U.S. ARMY CORPS OF ENGINEERS
PORTLAND DISTRICT

BONNEVILLE SECOND POWERHOUSE TAILRACE AND HIGH FLOW OUTFALL: ADCP AND DROGUE RELEASE FIELD STUDY

Final Report

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Table of Contents

Table of Figures

1 Introduction

The Bonneville Project is one of four US Army Corps of Engineers operated dams along the Lower Columbia River. Each year thousands of smolt pass through this Project on their way to the Pacific Ocean. High flow outfalls, if specifically designed for fish passage, are thought to have as good or better smolt survival rates as spillways. To better understand the hydrodynamic flow field around an operating outfall, the Corps of Engineers commissioned measurement of water velocities in the tailrace of the Second Powerhouse (see Figure 1). These data also are necessary for proper calibration and verification of three-dimensional numerical (i.e., CFD) and physical models of the outfall and tailrace areas.

Figure 1 Bonneville Project Overview. Upper figure shows the Bonneville Project. Inset shows the Second Powerhouse (large building on left) and the spilling high flow outfall (upper right corner).

The high flow outfall was operated at two flow rates during this study: 1000 and 2500 cfs. The study was conducted on October 3, 2000 between 7am and noon. Tailwater elevations during this period ranged from 10.7 to 11.0 ft (datum is mean sea level) and flows from the Second Powerhouse ranged from 96.6 to 104.7 kcfs, with all units operating except Unit 13 (see Appendix A). Total river flows ranged from 114.4 to 121.8 kcfs (mean was 116.6 kcfs).

2 Data Acquisition

Hydrodynamic characterization of the tailrace with and without the outfall operating was accomplished through use of a surface drogue and acoustic Doppler current profiler (ADCP). The ADCP was vertically mounted onto the gunnels of the boat so that it could be moved from location to location while gathering three-dimensional water velocity measurements throughout the water column. Both the ADCP and drogue were linked to a GPS (global positioning system); locating the data in both space and time. Measurements focused on the area nearest to the high flow outfall, however several ADCP transects and drogue releases were performed away from the outfall to document ambient flow field conditions when the outfall was not operating.

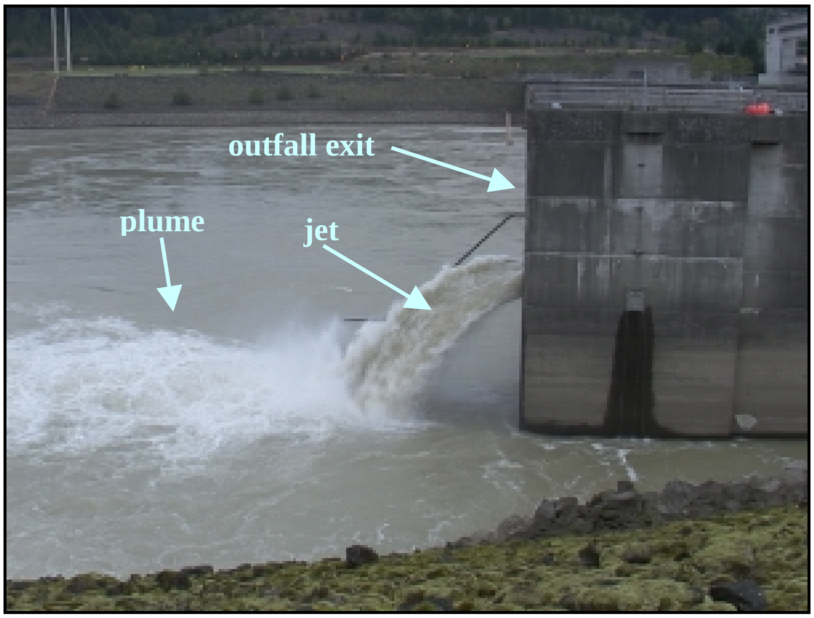

Figure 2 Side profile of the high flow outfall at 1000 cfs.

2.1 Acoustic Doppler Current Profiler

A 600kHz RD Instruments ADCP was used to collect vertical profiles of three-dimensional water velocity vectors. The ADCP collected a sample every 7-seconds with a vertical resolution of 1.64 ft (0.50 m). The instrument was operated in direct reading mode, and all data were exported directly to a laptop computer.

A GPS was used to determine the horizontal location of the ADCP at a frequency of 1 Hz. GPS readings were obtained through a Trimble Beacon Differential GPS system, which differentially corrected the data in real time to ±3-ft accuracy. The GPS antenna was placed on top of the boat's cabin (see Figure 3) and was 4 ft (in plan) away the ADCP. Because the error of the GPS was approximately the same as the distance the antenna was from the ADCP, additional corrections for the antenna location were not performed.

Both the ADCP and GPS recorded data with a synchronized time stamp. A program was then written to align the closest GPS collection point with a single velocity recording. Because the boat was traveling at approximately 3 ft/s or less, interpolation of the GPS data points was within the error tolerance of the GPS.

Figure 3 ADCP mounted on boat with the four transducer heads pointed upwards.

Figure 4 ADCP gathering velocity data.

Velocity vectors in the tailrace, and especially in the plume caused by the outfall jet, are transient (see Figures 2 and 5). Large shifts in velocity magnitude and direction are expected due to turbulence at many length scales, from the formation and decay of large-scale eddies that spin off in unpredictable directions, to smaller scale variations caused by rising air bubbles. Ideally, the boat would have been held at a measurement location for a period of time long enough to capture stable mean velocities. Before deployment, it was thought that adjustments in location, caused by turbulent eddies under the boat, could be corrected for by the boat driver using a set waypoint at the measurement location. The real-time differential GPS would then calculate (every second) the boats location and the corrective action necessary to maintain the boat at the waypoint. However when this scenario was tested *in situ* the day before sampling was to commence, it was found that the velocity field was so turbulent that it was not possible to hold the boat at the waypoint. Several attempts resulted in data collection swaths over an approximately 90-ft diameter circle. A sampling area this large for a “stationary location” was judged to be unacceptable, and an alternative strategy was implemented.

Instead of gathering velocity readings at several fixed-points, velocity transects were measured in the areas of interest. Although this sampling methodology was not ideal for transient flows, a generalized representation of the flow field was captured. Transects also provided a contiguous record of velocity measurements from start to finish, unlike fixed-point measurements which skip from point to point. This allowed for a more uniform coverage of the spatial velocity field without gaps in velocity data between fixed-point locations.

Figure 5 View from the tailrace of the high outfall (operating at 1000 cfs).

2.2 GPS Drogue

A surface drogue consisting of an aluminum kite and floating buoy with an attached GPS was repeatedly dropped in and around the plunge pool. The kite was approximately 4 ft tall and 2.5 ft across in an X-wing configuration (Figure 6). The float was comprised of a foam filled section of 16” diameter PVC pipe with caps sealing each end. A yellow pelican case was attached to the top of the float, which enclosed a Trimble Explorer II GPS unit. The GPS unit recorded the location of drogue at a frequency of 2 Hz. The drogue was released numerous times in three general zones: directly downstream of the outfall plunge pool, along the north side of the plunge pool, and upstream of the plunge pool along the outfall’s north side wall. The drogue was also released in the middle of the tailrace, where it was unaffected by the outfall, to gather ambient flow data. Due to the hazardous nature of the outfall jet, it was not possible to drop the drogue directly behind or under the outfall.

Data were imported into ESRI ARC/INFO for plotting and generation of movie (i.e., *.avi) files. Movie files, which have been linked to this document, can be viewed by clicking on the *.avi filename in the caption (highlighted in blue). Movie files display the time the data was recorded in Pacific standard time. All other times presented in this report have been shifted ahead one hour in accordance with Pacific daylight saving time.

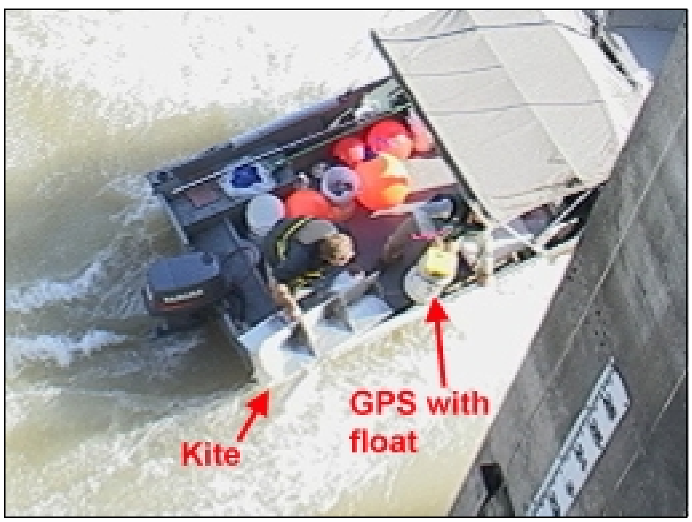

Figure 6 Boat positioning for a drogue release

3 Results

The high flow outfall plume extended for several hundred feet downstream from the exit of the outfall. For both the 1000 and 2500 cfs conditions, ADCP and drogue data were captured as close as possible to the outfall jet entry point and downstream plume. The GPS drogue had few limitations upon how close it could be dropped relative to the jet entry point. The drogue was sturdy, and several times was washed directly underneath the jet. The ADCP, however, was sensitive to large quantities of air bubbles, which prevented gathering data within close proximity to the outfall jet. Air bubbles reflect (i.e., are a barrier to) the acoustic signal, and when a large number exist in the flow field, ADCP measurements become impossible. ADCP measurements were attempted across the plume (i.e., laterally), as soon as a clear measurement signal was possible.

3.1 Project Operations

Project operations were obtained from the US Army Corps of Engineers, Portland District (see Figure 7 and Appendix A). Second Powerhouse releases during the data gathering periods declined approximately 8%, from a high of 104.7 kcfs at 7 am to a low of 96.6 kcfs at 11 am. All units of the Second Powerhouse were operating during the data gathering periods, except for Unit 13, which was out of service. Tailwater elevations fluctuated 0.2 ft, and the average elevation for all periods was 10.9 ft.

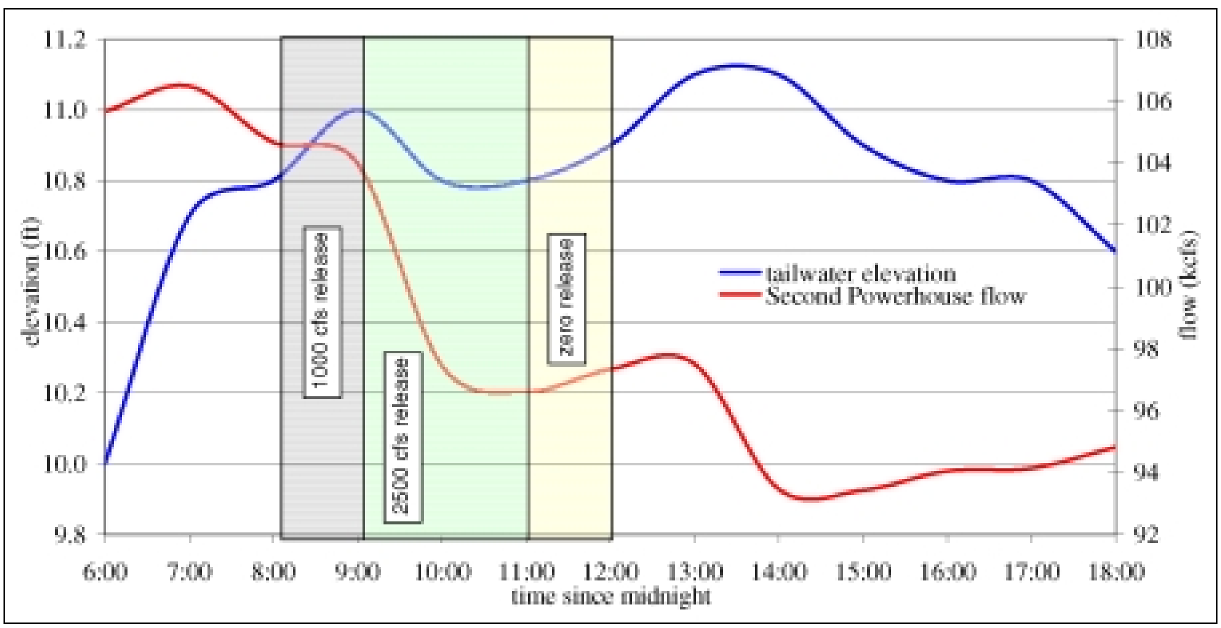

Figure 7 Second Powerhouse flows and tailrace elevations on October 3, 2000. Elevation datum is mean sea level.

3.2 1000 cfs Release Conditions

The smallest outfall discharge condition measured in this study was 1000 cfs. Three ADCP transects were performed, and GPS tracks showing the locations of these observations are presented in Figure 8. All data were collected after the outfall had run for at least 0.5 hrs at a constant flow. Field measurements were performed for approximately 1-hr, between 8 and 9:00 am.

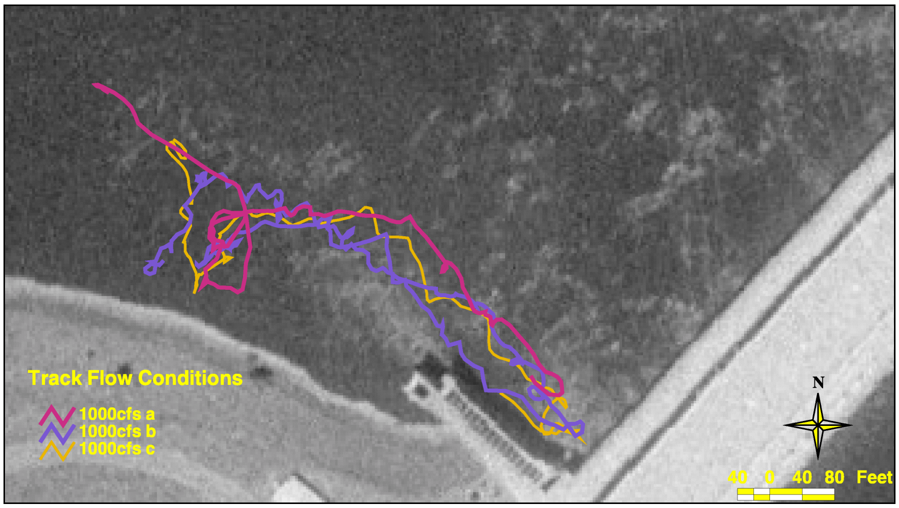

Figure 8 GPS tracks for ADCP measurements: 1000 cfs conditions.

The following series of figures (Figures 9-11) display measured velocity vectors for ADCP tracks shown in Figure 8. Velocity vectors and isobaths have been colored by elevation relative to mean sea level (water surface was at approximately 11 ft). From this top down perspective, velocity vectors downstream of the outfall exit appear uniform with depth, and directional differences are generally less than 90-degrees from top to bottom. Upstream, along the north east side of the exit, however, directional differences increase dramatically with some locations covering 180-degrees or more. This upstream area also contains a sudden 30 to 40 ft bathymetric rise from the draft tube exits.

Although velocity directions are non-uniform upstream of the outfall exit, their uniformity downstream implies that depth averaging is appropriate. Figure 12 displays depth averaged velocity vectors, color contoured by magnitude. All 1000 cfs ADCP velocity tracks have been placed on this single figure, and every other measurement was skipped for clarity. The general velocity trend is downstream, with few of the vectors pointing in a lateral direction. From these locations, there is little indication of any cross-current towards the southwest shoreline. Velocity magnitudes ranged from approximately 2 to 6 ft/s, with average magnitudes near 3 to 4 ft/s.

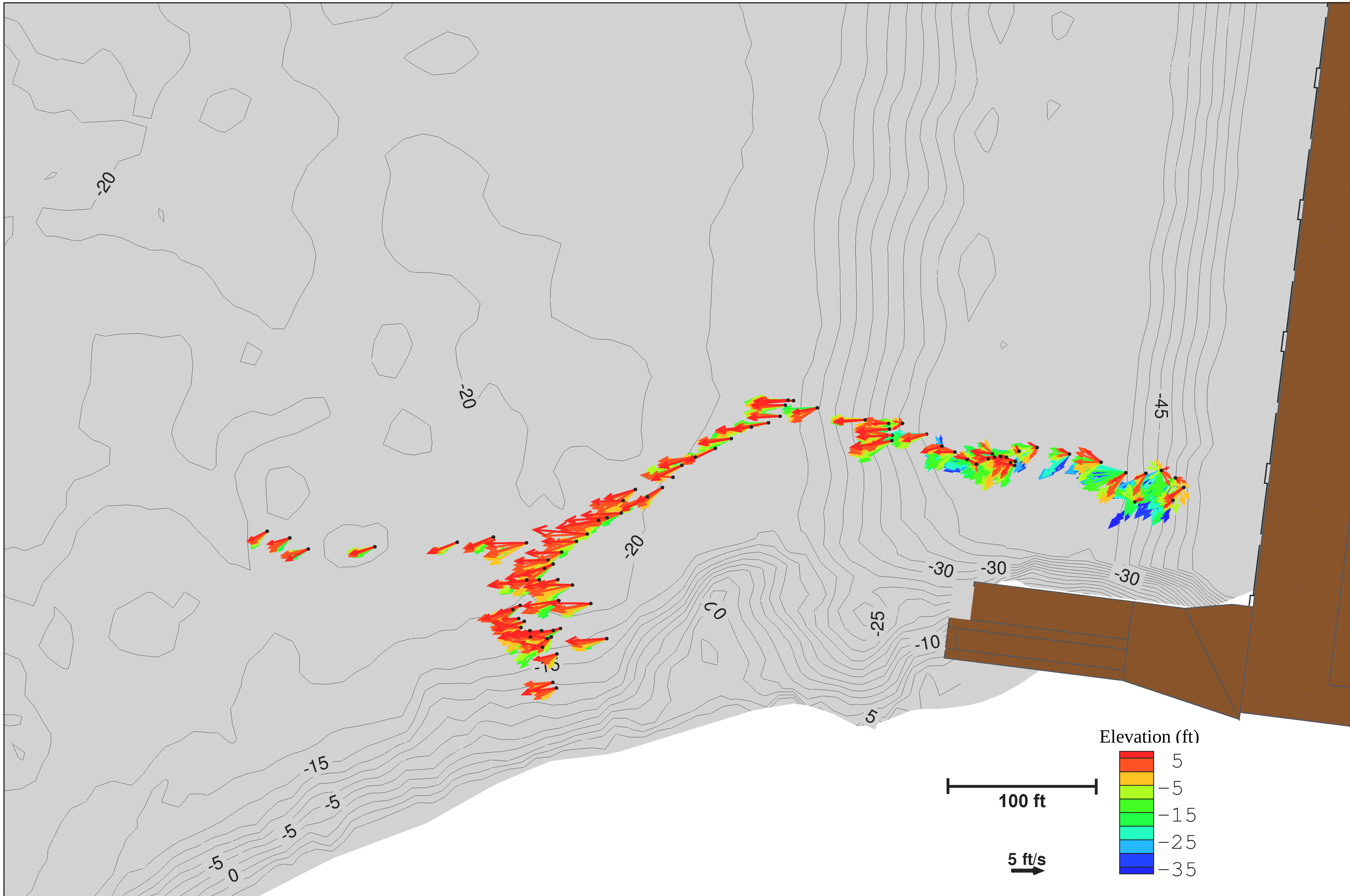

Figure 9 Track a (1000 cfs) ADCP data. Velocity measurements colored by elevation (datum is mean sea level).

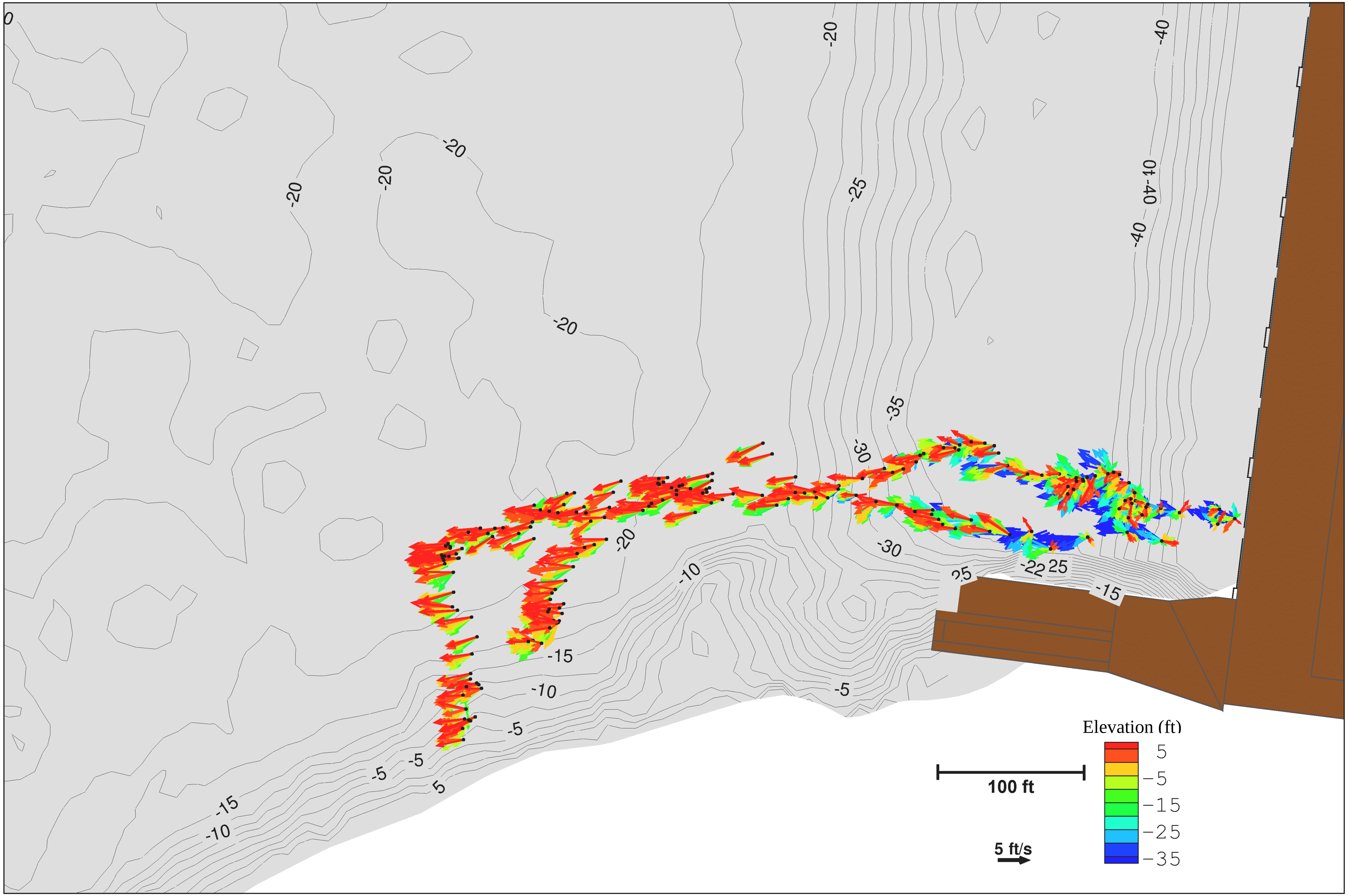

Figure 10 Track b (1000 cfs) ADCP data. Velocity measurements colored by elevation (datum is mean sea level).

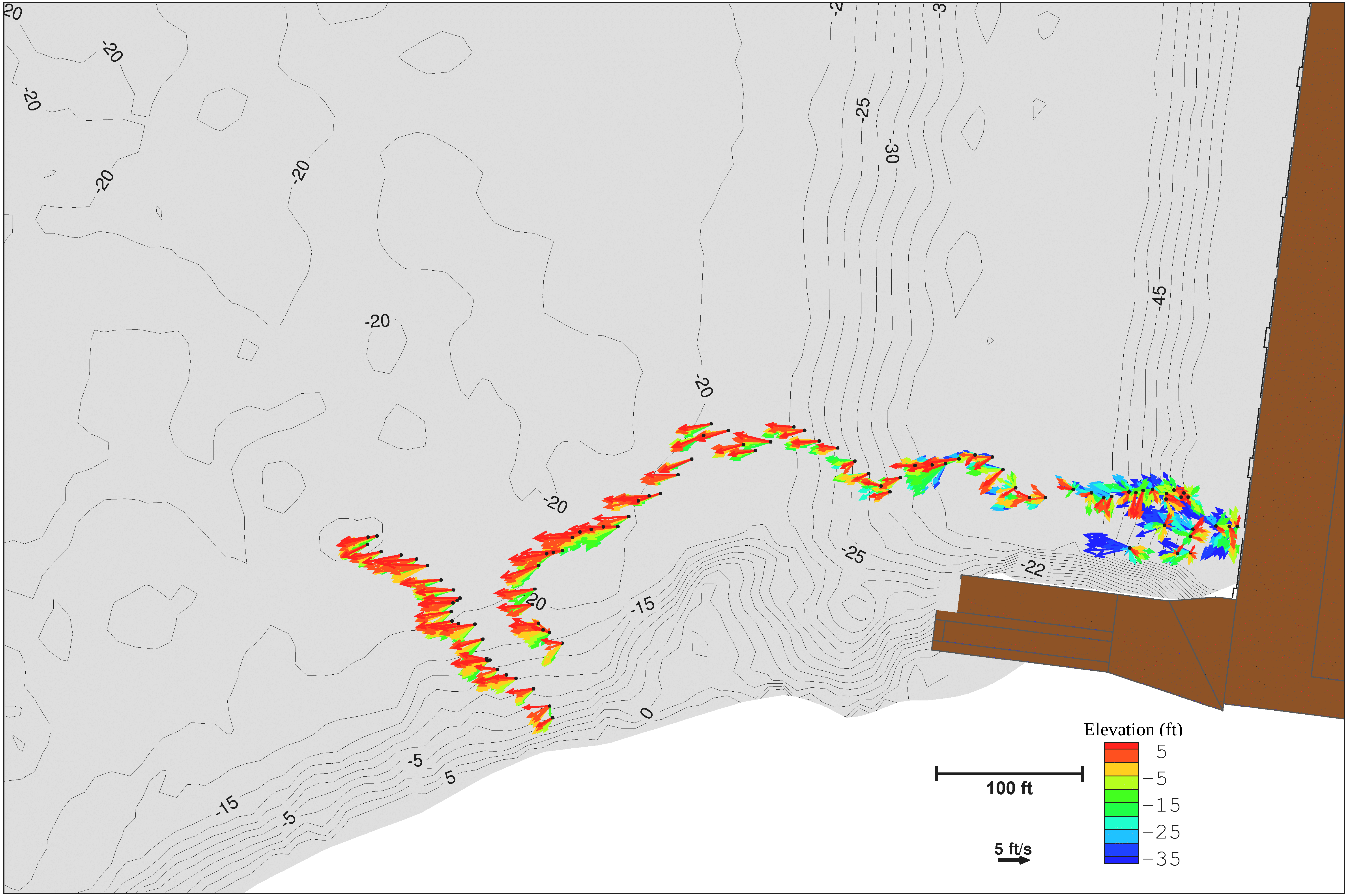

Figure 11 Track c (1000 cfs) ADCP data. Velocity measurements colored by elevation (datum is mean sea level).

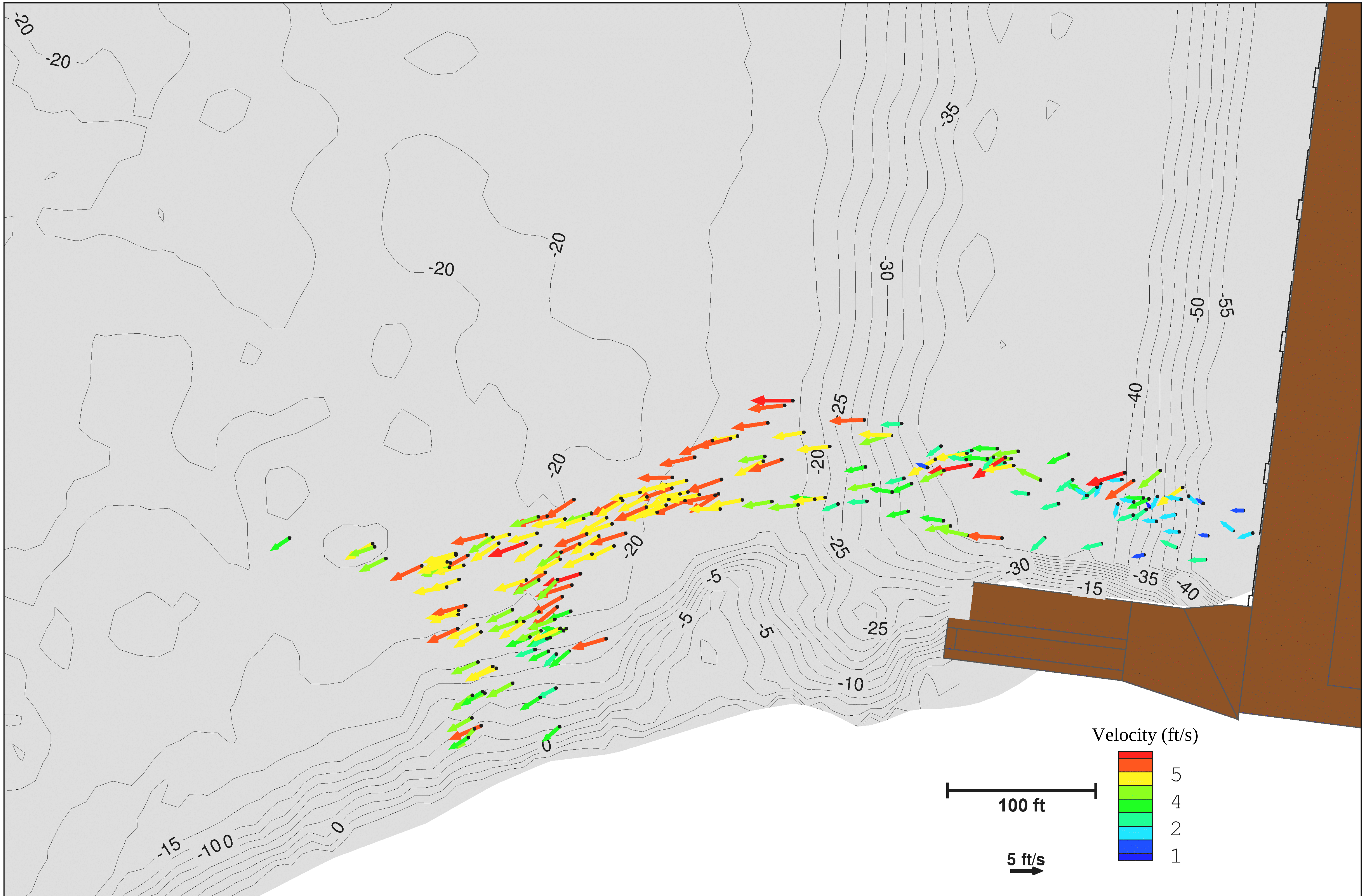

Figure 12 Depth averaged velocity measurements for all ADCP tracks at 1000 cfs. Every other measurement skipped for visual clarity. **Color indicates velocity magnitude.**

Three representative drogue tracks are shown in the next series of figures (Figures 13 through 15). When the drogue was released directly downstream of the jet's impact location (i.e., Figure 13), the drogue continued to float downstream and curve slightly towards the centerline of the channel. In contrast, when the drogue was released near the northeast exit of the outfall exit (i.e., Figure 14), the drogue was entrained by the jet, and after it surfaced, shot quickly towards the south bank. The drogue was then entrained in a large gyre that existed in this area, and it circled several times before it exited. The drogue then followed a downstream flow path, again traveling slightly towards the centerline of the channel. Drogues released farther upstream of the exit, although still on the northeast side (e.g., Figure 15), traveled away from the outfall exit, and were entrained in the prevailing downstream flow. All drogues placed in this location were not entrained by the plunging jet, and in fact, were pushed away from the downstream plume.

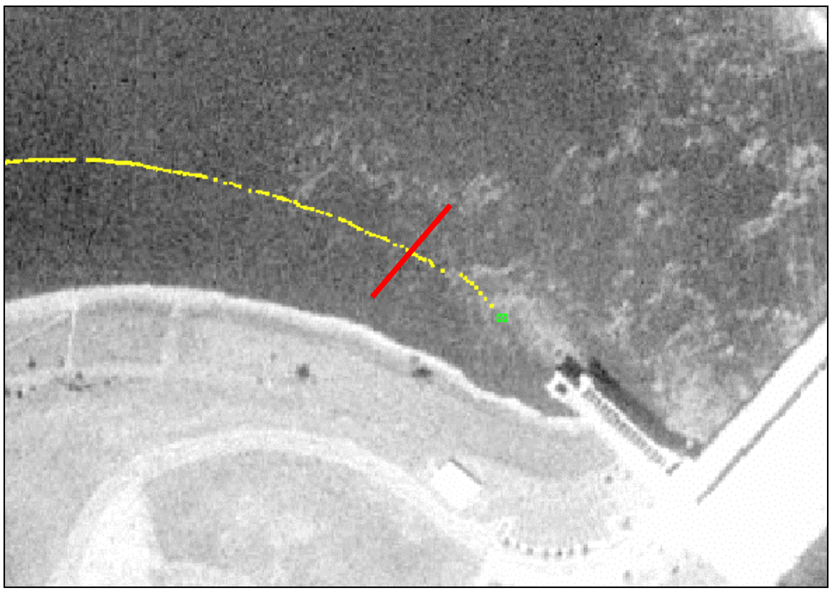

Figure 13 Released directly downstream of the outfall at 1000cfs: pnldrogue1.avi

Time integrated velocity measurements were calculated using the location and time stamp data from the drogue tracks. The drogue path shown in Figure 13 traveled downstream of the red line at an average velocity of 5.9 ft/s. Velocities upstream of this mark are larger than average, and inclusion of these points raised the overall average by more than 0.5 ft/s. This same procedure was repeated for the path shown in Figure 15. The average velocity along the entire path shown in the figure is 4.5 ft/s. Both of these values are consistent with ADCP measurements performed in the same general area (see Figure 12)

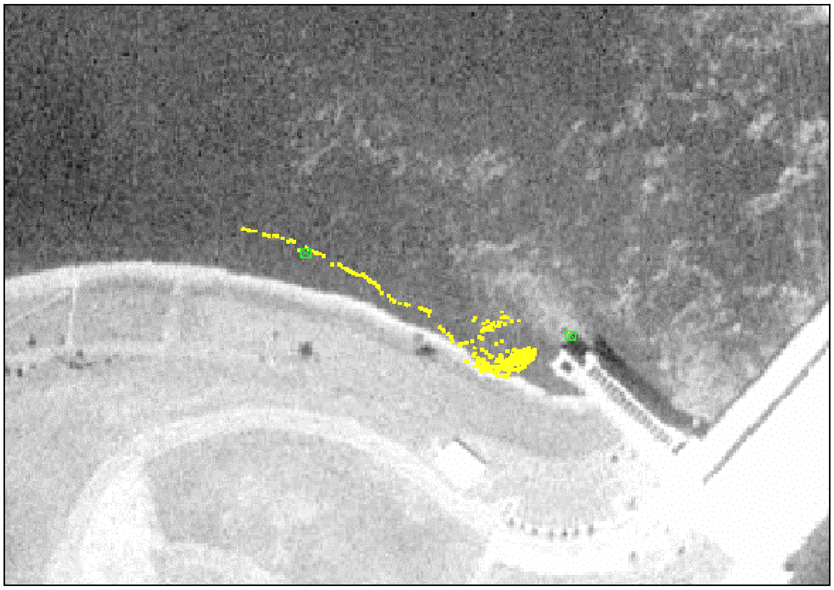

Figure 14 Released near the side of the outfall at 1000cfs and entrained: pnldrogue2.avi. Note: The drogue appears to contact the shoreline because the Bonneville image shown was flown in 1993 and substantial erosion of the shoreline rip-rap has occurred since that time.

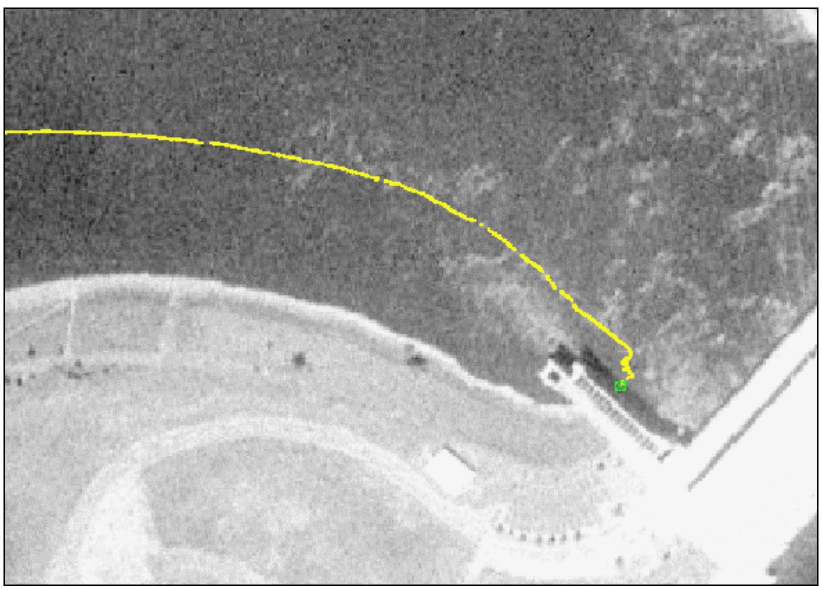

Figure 15 Released upstream of the outfall at 1000cfs not entrained: pnldrogue3.avi

3.3 2500 cfs Release Conditions

The largest outfall discharge condition measured in this study was at 2500 cfs. Two ADCP transects were performed, and GPS tracks showing the locations of these observations are presented in Figure 16. Data were collected after the outfall had run for at least fifteen minutes at a constant flow rate. Field collection was performed between approximately 9:00 and 11:00 am.

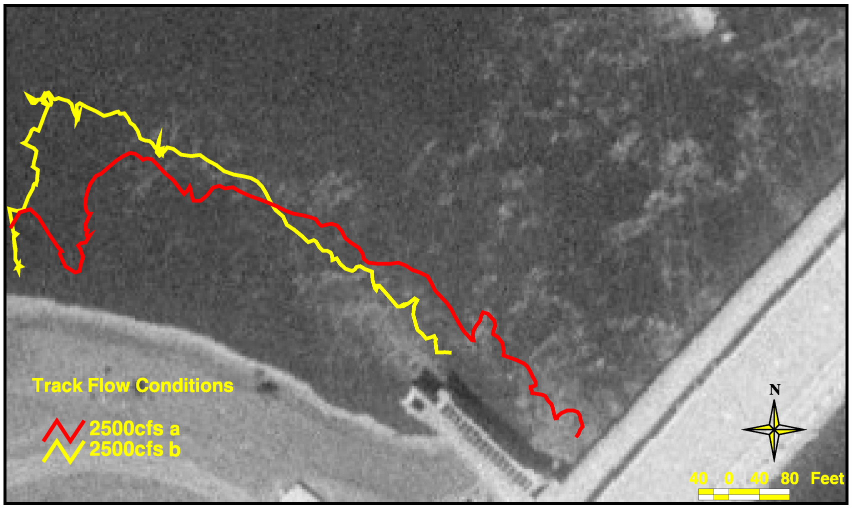

Figure 16 GPS tracks for ADCP measurements: 2500 cfs conditions.

Figure 17 displays measured velocity vectors for ADCP tracks shown in Figure 16. Velocity vectors and isobaths have been colored by elevation relative to mean sea level (water surface was at approximately 11 ft). From this top down perspective, velocity vectors downstream of the outfall appear uniform with depth, as was the case for the 1000 cfs condition. Lateral velocity measurements across the plume were performed, however they are farther downstream than for the 1000 cfs case because of the ADCP's sensitivity to air bubbles. Upstream, along the north east side of the outfall exit, directional differences again increased dramatically. At some locations vector directions spanned 180-degrees or more over the depth of the water column.

Downstream of the outfall exit, depth averaging of the velocity vectors is appropriate, and values for both ADCP transects are shown in Figure 18. Depth averaged vectors have been colored by magnitude, and every other measurement was shown to increase clarity. These vectors range from 2 to 6 ft/s, with a mean value of approximately 3 to 4 ft/s.

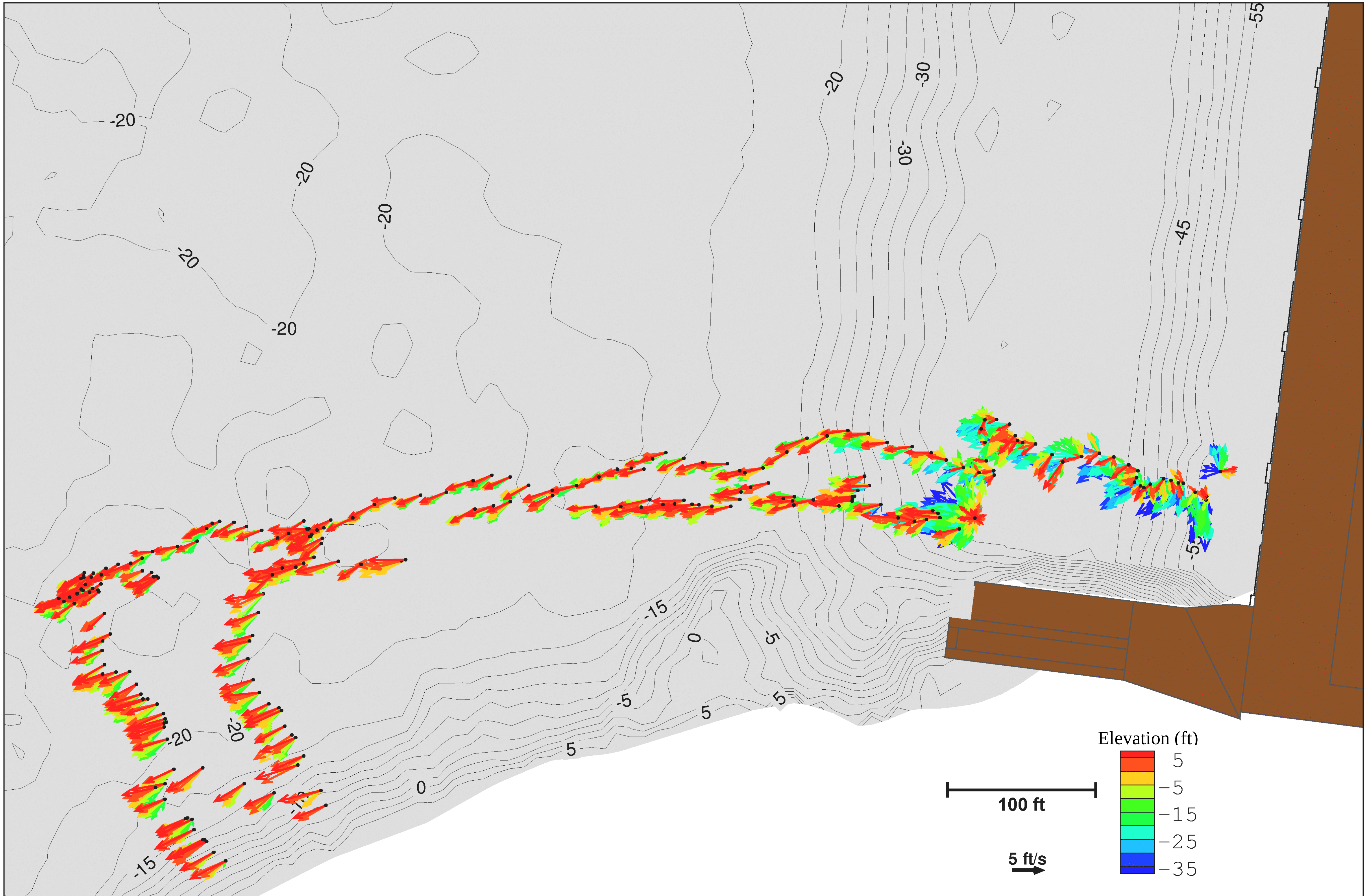

Figure 17 Tracks a and b (2500 cfs) ADCP data. Velocity measurements colored by elevation (datum is mean sea level).

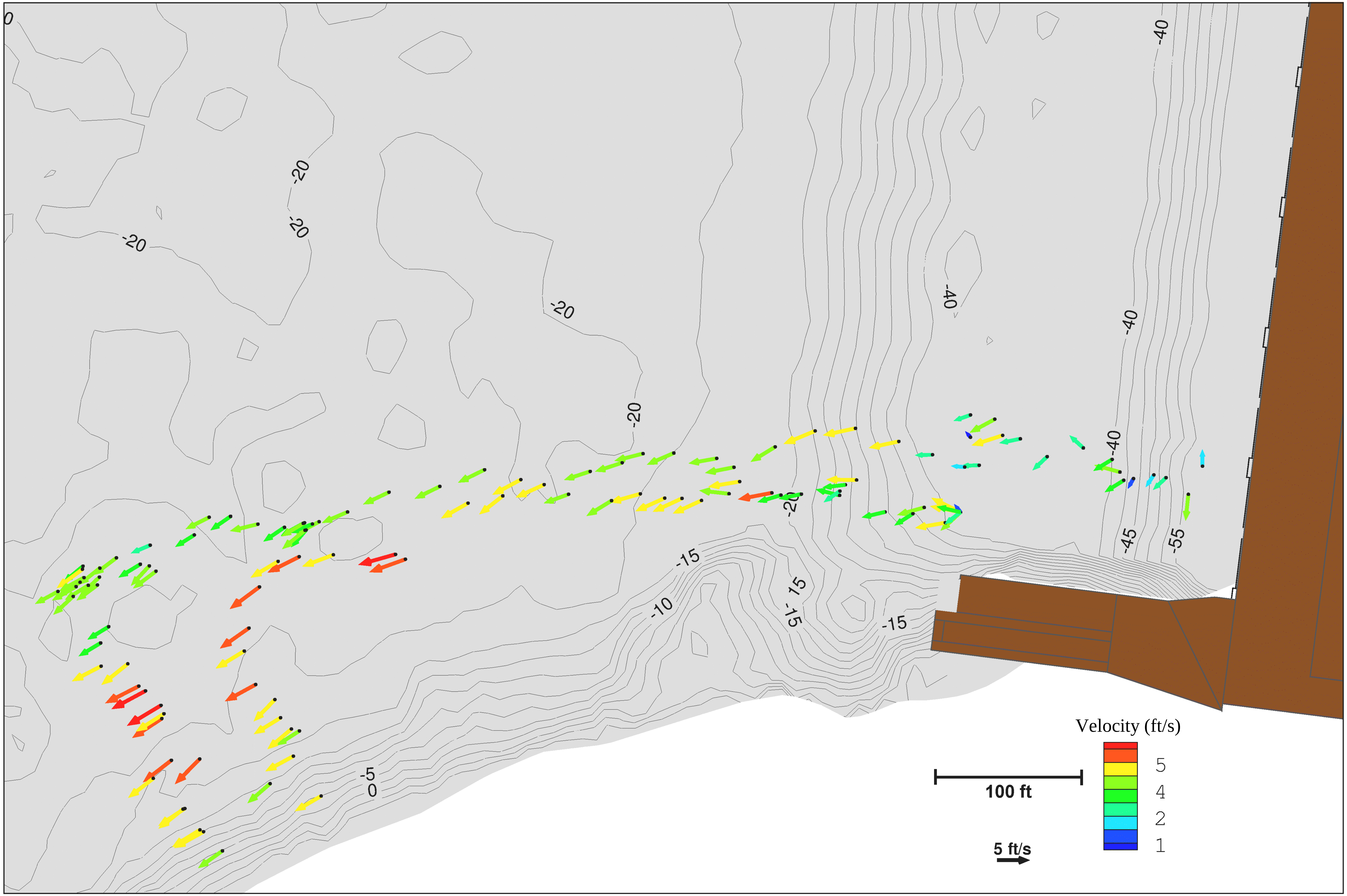

Figure 18 Depth averaged velocity measurements for all ADCP tracks at 2500 cfs. Every other measurement skipped for visual clarity. **Color indicates magnitude.**

Two drogue tracks are shown in Figures 19 and 20. In the first figure, the drogue has been released upstream of the northeast exit of the outfall. As with the 1000 cfs condition, the drogue was pushed away from the jet into the predominantly downstream flow. In the second figure, the drogue was released slightly closer to the exit. At this location, the drogue was pulled into the jet and submerged. The drogue resurfaced on the southwest side of the outfall. The drogue circled counter-clockwise, and again became submerged. Note that when the drogue became submerged, GPS values were not possible, which causes jump in drogue location displayed in the movie. Eventually, the drogue left the gyre and exited downstream.

Time integrated velocity measurements were calculated using the drogue paths shown in Figures 19 and 20. The average velocity along the entire path shown in Figure 19 is 4.9 ft/s. For the path shown in Figure 20, the average velocity downstream of the red line was 4.1 ft/s. Both of these values are approximately consistent with ADCP measurements performed in the same general area (see Figure 18)

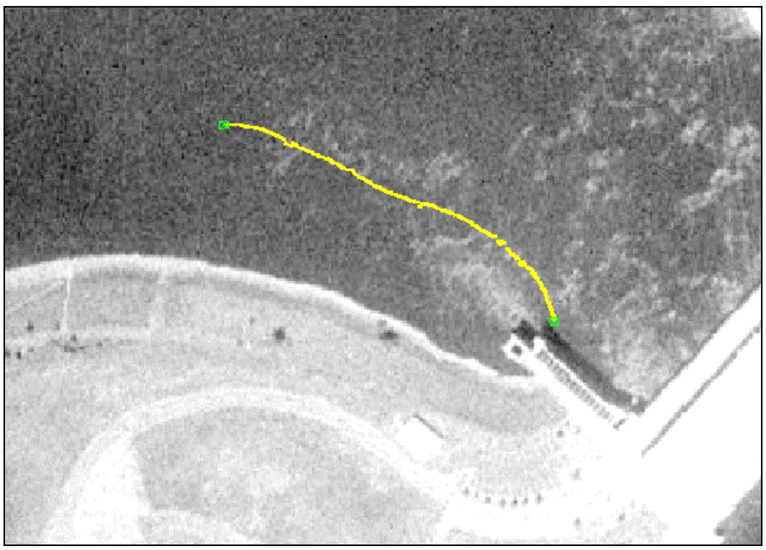

Figure 19 Released upstream of the outfall at 2500cfs and not entrained: pnldrogue4.avi

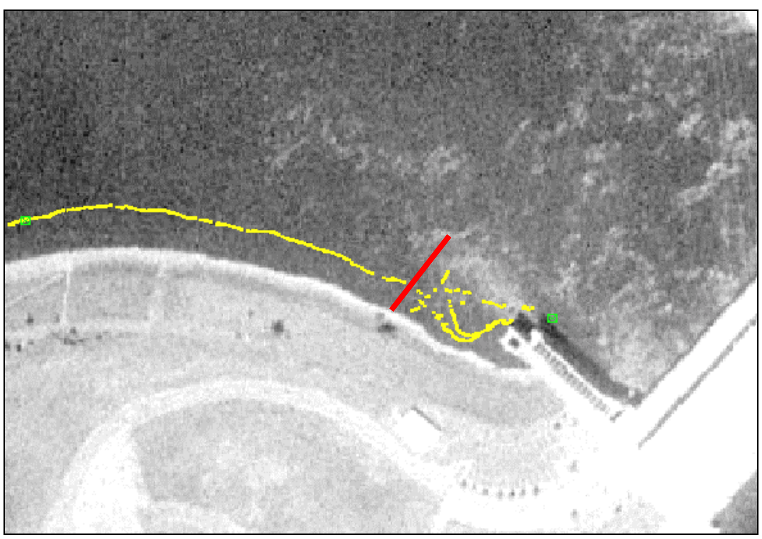

Figure 20 Released upstream of the outfall at 2500cfs and entrained: pnldrogue5.avi

3.4 Ambient Flows

Immediately following the conclusion of the 1000 and 2500 cfs outfall tests, ADCP and drogue measurements were performed in the tailrace with the outfall off. These tests were performed to gather information during ambient flow conditions downstream of the dam and directly downstream of the outfall. Three ADCP transects were performed, and GPS tracks showing the locations of these observations are presented in Figure 21.

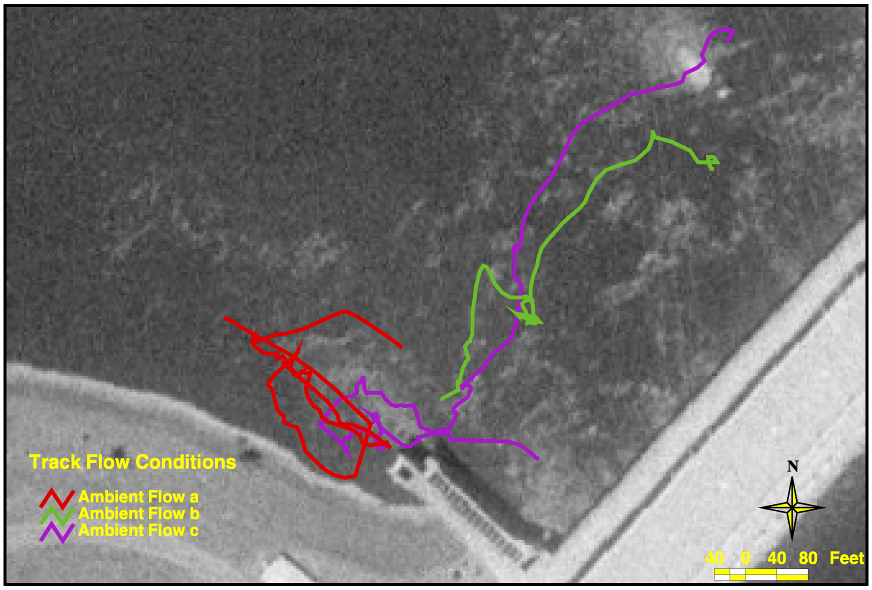

Figure 21 GPS tracks for ADCP measurements: Ambient flow conditions.

Figures 22 and 23 display measured velocity vectors for ADCP tracks shown in Figure 21. Near the outfall exit, velocity directions were variable over depth. Moving downstream from the exit, it was noted that this non-uniformity decreased, however depths in this area also become less so this result is not unexpected. Closer to the dam, velocity vectors were generally oriented in the downstream direction. It was noted however that velocity vectors are larger near the bottom of the water column. This coincides with the location of the outfall draft tubes, which extend from elevation –70 to –37 ft (i.e., the bottom of the water column). Velocity vectors were then averaged over the depth and are displayed in Figure 24.

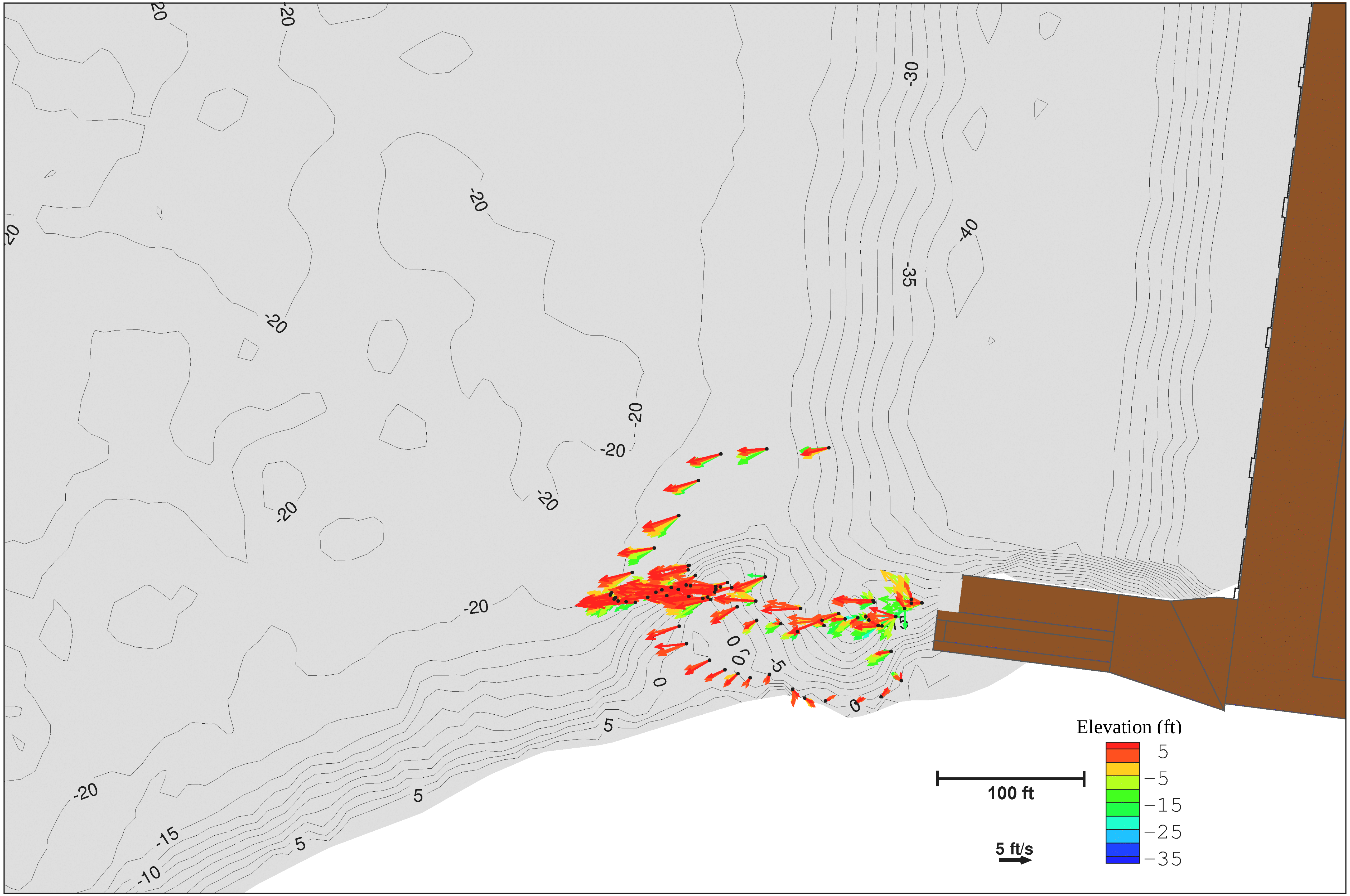

Figure 22 Track a (Ambient flow) ADCP data. Velocity measurements colored by elevation (datum is mean sea level).

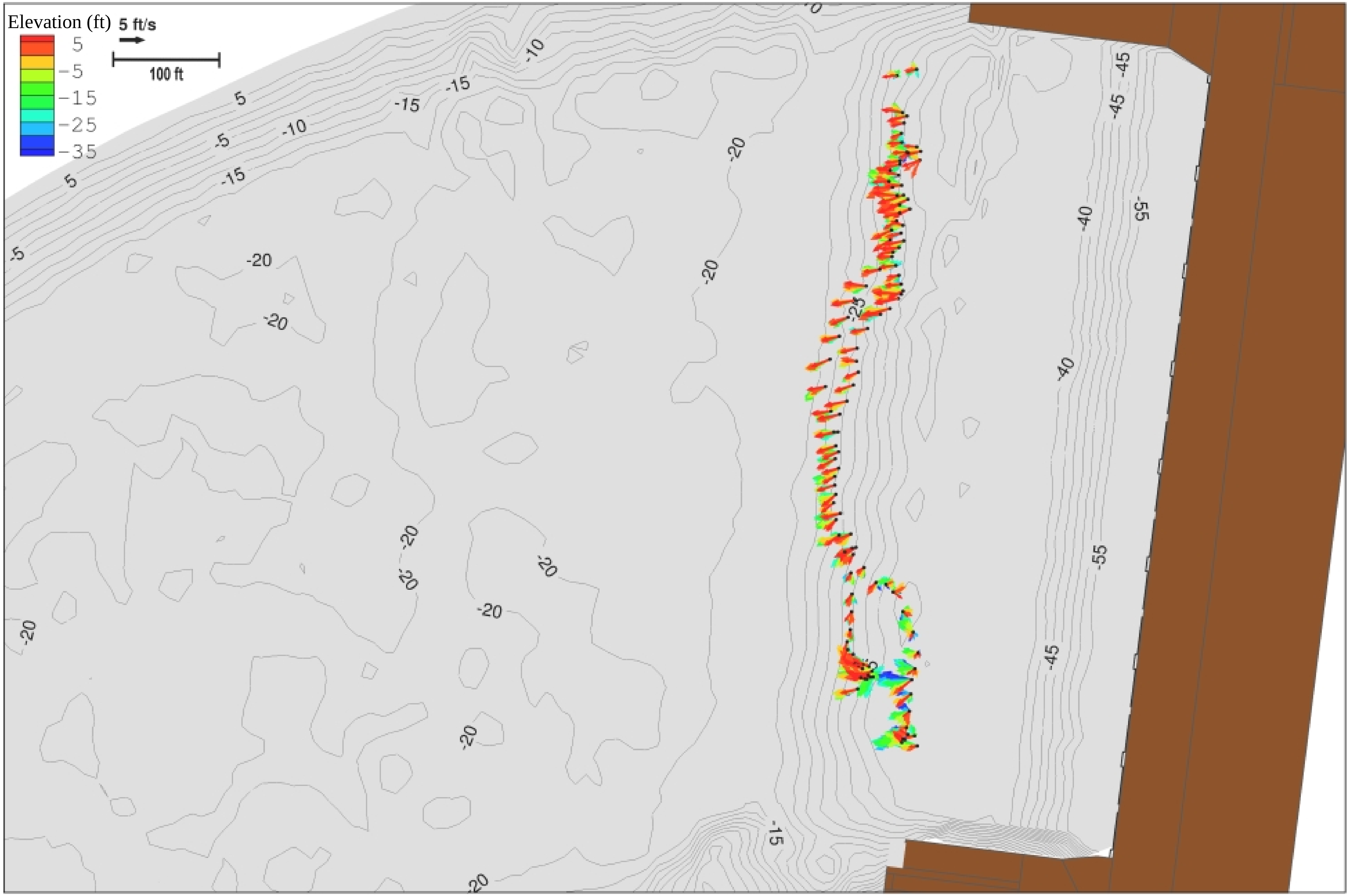

Figure 23 Tracks b (partial) and c (Ambient flow) ADCP data. Velocity measurements colored by elevation (datum is mean sea level).

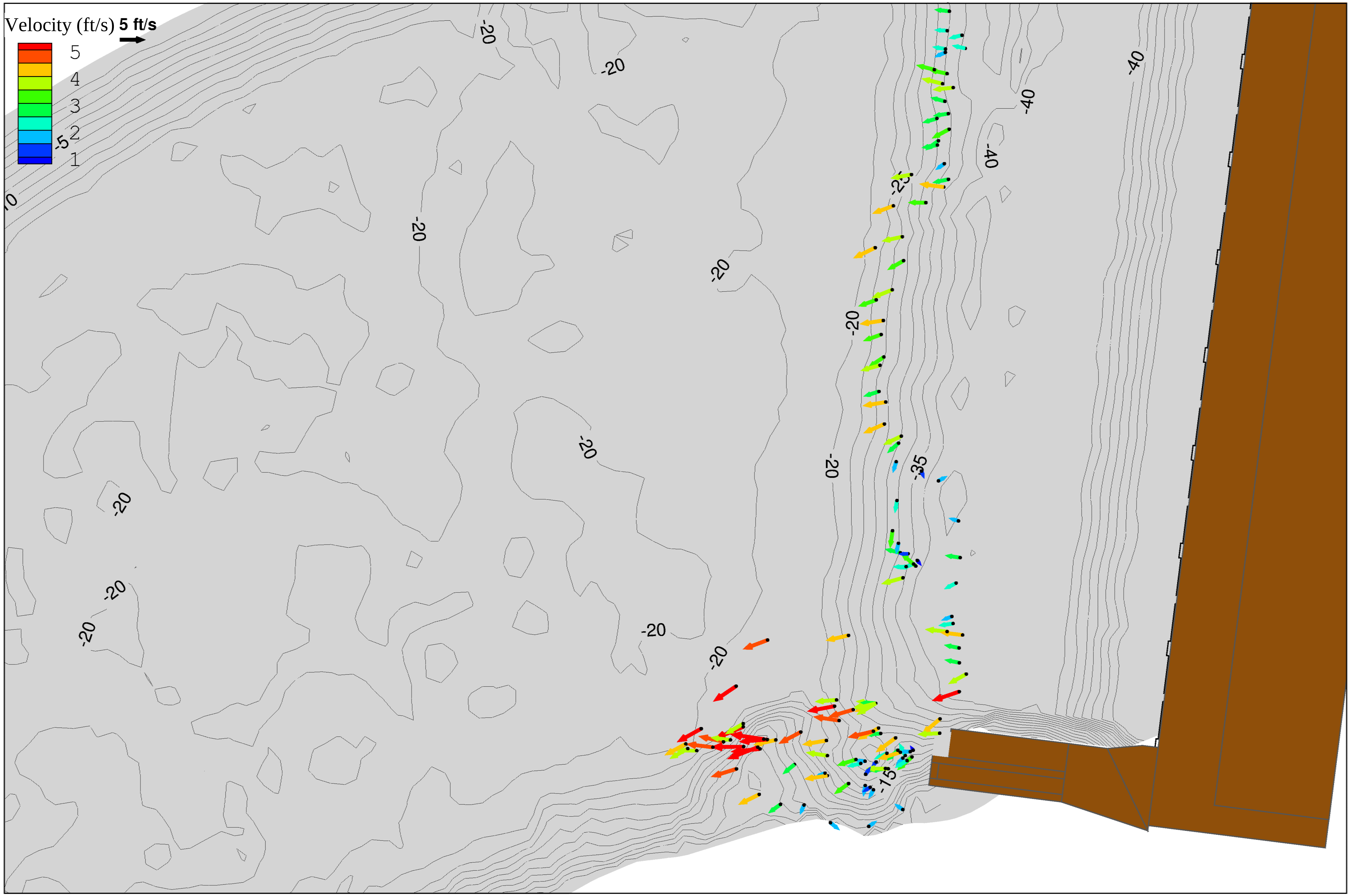

Figure 24 Depth averaged velocity measurements Tracks a (ambient flow). Every other measurement skipped for visual clarity. **Color indicates magnitude.**

Figure 25 displays a drogue track under ambient flow conditions when the outfall was not operating. The drogue follows a downstream path flowing the ambient flow field. The time-integrated velocity along the drogue path is 4.9 ft/s, indicative of the nearly full load (all units except 13) conditions at the Powerhouse during this period.

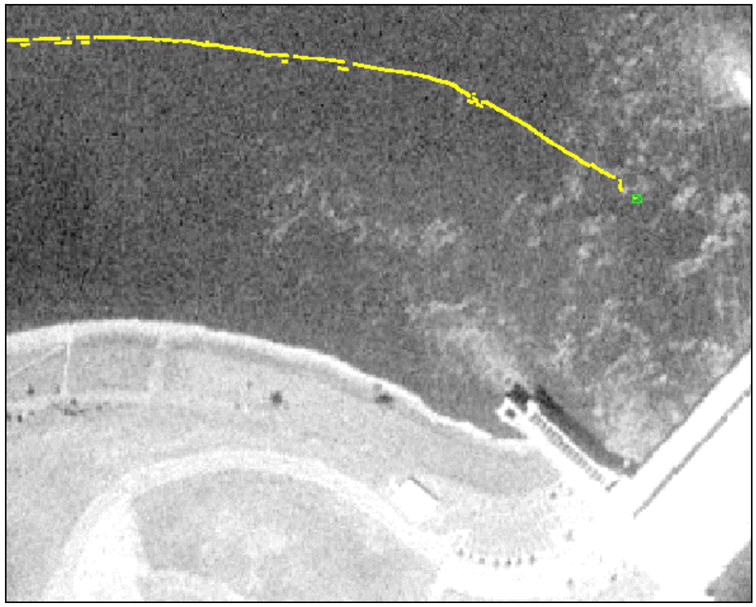

Figure 25. Released in center of tailrace during ambient flow conditions: pnldrogue6.avi

4 Summary

Three-dimensional velocity data and surface drogue tracks were collected in the tailrace downstream of the Bonneville Second Powerhouse on October 3, 2000. Data were collected under three different conditions: outfall off, outfall on at 1000 cfs, and outfall on at 2500 cfs. When the outfall was off, ambient flow conditions below the outfall and in the tailrace were measured.

Velocity data were collected using a 600 kHz RD Instruments ADCP. Data were collected in transects as close to the outfall plunge zone as possible for each outfall condition. Upstream and to the northeast of the outfall exit, velocity directions varied dramatically over the water column. Velocity vectors downstream of the outfall exit however were approximately uniform with depth. In this region, depth-averaged velocity magnitudes ranged from approximately 3 to 4 ft/s and were oriented downstream. Since the ADCP signal cannot penetrate areas with large concentrations of air bubbles, measurements were not obtained within the outfall pool zone. Away from this plume velocities were consistently oriented downstream, with a slight lateral component towards the south shore.

A GPS drogue was released approximately 20 times in the tailrace. Release locations were varied to examine differences in the flow field. The outfall jet entrained drogues released in close proximity to the northeast side of the outfall exit. After resurfacing, the drogue generally ended up along the south shore and was entrained into a large counter-clockwise gyre. The entrained drogue would then spin in the gyre for several revolutions, eventually breaking free of the gyre and migrating downstream. If the drogues were released farther away from the outfall exit however, they were generally not entrained and progressed rapidly downstream with the prevailing flow. Drogue paths released from these positions differed only slightly from those released under conditions when the outfall was not operating (compare Figures 15, 19, and 25).

The impact of the outfall on the tailrace flow field was minimal a short distance away from the jet impact area and downstream plume. In regions where ADCP data were taken (i.e. outside the plume region with large air bubble concentrations), observed currents were predominately oriented downstream. Water introduced by the outfall, and very near the jet impact location, tended to a follow significantly different flow path. Drogues released in this area were entrained into a counter-clockwise gyre on the south side of the outfall. These drogues rotated within the gyre for a period, occasionally re-entering the plunging jet (see Figures 14 and 20). Eventually these drogues would exit the gyre and would flow downstream.

Field data presented in this report provide useful information on the high flow outfall jet and plume downstream of the Second Powerhouse at the Bonneville Project. These data are limited however to one set of Project and two high flow outfall release conditions. Variations in tailrace conditions may lead to different results.

Appendix A: Project Operations

Table 1 Bonneville Dam Operations on October 3, 2000. Data source: Corps of Engineers, Portland District. Datum is mean sea level

BONNEVILLE DAM PROJECT OPERATIONS 3 OCTOBER, 2000

Miscellaneous Flows: 5.2

	Unit 0	Unit 1	Unit 2	Unit 3	Unit 4	Unit 5	Unit 6	Unit 7	Unit 8	Unit 9	Unit 10	Unit 11	Unit 12	Unit 13	Unit 14	Unit 15	Unit 16	Unit 17	Unit 18	Fish Unit 1	Fish Unit 2
Time	MW	MW	MW	MW	MW	MW	MW	MW	MW	MW	MW	MW	MW	MW	MW	MW	MW	MW	MW	MW	MW
600	2.6	0	0	0	0	0	0	0	0	0	0	71	67	0	70	69	67	70	66	10.5	9.6
700	2.6	0	0	0	0	0	0	0	0	0	0	67.5	66	0	69.4	69.2	68.9	70	71.3	10.5	9.5
800	2.6	0	0	0	0	0	0	0	0	0	0	67	65.6	0	67.8	68.7	65.6	69.2	66	10.5	9.6
900	2.6	0	0	0	41	0	0	0	0	0	0	64.2	66.3	0	65.6	65.6	66.1	66.9	66.3	11	10.1
1000	2.6	0	0	0	56	0	0	0	0	0	0	59.4	60.4	0	61.9	61.3	63.1	63.2	64.5	11	10.1
1100	2.6	0	0	0	56	0	0	0	0	0	0	59.2	60	0	61.6	61.2	63.2	63.2	64.2	11	10.1
1200	2.6	0	0	0	56	0	0	0	0	0	0	60	60.5	0	61.7	61.6	63.3	63.9	64.2	11	10.2
1300	2.6	0	0	0	55	0	0	0	0	0	0	59.6	60.5	0	61.7	61.5	63.3	63.9	64.2	11	10.1
1400	2.6	0	0	0	55	0	0	0	0	0	0	59.6	60.5	0	61.6	61	58.8	59.2	55	11	10.1
1500	2.6	0	0	0	55	0	0	0	0	0	0	59.6	60.5	0	61.8	61.4	58.1	58.6	55.3	11	10.1
1600	2.6	0	0	0	55	0	0	0	0	0	0	60	60.3	0	62	62.7	58.4	59.5	56	11	10.1
1700	2.6	0	0	0	55	0	0	0	0	0	0	60	60.7	0	61.6	61.5	62.6	59.5	56.1	11	10.1
1800	2.6	0	0	0	55	0	0	0	0	0	0	60.1	60.7	0	61.9	61.2	62.8	59.2	60.4	11	10.1

	Unit 11	Unit 12	Unit 13	Unit 14	Unit 15	Unit 16	Unit 17	Unit 18	Fish Unit 1	Fish Unit 2	Unit O	Unit 4	B2TW EL	B2 FB EL	Proj FB EL	B1 FB EL	Proj TW EL	B1 Ph Q	B2 Ph Q	Spillway Q	Tot Riv Q
Time	kcfs	kcfs	kcfs	kcfs	kcfs	kcfs	kcfs	kcfs	kcfs	kcfs	kcfs	kcfs	ft	ft	ft	ft	ft	kcfs	kcfs	kcfs	kcfs
600	15.00	14.16		14.79	14.58	14.16	14.79	13.95	2.22	2.03	0.55	0	10.0	74.6	74.7	74.3	9.5	0.5	105.7	9.6	115.4
700	14.40	14.00		14.59	14.76	14.27	14.90	15.21	2.24	2.03	0.55	0	10.7	74.7	74.6	74.4	10.1	0.6	106.5	9.6	116.2
800	14.31	14.01		14.40	14.68	14.01	14.78	14.10	2.24	2.05	0.55	0	10.8	74.7	74.7	74.7	9.9	0.5	104.7	9.6	114.4
900	13.78	14.23		14.12	14.12	14.19	14.36	14.66	2.36	2.17	0.55	8.1	11.0	74.6	74.6	74.4	10.3	8.7	104.0	9.6	121.8
1000	12.75	12.94		13.24	13.14	13.52	13.54	13.62	2.36	2.16	0.55	11.0	10.8	74.5	74.5	74.3	10.3	11.6	97.5	9.6	118.2
1100	12.61	12.78		13.12	13.03	13.46	13.46	13.67	2.34	2.15	0.55	11.0	10.8	74.9	74.5	74.3	10.2	11.6	98.8	9.6	117.4
1200	12.80	12.90		13.16	13.14	13.50	13.63	13.69	2.35	2.18	0.55	11.3	10.9	74.9	74.6	74.4	10.3	11.9	97.3	9.6	118.4
1300	12.75	12.94		13.20	13.16	13.54	13.67	13.74	2.35	2.16	0.55	11.3	11.1	74.9	74.3	74.2	10.1	11.9	97.5	9.6	118.6
1400	12.75	12.94		13.10	13.05	12.50	12.69	11.77	2.35	2.16	0.55	11.3	11.1	74.9	74.4	74.3	10.2	11.9	93.5	9.6	114.5
1500	12.73	12.92		13.20	13.12	12.62	12.52	11.81	2.35	2.16	0.56	11.3	10.9	74.8	74.8	74.3	10.4	11.9	93.4	9.6	114.5
1600	12.80	12.86		13.22	13.37	12.67	12.69	11.94	2.35	2.15	0.55	11.3	10.8	74.8	74.8	74.5	10.4	11.9	94.1	9.6	115.1
1700	12.78	12.93		13.12	13.10	13.33	12.67	11.73	2.34	2.15	0.55	11.3	10.8	74.9	74.9	74.5	10.4	11.9	94.1	9.6	115.2
1800	12.74	12.87		13.12	12.97	13.31	12.56	12.80	2.33	2.14	0.55	11.3	10.6	75.0	75.0	74.6	10.3	11.9	94.8	9.6	115.9
Average	13.24	13.27		13.56	13.55	13.47	13.56	13.30	2.32	2.13	0.55										
St Dev	0.82	0.58		0.65	0.70	0.59	0.91	1.17	0.05	0.05	0.00										
Service Hrs	13.00	13.00	0.00	13.00	13.00	13.00	13.00	13.00	13.00	13.00	13.00										

Remarks: A blank space for Unit MW reading indicates the unit was Out of Service

Note: MW requested for units 1-10 and kcfs requested for all other units if possible.