011)

North Battle Creek Feeder Fish Ladder Performance Evaluation (August, 2011)

North Battle Creek Feeder Fish Screen and Fish Ladder Hydraulic Performance Re-Evaluation (April, 2012)

North Fork Screens and Ladders – Eagle Canyon Diversion Dam Facility Start-Up Testing and Acceptance Plans (August, 2018)

North Fork Screens and Ladders – North Battle Creek Feeder Diversion Dam Facility Start-Up Testing and Acceptance Plans (September, 2018)

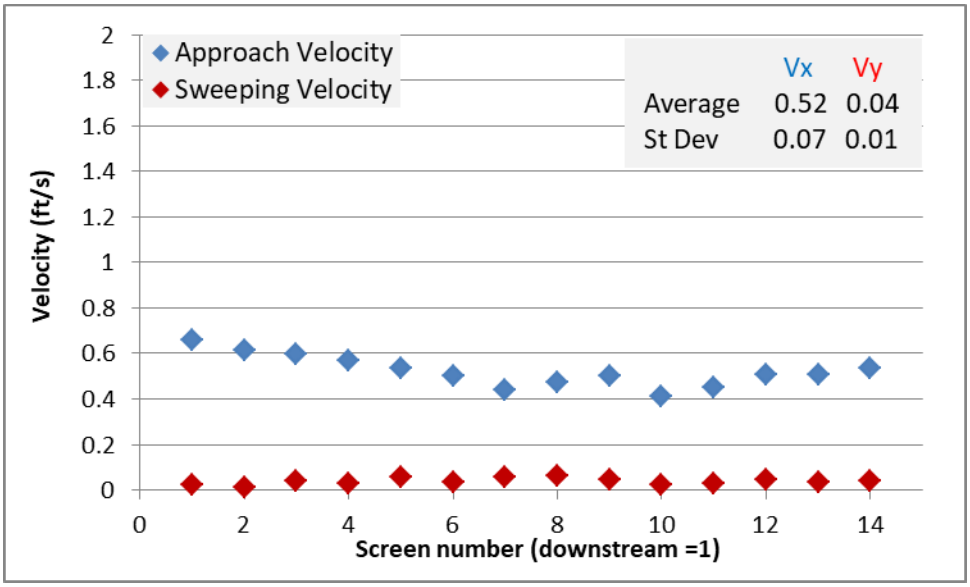
WinADV Windows based view and post processing utility for ADV files https://www.usbr.gov/tsc/techreferences/computer%20software/software/winadv/index.html

Appendix

Eagle Canyon Diversion Dam Fish Screen Test No. 1

Canal flow rate from FlowTracker measurement = 6.39 cfs
Continuity flow calculation = 5.27 cfs
Average Sweeping Velocity = 0.52 feet/second
Maximum Sweeping Velocity = 0.66 feet/second
Minimum Sweeping Velocity = 0.41 feet/second
Standard Deviation of all fish screen panel Sweeping Velocity measurements = 0.07 feet/second

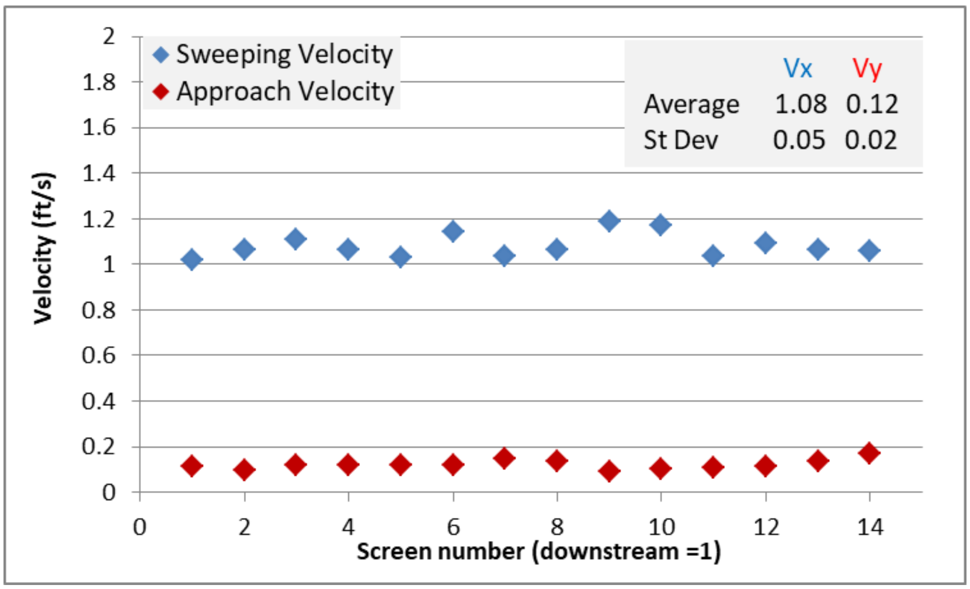
Average Approach Velocity = 0.04 feet/second
Maximum Approach Velocity = 0.06 feet/second
Minimum Approach Velocity = 0.01 feet/second
Standard Deviation Approach Velocity = 0.01 feet/second



Eagle Canyon Diversion Dam Fish Screen Test No. 2

Canal flow rate from FlowTracker measurement = 12.0 cfs
Continuity flow calculation = 10.73 cfs
Average Sweeping Velocity = 1.08 feet/second
Maximum Sweeping Velocity = 1.19 feet/second
Minimum Sweeping Velocity = 1.02 feet/second
Standard Deviation of all fish screen panel Sweeping Velocity = 0.05 feet/second

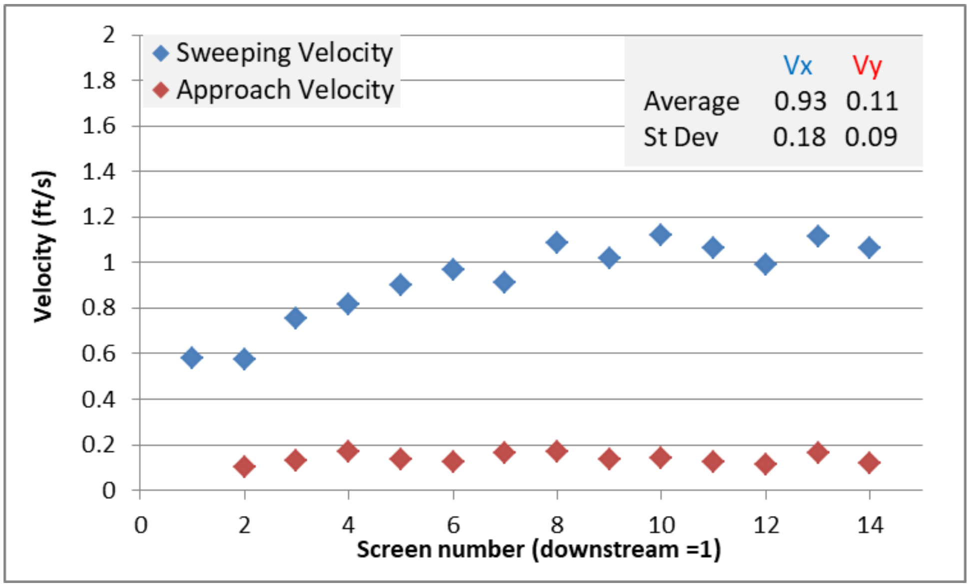
Average Approach Velocity = 0.12 feet/second
Maximum Approach Velocity = 0.17 feet/second
Minimum Approach Velocity = 0.09 feet/second
Standard Deviation Approach Velocity = 0.02 feet/second



Eagle Canyon Diversion Dam Fish Screen Test No. 3

Canal flow rate from FlowTracker measurement = 16.4 cfs
Continuity flow calculation = 14.03 cfs
Average Sweeping Velocity = 0.93 feet/second
Maximum Sweeping Velocity = 1.12 feet/second
Minimum Sweeping Velocity = 0.57 feet/second
Standard Deviation of all fish screen panel Sweeping Velocity = 0.18 feet/second

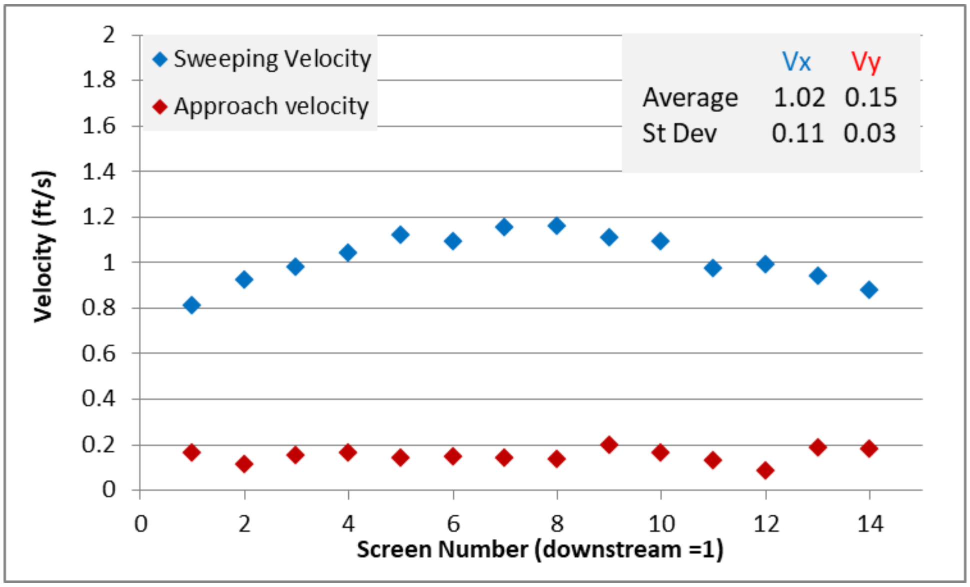
Average Approach Velocity = 0.11 feet/second
Maximum Approach Velocity = 0.17 feet/second
Minimum Approach Velocity = -0.2 feet/second
Standard Deviation Approach Velocity = 0.09 feet/second



Eagle Canyon Diversion Dam Fish Screen Test No. 4

Canal flow rate from FlowTracker measurement = 50.0 cfs
Continuity flow calculation = 42.73 cfs
Average Sweeping Velocity = 1.02 feet/second
Maximum Sweeping Velocity = 1.16 feet/second
Minimum Sweeping Velocity = 0.81 feet/second
Standard Deviation of all fish screen panel Sweeping Velocity = 0.11 feet/second

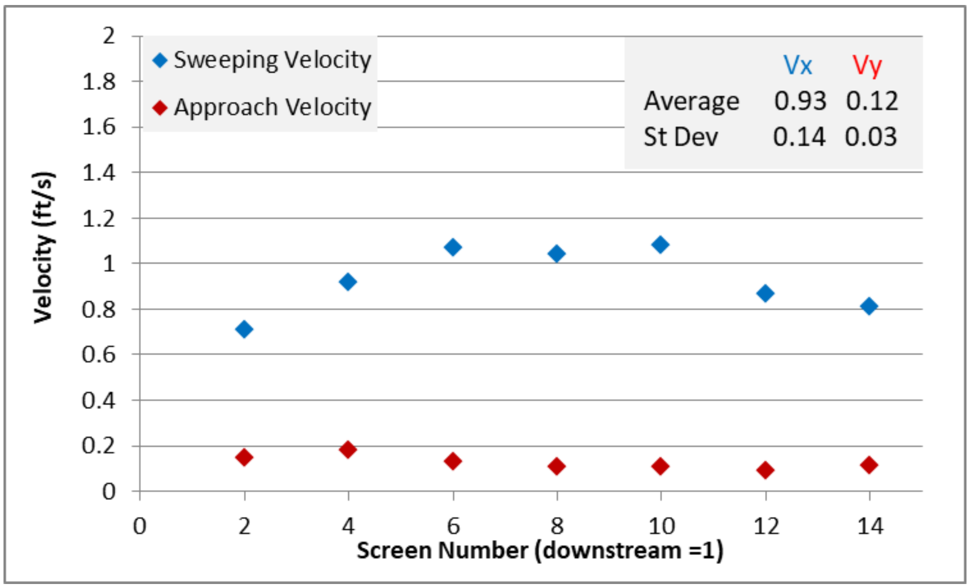
Average Approach Velocity = 0.15 feet/second
Maximum Approach Velocity = 0.20 feet/second
Minimum Approach Velocity = 0.09feet/second
Standard Deviation Approach Velocity = 0.03 feet/second



Eagle Canyon Diversion Dam Fish Screen Test No. 5

Canal flow rate from FlowTracker measurement = 52.04 cfs
Continuity flow calculation = 35.37 cfs
Average Sweeping Velocity = 0.93 feet/second
Maximum Sweeping Velocity = 1.08 feet/second
Minimum Sweeping Velocity = 0.71 feet/second
Standard Deviation of all fish screen panel Sweeping Velocity = 0.14 feet/second

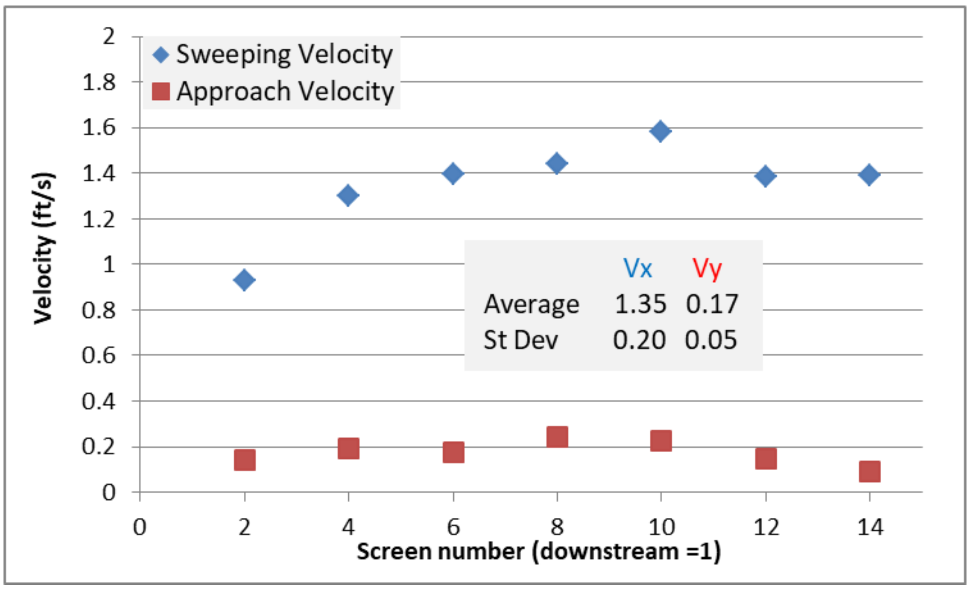
Average Approach Velocity = 0.12 feet/second
Maximum Approach Velocity = 0.18 feet/second
Minimum Approach Velocity = 0.09 feet/second
Standard Deviation Approach Velocity = 0.03 feet/second



Eagle Canyon Diversion Dam Fish Screen Test No. 6

Canal flow rate from FlowTracker measurement = 57.6 cfs
Continuity flow calculation = 43.7 cfs
Average Sweeping Velocity = 1.35 feet/second
Maximum Sweeping Velocity = 1.58 feet/second
Minimum Sweeping Velocity = 0.93 feet/second
Standard Deviation of all fish screen panel Sweeping Velocity = 0.20 feet/second

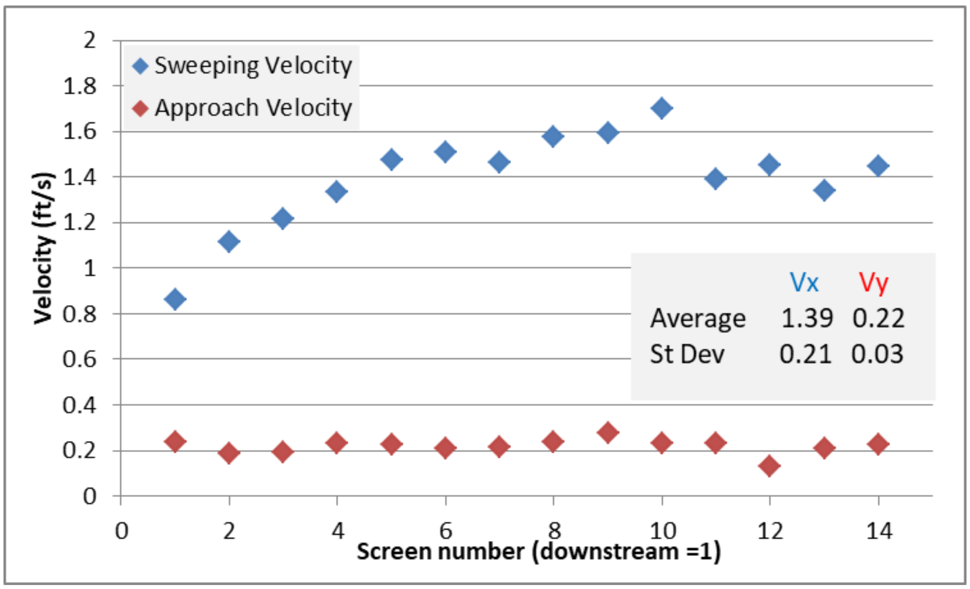
Average Approach Velocity = 0.17 feet/second
Maximum Approach Velocity = 0.24 feet/second
Minimum Approach Velocity = 0.09 feet/second
Standard Deviation Approach Velocity = 0.05 feet/second



Eagle Canyon Diversion Dam Fish Screen Test No. 7

Canal flow rate from FlowTracker measurement = 64.5 cfs
Continuity flow calculation = 61.4 cfs
Average Sweeping Velocity = 1.39 feet/second
Maximum Sweeping Velocity = 1.70 feet/second
Minimum Sweeping Velocity = 0.86 feet/second
Standard Deviation of all fish screen panel Sweeping Velocity = 0.21 feet/second

Average Approach Velocity = 0.22 feet/second
Maximum Approach Velocity = 0.27 feet/second
Minimum Approach Velocity = 0.13 feet/second
Standard Deviation Approach Velocity = 0.03 feet/second



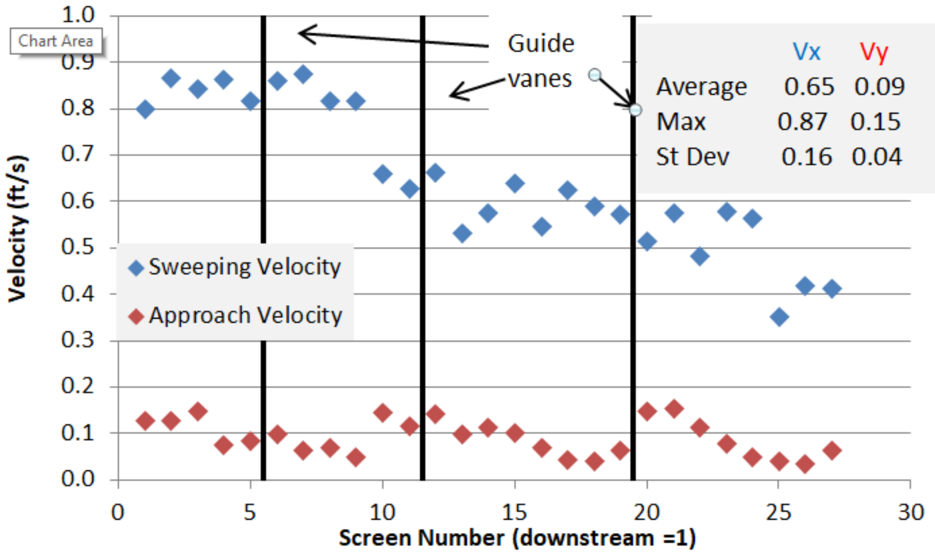
Eagle Canyon Diversion Dam Fish Ladder Tests

							LOW FLOW		
Date	28-Mar	28-Mar	28-Mar	25-Mar	25-Mar	25-Mar	14-Mar	3/14/2019	3/14/2019
Time	1246	1402	1554	1108	1356	1233	1011	1305	1342
Flood Gate 1 opening, %	29.87	10.27	10.27	34.14	34.14	34.14	8.38	20.25	20.25
Flood Gate 2 opening, %	0.34	0.35	0.34	18.58	18.58	18.58	4.07	0.33	0.33
Canal Gate opening, %	6.96	6.97	1.85	46.1	42.14	42.95	3.54	14.16	7.09
Screen Differential, ft	0.15	0.11	0.08	0.17	0.17	0.16	0.03	0.16	0.06
Ladder Differential, ft	9.76	9.2	9.33	9.81	10.03	10.44	9.64	9.79	9.85
CB43, ft	3.77	3.07	2.65	4.98	4.85	4.96	2.74	2.93	2.76
CB112, ft	3.32	3.34	3.38	2.74	2.84	2.78	3.22	3.18	3.17
US Headworks SS1, ft	1432.79	1432.64	1432.26	1431.74	1431.72	1431.69	1432.09	1432.15	1432.09
US Screen SS2, ft	1427.57	1426.62	1426.38	14.125	1429.61	1429.69	1427.86	11.5	12.5
DS Screen SS3, ft	1427.42	1426.51	1426.29	1429.54	1429.45	1429.94	1427.81	1429.86	1429.77
US Ladder SS4, ft	1429.95	1428.26	1428.37	1429.89	1428.91	1429.94	1429.28	1430.19	1430.38
Average Ladder Drop, ft	0.78	0.65	0.75	0.76	0.96	0.75	0.68	0.70	0.62
Ladder depth (=8 ft- chamber 8 reading	48	24	32	50	52	51	41	52	54
DS Ladder SS5, ft	1420.17	1418.75	1418.97	1420.21	1420.01	1419.48	1419.64	1420.49	1430.01
Canal Stoplog, inch	0	0	0	36	36	36	30	54	54
FB1 Stoplog, inch	30	18	12	54	48	48	54	54	54
FB2 Stoplog, inch	24	0	0	36	36	36	48	36	36
Ladder Stoplog, inch	0	0	0	0	0	0	0	0	0
Fish ladder Sill blocks, inch	9	9	9	9	9	9	22	22	22
Fish Screen Sluice, inch	9	9	9	9	9	9	9	9	9
Fish ladder baffle pool differentials (inch)									
1 - Upstream	11	8	10	11	13	9	10.75	11	11
2	12	13	14	13	13	12	12	13	12
3	14	13	13	14	13	11	11	12.5	12
4	14	12	14	12	15	13	13	11.5	10
5	13	12	14	12	12	-11	10.5	10	12
6	11	11	12	12	12	14	10	11	6
7	12	11	13	10	14	13	10	10	6
8	10	11	12	10	13	12	11	8	8
9	7	10	11	9	14	13	9	8	8
10	6	3	4	5	10	10	4	7	6
11	5	2	4	4.5	9	7	5	6	3.5
12	7	2	4	8	10	10	4	4	5
13	5	1	0	4	9	7	2	3	3
14-Downstream	4	1	1	3	5	6	2	2	2
Average, inch	**9.36**	**7.86**	**9.00**	**9.11**	**11.57**	**9.00**	**8.16**	**8.36**	**7.46**
Average, ft	**0.78**	**0.65**	**0.75**	**0.76**	**0.96**	**0.75**	**0.68**	**0.70**	**0.62**

North Battle Creek Feeder Diversion Dam Fish Screen Test No. 1

Canal flow rate from FlowTracker measurement = 7.4 cfs
Continuity flow calculation = 7.3 cfs
Average Sweeping Velocity = 0.65 feet/second
Maximum Sweeping Velocity = 0.87 feet/second
Minimum Sweeping Velocity = 0.35 feet/second
Standard Deviation of all fish screen panel Sweeping Velocity = 0.16 feet/second

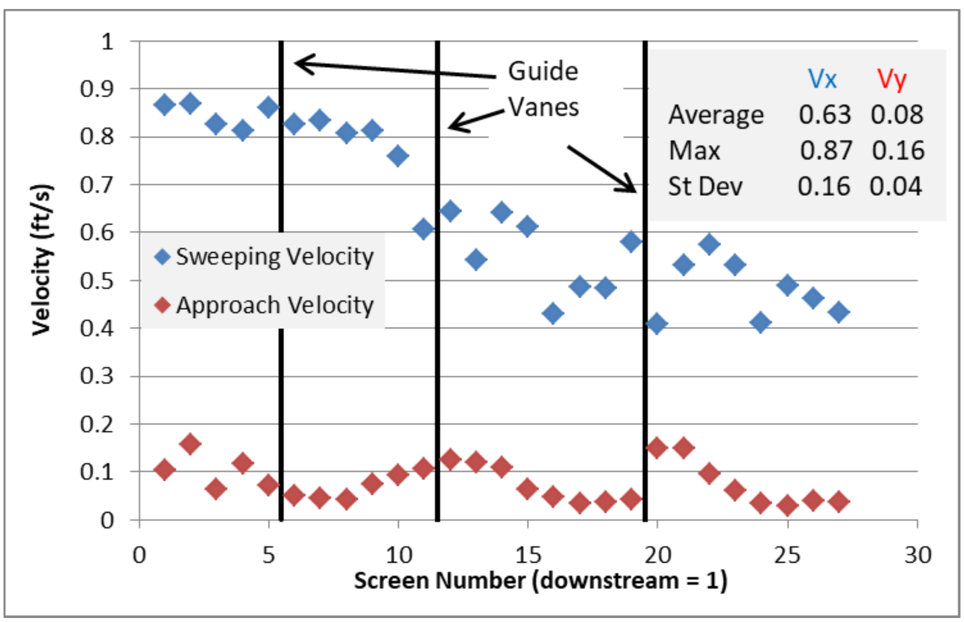
Average Approach Velocity = 0.09 feet/second
Maximum Approach Velocity = 0.15 feet/second
Minimum Approach Velocity = 0.03 feet/second
Standard Deviation Approach Velocity = 0.04 feet/second



North Battle Creek Feeder Diversion Dam Fish Screen Test No. 2, after louver adjustments

Canal flow rate from FlowTracker measurement = 7.4 cfs
Continuity flow calculation = 6.1 cfs
Average Sweeping Velocity = 0.63 feet/second
Maximum Sweeping Velocity = 0.87 feet/second
Minimum Sweeping Velocity = 0.41 feet/second
Standard Deviation of all fish screen panel Sweeping Velocity = 0.16 feet/second

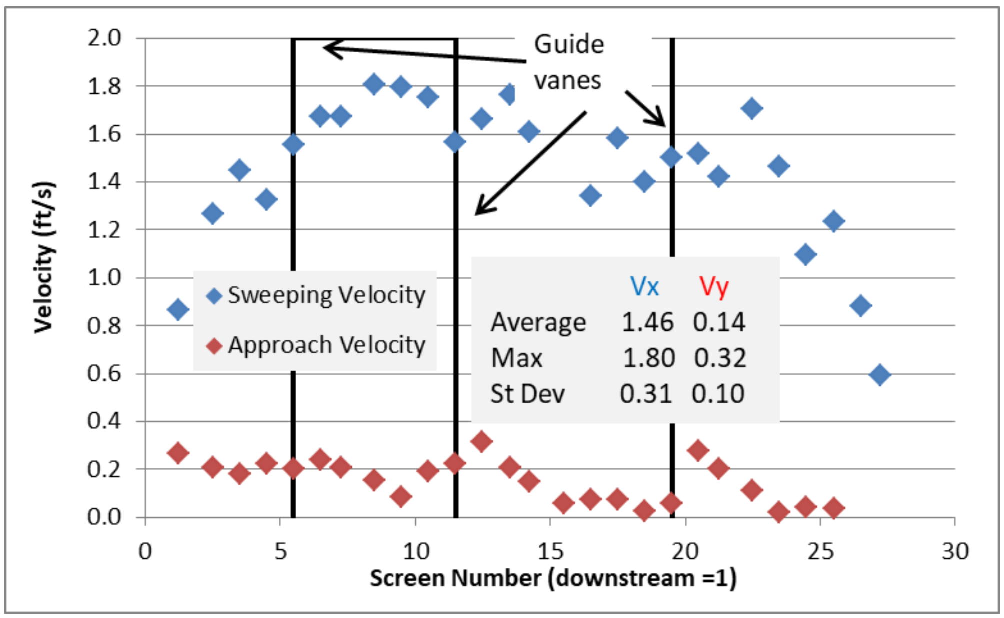
Average Approach Velocity = 0.08 feet/second
Maximum Approach Velocity = 0.16 feet/second
Minimum Approach Velocity = 0.03 feet/second
Standard Deviation Approach Velocity = 0.04 feet/second



North Battle Creek Feeder Diversion Dam Fish Screen Test No. 3

Canal flow rate from FlowTracker measurement = 55.8 cfs
Continuity flow calculation = 40.8 cfs
Average Sweeping Velocity = 1.46 feet/second
Maximum Sweeping Velocity = 1.80 feet/second
Minimum Sweeping Velocity = 0.59 feet/second
Standard Deviation of all fish screen panel Sweeping Velocity = 0.31 feet/second

Average Approach Velocity = 0.14 feet/second
Maximum Approach Velocity = 0.32 feet/second
Minimum Approach Velocity = 0.00 feet/second
Standard Deviation Approach Velocity = 0.10 feet/second



North Battle Creek Feeder Diversion Dam Fish Ladder Tests

Date	9/24/2018	9/25/2018	9/26/2018	9/27/2018
Time	3:45:00 PM	10:15:00 AM	8:43:00 AM	12:37:00 PM
Headworks level (SS1)	2081.01	2081.16	2081.12	2081.13
Downstream creek (SS2 - CB106 from panel)*	1.56	1.66	1.66	1.6
Fish Screen forebay (SS3)	2079.87	2079.89	2079.93	2079.89
Fish Screen Afterbay (SS4)	2079.72	2079.7	2079.73	2079.72
Juvenile Bypass weir setting	12"	12"	12"	12"
Canal Water level (SS5, CB31)	0.76	0.73	0.76	0.76
Headworks Gate		10.06	11.31	10.82
CB 112	1.38	1.45	1.31	1.44
*CB106 panel readings differ from manual staff gage readings				
Fish ladder baffle pool differential (inch)				
1 - Upstream	7.44	11.25	11	12
2	10.56	10	11	10
3	7.92	15	13.5	14.25
4	5.88	15.5	15.75	16
5	8.76	11.25	10.75	11.25
6	16.56	16	14	13.25
7	16.2	15	15	13.25
8	11.88	14	11.75	11.5
9	18.36	10.25	10	10.75
10	17.16	13	12.5	11.75
11- downstream	7.68	6	6.75	6.25
Average, in	11.67	12.48	12.00	11.84
Average, ft	0.97	1.04	1.00	0.99