chapter nine

TIDAL HYDROLOGY

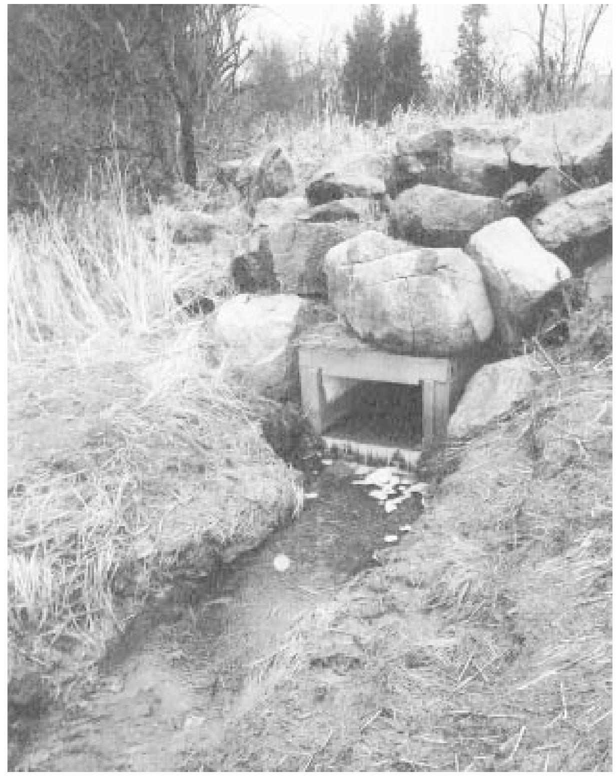
The presence, type, and potential effects of **tide restrictions** are critical information for salt marsh **monitoring** and assessment. Tidal influence is an important **parameter** to measure, and along with salinity can provide a very good understanding of the effect of tide restrictions on the physical and chemical nature of **salt marshes**.

Tide restrictions usually result from the construction of a travel route over a salt marsh, particularly where a bridge or culvert is installed on the tidal creek. Tidal crossings are restrictive if they block or inhibit water from flowing freely from one side of the marsh to the other, resulting in a reduction of tidal influence on the landward, or restricted, side of the **estuary**. The seaward, or unrestricted, side of the estuary is a good indication of what the restricted side would resemble in the absence of the tide restriction. In tidal influence studies, the unrestricted marsh is usually the **reference marsh** and the restricted marsh is the **study marsh**. A comparison of tidal ranges between the reference site and study site provides a good indication of the effect of the tide restriction on tidal **hydrology**.

There are two types of restrictive tidal crossings. One occurs when the opening of the culvert or bridge is too small or has started collapsing and does not allow natural amounts of water to pass through during each tidal cycle. The most common effect of this type of restriction is a decrease in salinity, and possibly wetness, in the restricted marsh. The second type of restrictive crossing occurs where a culvert is elevated too high in relation to the creek bed. In this case, sufficient amounts of water may enter the restricted marsh during an incoming tide, but with a delayed effect since the tidal level in the unrestricted side must reach the height of the culvert before passing through it. Elevated culverts may prevent complete drainage of the restricted side because water cannot leave once water levels drop below the culvert, and even during low tide, there is standing water in the restricted marsh. Bank erosion may be evident on either side of the culvert with both types of tidal restrictions. Bank erosion resulting from tide restrictions is often described as "onion-shaped pools," which form on either side and directly next to the culvert.

A reduction in tidal flow can have numerous adverse effects on salt marshes, the most important of which is a change in natural **salinity regimes**. Many plants and animals that exist in salt marshes are adapted to a specific range of physical and chemical conditions, and large-scale alterations such as tide restrictions can cause intolerant species to perish. When salinity levels fall below 20 parts per thousand (ppt), the invasion of opportunistic brackish plants such as *Phragmites australis* (common reed) becomes a problem. Tide restrictions may also block the passage of estuarine invertebrates and fish into the upper estuary, and reduce the export of organic matter from the salt marshes. A reduction in tidal flushing may result in the accumulation of detritus, nutrients, and pollutants in the restricted marsh.

A culvert placed too high in relation to the tidal creek. **Photo: Vivian Kooken**



An undersized culvert. **Photo: Vivian Kooken**

EQUIPMENT

Volunteers need some basic equipment to monitor tidal hydrology (Table 1), though this parameter is less expensive and easier to measure than most of the other parameters in this manual. Biodegradable paint or a waterproof marker and a weighted tape measure are required for the reference mark technique. Ideally, the measuring tape should be an open reel fiberglass variety, although other types may be more appropriate for your specific conditions. You should attach a lead weight or small stone to the end of the tape measure using duct tape. The added weight helps keep wind or water currents from moving the tape measure. Be sure that by adding weight you are not also adding extra length to the tape measure because this could affect your measurements.

The staff gauge technique requires the construction or purchase of two staff gauges (one each for the study site and reference site). Staff gauges are essentially large rulers staked in a fixed position, and are used to measure water levels. You can construct staff gauges from a variety of materials, and the only requirement is that they be durable and appropriate for the site location, budget, and needs of the investigators. Rustproof materials that can withstand wind and water currents work best. It is common to use PVC pipe to construct gauges, with units marked with paint or permanent marker. Another option is to use metal pre-marked gauges attached to garden stakes or fence posts. Our advice is to use cheap, readily available materials and your imagination!

The reference mark technique and staff gauge techniques both require field data sheets, pencils, a clock or watch, stopwatch, and clipboard. Extra copies of field data sheets and pencils are a good idea. As always, safety is your first priority. It may be desirable to have volunteers work in pairs, especially if the sampling site is in a remote location.

SAMPLING METHODS

Two different sampling methods — reference mark technique and staff gauge technique — can be used to collect tidal hydrology data at a tidal restriction. Since both of these sampling methods are easy and inexpensive, volunteer groups should employ both methods in their study. It is prudent to collect two independent data sets at the same time so that if an unforeseen problem arises with one method, you will still have one good set of data.

TABLE 1. EQUIPMENT FOR MEASURING TIDAL INFLUENCE

REFERENCE MARK TECHNIQUE
Waterproof marking material (biodegradable paint or permanent marker)
Tape Measure
Lead Weight or Small Stone
Watch or Clock
Clipboard
Field Data Sheets
Pencils
STAFF GAUGE TECHNIQUE
Staff Gauge
Hammer or Mallet
Watch or Clock
Clipboard
Field Data Sheets
Pencils

Reference Mark Technique

The idea behind the reference mark technique is that you can determine differences in tidal hydrology between a study site and a reference site by carefully measuring water levels at regular intervals over an entire tidal cycle. A reference mark is simply a fixed location, and the distance between a reference mark and the water's surface is used to measure tidal height. You can compute tidal range from this data, and differences in tidal range between a study site and a reference site indicates the overall effect of a tide restriction.

Step One: Fix a permanent or semi-permanent mark on both the study and reference sides of the tidal crossing from which to measure vertical distance to the water's surface. Here are some considerations for this important step:

- Place the mark on the head wall, bank, or bridge, depending on what is available.
- Reference points can be marked with either a small spot of paint or permanent marker and are best located near the center of the channel or where water is most likely to remain at low tide.
- You should visit the site at high and low tides prior to sampling to make sure that the mark is not covered during high tide and at low tide water does not recede beyond the vertical reach of the mark.

If your reference mark cannot be located above the high tide mark, it is possible to measure from the reference mark up to the surface of the water (Figure 1a). The easiest way to do this is to place a meter stick or staff gauge exactly perpendicular to the reference mark and record the distance between the mark and the water's surface. Be certain that the implement you choose uses the same units as your measuring tape. Alternatively, you can simply mark the distance from your reference mark to the water's surface with an unmarked pole and use the measuring tape to measure the length. Any measurements from the reference mark up to the water's surface must be recorded as negative numbers on the data sheet, and you should include notes to explain the change in sampling protocol. If high tide will cover your reference mark, make sure it is painted with a waterproof material!

You can use a couple different techniques if low water recedes beyond the vertical reach of the reference mark. The best solution is to use a leveled staff (such as a carpenter's level) to extend the reference mark horizontally far enough to reach the water (Figure 1b). You must be certain that the staff is level and at the same elevation as the reference mark;

Measuring tidal height using the reference mark method.
Photo: Vivian Kooken

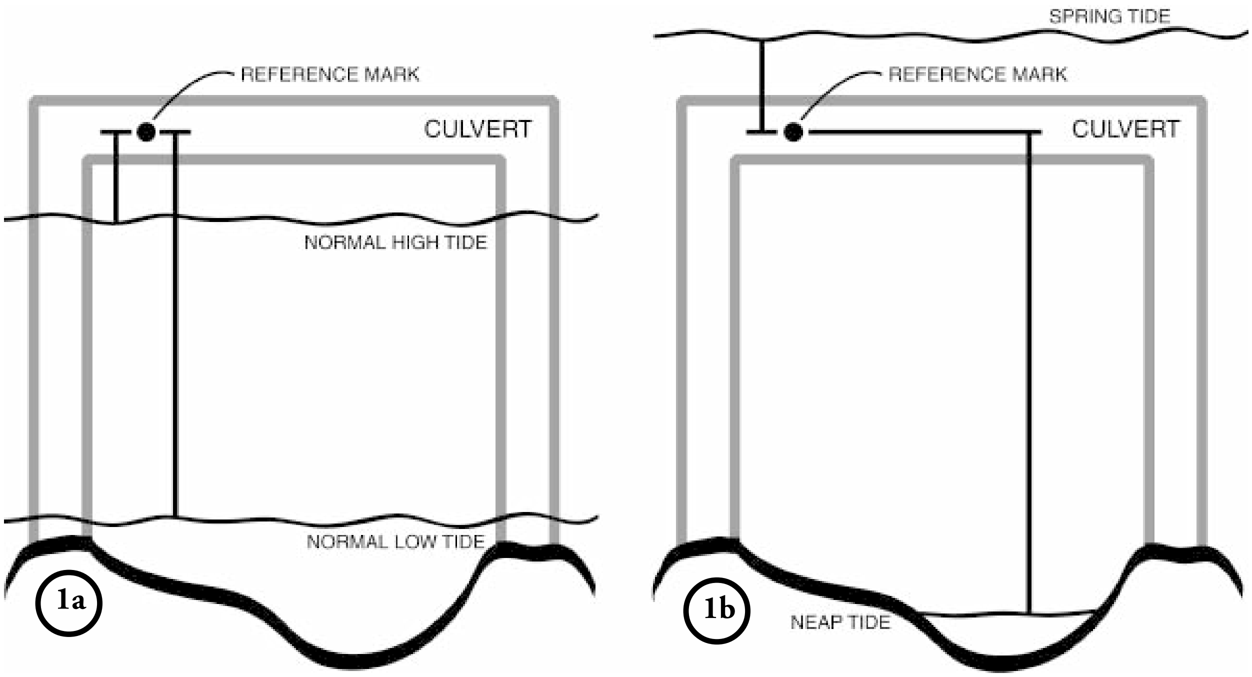


FIGURE 1. MEASURING TIDAL HEIGHT
Figure 1a shows how to measure tidal height from the reference mark when the reference mark is directly above the high water mark and low water mark. Figure 1b shows how to measure tidal height from the reference mark when the reference mark is below the high tide mark, or when water has receded below the vertical plane of the reference mark.

this is best accomplished with two people. You can still produce meaningful results by measuring from the reference mark to bare substrate as long as you record on the data sheet that there is no water. Finally, you can have more than one reference point for different stages of the tide as long as the relative vertical distance (elevation) between the marks are clearly marked on the data sheet.

Step Two: Gather necessary materials for data collection. The previous section lists and explains the equipment you will need.

Step Three: Collect the data. Using the tape measure, you should record distance from the reference mark to the water's surface every 15 minutes at both the study site and reference site. Fill out any other information required on the field data sheet.

Staff Gauge Technique

The staff gauge technique is similar to the reference mark technique and provides the same type of information. Staff gauges are commonly used to measure flood levels in rivers, and can often be seen bolted to bridge abutments. Staff gauges are graduated, meaning that units (feet or meters) are clearly written on the staff so that water levels can be recorded by simply looking at the gauge. The Equipment section describes how to construct or acquire staff gauges.

Step One: Find a suitable location for the staff gauges. You should investigate potential locations at different tidal stages to foresee possible difficulties with installation or sampling. You should try to install the gauge in an area of the creek that retains water at low tide, such as the center of the channel. However, be mindful of strong currents that may accompany incoming and outgoing tides, and if necessary place the staff closer to the bank. Strong currents can cause water to swirl around the base of the staff and make it difficult to take accurate readings, and currents can be dangerous for volunteers if they have to wade out to the staff.

Step Two: Install the staff gauges. Gauges should be installed a day or two before the sampling date to ensure they are in a suitable location. You should install staff gauges no further than 50 feet from the tidal restriction in both the study site and reference site. Two people may be necessary to install the gauge — one to hold the gauge while the other pounds it into the substrate with a hammer or mallet. Be sure to position the staff gauge so that the tick marks are readily visible by the observer.

A staff gauge installed on a culvert. **Photo: CZM Staff Photo**

Step Three: Gather necessary materials for data collection. The Equipment section lists and explains the equipment you will need for data collection.

Step Four: Collect the data. Record water levels (tidal height) on the staff gauges in the study site and reference site every 15 minutes, noting the time of day for each measurement on the field data sheet. Fill out any other information required on the field data sheet, such as names of investigators, date of sampling, and time of high tide.

Considerations for Both Methods

The field day should coincide with a particularly high tide, such as a "spring tide." On sampling day, record tidal measurements over a six-hour period, capturing both high and low tides. The six-hour period can be broken into shifts to shorten the amount of time that volunteers have to spend on the marsh. If using shifts, there should be a half-hour overlap between teams to be sure that the new team has a complete understanding of the sampling protocol. You may want to bring something to pass the time between readings. Good books and crossword puzzles can help ward off boredom! An egg timer might help to ensure you do not miss scheduled readings.

DATA ENTRY

Investigators should use a separate field data sheet for the study site and reference site. Also, use separate data sheets for the reference mark technique and staff gauge technique if you are planning to use both methods. A blank standard field data sheet is provided in Appendix 1 of this chapter. Basic information, such as the name of the observer(s), date, site name, site number, and the time of high tide at a specific station are included near the top of the field data sheet. Project leaders can modify field data sheets according to their specific objectives.

While in the field, it is extremely important to accurately record water height and time. It is essential not to confuse field data sheets, either between reference sites and study sites, or between staff gauge and reference mark techniques. If you are careful and thorough when filling out a field data sheet, there should be no confusion about where or how the data were collected and what the data represent. Confusion usually results from poor organization, such as mixing field data sheets from different sites or techniques and failure to completely fill out necessary information. One way to reduce confusion is to keep reference site and study site data sheets in their own clipboards and leave the clipboards on their respective sides of the tidal restriction.

In the office, investigators should transfer information on field data sheets into a spreadsheet program such as Microsoft Excel. Make any necessary unit conversions (such as feet to inches) when transferring the data from the field data sheet to the computer spreadsheet. The spreadsheet should have clearly marked rows and columns similar to Table 2. Table 2 is set up similar to a spreadsheet with column and row identifiers (letters for columns and numbers for rows), so that any cell in the figure can be identified. For example, cell D5 is located in column D and row 5.

TABLE 2. EXAMPLE DATA ENTRY SPREADSHEET

The following data table represents data collected using the reference mark technique, and is for illustration purposes only. See text for a complete explanation of this table and how to compute variables.

	A	B	C	D	E	F	G
1				**TIDAL HEIGHT (in)**		**CHANGE IN TIDAL HEIGHT (in)**	
2	**SITE**	**DATE**	**TIME**	**STUDY**	**REFERENCE**	**STUDY**	**REFERENCE**
3	Marsh X	8/15/01	0900	-29.61	-50.94	24.72	53.24
4	Marsh X	8/15/01	0915	-32.13	-25.86	27.24	28.16
5	Marsh X	8/15/01	0930	-26.61	-10.86	21.72	13.16
6	Marsh X	8/15/01	0945	-16.17	2.58	11.28	-0.29
7	Marsh X	8/15/01	1000	3.87	14.10	-8.76	-11.81
8	Marsh X	8/15/01	1015	14.79	22.14	-19.68	-19.85
9	Marsh X	8/15/01	1030	21.39	34.14	-26.28	-31.85
10	Marsh X	8/15/01	1045	25.35	33.06	-30.24	-30.77
11	**Average Tidal Height**			-4.89	2.30		
12	**Tidal Range**			57.48	85.08		
13	**Tidal Range Ratio**			67.56			
14	**Difference in Tidal Range**			27.60			

Steps in Data Entry

1. Enter site, date, and time intervals into the first three columns of the spreadsheet. Enter Tidal Height of the study site and reference site into columns D and E, respectively (Table 2). Raw data collected using the reference mark method can be entered directly into the spreadsheet for computation. Raw data collected using the staff gauge method must have reversed signs when entered into the spreadsheet. For example, enter any positive (+) numbers recorded on the field data sheet as negative (-) numbers in the spreadsheet, and visa versa.

2. Compute Average Tidal Height for the study site and reference site by averaging tidal height values over the entire time period. For example, in Table 2 enter the formula "=average(D3:D10)" into cell D11 to compute the average tidal height of the study site.

3. For each time interval, add the negative (-) tidal height at that time and station to the Average Tidal Height to compute Change in Tidal Height. For example, Change in Tidal Height for the first time interval at the study site is computed by typing the formula "=(-D3)+D11" into cell F3 of Table 2.

4. Compute Tidal Range by subtracting the minimum tidal height from the maximum tidal height over the entire time period. In Table 2, Tidal Range of the study site is computed by entering the formula "=max(D3:D10)-min(D3:D10)" into cell D12.

5. Compute Tidal Range Ratio by dividing the study site Tidal Range by the reference site Tidal Range. On Table 2, divide cell D12 (value = 57.48) by cell E12 (value = 85.08) and multiply by 100 to compute a Tidal Range Ratio of 67.56% (formula: "=(+D12/E12)*100").

6. Compute Difference in Tidal Range by subtracting the study site Tidal Range from the reference site Tidal Range. On Table 2, subtract cell D12 (value = 57.48) from cell E12 (value = 85.08) to compute a Difference in Tidal Range of 27.60 (formula: "=E12-D12").

DATA ANALYSIS AND COMPARISON

Data from the unadjusted reference marks and tidal gauges cannot be compared in raw form. Instead, data are analyzed as total change in the average tidal range on either side of a tidal restriction. The authors of this manual recommend that volunteer groups acquire the publication *Tidal Crossing Handbook: A Volunteer Guide to Assessing Tidal Restrictions* (Purinton and Mountain, 1998) before entering, analyzing, and comparing data [the publication is produced by the Parker River Clean Water Association (PRCWA), and their website is www.parker-river.org]. You should follow the steps outlined below to analyze and compare your data. This procedure is more completely outlined in Purinton and Mountain (1998).

Plot the Data

From Table 2, create a double line graph with columns F and G on the Y-axis and column C on the X-axis. The Y-axis represents the departure from mean tidal range, and the X-axis represents recorded time. Figure 2A-C (next page) provides three examples of what these graphs look like and how they are used to interpret data.

Difference in Tidal Range and Tidal Range Ratio

The difference in tidal range is computed by subtracting the study site tidal range from the reference site tidal range. This difference is the actual measurement of the amount of tidal restriction present on the day you measured — keep in mind that the height of tides varies from day to day according to factors like moon phase and wind speed and direction. This value should be a positive number because it assumes that the reference site has a greater tidal range than the study site. If the opposite is true and a negative number results, you may want to review the data collected to be sure the correct protocol was followed or revisit the overall study design. While the actual measurement of tidal range difference is important, the severity of the restriction is best understood by examining the Tidal Range Ratio.

The Tidal Range Ratio is computed by dividing the tidal range of the study site by the tidal range of the reference site. Multiply this ratio by 100 to express as a percentage. A tidal range ratio of 68% indicates that the study site receives only 68% of the tidal range experienced at the reference site. With free, unrestricted flow of the tides, the study site would have the same tidal range as the reference site (the tidal range ratio would be 1.0 and the percentage tidal range would be 100%). As the severity of the tidal restriction increases, so will the difference in tidal range between the two sites. Each **wetland** must be studied individually, however, to determine the effect of a tidal restriction on its ecology.

Using the data collected as part of a tidal influence study, as well as specific calculations such as the tidal range and tidal range ratio, provides valuable insight into the degree of tidal flushing at a specific salt marsh. Investigators can use this data to determine the presence, absence, or severity of a tidal restriction. When tidal influence data are coupled with biological monitoring, it can provide a better understanding of the effect of a tidal restriction on wetland ecology.

REFERENCES AND OTHER SUGGESTED READING

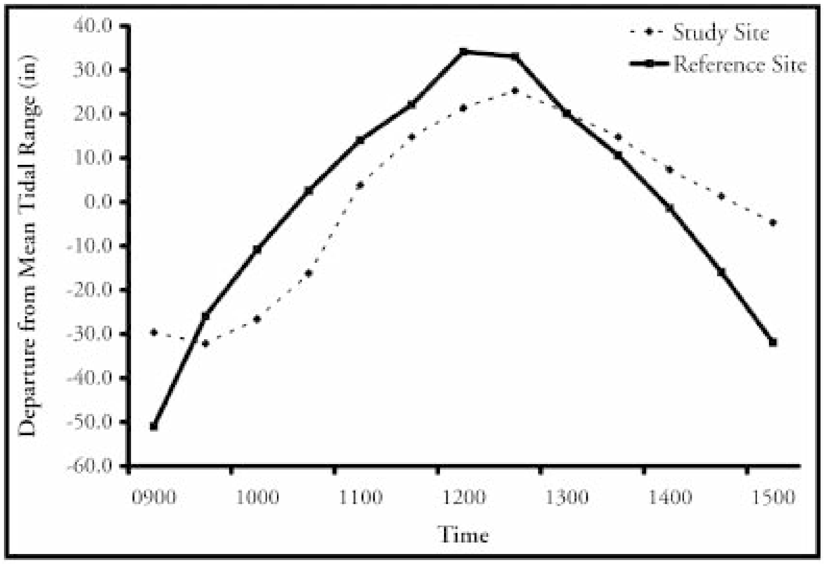
Mitsch, W.J. and J.G. Gosselink. 1993. *Wetlands.* Van Nostrand Reinhold Inc., New York, NY.

Purinton, T.A. and D.C. Mountain. 1998. *Tidal Crossing Handbook: A Volunteer Guide to Assessing Tidal Restrictions.* Parker River Clean Water Association, Byfield, MA.

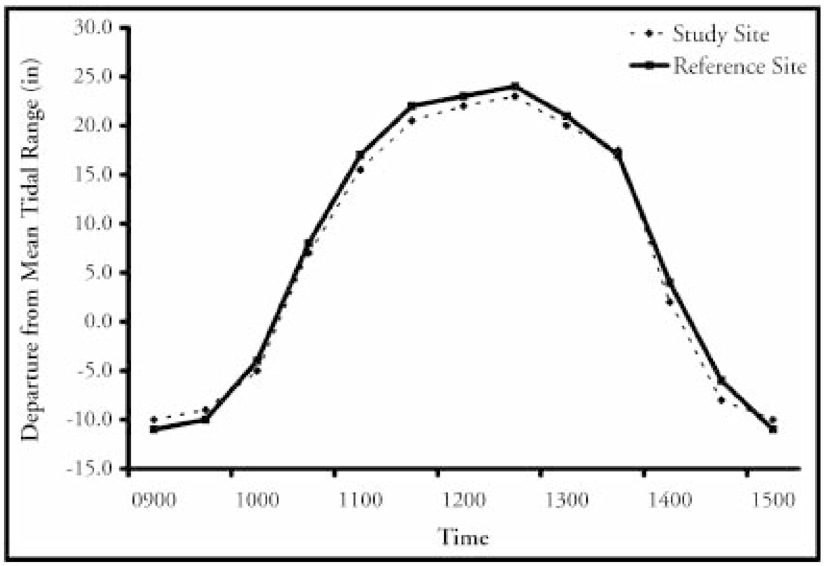
Rozas, L.P. 1995. Hydroperiod and Its Influence on Nekton Use of the Salt Marsh: A Pulsing Ecosystem. *Estuaries* 18(4):579-590.

Sinicrope, T.L., G. Hine, R.S. Warren, and W.A. Niering. 1990. Restoration of an impounded salt marsh in New England. *Estuaries* 13(1):25-30.

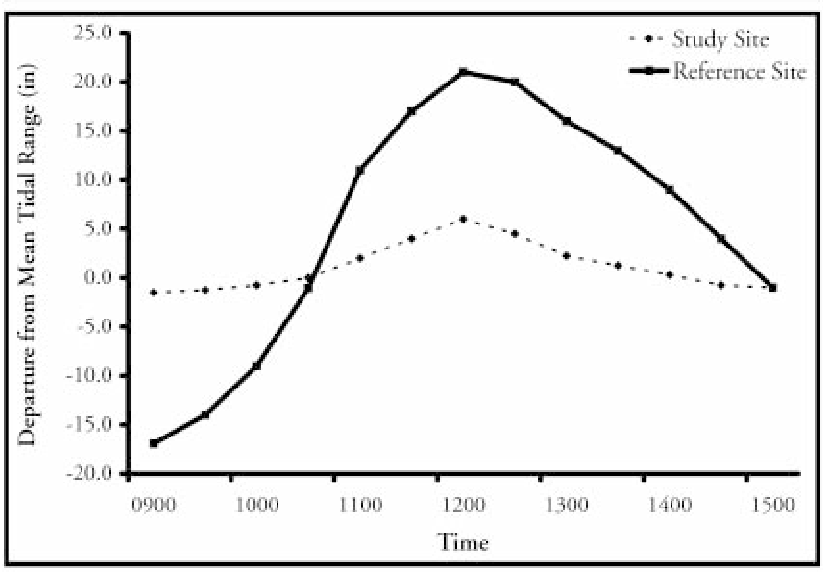
FIGURE 2. TIDE RESTRICTION GRAPHS



A. Tidal graph of a study site that has a culvert placed too high in relation to the creek bed, causing a tide restriction. The graph shows a delayed reaction to tidal changes, caused by the fact that the water level must rise at the reference site before it passes through the elevated culvert to the study site. The tidal peak at the study site occurs later than the reference site, and the study site begins draining after the reference site. The water level at the study site may not reach the low seen at the reference site because water gets trapped at the study site after the water level drops below the culvert.



B. Tidal graph of an unrestricted study site and reference site. The two lines are nearly identical, indicating little or no difference in tidal range between the two sites.



C. Tidal graph showing a severe tidal restriction caused by an insufficiently sized or collapsed culvert. The tidal peak occurs at the same time in the study site and reference site, but the change in tidal height is significantly less at the study site, indicating that water is prevented from flowing freely from one side of the marsh to the other.

chapter nine

APPENDICES

APPENDIX 1. TIDAL INFLUENCE FIELD SHEET

NOTES

TIDAL INFLUENCE FIELD SHEET

Site: ____________________

Date: ____________________

Investigators: ____________________

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High Tide: ____________________ (Boston Harbor)

Circle One: **REFERENCE SITE** **STUDY SITE**

[If in doubt regarding study and reference sites, just select one side to be Site 'A' and the other Site 'B', keep these consistent throughout the sampling and describe each site.]

	TIDAL HEIGHT (METERS)	
TIME (EVERY 15 MINUTES)	**STAFF GAUGE METHOD**	**REFERENCE MARK METHOD**