Seepage Measured at 17 Locations in Newtown Creek, New York

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Data collected May 19–June 19, 2015

Flow across the sediment-water interface, herein termed “seepage,” was measured with an electromagnetic seepage meter (ESM) at 17 locations in Newtown Creek, New York, from May 19, 2015, to June 19, 2015. Seepage was measured once every 5 seconds, and a digital datalogger calculated average values once every minute. Seepage was measured for three or more tidal cycles at each location to determine the direction and magnitude of seepage in response to tides. This summary report presents (1) a general overview of seepage at Newtown Creek, (2) summary statistics for each measurement location, and (3) a detailed description of seepage at each measurement location.

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Contents

Tables

Overview of Seepage Measured at Newtown Creek

Seepage generally flowed upward from groundwater to surface water at Newtown Creek. Median values from 1-minute output collected during two or more tidal cycles measured at 17 locations ranged from 0.0 to 9.8 centimeters per day (cm/d). Average values determined from the same data ranged from -20.4 to 8.3 cm/d, with negative values indicating downward seepage and positive values indicating upward seepage. Although both average and median values are included in the summary statistics, median values are discussed more often because they better represent typical seepage rates for datasets that may be skewed by short-term extreme seepage rates.

Upward seepage was typically less than 2 cm/d. The fastest upward median seepage rate of approximately 8 cm/d was measured at locations EK026 and NC218. Seepage at NC062 was also slightly faster than at most other locations. Exceptionally fast seepage, both upward and particularly downward, was measured at NC266, but the median value determined for two tidal cycles was 3.8 cm/d, which is only slightly faster than at most other locations.

Seepage was influenced by tidal cycles at most locations. In addition to the tidal influence, trends were evident during multiple tidal cycles at locations EB047, EK026, and NC277. Figure 1 shows median seepage values measured at each of the 17 Newtown Creek measurement locations. Figure 2 shows average values. Values in figures 1 and 2 are averages of two values determined during two data-analysis periods for each deployment, as presented in table 1, rounded to the nearest 0.1 cm/d.

Occasional brief departures from typical seepage rates were recorded at most measurement locations. In some cases, causes for these departures can be explained and are discussed in greater detail. The influence of passing watercraft, such as barge traffic, was large and easily measured when an observed passing watercraft was coincident with a measured sudden departure from typical seepage rates. In other cases, sudden departures are not explained. During previous studies at other locations, similar departures have been attributed to fish or other organisms, such as shrimp or crayfish.

Seepage was analyzed as consistently as possible to allow unbiased comparisons between locations. Although measurement duration at each location was at least three tidal cycles, the basic analysis period was two tidal cycles beginning with low tide (for example, low-high-low-high-low tide, which is abbreviated as “lo hi lo hi” in the tables). Analysis periods are indicated with green rectangles in the data charts associated with each measurement location, which are presented in the “Interpretations for Specific Measurement Locations” section. At 10 of the 17 locations, a longer data-collection period allowed analyses during three or more tidal cycles. In some instances, these longer periods began and ended with a high rather than a low tide. Data were summarized during early and late two-tidal-cycle periods at locations where trends in the data were detected. In some cases, multiple two-tidal-cycle periods were summarized because longer data-collection periods enabled more thorough analysis. At location NC288, some data were determined to be erroneous when it was discovered that a valve was in the wrong position during the first part of the data-collection period. Therefore, a single low-high-low tidal cycle was analyzed, along with a two-cycle period that began and ended with a high tide. Data summaries in table 1 show two analysis periods for each location. Because the data collected at Newtown Creek commonly included brief periods of much faster seepage (data “spikes”), non-normal distributions were a possibility; therefore, quartile values were determined in lieu of standard deviations. Averages were also determined for comparison with median values. Differences between average and median values usually were small except for locations NC266 and NC272, where average values were substantially affected by skewed datasets.

Approximates times of high and low tides were obtained from the NOAA Hunters Point, Newtown Creek, NY, Station 8517673 (https://tidesandcurrents.noaa.gov/noaatidepredictions/NOAATidesFacade.jsp?Stationid=8517673). Local, more specific, tidal information was obtained with In-Situ Mini Troll vented pressure transducers installed by Anchor QEA. These sensors were installed on the bulkhead near the Anchor QEA dock, located approximately half way between NC266 and NC271, and on the bulkhead southwest of NC288.

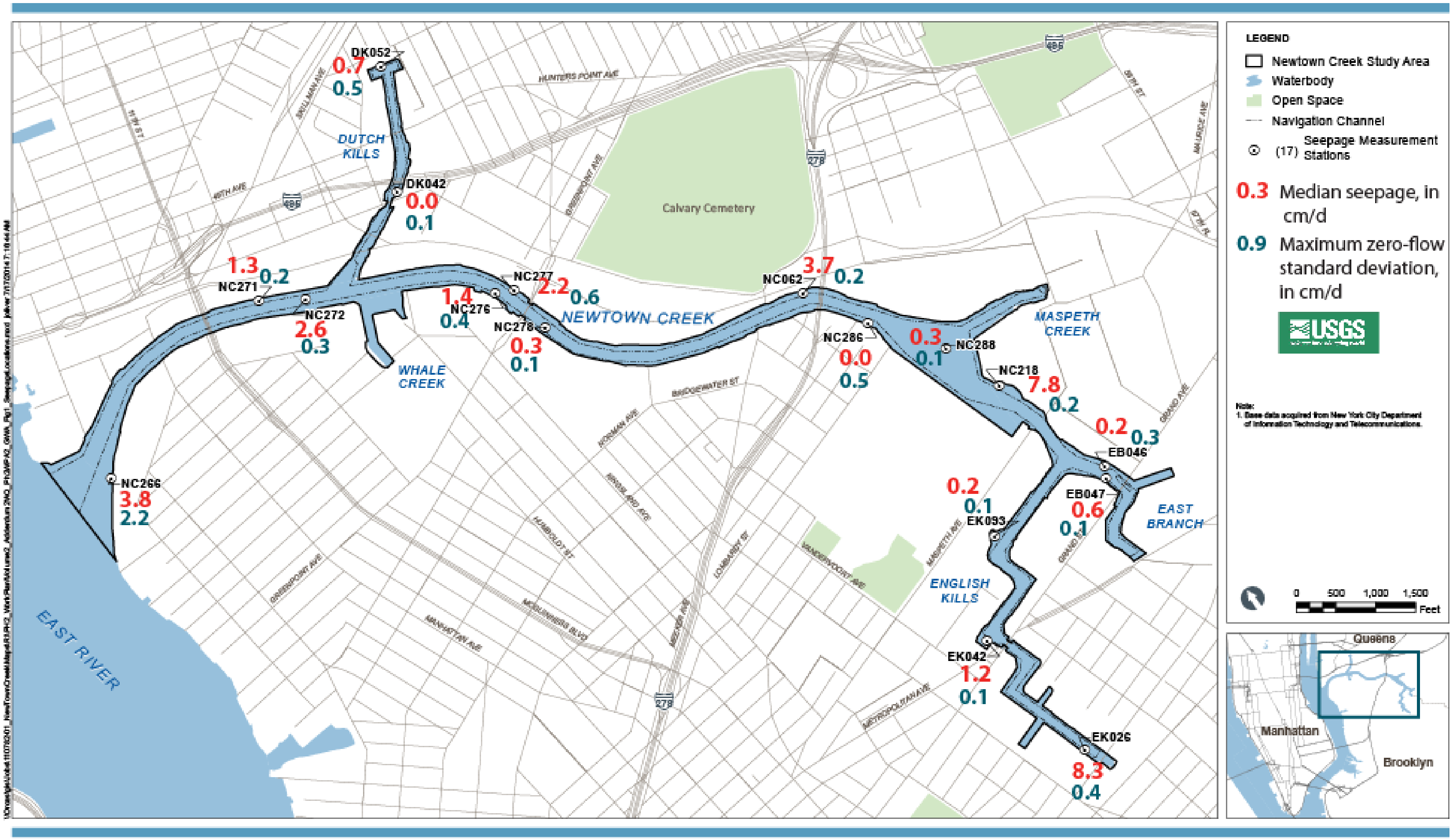

Figure 1 – Seepage-measurement locations at Newtown Creek.
Values in red are median seepage rates during sensor deployments.
Values in blue are maximum standard deviations during periods of induced zero flow through the flowmeter. [cm/d, centimeters per day]

Seepage Measurement Stations
Phase 2 FSAP – Volume 2 Addendum No. 2
Newtown Creek RI/FS
Base map prepared by Anchor QEA

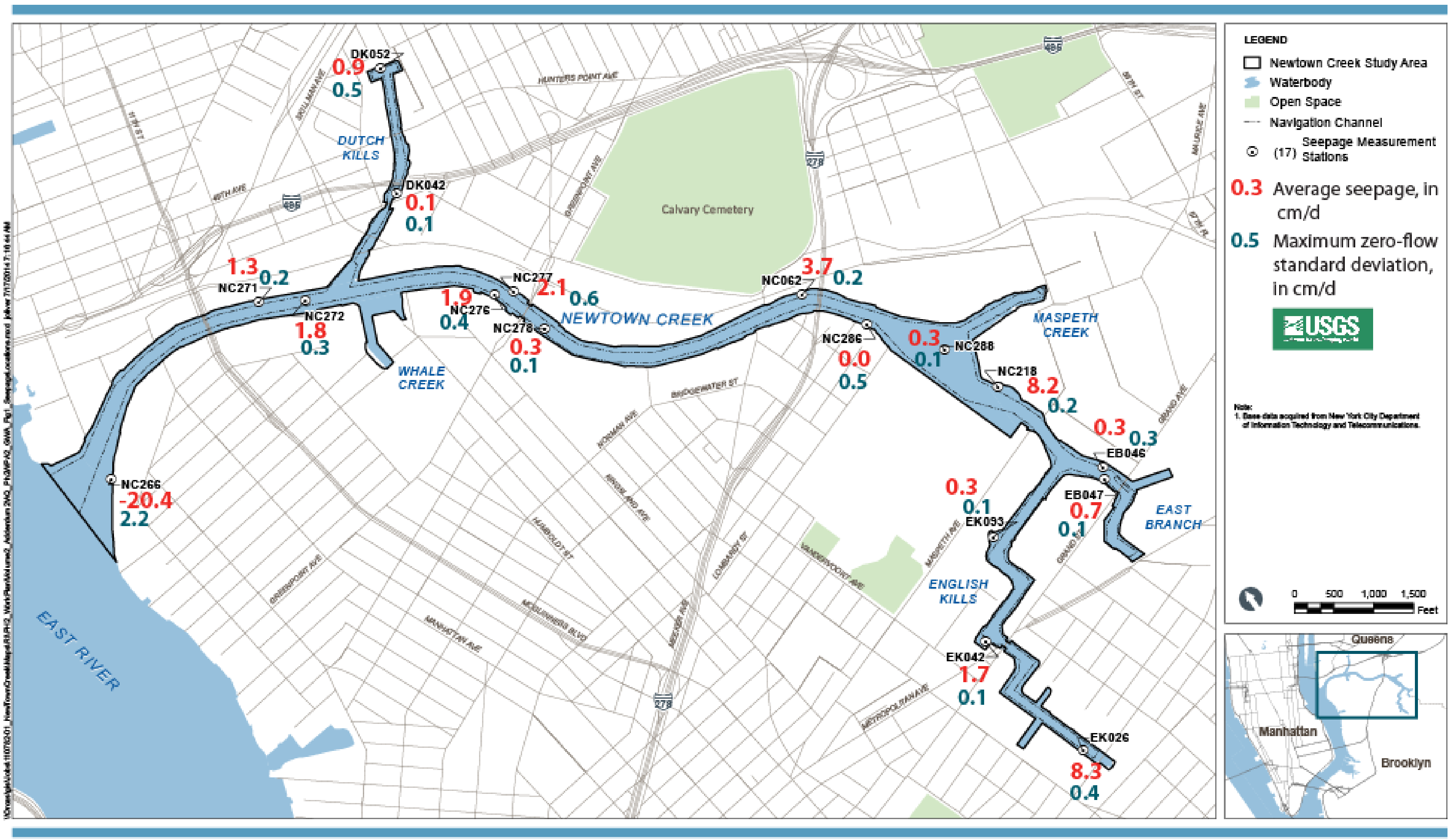

Figure 2 – Seepage-measurement locations at Newtown Creek.
Values in red are average seepage rates during sensor deployments.
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Table 1. Summary of Newtown Creek seepage data.

[Data were summarized during six specified tidal cycles: (1) "lo hi lo hi" indicates two complete tidal cycles beginning and ending with low tide, (2) "hi lo hi lo" indicates two complete tidal cycles beginning and ending with high tide, (3) "lo hi" indicates one complete tidal cycle beginning and ending with low tide, (4) "hi lo hi lo" indicates two complete tidal cycles beginning and ending with high tide, (5) "3 cycles" indicates three complete tidal cycles beginning and ending with low tide, and (6) "5 cycles" indicates five complete tidal cycles beginning and ending with low tide. "Early" or "late" indicates timing of an analysis period relative to the site-specific data-collection period. Seepage data given in centimeters per day (cm/d). All values (except n) in cm/d. n, number of 1-minute values; Med, median of n values; Ave, average of n values; Max, maximum of n values; Min, minimum of n values; 0.75 quart , 75th quartile; 0.25 quart, 25th quartile; 0.75–0.25, the difference between the 75th and 25th quartiles (representing the range of half of the data); lo, low tide; hi, high tide; cy, cycles; cyc, cycles]

EK093	n	Med	Ave	Max	Min	0.75 quart	0.25 quart	0.75-0.25
lo hi lo hi	1433	0.2	0.3	12.9	-5.7	0.5	-0.1	0.5
3 cycles	2171	0.3	0.4	12.9	-5.7	0.6	0.0	0.6
EK042	n	Med	Ave	Max	Min	0.75 quart	0.25 quart	0.75-0.25
lo hi lo hi	1335	1.8	2.1	10.9	-7.1	4.7	-0.3	5.0
3 cycles	2073	0.6	1.2	10.9	-7.1	3.1	-0.9	4.0
EB046	n	Med	Ave	Max	Min	0.75 quart	0.25 quart	0.75-0.25
lo hi lo hi	1445	0.3	0.3	4.7	-3.1	1.2	-0.7	1.9
3 cycles	2195	0.2	0.3	4.7	-3.1	1.2	-0.7	1.9
EB047	n	Med	Ave	Max	Min	0.75 quart	0.25 quart	0.75-0.25
lo hi early	1449	1.0	1.1	9.3	-4.1	2.1	-0.3	2.4
lo hi late	1429	0.2	0.2	8.3	-4.1	1.2	-0.7	1.9
EK026	n	Med	Ave	Max	Min	0.75 quart	0.25 quart	0.75-0.25
3 cy early	2228	6.7	6.7	14.7	0.8	8.4	5.0	3.4
3 cy late	2266	9.8	10.0	17.4	5.4	11.1	8.8	2.3
NC218	n	Med	Ave	Max	Min	0.75 quart	0.25 quart	0.75-0.25
lo hi 3 cyc	2257	7.7	7.5	14.4	-1.0	9.1	6.2	2.9
5 cycles	3709	7.9	8.9	41.5	-4.6	10.3	5.9	4.4

Table 1 – continued.

NC286	n	Med	Ave	Max	Min	0.75 quart	0.25 quart	0.75-0.25
lo hi 3 cyc	2257	0.0	0.0	2.2	-2.7	0.3	-0.3	0.7
5 cycles	3709	0.0	0.0	2.4	-2.7	0.3	-0.3	0.6
NC277	n	Med	Ave	Max	Min	0.75 quart	0.25 quart	0.75-0.25
lo hi early	1435	2.8	2.6	10.3	-36.9	4.2	1.3	2.9
lo hi late	1454	1.5	1.5	10.3	-36.9	2.5	0.6	1.9
NC278	n	Med	Ave	Max	Min	0.75 quart	0.25 quart	0.75-0.25
lo hi lo hi	1391	0.3	0.3	8.8	-5.9	0.6	0.0	0.6
3 cycles	2151	0.3	0.3	8.8	-5.9	0.6	0.0	0.5
NC276	n	Med	Ave	Max	Min	0.75 quart	0.25 quart	0.75-0.25
lo hi lo hi	1450	1.3	1.8	14.3	-5.2	2.4	0.5	1.9
3 cycles	2224	1.5	2.0	14.3	-5.2	2.7	0.6	2.1
DK042	n	Med	Ave	Max	Min	0.75 quart	0.25 quart	0.75-0.25
lo hi lo hi	1492	0.0	0.1	4.1	-3.6	0.8	-0.7	1.4
3 cycles	2244	0.0	0.1	4.1	-3.6	0.8	-0.6	1.4
DK052	n	Med	Ave	Max	Min	0.75 quart	0.25 quart	0.75-0.25
lo hi early	1495	0.1	0.6	24.4	-18.1	3.9	-2.7	6.6
lo hi late	1483	1.2	1.1	15.1	-22.9	5.1	-2.5	7.6
NC062	n	Med	Ave	Max	Min	0.75 quart	0.25 quart	0.75-0.25
lo hi early	1501	4.1	4.0	8.2	-2.8	5.0	3.1	2.0
lo hi late	1483	3.4	3.4	8.9	-3.6	4.4	2.5	1.9
NC266	n	Med	Ave	Max	Min	0.75 quart	0.25 quart	0.75-0.25
lo hi lo hi	1435	3.5	-20.7	49.2	-174.6	15.4	-53.1	68.5
hi lo hi lo	1444	4.0	-20.2	49.2	-174.6	15.4	-52.8	68.2
NC288	n	Med	Ave	Max	Min	0.75 quart	0.25 quart	0.75-0.25
lo hi	757	0.2	0.3	2.5	-1.3	0.8	-0.3	1.1
hi lo hi lo	1430	0.3	0.3	2.5	-2.2	0.8	-0.2	1.0

Table 1 – continued.

NC271	n	Med	Ave	Max	Min	0.75 quart	0.25 quart	0.75-0.25
lo hi lo hi	1453	1.3	1.4	20.5	-23.5	1.8	0.9	0.9
3 cycles	2215	1.3	1.2	20.5	-25.3	1.7	0.8	0.9
NC272	n	Med	Ave	Max	Min	0.25 quart	0.75 quart	0.75-0.25
lo hi lo hi	1438	2.7	0.9	17.3	-51.5	-2.1	4.1	-6.2
hi lo hi lo	1426	2.5	2.6	17.3	-26.9	0.9	3.9	-3.0

Methods

The following is a brief description of the procedure that was used to measure seepage at Newtown Creek. More details are presented in the standard operating procedure SOP NC-34 (Anchor QEA, 2015).

An electromagnetic seepage meter (ESM) (Rosenberry and Morin, 2004; Swarzenski and others, 2004; Waldrop and Swarzenski, 2006) was deployed at each of 17 measurement locations within the Newtown Creek area. The ESM (fig. 3) consisted of an electromagnetic flowmeter connected to a seepage cylinder with a diameter of approximately 3.5 feet. Output from the flowmeter was sent to a signal-processing unit deployed in a boat anchored at least 10 to 20 meters (m) from the seepage cylinder. Two or more deep-cycle marine batteries wired in parallel supplied power to the ESM. At some locations, the boat was anchored farther away, but within the 100-m reach of the signal cable, to minimize exposure to barge traffic. At NC266, the signal-processing unit was placed onshore to eliminate exposure to large waves from watercraft in the East River.

Three ESM systems were available for use at Newtown Creek. Aluminum cylinders covering 9,260 square centimeters (cm^2) of sediment bed were used with two of the systems; a plastic cylinder covering 8,938 cm^2 was used with the third system. At each measurement location, the seepage cylinder and attached flowmeter were lowered slowly onto the sediment to minimize sediment disturbance. A hard-hat diver observed and facilitated cylinder installation to ensure that the bottom edge of the seepage cylinder was inserted at least 5 centimeters but no more than 20 centimeters into the sediment bed along the entire cylinder perimeter. The diver pushed 1.5-m lengths of polyvinyl chloride (PVC) pipe vertically into the sediment until refusal. Each of the three pipes was then secured to the seepage cylinder with a set screw to eliminate the possibility of any movement of the seepage cylinder in the soft sediment. Once installation was complete, the diver closed a relief valve designed to vent any gas released from the sediment and, with the flowmeter exhaust-port valve open, the meter was ready to log seepage.

Output in millivolts (mV) from each ESM was recorded every 5 seconds by a Campbell Scientific[1] digital datalogger that calculated average values and standard deviations every minute. Output in milliliters per minute was also calculated by the datalogger using initial calibrations determined in Lakewood, Colorado, prior to deployment.

At least twice during each deployment, output from the ESM was recorded while flow through the flowmeter was stopped. These periods, called "zero-flow periods," were designed to correct for sensor drift during deployment on the sediment bed. To initiate each zero-flow period, the diver closed the flowmeter exhaust-port valve and opened the relief valve (called a bag-port valve in the standard operating procedure SOP NC-34 [Anchor QEA, 2015]). The relief valve allowed flow across the sediment-water interface to continue while flow through the flowmeter was stopped. Each zero-flow period lasted a minimum of 15 minutes. Once output from the ESM stabilized following valve closure, averages were calculated for each zero-flow period. Linear interpolation was used to determine zero-flow values for every minute increment between actual zero-flow periods. Measured or interpolated zero-flow values were then subtracted from the raw ESM output. Zero-flow adjusted values were converted to output in milliliters per minute by multiplying by a regression coefficient determined for each sensor system at the Anchor QEA dock. Onsite calibrations were conducted once during the May 2015 deployment and once during the June 2015 deployment. Output in milliliters per minute was then converted to output in centimeters per day by dividing the milliliters per minute value by the area covered by the seepage cylinder (9,260 cm^2 for the aluminum cylinders or 8,938 cm^2 for the plastic cylinder) and multiplying by 1,440 minutes in each day.

[1] Any use of trade, firm, or product names is for descriptive purposes only and does not imply endorsement by the U.S. Government

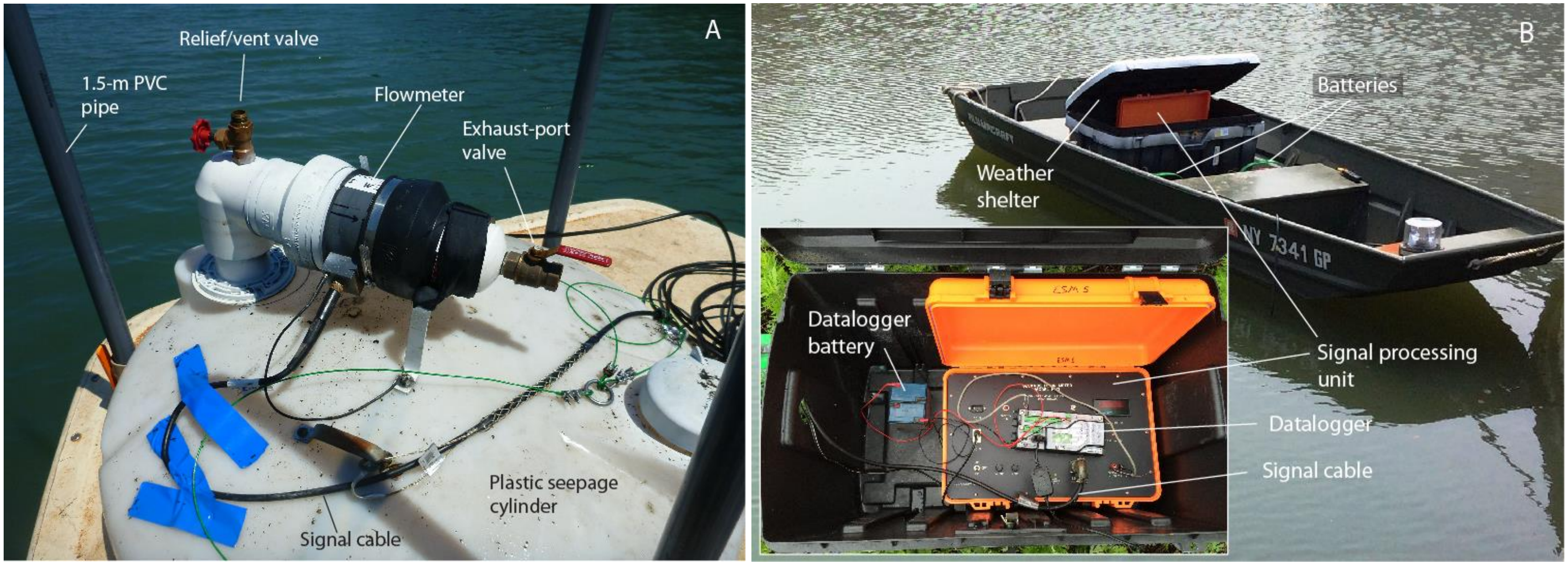


Figure 3. Photos of an electromagnetic seepage meter deployed at Newton Creek. *A*, Seepage cylinder and flowmeter prior to being lowered onto the sediment bed; photograph also shows the three polyvinyl chloride (PVC) pipes that will be pushed into the sediment by a diver. *B*, Signal-processing unit in an anchored boat; inset photograph shows close-up of weather shelter interior.

Accuracy

The electromagnetic flowmeters used at Newtown Creek are designed to output 1 mV for each milliliter per minute of flow through the meter over a range of three orders of magnitude. These sensors typically operate near the low end of their designed input range when used to measure flow between groundwater and surface water. Therefore, sensors were calibrated specifically for the range of anticipated seepage rates in a seepage-calibration tank in Lakewood, Colo., before the equipment was shipped to Newtown Creek. Output quality was further improved with onsite calibrations against known rates of flow for the range of seepage rates measured at Newtown Creek. Onsite calibrations were made at the Anchor QEA dock near the end of the May 2015 field trip and near the end of the June 2015 field trip in accordance with the standard operating procedure SOP NC-34 (Anchor QEA, 2015). Calibrations were made by comparing the time-integrated output from a flowmeter in millivolts to the total change in volume of a seepage bag attached to the exhaust port of the flowmeter. Manual measurements were made with seepage bags in accordance with the guidelines presented in Rosenberry and others (2008). Flow was generated by connecting an adjustable-rate low-volume pump to the relief/vent port and creating a constant rate of flow through the electromagnetic flowmeter. A tube extended from the flowmeter exhaust port to a seepage bag installed inside a bag shelter immersed near the water surface. Outputs from the ESM for the duration of each seepage-bag connection were summed. To convert output to seepage flux in centimeters per day, regression-adjusted (that is, calibrated) output in milliliters per minute, which is equivalent to cubic centimeters per minute, was divided by the area covered by the seepage cylinder (9,260 cm^2 for the aluminum cylinders or 8,938 cm^2 for the plastic cylinder) and multiplied by 1,440 minutes per day. Flow and bag measurements were made for a velocity range similar to the range in flow measured at Newtown Creek during onsite seepage-data collection. Calibrations are summarized in table 2.

Table 2. Laboratory and onsite calibrations of electromagnetic seepage meters.
[ND, no data]

Electromagnetic seepage meter (ESM)	Regression multiplier			Regression R-squared		
	Location and date of calibration			Location and date of calibration		
	Lakewood	Newton Creek 05/27/15	Newton Creek 06/19/2015	Lakewood	Newton Creek 05/27/15	Newton Creek 06/16/15
ESM4/4	1.014	1.125	ND	0.9979	0.9999	ND
ESM5/4*	ND	ND	1.164	ND	ND	0.9996
ESM3/1**	1.127	1.050	1.050	0.9993	0.9981	0.9995
ESM2/2†	1.064	1.070	ND	0.9992	ND	ND

*ESM5/4 consisted of electronics box 5 connected to flowmeter 4. ESM5/4 was operated at NC266 and NC272 after ESM4 was damaged when the boat sank during deployment at DK052. The datalogger program and output file were still labeled ESM4.

**ESM5/5 was originally deployed at EK026, but the system produced data of poor quality and was replaced with ESM3/1. Electronics box 3 ran on AC power supplied by a pure-sine-wave inverter. The datalogger program and output file were still labeled ESM5.

†Onsite calibrations were not done for ESM2/2 during June 2015 because flowmeter 2 failed and was not operable during calibrations.

Accuracy is a measure of the difference between measured and true values and can be viewed as a combination of precision and bias. Instrument precision was determined from short-term variability in sensor output during a period of constant input. When no water flows through an immersed flowmeter, variability in sensor output, also referred to as “noise,” is an indication of instrument precision. Instrument precision was determined by analyzing standard deviations that were recorded during periods when flow was manually shut off (that is, “zeroed”). Sensor bias was minimized in two steps. First, sensors were calibrated using instrument-specific output multipliers that were determined using regression analysis against “known” values, as described earlier (for example, table 2). Second, to correct for sensor drift, flow into the ESMs was zeroed two to five times during each sensor deployment at Newtown Creek. Standard deviations during zero-flow periods are presented in table 3 and summary values are presented in table 4. Whether the average or maximum values are used, standard deviations are suitable error bars for measurements made during each seepage meter deployment, as shown by the blue values in figures 1 and 2.

Table 3. Averages of sensor output (in both millivolts and centimeters per day) during periods when flow was turned off during sensor deployment. The range in zero-flow average values during each sensor deployment is also presented. Average standard deviation during each zero-flow period is shown in the rightmost column.

[Date is given in M/DD/YYYY format; time is given in HH:MM format on a 24-hour clock. Ave., average; mV, millivolt; cm/d, centimeter per day; StDev, standard deviation]

Electromagnetic seepage meter (ESM)	Location	Date and time	Ave. zero (mV)	Ave. zero (cm/d)	Zero range (cm/d)	Zero StDev (cm/d)
ESM 4/4	EK093	5/19/2015 13:39	−37.4	−6.54	0.20	0.06
ESM 4/4	EK093	5/20/2015 09:59	−37.0	−6.47		0.03
ESM 4/4	EK093	5/20/2015 15:12	−38.1	−6.67		0.06
ESM 2/2	EK042	5/19/2015 15:08	21.6	3.59	6.54	0.09
ESM 2/2	EK042	5/20/2015 12:08	21.5	3.58		0.07
ESM 2/2	EK042	5/20/2015 15:40	−17.7	−2.95		0.03
ESM 2/2	EK042	5/21/2015 13:49	6.6	1.10		0.03
ESM 4/4	EB046	5/21/2015 11:00	−38.5	−6.74	0.62	0.19
ESM 4/4	EB046	5/21/2015 15:29	−39.4	−6.89		0.18
ESM 4/4	EB046	5/22/2015 11:10	−39.5	−6.91		0.32
ESM 4/4	EB046	5/22/2015 15:03	−41.3	−7.23		0.04
ESM 4/4	EB046	5/23/2015 09:29	−37.8	−6.61		0.33

Table 3 – continued

ESM 2/2	EB047	5/21/2015 15:03	6.2	1.03	1.21	0.15
ESM 2/2	EB047	5/22/2015 10:46	3.3	0.55		0.03
ESM 2/2	EB047	5/22/2015 15:28	2.7	0.45		0.05
ESM 2/2	EB047	5/23/2015 07:57	−1.1	−0.18		0.01
ESM 3/1	EK026	5/22/2015 12:32	−5.8	−0.98	2.15	0.10
ESM 3/1	EK026	5/22/2015 14:32	−5.8	−0.98		0.08
ESM 3/1	EK026	5/23/2015 11:09	2.6	0.44		0.07
ESM 3/1	EK026	5/26/2015 13:33	6.9	1.17		0.36
ESM 2/2	NC218	5/23/2015 09:00	4.3	0.72	3.27	0.23
ESM 2/2	NC218	5/26/2015 12:42	24.0	3.99		0.03
ESM 4/4	NC286	5/23/2015 10:36	−38.2	−6.68	0.37	0.48
ESM 4/4	NC286	5/26/2015 12:05	−40.3	−7.05		0.52
ESM 4/4	NC277	6/8/2015 13:06	−39.4	−7.13	0.29	0.59
ESM 4/4	NC277	6/9/2015 09:10	−40.7	−7.38		0.58
ESM 4/4	NC277	6/9/2015 13:06	−41.0	−7.42		0.21
ESM 4/4	NC277	6/10/2015 09:44	−39.9	−7.22		0.26
ESM 4/4	NC277	6/10/2015 13:39	−40.1	−7.26		0.53
ESM 3/1	NC278	6/8/2015 14:29	−3.6	−0.61	0.27	0.09
ESM 3/1	NC278	6/9/2015 10:04	−3.1	−0.52		0.11
ESM 3/1	NC278	6/9/2015 13:36	−3.0	−0.51		0.08
ESM 3/1	NC278	6/10/2015 09:03	−2.0	−0.34		0.09
ESM 4/4	NC276	6/10/2015 14:41	−38.2	−6.91	0.42	0.32
ESM 4/4	NC276	6/11/2015 10:11	−39.4	−7.13		0.31
ESM 4/4	NC276	6/11/2015 14:17	−40.3	−7.29		0.43
ESM 4/4	NC276	6/12/2015 09:21	−40.5	−7.33		0.23
ESM 3/1	DK042	6/10/2015 10:47	−3.4	−0.58	0.17	0.12
ESM 3/1	DK042	6/11/2015 10:44	−2.4	−0.41		0.14
ESM 3/1	DK042	6/12/2015 11:25	−2.8	−0.47		0.12

Table 3 – continued.

ESM 4/4	DK052	6/12/2015 10:59	−40.4	−7.31	0.04	0.49
ESM 4/4	DK052	6/12/2015 13:08	−40.6	−7.35		0.22
ESM 3/1	NC062	6/12/2015 12:42	−2.6	−0.44	0.00	0.10
ESM 3/1	NC062	6/15/2015 11:35	−2.6	−0.44		0.17
ESM 5/4	NC266	6/16/2015 13:35	−37.4	−6.77	0.49	0.20
ESM 5/4	NC266	6/17/2015 09:53	−34.7	−6.28		2.20
ESM 3/1	NC288	6/15/2015 12:43	−2.1	−0.36	0.18	0.08
ESM 3/1	NC288	6/16/2015 09:51	−2.1	−0.36		0.04
ESM 3/1	NC288	6/16/2015 14:11	−2.6	−0.44		0.05
ESM 3/1	NC288	6/17/2015 09:05	−3.2	−0.54		0.10
ESM 3/1	NC288	6/17/2015 11:51	−2.6	−0.44		0.05
ESM 3/1	NC271	6/17/2015 13:11	−4.3	−0.73	0.27	0.08
ESM 3/1	NC271	6/17/2015 14:59	−2.9	−0.49		0.16
ESM 3/1	NC271	6/18/2015 09:35	−2.7	−0.46		0.07
ESM 3/1	NC271	6/18/2015 14:01	−3.5	−0.59		0.06
ESM 3/1	NC271	6/19/2015 08:20	−3.0	−0.51		0.13
ESM 5/4	NC272	6/17/2015 11:17	−38.3	−6.93	0.81	0.25
ESM 5/4	NC272	6/17/2015 15:07	−37.8	−6.84		0.34
ESM 5/4	NC272	6/18/2015 09:09	−33.8	−6.12		0.30
ESM 5/4	NC272	6/18/2015 13:29	−35.0	−6.34		0.22
ESM 5/4	NC272	6/19/2015 07:46	−35.7	−6.46		0.31

Table 4. Average and maximum standard deviations during zero-flow periods, centimeters per day.
[ESM, electromagnetic seepage meter]

Electromagnetic seepage meter (ESM)	Location	Average standard deviation	Maximum standard deviation
ESM2/2	EK042	0.06	0.09
ESM2/2	EB047	0.06	0.15
ESM2/2	NC218	0.13	0.23
ESM4/4	EK093	0.05	0.06
ESM4/4	EB046	0.21	0.33
ESM4/4	NC286	0.50	0.52
ESM4/4	NC277	0.44	0.59
ESM4/4	NC276	0.32	0.43
ESM4/4	DK052	0.35	0.49
ESM5/4	NC266	1.20	2.20
ESM5/4	NC272	0.29	0.34
ESM3/1	EK026	0.16	0.36
ESM3/1	NC278	0.09	0.11
ESM3/1	DK042	0.13	0.14
ESM3/1	NC062	0.13	0.17
ESM3/1	NC288	0.06	0.10
ESM3/1	NC271	0.10	0.16

Accuracy Where Seepage was Particularly Slow

Errors can overwhelm the input signal when seepage rates are particularly slow. Random errors during periods of seconds to minutes can be substantially reduced by averaging output during periods of hours to days. If errors are random, the standard deviation is halved every time the sample size increases by four times. Accuracy can be determined on the basis of (1) differences between measured and regression-modeled values, (2) variability in sensor output during periods of zero flow, and (3) the standard deviation of average values during zero-flow periods.

1. Regression modeling
   Differences between measured and modeled values is a commonly used measure of accuracy. Regression-based calibrations for each ESM all have very large R-squared values (table 2) but because of the relatively large range for which field-based calibrations were made, even small offsets from the regression line can cause substantial inaccuracy when flows are slow. Table 5 presents the differences between measured and modeled values for each of the onsite calibration measurements made during the May 2015 and June 2015 field deployments. Comparisons are remarkably good, with 18 of 21 differences 0.5 cm/d or less. Meter ESM2/2 was not calibrated onsite during June 2015 because it failed after two successful May 2015 deployments.

2. Sensor drift
   Adjustments made for sensor drift assumed that the drift was linear between periods when flow was shut off. If drift was indeed linear and several periods of zero-flow measurements were generated during each sensor deployment, sensor drift can be eliminated. One indicator of the degree of potential error that would occur if this assumption were not true is to compare the range in average values of zero-flow periods during each sensor deployment, as given in table 3. The range in zero-flow values for each deployment was less than 1 cm/d for 13 of the 17 deployments. The deployment with the largest range in zero-flow-value output was at location EK042, where zero-flow values varied by more than 6 cm/d during the deployment period (table 3).
   Plots of unadjusted and zero-flow-adjusted data demonstrate the effect of adjusting for the larger-than-normal range in zero-flow values at EK042 (fig. 4). A possible explanation for the relatively poor system performance shown in this plot is that air may have been trapped inside the flow-through cylinder of the flowmeter following low tide during the early morning of May 20, 2015, as indicated by the very large range in sensor output just prior to 06:00. Air may have been introduced when the low-tide water surface was at or slightly above the flowmeter orifice, during which air and water could flow rapidly through the flowmeter in response to small waves on the water surface. The subsequent sudden change in sensor output on May 20, 2015, at 14:15 is unusual and may be related to trapped air being flushed from the flowmeter, which would affect sensor output as well as the value during a zero-flow measurement period. No matter the cause, the larger-than-expected range in zeroed values, and the resulting zero-flow-offset adjustments, did not affect the interpretation that flow is generally upward and slow at EK042.

Table 5. Differences between seepage calculated from field-based calibration (modeled) values and seepage determined with time-integrated seepage-bag (measured) measurements.

[Differences of modeled values minus measured values are given in centimeters per day, based on output data in millivolts applied to regression equations. ESM2/2 was not calibrated in June 2015 because it failed after two successful deployments in May 2015. ESM5/4 was calibrated in June 2015 in place of ESM4/4 after it was damaged during deployment at DK052. No data is indicated by --.]

Electromagnetic seepage meter (ESM)	Field-based calibrations	
	May 2015	June 2015
ESM2/2	-0.6	--
ESM2/2	0.9	--
ESM2/2	-0.5	--
ESM2/2	0.2	--
ESM3/1	0.7	-0.4
ESM3/1	-0.6	-0.2
ESM3/1	-0.1	0.3
ESM3/1	--	-0.5
ESM3/1	--	0.2
ESM3/1	--	0.6
ESM4/4	-0.1	--
ESM4/4	0.3	--
ESM4/4	-0.1	--
ESM4/4	-0.1	--
ESM4/4	0.0	
ESM5/4	--	0.1
ESM5/4	--	0.0
ESM5/4	--	-0.1
ESM5/4	--	0.2
ESM5/4	--	-0.1
ESM5/4	--	0.0
ESM5/4	--	-0.1

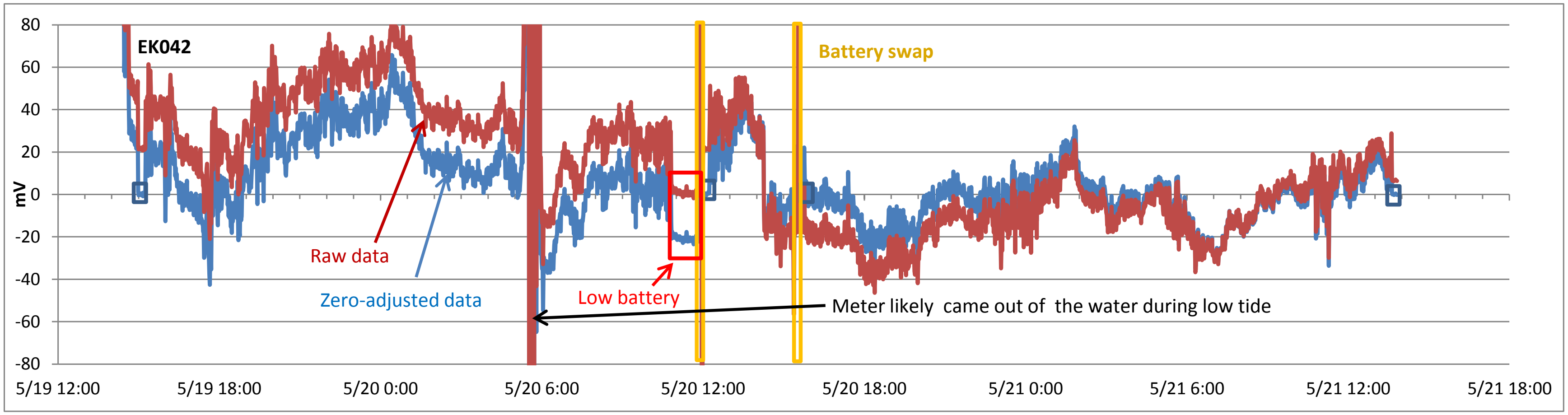


Figure 4. Effect of correcting seepage-meter output using zero-flow-offset measurements at EK042. Unadjusted data shown in red and zero-flow-adjusted data shown in blue. Blue rectangles indicate periods when flow was zeroed. (mV, millivolts)

3. Standard deviation
   Standard deviations were generally very small during zero-flow periods; maximum values ranged from 0.06 cm/d to generally less than 0.4 cm/d (table 4). The largest standard deviations were associated with output from ESM4/4 (or ESM5/4 during later deployments), with standard deviations exceeding 0.4 cm/d starting at location NC286 (table 4). Values at locations NC286, NC277, NC276, DK052, and NC272 ranged from 0.34 to 0.59 cm/d. The largest standard deviations occurred during sensor deployment at NC266, where the maximum standard deviation was 2.20 cm/d. Fortunately, flows at NC266 were so large that this larger-than-normal standard deviation had no effect on interpretation of the data. The cause of this increased sensor noise was an intermittent short in the data cable between the electronics box and the digital datalogger, which caused intermittent spikes in the output generated by the flowmeter. The cable was manipulated during deployment at NC266 until the frequency of intermittent spikes was greatly reduced. This manipulation substantially improved sensor output during the subsequent and final deployment at NC272.

Collectively, these three measures of ESM accuracy indicate that, unless special circumstances were noted, accuracy was approximately 0.5 cm/d and sensor drift was the largest source of error.

Interpretations for Specific Measurement Locations

Two charts are presented at the beginning of the description for each measurement location. Location descriptions are presented in the same order as data collection. The upper chart displays seepage data that have been smoothed. Each value is an average of seven 1-minute values centered in time around each time-averaged value. Relative tide in units of feet, measured at the nearer of two tide gages installed in Newtown Creek (described earlier in “Overview of Seepage Measured at Newtown Creek”), is also shown. Tide is plotted on the left axis along with seepage, unless a right axis is present, in which case tide is plotted on the right axis. Green rectangles indicate periods for which data were summarized. For all deployments, two periods were analyzed; therefore, two green rectangles indicate the durations of those data-summary periods. Summary statistics for each analysis period are displayed in table 1. For convenience, data statistics are also presented in a table embedded in the upper of the two charts. The lower chart displays the actual 1-minute data generated by the ESM. Values collected during drift-correction zero-flow calibration periods are deleted. A qualitative summary describing the perceived overall quality of data collected at each measurement location is presented in table 6.

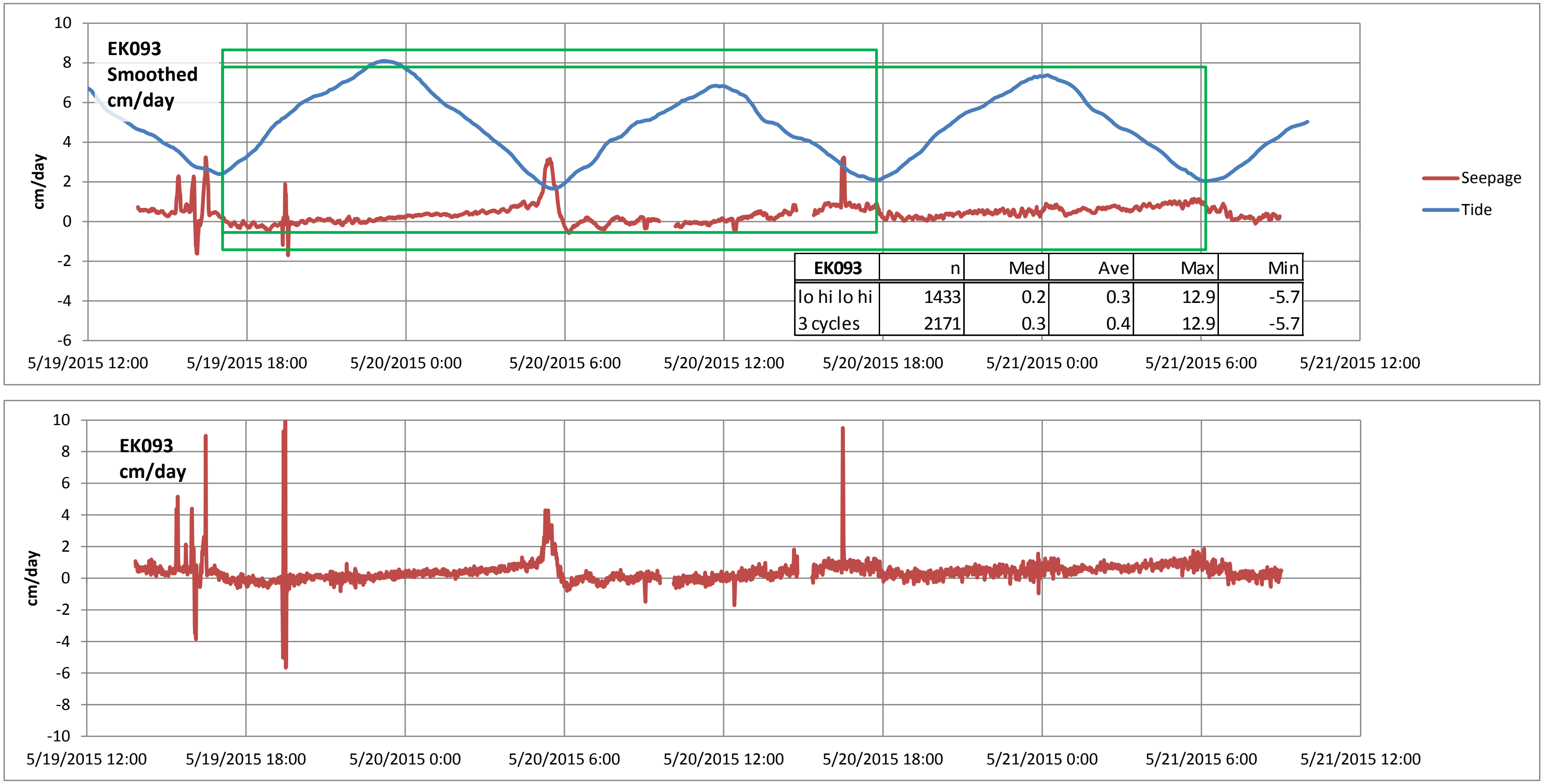
Table 6. Relative quality and usability of data collected at Newtown Creek seepage-measurement locations.
[cm/d, centimeters per day]

Location	Usability of data	Notes/discussion
EK093	Good	Slow seepage but with easily detectable features. Small system drift. Discarding a few data spikes caused almost no change in statistics.
EK042	Moderate/poor	Approximately 9 hours of data record are questionable because air may have been introduced into the flowmeter during low tide, which created an apparent offset in sensor output, as well as a large range in the zero-flow values during deployment. Furthermore, output from ESM2/2 was the noisiest of all of the ESM systems.
EB046	Excellent	No problems detected. Although time-averaged values may be less than system accuracy, the deployment provided nicely consistent output, and zero-flow values ranged by only 0.6 cm/d.
EB047	Good	No problems detected. However, ESM2/2 was used to collect data so modeled values and measured values were not as close as with other ESM systems.
EK026	Good	The only cause for concern was a larger-than-normal range in zero-flow values during deployment. This was offset, however, by the consistently large seepage rates that were well beyond potential drift-related errors.
NC218	Moderate	Data variability is small for three tidal cycles, but large variability existed before and after those three cycles. Reasons for the much larger variability that bookends the low-variability data are unknown.

Table 6 – continued.

NC286	Excellent	No apparent problems or aberrations in the dataset with an average value indistinguishable from zero-flow values. Nice tidal signal.
NC277	Moderate/poor	Data were very noisy during the early part of the deployment. Datalogger was replaced at 12:47 on June 9, 2015, and standard deviations improved somewhat. Cause of large downward spikes is unknown.
NC278	Excellent	No problems detected. Large downward spikes are nearly coincident with similar spikes recorded across the channel at NC277.
NC276	Good	No problems but standard deviations of zero-flow periods are slightly larger than at other sites, ranging from 0.23 to 0.43 cm/d. Data were noisy during the first recorded tidal cycle but then variability decreased.
DK042	Excellent	Very clean data during the entire deployment. Strong tidal influence.
DK052	Moderate/good	Clean data during entire deployment until boat overturned. Standard deviations are about twice those at DK042 but they are still small, ranging from 0.22 to 0.49 cm/d. Strong tidal influence.
NC062	Excellent	Clean data, small range in zero-flow values and small standard deviations during zero-flow periods.
NC266	Good	Noise was generated by an intermittent short in the data cable, but values were so large that the noisy data and large standard deviations were irrelevant to the data interpretation.
NC288	Poor, then excellent	Data were very noisy because a valve was in the wrong position until 09:37 on June 16, 2015. Data were very good after that with very small standard deviation and small range in zero-flow values.
NC271	Excellent	No problems; small bias range and small standard deviation of zero-flow values.
NC272	Moderate/poor	Noisy data (large zero-flow standard deviations) likely due to an intermittent short in data cable. Smaller seepage rates during the first 12 hours are unexplained.

EK093



EK093	n	Med	Ave	Max	Min
lo hi lo hi	1433	0.2	0.3	12.9	-5.7
3 cycles	2171	0.3	0.4	12.9	-5.7

Figure 5. Seepage measured each minute during deployment at EK093, in centimeters per day. The upper plot displays smoothed seepage data based on a 7-minute moving average and relative tide in feet. The lower plot presents the actual 1-minute values. The green rectangles indicate the duration of the data-summary periods. In the inset table, “lo hi lo hi” indicates two complete tidal cycles beginning and ending with low tide, and “3 cycles” indicates that seepage was measured over three tidal cycles. (cm/d, centimeters per day; n, number of 1-minute values; Med, median of n values; Ave, average of n values; Max, maximum of n values; Min, minimum of n values)

Seepage was slow, relatively steady, and mostly upward at EK093 (fig. 5). The median value was 0.2 to 0.3 cm/d, depending on the period of analysis. The spikes in the dataset did not have an appreciable effect on the summary statistics. Even after discarding 101 values (see “Censored” in table 7) to remove data spikes centered around May 19, 2015, at 19:25 and May 20, 2016, at 05:20 and 16:30, all summary statistics remain virtually the same except for maximum, minimum, and 0.75 quartile values.

Upward seepage increased slightly during each falling tide (fig. 5). Upward seepage was most pronounced during the lowest of the low tides on the morning of May 20, 2015. Seepage increased substantially just prior to the lowest-tide nadir. Once the tide began rising, seepage decreased and became slightly downward. This stronger tidal response occurred only during the lowest tide during the measurement period. Similar seepage response to extreme low tides has also been observed in Puget Sound, Washington (Simonds and others, 2008).

Very slow downward seepage occurred during two of the three rising tides shown in the chart. Seepage was upward during the third tidal cycle and increased steadily during the rising and subsequent falling limbs from approximately 0.1 to approximately 0.5 cm/d. There is no obvious explanation for the upward and downward spikes just prior to 19:30 on May 19, 2015, and the upward spike at about 16:30 on May 20, 2015. However, benthic or epipelagic fauna can cause spikes when they crawl or swim through the orifice of the electromagnetic flowmeter.

Table 7. Summary statistics for measurement location EK093 showing complete dataset (Original) followed by analysis of an abbreviated dataset after removing 101 questionable values (Censored), in centimeters per day.

[“Lo hi lo hi” indicates two complete tidal cycles beginning and ending with low tide and “3 cycles” indicates that seepage was measured over three tidal cycles. n, number of 1-minute values; Med, median of n values; Ave, average of n values; Max, maximum of n values; Min, minimum of n values; 0.75 quart, 75th quartile; 0.25 quart, 25th quartile]

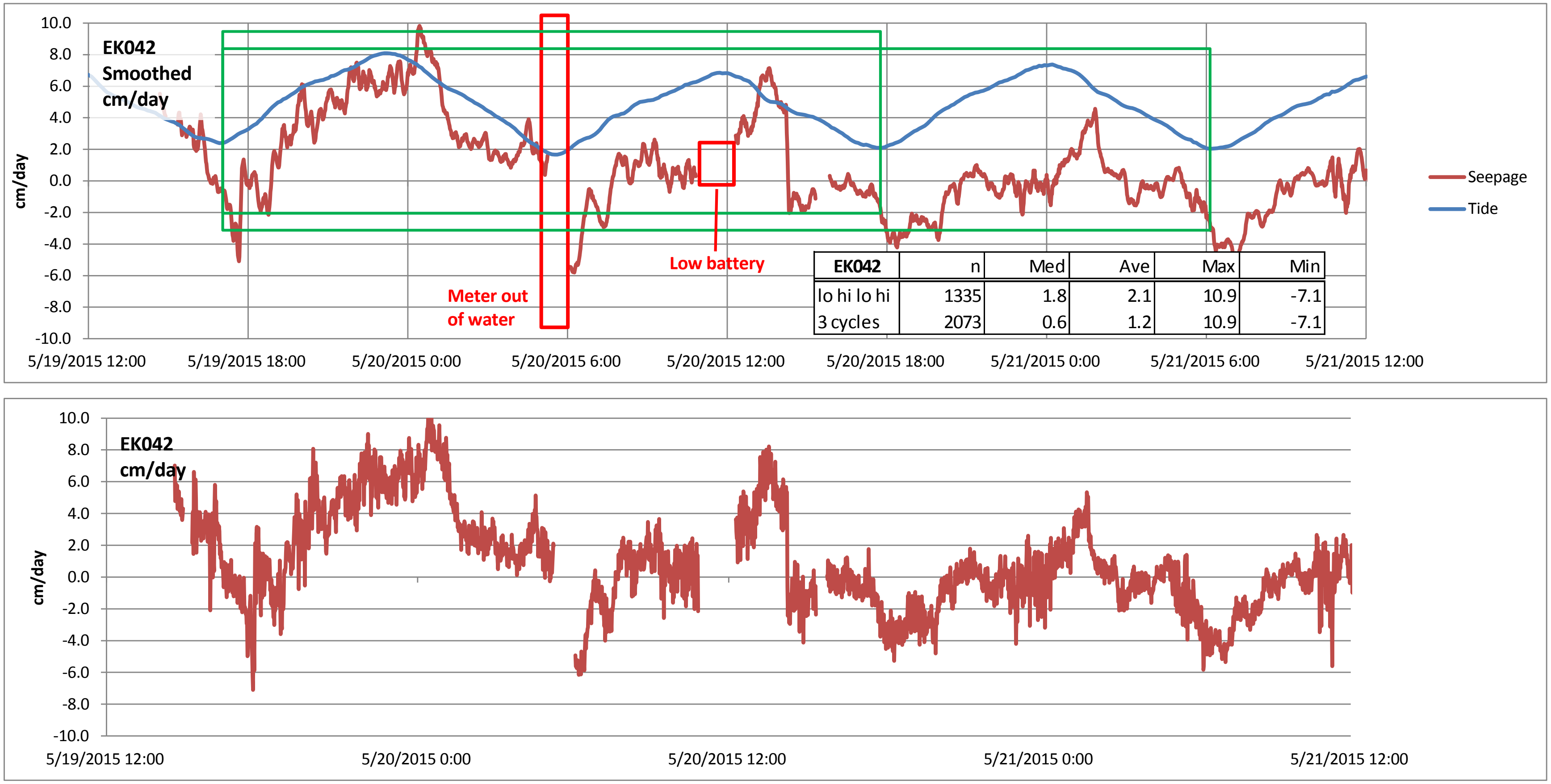
Original

EK093	n	Med	Ave	Max	Min	0.75 quart	0.25 quart
lo hi lo hi	1433	0.2	0.3	12.9	-5.7	0.5	-0.1
3 cycles	2171	0.3	0.4	12.9	-5.7	0.6	0.0

Censored

EK093	n	Med	Ave	Max	Min	0.75 quart	0.25 quart
lo hi lo hi	1332	0.2	0.2	1.9	-1.7	0.4	0.0
3 cycles	2070	0.3	0.3	1.9	-1.7	0.6	0.0

EK042



EK042	n	Med	Ave	Max	Min
lo hi lo hi	1335	1.8	2.1	10.9	-7.1
3 cycles	2073	0.6	1.2	10.9	-7.1

Figure 6. Seepage measured each minute during deployment at EK042, in centimeters per day. The upper plot displays smoothed data based on a 7-minute moving average and relative tide in feet. The lower plot presents the actual 1-minute values. The green rectangles indicate the duration of the data-summary periods. In the inset table, “lo hi lo hi” indicates two complete tidal cycles beginning and ending with low tide, and “3 cycles” indicates that seepage was measured over three tidal cycles. (cm/d, centimeters per day; n, number of 1-minute values; Med, median of n values; Ave, average of n values; Max, maximum of n values; Min, minimum of n values)

Median seepage originally determined at EK042 ranged from 0.5 to 1.6 cm/d, depending on whether two or three tidal cycles were analyzed. However, two periods of questionable data may have affected summary statistics. The large variability from about 05:30 to 05:50 on May 20, 2015, (fig. 6) was likely caused by the water surface falling to near the orifice of the electromagnetic flowmeter; water would be able to pulse through the flowmeter with the passage of small waves and ripples in the water surface. A low battery was responsible for erroneous data collection beginning at 10:49 on May 20, 2015. If these two periods of erroneous data are discarded, seepage ranged from -7.1 to 10.9 cm/d. Median values increased slightly compared to the original data and ranged from 0.6 to 1.8 cm/d. These are the values shown in the table embedded in the upper chart in figure 6 and in table 1.

Values were substantially variable, and seepage was responsive to tides. Upward seepage increased steadily during each rising tide until 1 to 2 hours after high tide; seepage then decreased substantially, sometimes at a rapid rate. Downward seepage occurred generally at about the halfway point between high and low tide, but seepage did not become downward on May 20, 2015, until the low-tide nadir (fig. 6). Much of the short-term variability in the seepage data can be explained by small changes in the rate of surface-water stage increase or decrease during each tidal cycle. If the difference in stage from one measurement to the next is plotted instead of stage, as shown in figure 7, inflections in the change in stage correlate well with inflections in seepage rate. Furthermore, the timing of inflections in seepage is similar for both locations shown in figure 7. The much smaller range in variability at EK093 also correlates with changes in the rate of tidal change. This correlation is particularly apparent from 06:00 to 10:00 on May 20, 2015, and from 06:00 to 09:00 on May 21, 2015 (fig. 7B).

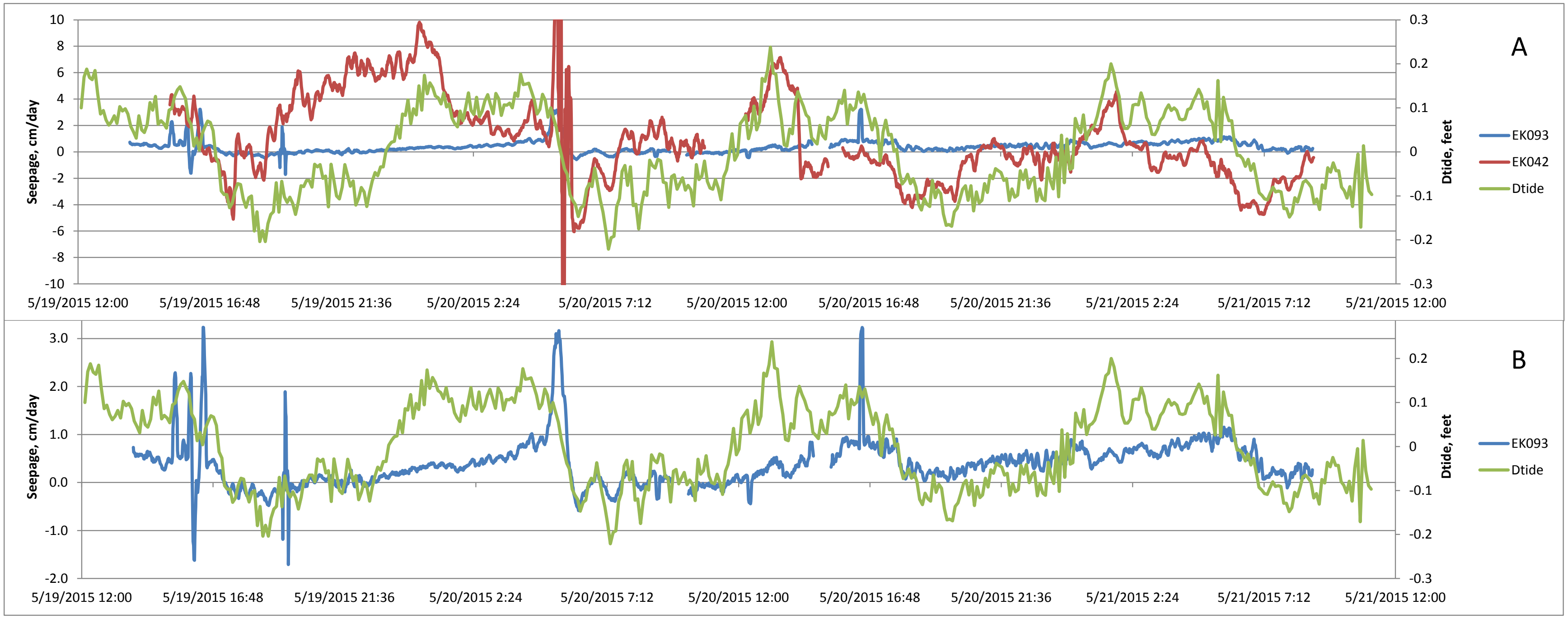
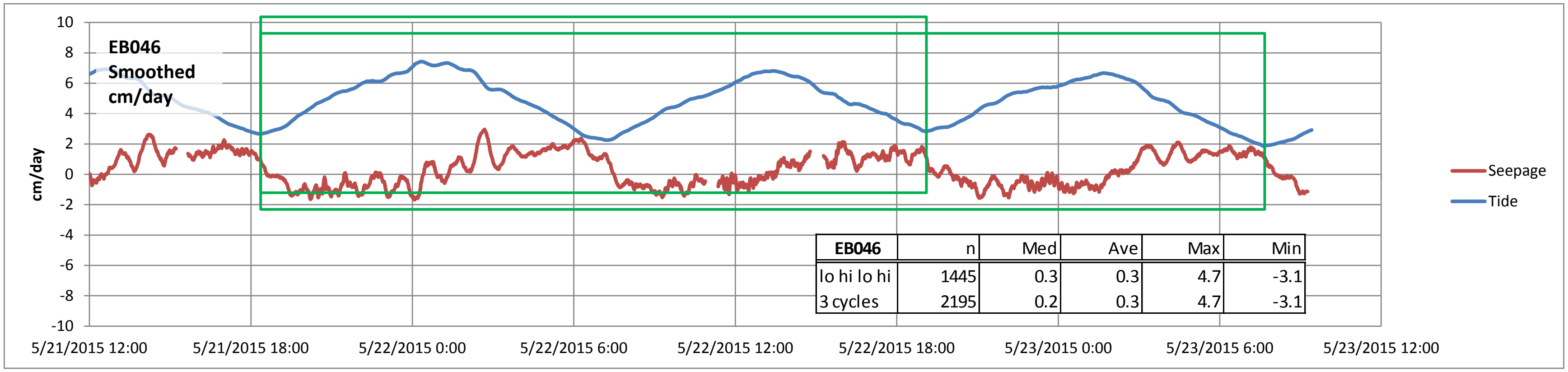


Figure 7. (A) Smoothed seepage measured at EK042 and EK093, in centimeters per day (cm/d), with the previous tidal value minus the current tidal value (Dtide), in feet, plotted on the right axis. (B) Variability at EK093 is plotted over a narrower range.

EB046



EB046	n	Med	Ave	Max	Min
lo hi lo hi	1445	0.3	0.3	4.7	-3.1
3 cycles	2195	0.2	0.3	4.7	-3.1

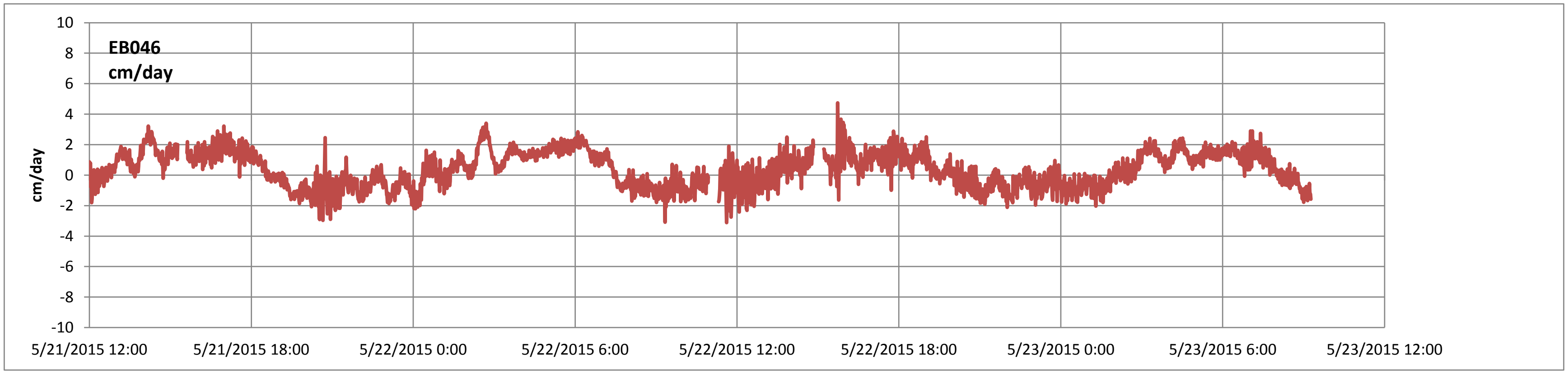
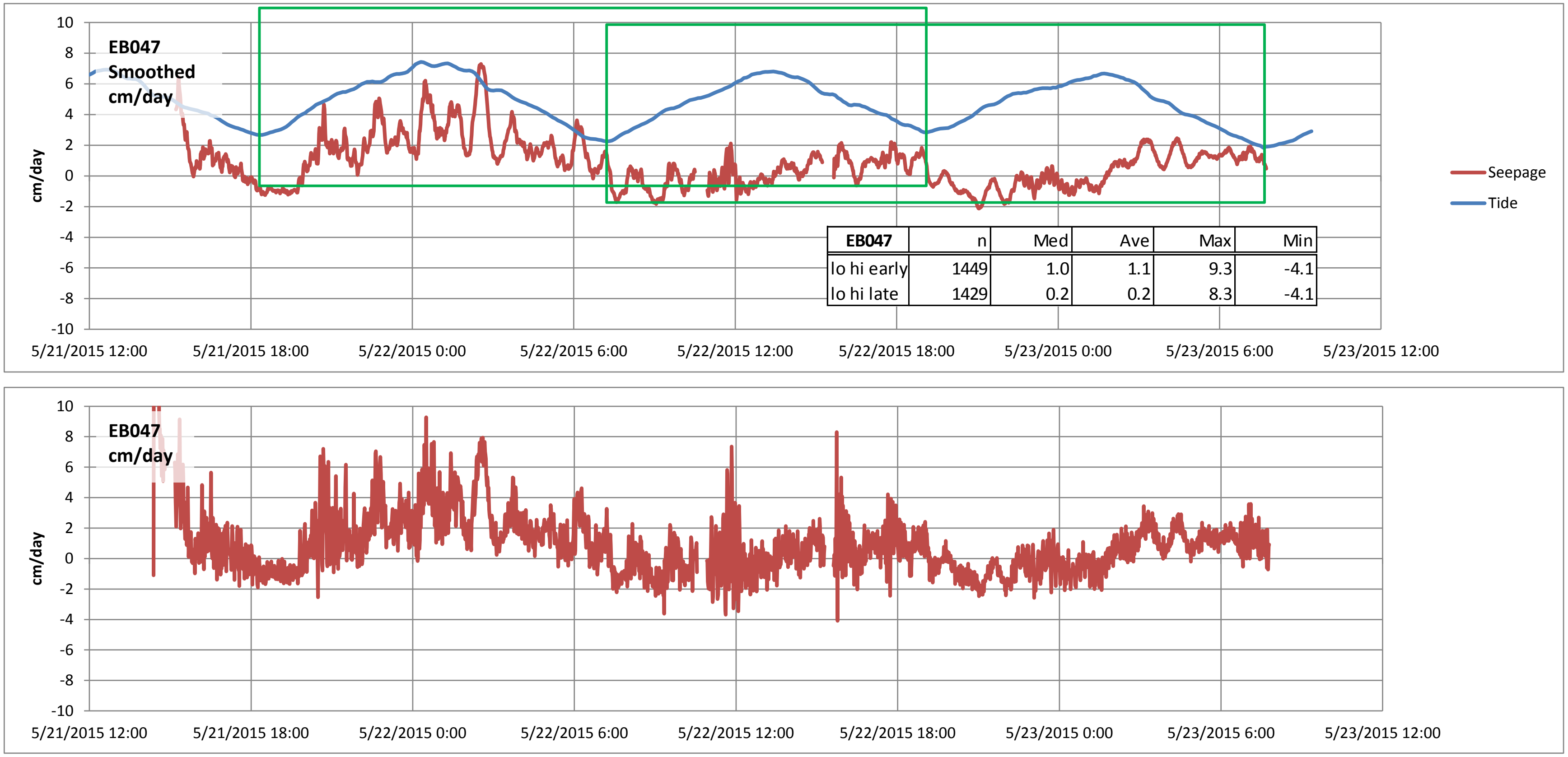


Figure 8. Seepage measured each minute during deployment at EB046, in centimeters per day. The upper plot displays smoothed data based on a 7-minute moving average and relative tide, in feet. The lower plot presents the actual 1-minute values. The green rectangles indicate the duration of the data-summary periods. In the inset table, “lo hi lo hi” indicates two complete tidal cycles beginning and ending with low tide and “3 cycles” indicates that seepage was measured over three tidal cycles. (cm/d, centimeters per day; n, number of 1-minute values; Med, median of n values; Ave, average of n values; Max, maximum of n values; Min, minimum of n values)

Seepage at EB046 was slow, ranging from -3.1 to 4.7 cm/d (fig. 8). Median seepage was slightly upward at 0.2 or 0.3 cm/d, depending on the analysis period. As at other sites near the eastern end of Newtown Creek, seepage became slightly downward shortly after the beginning of a rising tide and became slightly upward at or soon after tidal apex. Transition from upward to downward seepage was particularly rapid at or just after tidal nadir.

EB047

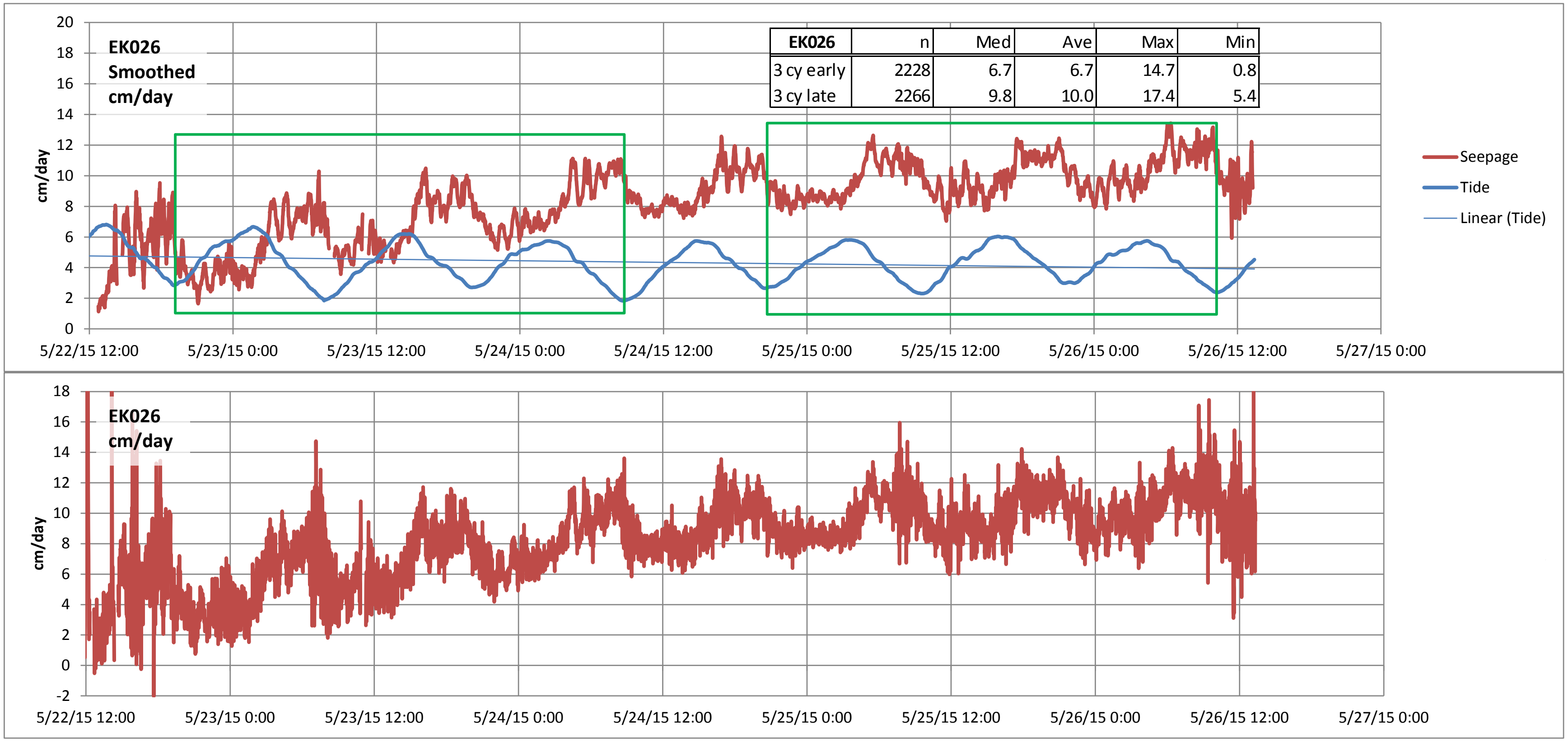


EB047	n	Med	Ave	Max	Min
lo hi early	1449	1.0	1.1	9.3	-4.1
lo hi late	1429	0.2	0.2	8.3	-4.1

Figure 9. Seepage measured each minute during deployment at EB047, in centimeters per day. The upper plot displays smoothed data based on a 7-minute moving average and relative tide, in feet. The lower plot presents the actual 1-minute values. The green rectangles indicate the duration of the data-summary periods. In the inset table, “lo hi” indicates one complete tidal cycle beginning and ending with low tide, and “early” or “late” indicates the timing of the analysis period. (cm/d, centimeters per day; n, number of 1-minute values; Med, median of n values; Ave, average of n values; Max, maximum of n values; Min, minimum of n values)

A slight decrease in seepage was detected during the EB047 measurement period, hence the early- and late-period analyses shown in figure 9. Comparing tidal cycles 1 and 2 (early) to cycles 2 and 3 (late) shows that median seepage decreased from 1.0 to 0.2 cm/d. Extremes ranged from -4.1 to 9.3 cm/d. Seepage was generally downward shortly after tidal nadir and then transitioned to upward seepage before tidal apex. Seepage was generally fastest from about 20:00 on May 21, 2015, until 04:00 on May 22, 2015.

EK026



EK026	n	Med	Ave	Max	Min
3 cy early	2228	6.7	6.7	14.7	0.8
3 cy late	2266	9.8	10.0	17.4	5.4

Figure 10. Seepage measured each minute during deployment at EK026, in centimeters per day. The upper plot displays smoothed data based on a 7-minute moving average and relative tide, in feet. A simple linear regression of tide is also presented in blue. The lower plot presents the actual 1-minute values. The green rectangles indicate the duration of the data-summary periods. In the inset table, “3 cy early” and “3 cy late” indicate the number of tidal cycles during which seepage was measured and the timing of the analysis period. (cm/d, centimeters per day; n, number of 1-minute values; Med, median of n values; Ave, average of n values; Max, maximum of n values; Min, minimum of n values; cy, cycles)

Seepage at location EK026 was relatively fast, responded to tides, and increased gradually during the measurement period (fig. 10). This site had either the second largest or largest upward seepage rate, depending on whether the early or late part of the dataset is analyzed. A strong temporal trend was detected during a fairly long seven-tidal-cycle measurement period. Median seepage determined during the first three tidal cycles was 6.7 cm/d, and median seepage determined during the last three tidal cycles was 9.8 cm/d. The cause of the steady increase in seepage is unknown. A seepage meter slowly sinking into soft sediment could generate spurious upward flow. However, the diver checked the anchor pipes that held the seepage cylinder in place and they were firmly planted and secured to the seepage cylinder as designed. Another explanation could be an increasing hydraulic gradient that drives seepage discharge. Hydraulic gradient was not measured at this location. However, mean daily surface-water stage during the EK026 deployment decreased from approximately 4.75 feet to approximately 3.95 feet, as shown in the upper plot in figure 10. This decrease would result in an increasing hydraulic gradient assuming that the hydraulic head in groundwater adjacent to the water in Newtown Creek remained steady.

Seepage was almost always upwards, with just a few minutes of downward seepage indicated during the early part of the data-collection period. Seepage was very sensitive to changes in water-surface stage. The cyclic 2 to 3 cm/d variations in seepage during an approximately hourly time scale were caused by small changes in the rate of tidal change, perhaps because of wave amplification, as shown in figure 11. As previously shown in figure 7, Dtide in figure 11 is a plot of the differences between two incremental 1-minute tidal values.

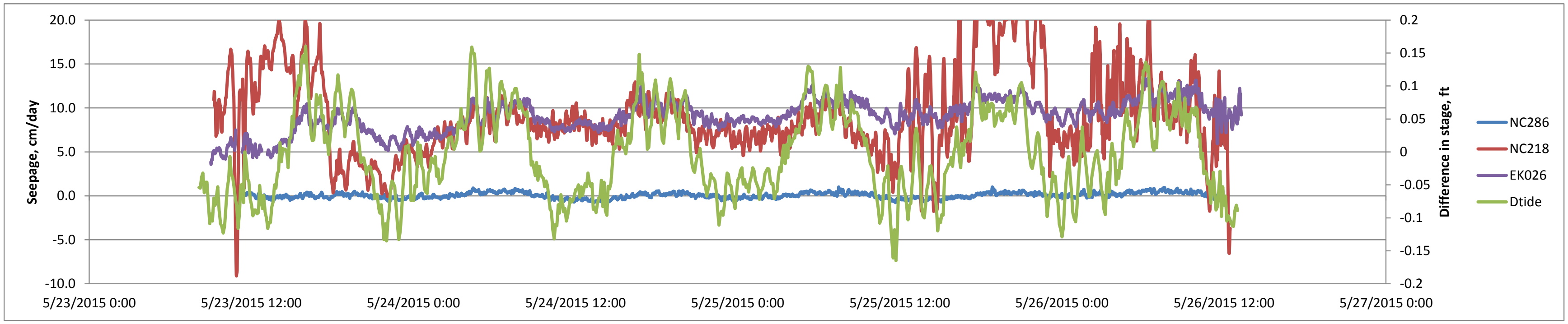


Figure 11. Smoothed seepage measured at NC286, NC218, and EK026, in centimeters per day (cm/d), with the previous tidal value minus the current tidal value (Dtide), in feet, plotted on the right axis.

NC218

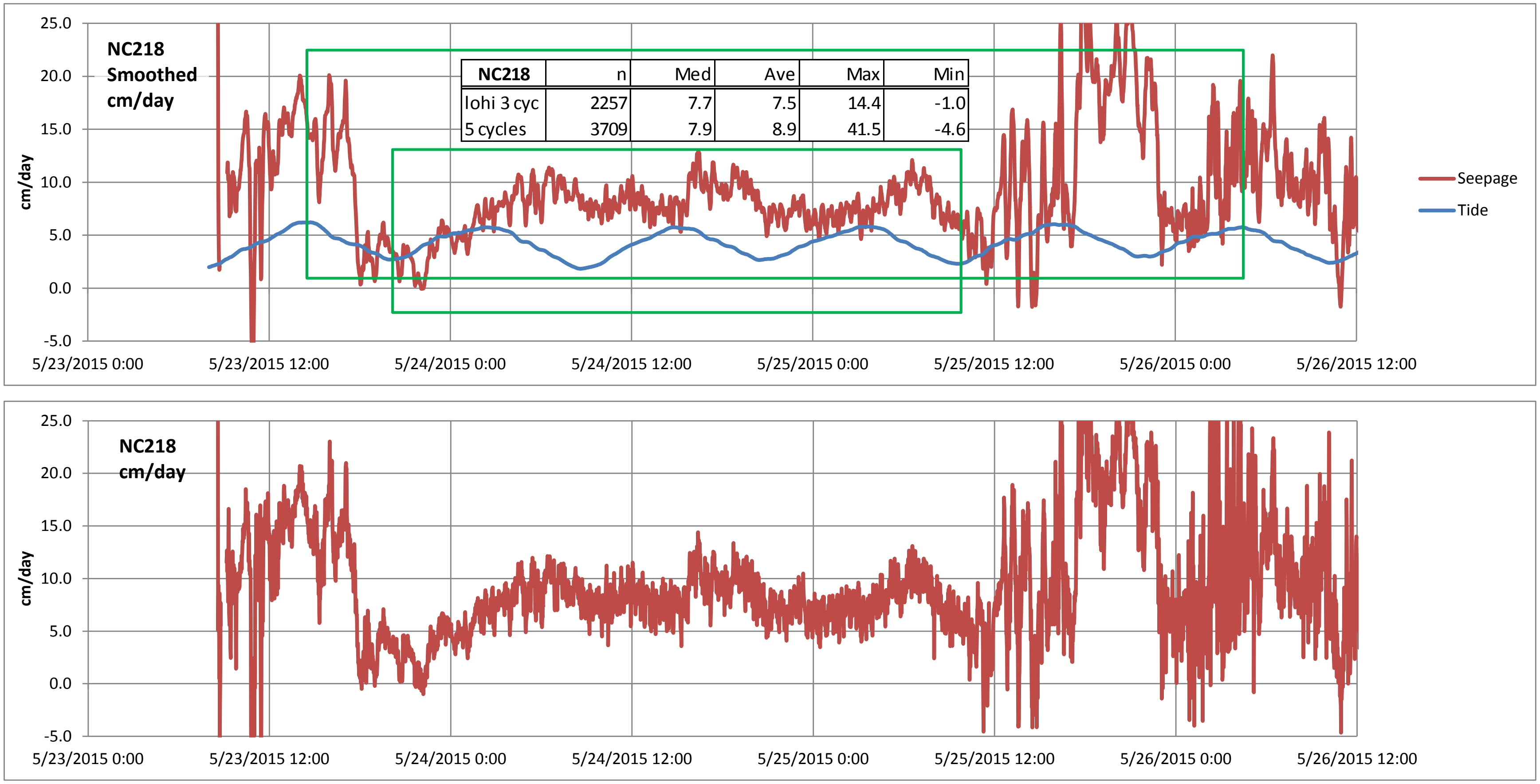


Figure 12. Seepage measured each minute during deployment at NC218, in centimeters per day. The upper plot displays smoothed data based on a 7-minute moving average, and relative tide, in feet. The lower plot presents the actual 1-minute values. The green rectangles indicate the duration of the data-summary periods. In the inset table, "lo hi" indicates one complete tidal cycle beginning and ending with low tide, and "3 cyc" and "5 cycles" indicate the number of tidal cycles during which seepage was measured. (cm/d, centimeters per day; n, number of 1-minute values; Med, median of n values; Ave, average of n values; Max, maximum of n values; Min, minimum of n values; cyc, cycles)

Seepage at NC218 was nearly always upward and was either the fastest or second fastest of the 17 measurement locations. Seepage was substantially variable during the 3-day data-collection period (fig. 12) with periods of large-amplitude variability interspersed with periods of lower-amplitude variability. The three-tidal-cycle analysis extended during a more stable period of measured seepage when seepage varied between -1.0 and 14.4 cm/d with a median value of 7.7 cm/d. A longer five-tidal-cycle analysis period indicated a range of seepage from -4.6 to more than 41 cm/d, but with a similar median value of 7.9 cm/d. Although short-term seepage variability changed substantially during the measurement period, no trend was evident during the data-collection period. The cause for larger (10 to 20 cm/d) seepage rates centered around 12:00 on May 23, 2015, and around 21:00 on May 25, 2015, is unknown. Wind has been related to either faster seepage or greater seepage variability (Rosenberry and others, 2013). However, as shown in figure 13, although both periods of faster seepage at NC218 were relatively windy, other periods were equally windy when seepage was much slower.

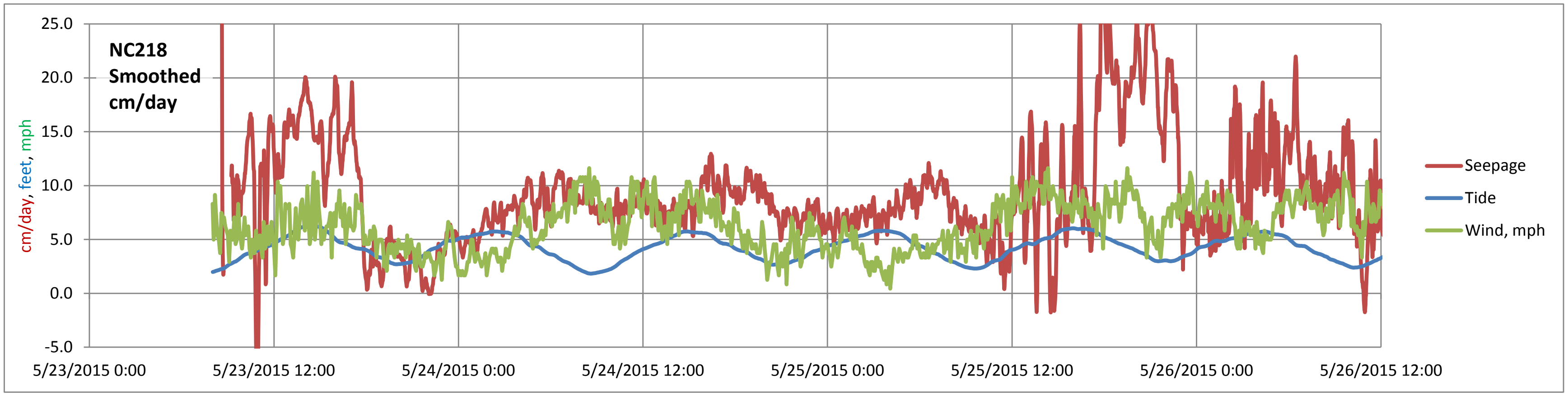
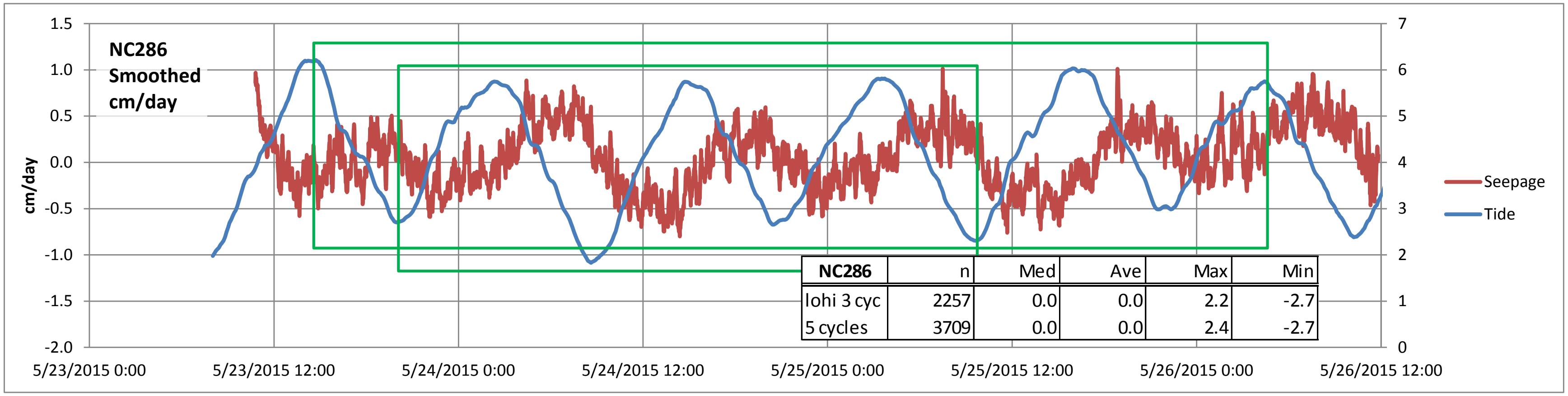


Figure 13. Smoothed seepage measured at NC218, in centimeters per day (cm/d); tide, in feet; and wind speed, in miles per hour (mph).

NC286



NC286	n	Med	Ave	Max	Min
lohi 3 cyc	2257	0.0	0.0	2.2	-2.7
5 cycles	3709	0.0	0.0	2.4	-2.7

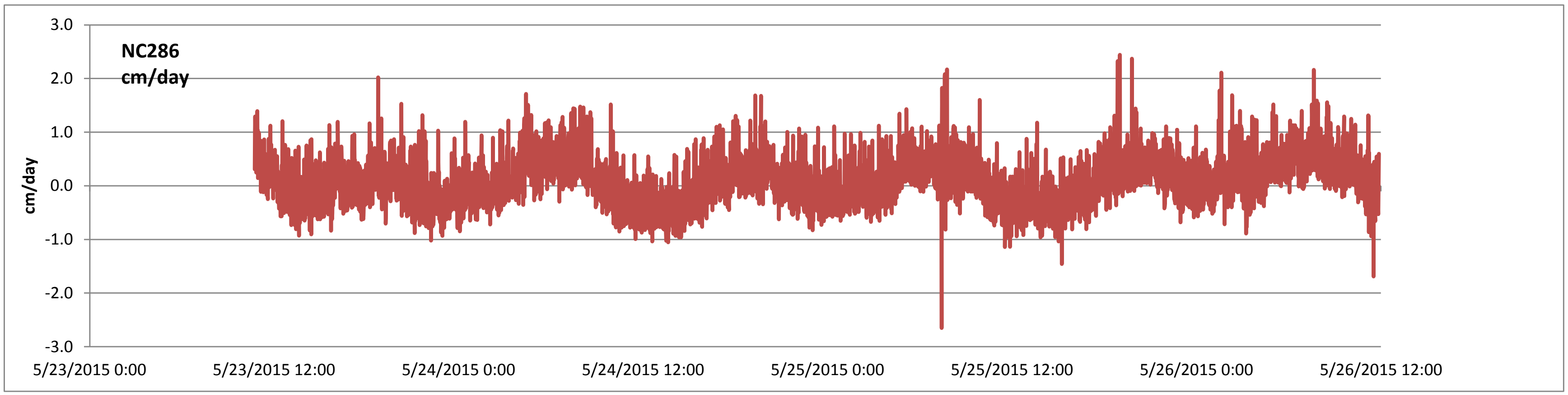
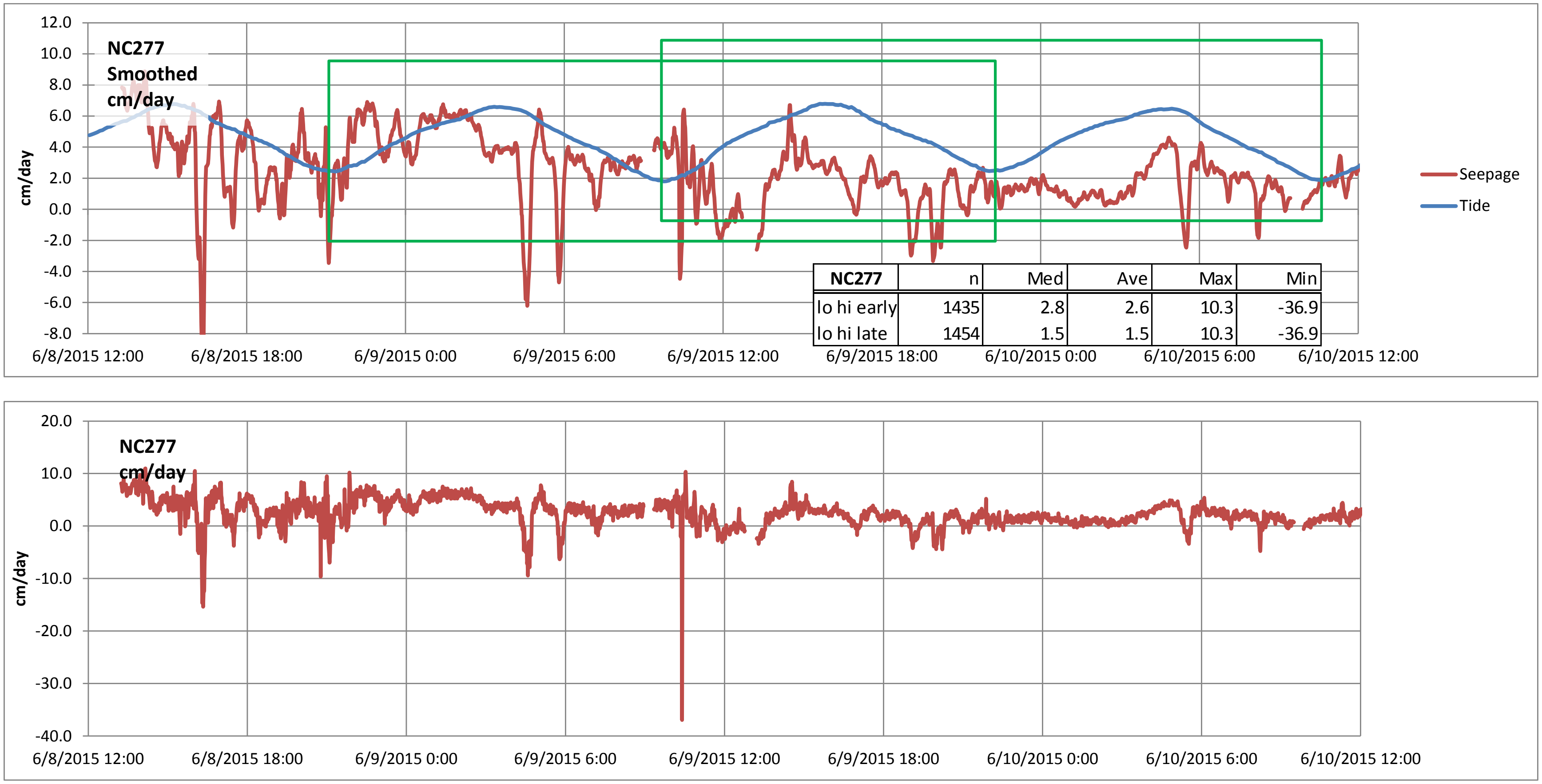


Figure 14. Seepage measured each minute during deployment at NC286, in centimeters per day. The upper plot displays smoothed data based on a 7-minute moving average, with relative tide, in feet, plotted on the right axis. The lower plot presents the actual 1-minute values. The green rectangles indicate the duration of the data-summary periods. In the inset table, “lo hi” indicates one complete tidal cycle beginning and ending with low tide, and “3 cyc” and “5 cycles” indicate the number of tidal cycles during which seepage was measured. (cm/d, centimeters per day; n, number of 1-minute values; Med, median of n values; Ave, average of n values; Max, maximum of n values; Min, minimum of n values; cyc, cycles)

Net seepage was zero at NC286 (fig. 14). A small response to tides was detected. Seepage commonly ranged between -0.5 and 0.5 cm/d with a phase lag relative to tide of approximately 4 hours. This was among the most stable and consistent datasets collected at Newtown Creek. The cause of the small downward spike shortly after 07:00 on May 25 is unknown.

NC277



NC277	n	Med	Ave	Max	Min
lo hi early	1435	2.8	2.6	10.3	-36.9
lo hi late	1454	1.5	1.5	10.3	-36.9

Figure 15. Seepage measured each minute during deployment at NC277, in centimeters per day. The upper plot displays smoothed data based on a 7-minute moving average, and relative tide, in feet. The lower plot presents the actual 1-minute values. The green rectangles indicate the duration of the data-summary periods. In the inset table, “lo hi” indicates one complete tidal cycle beginning and ending with low tide, and “early” or “late” indicates timing of an analysis period relative to the site-specific data-collection period. (cm/d, centimeters per day; n, number of 1-minute values; Med, median of n values; Ave, average of n values; Max, maximum of n values; Min, minimum of n values)

Moderately slow seepage at NC277 gradually became slower during the 2-day measurement period (fig. 15). Median seepage during the first two of three tidal cycles was 2.8 cm/d, and during the latter two-cycle period it decreased by nearly half to 1.5 cm/d. Seepage showed very little response to tides. Several periods of prolonged downward seepage were detected, most persisting for 20 to 30 minutes (fig. 16). Examples include downward spikes at 16:22 on June 8, 2015, and at 04:36 and 05:47 on June 9, 2015. Most of these downward spikes occurred 1 hour or 3 hours after high tide, and no downward spikes were detected during a rising tide. None of these departures from more typical seepage rates is related to changes in surface-water stage. The largest downward seepage spike, at 10:24 on June 9, 2015, (fig. 15, lower chart) occurred only 2 minutes prior to a similar but smaller downward spike measured at NC278 (fig. 17), located across the channel. The causes for these nearly coincident departures are unknown but, because of their proximity, they may be related.

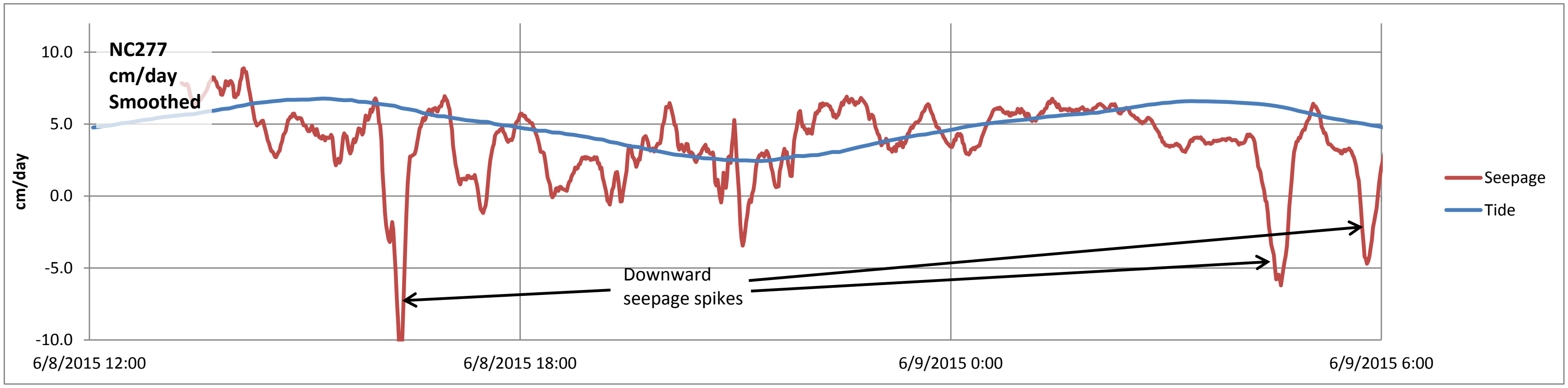
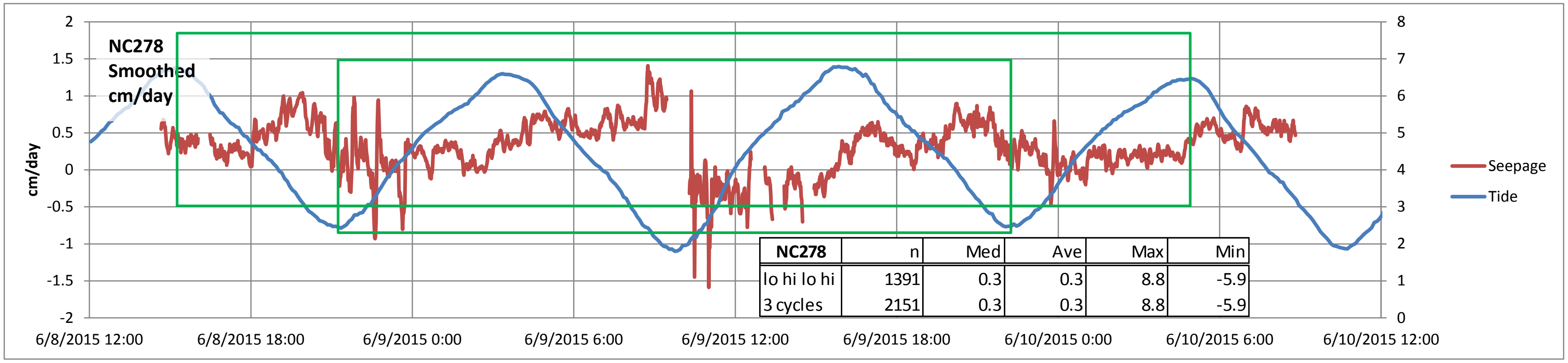


Figure 16. Smoothed seepage, in centimeters per day (cm/d), and relative tide, in feet, measured at NC277 showing three brief periods of substantial downward seepage.

NC278



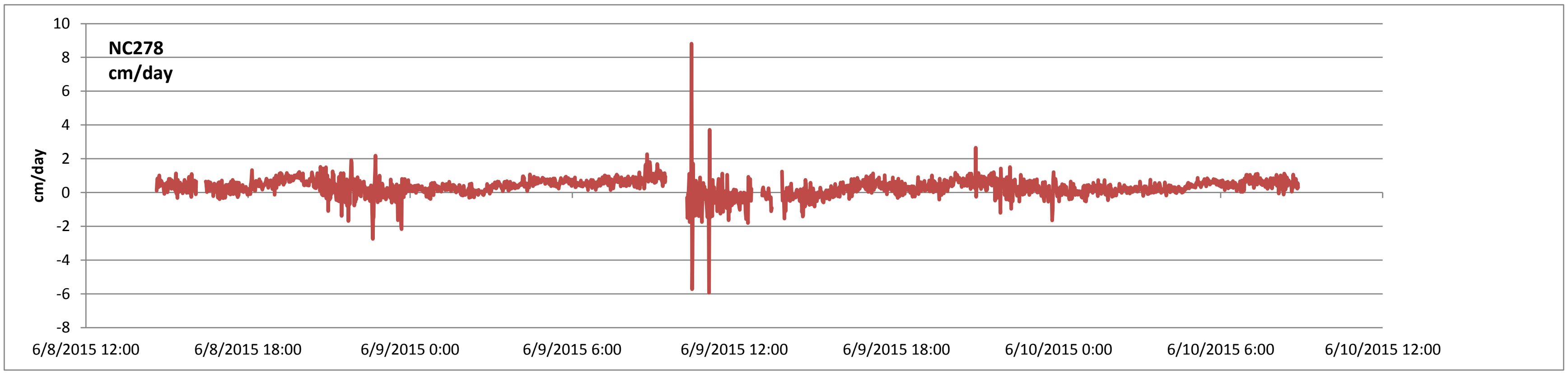


Figure 17. Seepage measured each minute during deployment at NC278, in centimeters per day. The upper plot displays smoothed data based on a 7-minute moving average, with relative tide, in feet, plotted on the right axis. The lower plot presents the actual 1-minute values. The green rectangles indicate the duration of the data-summary periods. In the inset table, “lo hi lo hi” indicates two complete tidal cycles beginning and ending with low tide, and “3 cycles” indicates that seepage was measured over three tidal cycles. (cm/d, centimeters per day; n, number of 1-minute values; Med, median of n values; Ave, average of n values; Max, maximum of n values; Min, minimum of n values)

Seepage was slow and mostly upward at NC278 with a median value of 0.3 cm/d and maximum values for downward and upward flow of -5.9 cm/d and 8.8 cm/d, respectively (fig. 17). Flow was zero to slightly downward for several hours following tidal nadir but was upward the rest of the measurement period. The upward spike at 10:25 on June 9, 2015, followed by a downward spike at 10:26, as shown in figure 18, may be related to the aforementioned 10:24 downward spike at NC277, which is located across the channel. The downward spike at 11:04 followed by an upward spike at 11:05 on June 9, 2015, may be related to passing barge traffic as described in detail for location NC271.

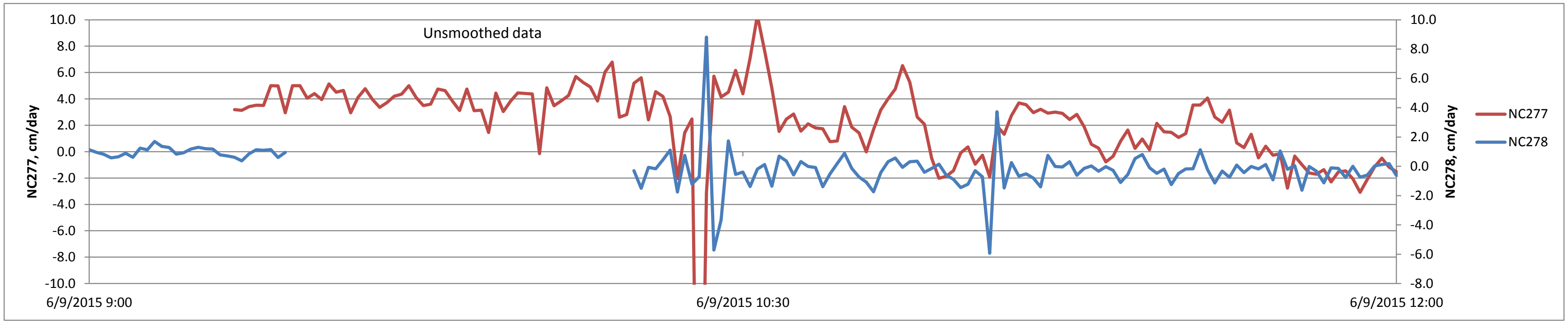
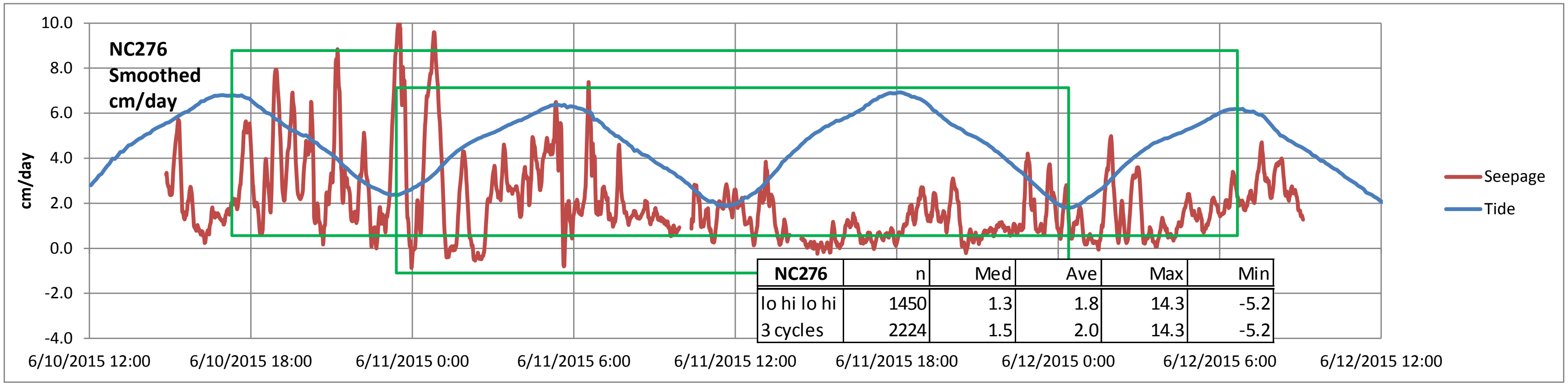


Figure 18. Unsmoothed seepage, in centimeters per day (cm/d), measured at NC277 (left axis) and NC278 (right axis).

NC276



NC276	n	Med	Ave	Max	Min
lo hi lo hi	1450	1.3	1.8	14.3	-5.2
3 cycles	2224	1.5	2.0	14.3	-5.2

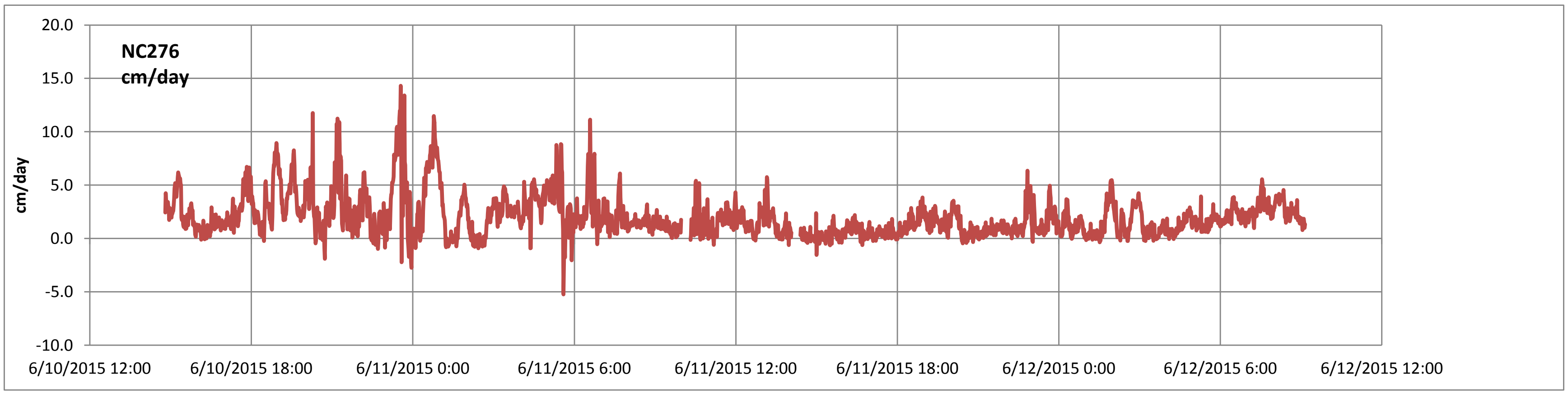
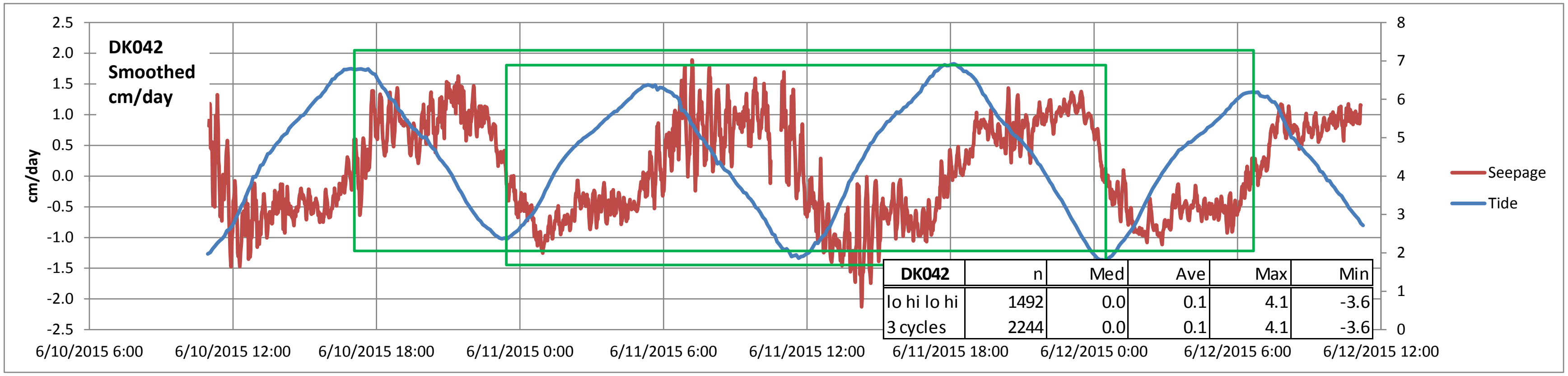


Figure 19. Seepage measured each minute during deployment at NC276, in centimeters per day. The upper plot displays smoothed data based on a 7-minute moving average, with relative tide, in feet, plotted on the right axis. The lower plot presents the actual 1-minute values. The green rectangles indicate the duration of the data-summary periods. In the inset table, “lo hi lo hi” indicates two complete tidal cycles beginning and ending with low tide, and “3 cycles” indicates that seepage was measured over three tidal cycles. (cm/d, centimeters per day; n, number of 1-minute values; Med, median of n values; Ave, average of n values; Max, maximum of n values; Min, minimum of n values)

Seepage at NC276 was upward and slightly faster than at NC278 but generally slightly slower than at NC277. Median seepage was 1.3 to 1.5 cm/d, depending on the number of tidal cycles analyzed (fig. 19). Seepage was nearly always upwards, with only 7 percent of the 1-minute values indicating downward seepage. The largest downward and upward seepage rates were -5.2 cm/d and 14.3 cm/d, respectively. Seepage was slightly more variable during the first 15 hours of data collection; variability was noticeably smaller during the rest of the data-collection period. Seepage variability increased slightly within a few hours of tidal nadir.

DK042



DK042	n	Med	Ave	Max	Min
lo hi lo hi	1492	0.0	0.1	4.1	-3.6
3 cycles	2244	0.0	0.1	4.1	-3.6

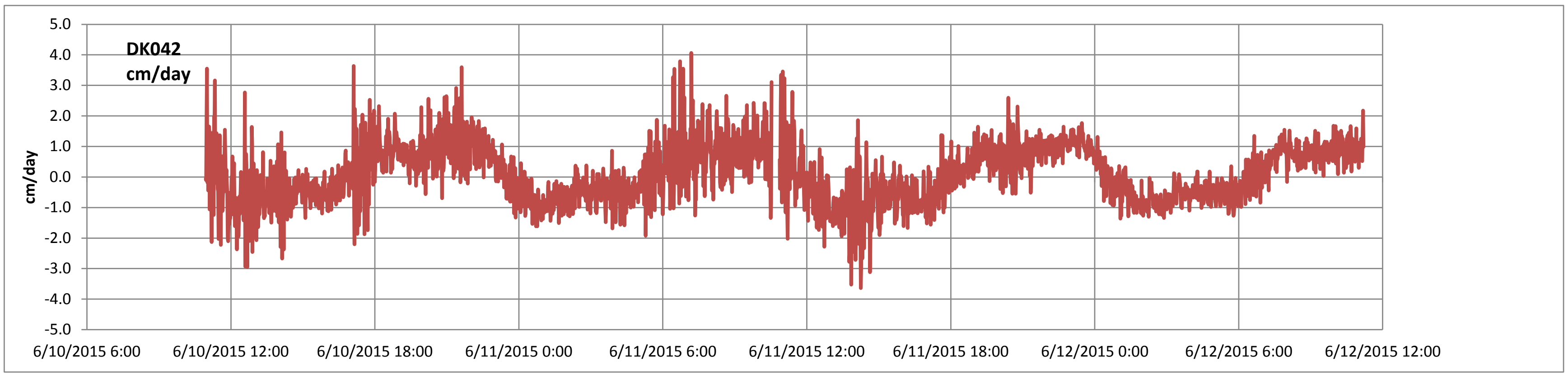


Figure 20. Seepage measured each minute during deployment at DK042, in centimeters per day. The upper plot displays smoothed data based on a 7-minute moving average, with relative tide, in feet, plotted on the right axis. The lower plot presents the actual 1-minute values. The green rectangles indicate the duration of the data-summary periods. In the inset table, “lo hi lo hi” indicates two complete tidal cycles beginning and ending with low tide, and “3 cycles” indicates that seepage was measured over three tidal cycles. (cm/d, centimeters per day; n, number of 1-minute values; Med, median of n values; Ave, average of n values; Max, maximum of n values; Min, minimum of n values)

DK042 is another site where seepage was small and only slightly variable. Median seepage was 0.0 cm/d, and values ranged from-3.6 to 4.1 cm/d during the 2-day data-collection period (fig. 20). However, seepage was strongly controlled by surface-water stage. Figure 21 shows a very good correlation between seepage and change in surface-water stage.

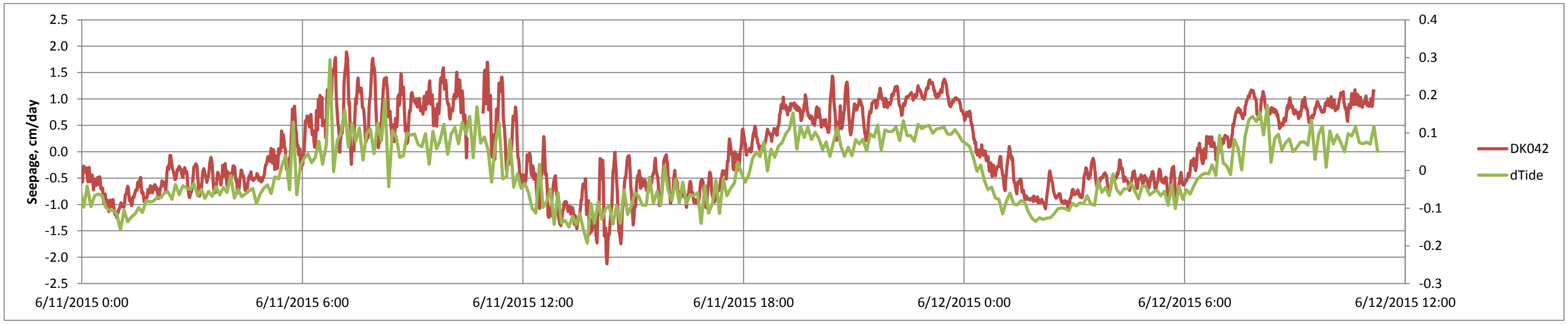
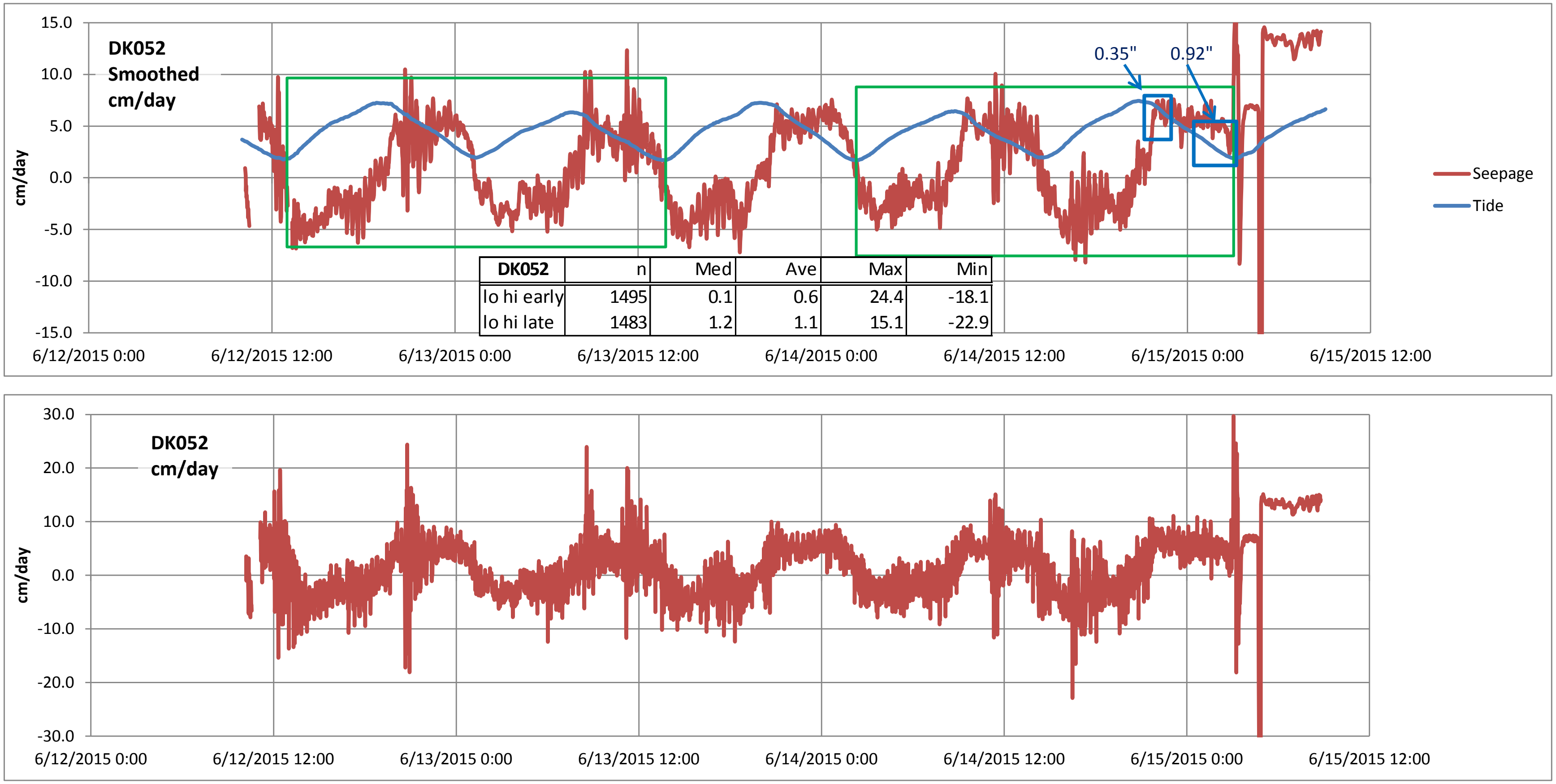


Figure 21. Smoothed seepage measured at DK042, in centimeters per day (cm/d), with the previous tidal value minus the current tidal value (Dtide), in feet, plotted on the right axis.

DK052



DK052	n	Med	Ave	Max	Min
lo hi early	1495	0.1	0.6	24.4	-18.1
lo hi late	1483	1.2	1.1	15.1	-22.9

Figure 22. Seepage measured each minute during deployment at DK052, in centimeters per day. The upper plot displays smoothed data based on a 7-minute moving average, with relative tide, in feet, plotted on the right axis. The lower plot presents the actual 1-minute values. Blue rectangles in the upper plot indicate periods of rainfall with amounts indicated in inches. The green rectangles indicate the duration of the data-summary periods. In the inset table, “lo hi” indicates one complete tidal cycle beginning and ending with low tide, and “early” or “late” indicates timing of an analysis period relative to the site-specific data-collection period. (cm/d, centimeters per day; n, number of 1-minute values; Med, median of n values; Ave, average of n values; Max, maximum of n values; Min, minimum of n values)

Time-averaged seepage at DK052 also was very slow. Median seepage was 0.1 cm/d during the early part of the data-collection period (fig. 22). A slight increase in seepage occurred during the deployment. If the first four tidal cycles are analyzed, median seepage is 0.5 cm/d. However, possibly because rain fell during the last tidal cycle, median seepage during the last two tidal cycles increased to 1.2 cm/d. Rain has been shown elsewhere to substantially affect seepage rates (Rosenberry and others, 2013). Although seepage was small when averaged over time, seepage varied substantially in response to tides. This location, more than any other, had a remarkably large diurnal variability in seepage relative to the time-averaged value. Maximum downward and upward seepage were -22.9 cm/d and 24.4 cm/d, respectively. Seepage was also strongly controlled by subtle changes in surface-water stage, as seen in figure 23 where dTide is plotted on the right axis.

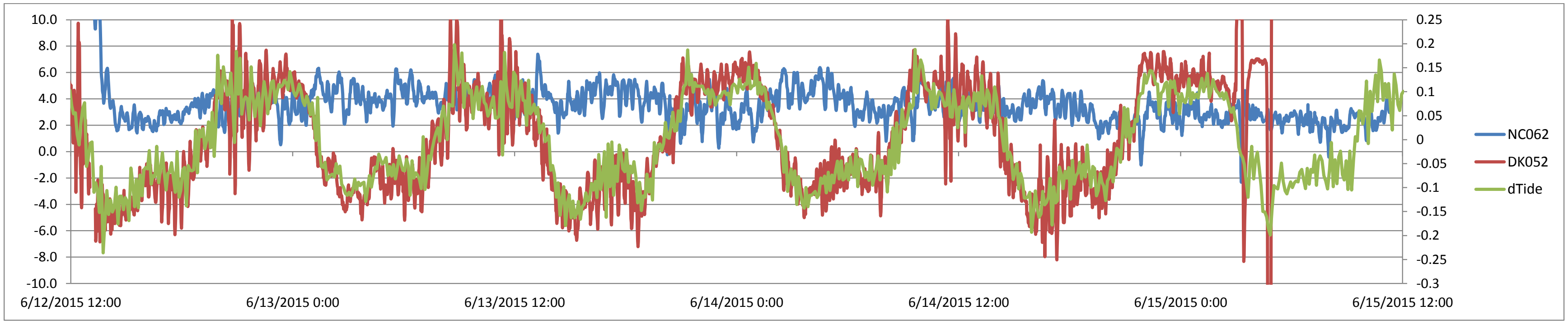


Figure 23. Smoothed seepage measured at DK052 and NC062, in centimeters per day (cm/d), with the previous tidal value minus the current tidal value (dTide), in feet, plotted on the right axis.

Seepage responded substantially to rain and perhaps other factors on June 14–15, 2015. Rain fell from 21:00 until just before midnight on June 14, 2015, followed by a larger rainfall that occurred from 01:15 to 03:45 on the morning of June 15, 2015. The rain totals during the periods shown by the blue rectangles in the upper chart in figure 22 were from the roof-top weather station at the Anchor QEA warehouse at Newtown Creek, located on the north shore about half way between NC266 and NC271 (Figures 1,2). The amount of water found in the boat at location NC062 indicates that even more rain may have fallen at the two sites where data were collected during the storm.

The anchored boat that normally contained the electronics box and associated batteries for the seepage meter was found upside down upon arrival at the site during the early afternoon of June 15, 2015. Unusual variability in seepage occurred from 03:04 to 03:24 on June 15, 2015 (fig. 24), including both downward and upward seepage spikes as large as -18.1 cm/d and 21.7 cm/d, respectively. The cause of boat overturn is unknown, but clues exist regarding the timing of overturn. Standard deviation decreased substantially at 03:35, potentially indicating the time of boat overturn. The very fast downward seepage from 04:44 until 04:52 may also indicate that the boat overturned during that time. Although the ESM stopped operating because the deep-cycle batteries that powered the meter fell to the sediment when the boat capsized, the shelter that housed the datalogger floated, allowing continued datalogger operation and subsequent downloading of the stored data.

The unusual data collected from 03:04 to about 03:37 (fig. 24) are also difficult to interpret. These perturbations could be due to ebullition, seepage-related noise caused by rain and (or) lightning, or waves associated with a windy period. No matter the cause, this period was a substantial departure from previous seepage trends when seepage would sharply decrease prior to and following tidal nadir. Low tide occurred at 03:03 on June 15, 2015, at the tide gage next to the Anchor dock.

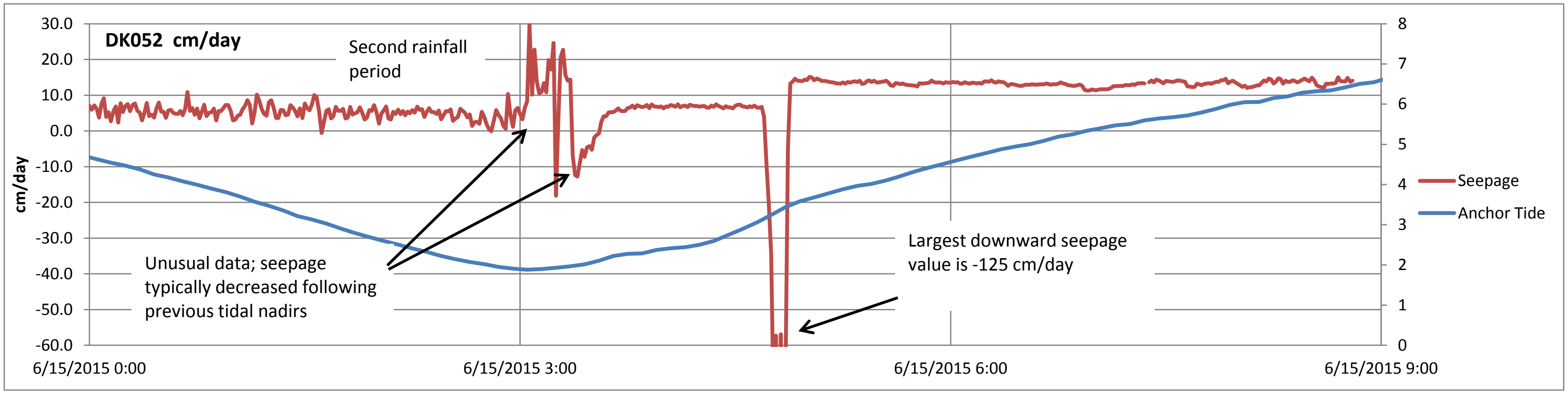


Figure 24. Smoothed seepage measured at DK052, in centimeters per day (cm/d), with relative tide measured at the Anchor dock, in feet, plotted on the right axis.

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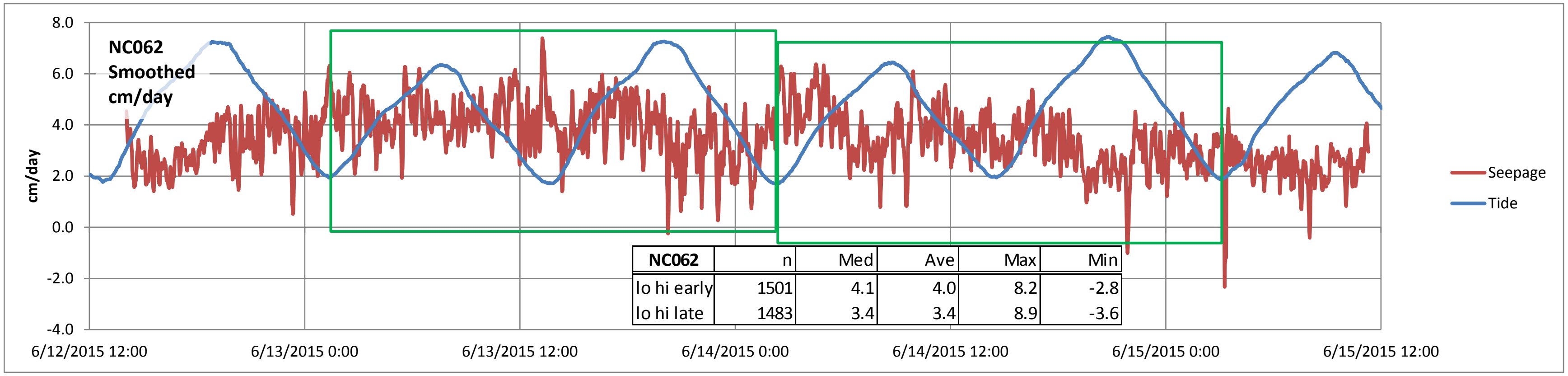
NC062



NC062	n	Med	Ave	Max	Min
lo hi early	1501	4.1	4.0	8.2	-2.8
lo hi late	1483	3.4	3.4	8.9	-3.6

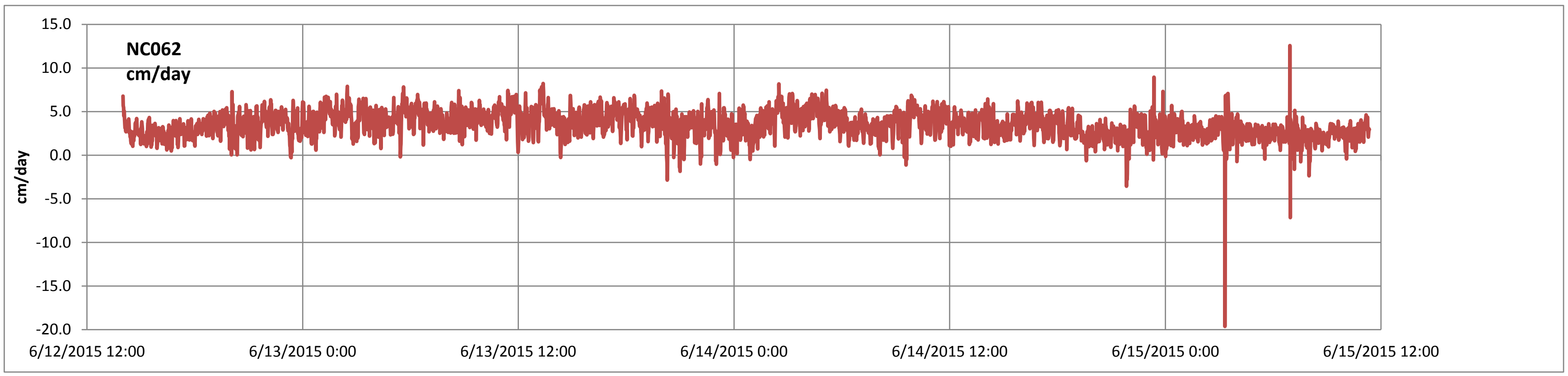
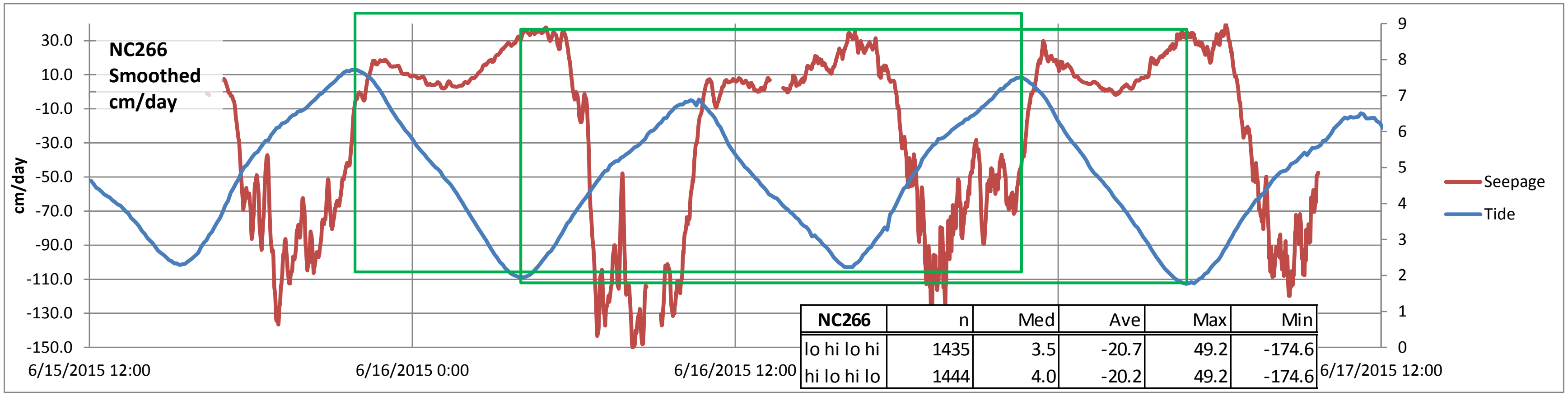


Figure 25. Seepage measured each minute during deployment at NC062, in centimeters per day. The upper plot displays smoothed data based on a 7-minute moving average, with relative tide, in feet, plotted on the right axis. The lower plot presents the actual 1-minute values. The green rectangles indicate the duration of the data-summary periods. In the inset table, “lo hi” indicates one complete tidal cycle beginning and ending with low tide, and “early” or “late” indicates timing of an analysis period relative to the site-specific data-collection period. (cm/d, centimeters per day; n, number of 1-minute values; Med, median of n values; Ave, average of n values; Max, maximum of n values; Min, minimum of n values)

Seepage at NC062 was somewhat faster compared to other locations at Newtown Creek and slightly responsive to tides (fig. 25). Median values were 4.1 cm/d and 3.4 cm/d during the early and late parts of the data-collection period, respectively. Seepage range was relatively small, with largest downward and upward seepage values of -3.6 cm/d and 8.9 cm/d, respectively. The large downward spike at 03:19 on June 15, 2015, is similar to the spike that was recorded elsewhere during the passing of a barge, as detailed in the description for NC271.

NC266



NC266	n	Med	Ave	Max	Min
lo hi lo hi	1435	3.5	-20.7	49.2	-174.6
hi lo hi lo	1444	4.0	-20.2	49.2	-174.6

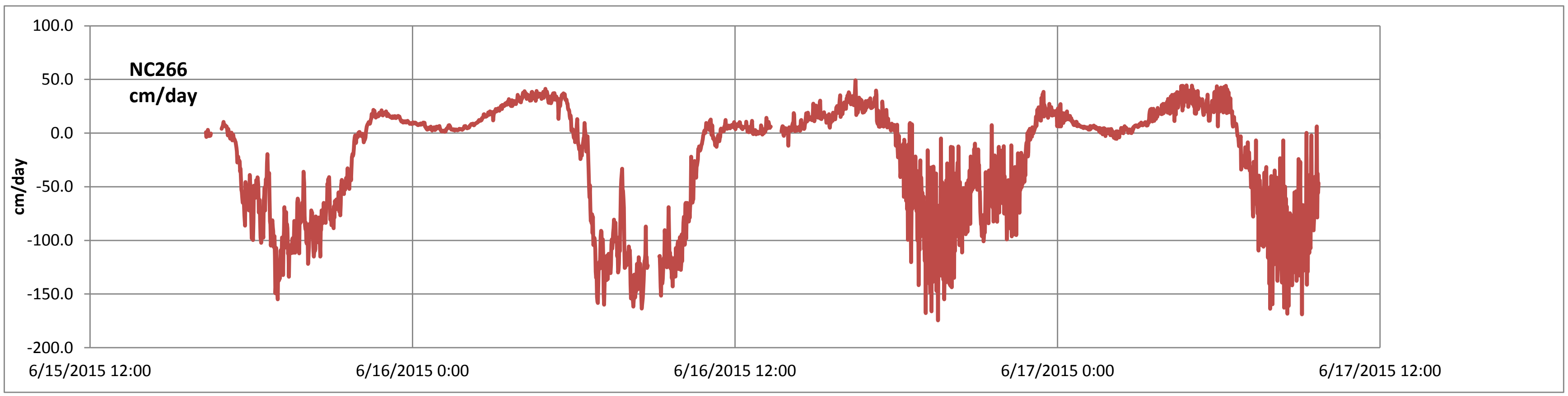
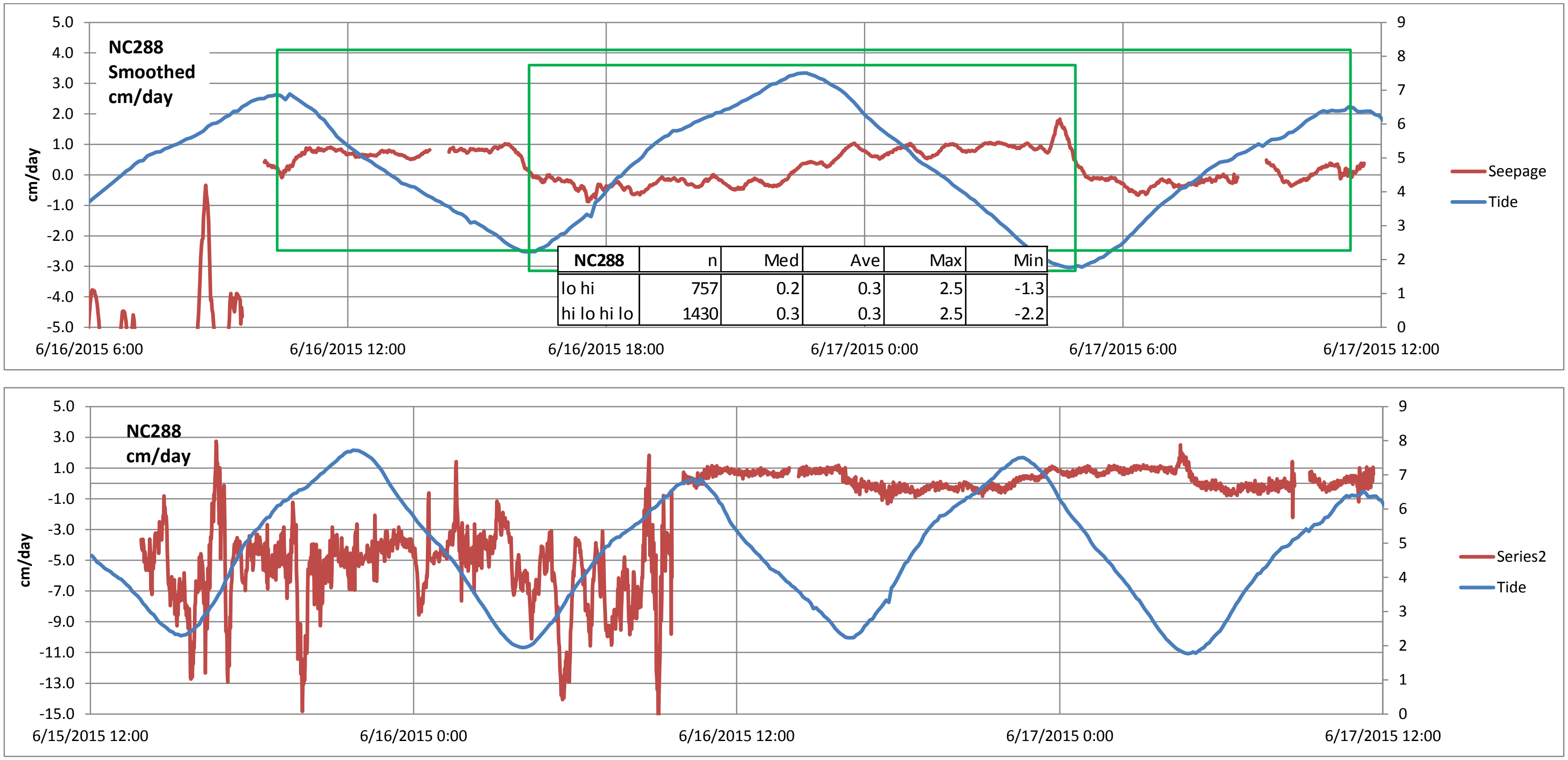


Figure 26. Seepage measured each minute during deployment at NC266, in centimeters per day. The upper plot displays smoothed data based on a 7-minute moving average, with relative tide, in feet, plotted on the right axis. The lower plot presents the actual 1-minute values. The green rectangles indicate the duration of the data-summary periods. In the inset table, “lo hi” indicates one complete tidal cycle beginning and ending with low tide, and “hi lo” indicates one complete tidal cycle beginning and ending with high tide. (cm/d, centimeters per day; n, number of 1-minute values; Med, median of n values; Ave, average of n values; Max, maximum of n values; Min, minimum of n values; cyc, cycles)

Seepage at NC266 was by far the most variable of all the locations at Newtown Creek (fig. 26). Very fast rates of downward seepage occurred following low tide, starting approximately 2 to 2.5 hours after tidal nadir. Downward seepage of greater than -150 cm/d was recorded following all four low tides. Downward seepage ended and upward seepage began within one hour following high tide. In spite of the large downward seepage rates, median values during two tidal cycles were positive at 3.5 and 4.0 cm/d for the two analysis periods. Average values were negative (-20.7 and -20.2 cm/d) largely because hours-long periods of very fast downward seepage occurred. Seepage varied by the largest range by far of all the Newtown Creek locations, ranging from -174.6 to 49.2 cm/d during the analysis periods.

NC288

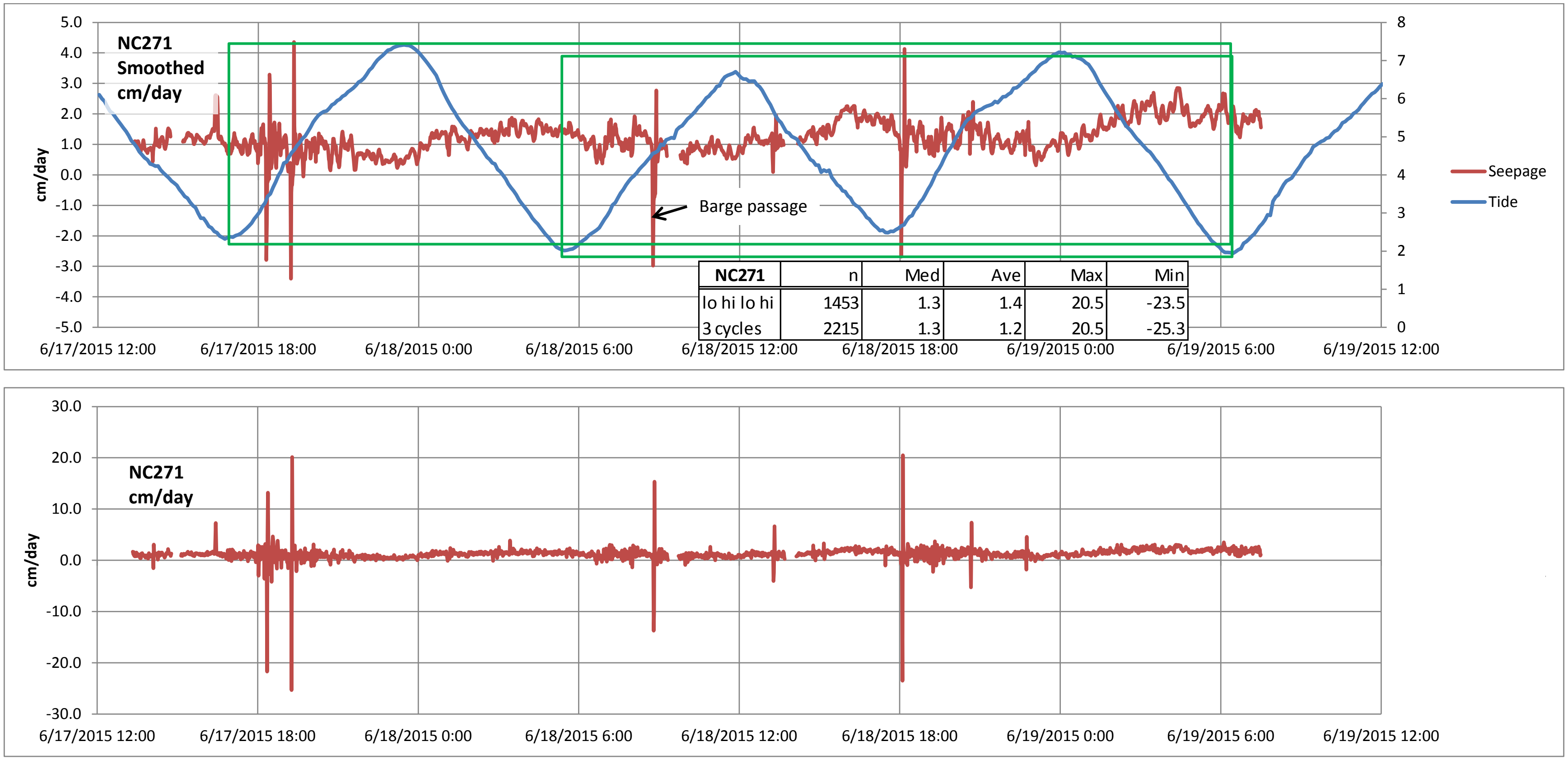


NC288	n	Med	Ave	Max	Min
lo hi	757	0.2	0.3	2.5	-1.3
hi lo hi lo	1430	0.3	0.3	2.5	-2.2

Figure 27. Seepage measured each minute during deployment at NC288, in centimeters per day. The upper plot displays smoothed data based on a 7-minute moving average, with relative tide, in feet, plotted on the right axis. The lower plot presents the actual 1-minute values. The green rectangles indicate the duration of the data-summary periods. In the inset table, “lo hi” indicates one complete tidal cycle beginning and ending with low tide, and “hi lo” indicates one complete tidal cycle beginning and ending with high tide. (cm/d, centimeters per day; n, number of 1-minute values; Med, median of n values; Ave, average of n values; Max, maximum of n values; Min, minimum of n values; cyc, cycles)

Seepage measured near the center of the turning basin during the first 19 hours of deployment at NC288 was corrupted because a valve that should have been closed had been left open. Therefore, only slightly more than 2 tidal cycles of usable data were collected, and only one tidal cycle that extended during the low-high-low cycle (fig. 27). Two analysis periods were selected, extending over one cycle starting with low tide and extending over two cycles starting with high tide. (Note that the upper of the two charts for NC288 does not include most of the period during which corrupted data were collected.) Median seepage was small for both analysis periods, at 0.2 cm/d for the shorter analysis period and 0.3 cm/d for the longer. Seepage was only slightly responsive to tides, decreasing and becoming downward for several hours immediately following low tide. Seepage ranged from -2.2 to 2.5 cm/d during the analysis periods.

NC271



NC271	n	Med	Ave	Max	Min
lo hi lo hi	1453	1.3	1.4	20.5	-23.5
3 cycles	2215	1.3	1.2	20.5	-25.3

Figure 28. Seepage measured each minute during deployment at NC271, in centimeters per day. The upper plot displays smoothed data based on a 7-minute moving average, with relative tide, in feet, plotted on the right axis. The lower plot presents the actual 1-minute values. The green rectangles indicate the duration of the data-summary periods. In the inset table, “lo hi lo hi” indicates two complete tidal cycles beginning and ending with low tide, and “3 cycles” indicates that seepage was measured over three tidal cycles. (cm/d, centimeters per day; n, number of 1-minute values; Med, median of n values; Ave, average of n values; Max, maximum of n values; Min, minimum of n values)

Seepage was slow but consistently upward at NC271 (fig. 28). Median values were 1.3 and 1.3 cm/d for the two summary periods, with largest downward and upward seepage rates of -25.3 cm/d and 20.5 cm/d, respectively. However, these large extremes were almost certainly due to barge traffic. We were at NC271 and noted the passage of a barge on June 18, 2015, from 08:47 to 08:51 while observing a coincident downward then upward spike in measured seepage. A similar spike appears in the NC272 dataset, offset by one minute (fig. 29), as the same barge passed by that location. If the known and likely barge-generated spikes are removed, extreme values during the data-analysis periods are -4.2 and 4.7 cm/d. A small tidal response is evident; seepage increased for several hours following the high-tide apex and generally decreased slowly starting within an hour of low tide.

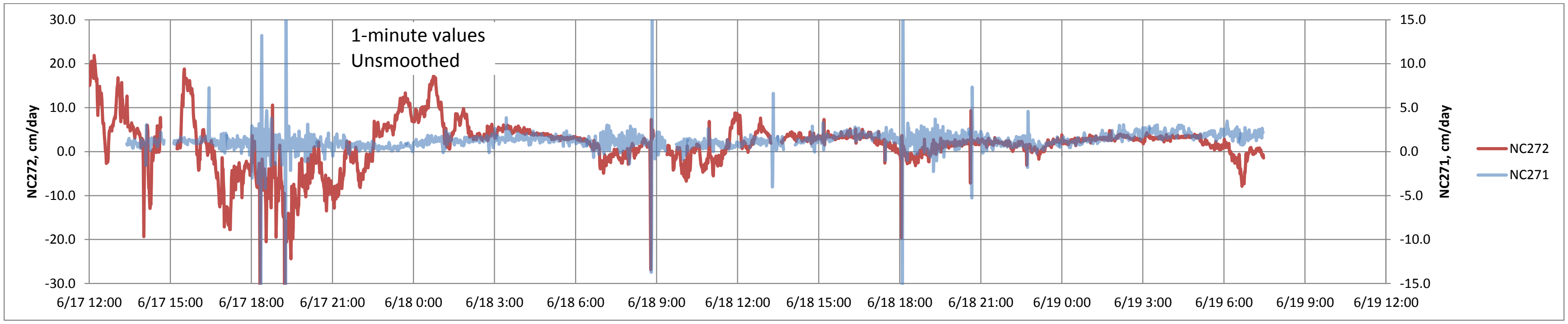


Figure 29. Unsmoothed seepage, in centimeters per day (cm/d), measured at NC272 (left axis) and NC271 (right axis).

Effect of Passing Large Watercraft on Seepage

Several times at several locations during seepage-meter deployment, it was suspected that brief intervals of large departures in measured seepage were caused by passing boat traffic. As mentioned earlier, the crew was anchored near NC271 on the morning of June 18, 2015, when a barge passed by. The effect on seepage is shown in detail in figure 30A. As the barge approached, downward seepage occurred. When the passing barge was closest to the seepage meter, measured seepage changed from being downward to neutral and then to upward within 10–15 seconds. Positive seepage occurred as the barge moved beyond and away from the seepage-measurement location. The effect lasted only a few minutes. Instantaneous 5-second values ranged from -215 cm/d to approximately 100 cm/d during the 08:49 barge passage on June 18, 2015. Another barge passage later that same day is also evident in the data; the effect is shown in figure 30B.

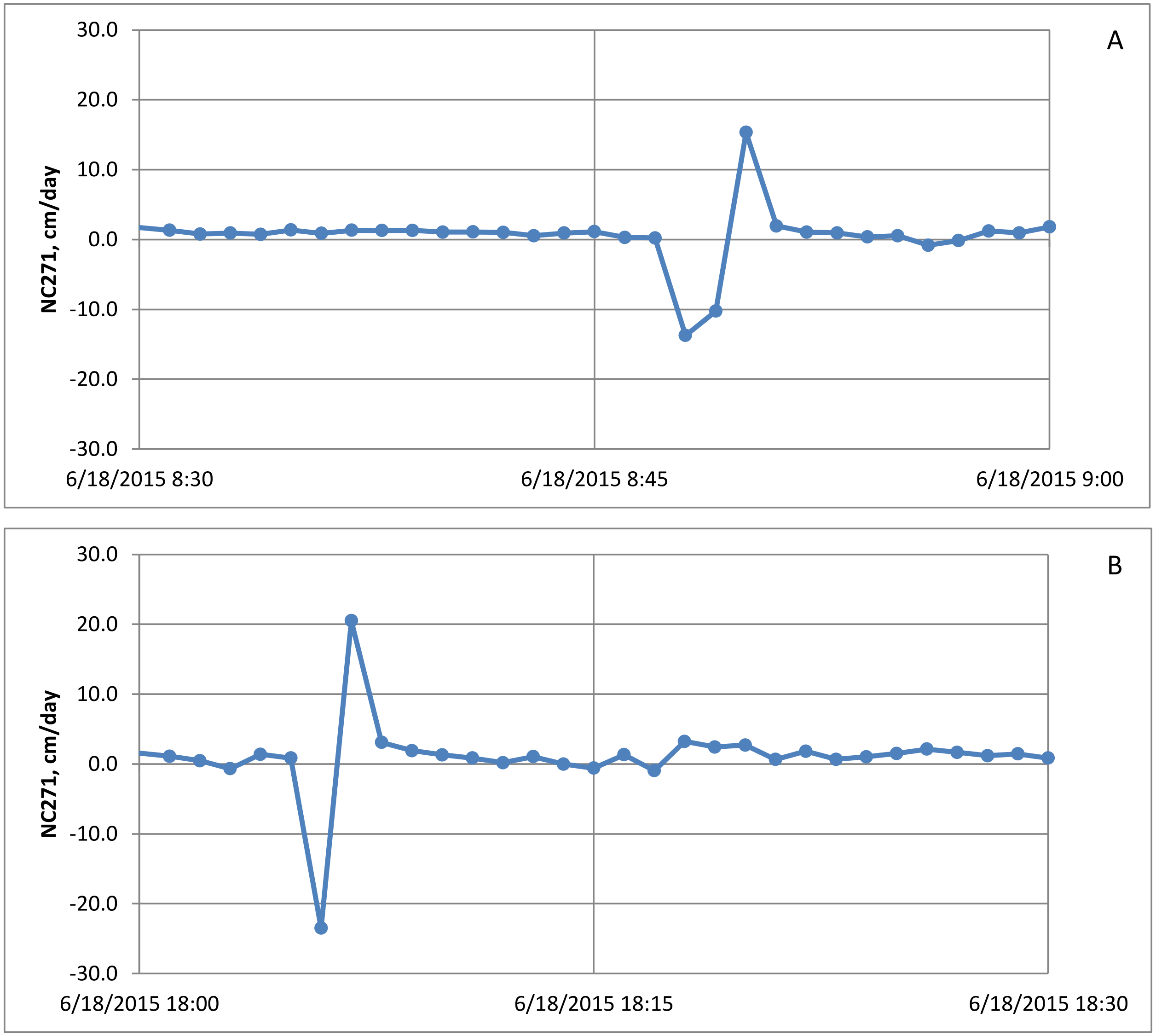


Figure 30. Seepage determined each minute (unsmoothed) at NC271, in centimeters per day (cm/d), on June 18, 2015, during (A) 08:30–09:00 and (B) 18:00-18:30.

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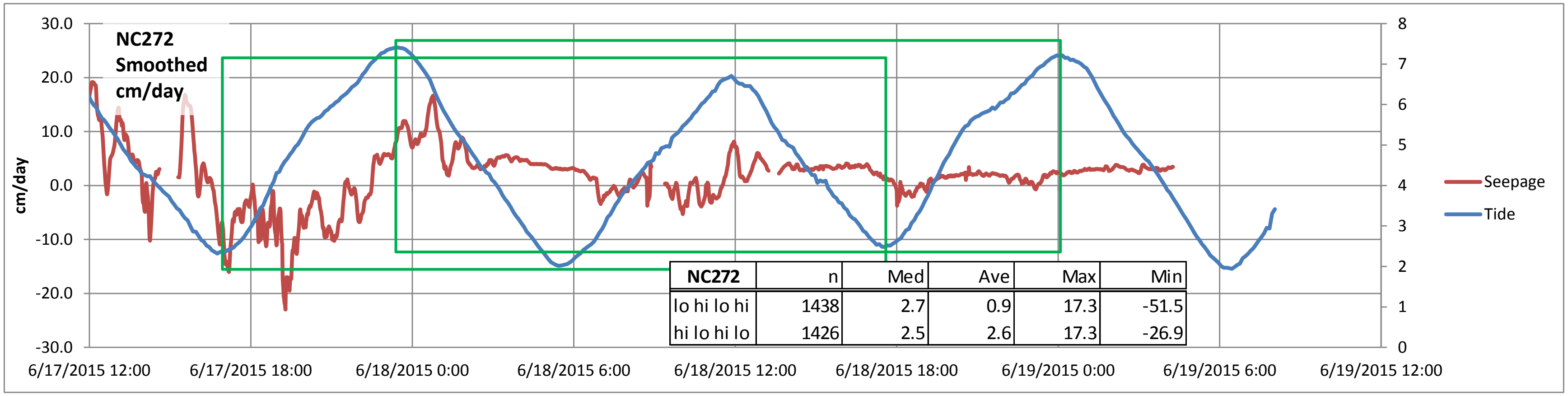
NC272



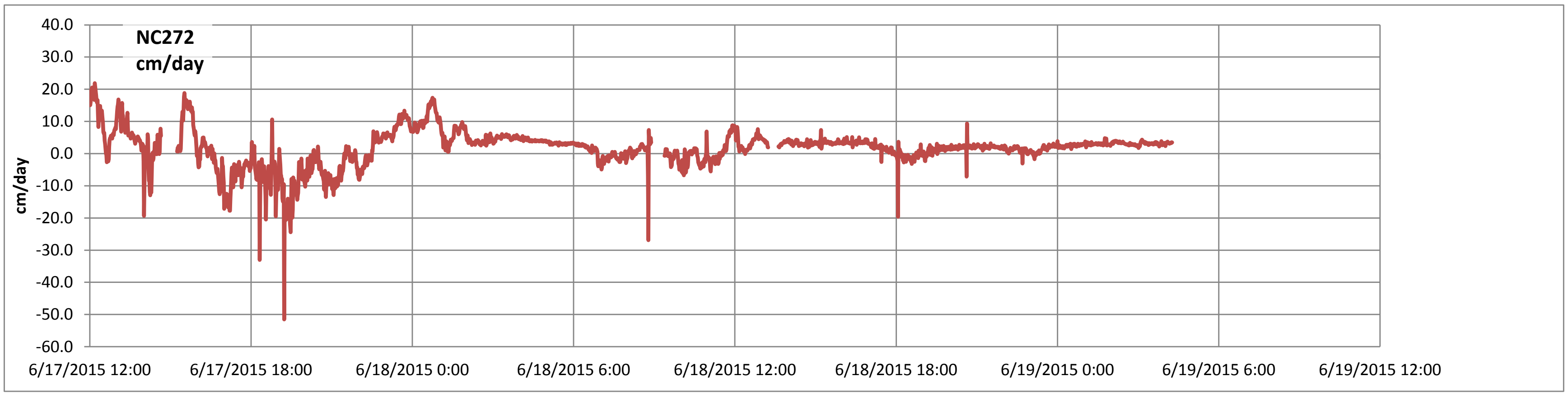


Figure 31. Seepage measured each minute during deployment at NC272, in centimeters per day. The upper plot displays smoothed data based on a 7-minute moving average, with relative tide, in feet, plotted on the right axis. The lower plot presents the actual 1-minute values. The green rectangles indicate the duration of the data-summary periods. In the inset table, “lo hi lo hi” indicates two complete tidal cycles beginning and ending with low tide, and “hi lo hi lo” indicates two complete tidal cycles beginning and ending with high tide. (cm/d, centimeters per day; n, number of 1-minute values; Med, median of n values; Ave, average of n values; Max, maximum of n values; Min, minimum of n values)

The relatively noisy data during the first 12 hours of deployment at NC272 (fig. 31) are difficult to interpret; the cause for this greater variability is unknown. The decrease in seepage during the first 5 hours may indicate seepage coming into equilibrium following sediment disturbance during meter insertion. However, data collected starting after midnight on June 18, 2015, appear reasonable and are similar to data from many of the other locations at Newtown Creek. The data-analysis period that begins with high tide largely excludes the perhaps questionable early noisy data. Median seepage for that period is 2.5 cm/d with extreme values ranging from -26.9 to 17.3 cm/d. The data-analysis period that does include much of the early noisy data has a nearly identical median seepage rate of 2.7 cm/d. As at the NC271 site, exclusion of the large negative spikes cause by barge traffic greatly decreases the range of the seepage data.

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