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

Final Report Prepared
for Microinorganics
August, 2001

1.0 Introduction

A 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. Flow in estuaries occurs over a range in temporal and spatial scales in response to a variety of competing driving mechanisms. Estuaries exhibit both high frequency tidal and lower frequency non-tidal flow. Narragansett Bay, on average, is well mixed because of strong tidal motions interacting with highly variable bottom topography. Circulation in the upper Bay has been shown to be driven in roughly equal parts by tidal and wind forcing [Weisburg, 1976]. These landmark studies (Weisberg 1972; 1976; Weisberg and Sturges, 1976) show that wind effects can permeate the entire water column and highlight the importance of the wind in net estuarine circulation and transport patterns, a finding which is consistent with other areas (e.g., Garvine, 1985; Goodrich, 1988). Narragansett Bay is generally classified as a temperate, partially to well-mixed estuary. Because vertical density gradients are considered to be small in well mixed estuaries, density driven flow in the Bay is not expected to be as significant as other forcing mechanisms. However, both survey areas are more typical of partially mixed or salt wedge estuaries, with significantly larger vertical gradients in salt and temperature. Moreover, these surveys are conducted during the summer period, when vertical density gradients are expected to reach maximum values in terms of seasonal variations.

Narragansett Bay clearly represents an important ecosystem and an important resource for the State of Rhode Island. Stress levels on the Bay ecosystem have been rising as a consequence of both man-made and natural sources. 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 instrument was purchased in the early 90's, but underwent a full hardware and software RDI manufacturers upgrade/refurbishment process in 2000. 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 each line is sampled twice, first west to east and then east to west. On the east to west pass a SeaBird SB19 CTD was dragged behind the boat at roughly 1 meter depth. Sampling began on July 22, 2001, on the southernmost line (4) and progressed northward to lines 3, 2 and 1. A complete sampling of each transect line is referred to as a circuit. Five circuits were completed over the course of the day (Table 1). The first two coincided roughly with early and late flood conditions. Circuits 3 and 4 covered roughly early and late ebb conditions. Circuit 5 was late in the day, corresponding to slack before flood conditions, and included only transect lines 2 and 3 (Table 1A). The wind was moderately high (10-20 mph) out of the south-southwest for most of the day.

A second day of sampling (July 23,2001) 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 22). 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 22). Four circuits were completed over the course of the day. Sampling followed the methodology from the Providence River survey, beginning at the southernmost line (4) and progressing northward.

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 2-3 transect lines (for lateral structure) within the channel and, if possible, out over the shoals. Next, a time series data set (4-5 minutes of data collection) would be conducted by holding position within the channel using an anchor to provide maximum data quality for vertical flow structures within the channel. As shown in Table 2a, not all transect lines were sampled on each circuit. Once the water level became high enough, it was determined, through consultation with the Cullen (Lead Investigator) that emphasis should be placed on lines 2 and 3. Attempts were made to drive transect lines over as much of the shoals as possible, particularly on line 2 near the outfall. For this reason line 1 was not sampled in circuits 3 and 4.

The set of sampling parameters for the ADCP are referred to by configuration file numbers in Tables 1a and 2a. 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. Tables 1b and 2b list the details of each configuration file. 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 2-6). 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 running smoothing filter. Often data collected with the ADCPs in such a manner is averaged in the field. For example, 4 pings of data will be averaged together and saved as a single data ensemble. Our experience has been that it is preferable to save all pings, or ensembles, referred to as single ping data, so that bad profiles may be removed before the averaging process.

The contour plots provide the best representation of lateral structure in flow through the transect plane. Circuit 1 was conducted during early flood conditions and results are shown in Figure 2. The two southern lines exhibit somewhat similar patterns with weakly flooding water at depth in the channel and weakly ebbing water at the surface in the channel. Velocities in the channel are roughly 10-15 cm/s. The shallower shoals exhibit more variable conditions, with alternating inflows and outflows, typical of transitional periods where the water moves in eddies. Further north, on line 2, the majority of the channel is flooding, with maximum velocities (35-40 cm/s) recorded on the eastern side. These strong flooding currents were noted in the field record, specifically in terms of difficulty maintaining a straight course. A well defined, southerly flowing or ebbing pool of water is recorded on the western side of the channel, extending onto the eastern side of the shoal. The western portion of this line extends across the shoal to the shore on the south side of Fields Point. This section of water shows northerly flow. Finally, along Line 1, north of Fields Point, the water is predominantly flooding, with maximum velocities (>30cm/s) recorded on the bottom. Interestingly, a pool of southward flowing surface water is recorded on the eastern side of the line.

Highlights of this circuit are variable inflow and outflow conditions, with maximum inflows generally seen in the deeper waters on each line. The pools of ebbing surface water evident in lines 1 and 2, at this stage of the flood, are also of interest.

Circuit 2 was conducted over a period running from mid-flood (Lines 3-4) to late flood (Lines 1-2). Line 4 exhibits strongly flooding currents throughout the entire channel, extending onto the eastern shoal (Figure 3). Velocities vary between 25-60+ cm/s. On the far eastern side of the line, water flow is weakly northward. On the western side of the line water flow is weakly ebbing. A similar feature is seen on the western side of line 3. Here the stronger flooding water is confined to the deeper portion of the channel and the shoal just east of the channel. Flow of surface waters in the channel are only weakly to the north as is the flow on the far eastern portion of the line. Line 2, south of Fields Point, exhinits a similar structure to line 3, with the strongest inflow in the deep portion of the channel (>40cm/s). Pods of outflowing water are recorded in the surface water of the channel. Water on the shoals on line 2 is generally moving northward.

Circuit 3 (Figure 4) began at line 4 near the transition between flood and ebb stages of the tide. The remainder of the circuit covered the early ebb stage of the tide. On line 4, the region just east of the channel is still weakly flooding. Water in the channel has started to ebb (<25 cm/s). By the time line 3 is sampled (Table 1a) the ebb is more developed, with stronger southward flows in the channel and just east of the channel. Water on the western edge of the line is flowing weakly to the south. The far eastern portion of the line appears to be forming an eddy, marked by closely spaced oscillations in flow orientation. Both vertical and lateral structure is recorded on line 1, where deep water is flowing north on the west side and out at the surface. The strongest outflows hug the eastern side of the line. This general pattern is opposite what is typically expected for flows influenced by Coriolis acceleration, suggesting the cross section is influenced by the entrance to the Seekonk River, directly above, or north of, the eastern side of this line.

The latter half of the ebb is characterized during circuit 4 (Figure 5). Figure 5 C-D show results for line 4, along which the computer crashed forcing the transect to be divided into two separate files. Line 4 exhibits features which are opposite from conventional estuarine flow influenced by Coriolis acceleration, similar to Line 1. The strongest ebb currents are in the channel, with magnitude in range of 40-70 cm/s. The eastern shoals are also ebbing at a slightly reduced rate (10-30 cm/s). Here it is the western portion of the line which exhibits weak northerly currents. Again simple reasoning would suggest that Coriolis acceleration should produce more northerly currents (inflows) on the eastern side, instead of the western side.

Line 3, across Sabin Point, exhibits a similar pattern in flow to that of Line 4, except that it is essentially flipped about the channel axis. Here maximum ebb currents are in the channel, however it is the eastern shoal which exhibits weak northerly flow during the eb portion of the tidal cycle. Water on the western side of line 3 is weakly ebbing. This pattern is consistent with what would be expected from flow influenced by Coriolis forcing.

One of the more interesting transect lines is recorded along line 2 during this period (Figure 5A). One important question is whether a strong outflow from Fields Point turns west at this point, heading for the shoreline along the Edgewood region of Cranston. A strong influence from Coriolis acceleration might be predicted to turn surface waters to the right (looking in the direction of flow, or down river). However, data along this transect show the strongest outflow core is concentrated along the eastern edge of the shoals and western half of the channel. The portion of the transect (western shoal) which would record such a flow headed toward Edgewood shows northerly moving water. Interestingly, the eastern side of the line also exhibits flooding water. As mentioned previously, the majority of the transect lines where driven twice before moving on to the next station (Table 1). Figure 6 shows data from Line 2 for this same time period for different passes, using two distinct ADCP settings. The shallow water portion of the line (Line 2c in Figure 1) was sampled a second time with a high resolution setting (water mode 5). The same basic structure (Figure 6B) of outflow on the eastern shoal and northward flow on the western shoal is seen on this pass as on the first pass with a courser ADCP setting (Figure 6A). This result suggests such a westward deflection of the outflow is not occurring.

A final abbreviated circuit was conducted at the end of the day, covering lines 3 and 2. Data are shown in Figure 7. The wind had picked up at this time increasing wave activity and lowering data quality. Wave activity and increased pitch and roll often produce striping in the data, which is the case here, particularly along Line 3. The data generally show little coherent structure on line, which is often recorded during transitional periods. Line 2 shows a more coherent region of flooding over the majority of the cross section.

Providence River Salinity/Temperature

The CTD data collected during the individual circuits are summarized in Figures 8-11. During the early flood conditions of circuit 1 (Figure 8), the surface water roughly progresses from warm/fresh to cool/salty in moving from north to south. Line 3 shows the most interesting lateral structure. Fresher water is recorded on the western half of the line. Lines 4 and 1 show more uniform water properties across the estuary, although the water on the eastern side of line 1 is slightly fresher. Line 4 shows no evidence of fresher water on the western side. Late flood conditions show all lines to be roughly uniform from one side to the other (Figure 9). During early ebb conditions (Figure 10) strong lateral structure is again recorded on line 3, with the western side of the line again exhibiting fresher, warmer water which is consistent with a concentrated outflow in this region. Line 1 shows a slight pattern of freshening towards the central to eastern portion of the cross section.

An idea of vertical CTD structure is apparent in the data from Line 2. While crossing Line 2 we stopped to let a boat pass and the CTD fell to 3 meters depth. A drastic change in properties to high salinity, low temperature reading is seen in Figure 10B which demonstrates the strong vertical density structure within the Providence River.

Circuit 4, covering later ebb conditions, showed interesting flow structure on Line 2 (Figure 6). Figure 11A shows that the northeasterly flow on the western portion of the line is carrying relatively warm, salty water. A rapid change in properties (towards fresher water) is also recorded roughly half way across the shoals, where the ADCP recorded ebbing currents. Interestingly, Line 3 again shows significantly fresher water on the western side of the line and saltier water to the east, a pattern which is reversed for line 4 as was the case with the general flow patterns.

Providence River: Average Velocity Profiles by Quadrant

Lines 2 and 3 are of particular interest in this study. In order to further assess flow patterns along these lines an additional processing step was made for these data. Each transect was divided into four 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 12-16 summarize averaged velocity profiles for transect Line 2, which is divided into western and eastern shoal and western and eastern channel regions. During early flood conditions (Figure 12) water in the deep channel is flooding north. Water on the western shoal is also heading north-northeast. Surface water along the western channel is heading west, feeding the southerly surface flow recorded within the eastern portion of the shoal.

Later in the flood the deep channel and the entire shoal is flooding while the surface water in the western channel region is ebbing (Figure 13). On average, the whole cross section is ebbing during circuit 3 (Figure 14), although flows on the western shoal are generally weak. Circuit 4 (late ebb) shows the structure discussed previously, where a central outflow core is confined to the eastern shoal and western channel regions, while the western portion of the shoals moves northward (Figure 15). An interesting, intermediate depth outflow lense is recorded during circuit 5 (Figure 16) in both channel profiles, while all other portions of the line are flooding.

A similar set of plots are shown for Line 3 (Figures 17-21). During flood conditions maximum inflows are recorded in the deep channel, while the shoals to either side are generally sluggish. An important result is that flow is, on average, weakly out on the western shoal during the both circuits covering the flood (Figures 17,18). During the ebb everything is pretty uniformly flowing south, on average (Figures 19,20). The channel shows fairly uniform outflow magnitudes with depth during the egg stage, as opposed to the deep inflow maximums from the flood period. Water on the far eastern portion of the line is sluggish, without any prevailing inflow/outflow structure. The only relatively strong flow in this region is recorded during the very early flood period (Circuit 5; Figure 21) when the rest of the cross section exhibits sluggish and spatially variable water flow.

Seekonk River Currents: Lateral Structure

The Seekonk River was sampled on July 22, 2001, one day after the Providence River. The wind again was out of the south which caused periods of increased wave height (~1' chop) on the river. Because the river's bathymetry includes a channel and extremely shallow shoals, two sampling strategies were followed (Table 2a). When possible, transects were driven to provide information on lateral and vertical structure of flow (Figure 22). Time averaged vertical profiles were collected at moored stations within the channel to provide information on vertical flow structure over different tidal stages. During circuit 1, which represented ebb to flood transition, the two southern Lines 3 and 4 show significant lateral structure. In Figure 23b, water is ebbing on the western side, in the bottom of the water column. A weak inflow is seen on the eastern side of the line, which may extend further east over the shoals. Further north on Line 3 the eastern side of the line shows flooding water in the 3/4 of the channel cross section, while the western channel and probably western shoals are ebbing (Figure 23A). When the flood is fully established (circuit 2), a strong inflow core of water, with velocities >60cm/s, hugs the eastern side of the channel at lines 3 and 4 (Figure 24).

During high water conditions, transect lines were extended out over the shoals and sampling was focussed on Line 2. Figure 25 summarizes flow conditions during early ebb period of the tide. Water is seen to flow outwards (southward) over the entire cross sections of transects 2-4 at average speeds of 20 cm/s. Pods of faster moving water are recorded, particularly in the western half of the channel on Lines 3 and 4. Figure 25A shows a line that extends eastward to a point just south of the outfall pipe at Bucklin Point. While the water here is ebbing, it is more sluggish than the rest of the transect line. A similar pattern of slower flow than the rest of the cross section is recorded later in the ebb (Figure 26). Figures 26 A and B characterize water flow patterns in the channel and up close to the Bucklin Point outfall, respectively. Maximum ebb currents are recorded in the surface waters of the channel and weaker outflow is seen near the outfall.

Seekonk River Currents: Vertical Structure in the Channel

Figures 27-30 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. Figure 28 shows data from transect line 2. During circuits 1 and 2 water is flowing north over the entire profile. Higher inflows are recorded in the bottom half of the water column (30 cm/s versus 16 cm/s) during mid-late flood conditions (Figure 28B). During ebb conditions the deeper outflow is weaker than the surface (18cm/s versus 30cm/s: Figure 28D). This pattern is characteristic of a partically mixed estuary where in a net, non-tidal sense, deeper water flows in and surface water flows out. The transition in flow seems to be between 2.5 and 3 meters depth (Figures 28B,D).

Results within the channel at line 3 are similar. Figure 29 summarizes vertical flow structure over the tidal cycle at line 3. Figures 29 B and C show profiles during flood and ebb conditions. During flood the mid-depth water is moving north the fastest and both bottom and surface water are more sluggish. During ebb conditions the lower 2/3 of the water column moves south, but at a low rate (10 cm/s), while the upper 1/4 of the water column moves out at close to 30 cm/s. Later in the ebb (Figure 29D), the pattern is similar except that bottom water is even weaker, almost stagnant. Line 4 shows a similar pattern of water flooding stronger on the bottom and ebbing stronger near the surface over the tidal cycle. An interesting feature of these profiles seems to be that the vertical structure in flow between flood and ebb conditions becomes less distinct, or more diffuse, in moving from stations 2 to 4, or from north to south.

5.0 Conclusions

<u>Providence River:</u> The combination of flow and CTD information suggests that line 3 behaves in a manner consistent with classical Coriolis influenced estuarine flow. Maximum inflows/outflows are seen in the channel and a net outflow, carrying fresher water is persistent on the western side of the line. Line 2 does not show a similar pattern. Here the outflow generally hugs the western side of the channel and is likely fed, on average, by a clockwise eddy existing in the western portion of the river. Transects 1 and 4 behave in an opposite sense to this classical picture. Generally fresher water and more persistent outflows are recorded on the eastern portions of the transect lines. The pronounced lateral structure in outflow recorded at line 3 is not present further south on line 4, where only subtle differences in water properties are recorded

across the transect. Line 1 appears to be influenced by the local geometry, specifically the entrance of the Seekonk River into the eastern side of the Providence River.

<u>Seekonk River:</u> ADCP measurements within the Seekonk River show high degrees of lateral and vertical structure in the flow. Water appears to move inward, in a net sense, on the eastern side of the river and at depth within the channel. While we were not able to sample over the eastern portion of line 4, there appears to be a very strong lateral structure at this point. Water moves out, or ebbs, in a net, non-tidal sense over the western shoals and at the surface in the channel. In the vicinity of the Bucklin Point the water, when we could measure it during early to mid ebb conditions (e.g., high water), was moving more slowly to the south than the rest of the Line 2 cross section. Although it is difficult to say without more measurements over the flood stage of the tide, the weak outflows recorded here and the local geometry suggest the area of Bishop Cove, south of the outfall, might be marked by a weak eddy which limits water exchange from the region. The Seekonk River channel exhibits characteristics which are typical of density driven estuaries where net non-tidal flows are in at depth and out at the surface. The transition between flow regimes is relatively sharp at Line 2, occuring at ~2.5 meters depth, and appears to be more diffuse further south on Lines 3 and 4.

6.0 References.

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Table 1a: Summary of information for Providence River ADCP survey, July 23, 2001. Information includes the time the transect line was started, circuit number, transect line number and the ADCP internal file number. The configuration file number refers to the software file ead by the ADCP which controls the ping and averaging characteristics of the ADCP. Also included is the trend of the line (E=east; W=west) and whether a CTD tow was conducted on that line.

Time	Circuit #	Transect Line	ADCP File #	Config. File	Trend	CTD Cast #
05:42	1	4	01	04	W>E	-
06:00	1	4	02	04	E>W	22
06:31	1	3	03	04	W>E	-
06:51	1	3	04	04	E>W	23
07:18	1	2a	05	04	W>E	-
07:26	1	2b	06	04	E>W	24
07:30	1	2c	07	05	E>W	24
07:47	1	1	09	04	W>E	-
07:51	1	1	10	04	E>W	25
08:13	2	4	11	04	W>E	-
08:29	2	4	12	04	E>W	26
08:52	2	3	13	04	W>E	-
09:11	2	3	14	04	E>W	27
09:35	2	2a	15	04	W>E	-
09:43	2	2b	16	04	E>W	28
09:46	2	2c	17	05	E>W	28
09:53	2	2c (2/3 of line)	19	04	E>W	on/off, 29
10:06	2	1	20	04	W>E	-
10:11	2	1	21	04	E>W	30
10:57	3	4	22	04	W>E	-
11:14	3	4	23	04	E>W	31
11:43	3	3	24	04	W>E	-
12:00	3	3	25	04	E>W	32
12:28	3	2a	26	04	W>E	-
12:37	3	2b	27	04	E>W	33
12:44	3	2c	29	?05 or 04?	E>W	33

13:06	3	1	30	04	W>E	-
13:11	3	1	31	04	E>W	34
14:10	4	4	32 and 33	04	W>E	35
14:36	4	3	34	04	W>E	-
14:54	4	3	35	01	E>W	36
15:29	4	2a	36	04	W>E	-
15:44	4	2b	37	04	E>W	37
15:48	4	2c	38	04or 05?	E>W	37
16:17	5	3	39	04	W>E	
16:47	5	2	40	04	W>E	

Table 1b: Configuration files/characteristics for Providence River ADCP survey

SPRAY04; Used water Mode 4, single ping(no ensemble averaging), 25cm bins
SPRAY04A: Used water Mode 4, but with 5 water, 4 bottom pings per ensemble, 25 cm bins
SPRAY05: Used shallow water Mode 5, single ping, 10 cm bins
SPRAY05A: Used shallow water Mode 5, but with 5 water, 4 bottom pings per ensemble, 10 cm bins

Table 2a: Summary of information for Seekonk River ADCP survey, July 24, 2001. Information includes the time data colletion was initiated, the circuit number, transect line number and the ADCP internal file number. The configuration file number refers to the software file ead by the ADCP which controls the ping and averaging characteristics of the ADCP. Also included is the trend of the line (E=east; W=west) for transect lines or whether the data collection was in time series mode, were the boat's position was fixed.

Time	Circuit #	Transect Line	ADCP File #	Config. File	Trend
06:40	1	4	02	04	E>W
	1	4	03	04	W>E
	1	4	04	05	E>W
07:40	1	3	05	04	E>W
07:45	1	3	06	04A	W>E
07:46	1	3	07	05	E>W
08:30	1	2	08	04	Time series GC17
08:35	1	2	09	05	Time series GC17
08:52	1	1	10	05	TS mid channel
08:57	1	1	11	05	RC22>GC21
09:11	2	4	12	05	E>W BAD
09:13	2	4	13	05	W>E BAD
09:19	2	4	14	05	TS mid chan BAD
09:21	2	4	15	04	TS mid chan.
09:26	2	4	16	05	TS BAD
	2	4	17	05B	TS BAD
09:31	2	4	18	04	E>W
09:33	2	4	19	04	W>E
09:37	2	3	20	04	E>W
09:38	2	3	21	04	W>E
			22	05	BAD
09:42	2	3	23	04	TS MID CHAN
09:56	2	2	24	04	E>W
09:58	2	2	25	04	W>E
10:00	2	2	26&27	05	E>W BAD
10:03	2	2	28	04	TS mid chan
	2	2	30/31	05B	1^{st} 20cm/s ambV, 2^{nd} 40 bins BAD

10:31	2	1	34	04	E>W GC22>RC21
10:33	2	1	35	04	W>E
	2	1	36	05 BAD	
10:45	2	1	38	04?	TS
10:55	2	1	40	05C	RC22>2/3 W shore
12:47	3	4	41	04	E>W
12:50	3	4	42	04	W>E
12:52	3	4	43	04	TS drift
13:05	3	2	44	04	E>W mid chan>GC
13:10	3	2	45	04	W>E
13:12	3	2	46	05C	E>W
	3	2	47	05	midwest shoal>GC BAD
13:20	3	2	48	04	midwest shoal>outfall
*13:30	3	2	50	05D	Outfall>Swan PT**
13:44	3	2	51	04	TS mid chan
13:56	3	3	52	04	E>W, 2/3 to shore
14:02	3	3	53	05D	W>E;4/5 shoal>barge
14:12	3	3	54	04	TS mid chan
14:29	4	2	55	04	E>W
*14:34	4	2	56	05D	3/4 to swan pt to outfall
***Water sampling ongoing at our start point					
14:44	4	2	57	05D?	outfall, lost power
14:56	4	2	58	04	TS mid chan
15:16	4	3	63	04	E>W
15:21	4	3	64	04	W>E
15:23	4	3	65	04	TS mid chan
15:32	4	4	66	04	E>W
15:33	4	4	67	04	W>E
15:34	4	4	68	04	TS drift

Table 2b: Configuration files/characteristics for Seekonk River ADCP survey
SSRAY04 used water Mode 4, single ping, 25cm bins
SSRAY05 used shallow water Mode 5, single ping (no averaging), 10 cm bins
SSRAY05B used shallow water Mode 5 , single ping(no averaging), 15 cm bins; at file 30-31 05B=ambiguity velocity=20 cm/s
SSRAY05C; used shallow water Mode 5 , single ping(no averaging), 15 cm bins; ambiguity velocity=10 cm/s
SSRAY05D; used shallow water Mode 5 , 4 water, 4 bottom pings averaged per ensemble, 15 cm bins, ambiguity velocity=10 cm/s

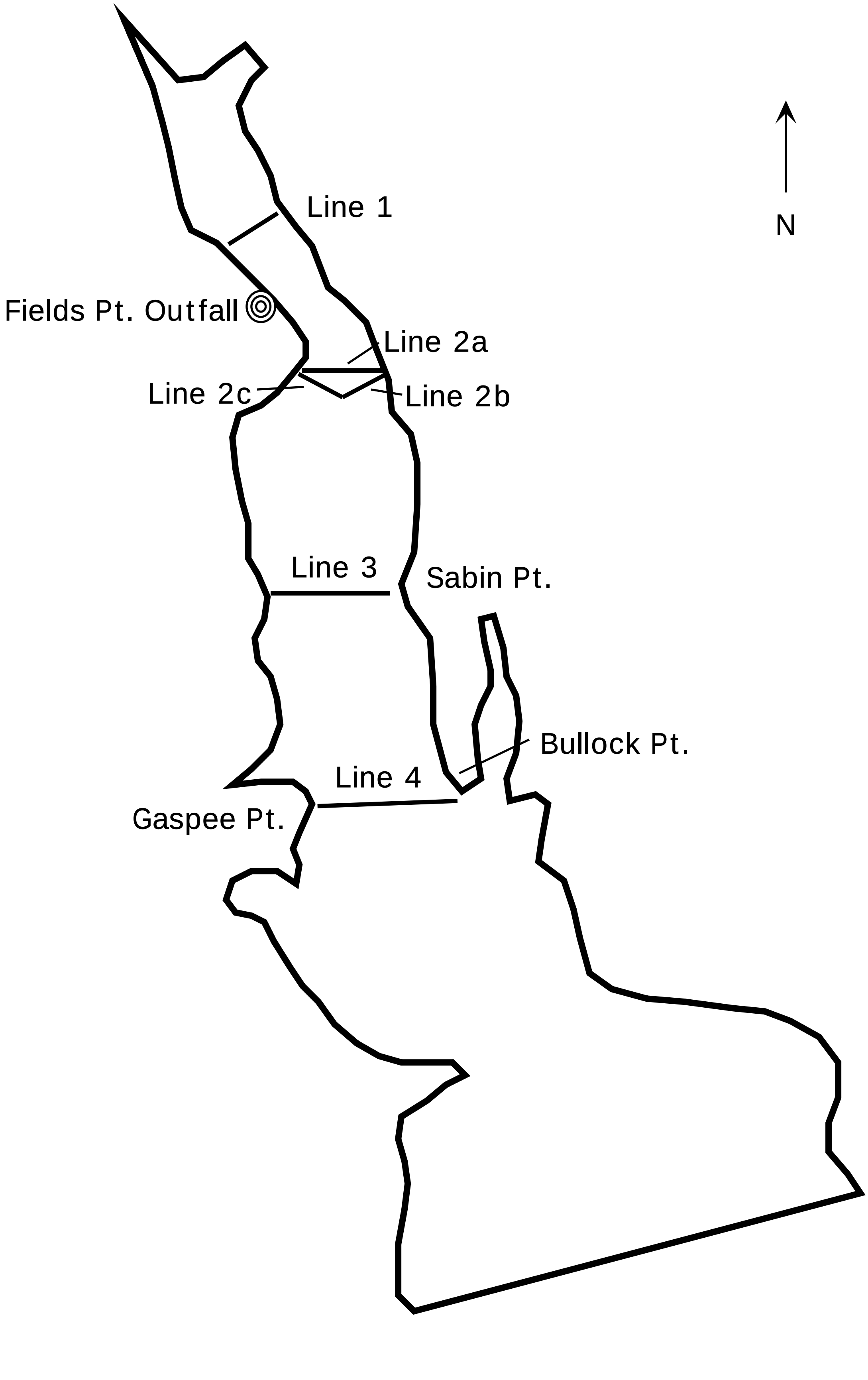

Figure 1: Map of Providence River showing locations of transect lines.

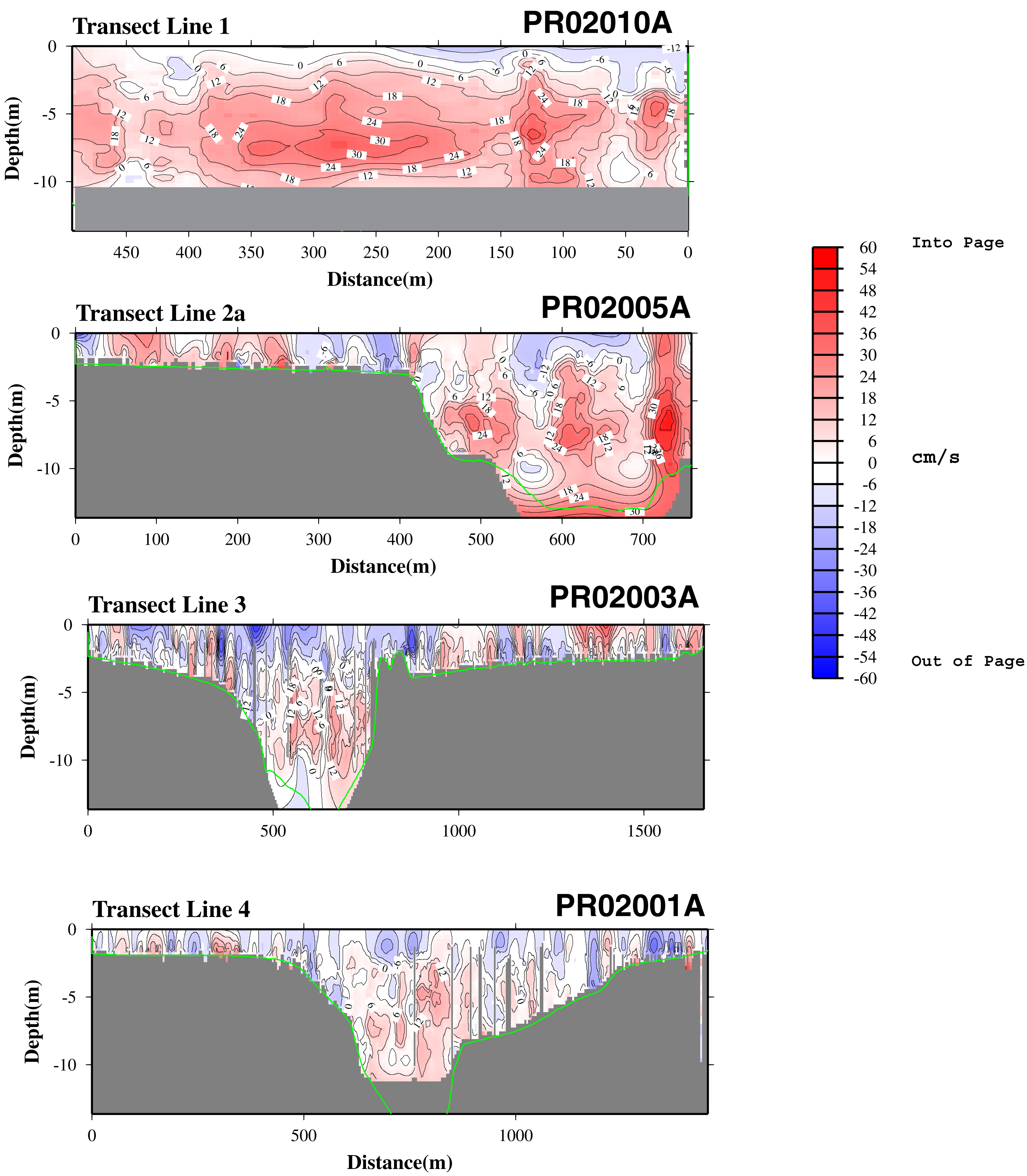

Figure 2: Velocity contour plots for circuit 1, early flood conditions. Orientation is looking north, such that west is to the left and east is to the right. Red colors are flow into the page or flooding waters, blue colors represent flow out of the page , or ebbing water.

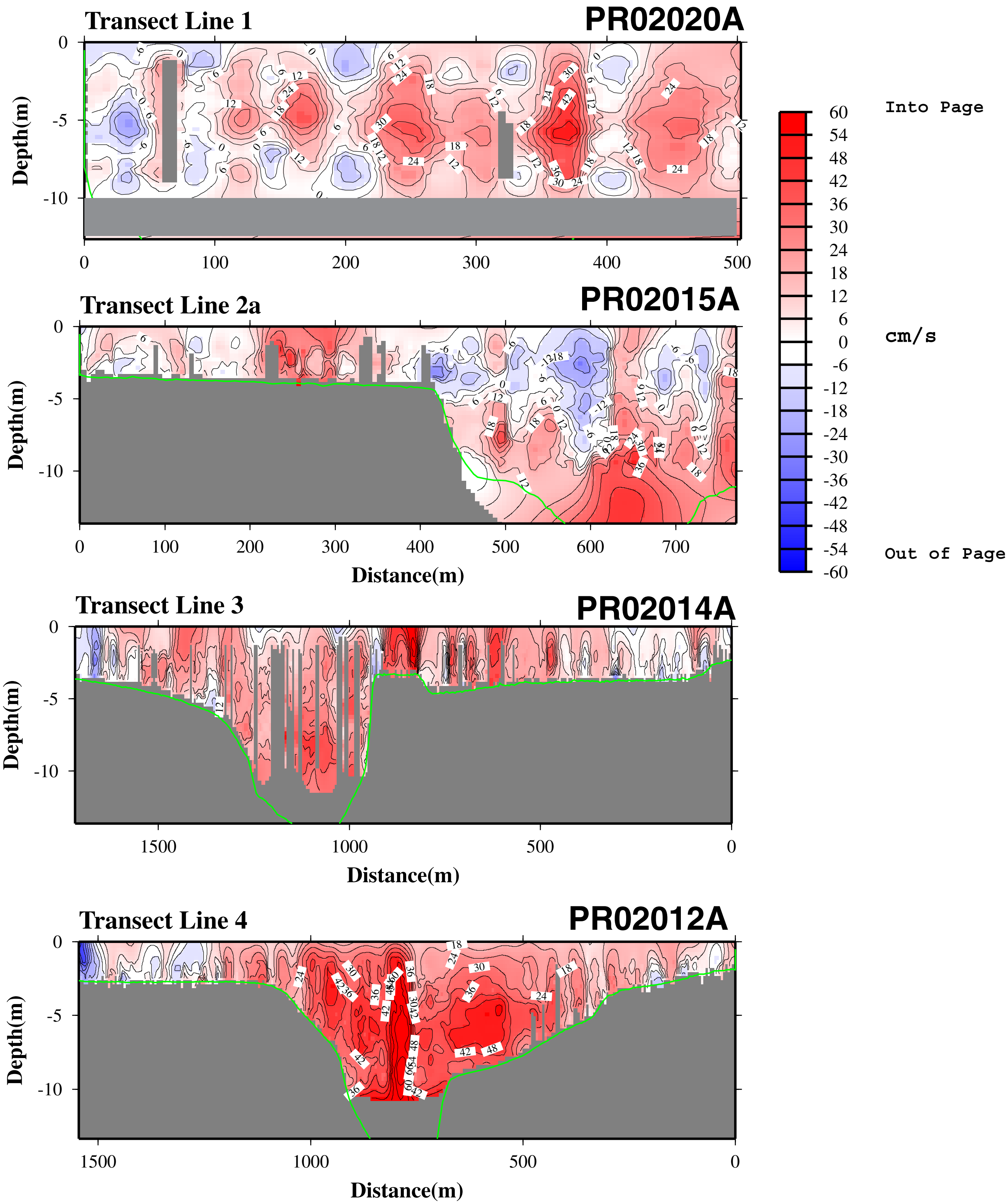

Figure 3: Velocity contour plots for circuit 2, mid-late flood conditions. Orientation is looking north, such that west is to the left and east is to the right. Red colors are flow into the page or flooding, blue colors are out of the page , or ebbing water.

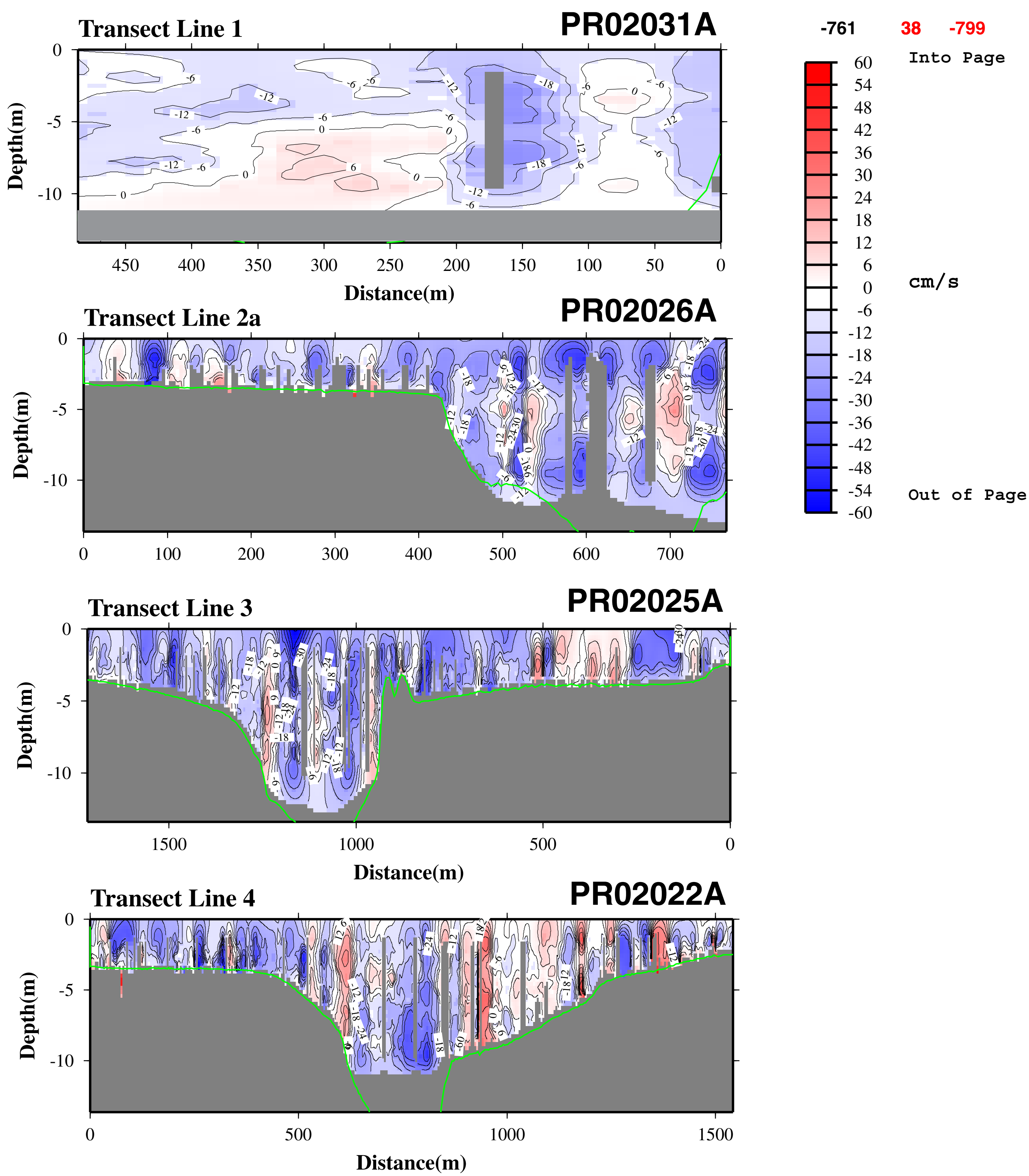

Figure 4: Velocity contour plots for circuit 3, early ebb conditions. Orientation is looking north, such that west is to the left and east is to the right. Red colors are flow into the page or flooding, blue colors are out of the page , or ebbing water.

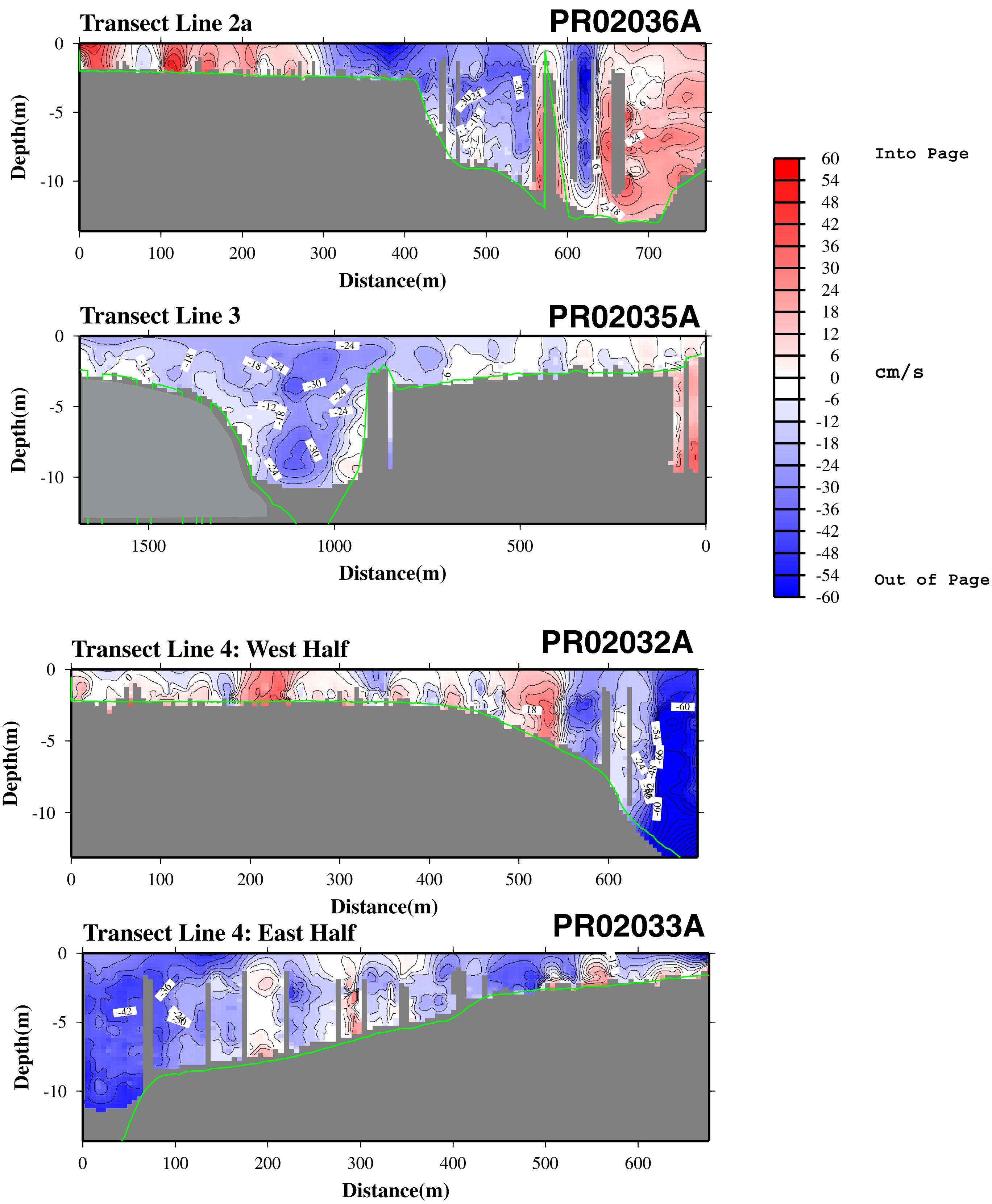

Figure 5: Velocity contour plots for circuit 4, late ebb conditions. Transect 1 is missing from this sequence. Frames represent (top to bottom); transect 2, transect 3 and the western and eastern portions of transect 4, respectively.

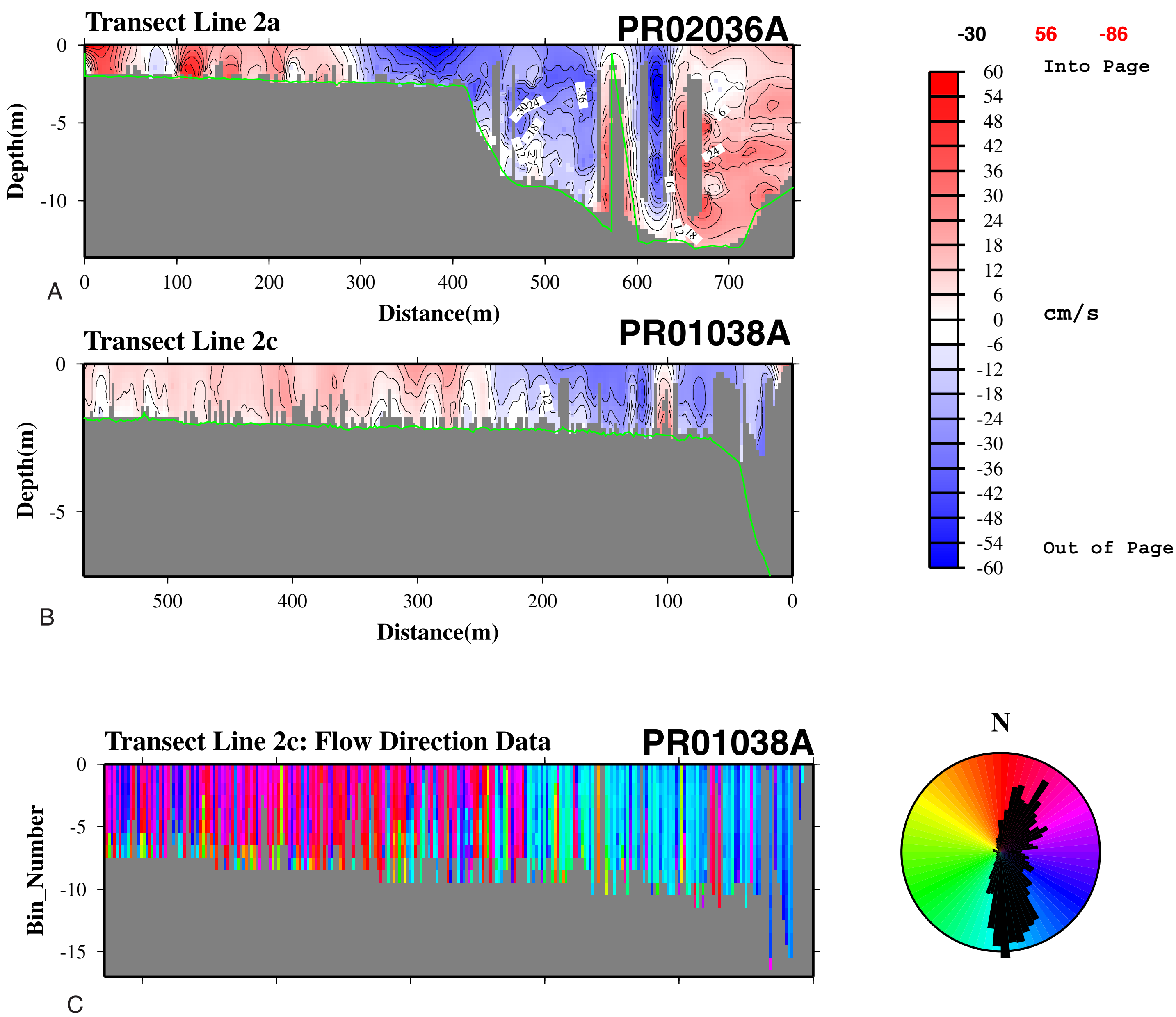

Figure 6: Velocity contour plots for circuit 4 (late ebb) conditions along transect 2, just south of fields point. Frames A and B show the velocity structure along the entire transect line (2a) and a close up of the shallower wetern section (2c). Frame C shows the flow direction information for raw data for line 2c (Frame B), prior to applying the median filter to remove "striping" in the data. Here the colors correspond to the directions indicated on the color wheel to the right of the plot. A clear line is seen in all frames between northerly flow on the western shoals of the river and a southerly flow hugging the western side of the channel.

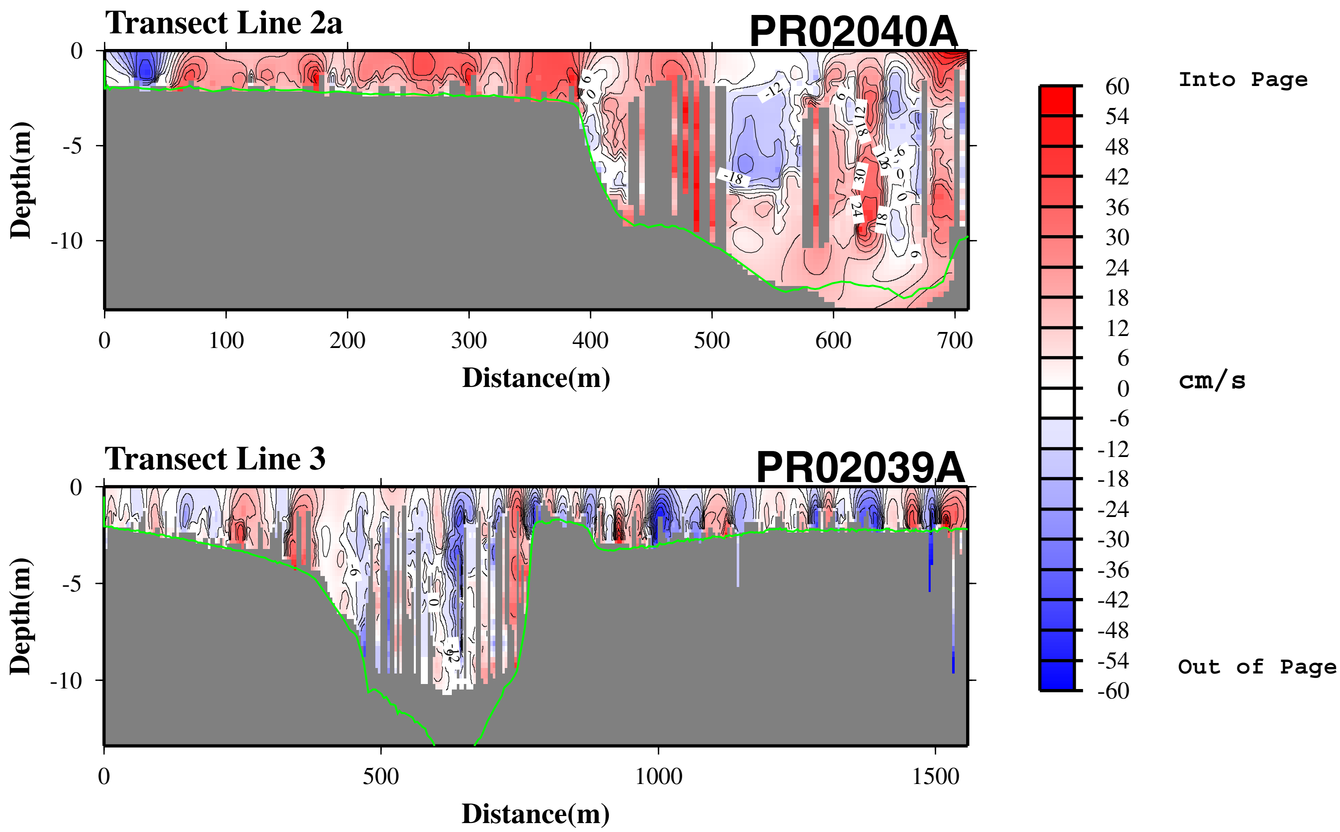

Figure 7: Contour fields of velocity projected normal to the transect line for circuit 5, or slack before flood conditions. Only two transects, 2(A) and 3(B) were occupied on this final circuit. Water is flooding now along the entire western shallow region of transect 2 and a small core of outflowing water is still seen within the channel. Further south on transect 3, the water flow is more confused, with neither dominant ebbing or flooding water masses. Instead the transect line, which was sampled ~30 minutes prior to frame A, is marked by a series of eddies.

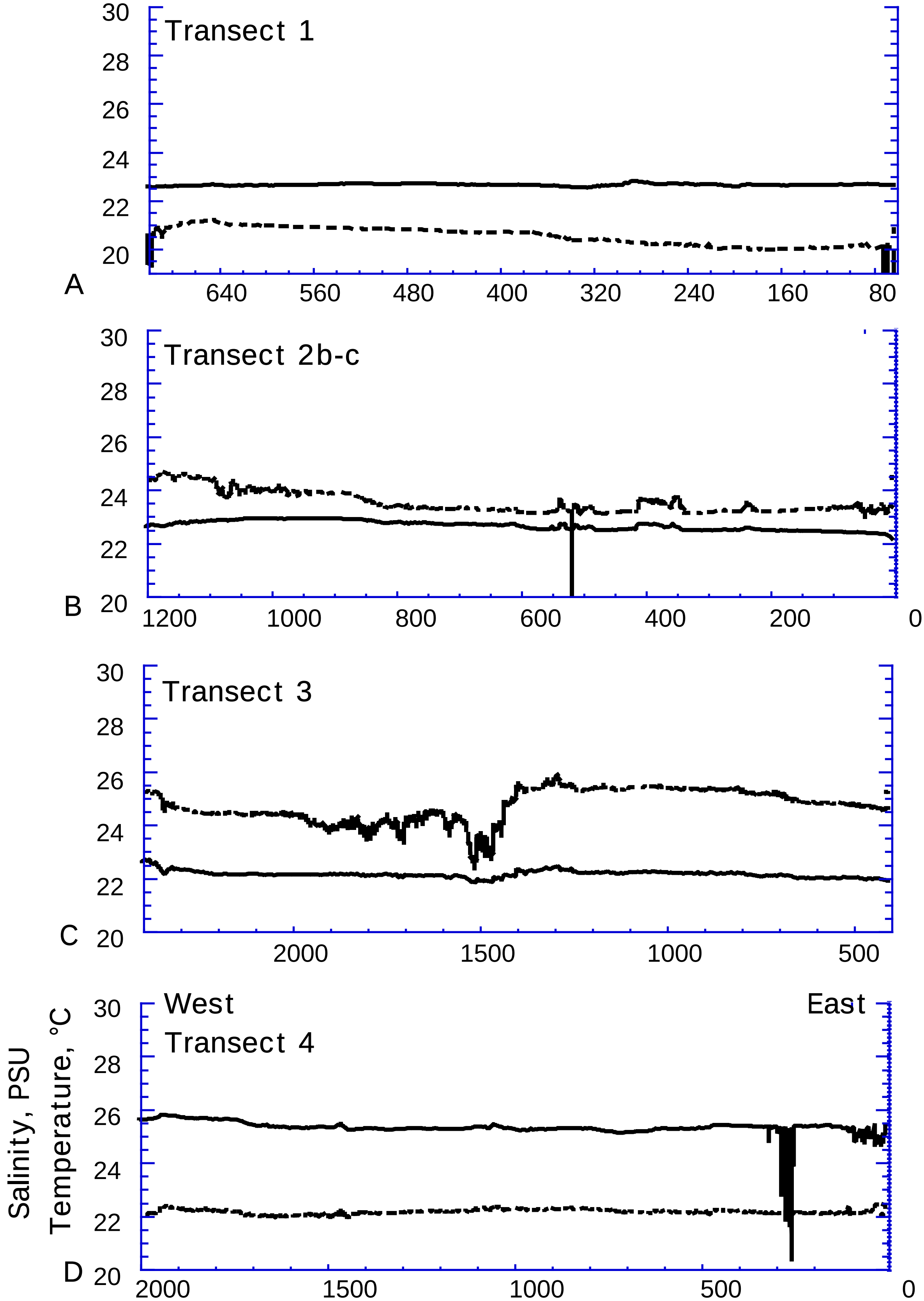

Figure 8: Plots of salinity (dashed line) and temperature (solid) versus distance across the Providence River for circuit 1. The CTD was towed behind the boat at approximately 1 meter depth. Frames A-D are for transect lines 1-4, respectively. The x-axis is sample number.

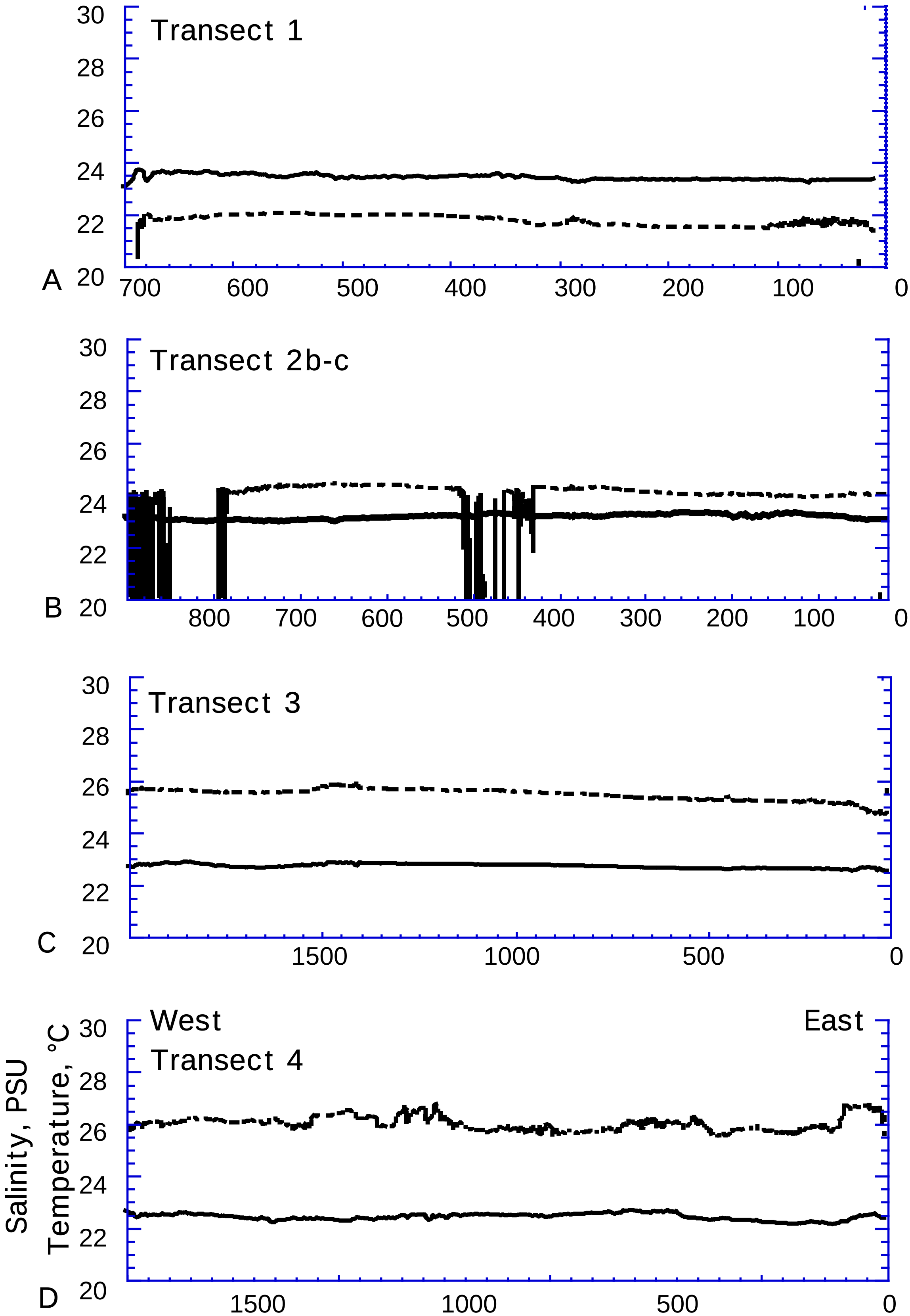

Figure 9: Plots of salinity (dashed line) and temperature (solid) versus distance across the Providence River for circuit 2. The CTD was towed behind the boat at approximately 1 meter depth. Frames A-D are for transect lines 1-4, respectively. The x-axis is sample number.

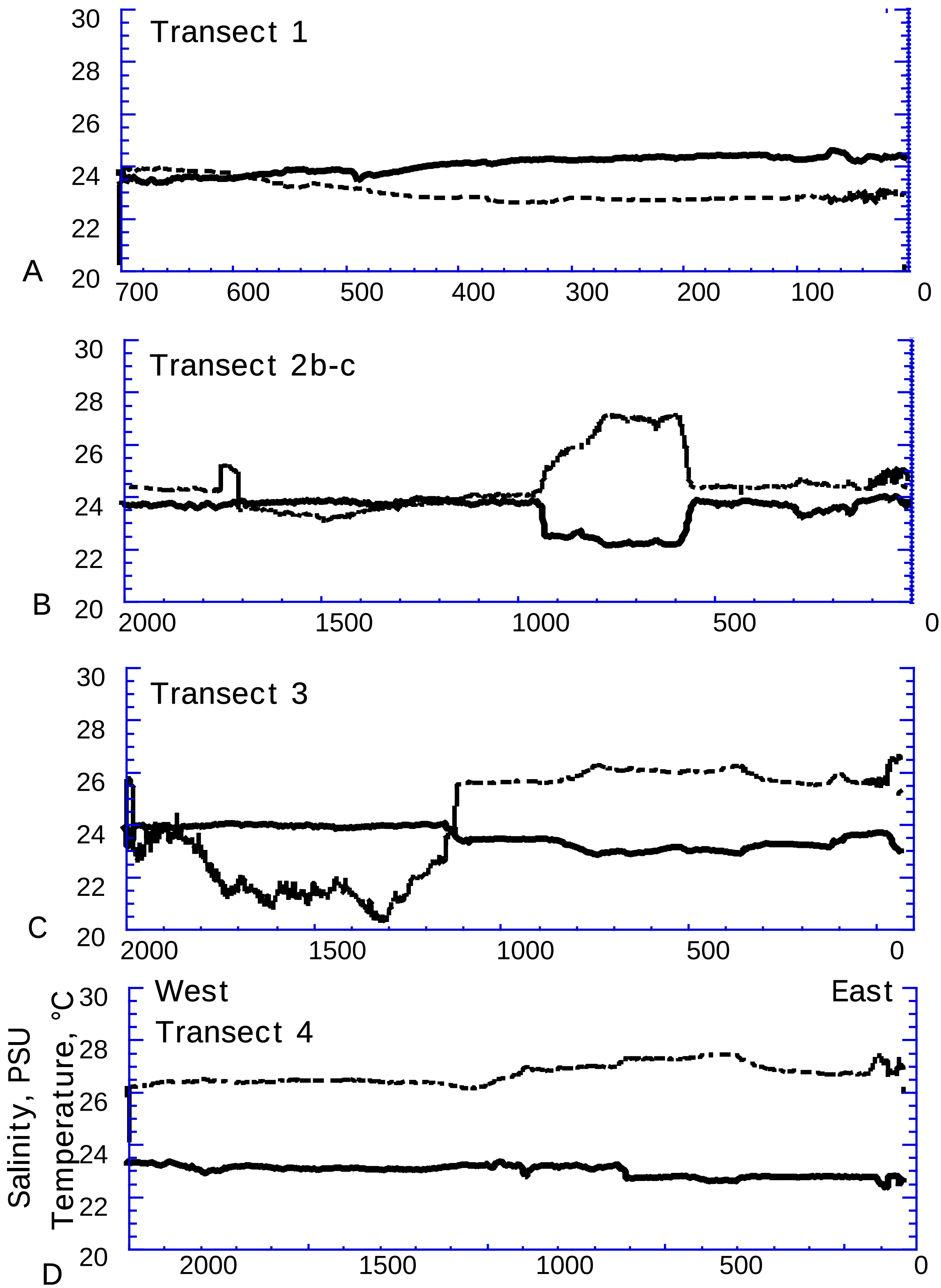

Figure 10: Plots of salinity (dashed line) and temperature (solid) versus distance across the Providence River for circuit 3. The CTD was towed behind the boat at approximately 1 meter depth. Frames A-D are for transect lines 1-4, respectively. The x-axis is sample number.

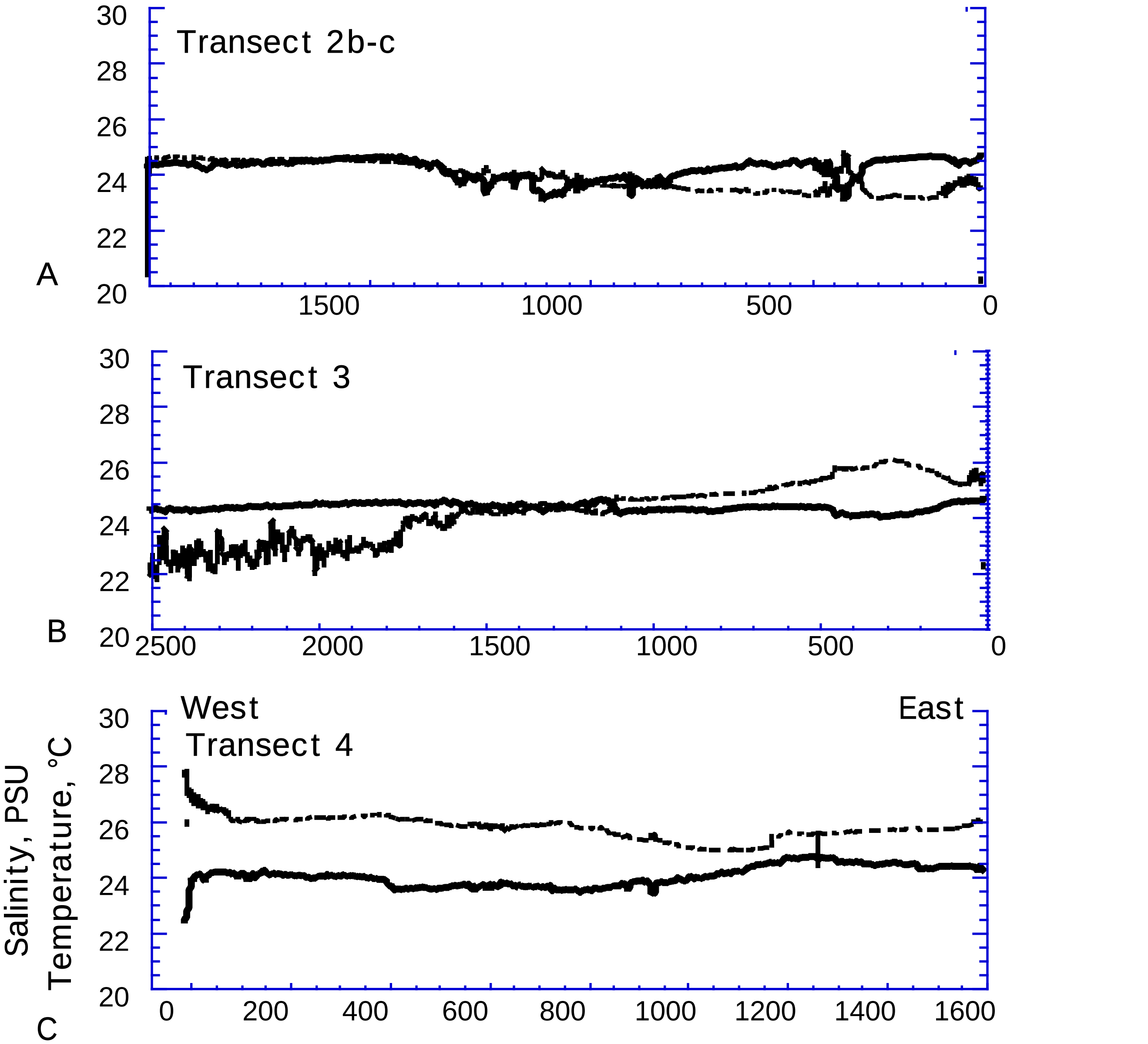

Figure 11: Plots of salinity (dashed line) and temperature (solid) versus distance across the Providence River for circuit 4. The CTD was towed behind the boat at approximately 1 meter depth. Frames A-C are for transect lines 2-4, respectively. The x-axis is sample number.

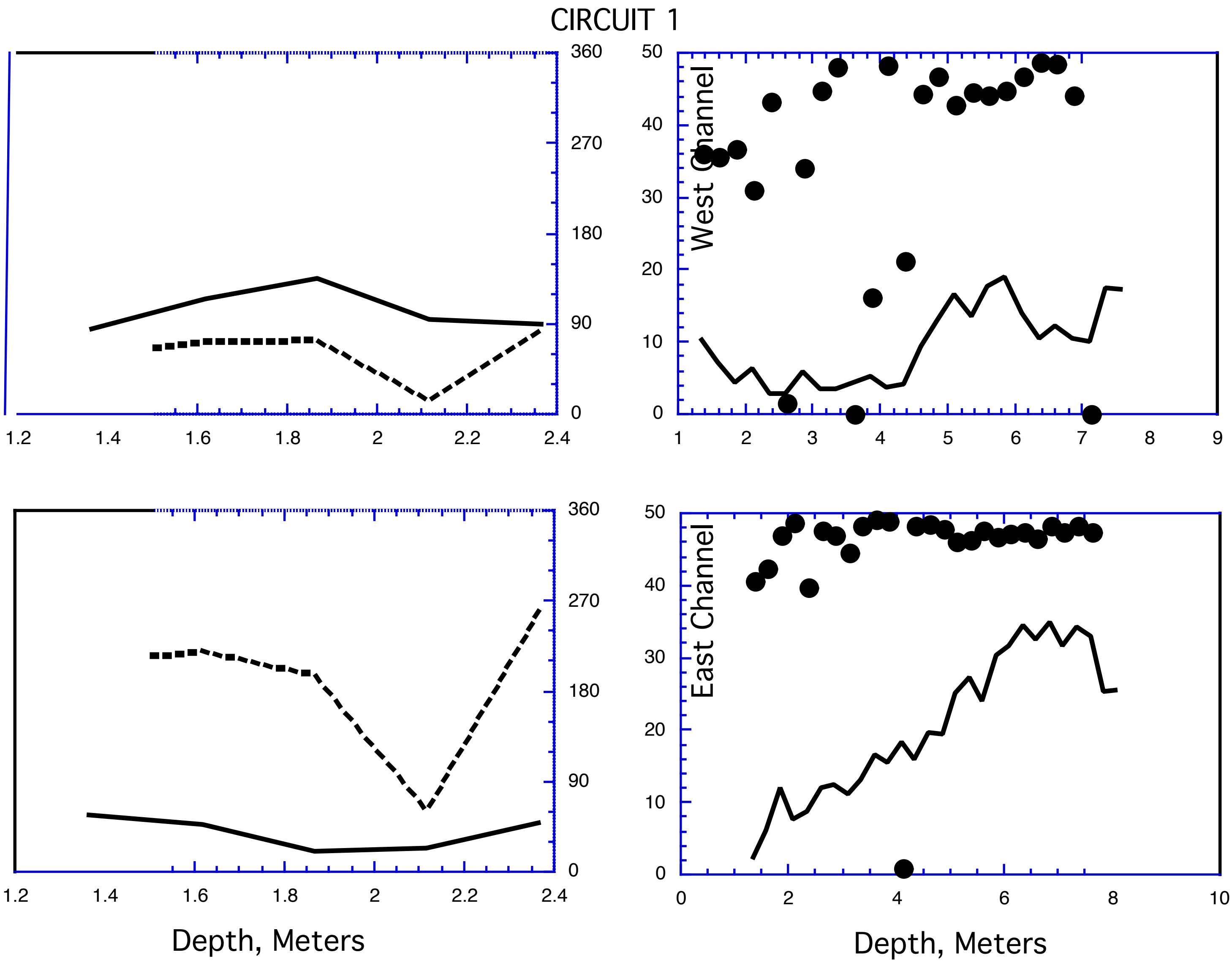

Figure 12: Laterally averaged velocity profiles for distinct sections of transect 2, south of Fields Point. Sections include shallow or shoaling region on the western half of the line and the channel, on the eastern half of the line. Time period is circuit 1, early flood conditions. Data for velocity magnitudes (or speed) are shown as solid lines. Velocity directions are shown as either dashed lines or filled circles.

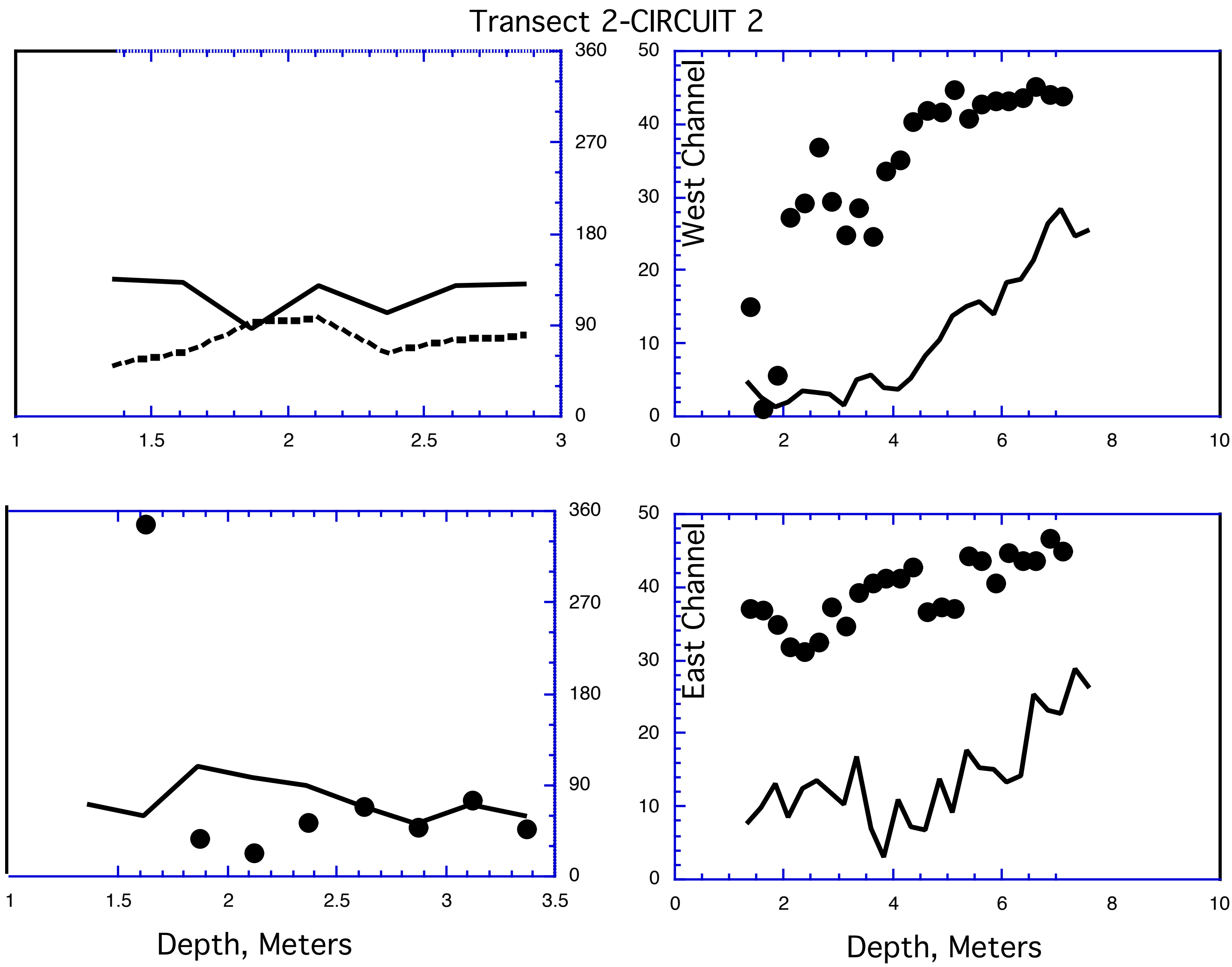

Figure 13: Laterally averaged velocity profiles for distinct sections of transect 2, south of Fields Point. Sections include shallow or shoaling region on the western half of the line and the channel, on the eastern half of the line. Time period is circuit 2, mid-late flood conditions. Velocity magnitude is shown as solid line.

Transect 2-Circuit 3

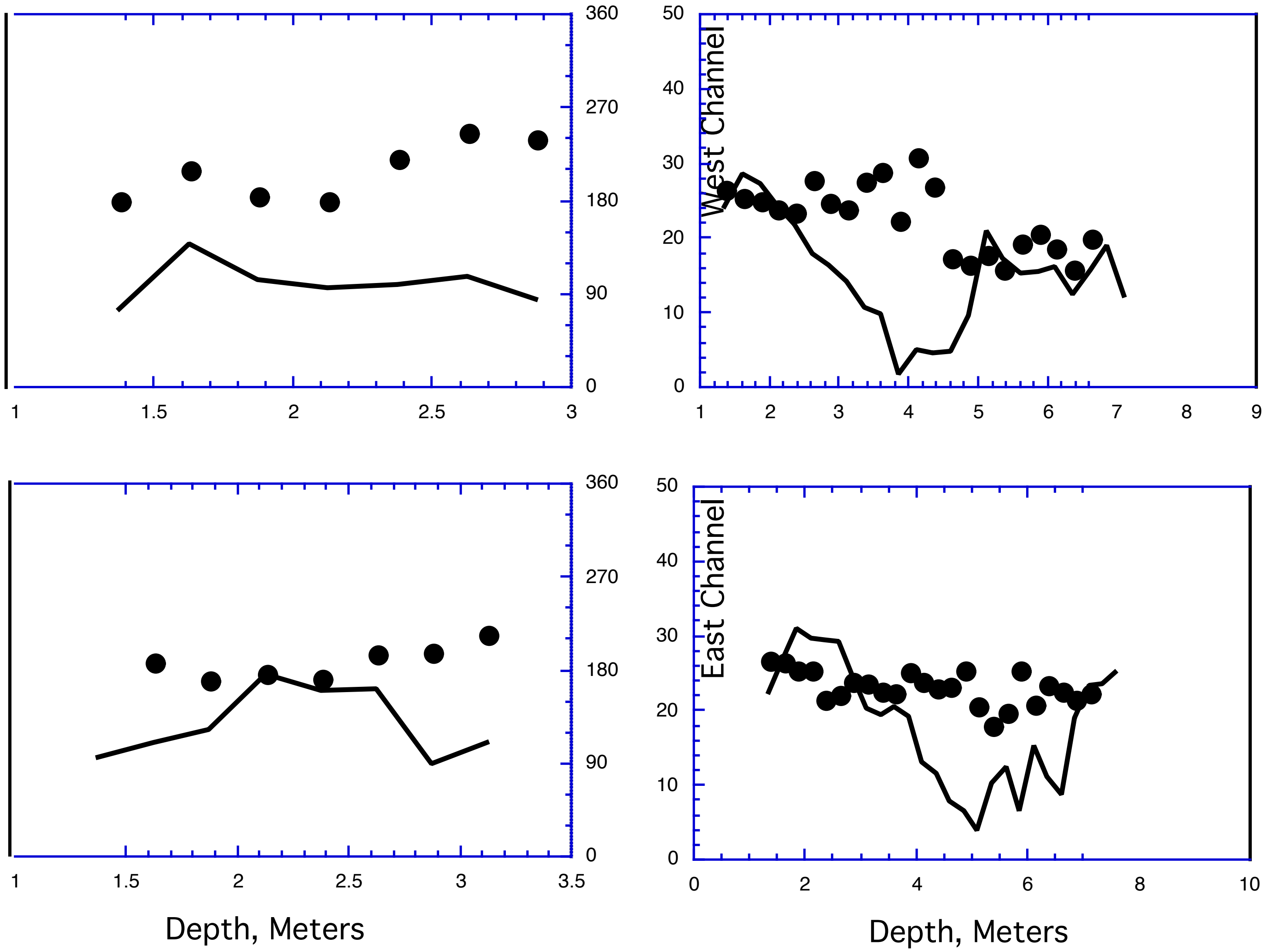

Figure 14: Laterally averaged velocity profiles for distinct sections of transect 2, south of Fields Point. Sections include shallow or shoaling region on the western half of the line and the channel, on the eastern half of the line. Time period is circuit 3, early ebb conditions. Velocity magnitude=solid line. Velocity direction=Solid dots.

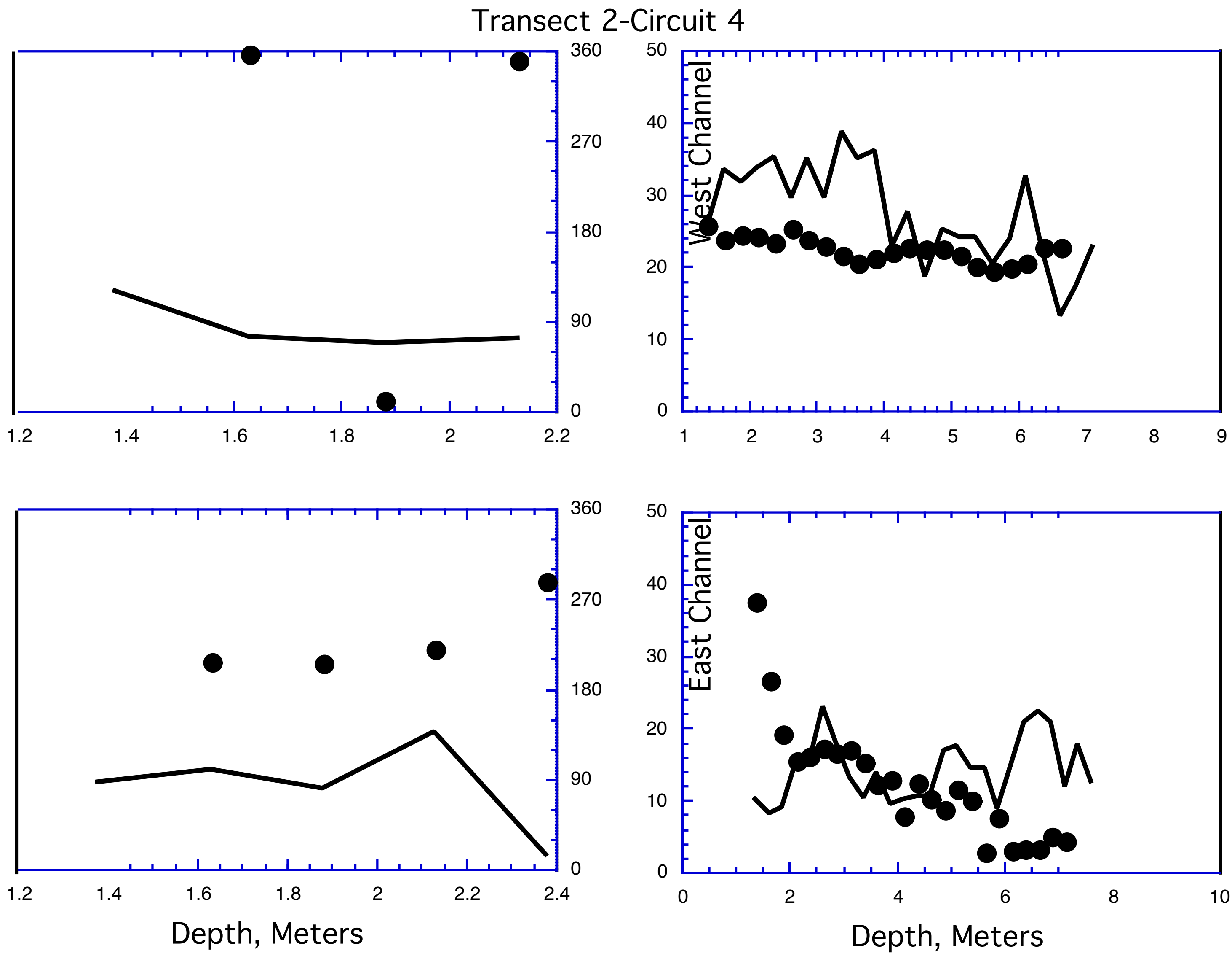

Figure 15: Laterally averaged velocity profiles for distinct sections of transect 2, south of Fields Point. Sections include shallow or shoaling region on the western half of the line and the channel, on the eastern half of the line. Time period is circuit 4, ebb conditions. Velocity magnitude=solid lines. Velocity direction=solid dots.

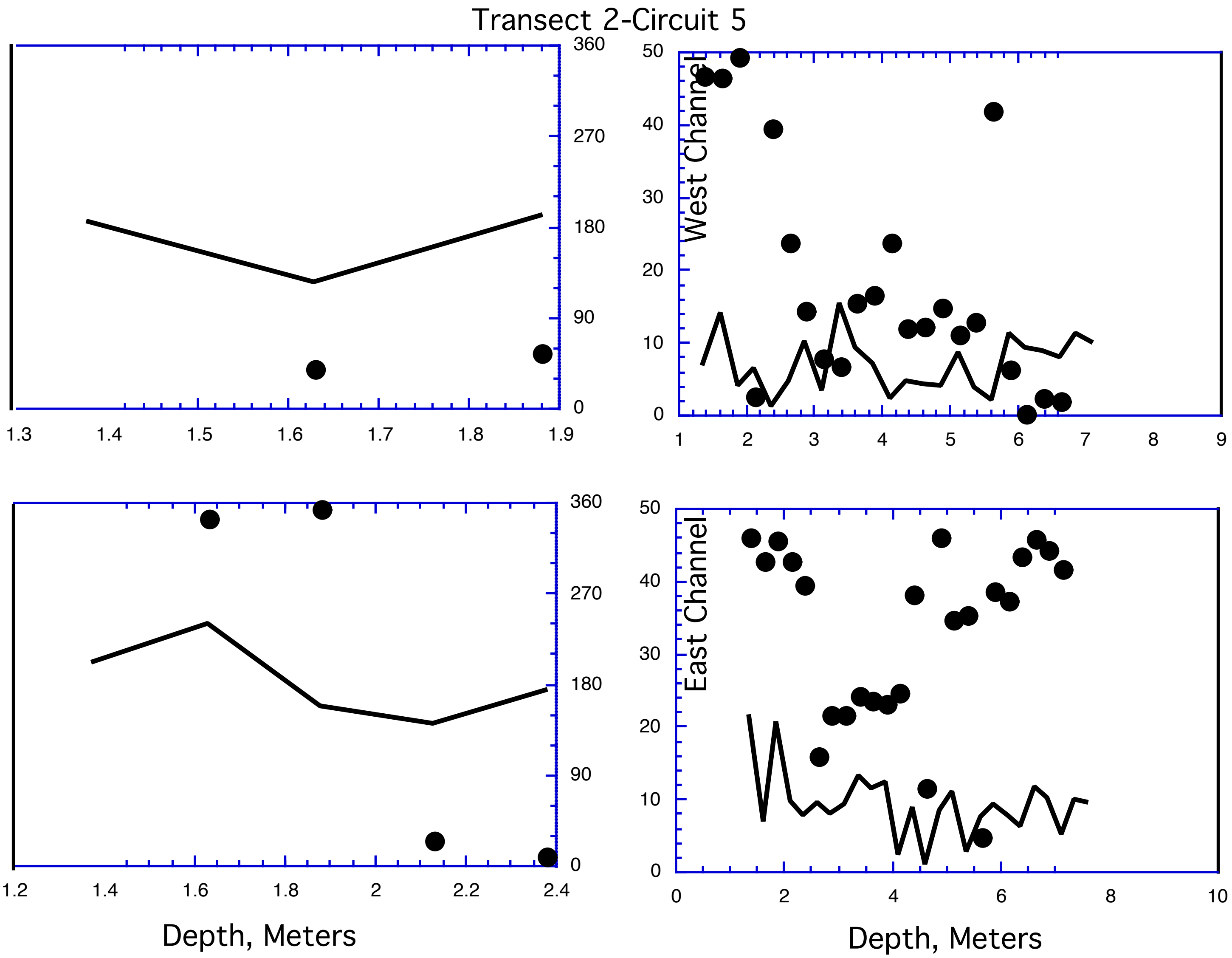

Figure 16: Laterally averaged velocity profiles for distinct sections of transect 2, south of Fields Point. Sections include shallow or shoaling region on the western half of the line and the channel, on the eastern half of the line. Time period is circuit 5, transition from ebb to flood. Velocity magnitude=solid line. Velocity direction=solid dots.

Transect 3-Circuit 1

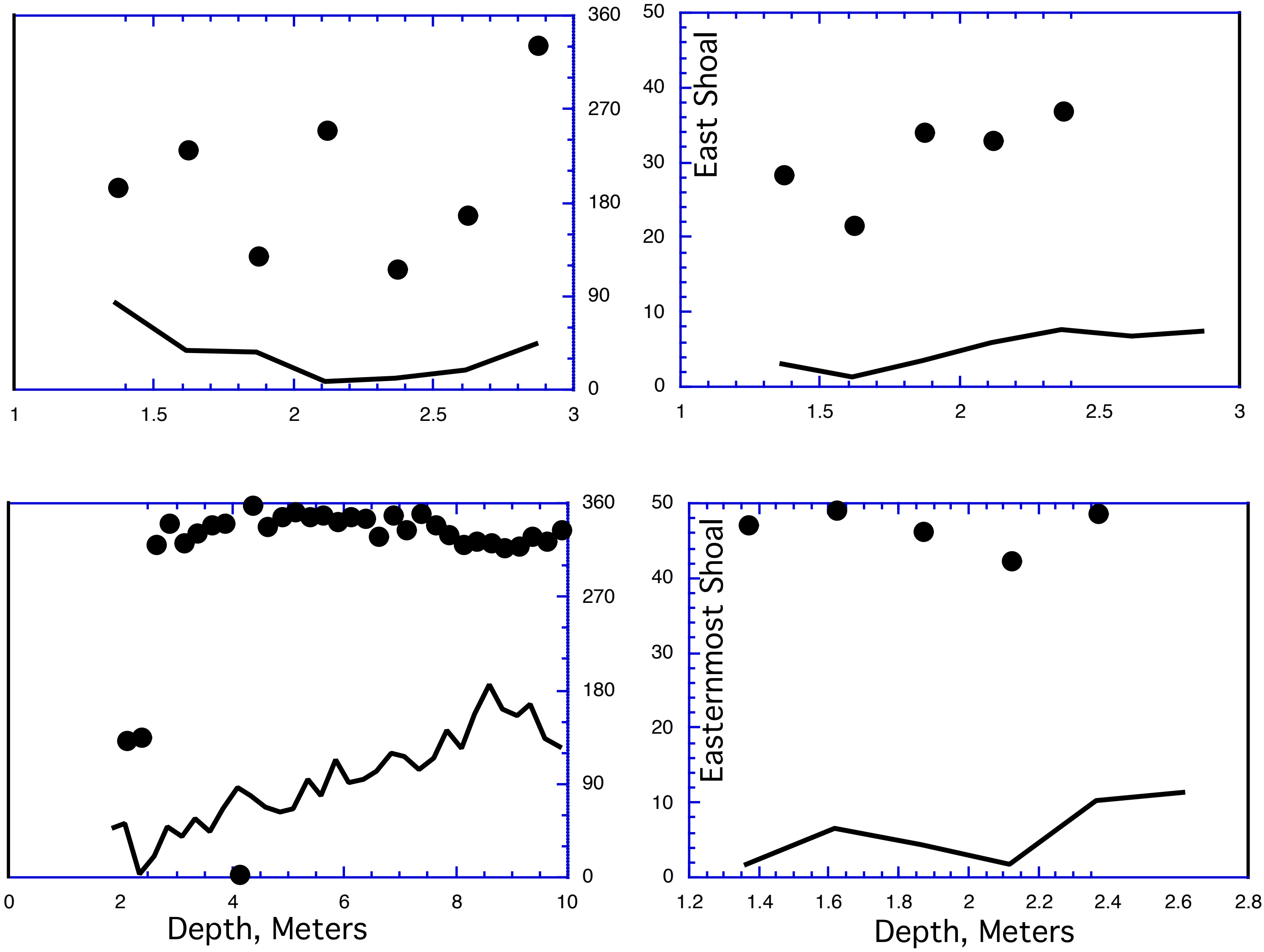

Figure 17: Laterally averaged velocity profiles for distinct sections of transect 3, across Sabin Point. Sections include shoals to the east and west of the channel. The eastern shoal is divided into two sub-sections. Time period is circuit 1, or early flood conditions. Velocity magnitude(direction) = solid lines (dark circles).

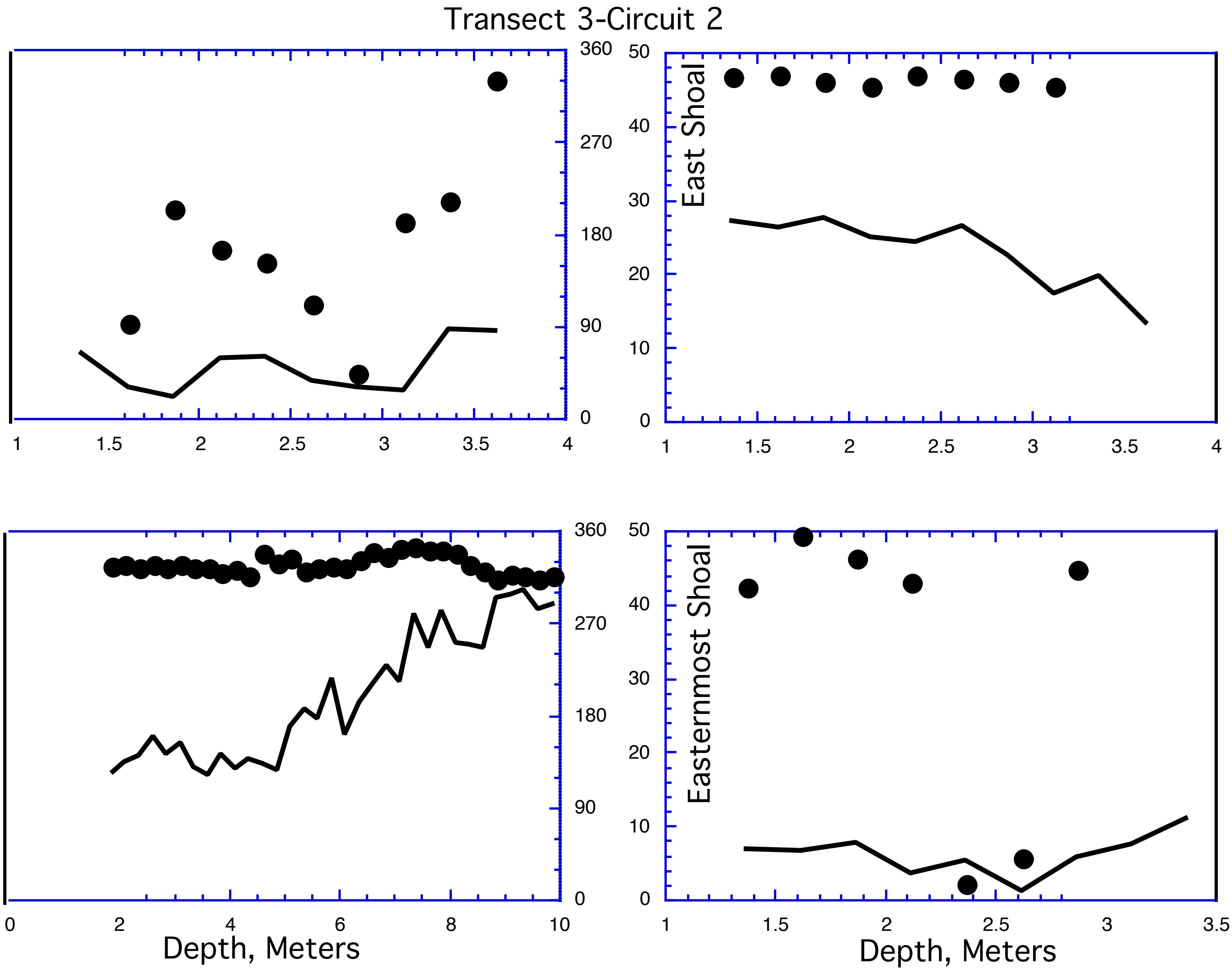

Figure 18: Laterally averaged velocity profiles for distinct sections of transect 3, across Sabin Point. Sections include shoals to the east and west of the channel. The eastern shoal is divided into two sub-sections. Time period is circuit 2, or mid-late flood conditions. Velocity magnitude(direction)=solid lines(dark circles).

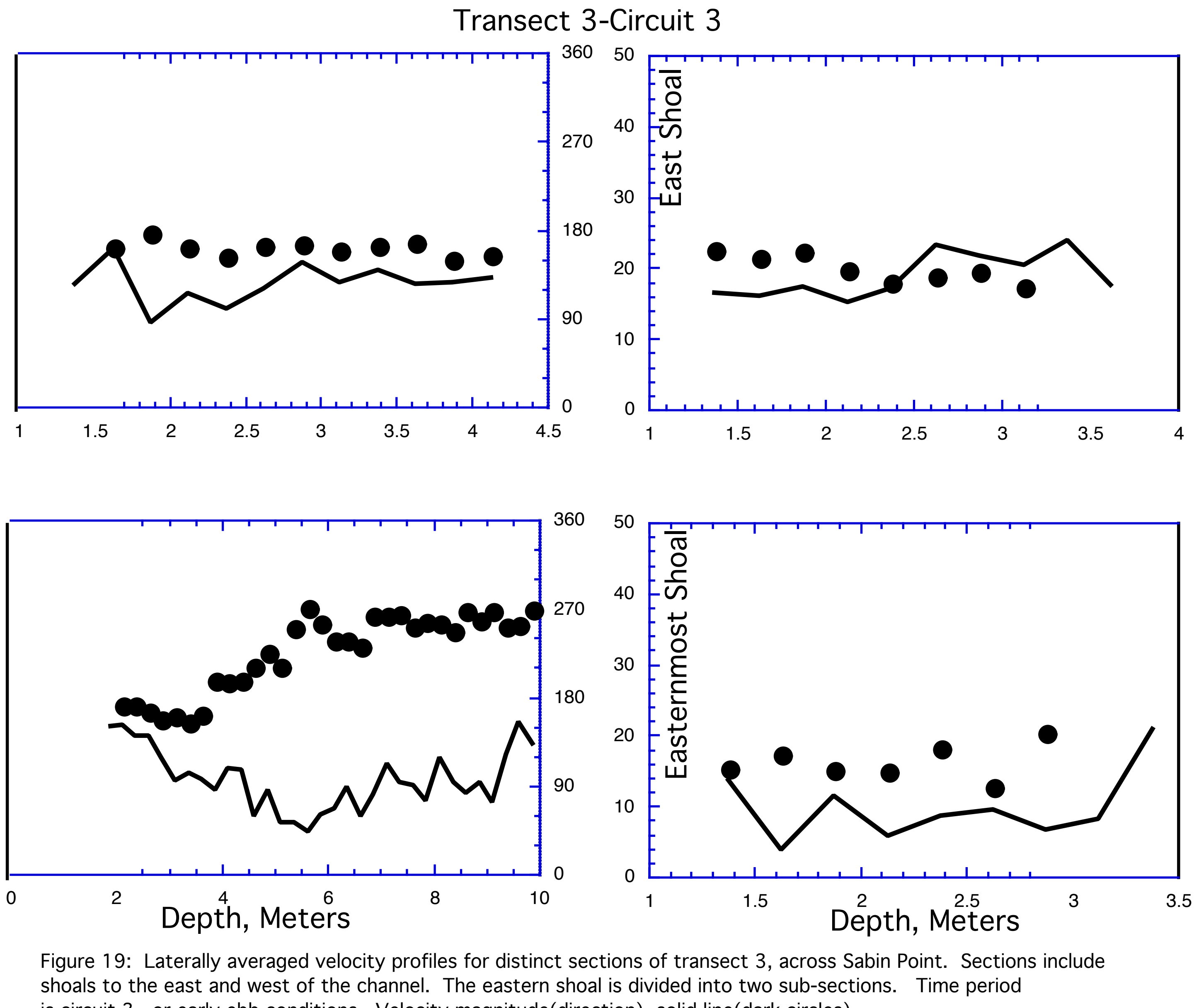

Figure 19: Laterally averaged velocity profiles for distinct sections of transect 3, across Sabin Point. Sections include shoals to the east and west of the channel. The eastern shoal is divided into two sub-sections. Time period is circuit 3, or early ebb conditions. Velocity magnitude(direction)=solid line(dark circles).

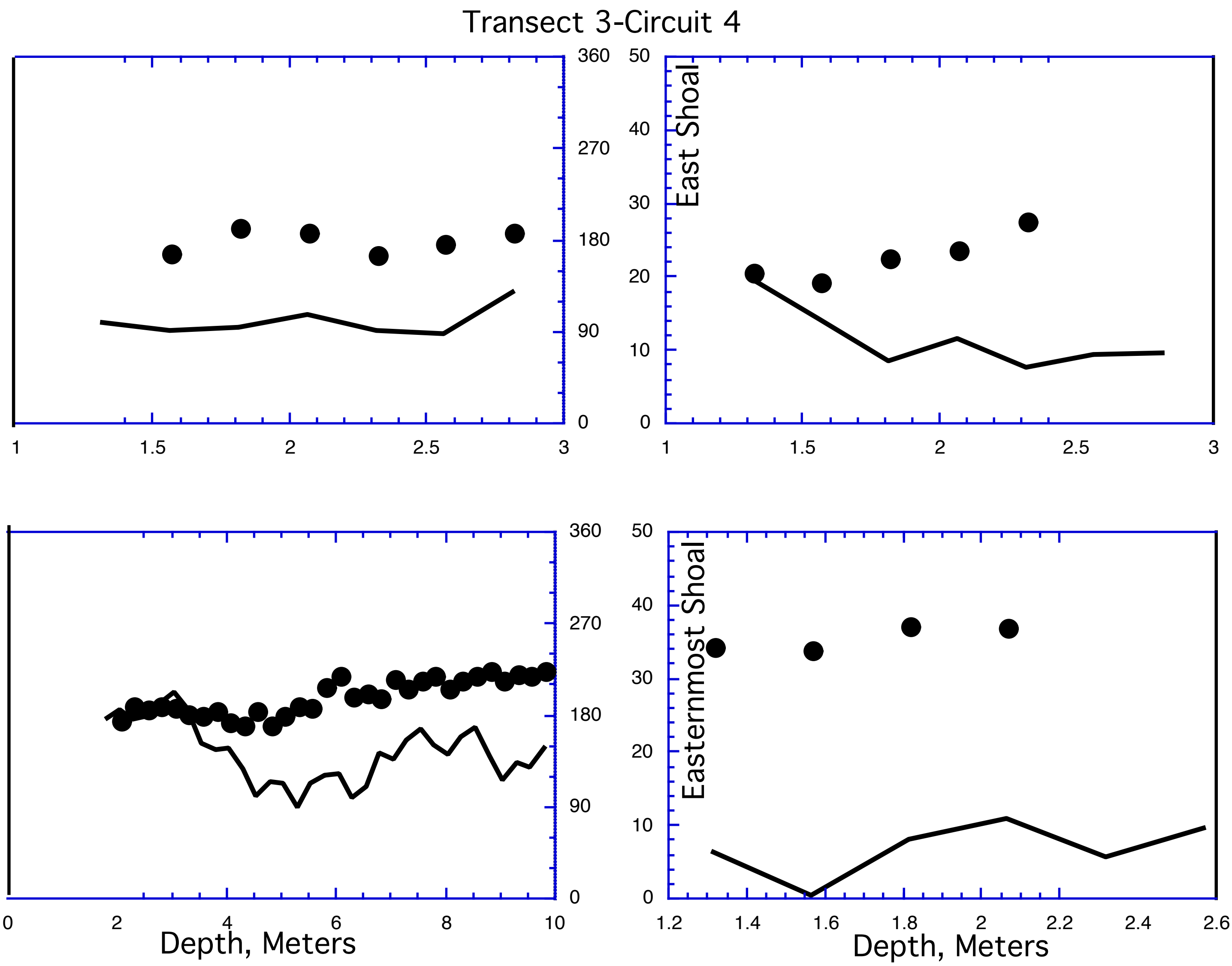

Figure 20: Laterally averaged velocity profiles for distinct sections of transect 3, across Sabin Point. Sections include shoals to the east and west of the channel. The eastern shoal is divided into two sub-sections. Time period is circuit 4, or late ebb conditions. Velocity magnitude(direction)=solid line(dark circles).

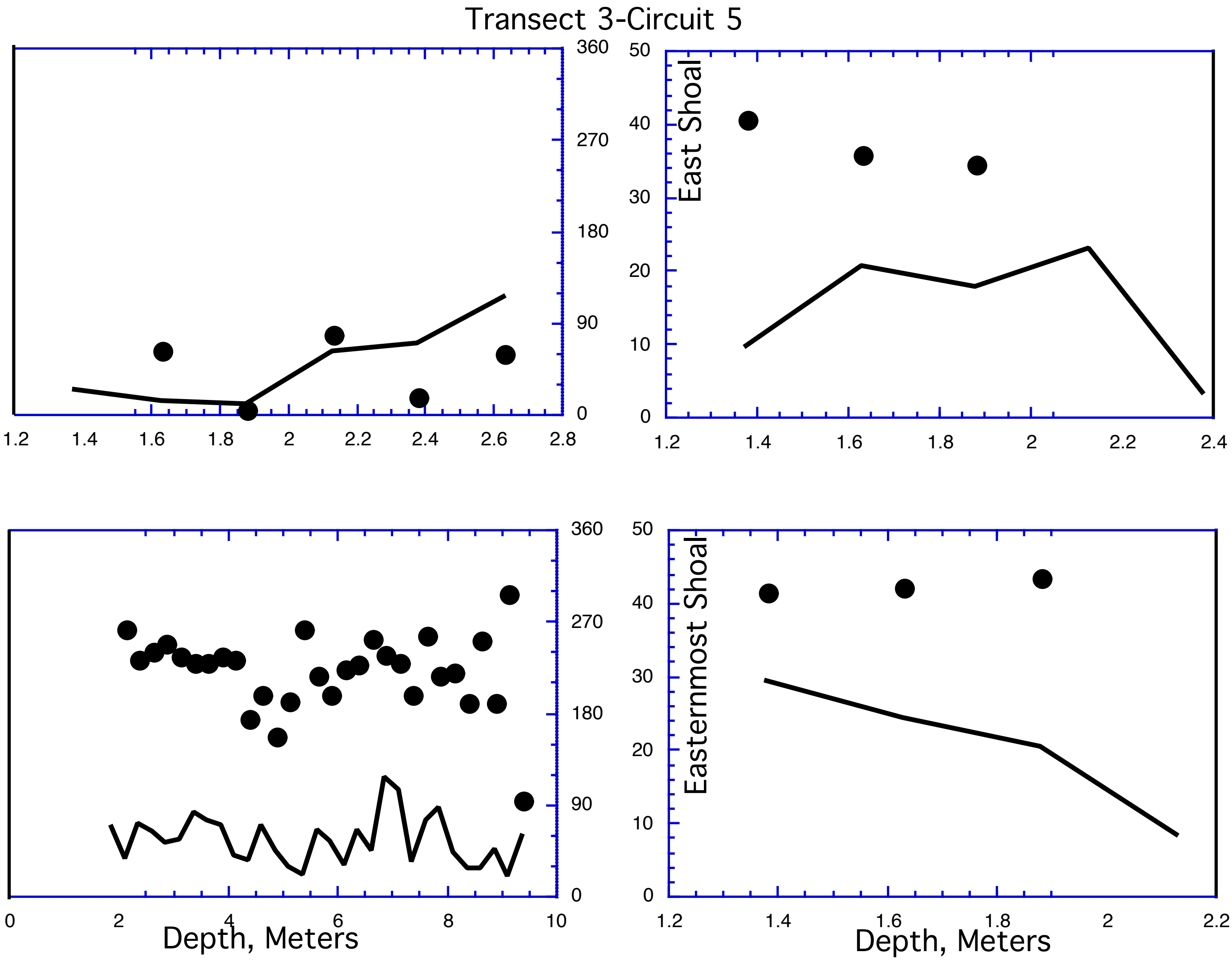

Figure 21: Laterally averaged velocity profiles for distinct sections of transect 3, across Sabin Point. Sections include shoals to the east and west of the channel. The eastern shoal is divided into two sub-sections. Time period is circuit 5, or the transition from ebb to flood conditions. Velocity magnitude(direction)=solid line(dark circles).

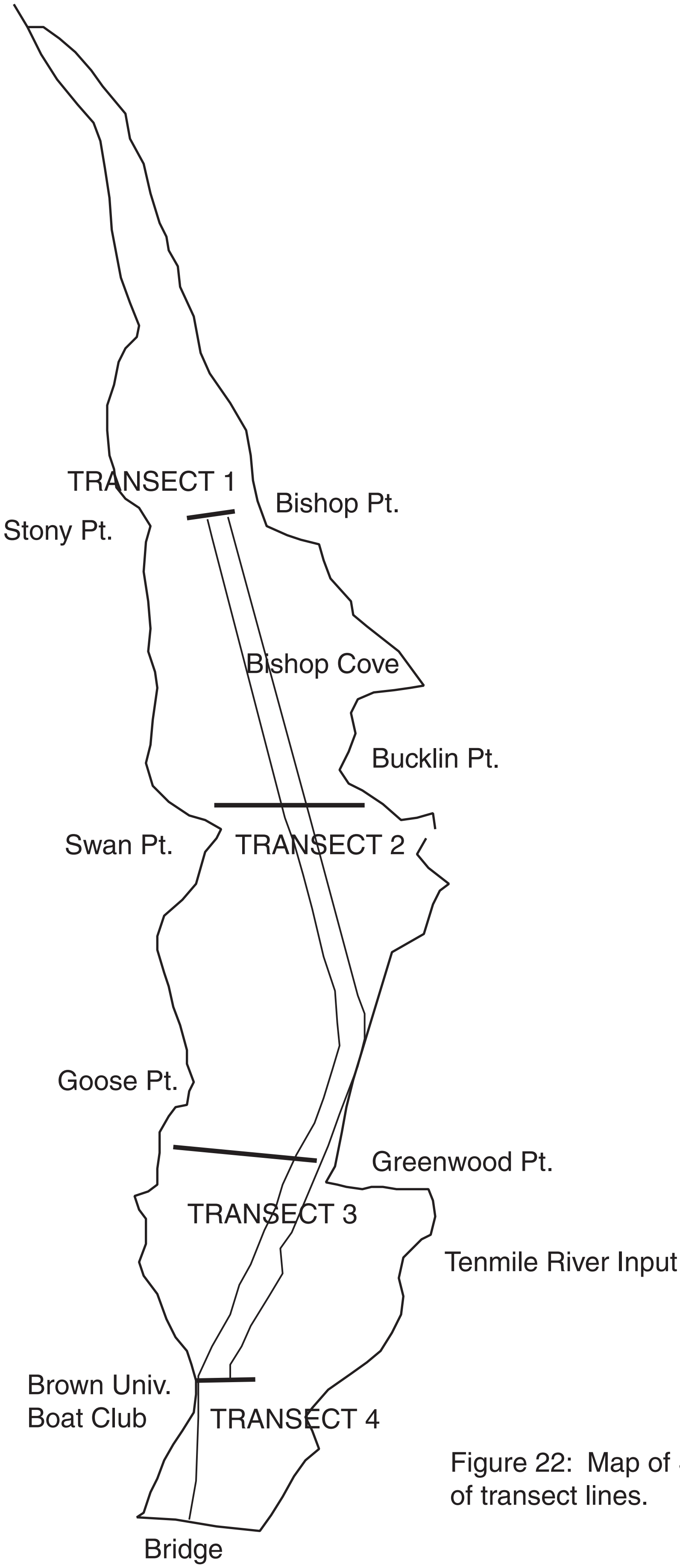

Figure 22: Map of Seekonk River with locations of transect lines.

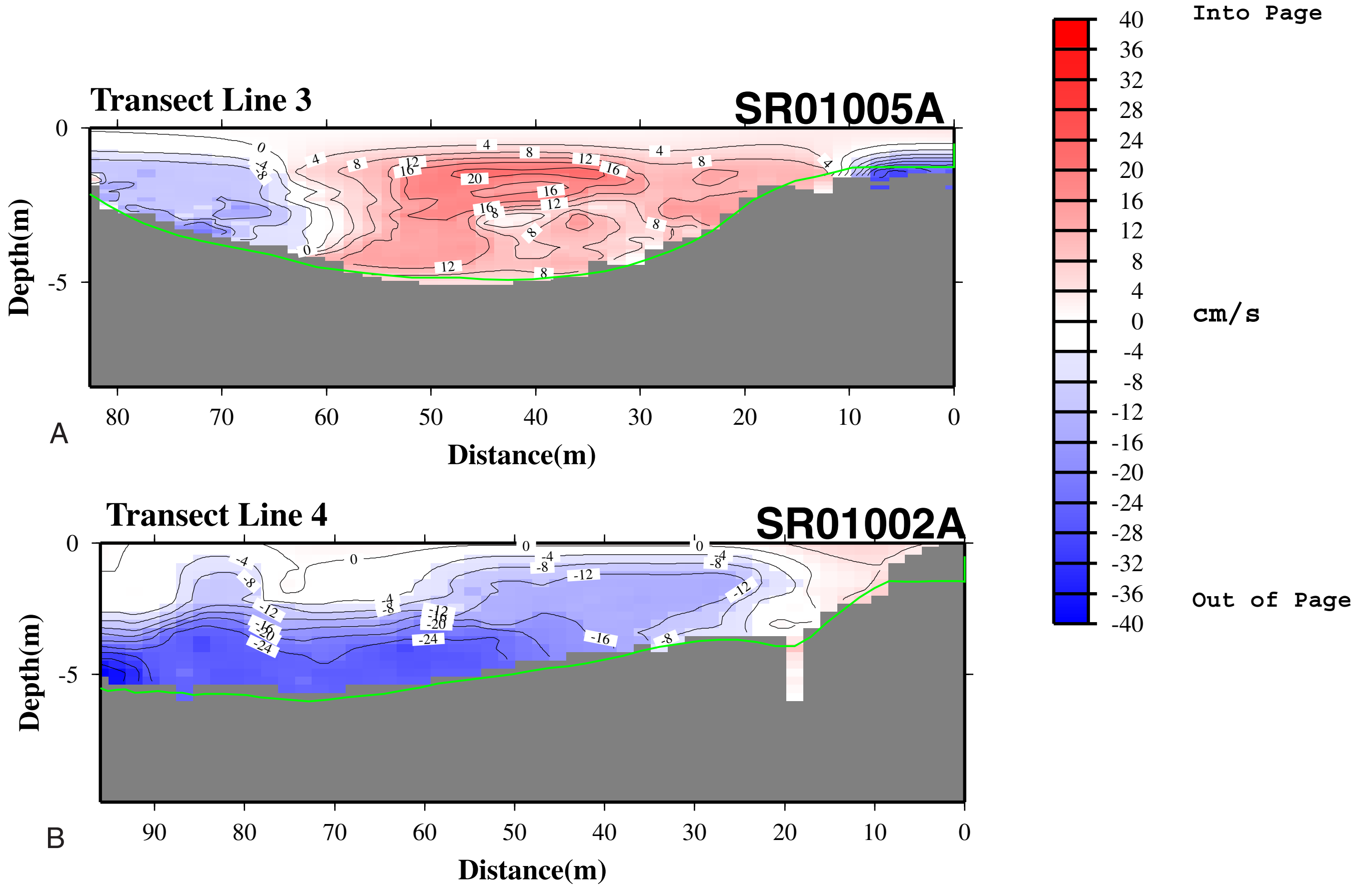

Figure 23: Contours of velocity projected normal to the transect line for circuit 1. Transect lines are number 3 (A) and 4 (B). Transect 4 is sampled earlier and only a small fraction of the cross section shows flooding water, along the eastern side. The river extended beyond this point but was too shallow to be sampled. The majority of the cross section at line 3 is flooding when roughly 1 hour later. The western side which could be sampled is still ebbing.

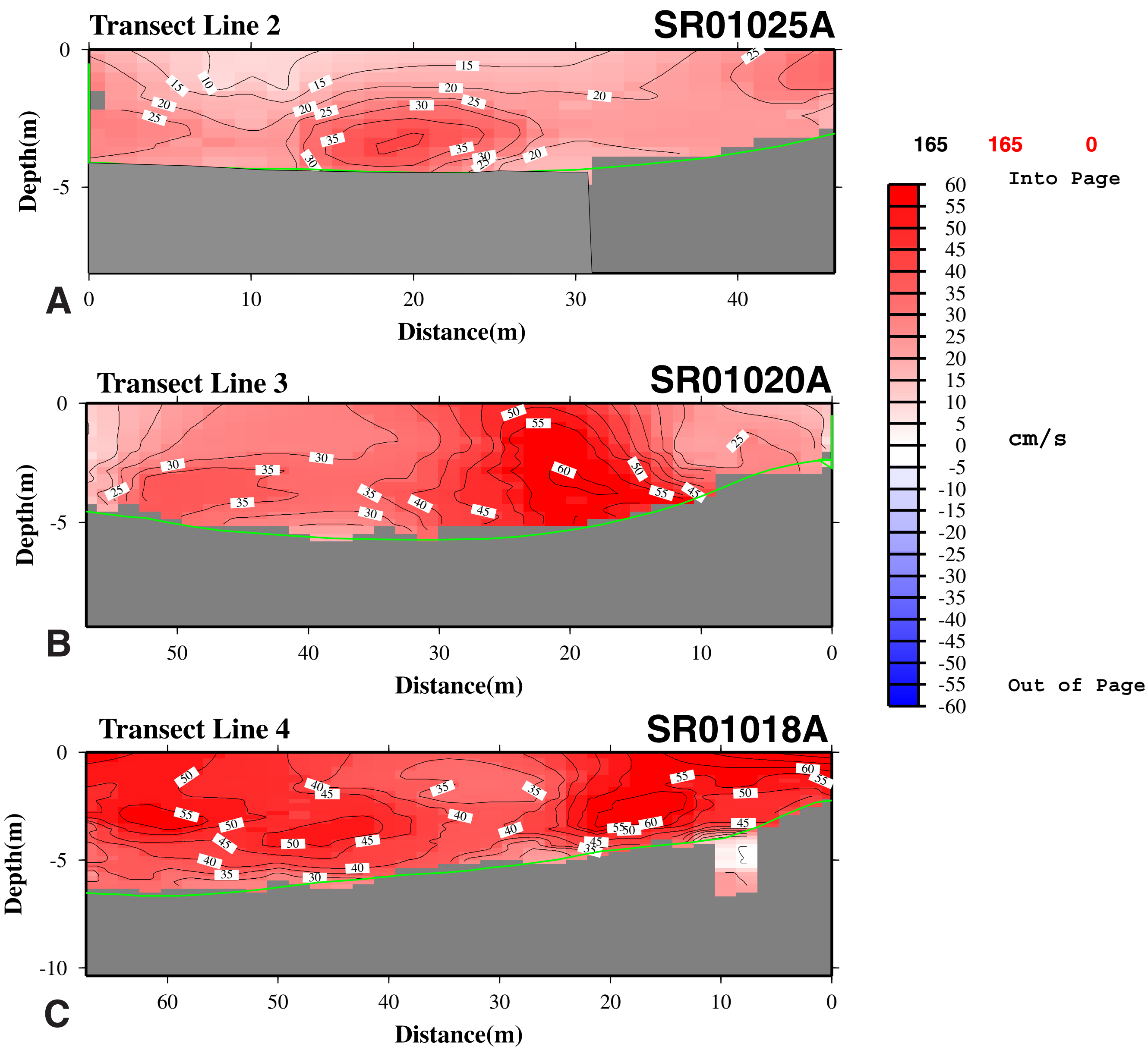

Figure 24: Contour plots for velocity component projected normal to the transect line for data collected on circuit 2, or flood conditions. A: Transect 2, B: Transect 3 and C: Transect 4. Because of low water, lines are only driven within the channel. Strongest flood velocities are recorded on the eastern sides of the channel for lines 3 and 4.

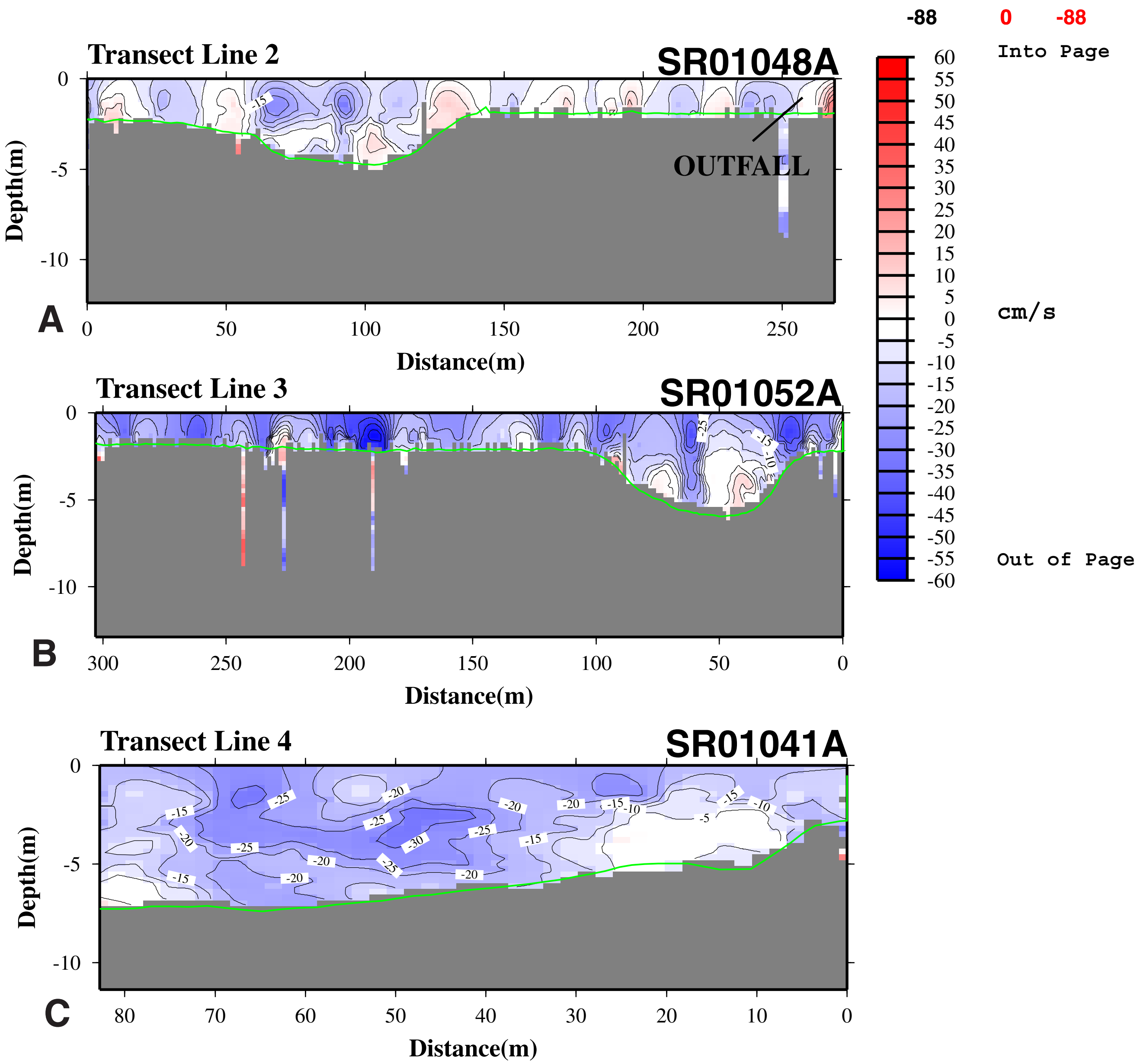

Figure 25: Contour plots for velocity component projected normal to the transect line for circuit 3, or early ebb conditions. Frame A is line 2, which runsclose to the Bucklin Point outfall, on the eastern end of the line. Frames B and C are transect lines 3 and 4. The strongest ebbing flow is seen on the eastern side of line 3, out on the shoals. Lateral variations in flow are seen in the channel on this line. Line 2 also shows significant lateral variability, with outflow in the channel and alternating inflow/outflow patterns on the shoals, particualry near the outfall.

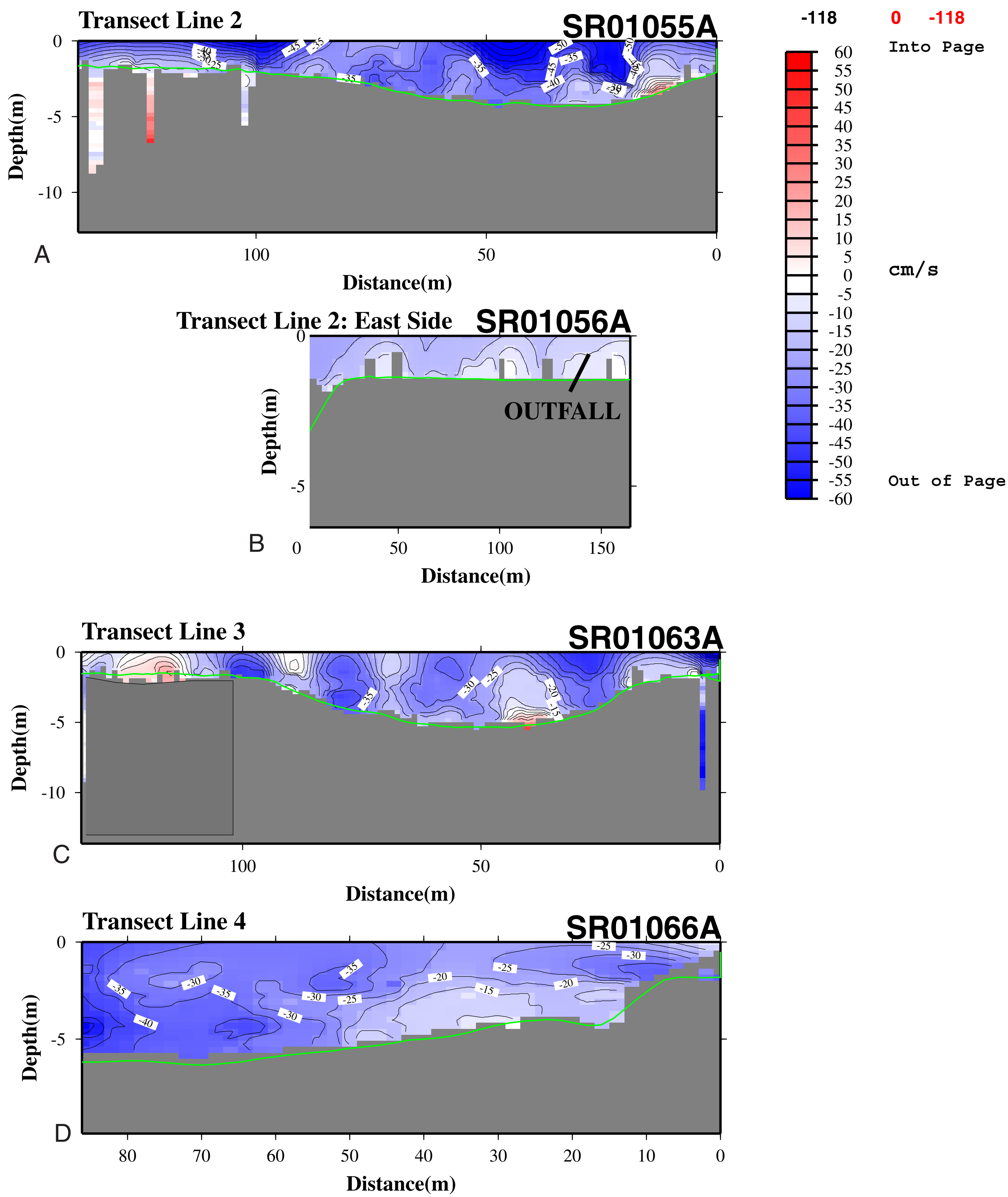

Figure 26: Contour plots for velocity component projected normal to the transect line for circuit 4, or mid to late ebb conditions. Frames A and B are both line 2. Frame B shows a closeup of the eastern shoal near the Bucklin Point sewage outfall. Ebing flow here is weaker than the rest of the line. Frames C and D show ebbing currents on transect lines 3 and 4. Line 3 shows weakly flooding currents on the western shoal and ebbing flow in the channel. Ebb flow is strongest on the western side of line 4.

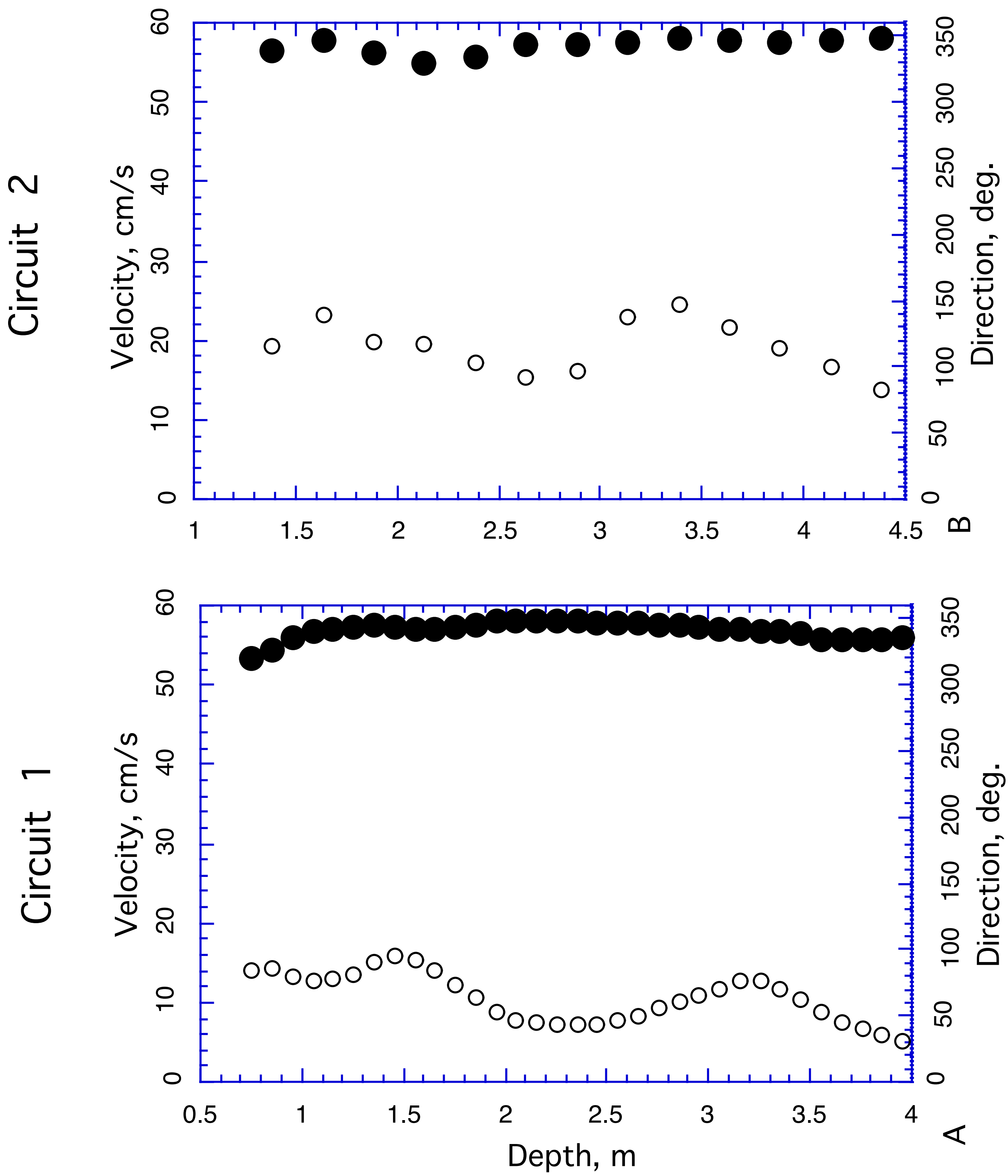

Figure 27: Velocity profiles obtained for transect 1 by holding position within the channel and collecting data for five minutes. Data have been averaged into a single profile of velocity versus depth. Shown are velocity magnitude (open circles) and direction (dark circles).

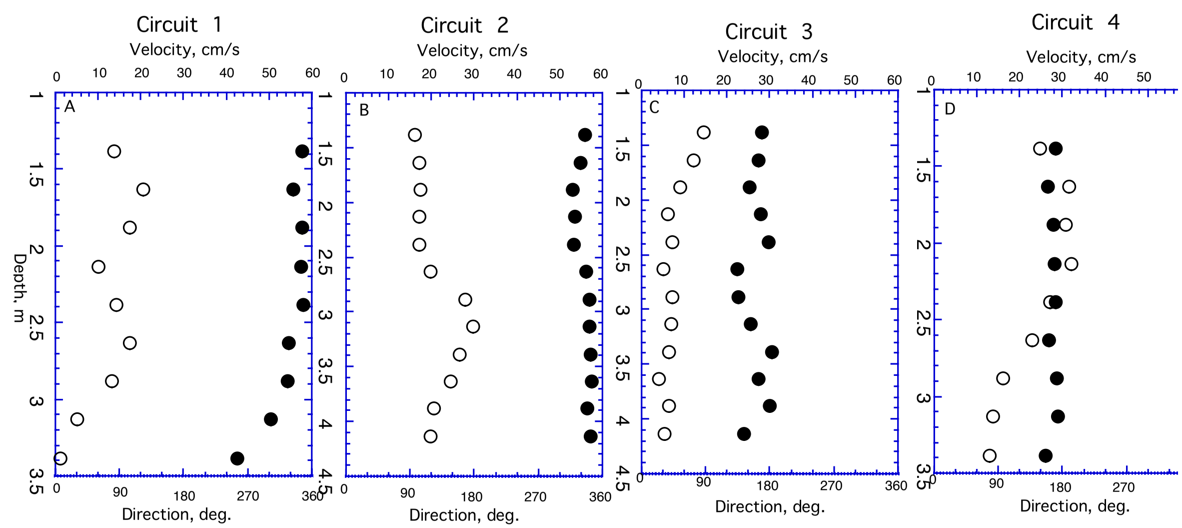

Figure 28: Time averaged velocity profiles collected within the channel
for transect 2. Shown are velocity magnitude (open circles) and direction (dark circles).

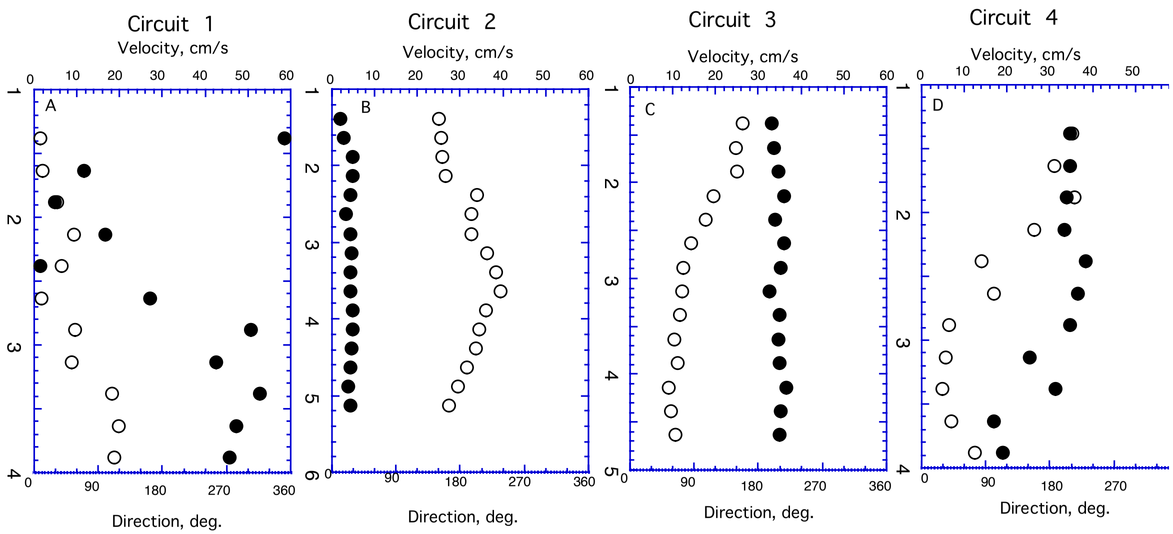

Figure 29: Time averaged velocity profiles collected within the channel
for transect 3. Shown are velocity magnitude (open circles) and direction (dark circles).

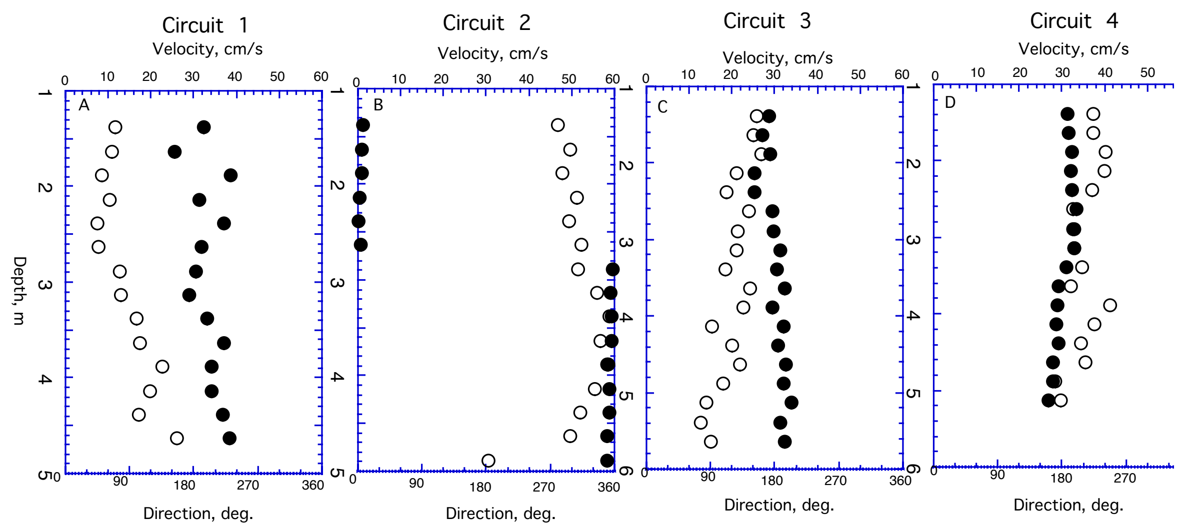

Figure 30: Time averaged velocity profiles collected within the channel
for transect 4. Shown are velocity magnitude (open circles) and direction (dark circles).