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

Draft Report Prepared
for Microinorganics
January, 2002

1.0 Introduction

A third 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 winter seasonal conditions. The cruises provide a baseline for comparison with the first two sets of cruises performed during the summer and fall periods (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.

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). An additional survey line was added between lines 2 and 3 for the second survey, called line 2.5, which was also occupied during this survey. 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 occupied 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. During the first half of the first circuit the winds were strong and out of the north, making conditions on the southern lines rough and difficult for data collection. A SeaBird SB19 CTD was dragged behind the boat at roughly 1 meter depth for all transects.

Because of the limited daylight period and cold temperatures during the winter period, the sampling on this third survey was scheduled to allow us to cover a full ebb cycle of the tide. High water occurred at roughly 8:30 am on the first day. Sampling began on December 16, 2001, on the southernmost line (4) and progressed northward to lines 3, 2.5, 2 and 1. Two circuits were completed which coincided roughly with early and late ebb conditions. A detailed summary of data collection locations and times is given in table 1.

A second day of sampling (December 17,2001) 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.

Sampling began at 7:15 am in the Seekonk in order to cover one circuit during late flood conditions, prior to high water which occurred at roughly 9:30 am. An additional three circuits were completed covering the ebb cycle of the tide. The sampling plan was slightly different for survey 3, from the previous two surveys. The Seekonk is characterized by a narrow channel with shallow shoals on either side of the channel. Driving transects from the channel out across the shoals is risky because of the limited water depths. In the past we have used an oar to test water depth as we moved in an attempt to protect the ADCP transducers. Given the severe winter conditions it was not possible to drive full transects, outside the channel boundaries. A sampling protocol was developed which involved driving 1 transect line (for lateral structure) within the channel. Next, a time series data set (4 minutes of data collection) was conducted by holding position within the channel to provide maximum data quality for vertical flow structures within the channel. Subsequently time series stations were occupied in the shallow water regions of each transect (Table 2) to provide information on average velocities in these areas. Because the boat was not moving it was easier to protect the ADCP, even given the weather conditions.

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 each of the lines in the Seekonk survey, we also used ADCP water mode 5, which is tuned for extreme shallow water environments (e.g., depth bins of 10 cm).

4.0 Results:

Providence River Currents

Data on circulation patterns are presented in a series of contour plots (Figures 2-4) and laterally averaged velocity profiles (Figures 5-10). 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. Flow patterns vary significantly between transect lines. As with every survey, flows are generally weaker (<10 cm/s) on the northern line 1 and little coherent structure is seen within the flow field. On line 2 , south of Fields Pt., water is generally ebbing over the entire line. The western shoals are weakly ebbing (10-15 cm/s). A structure which is repeated on this line between surveys is seen in Figure 2B, where a stronger outflow core is centered on the western side of the channel, in the surface waters (30 cm/s). The deep water in the channel at this transect (below 5 meters) is stagnant or weakly northward, or flooding. Line 2.5 shows an interesting pattern in flow. Water on the western shoals and within the channel is also generally flowing southward, or ebbing. However, flow is stronger on the just west of the channel (12-25 cm/s) than in the channel (10 cm/s). As with line 2, the deep water in the channel is stagnant or weakly flooding. An interesting inflow structure extends upward to the surface waters on the extreme eastern end of the line, just south of the East Providence outfall (Figure 2c). Data fro the intermediate line 1.5, located at the outfall, are shown in Figure 4. As with line 1, flow is generally weak and exhibits little lateral structure.

The southern two lines show very different results. Along Line 3 at Sabin Point water in the channel is vertically stratified with shallow (<4m) water moving southward at 10 cm/s and deeper water moving north or in at 5 cm/s. Higher velocities are recorded at this stage outside the channel to the east and west (15-25 cm/s). The maximum outflow is recorded just east of the channel where flow magnitudes exceed 25 cm/s. Sampling begin on the furthest south line 4 at Gaspee Pt. Here the water was still flooding in the channel. The eastern and western shoals of this transect show flow which is weak and of an opposite sense (ebbing) than the channel flow Figure 2e).

Circuit 2 covered the later stage of the ebb tide (Figure 3). On line 1, which was sampled toward the very end of the ebb, water over the lower 2/3 of the water column is moving north at 5-15 cm/s. The very surface water is still moving southward. Little lateral flow structure is recorded on this line. On line 2 a weak clockwise gyre is seen on the western portion of the transect. The western side of the shallows is moving northward at 5-10 cm/s, while the eastern side of the shoals shows water moving southward at roughly 5 cm/s (Figure 6d). On average, flow in the channel is nearly stagnant, with just the top 2 meters showing southerly flow at 5-10 cm/s (Figure 6e). Below 6 meters the water is moving northward at <5 cm/s.

Along line 2.5 a somewhat similar pattern is recorded. The very shallow water (above 2 meters) in the channel is moving southward at 10 cm/s. Below this level water moves weakly south, on average, at < 5 cm/s. The majority of the western shoals on this line shows weakly ebbing water (10 cm/s) (Figure 8) except the extreme western side which nearly stagnant, or slighly west at <5 cm/s. Flotsam seen at this extreme western end of the line was noted to have moved less than 100 feet between circuits. It is interesting to note that along the extreme easten end of the line, a persistent northerly flow is recorded over the entire water column (Figure 3c), which also shows up on line 2 to the north (Figure 3b).

At the southern two lines, 3 and 4, stronger ebb currents are recorded. Here flow magnitudes reach 30-40 cm/s (Figure 3d,e). On average at Sabin Point (Figure 10), southerly flows are maximum in the channel (20-30 cm/s) and weaker on the western side at 10-15 cm/s. The eastern side of line 3 appears to be a weak recirculation eddy feeding the channel outflow with flows (~5 cm/s) varying from westward on the extreme eastern side of the line to southwestward nearer the channel. At Gaspee Point, line 4, the pattern is similar with strong outflow in the channel and weak or sluggish water flow on the shallower portions of the line, east and west of the channel.

Providence River Salinity/Temperature

The CTD data collected during the individual circuits are summarized in Figures 11-12. During the early ebb conditions of circuit 1 (Figure 11), the surface water exhibits salinities in the range of 28-29 ppt, with generally higher values to the south (e.g., 29 ppt at Gaspee Pt.). These values are similar to those recorded during survey 2. Temperatures range between 8-9°C. Very little difference is seen between northern and southern lines. Line 4 exhibits a pattern of higher salinity on the eastern side of the transect lower values on the western side. The pattern across Line 2.5 is higher salinities for water on the extreme western end of the line. A broad region of generally lower salinity occupies the majority of the shoals and the western portion of the channel. Line 2 also repeats this pattern of higher salinity water on the far western side of the transect. Temperatures lack significant lateral structure.

During circuit 2 (Figure 12) similar ranges in temperature and salinity are recorded. On line 1, salinities are higher on the eastern side of the transect by ~ 2ppt (Figure 12a). Both lines 2 and 2.5 show slightly higher salinity values on the far western sides of the estuary. Sabin Point shows almost no lateral structure in salinity/temperature. Line 4 at Gaspee Pt. again shows a patterns of reduced salinity and temperature on the western portion of the transect.

Seekonk River Currents: Lateral Structure

The Seekonk River was sampled on December 17, 2001, one day after the Providence River (Table 2). Data are presented as contour plots of velocity information collected along transects covering the channel and as time averaged vertical profiles of water velocity collected at fixed points to provide information on vertical flow structure over different tidal stages. Figures 14-17 show cross sections of flow structure normal to each transect for lines 2-4 for each circuit.

Seekonk River Currents: Vertical Structure in the Channel

Figure 18 shows velocity profiles for the channel and eastern shoal regions of Line 4. Waters in both areas are flooding at 20-25 cm/s. Flow is generally faster at the surface and within the channel. By circuit 2, the flow has begun to turn. Within the channel the deep water is still moving northward at 10 cm/s. The shallow water is turning to ebb. On the eastern shoals the very surface (<1.5m) water is ebbing. More developed ebb conditions are recorded during circuit 3 (Figure 18 c). Southward flows are slightly faster on the shoals (20-30 cm/s) than in the channel (20-25 cm/s). By circuit 4 approaching the end of the ebb, flow patterns are generally similar but flow magnitudes are reduced (10-20 cm/s in the channel; 5-15 cm/s in the eastern shoals).

Figure 19 summarizes velocity profile information for Line 3. Flooding currents are recorded during circuit 1, with stronger flows in the surface waters of the channel (30 cm/s) versus the deep channel (10 cm/s) or the western shoals (10 cm/s). Circuit 2 (Figure 19b) records the transition from flood to ebb when flows are generally weak and without a coherent flow direction. During circuits 3 and 4 some vertical structure is recorded in the ebb currents. Generally above 3 meters, the outflows are larger (10-20 cm/s) than the deeper water (5-10 cm/s).

Sampling along line 2 included time series measurements in the channel and on both the eastern (by the outfall) and western shallow regions of the transect (Figure 20). During the late flood conditions of circuit 1, higher inflows are recorded in the channel (20 cm/s) than on either eastern or western shoals (<10 cm/s). During the transition to the ebb (circuit 2), the western side of the line appears to be acting as a counterclockwise eddy while nearer the outfall water is more coherently flowing southward (5 cm/s). During the maximum ebb conditions of circuit 3, maximum outflows are recorded in the channel waters (20-30 cm/s). The next fastest flows are on the western shoals (10-20 cm/s). The slowest flow is on the eastern end of the line, neasr the outfall, where water moves southward at <10 cm/s. Similar basic patterns are recorded within the channel waters of line 1 (Figure 21).

5.0 Conclusions

Providence River: The flow patterns within the Providence River were recorded during winter seasonal conditions over the ebb stage of the tide. Many patterns are similar to past surveys, such as the strong outflow core on line 2 centered on the western side of the channel and vertical structure within the channel (surface outflow, deep inflow). Data from the southern two lines shows that the maximum flows occur in the channel, while the shoals to either side of the channel are sluggish, often moving opposite to the trend of the channel flow, a characteristic of recirculation eddies. Line 1 shows generally weak flows, with little lateral structure. The line at Pomham Rocks (Line 2.5) shows that water generally moves southward across the shoals, with the exception of the far western side, which moves westerly. A very interesting feature was apparent on line 2.5 in survey 2 data. This was the persistent northward flow on the extreme eastern end of the line, by the East Providence outfall. This feature is also apparent in the winter data set. CTD data generally show the lower salinity water moves out the western side of line 1 and spreads out by lines 2 and 2.5, where a broad, reduced salinity pool is recorded over much of the shoals. Interestingly, higher salinity water is recorded on the extreme western ends of both these lines. A prevailing plug of lower salinity water appears on the western side of line 4.

Seekonk River:. Flow patterns were recorded in the Seekonk River for winter seasonal conditions covering the late flood through ebb conditions. In general the shoals and channel waters behave similarly, with slightly higher flow magnitudes being recorded within the channel. Water on the eastern shoal of line 4 turns to ebb faster than within the channel. In addition, during this transitional period water over the majority of line 2 appears to swirl without a coherent flow direction, while water near the outfall turns uniformly to a southerly outflow. Without the complete flood it is difficult to comment on net, or non-tidal patterns in vertical flow structure within the Seekonk during winter conditions.

6.0 References.

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Table 1: Providence River Survey 3: December 16, 2001

Time	Circuit	Transect Line	ADCP File	CFG File	Trend	CTD	Note
8:23	1	4	1	4	W>E	17	1-2’ chop
9:29	1	3	2	4	W>E	18	
10:12	1	2.5	3	4	W>E	19	west side to west of channel
10:30	1	2.5	4	4	W>E	20	west chan. to east shore
10:53	1	2	5	4	W>E	21	
11:25	1	1	6	4	W>E	22	
11:39	1	1	7	6*	E>W		
11:50	1	1.5	8	6	W>E		
12:15	2	4	9	4	W>E	23	
12:46	2	3	10	4	W>E	24	
13:20	2	2.5	11	4	W>E	25	
13:50	2	2	12	4	W>E	26	
14:08	2	1.5	13	4	W>E		
14:19	2	1	14	6	W>E	27	

*Config. file 6 uses 1/2 meter bins.

Table 2: Narragansett Bay Commision Seekonk River Survey 3: December 17, 2001

Time	Circuit	Transect Line	ADCP File	CFG File	Trend/Note
7:18	1	4	1	4	W>E
	1	4	2	4	TS Channel
	1	4	3	5	TS East side
7:39	1	3	4	4	E>W
	1	3	5	4	TS Channel
	1	3	6	5	TS West side
8:05	1	2.5	7	4	W>E
	1	2.5	9	4	TS Channel
	1	2.5	10	5	TS East Side
	1	2.5	11	5	TS West Side
8:37	1	2	12	4	W>E
	1	2	13	4	TS Channel
	1	2	14	5	TS East Side
	1	2	15	5	TS West Side
	1	1	16	4	TS Channel
9:37	2	4	17	4	W>E
	2	4	18	4	TS Channel
	2	4	19	5	TS East Side
10:05	2	3	20	4	E>W
	2	3	21	4	TS Channel
	2	3	22	5	TS West Side
10:31	2	2.5	23	4	W>E
	2	2.5	25	4	TS Channel
	2	2.5	26	5	TS East Side
	2	2.5	27	5	TS West Side
11:03	2	2	28	4	W>E
	2	2	29	4	TS Channel
	2	2	30	5	TS Outfall
	2	2	31	5	TS West Side
	2	1	32	4	TS Channel
11:51	3	4	33	4	W>E
	3	4	34	4	TS Channel
	3	4	35	5	TS East Side
12:12	3	3	36	4	E>W
	3	3	37	4	TS Channel
	3	3	38	5	TS West Side
12:34	3	2.5	39	4	W>E
	3	2.5	40	4	TS Channel
	3	2.5	41	5	TS East Side
	3	2.5	42,43	5	TS West Side,no data
	3	2	44	5	TS Outfall
13:05	3	2	45	4	W>E
	3	2	46	4	TS Channel
	3	2	47	5	TS West Side
	3	1	48	4	TS Channel

	4	4	51	5	TS East Side
	4	3	52	4	TS Channel
	4	2.5	53	4	TS Channel
	4	2	54	4	TS Channel
14:37	4	1	55	4	TS Channel

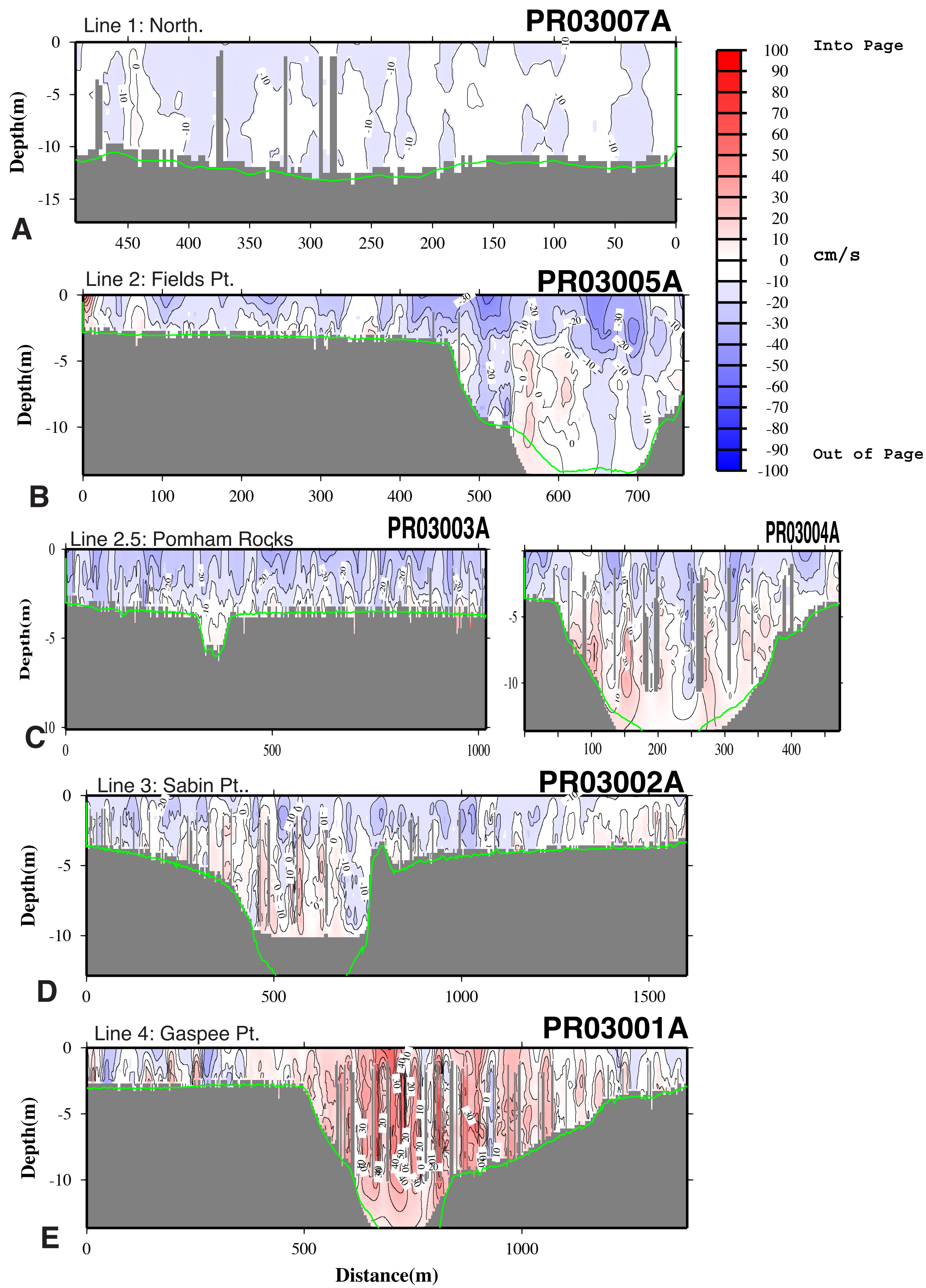


Figure 2: Velocity contour plots for circuit 1, early ebb conditions. Orientation is looking north, such that west is to the left and east is to the right. Red colors are flow into the page or flooding, blue colors are out of the page , or ebbing water.

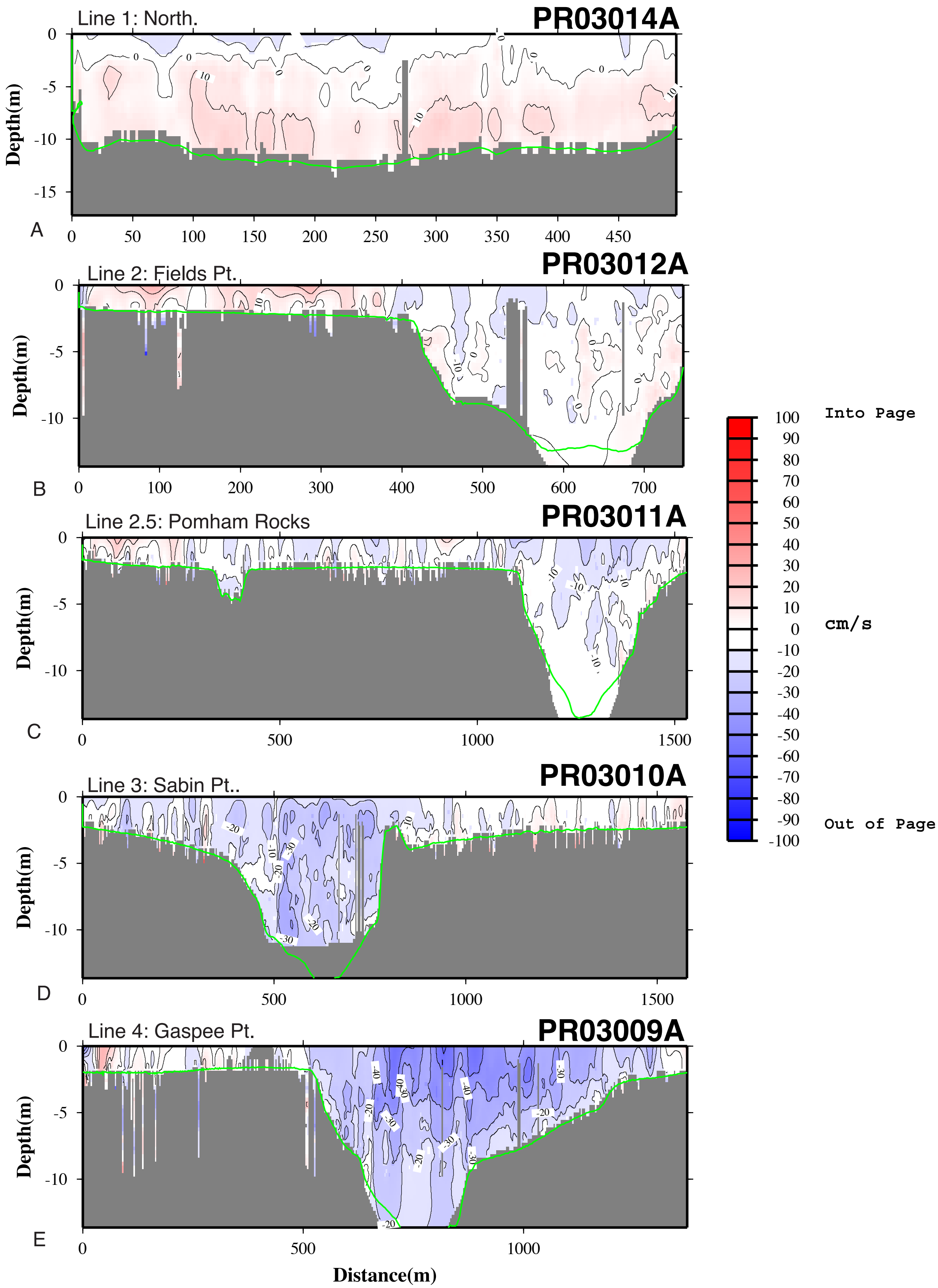


Figure 3: Velocity contour plots for circuit 2, late ebb conditions. Orientation is looking north, such that west is to the left and east is to the right. Red colors are flow into the page or flooding, blue colors are out of the page , or ebbing water.

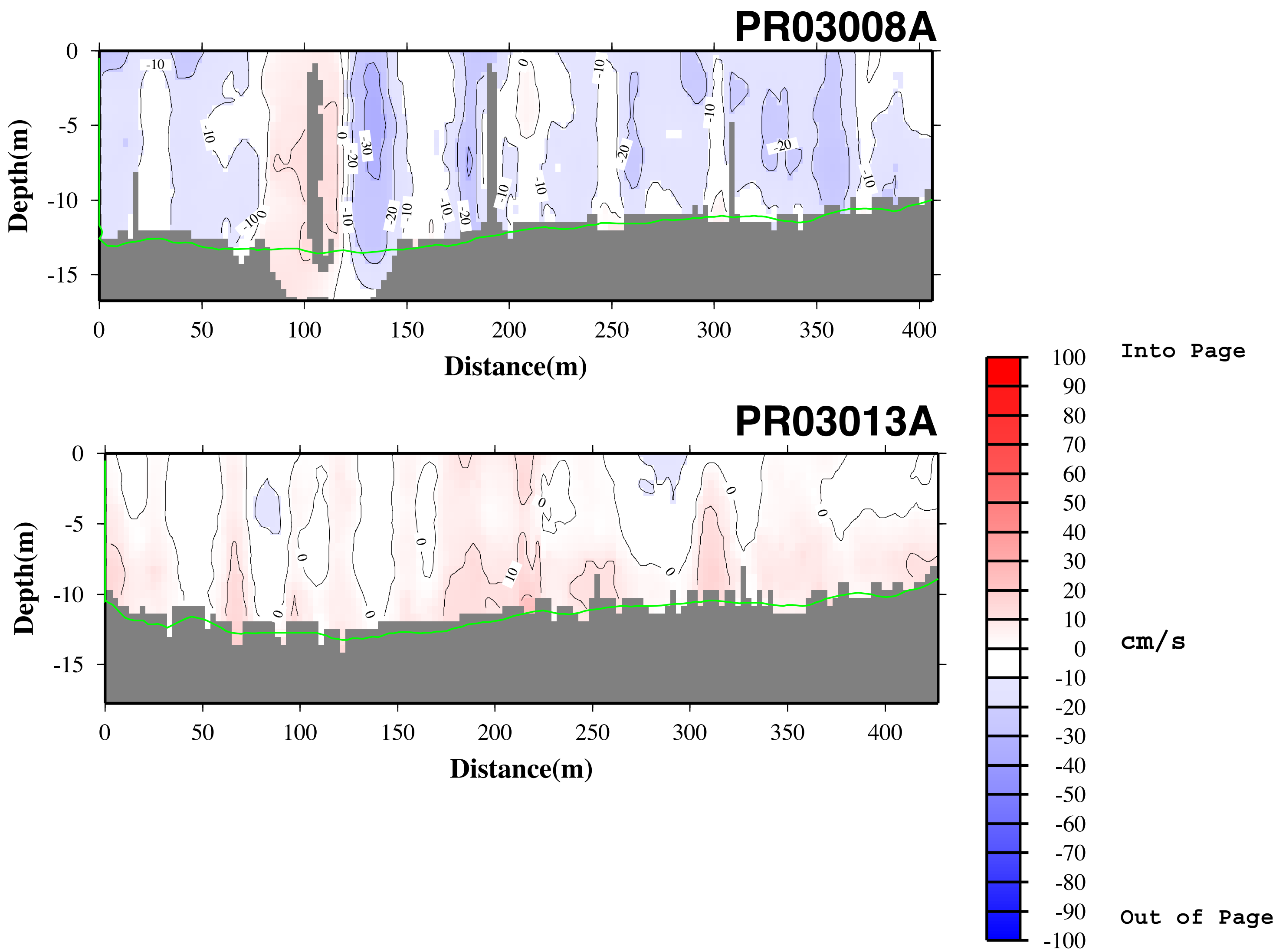


Figure 4: Velocity contour plots for circuit 1 (A) and circuit 2 (B) on new line 1.5, which begins at the Fields Point outfall site.

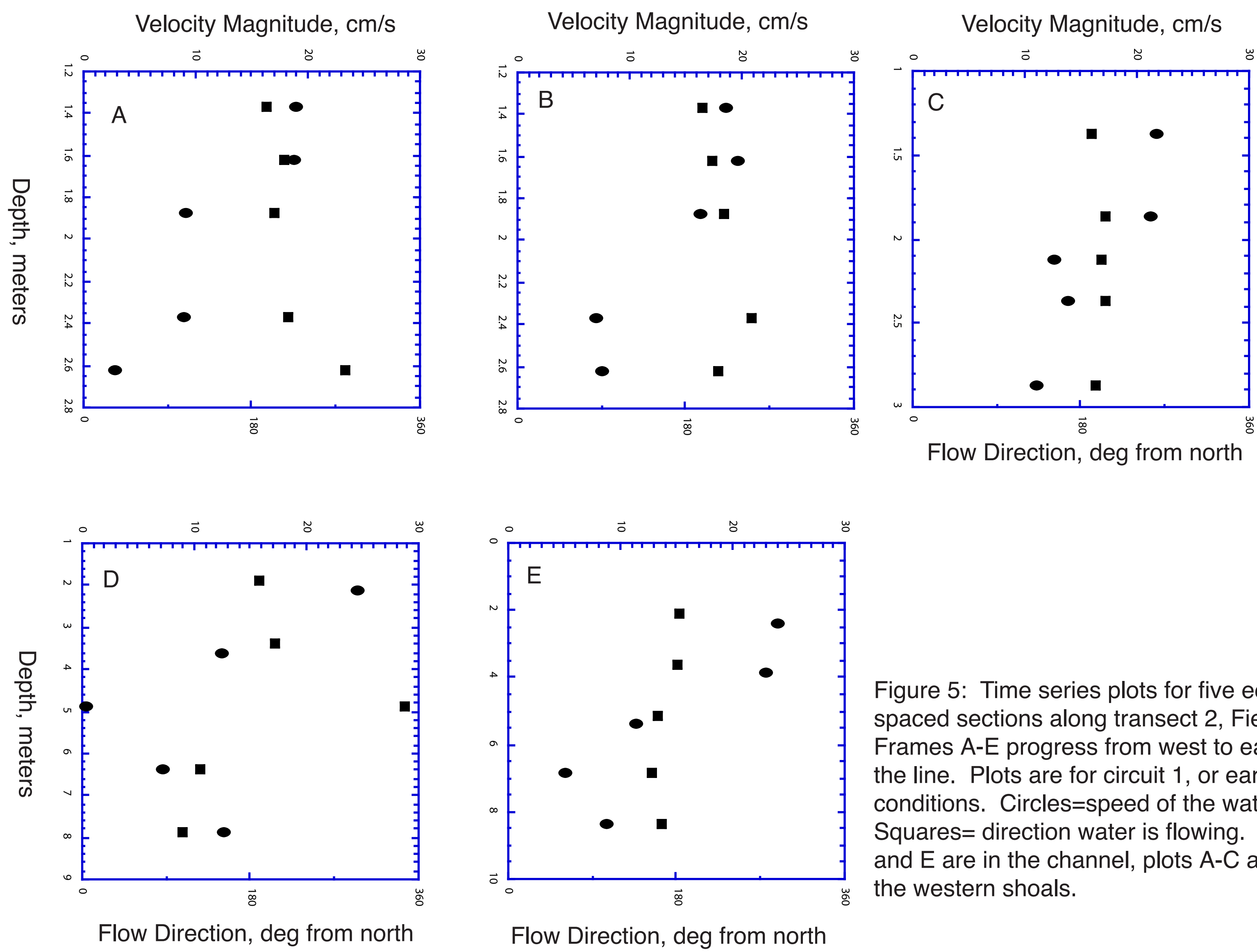


Figure 5: Time series plots for five equally spaced sections along transect 2, Fields Pt. Frames A-E progress from west to east along the line. Plots are for circuit 1, or early ebb conditions. Circles=speed of the water. Squares= direction water is flowing. Plots D and E are in the channel, plots A-C are on the western shoals.

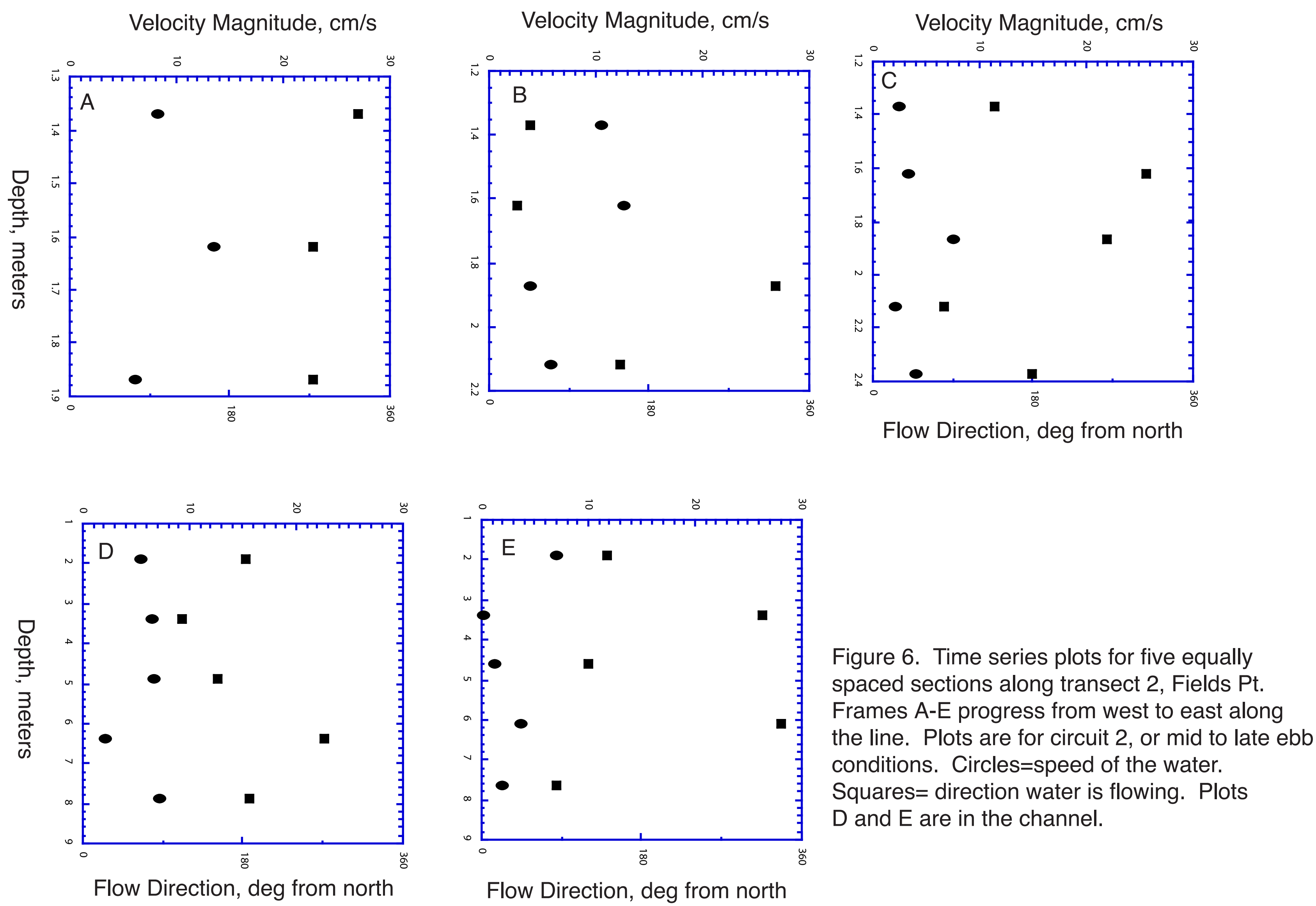
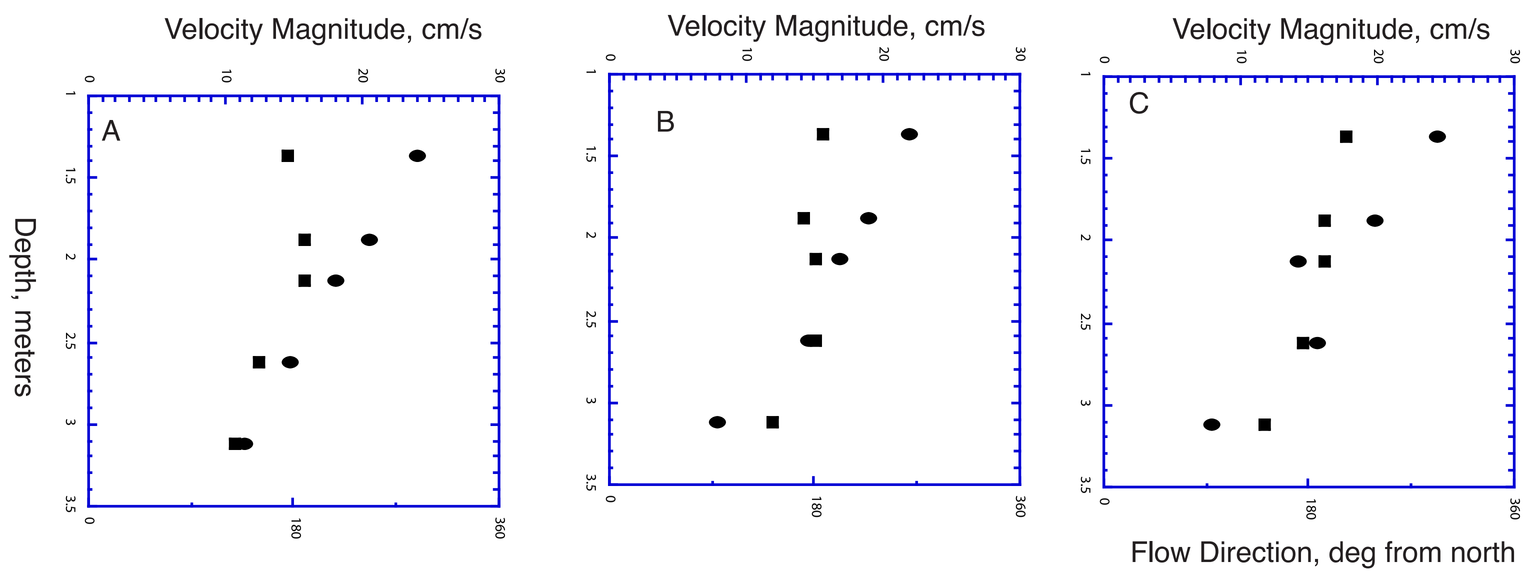


Figure 6. Time series plots for five equally spaced sections along transect 2, Fields Pt. Frames A-E progress from west to east along the line. Plots are for circuit 2, or mid to late ebb conditions. Circles=speed of the water. Squares= direction water is flowing. Plots D and E are in the channel.



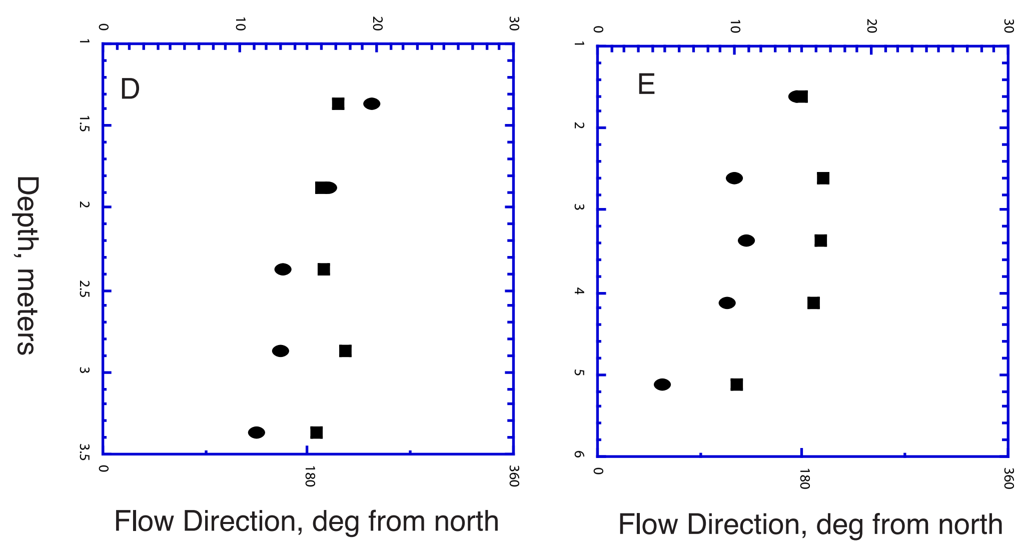


Figure 7. Time series plots for five equally spaced sections along transect 2.5. Frames A-E progress from west to east along the line. Plots are for circuit 1, or early ebb conditions. Circles=speed of the water. Squares= direction water is flowing. Plot E is an average profile within the channel, the others are spaced out across the western shoals.

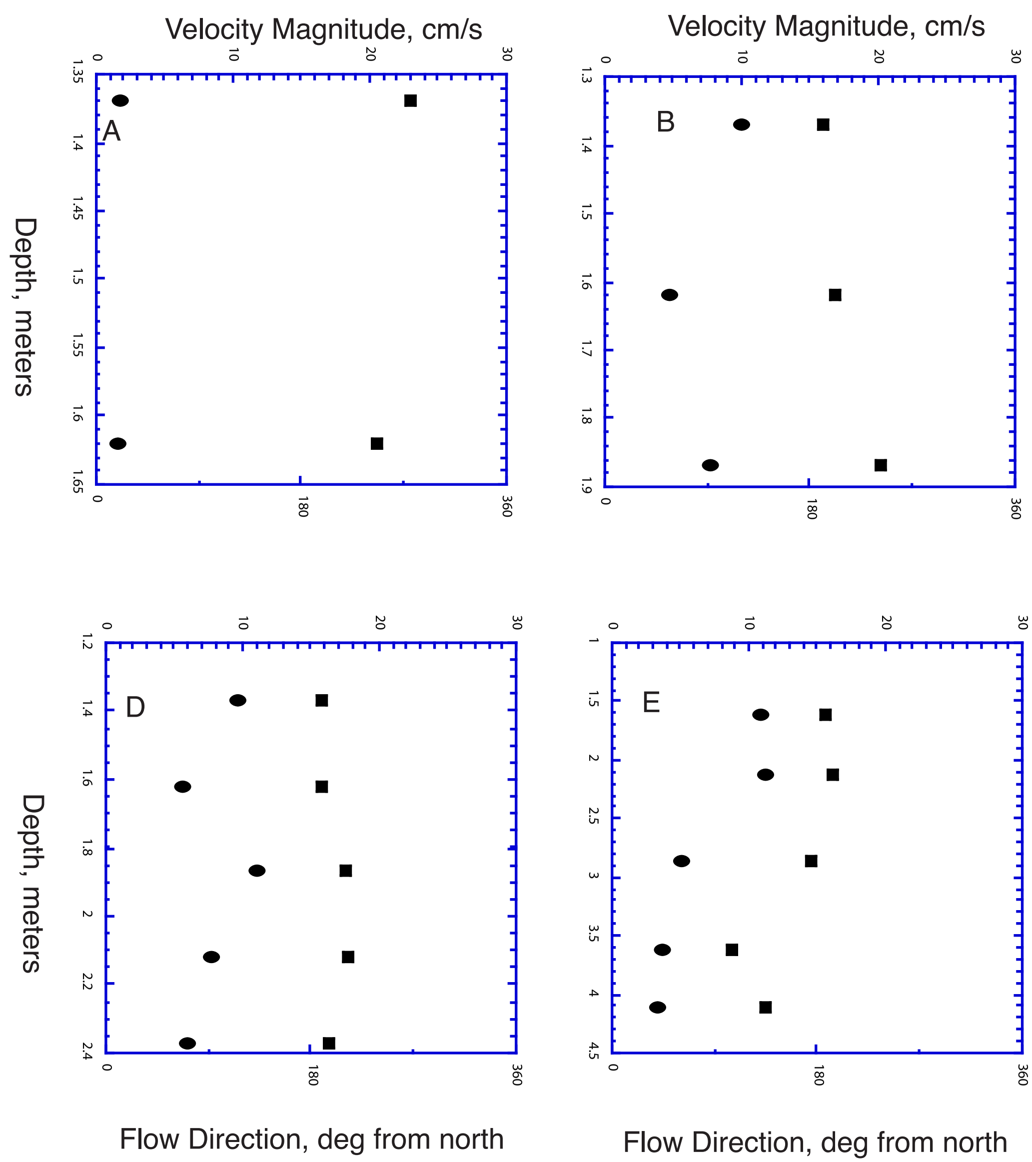
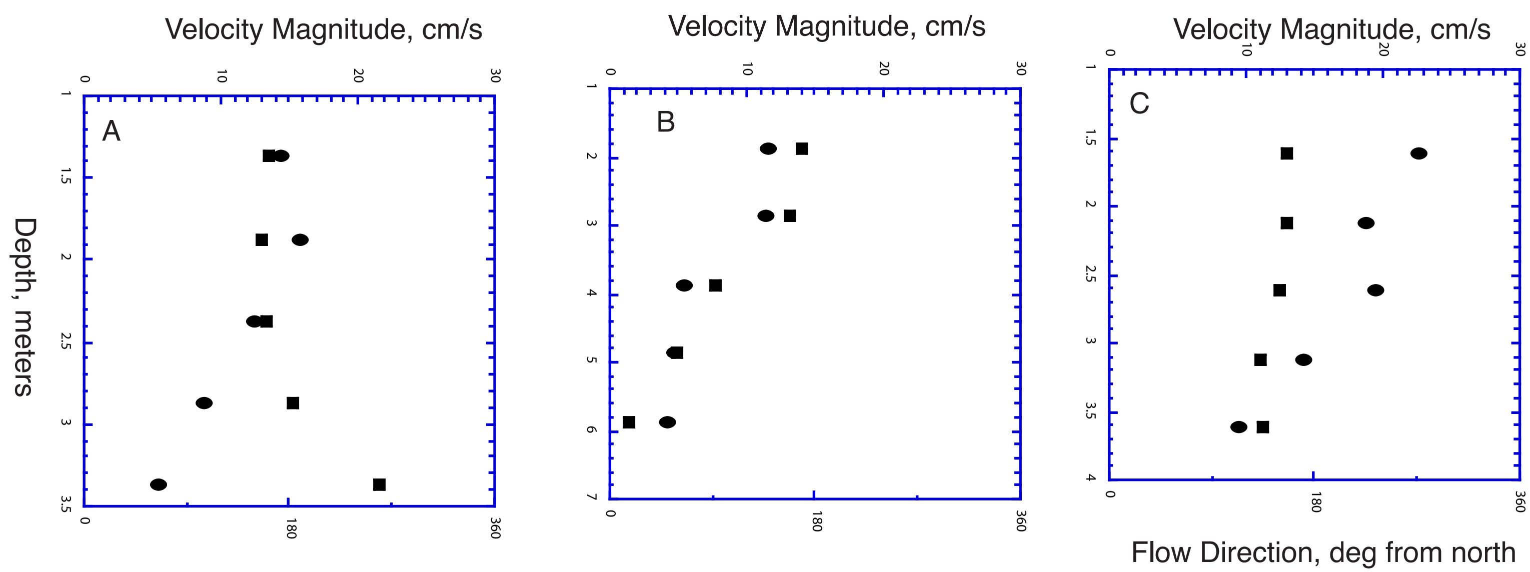


Figure 8. Time series plots for five equally spaced sections along transect 2.5. Frames A-E progress from west to east along the line. Plots are for circuit 2, or mid-late ebb conditions. Circles=speed of the water. Squares= direction water is flowing. Plot E is an average across the channel.



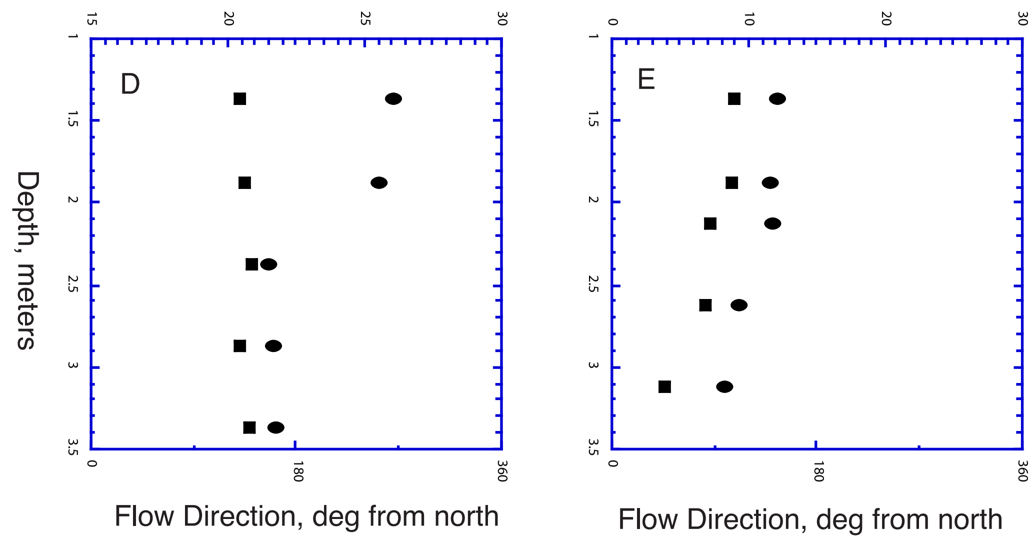


Figure 9. Time series plots for five equally spaced sections along transect 3, Sabin Pt. Frames A-E progress from west to east along the line. Plots are for circuit 1, or early ebb conditions. Circles=speed of the water. Squares= direction water is flowing. Plot B is in the channel. Plots A and C-E are on the western and eastern sides of the line, respectively.

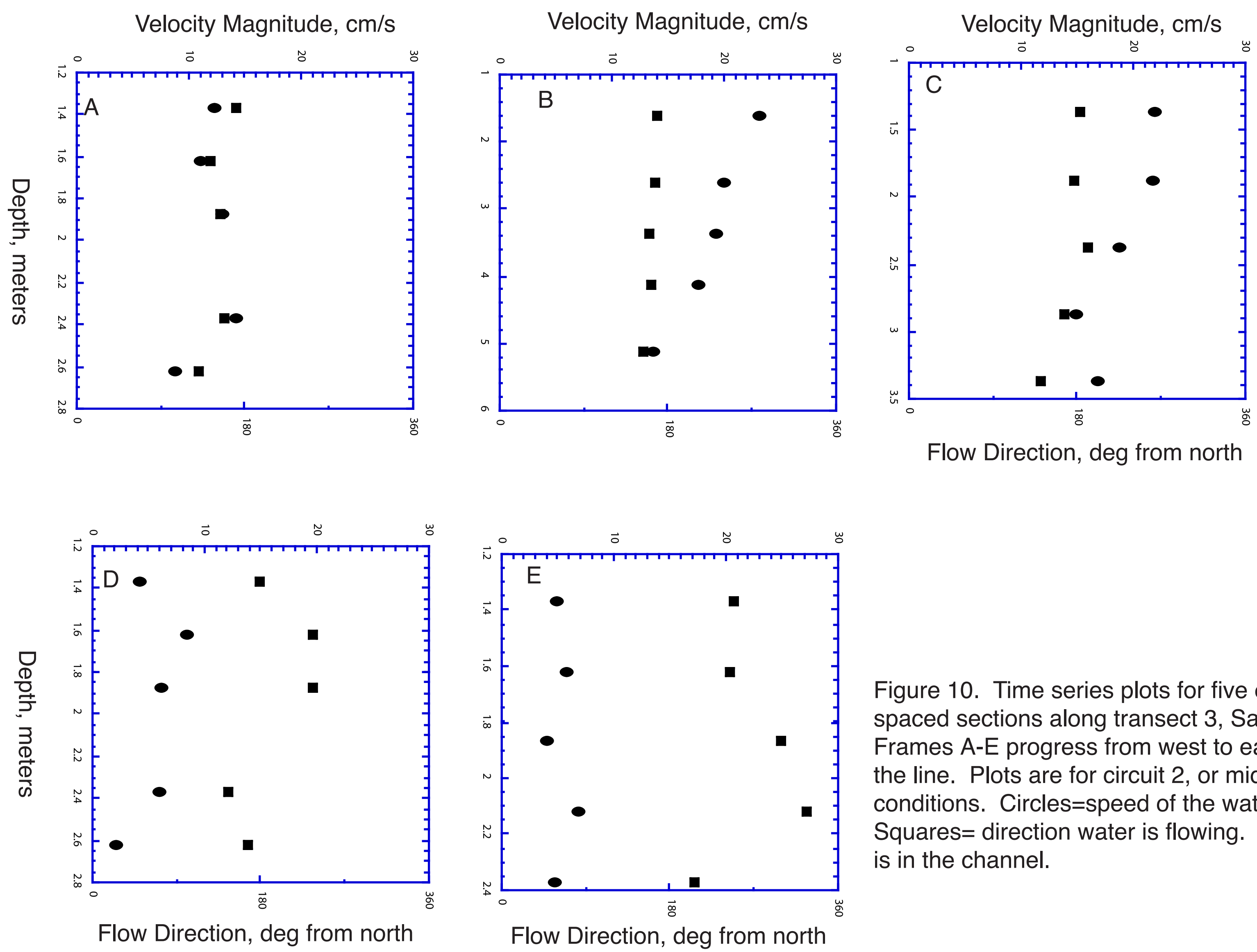


Figure 10. Time series plots for five equally spaced sections along transect 3, Sabin Pt. Frames A-E progress from west to east along the line. Plots are for circuit 2, or mid-late ebb conditions. Circles=speed of the water. Squares= direction water is flowing. Plot B is in the channel.

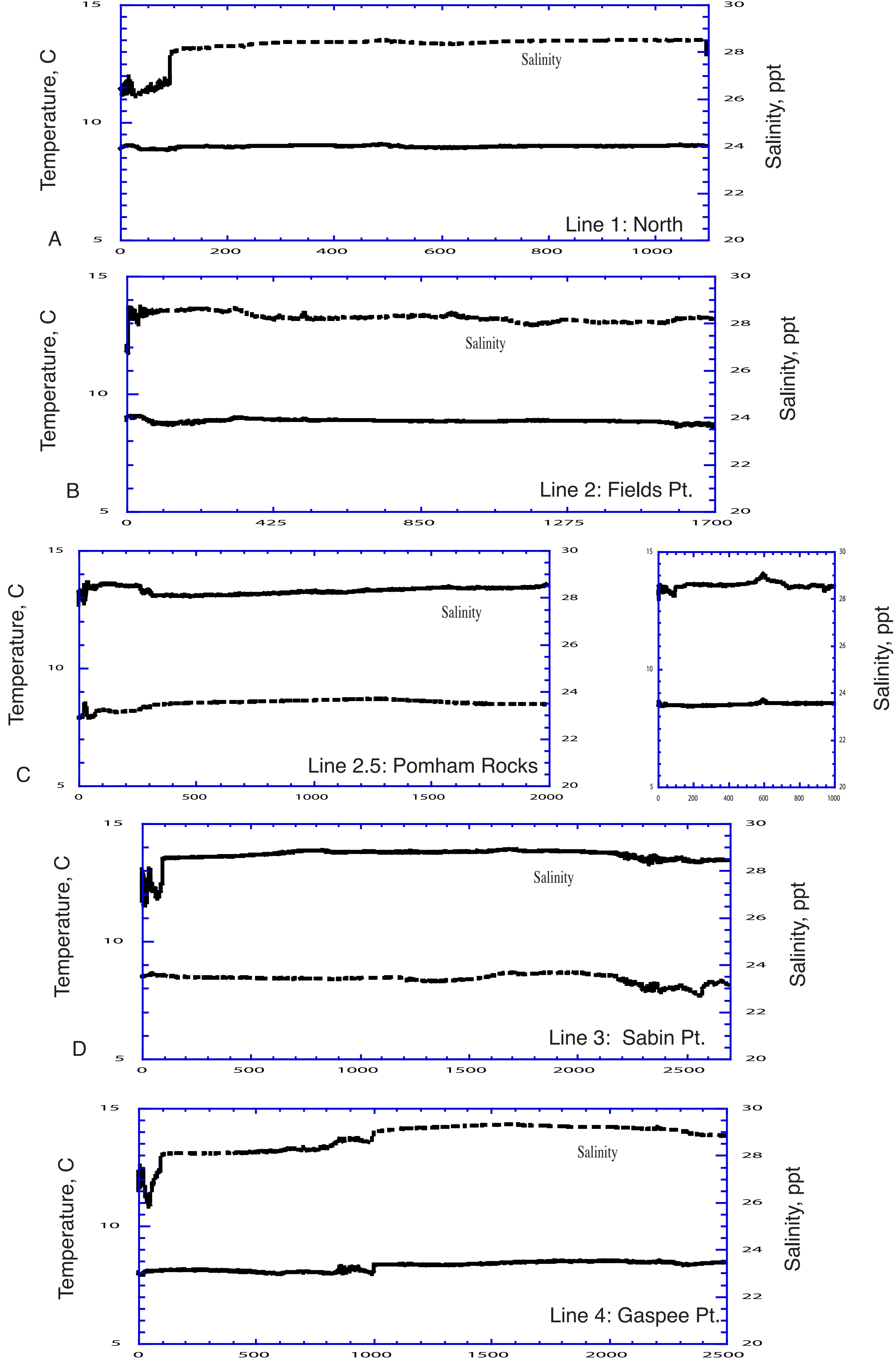


Figure 11: Plots of temperature and salinity measured at the surface versus distance across the estuary for Circuit 1 (early ebb). Orientation is east on the right, west on the left.   Plot C, Line 2.5, is split in two parts due to a delay at the channel from passing ships.

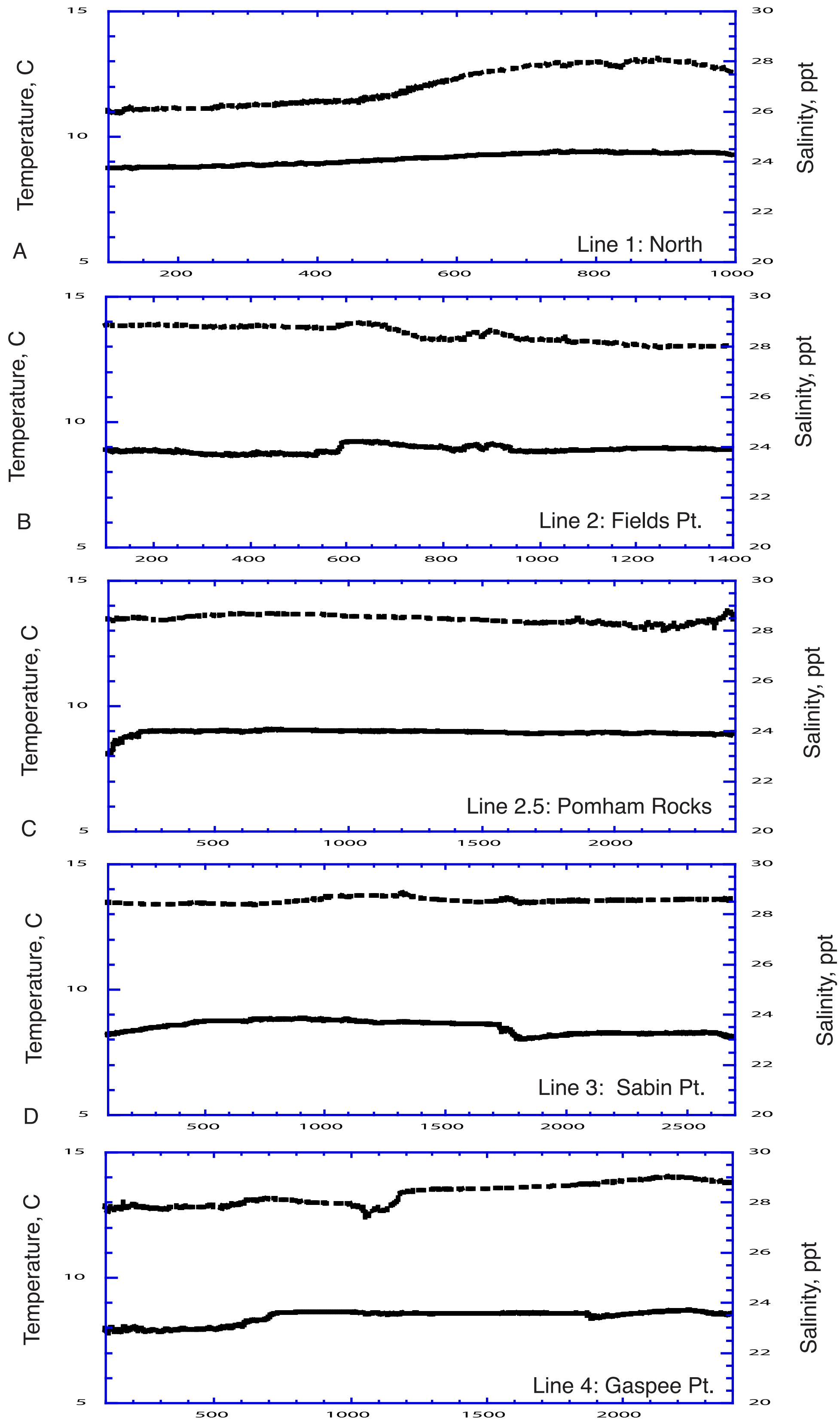


Figure 12: Plots of temperature (SOLID) and salinity (DASHED) measured at the surface versus distance across the estuary for Circuit 1 (early ebb). Orientation is east on the right, west on the left.   Plot C, Line 2.5, is split in two parts due to a delay at the channel from passing ships.