Results of Hydrographic Surveys on the Providence and Seekonk Rivers: Fall Period, 2001

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1.0 Introduction

A second set of hydrographic surveys have been conducted within the Providence and Seekonk Rivers to characterize both the magnitudes and patterns of circulation within each body of water for fall seasonal conditions. The cruises provide a baseline for comparison with the first set performed the summer period (2001). The goal of this project is to map out basic aspects of flow and chemical transport within each river with particular emphasis on characterizing the levels of lateral and vertical structure in the flow during flood versus ebb periods of the tidal cycle. Specific questions involve mapping patterns for the outflows (e.g. plumes) for both near and far field regions of the rivers containing the Fields Point and Bucklin Point sewage discharge pipes

2.0 Instrument:

Circulation patterns and energies are constrained within each river using an RD Instruments Broadband (1200 kHz) Acoustic Doppler Current Profiler. The ADCP consists of an array of four transducers oriented such that sound beams are transmitted out 90° angles from each other and a know angle from the central axis of the instrument. Sound pulses emitted by the transducers are reflected by scatterers throughout the water column, such as biological and other particulate matter. The reflected sound pulses are Doppler shifted due to the movement of the scatterers in the moving water. The ADCP processes the Doppler shifted return echoes to obtain along-beam velocity components which are then combined for each transducer and converted into a three-dimensional (3-D) velocity pattern. Through a process called "range gating" the ADCP listens to the returning sound pulses over uniform time increments. Progressively later time increments correspond to energy returning from greater depths. In this way velocities are resolved into depth cells, or bins. For each energy pulse sent out, or set of energy pulses, which are subsequently averaged, the resulting velocity versus depth profile is called an "ensemble".

ADCP technology has been in use in coastal applications since 1991 and the instruments have been tested in a number of environments against moored current meter arrays (Winant et al., 1994). In particular the shallow water ADCP has been used to characterize currents and volume fluxes in Sydney Australia (Trenaman and Metcalf, 1992) and the Rhine River (Gordon and Bornhoft, 1991). In the latter example, repeatability of ADCP discharges were found to be within 1% and values were within 10% of those obtained using conventional current meters. The ADCP has been used for a number of studies within Narragansett Bay (Deleo, 2000; Sifling, 1996; Kincaid et al., 1996; 1999)

The instrument used in this study is mounted to the side of a 20' skiff. Two modes of data collection are possible in this configuration. In one mode, the skiff is driven along lines, called "transects", such as those highlighted in figure 1. Energy pulses are sent out on average every 5 seconds. Given an average boat speed of 1 m/s, a velocity ensemble is collected roughly every 5 meters. Over a complete transect, therefore, information is obtained on 3-D velocity as a function both depth and horizontal position. Plots can be made showing velocity contours through a vertical slice of the river oriented along the transect line. The second mode of data collection used in this study involves recording a time series of velocity profiles at fixed position (Figure 1).

3.0 Methods/Sampling Plan:

A goal of the hydrographic surveys was to characterize flow patterns within each river. Within the Providence River a series of transect lines (Figure 1) where defined for mapping flow structure both above (north of) and below (south of) the Fields Point discharge site along Lines 1 and 2, respectively. Additional transect lines were positioned further south at Sabin Point (Line 3) and between Gaspee and Bullock Points (Line 4). For this survey a new line was added between lines 2 and 3, called line 2.5. This transect extends between Edgewood Yacht Club to the west and Pomham Rocks to the east. The line ended at the East Providence sewage outfall pipe. One additional line was added right at the Fields Point outfall, referred to as line 1.5. As opposed to survey 1, where each line was sampled twice, the on Providence River surveys we attempted to occupy each line once per circuit, where a circuit is defined as a complete set of transect lines. The goal was to increase the number of circuits we could complete over the tidal cycle. During the first half of the day the winds were strong and out of the north, making conditions on the southern lines rough and difficult for data collection. Because of poor data quality, line 4 was not occupied on the second circuit, and instead we added line 2.5 to circuit 2, which was further north, experiencing a reduced sea state. Also, because of the relatively high sea state our transit time between transects was greatly increased. We occupied the same number of transects as the summer surveys. A SeaBird SB19 CTD was dragged behind the boat at roughly 1 meter depth for all transects.

Sampling began on October 28, 2001, on the southernmost line (4) and progressed northward to lines 3, 2 and 1. The first two circuits coincided roughly with early and late flood conditions. Circuits 3 and 4 covered roughly early and late ebb conditions. A detailed summary of data collection locations and times is given in table 1.

A second day of sampling (October 29,2001) was conducted on the Seekonk River. Four transect lines were defined in a similar pattern to the Providence River survey, with Line 1 above the Bucklin Point discharge site and three lines below this site (Figure 21). Line 2 was oriented across the channel, immediately south of the outfall. Line 3 was located at a wharf just north of the confluence with the Tenmile River tributary. Line 4 was located just north of the clubhouse for the Brown University Rowing Club (Figure 21). Four complete circuits were completed over the course of the day and a partial circuit 5 was completed on line 4. Sampling followed the methodology from the Providence River survey, beginning at the southernmost line (4) and progressing northward. An additional line was added to this survey, called line 2.5, located between lines 2 and 3.

The Seekonk is characterized by a narrow channel with shallow shoals on either side of the channel. For much of the tidal cycle sampling could only take place within the channel. Full transects were attempted around the high tide. Because of the variable nature of the water depth, the sampling for the Seekonk survey was more variable than the Providence River survey. Because the goals are to map out both vertical structure within the channel and lateral structure between the channel and the shoals, both transect line sampling and time series sampling were performed. A rough sampling protocol was developed which involved driving 2 transect lines (for lateral structure) within the channel and, if possible, out over the shoals. Next, a time series data set (4 minutes of data collection) was conducted by holding position within the channel using an anchor to provide maximum data quality for vertical flow structures within the channel. Attempts were made to drive transect lines over as much of the shoals as possible, particularly on line 2 near the outfall.

The set of sampling parameters for the ADCP are referred to by configuration file numbers in Tables 1 and 2. The configuration file is read by the ADCP and defines how the instrument should ping in terms of things like depth range, number of vertical bins, ping rate, and averaging of data into ensembles. For the majority of the data files the standard water mode of 4 was used, with depth bins of 25 cm. Because of the shallow water shoals on line 2 of the Providence River survey and each of the lines in the Seekonk survey, we also experimented with ADCP water mode 5, which is tuned for extreme shallow water environments (e.g., depth bins of 10 cm). Unfortunately, this mode is also best for sluggish flow regions and has a limited depth range. Therefore results using this collection mode were mixed, depending on the stage of the tide and water flow rates. In some cases however, this sampling mode provided a high quality data set for shallow water flow.

4.0 Results:

Providence River Currents

Data on circulation patterns are presented in a series of contour plots (Figures 2-5). The data have been processed using a series of software codes developed at URI-GSO by Pockalny and Kincaid. The processing software utilizes GMT based commands for stripping the data of bad bins and bad ensembles using a running median filter. Filtering takes place after the velocity vectors for each depth and horizontal position have been projected into components normal to the average trend of the transect line. Data gaps are replaced with estimated values calculated from neighboring points using a cubic spline. Data are then averaged using a smoothing filter.

The contour plots provide the best representation of lateral structure in flow through the transect plane. Circuit 1 was conducted during early ebb conditions and results are shown in Figure 2. Each of the lines exhibit somewhat similar patterns with ebbing water in the upper half of the water column and flooding currents in the deep channel. For the southern two lines, ebb velocities in the channel reach 30-35 cm/s. The deeper inflow is weaker, <20 cm/s. The maximum ebb velocities recorded on this circuit are >40 cm/s, hugging the western edge of the channel on Fields Point, line 2. Flows are generally weaker on the northern line 1. The shallower shoals exhibit more variable conditions, with alternating inflows and outflows, typical of transitional periods where the water moves in eddies. The Gaspee Pt. line shows coherent ebbing water on the east side, and weak and variable eddies on the west. In opposition, the Sabin Pt. line shows southerly, or ebb currents on the west and northward, or flooding water on the east. The Fields Pt. line shows a similar structure to the summer, with outflow focussed on the shoals and the western side of the channel. The extreme west end of the line shows weakly flooding currents, which was an interesting observation from the summer surveys.

Highlights of this circuit are the two-layer flow structures seen on every line, characteristic of classical estuarine circulation. The occurrence of lateral structure in flow is interesting, in particular the opposite patterns seen between Gaspee and Sabin Pt. Lines.

Circuit 2 covered the end of the ebb stage of the tide. Wave heights were quite high on at this time, and increased to the south. Line 4 was not occupied on this circuit and the new line, 2.5, was added to the circuit. In figure 3, the Sabin Pt. line shows a similar structure to circuit 1, were the surface waters are ebbing and the eastern portion of the line exhibits flooding conditions. Line 2.5 covers a large western shoal and the channel on the extreme eastern side of the line. A goal of adding this line was to see if we could define a recirculation pattern, or eddy feature on this shoal which feeds the northeasterly flow recorded during summer on line 2, south of Fields Pt. The flow on the shoals is generally weak and variable. The channel at this tidal stage exhibits 2-layer flow with weak surface outflow (10-15 cm/s) and a volumetrically larger, deep inflow (20 cm/s). Line 2 is interesting in that the deeper 2/3 of the channel is flooding, as is the western portion of the shoals. A persistent, though weakened, outflow plug is still apparent on the western edge of the channel and within the shallow waters of the channel. Line 1, sampled at the end of circuit 2, shows the majority of the cross section to be flooding, with only minor ebb currents recorded on the eastern side of the line..

Circuit 3 (Figure 4) begins at line 4 and covers the early to mid flood stages of the tide. A large percentage of the cross section, centered on the channel, is flooding. Interestingly, the east side of the line shows weak southerly flow. To the north, on the Sabin pt. line 3, water is moving in or northward in the deep channel and the eastern shoal. There is clearly a persistent inflow on the east side of Sabin pt. and a persistent outflow on the eastern side of Gaspee Pt. The shallow waters along the Sabin Pt. line are nearly stagnant, or weakly ebbing. On line 2 a strong inflow is recorded within the deeper 3/4 of the channel. A coherent outflow, with flow rats of 20 cm/s is still apparent in the shallowest water of this line, near the western side of the channel. Weak southerly flows are also seen across the western shoals on this line.

Conditions later in the flood are recorded during circuit 4 (Figure 5). On each line the channel is dominated by flooding waters, with maximum velocities, > 25 cm/.s, recorded in the deepest regions of the channel. The water on the shoals of lines 3 and 4 is generally weak and flowing in a southerly direction. This pattern of flow may be due to weak counter eddies moving in response to the inflow within the channel. The entire channel cross section of line 2 shows northerly flow and here also the western shoal shows weak southerly flow, perhaps responding like a counter eddy to the rapid northerly flow in the channel.

Providence River Salinity/Temperature

The CTD data collected during the individual circuits are summarized in Figures 6-9. During the early ebb conditions of circuit 1 (Figure 6), the surface water exhibits salinities in the range of 28-29 ppt, with higher values to the south. Temperatures range from 14-15 C, with higher values to the north. The water to the south is cooler and saltier. There is very little across estuary variation in temperature. Lines 3 and 4 show saltier (by 1 ppt). On line 3 the water on the eastern side is slightly cooler (<.5 C). The currents show persistent northerly flow on the eastern side of line 3, which is consistent with cooler, saltier water.

Later in the ebb (circuit 2, figure 7) more lateral structure in surface water properties is recorded. On line 1, water on the eastern side ~2ppt more saline. On line 2, interestingly, a high salinity (close to 30 ppt), slightly lower temperature plug of water is seen on the western shoals. Just south of this section, on the Pomham Rocks line, the water on the far western portion of the transect is lower salinity than this. The surface water in the central portion of this line matches the salinity-temperature of the western portion of line 2. Lower salinity water is recorded on the western sides of line 3 and 4, which is similar to patterns seen in the summer surveys. Circuit 3 (Figure 8, early flood) exhibits similar patterns in salinity and temperature. Higher salinities are recorded on the eastern side of line 1 and the western, shoal region of line 2. Both transects 3 and 4 have lower salinity water on the western side of the line, with the Gaspee Pt. line showing a larger (2 ppt) lateral variation. On the final circuit 4 (figure 9), which covers flood conditions, a number of lines exhibit the same basic patterns in lateral salinity structure. Lines 1 and 4 both record higher salinities (2 ppt) on the eastern sides of the transect, while temperatures are nearly uniform across the line. Line 3, at Sabin Pt., shows a structure which is similar to circuits 2 and 3 where salinities are nearly constant over the section, with slightly decreased values on the extreme eastern and western edges of the transect (Figure 9D). The Pomham Rocks line (Figure 9C) exhibits a reversal in salinity structure relative to late ebb conditions of circuit 2 (Figure 7C) with the lowest salinities over the middle of the shoal and higher values on the extreme western end of the line and within the channel. As with circuit 2, the westernmost shoal on line 2 (Figure 9B) matches the water properties of this middle portion of the Pomham Rocks line (Figure 9C). Maximum salinities are ~28.5 ppt recorded on the eastern side of lines 2.5, 3 and 4 and the westernmost side of line 2.5. The lowest value of 24 ppt is recorded on the western side of line 1. The next lowest value is 26 ppt recorded much farther south on the western side of line 4. The lower 26 ppt value on this portion of Gaspee Pt Line is seen over all phases of the tide.

Providence River: Average Velocity Profiles by Quadrant

Data from survey 1 during July, 2001 showed that persistent outflows from the Providence River hugged the western channel on line 2 and the western side of the River down by line 3 at Sabin Pt. To further assess flow patterns along these lines, and the added line 2.5, an additional processing step was made for these data. Each transect was divided into 4-5 distinct subsections. Within each subsection the data was laterally averaged and resulting velocity profiles are plotted. In this step the details of the lateral flow structures are lost in order to gain an average sense for the magnitudes and directions of water flow for each sub-region. Figures 10-13 summarize averaged velocity profiles for transect Line 2, which is divided into western and far western shoal regions and western and eastern channel regions. During early ebb conditions (Figure 10) water in the western portion of the channel is ebbing at 30-40 cm/s. The upper 3 meters of the water column on the eastern side is ebbing at 20 cm/s, whereas the deeper water is nearly stagnant. Water on the western shoal is also ebbing at 20 cm/s. On the far western shoal water is moving at 10 cm/s to the west. The next circuit, 2, is near the ebb to flood transition (Figure 11). In the eastern channel the very shallow surface water is moving out while the lower 2/3 of the water column is flooding at 20 cm/s. The western channel waters are still ebbing but at magnitudes of 5-10 cm/s, versus 40 cm/s during circuit 1. The water just west of the channel is moving slowly (5 cm/s) in a east-southeast direction while the far western shoal water moves northeasterly, similar to prevailing trends seen during summer 2001 in this region. Figures 12 and 13 show profiles from regions of line 2 during flood conditions. The eastern channel waters are flooding at 20 cm/s, on average, from 3 meters depth downwards. Surface waters are stagnant or weakly south. The western channel waters are flowing slowly southwards (Figure 12 C). The combination of profiles on the far western and western shoal regions are indicative of eddy or swirling flow where the far western shoal water moves east towards the western shoal region where water is moving west – southwest. Circuit 4 (figure 13) finally shows full flood conditions with all channel water moving northwards at 10-30 cm/s and the water over the shoals moves in an east-northeasterly fashion at <10 cm/s.

In an attempt to define the character of flow on the western shoals, a new line (2.5) was added to the sampling. Figures 14 and 15 summarize data profiles for late ebb and full flood conditions, respectively. During late ebb, water over the majority of the shoals is moving south-southwest at 5-10 cm/s. Only the far western shoal water, which showed a distinct salinity signature, is moving slowly northward. Channel water is ebbing slowly (<10 cm/s) on average (Figure 14E). During flood conditions, water is over the entire section is moving, on average, in a north-northeasterly direction at speeds of 5-10 cm/s, except in the deep channel where water moves north at up 30 cm/s. This flow feeds into the western shoal flow pattern of line 2, which was also northeasterly to easterly.

Figures 16-19 highlight flow patterns farther south on line 3 at Sabin Pt. During early ebb conditions (circuit 1; Figure 16) flow is southerly over the entire cross section at 10-30 cm/s. Flows generally decrease towards either side of the river. Figure 16 C shows that the laterally averaged flow within the channel has significant vertical structure. In the upper 5 meters of the water column water moves southward at 15-32 cm/s. Below this level water moves northward at <10 cm/s. Later in the ebb, approaching the transition to flood (circuit 2; Figure 17) water over the majority of the cross section moves southward at 10-20 cm/s. Only the far eastern portion of the line shows water moving northward at <10 cm/s. During early flood conditions (circuit 3; Figure 18) the western shoal water continues to move south-southwesterly at < 10 cm/s. Water in the channel has turned and is starting to flow northward at depth (~10 cm/s). The entire eastern side of the line moves northward at ~10 cm/s. Finally, during full flood conditions (circuit 4; Figure 19) the entire eastern side of the line, including the channel shows water moving northward at ~ 10 cm/s. Maximum velocities are seen in the channel. The western side of the line is essentially stagnant or weakly swirling. Averaged over a tidal cycle the water on the western side of the line moves in a net southerly direction, while the water on the eastern side moves in a net northerly direction.

Seekonk River Currents: Lateral Structure

The Seekonk River was sampled on October 29, 2001, one day after the Providence River. Because the river's bathymetry includes a channel and extremely shallow shoals, two sampling strategies were followed (Table 2). When possible, transects were driven to provide information on lateral and vertical structure of the circulation (Figure 21). Time averaged vertical profiles of water velocity were collected at fixed points within the channel to provide information on vertical flow structure over different tidal stages. Figure 22 shows cross sections of flow structure normal to each transect line during circuit 1, which represented the transition from late flood to early ebb. Flow at each line is generally weak, with significant lateral variability in flow magnitude and direction. The majority of line 4 shows water still moving northward, with maximum velocities on the eastern side of the transect. Interestingly the eastern side of line 2, at the outfall, shows northward flowing water. Figure 23 shows velocity contour fields for circuit 2, during ebb conditions for lines 3 and 4. Water is moving uniformly southward at 10-20 cm/s. Lines 1 and 2 were already to shallow at this point to sample outside of the channel during underway surveys. During circuit 3 (Figure 24), water is ebbing more rapidly through cross sections along lines 3 and 4. Here velocities reach 50 cm/s. Comparisons between transects show a pattern in maximum flow cores that are characteristic of a meandering river. At line 3 maximum outflows occur on the eastern side of the line, but farther south on line 4 the maximum outflow is on the western side of the river. Circuits 4 and 5 (Figure 25) capture flooding conditions on lines 3 and 4. In figure 25B line 3 exhibits weak two layer flow, which is opposite from typical estuarine flow. Here surface water is flooding while deeper channel water is weakly ebbing. A similar flow structure is recorded during circuit 5 on line 4 (Figure 25A), where surface water moves northward, flooding at speeds in excess of 50 cm/s, while deeper water moves out of the river. This type of flow pattern is characteristic of reverse estuaries, where a source of high density water exists at the head of the system. This pattern is opposite from that observed during the summer survey in the Seekonk.

Seekonk River Currents: Vertical Structure in the Channel

Figures 26-30 show time averaged vertical profiles of flow magnitude and direction within the channel for different transects. These composite figures are constructed with information from the same transect number, but from different time periods. On the northernmost line 1, water moves southward over the course of the entire survey (Figure 26), with the exception of circuit 1, where deep water moves southward while surface water is stagnant and variable.

Data for line 2, located at the Bucklin Pt. outfall are summarized in Figures 27 and 28 for stations within and outside of the channel, respectively. Figure 27 highlights this patterns of deep southerly flow over the majority of the cycle. Circuits 2 and 3 (Figures 27b and C) show the whole water column ebbing, while during circuit 1 the surface water is slowly moving northward, while deep water ebbs. During circuit 4 (Figure 27D), water in the channel has turned to a northerly flow. During circuits 1 and 2 time series stations were also occupied on line 2 directly south of the outfall and on the western side of line 2. On the outfall side, the flow is 5-10 cm/s in a southerly direction (Figures 28A, C) . On the west side, flow is also in a southerly direction with magnitudes reaching 15 cm/s at the surface and decaying towards 0 cm/s towards the bottom (1.5 m).

Time series data from line 3 show more variation in flow between circuits (Figure 29). During circuit 1 flow is weakly flooding. Ebb conditions are recorded during circuits 2 and 3, with maximum outflow velocities (35 cm/s) occurring in the surface waters during circuit 3. Maximum ebb velocities are seen at ~10:30am, or roughly 30 minutes before low water as recorded at the PORTS Providence River station. While it is difficult to say without more detailed data coverage in time, this result suggests the that maximum ebb velocities occur close to low water, which means the Seekonk is behaving as a progressive wave in terms of tidal flow. By circuit 4 (Figure 29D), the surface water on line 3 has started flooding, while the deep water is stagnant, again suggesting the deep water is net outward over a tidal cycle.

Line 4 was sampled at five distinct periods of the tidal cycle. Figure 30 summarizes time series data, or averaged velocity profiles for line 4. In many respects, the patterns are similar to line 3. Circuits 2 and 3 show ebbing currents, with the maximum outflows (35 cm/s) seen on circuit 3. Circuit 1 shows weakly flooding velocities and the last profile, circuit 5, shows the upper 4 meters of the water column flooding at 10-20 cm/s. Her also, the deep water is moving distinctly from the rest of the water column with a weak east-southeasterly motion.

5.0 Conclusions

Providence River: As with survey 1 during the summer, the combination of flow and CTD information suggests that line 3 at Sabin Pt. behaves in a manner consistent with classical Coriolis influenced estuarine flow. Maximum inflows/outflows are seen in the channel and a net outflow, is persistent on the western side of the line. Net inflows are recorded on the eastern side of this line. Line 2 shows a similar outflow pattern to that recorded during the summer survey. A persistent outflow core is recorded that is centered on the western side of the channel. The outflow seems to extend further laterally within the surface waters than in summer. On circuit 2, during ebb conditions, the water on the far western side of the shoals of lines 2 and 2.5 moves northward and then eastward, while the water over the remainder of the shoals moves southward. It is interesting to note that water on the western shoals of line 2 is distinctly more saline than the remainder of the line, particularly the channel water. Also, the lines 1 and 4 showed the largest degrees of lateral variability in salinity, with higher salinity water on the eastern side. The temperatures were nearly uniform across the transects. A low salinity plug is seen on the west side of the Gaspee Pt. line. The low density plug seen on the Sabin Pt. line during the summer is far less apparent in this survey. In general the sharp lateral fronts in surface water properties recorded during the summer are not apparent in this data set. Except for during maximum flood conditions, a strong 2 layer estuarine flow is recorded within the channel waters, with shallow surface outflows and deep water return, or northerly flow.

<u>Seekonk River:</u> ADCP measurements within the Seekonk River show lower degrees of lateral and vertical structure in the flow from the summer surveys. An interesting feature of the data is that the Seekonk seems to be behaving completely opposite from the way it did in the summer, where a classical 2 layer estuarine circulation was noted, with surface water moving out and deep water moving in. Here the deeper channel water appears to be moving outward in a net sense, while surface water may be net inward. This pattern is more typical of reverse style estuaries, like the Rio Chone in Ecuador, where high density water is produced at the head, typically due to evaporation to produce highly saline water or the input of cold water. Where we could measure it, water just below the outfall was moving southward at slightly lower rates than ebb flows in the channel.

6.0 References.

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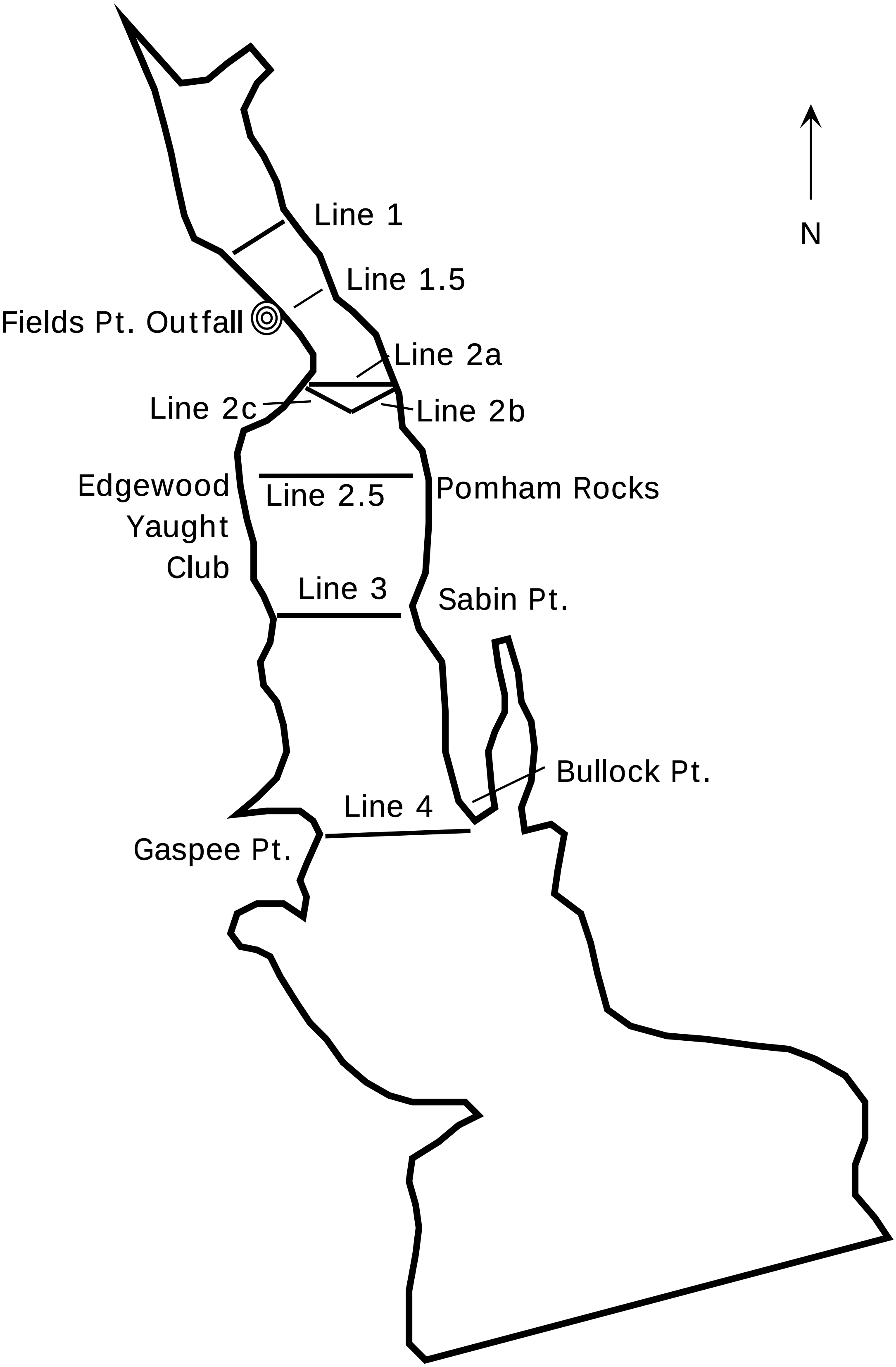


Figure 1: Map of Providence River showing locations of transect lines. Line 2.5 represents a new transect from survey 1, extending from Edgewood Yacht Club to the East Providence sewage outfall at Pomham Rocks.

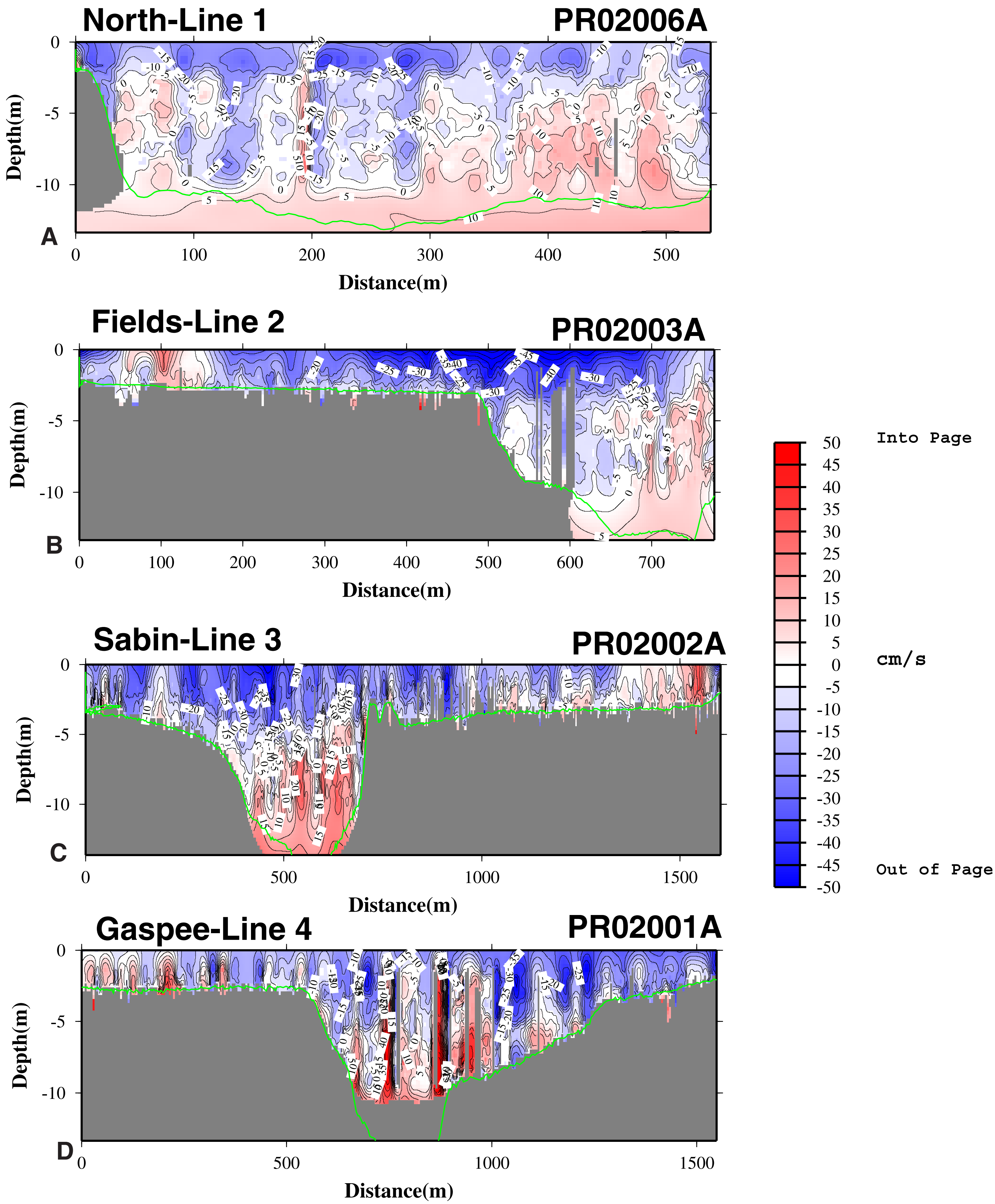


Figure 2. Circuit 1 contours of velocity projected normal to transect line. Tidal stage is early ebb conditions. The view is looking north, with east(west) on the right(left). The green line marks the bottom, or the limit of good data.

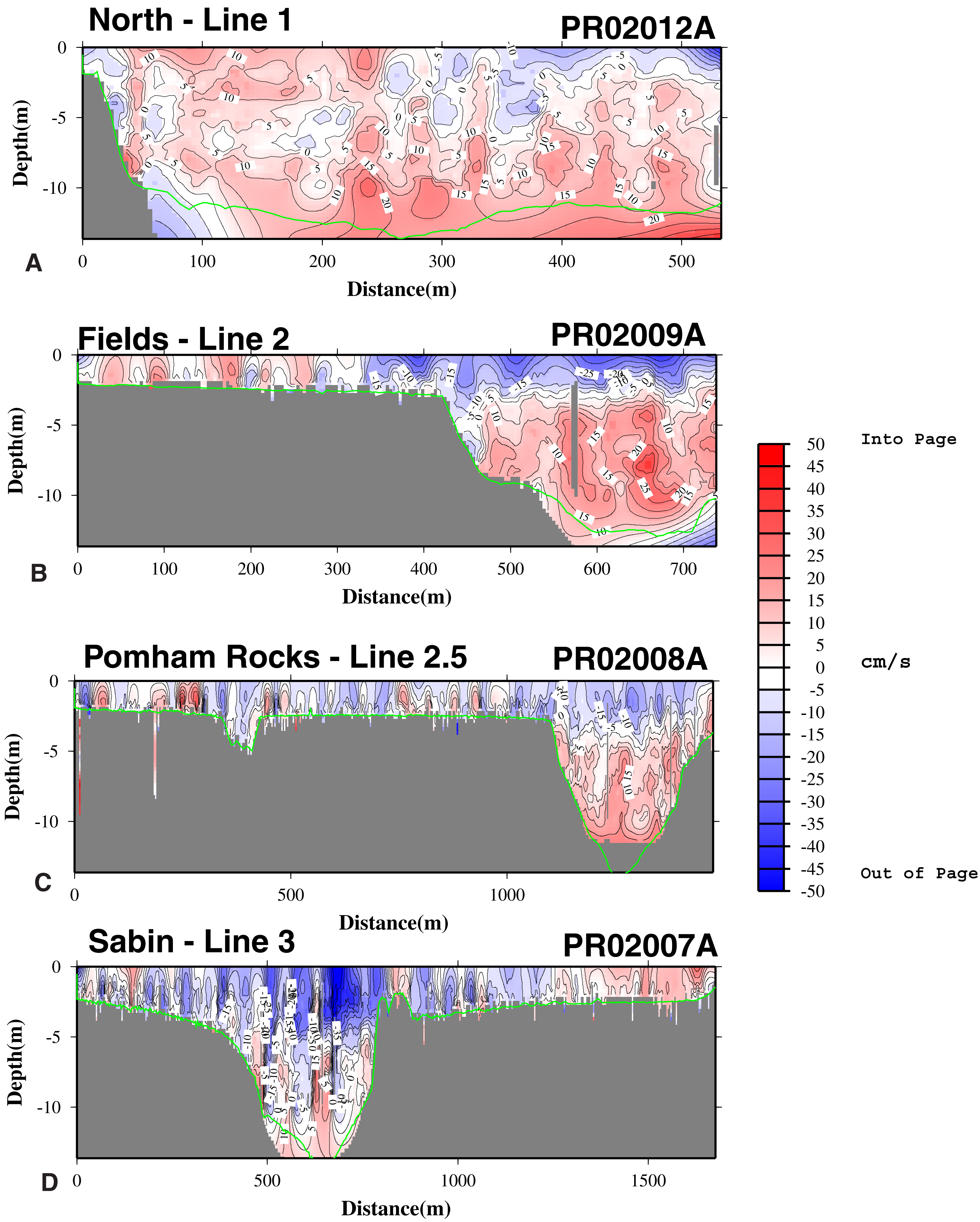


Figure 3: Circuit 2 (late ebb) velocity contours, values projected normal to transect line. View is north, west is on left, east is on right. The green line marks the bottom, or the limit of good data.

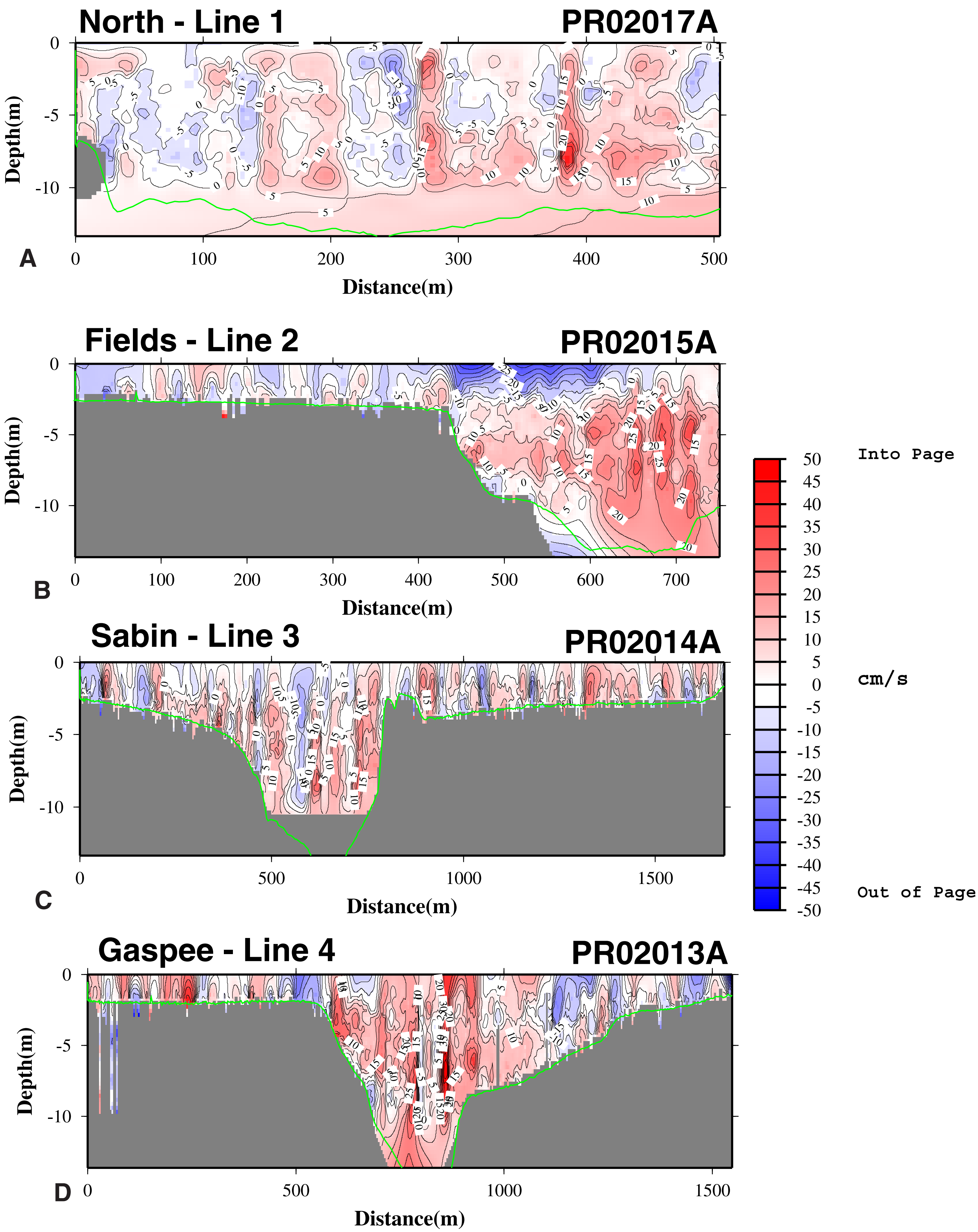


Figure 4: Circuit 3 (early flood) velocity contours where values are projected normal to transect line. West is on the left, east is on the right, view is looking north. Red colors are flooding waters, or into the page, blue colors are ebbing waters, or flow out of the page. The green line marks the depth limit of reliable data.

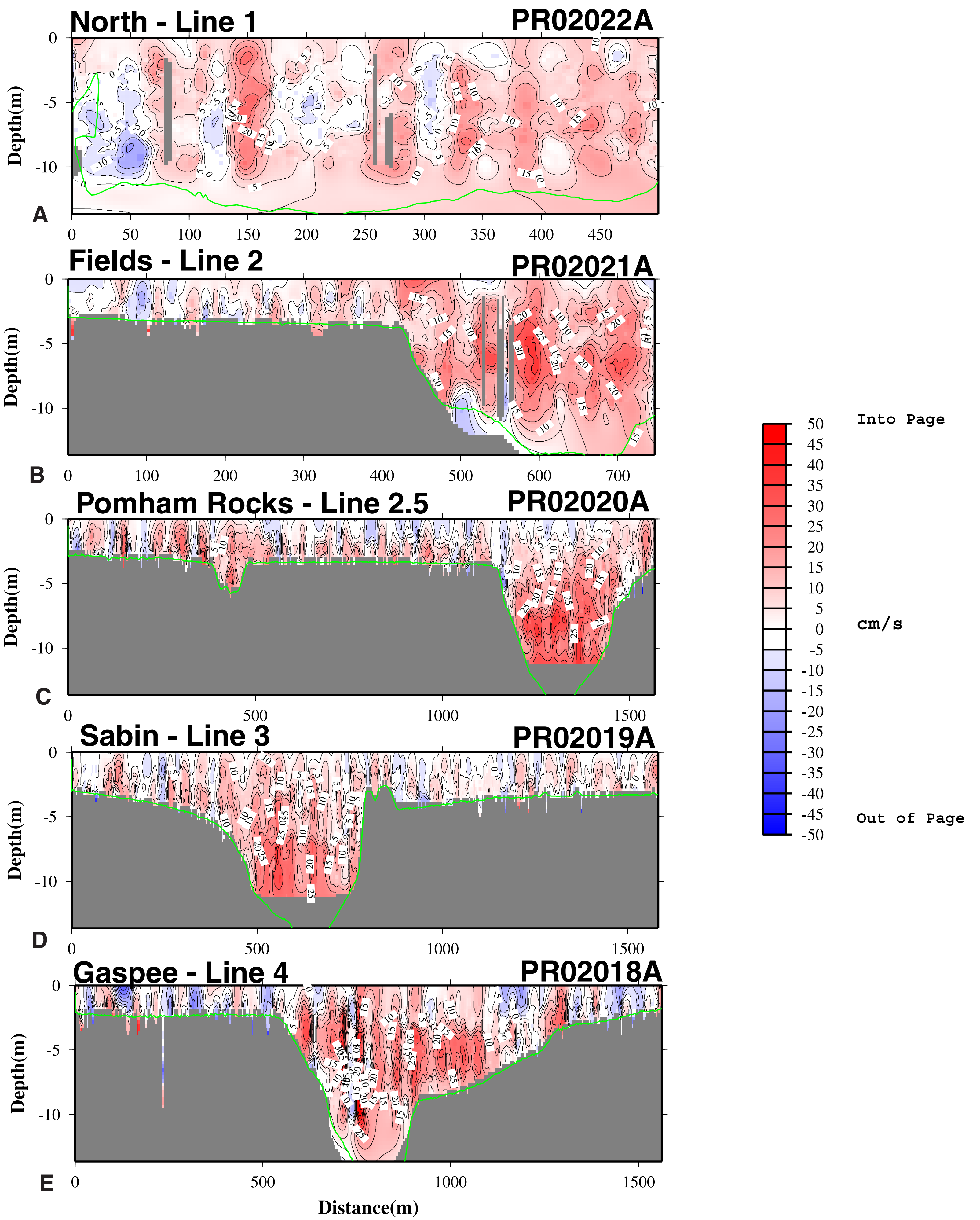


Figure 5: Circuit 4 (late flood) velocity contours. Velocity vectors are projected normal to the transect line. West is on the left, east is on the right. Red colors are flooding waters, or into the page, blue colors are ebbing waters, or flow out of the page. The green line marks the depth limit of reliable data.

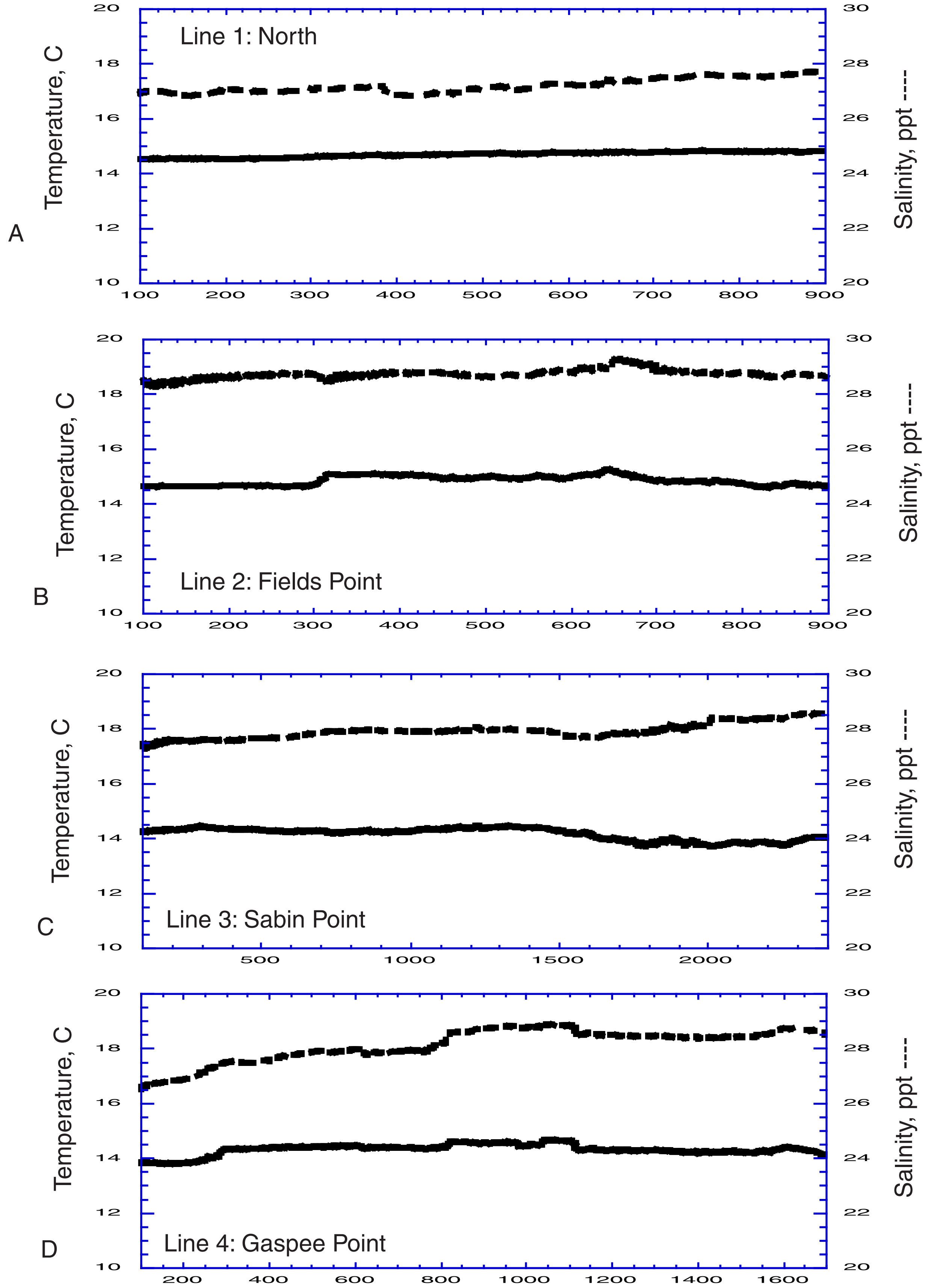


Figure 6: Plots of temperature and salinity measured at the surface versus distance across the estuary for Circuit 1 (early ebb). Orientation is east on the right, west on the left.

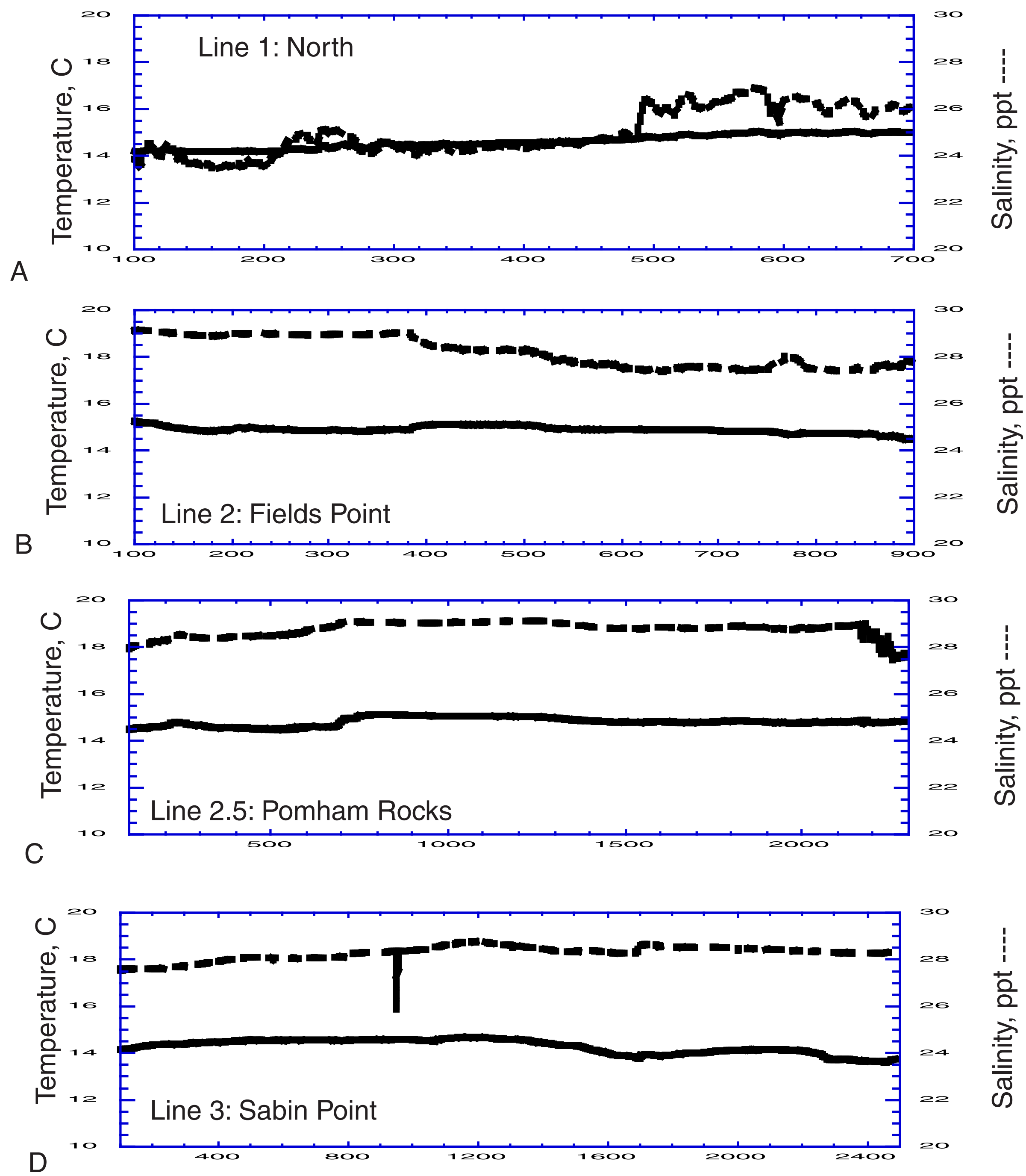


Figure 7: Plots of temperature and salinity measured at the surface versus distance across the estuary for Circuit 2 (late ebb). Orientation is east on the right, west on the left.

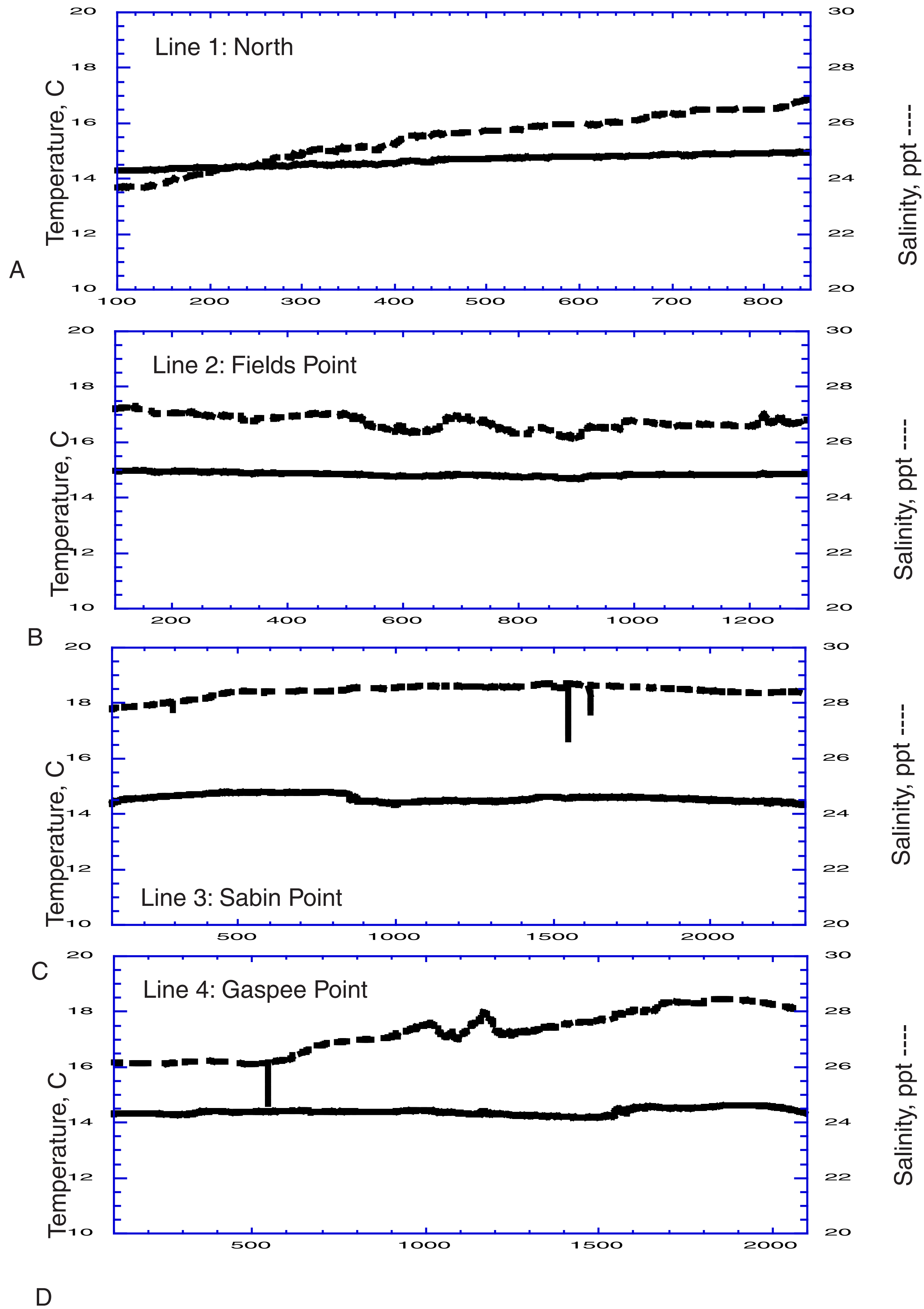


Figure 8: Plots of temperature and salinity measured at the surface versus distance across the estuary for Circuit 3 (early flood). Orientation is east on the right, west on the left.

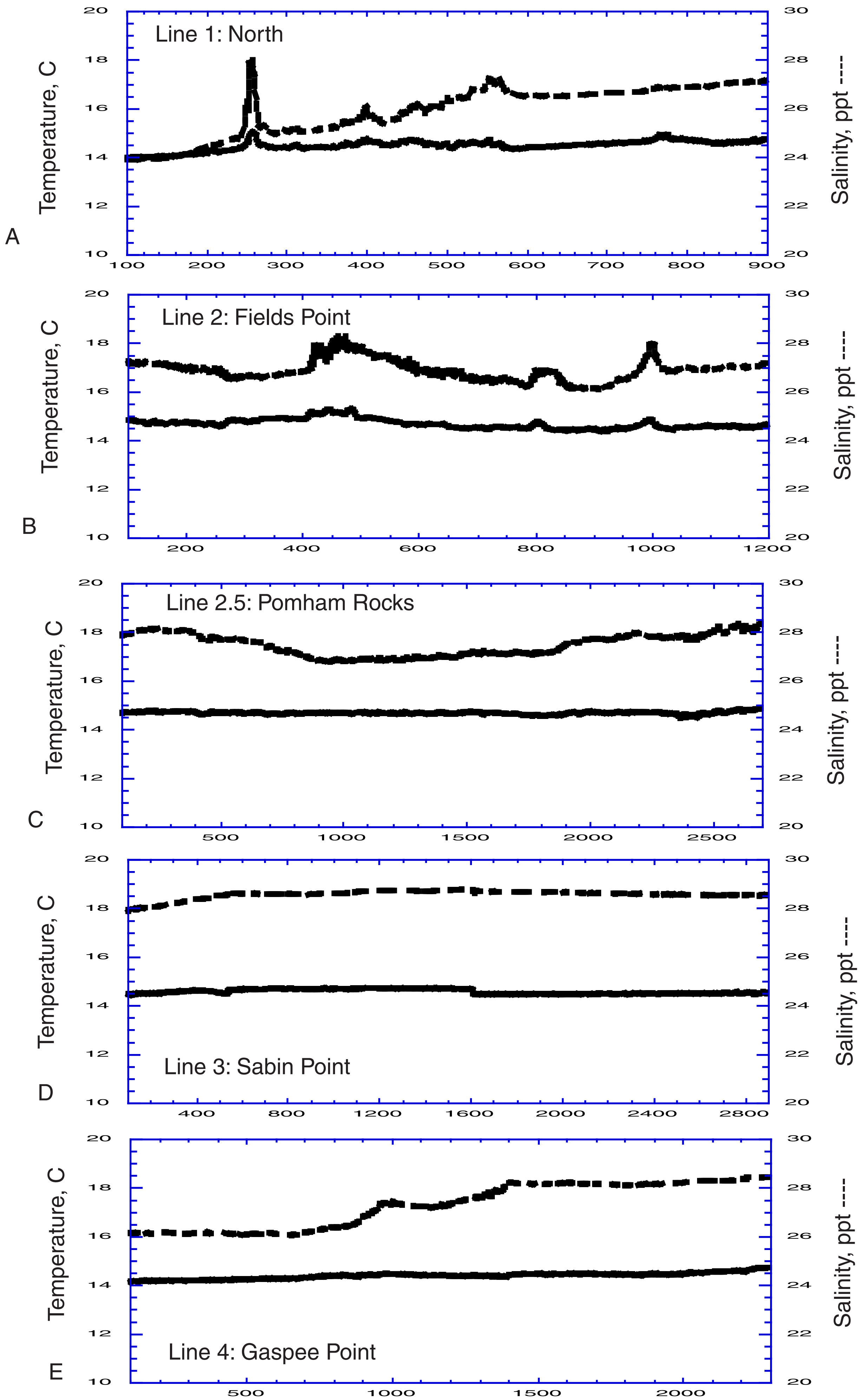


Figure 9: Plots of temperature and salinity measured at the surface versus distance across the estuary for Circuit 4 (late flood). Orientation is east on the right, west on the left.

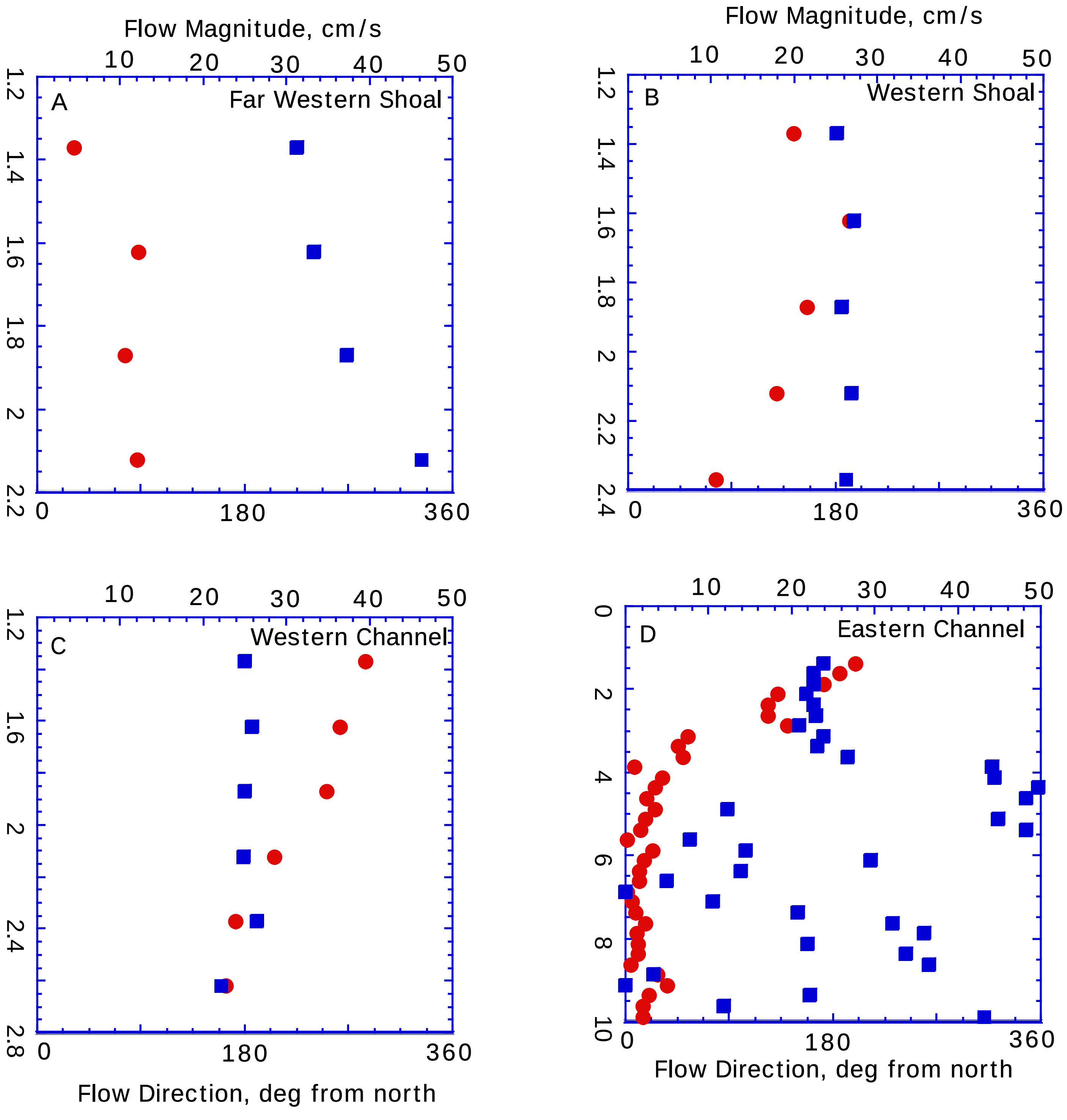


Figure 10: Laterally averaged velocity profiles for subsections of transect line 2, Fields Pt. Data are velocity magnitude (CIRCLES) and direction (SQUARES). The subsections include shallow regions to the west of the channel, and two subsections of the channel. The tidal stage is CIRCUIT 1, or ebb conditions.

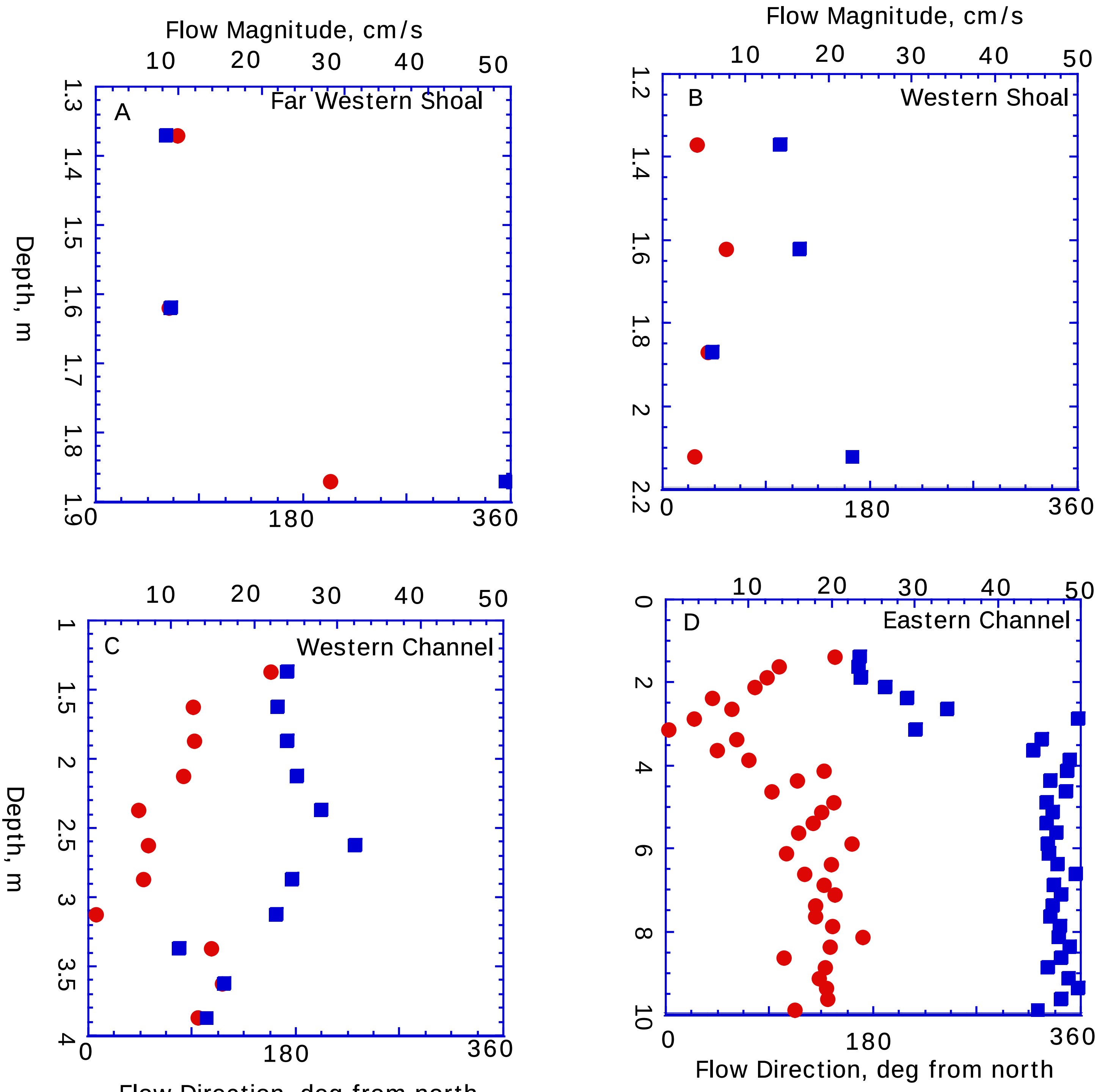


Figure 11: Laterally averaged velocity profiles for subsections of transect line 2, Fields Pt. Data are velocity magnitude (CIRCLES) and direction (SQUARES). The subsections include shallow regions to the west of the channel, and two subsections of the channel. The tidal stage is CIRCUIT 2, or late ebb conditions.

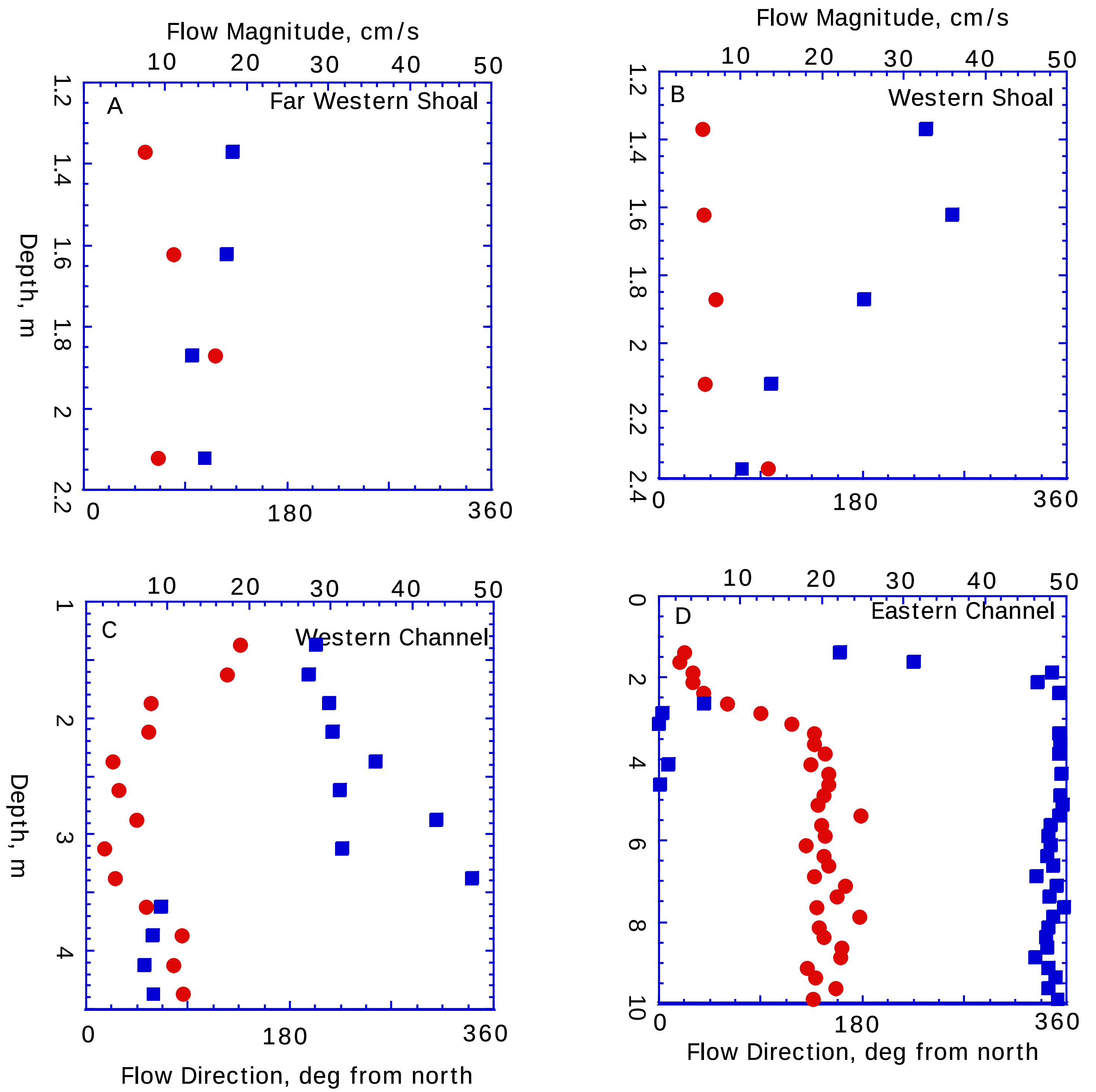


Figure 12: Laterally averaged velocity profiles for subsections of transect line 2, Fields Pt. Data are velocity magnitude (CIRCLES) and direction (SQUARES). The subsections include shallow regions to the west of the channel, and two subsections of the channel. The tidal stage is CIRCUIT 3, or early flood conditions.

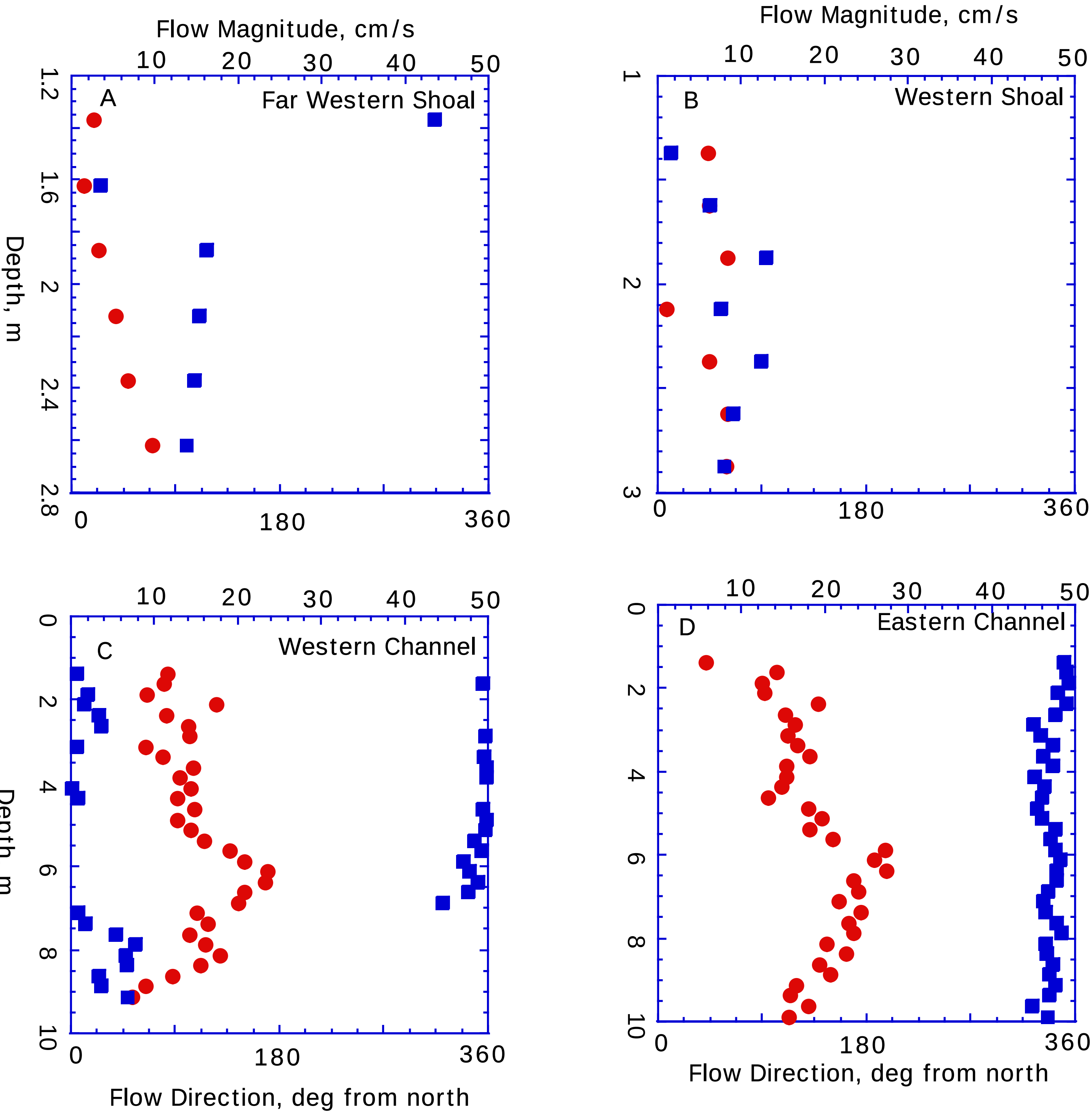


Figure 13: Laterally averaged velocity profiles for subsections of transect line 2, Fields Pt. Data are velocity magnitude (CIRCLES) and direction (SQUARES). The subsections include shallow regions to the west of the channel, and two subsections of the channel. The tidal stage is CIRCUIT 4, or late flood conditions.

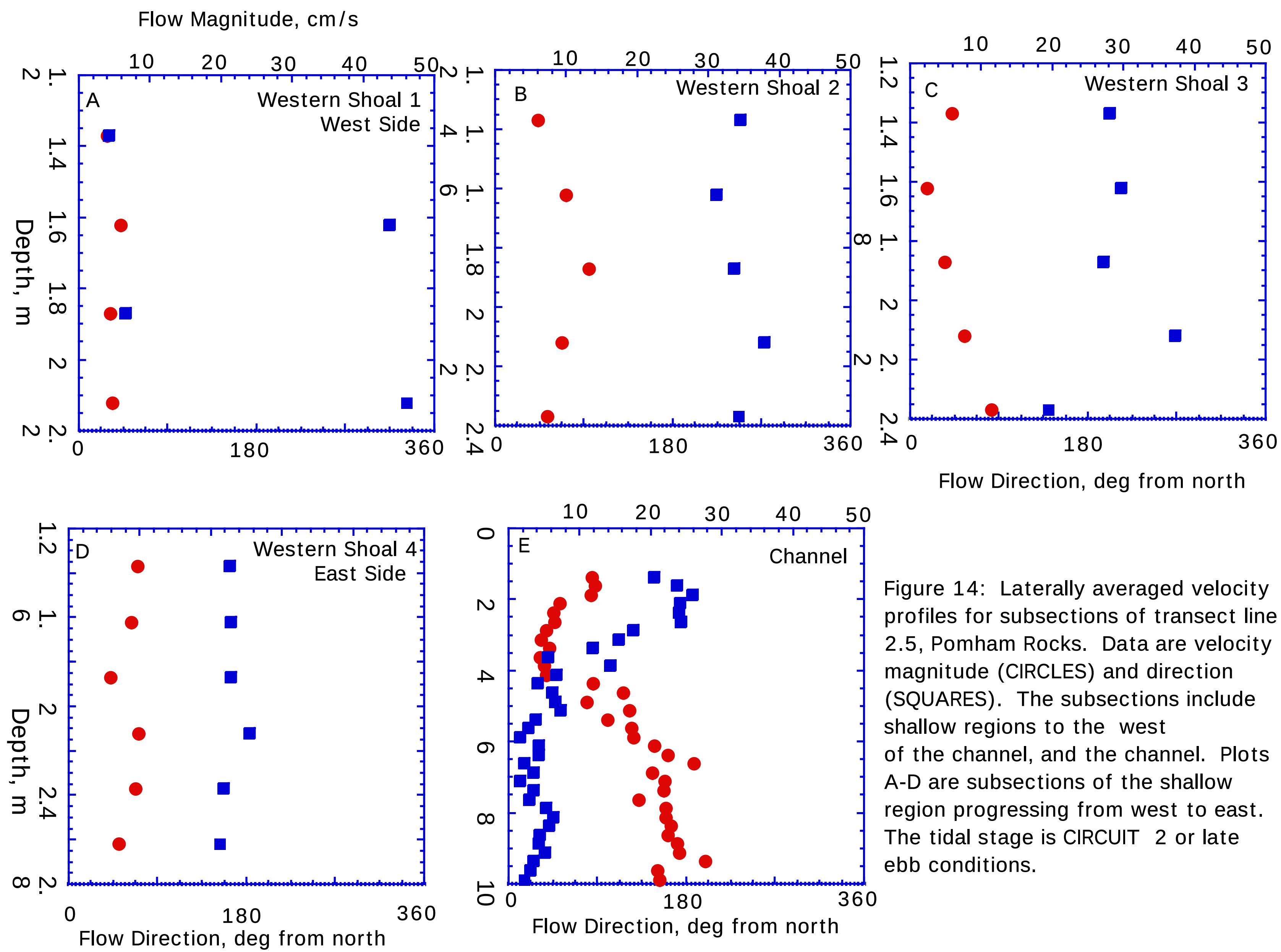


Figure 14: Laterally averaged velocity profiles for subsections of transect line 2.5, Pomham Rocks. Data are velocity magnitude (CIRCLES) and direction (SQUARES). The subsections include shallow regions to the west of the channel, and the channel. Plots A-D are subsections of the shallow region progressing from west to east. The tidal stage is CIRCUIT 2 or late ebb conditions.

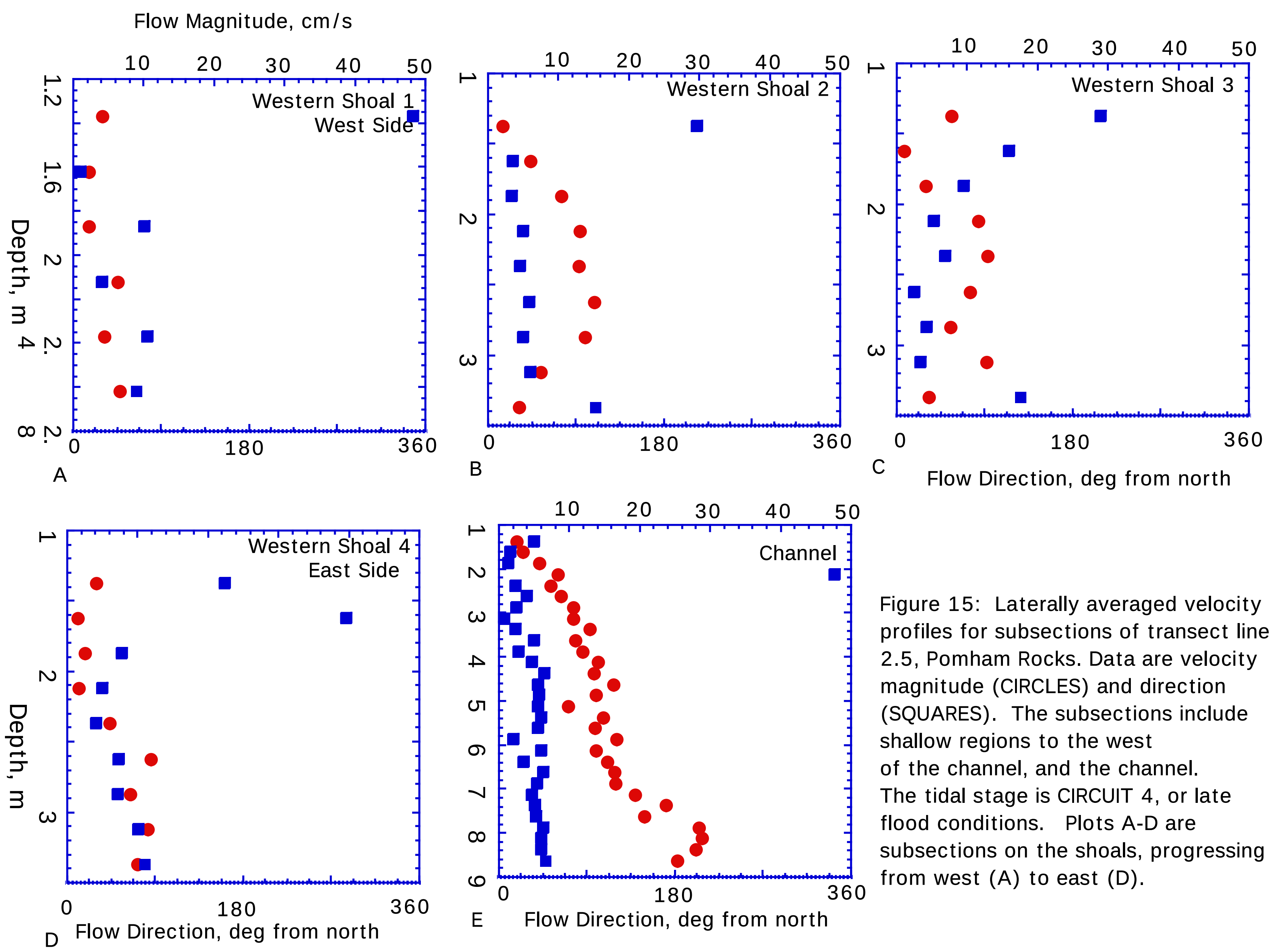


Figure 15: Laterally averaged velocity profiles for subsections of transect line 2.5, Pomham Rocks. Data are velocity magnitude (CIRCLES) and direction (SQUARES). The subsections include shallow regions to the west of the channel, and the channel. The tidal stage is CIRCUIT 4, or late flood conditions. Plots A-D are subsections on the shoals, progressing from west (A) to east (D).

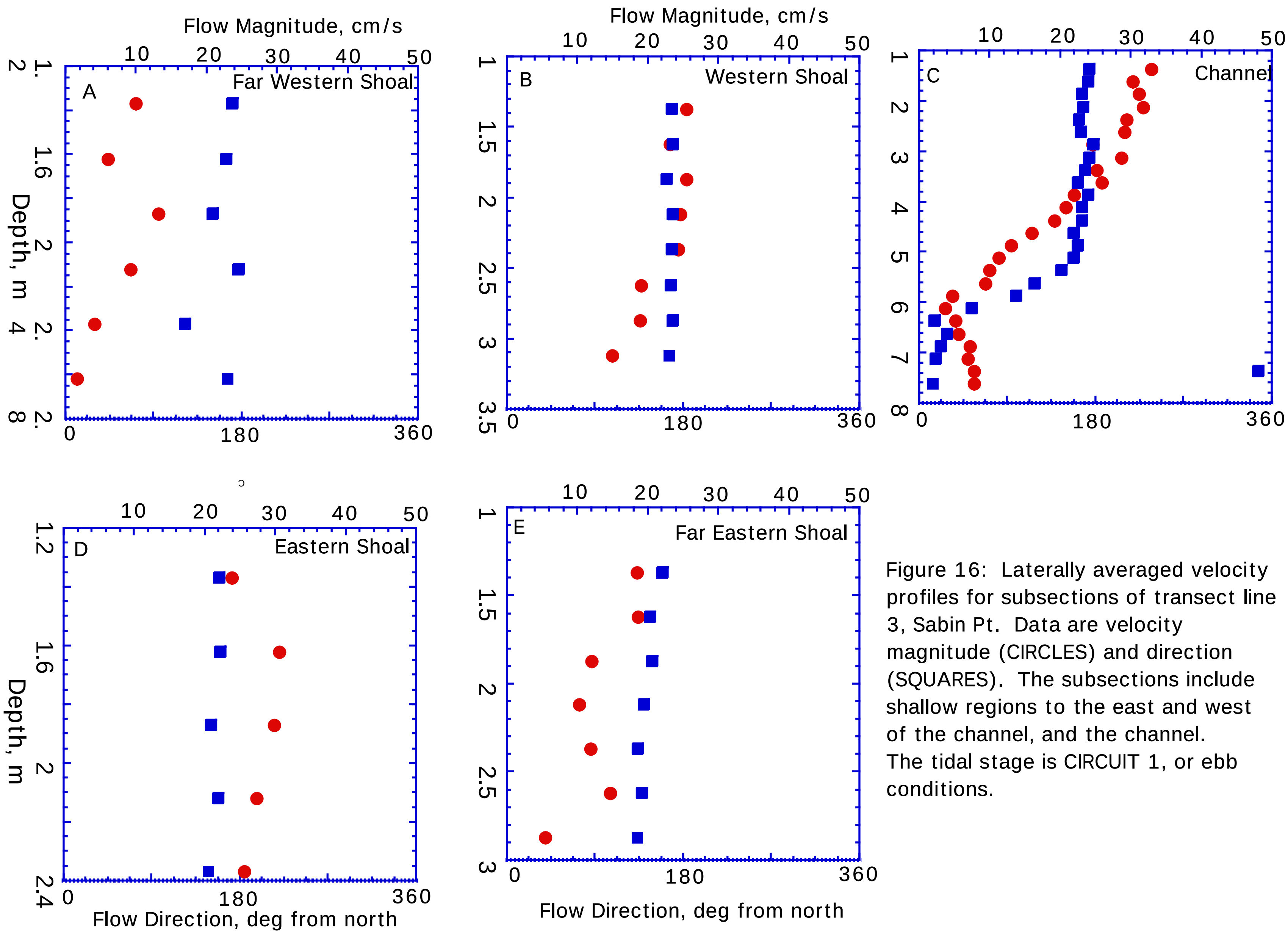


Figure 16: Laterally averaged velocity profiles for subsections of transect line 3, Sabin Pt. Data are velocity magnitude (CIRCLES) and direction (SQUARES). The subsections include shallow regions to the east and west of the channel, and the channel. The tidal stage is CIRCUIT 1, or ebb conditions.

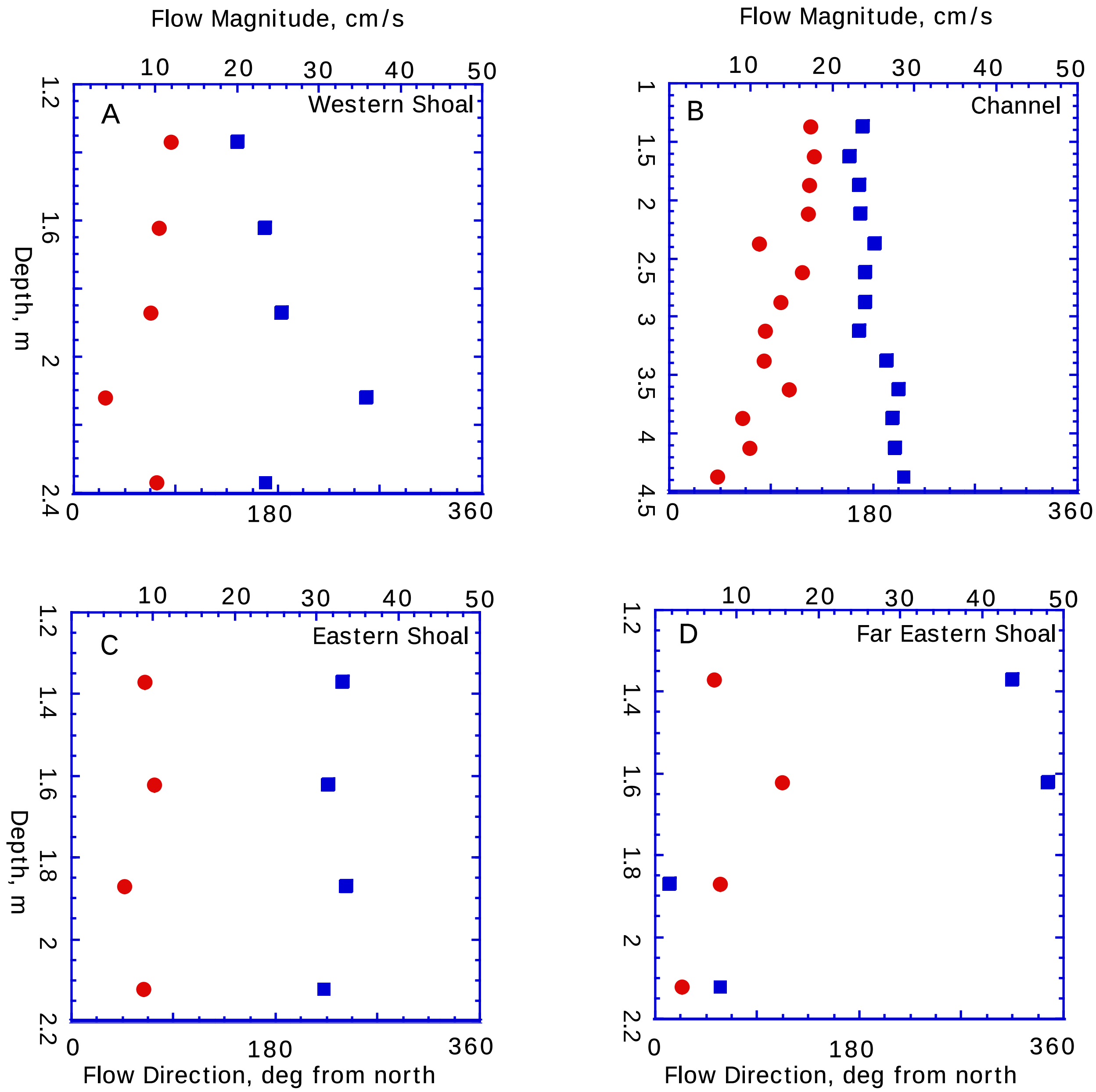


Figure 17: Laterally averaged velocity profiles for subsections of transect line 3, Sabin Pt. Data are velocity magnitude (CIRCLES) and direction (SQUARES). The subsections include shallow regions to the east and west of the channel, and the channel. The tidal stage is CIRCUIT 2, or late ebb conditions.

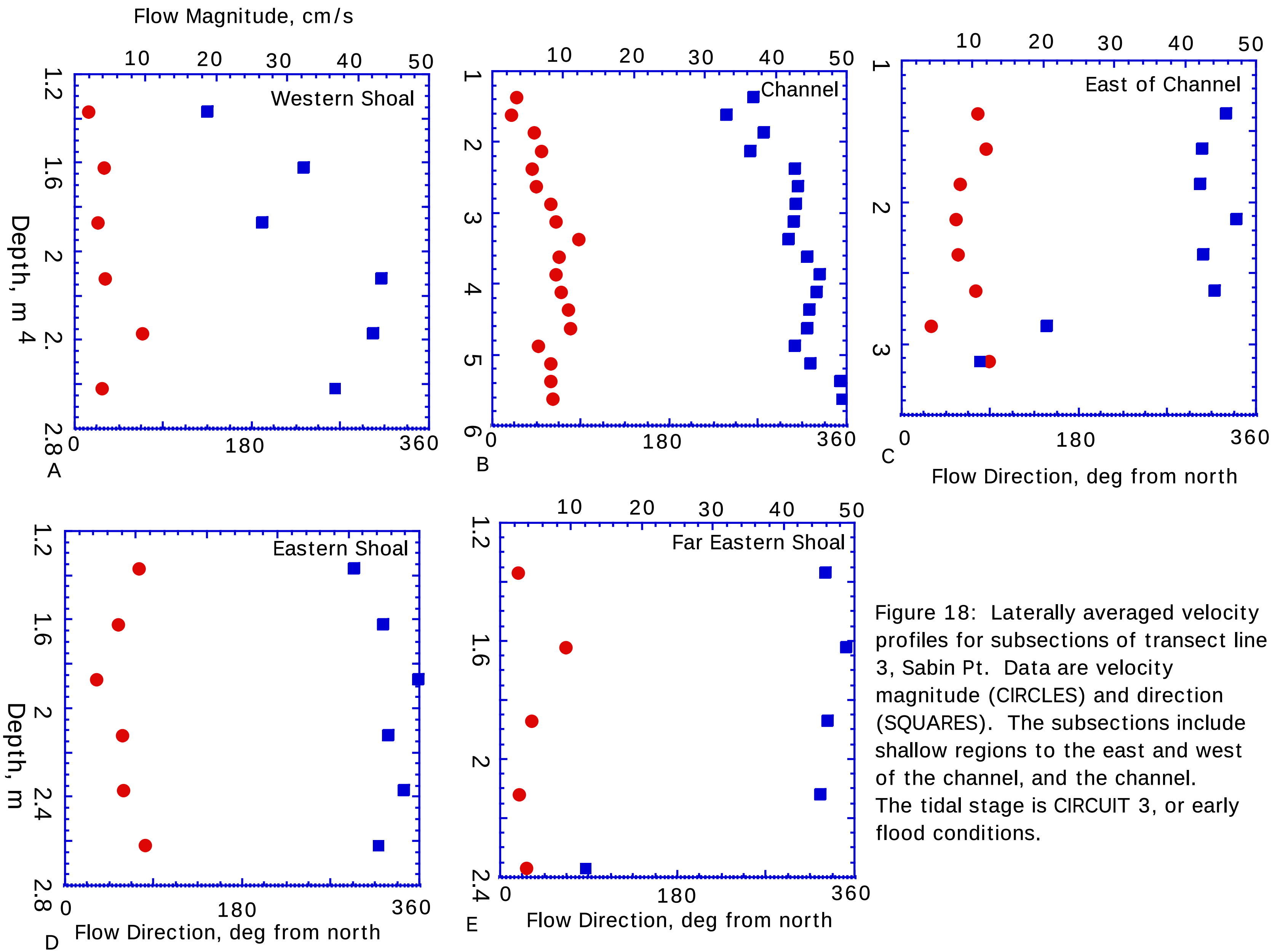


Figure 18: Laterally averaged velocity profiles for subsections of transect line 3, Sabin Pt. Data are velocity magnitude (CIRCLES) and direction (SQUARES). The subsections include shallow regions to the east and west of the channel, and the channel.
The tidal stage is CIRCUIT 3, or early flood conditions.

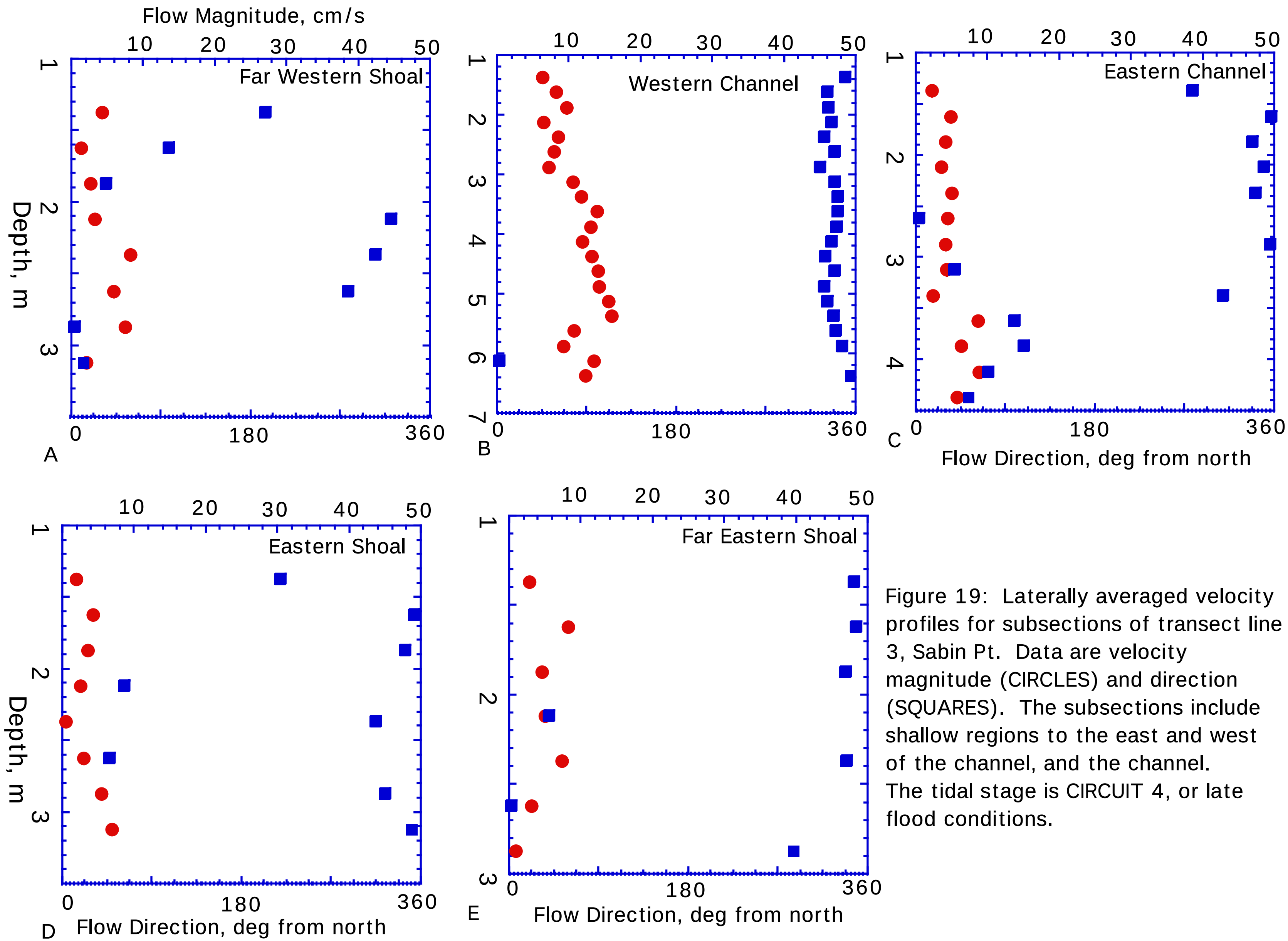


Figure 19: Laterally averaged velocity profiles for subsections of transect line 3, Sabin Pt. Data are velocity magnitude (CIRCLES) and direction (SQUARES). The subsections include shallow regions to the east and west of the channel, and the channel. The tidal stage is CIRCUIT 4, or late flood conditions.

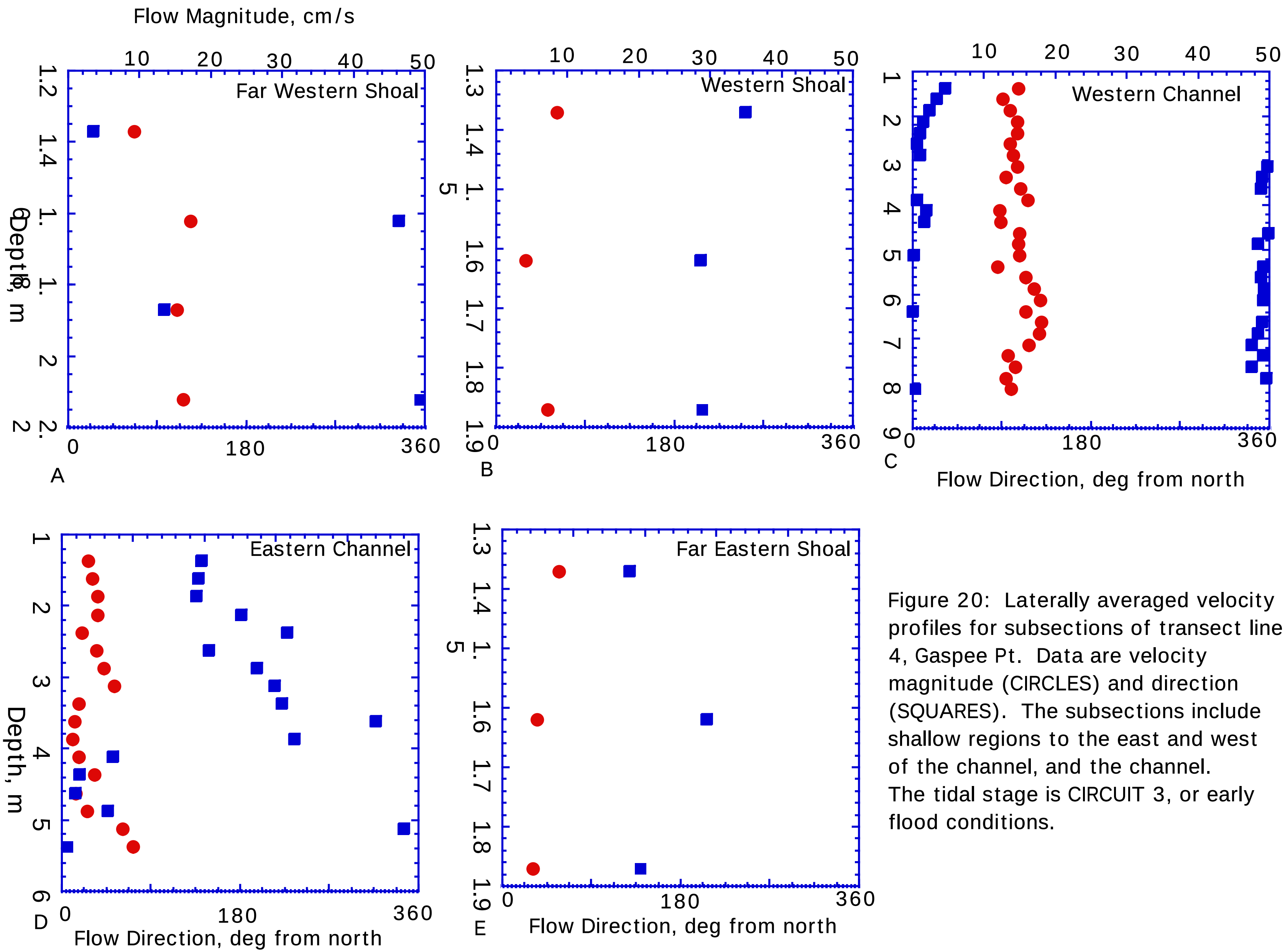


Figure 20: Laterally averaged velocity profiles for subsections of transect line 4, Gaspee Pt. Data are velocity magnitude (CIRCLES) and direction (SQUARES). The subsections include shallow regions to the east and west of the channel, and the channel. The tidal stage is CIRCUIT 3, or early flood conditions.

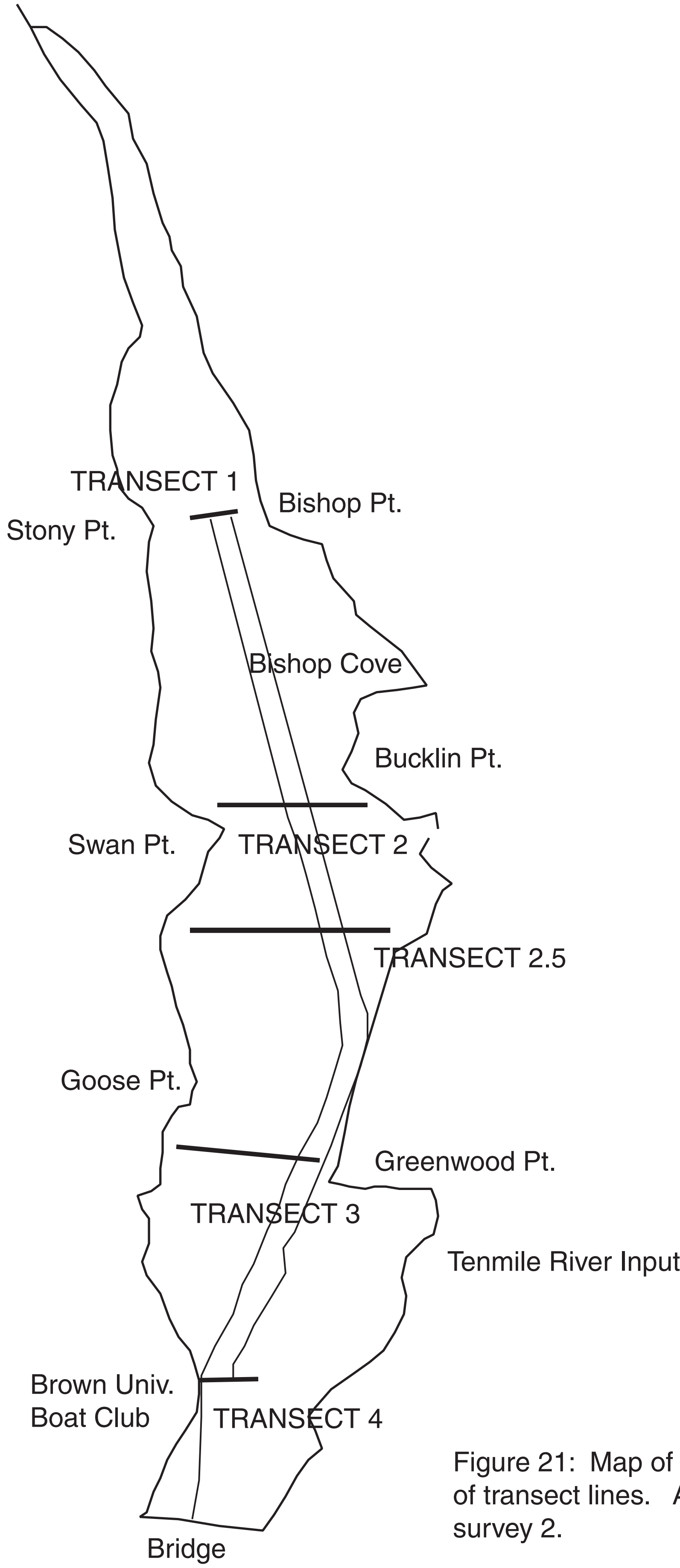


Figure 21: Map of Seekonk River with locations of transect lines. A new line, 2.5 is added for survey 2.

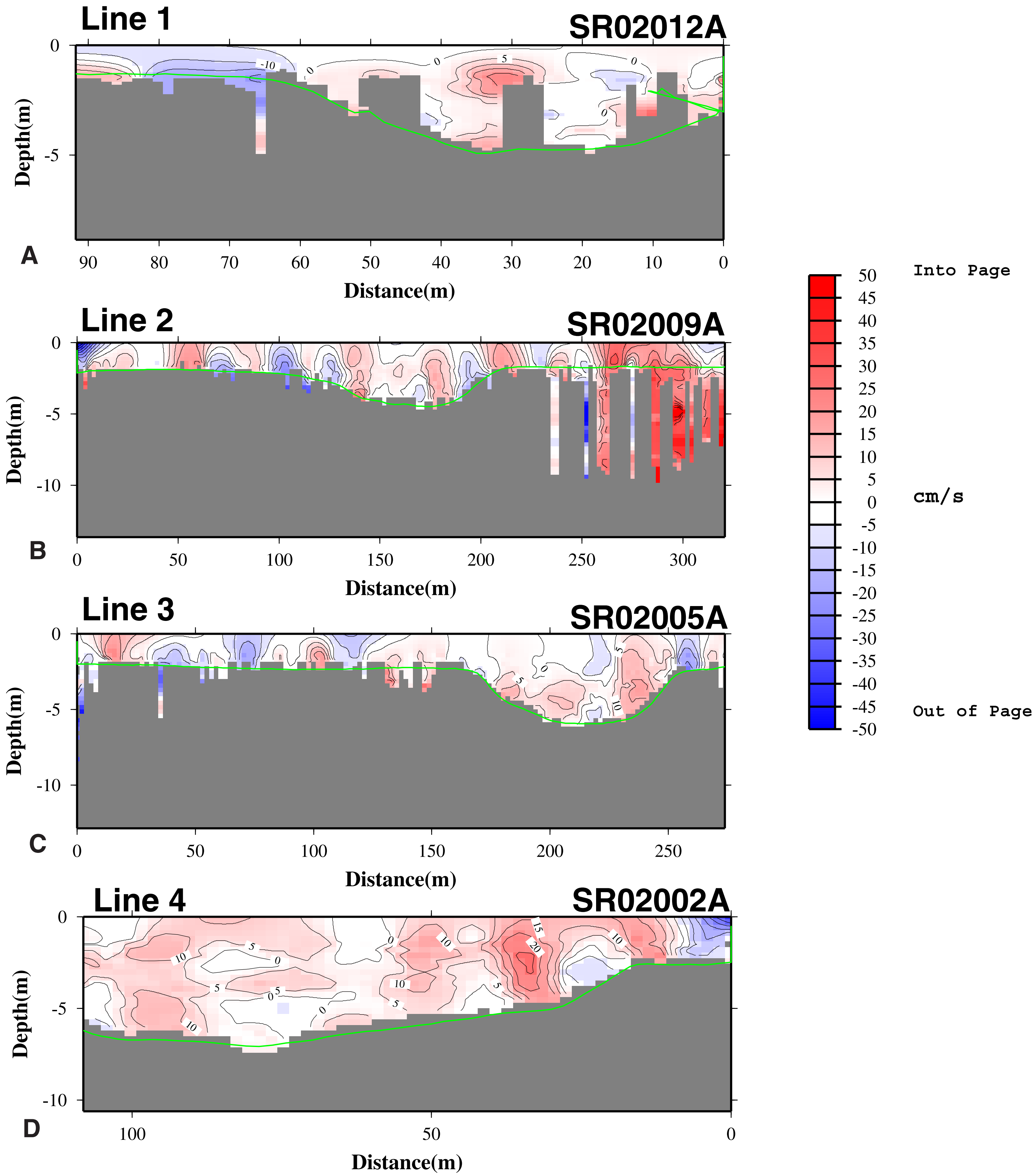


Figure 22 : Circuit 1 (early ebb) velocity contours for Seekonk River Survey. Data are projected normal to transect lines. Lines are oriented roughly west(left) to east(right), with the view looking north. Red colors are flooding waters, or flow into the page, and blues are ebbing water, or flow out of the page. The green line marks the depth limit of reliable data.

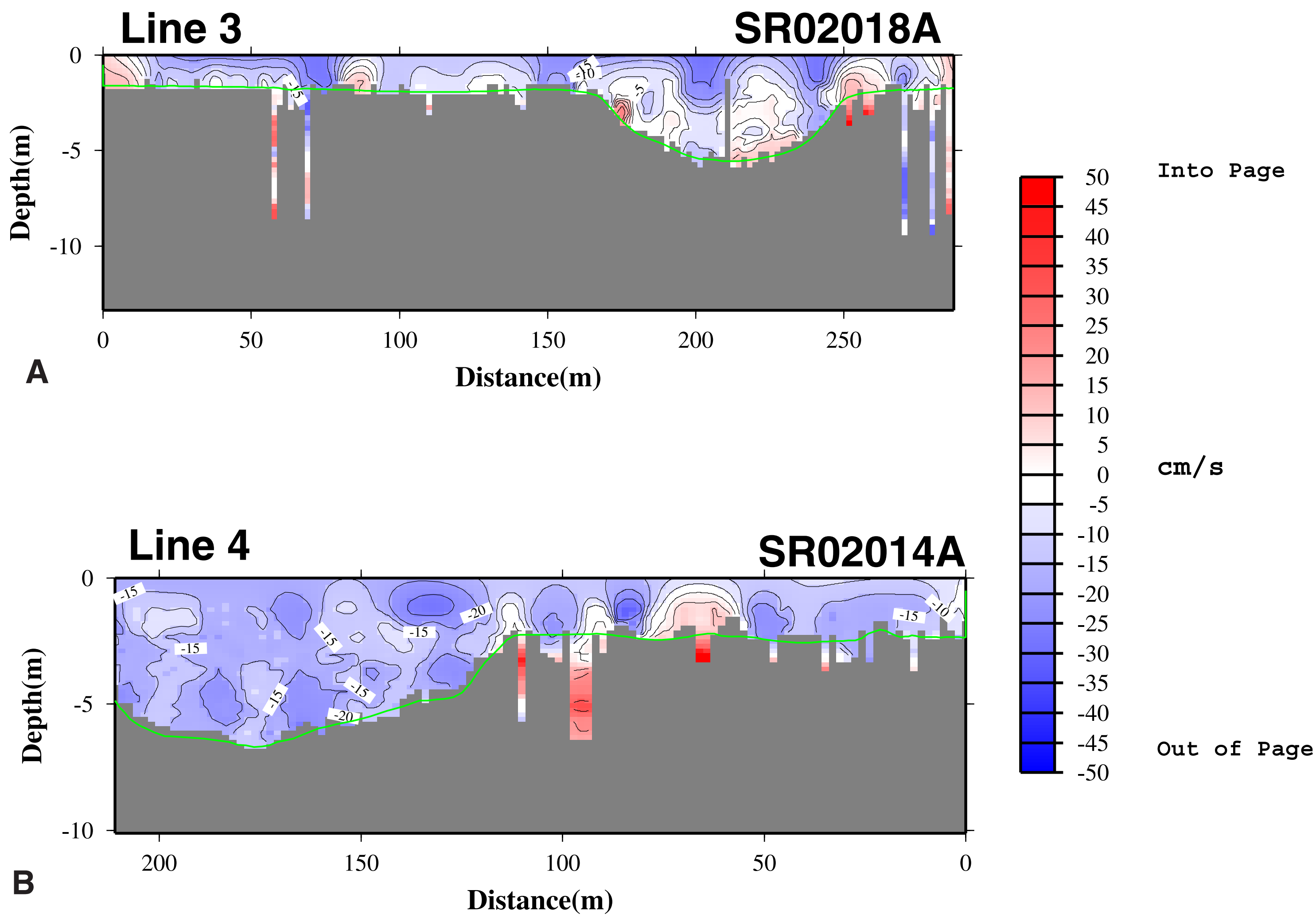


Figure 23 : Circuit 2 (mid-ebb) velocity contours for Seekonk River Survey. Data are projected normal to transect lines. Lines are oriented roughly west(left) to east(right), with the view looking north. Red colors are flooding waters, or flow into the page, and blues are ebbing water, or flow out of the page. The green line marks the depth limit of reliable data.

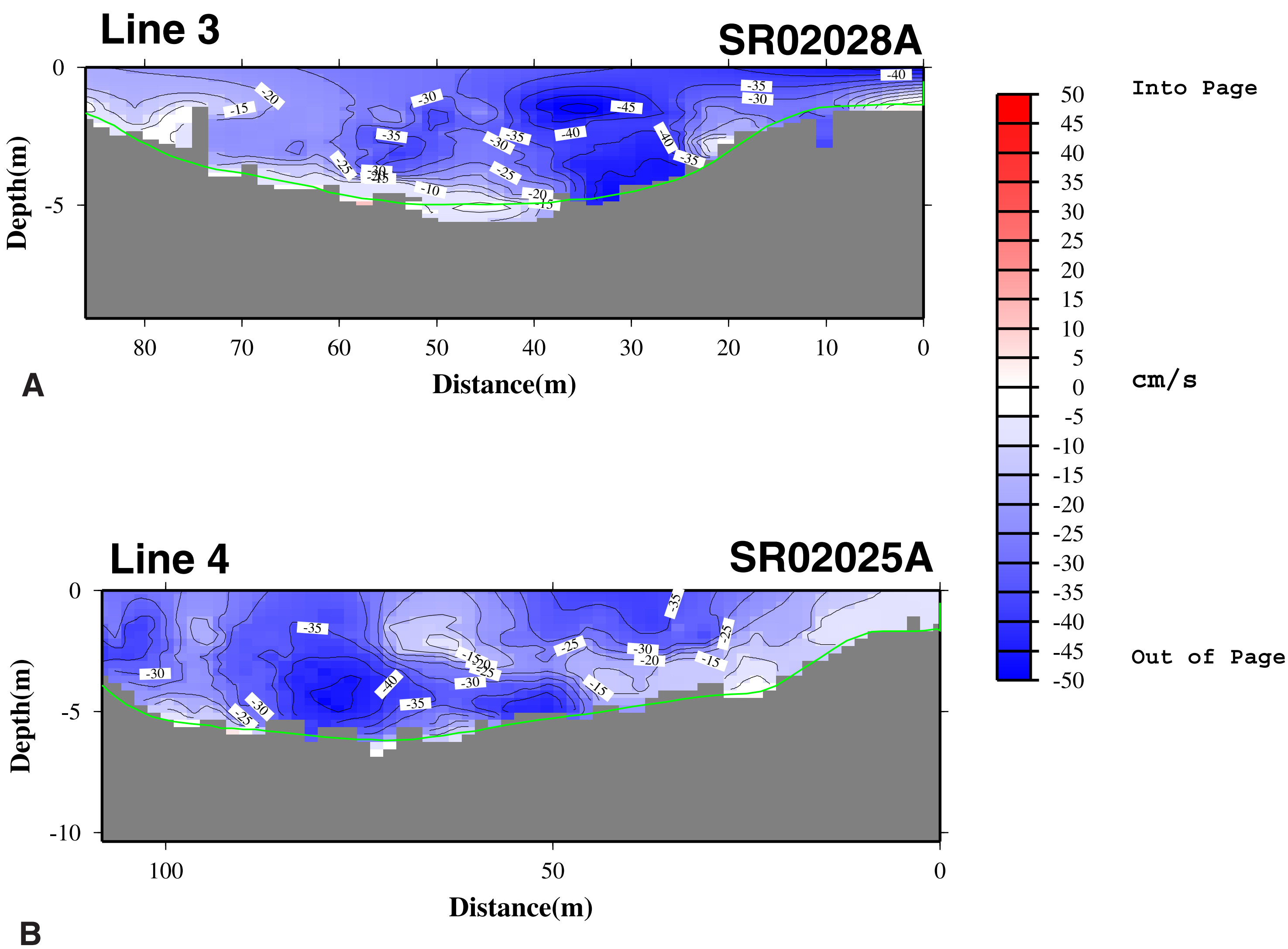


Figure 24 : Circuit 3 (late ebb) velocity contours for Seekonk River Survey. Data are projected normal to transect lines. Lines are oriented roughly west(left) to east(right), with the view looking north. Red colors are flooding waters, or flow into the page, and blues are ebbing water, or flow out of the page. The green line marks the depth limit of reliable data.

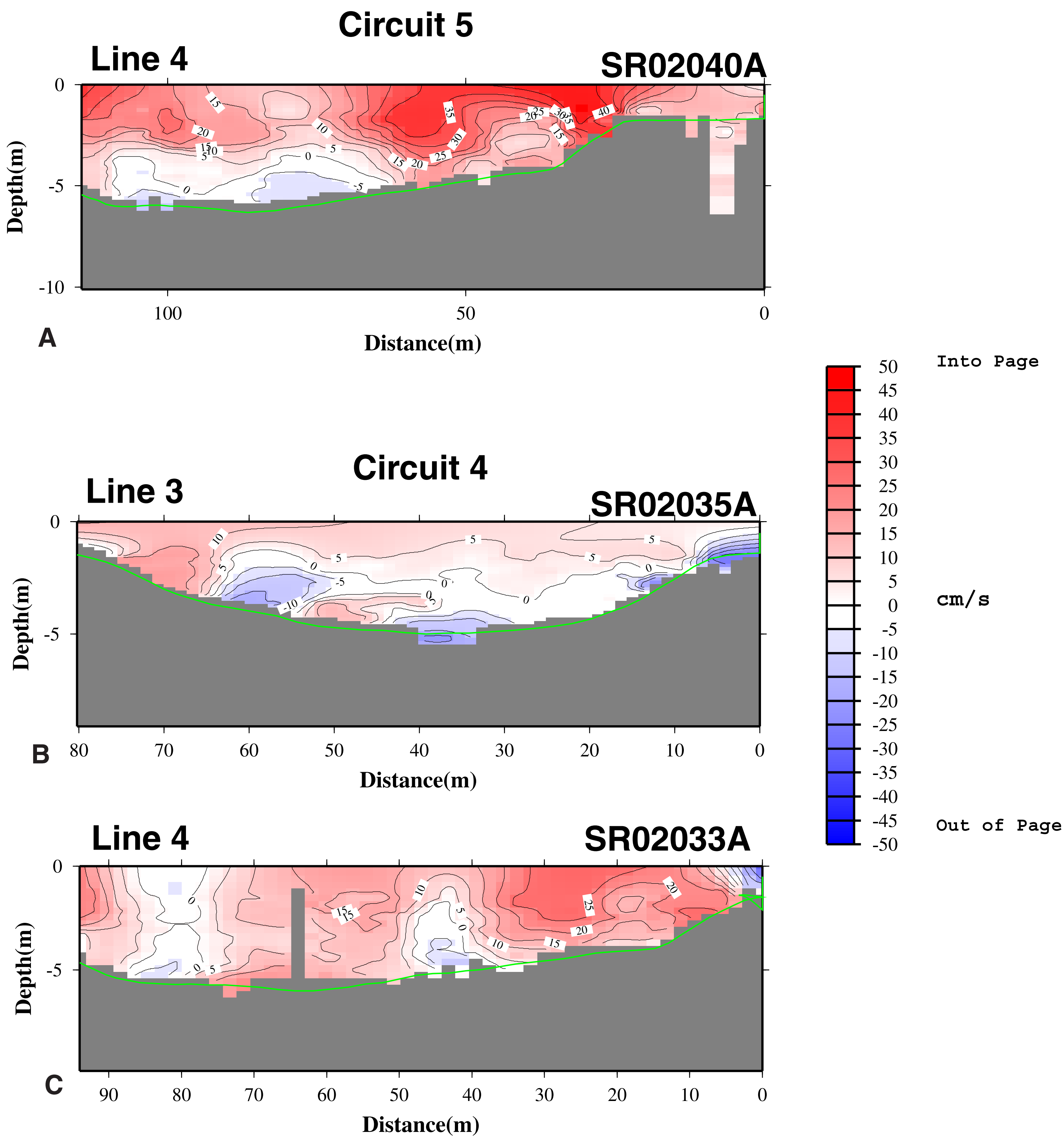


Figure 25 : Plots of transect normal velocity data from Circuits 4 (early flood) and 5 (mid-flood) of the Seekonk River survey. Cross channel transects were only driven on lines 3 and 4 during this stage of the tide.

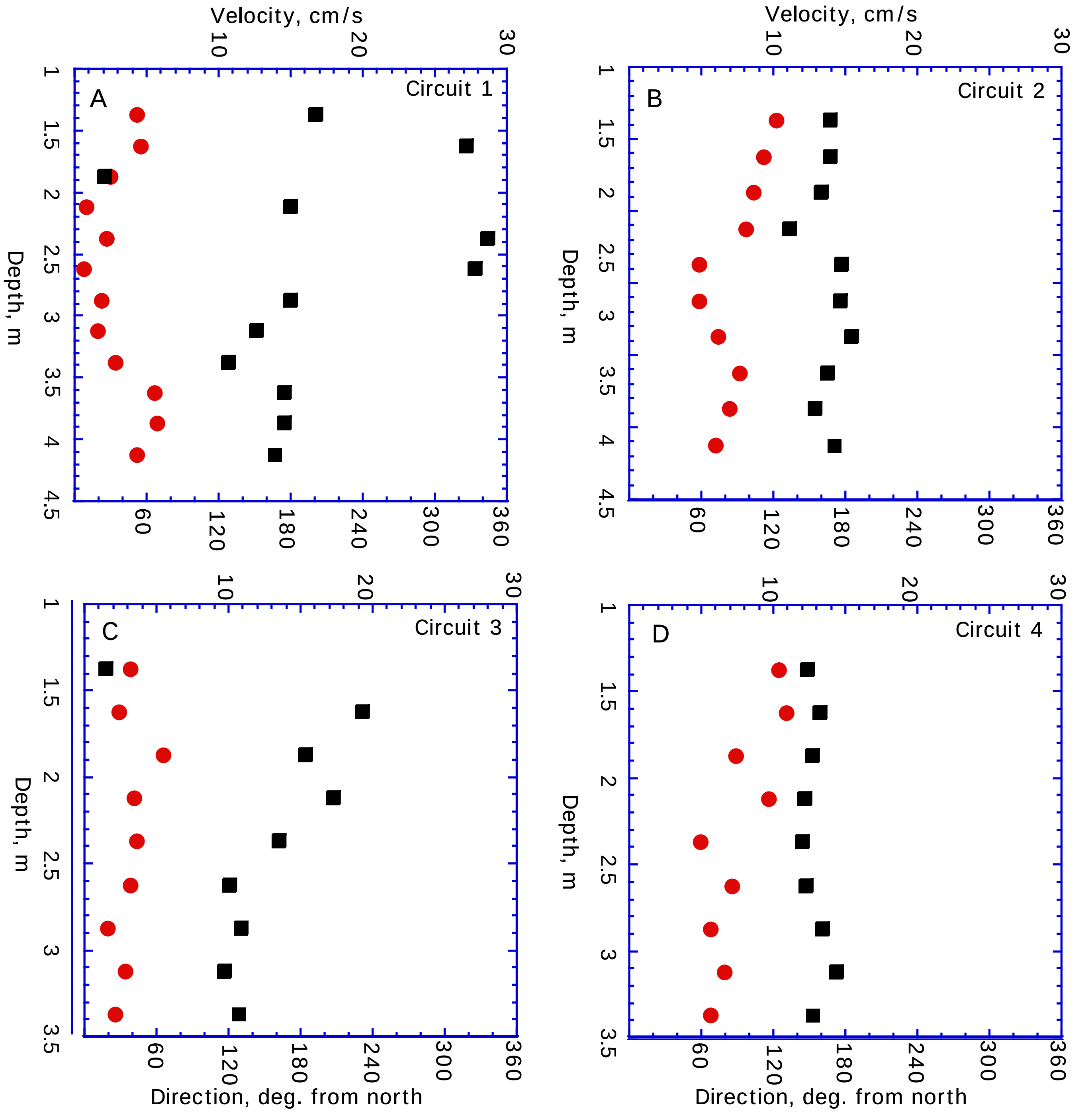


Figure 26: Velocity profiles obtained for transect 1 , northernmost line, by holding position within the channel and collecting data for four minutes. Data have been averaged into a single profile of velocity versus depth. Shown are velocity magnitude (circles) and direction (squares), for each of the circuits; 1=early ebb, 2=mid-ebb, 3=late ebb and 4=early flood stages of the tide.

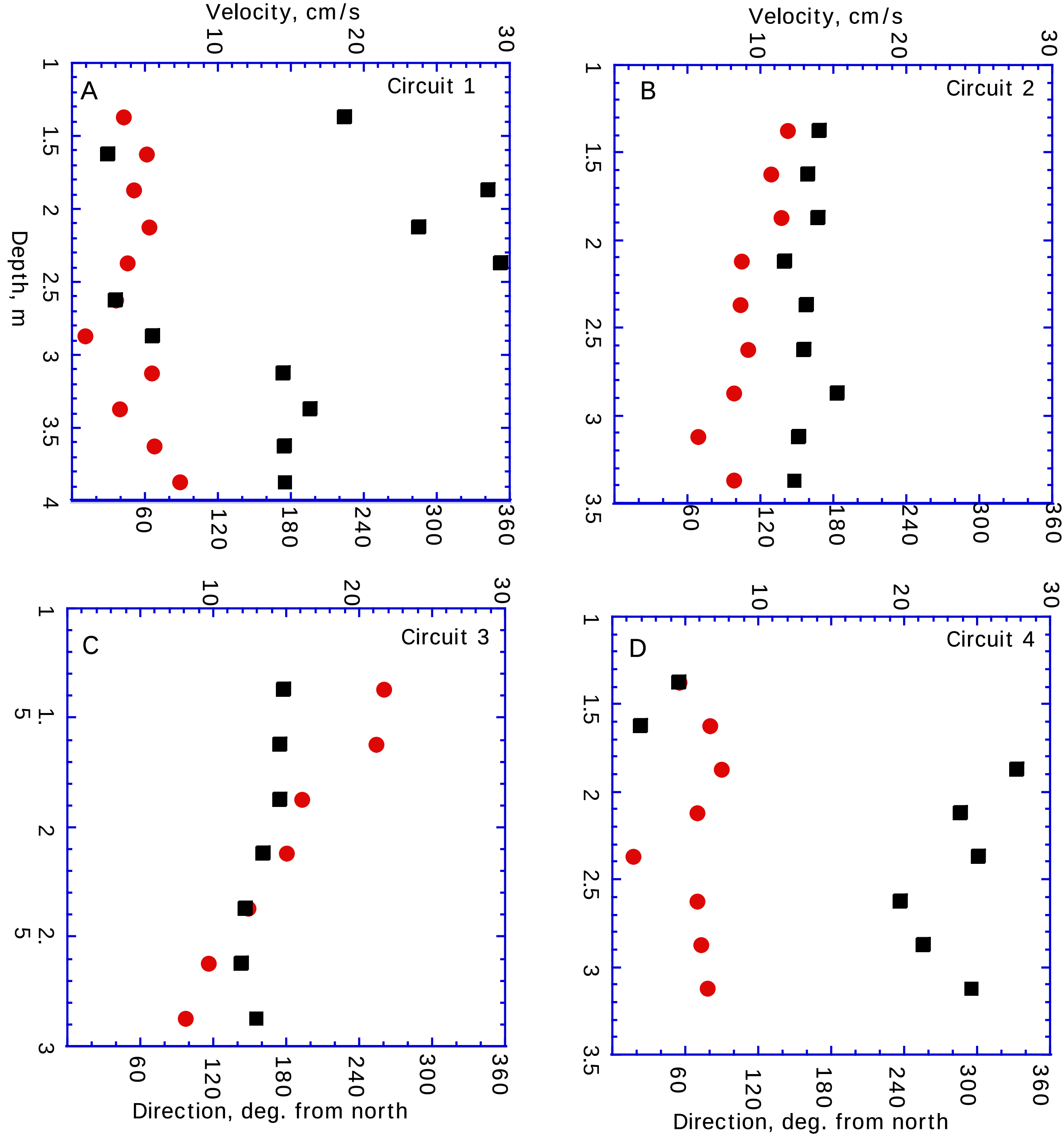


Figure 27: Velocity profiles obtained for transect 2 , at the outfall, by holding position within the channel and collecting data for four minutes. Data have been averaged into a single profile of velocity versus depth. Shown are velocity magnitude (circles) and direction (squares), for each of the circuits; 1=early ebb, 2=mid-ebb, 3=late ebb and 4=early flood stages of the tide.

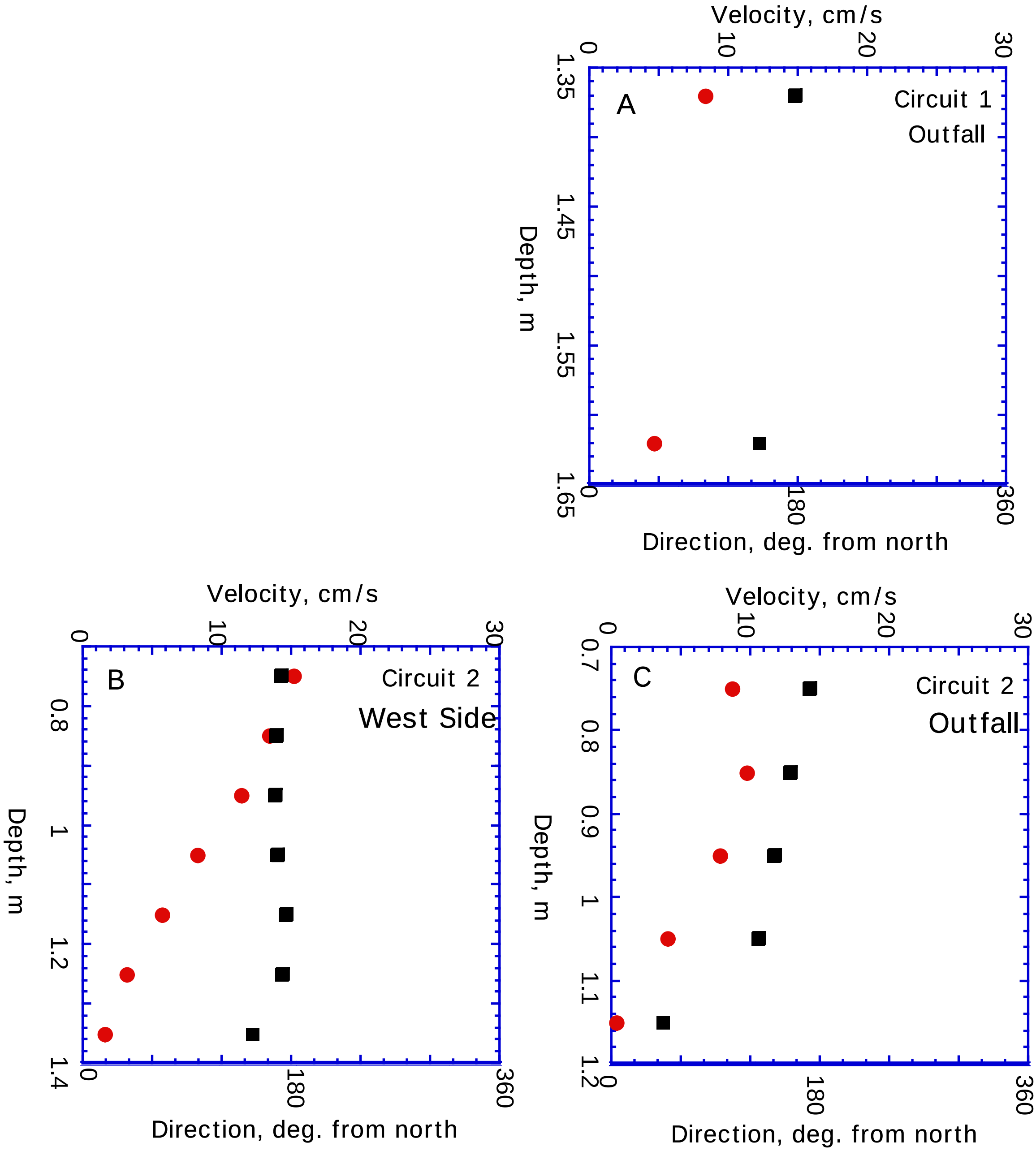


Figure 28: Velocity profiles obtained for transect 2 from times series data collection performed outside the channel, within the eastern (outfall side) and western portions of the Seekonk River. Shown are velocity magnitude (circles) and direction (squares). Data are from circuit 1 (early ebb) and circuit 2 (mid ebb) stages of the tide.

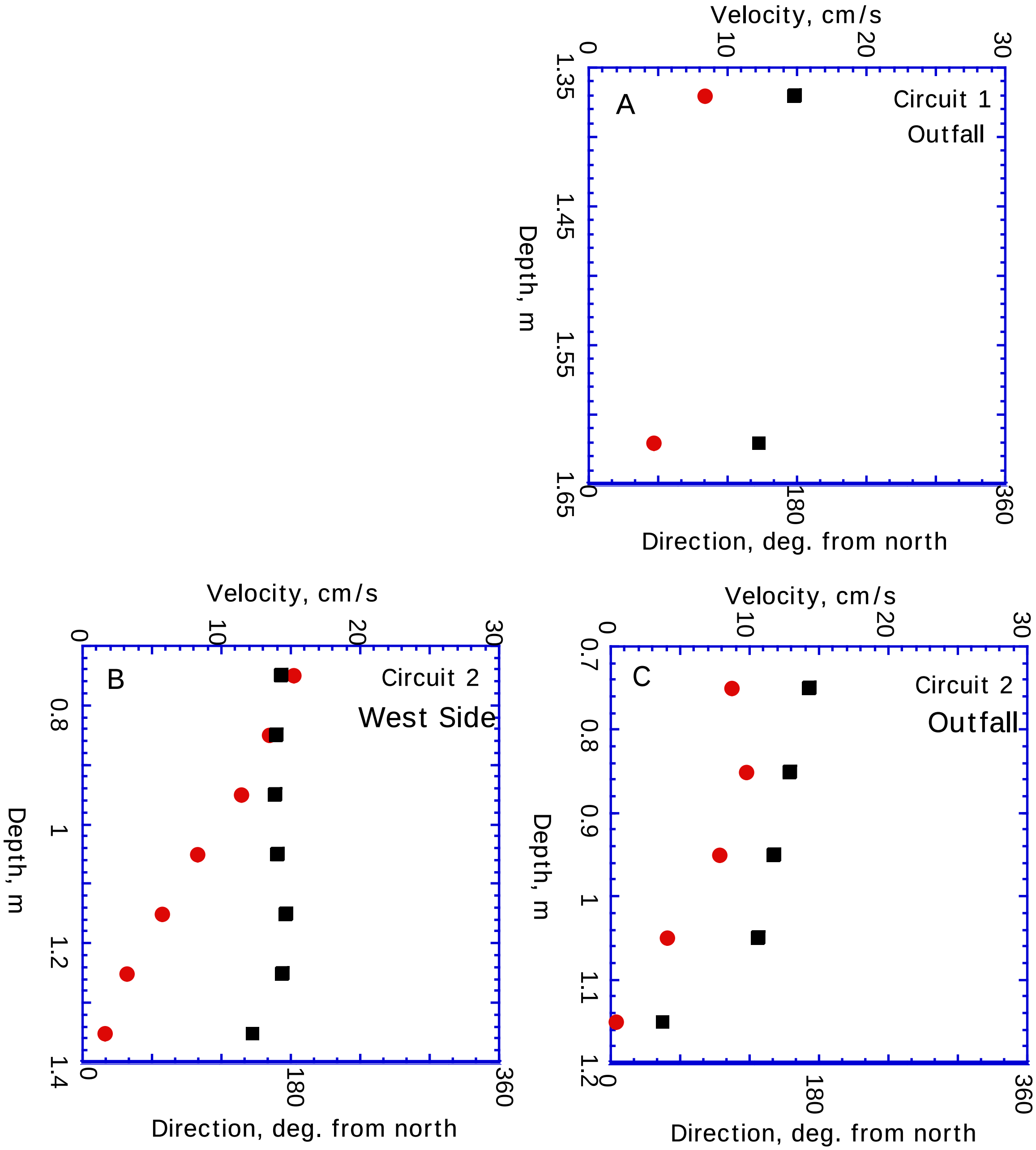


Figure 28: Velocity profiles obtained for transect 2 from times series data collection performed outside the channel, within the eastern (outfall side) and western portions of the Seekonk River. Shown are velocity magnitude (circles) and direction (squares). Data are from circuit 1 (early ebb) and circuit 2 (mid ebb) stages of the tide.

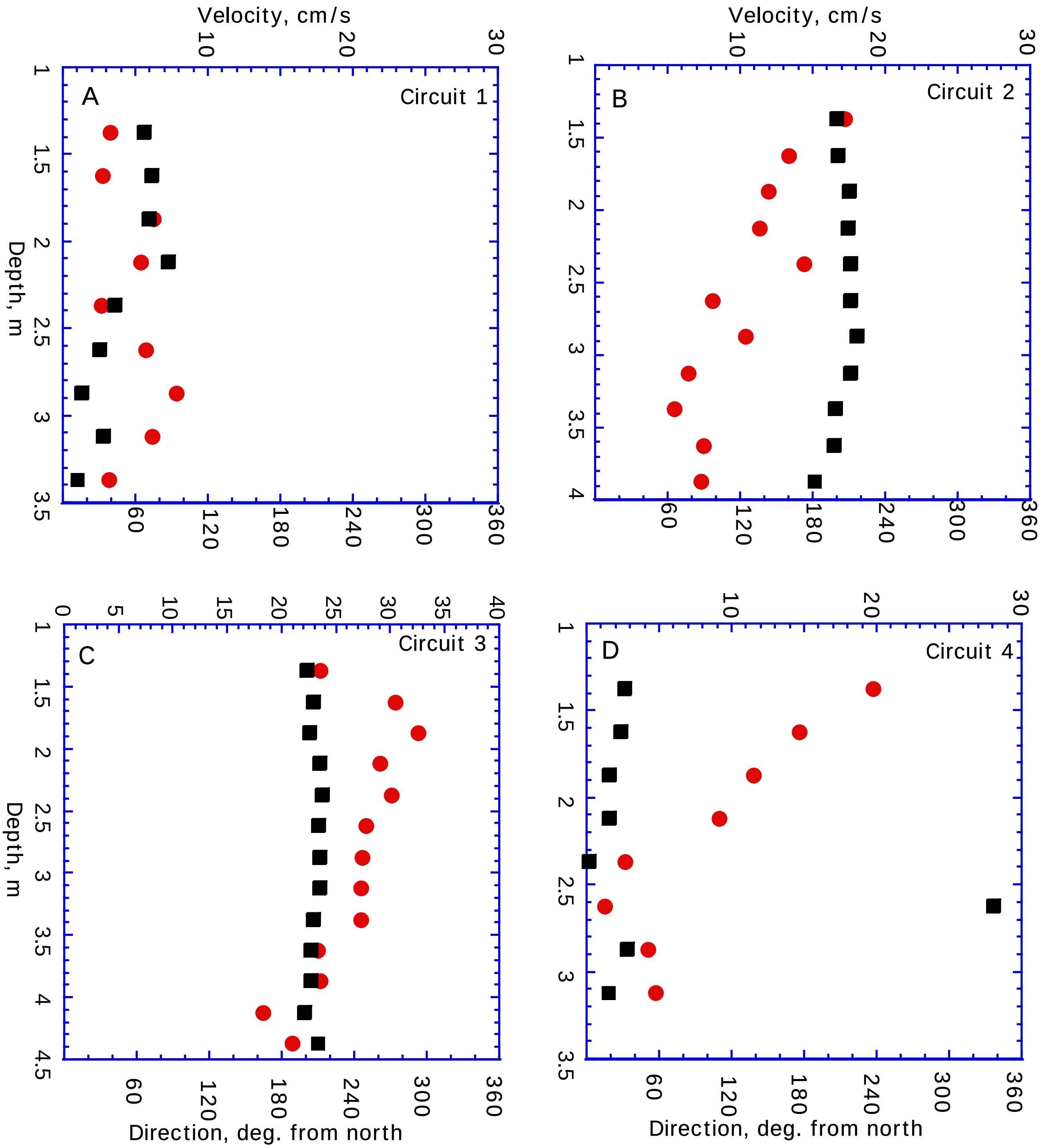
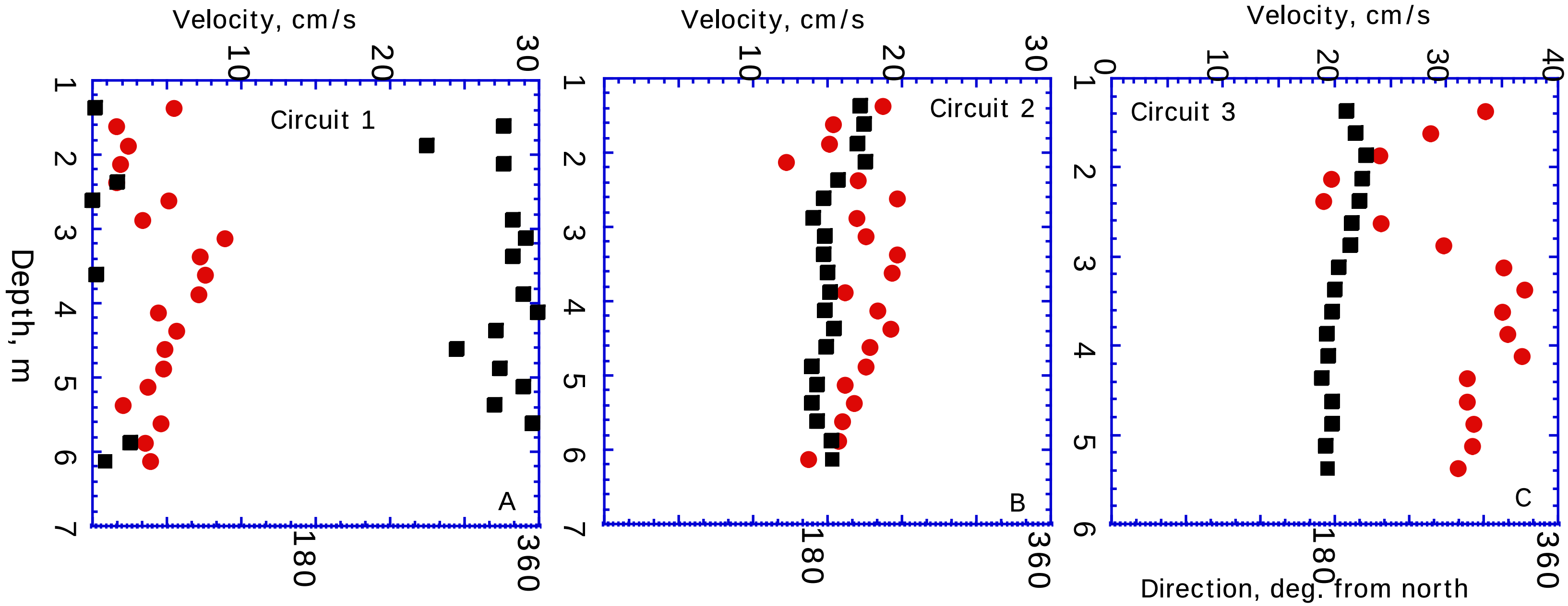


Figure 29: Velocity profiles obtained for transect 3 by holding position within the channel and collecting data for four minutes. Data have been averaged into a single profile of velocity versus depth. Shown are velocity magnitude (circles) and direction (squares). Time periods are circuits 1,2 and 3 or early, mid and late ebb conditions. Circuit 4 is early flood.



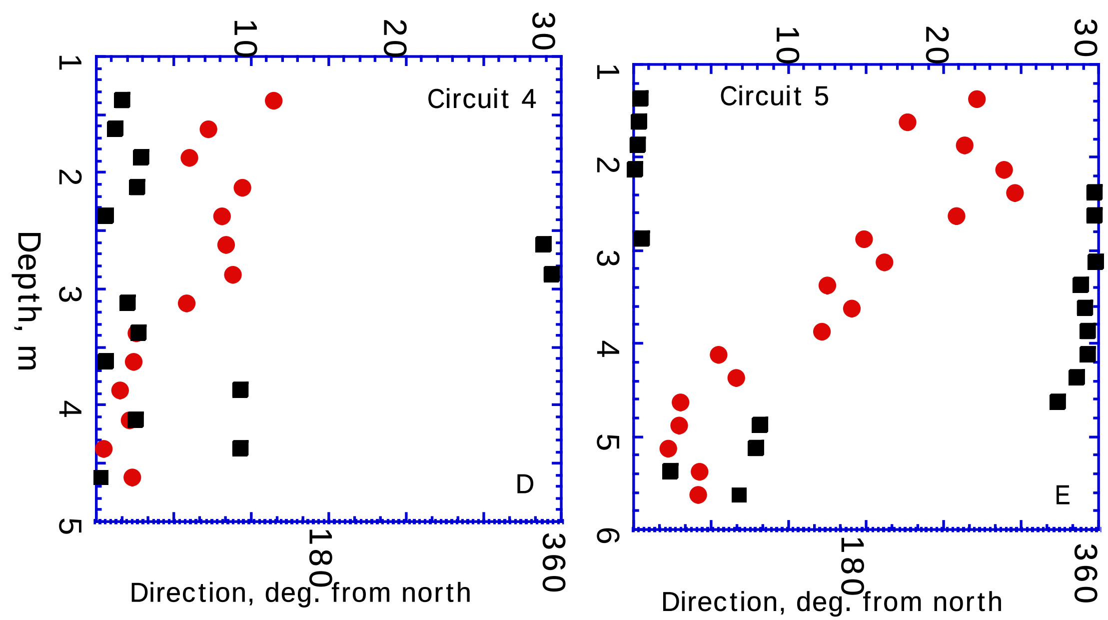


Figure 30 : Velocity profiles obtained for transect 4 by holding position within the channel and collecting data for four minutes. Data have been averaged into a single profile of velocity versus depth. Shown are velocity magnitude (circles) and direction (squares). Data cover tidal stages from early (A), mid(B) and late ebb (C) through to early (D) and mid (E) flood conditions.

Table 1: Providence River Survey 2: October 28, 2001

Time	Circuit	Transect Line	ADCP File	CFG File	Trend	CTD	Note
6:27	1	4	1	4	W>E	1	
7:21	1	3	2	4	W>E	2	
8:26	1	2a	3	4	W>E	3	
8:35	1	2b	4	4	E>W		
8:44	1	2c	5	5	E>W		
9:10	1	1	6	4	W>E	4	
9:39	2	3	7	4	W>E	5	cross@ens 163
10:25	2	2.5	8	4	W>E	6	new line EYC to E Prov. Outfall
---------------------------------low water = 10:30, transition to flood							
11:00	2	2a	9	4	W>E	7	cross @ ens 180
11:14	2	2c	10	5	E>W		cross @ ens 150
11:40	2	1.5	11	4	W>E		new line @ Fields Pt. Outfall
11:56	2	1	12	4	W>E	8	
12:26	3	4	13	4	W>E	9	
13:02	3	3	14	4	W>E	10	ens 205 slow for boat
13:50	3	2a	15	4	W>E	11	
14:05	3	2c	16	5	E>W		
14:27	3	1	17	4	W>E	12	
14:49	4	4	18	4	W>E	13	cross @ ens 23
15:24	4	3	19	4	W>E	14	cross@ ens 224
16:00	4	2.5	20	4	W>E	15	boats on W pushed south
16:40	4	2a	21	4	W>E	16	cross @ ens 45, boat @ 130
16:55	4	1	22	4	W>E	17	

Wind out of north all day; 20mph in morning, 5-10 rest of day. PORTS data (Providence River station) shows high water at 6:00, low water at 10:30 and high again at 18:00.

Table 2: Narragansett Bay Commision Seekonk River Survey 2: October 29,2001

Time	Circuit	Transect Line	ADCP File	CFG File	Trend/Note
6:14	1	4	1	4	W>E
	1	4	2	4	E>W
6:29	1	4	3	4	TS Channel
	1	3	4	4	E>W
	1	3	5	4	W>E
	1	3	6	4	TS Channel
	1	2.5	7	4	E>W
	1	2	8	4	E>W
	1	2	9	4	W>E
	1	2	10	4	TS Outfall
	1	2	11	4	TS Channel
	1	1	12	4	E>W
	1	1	13	4	TS Channel
8:07	2	4	14	4	E>W
	2	4	15	4	W>E
	2	4	16	4	TS Channel
	2	3	17	4	E>W
	2	3	18	4	W>E
	2	3	19	4	TS Channel
	2	2	20	4	TS Outfall
	2	2	21	4	TS Channel
	2	2	22	5	TS Outfall
	2	2	23	5	TS west side
	2	1	24	4	TS Channel
9:50	3	4	25	4	E>W
	3	4	26	4	TS Channel
	3	4	27	5	TS East Side
10:17	3	3	28	4	E>W
	3	3	29	4	TS Channel
	3	3	30	5	TS West Side, no data
	3	2	31	4	TS Channel with Cullen
	3	1	32	4	TS Channel
-----------------low water ~11:15, transition to flood					
13:00	4	4	33	4	E>W
	4	4	34	4	TS Channel
	4	3	35	4	E>W
	4	3	36	4	TS Channel
13:35	4	2.5	37	4	TS Channel with Cullen
	4	2	38	4	TS Channel
	4	1	39	4	TS Channel
14:31	5	4	40	4	E>W
	5	4	41	4	TS Channel
	5	4	42	5	TS East Side

The PORTS Providence River Station shows times for high and low water as:
high water at 6:00, low water at 11:15, high water again 18:15.