WHAT CAUSES THE TIDES?

Concepts

1. Model building helps us understand the tides.
2. The gravitational pull of the moon causes high tides.
3. High tides occur twice a day.
4. The gravitational pull of the sun works with the pull of the moon to cause higher high tides and lower low tides (spring tides) when the sun, moon, and earth are in line.
5. When at 90° to the moon/earth axis, the gravitational pull of the sun causes a damping effect, making tides not as high or low as usual (neap tides).

Vocabulary

gravity
force
mass
high tide
low tide
spring tide
neap tide

Introduction

Knowledge of tides is of major importance to those interested in estuaries, whether they be scientists studying estuarine dynamics or sailors planning a weekend cruise. While a thorough understanding involves study of many factors, the chief ones involved are the relative positions of the earth, moon, and sun, and the gravitational forces between these bodies. In this activity students will construct a simple model of the earth and its oceans, and investigate how these factors interact to produce tidal cycles.

For advanced students and older groups the project provides a valuable opportunity to grasp ideas that otherwise may be treated superficially or only on a theoretical basis. It also fosters discussion of the value of models used to explain phenomena. This may be linked to the development of scientific theories and technological advancement.

The model building will take approximately 25-35 minutes of class time. It is designed for students in Grades 5 to 8, but can be adapted for other age groups.

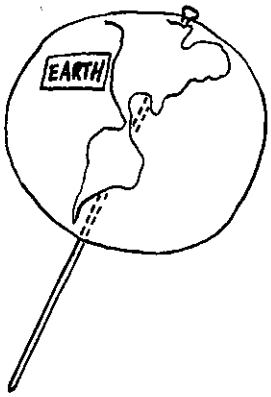
Materials needed

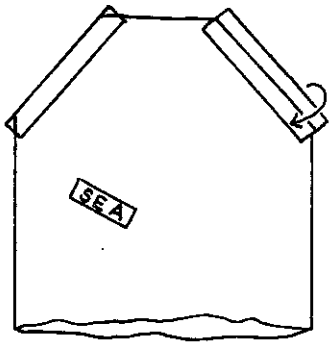
Each pair/group of students should have:

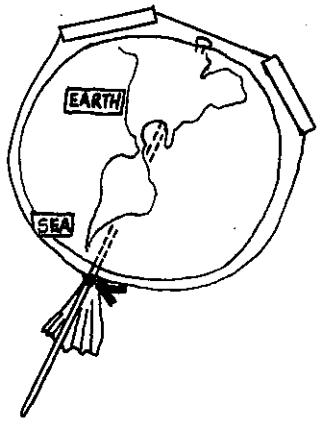
- ☐ 1 foam ball (any type of ball can be used if it can be pierced by the knitting needle)
- ☐ 1 knitting needle (or piece of thick wire looped at one end)
- ☐ 1 clear plastic bag (should be free of holes and ideally just big enough so the ball can fit into it and turn freely)
- ☐ 1 wire tie (freezer ties ideal)
- ☐ 1 marking pen
- ☐ 1 pair of scissors
- ☐ sticky labels—a minimum of 4
- ☐ cellophane tape
- ☐ 1 copy of student "What Causes the Tides?" lesson
- ☐ a pencil or pen

The teacher should have the following on hand:

- ☐ spare plastic bags







Procedure

Many students will already know what a tide and the force of gravity are from personal experience. A few may know how often high tides occur. On the other hand, many might have the mistaken impression that waves washing a beach are caused by tides. A brief recounting of their experiences may help set the scene for the lesson. Students may not be aware that the force of gravity occurs between any two objects (between the sun and earth for example). **A reminder of facts about the orbits and relative distances between the earth, sun, and moon may help later understanding.**

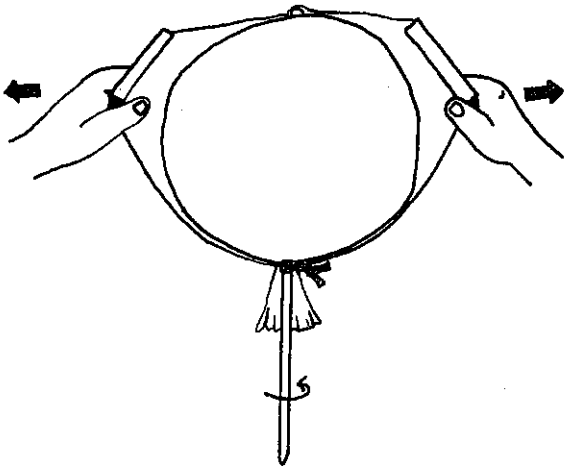
Students may undertake the project in pairs or small groups. The teacher may have them work through the lesson individually, or extend the introductory discussion to cover the directions for building the model.

Some students may be quite capable of carrying out the project under their own initiative. Others may need more advice and supervision on a one-to-one basis.

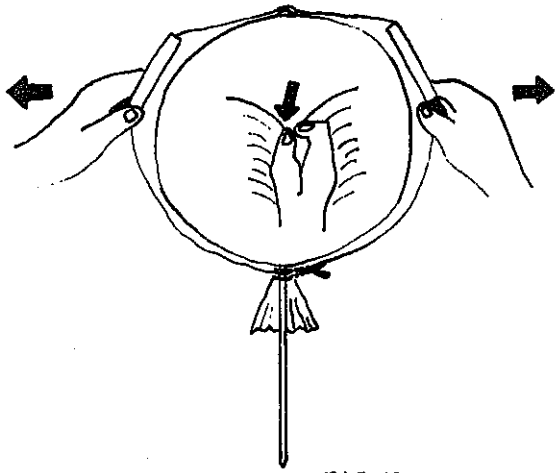
For young children just the building of a model may increase their awareness of some of the processes involved in forming the tides; they need not attempt further understanding. Further comprehension of the abstract concepts involved requires children to have reached Piaget's stage of formal thought.

It is recommended that you attempt the project yourself before the lesson. By doing this the observations to be made and potential problems that may be encountered become obvious. In particular note the following:

1. High spring and neap tides may be modelled by having two students pulling the bag's flaps.
2. The high tide flaps should be bigger (showing extreme spring tides) when the student representing the sun pulls in line with the student representing the moon.
3. The flaps should be smaller (representing moderate neap tides) when the student representing the sun pulls at right angles to the student representing the moon.
4. Note also the effect on the low tide height (at right angles to the flap). It should be lower during spring tides, higher during neap tides.



DEMONSTRATING HIGH TIDES



DEMONSTRATING NEAP TIDES

Discussion

At the end of the lesson students should be reminded of the relevant facts — high tides are caused by the gravitational force between the moon and the earth and modified by the gravitational force between the sun and the earth.

In particular, the reason why a second high tide occurs on the side of the earth away from the moon is difficult to understand and may need reinforcing.

The model itself may be discussed. Modelling is widely used in science to help understand complex processes and systems and to generate questions on how these processes and systems work.

Encourage pupils to suggest ways in which the model is limited. Some possibilities include:

1. **Scale:** The seas are actually an extremely thin skin on the surface of the planet.
2. **Materials:** The bag does not uniformly cover the ball. As represented by the bag, water is not confined by land.
3. **Forces:** Gravity does not behave like a pull on a flap. It acts on the whole.
4. **Simplicity:** The model is too simple. For example, geography will have a profound effect on the tides but is not covered. The seas rotate with the earth, rather than staying in one place while the land rotates underneath.

Further explorations

Diagrams of the relative positions and orbital relationships of the earth, moon, and sun — such as those in the student worksheet — are useful, but here, too, three-dimensional models can provide better understanding. Simple models showing these relationships are available from scientific supply houses. The earth is mounted at the end of an arm which pivots around the sun. As this arm is moved to show the earth's orbit, another arm — on which the moon is mounted — rotates around the earth. Phases of the moon, earth/sun/moon positions, and their correspondence to tidal forces can be readily illustrated. You can probably find one of these models in a classroom or closet of some school in your district. Check with your science coordinator or an earth science teacher in the junior high or high school.

Resources

Brindze, Ruth. *The Rise and Fall of the Seas — The Story of the Tides.* Harcourt, Brace, & World, New York: 1964. A good description of tidal phenomena written for upper elementary and junior high students; it's out of print but available in libraries.

Roberts, Merwin F. *The Tidemarsh Guide.* E.P. Dutton, New York: 1979. In addition to providing a clear, often entertaining introduction to tidemarshes and their diverse inhabitants, Roberts offers an explanation of tides that presents the complexity of forces responsible for them without overwhelming the reader.

READING THE TIDE TABLES

Concepts

1. Using a 24 hour clock.
2. Reading a simple tide table.
3. High tides occur approximately 50 minutes later each day.
4. The time at which a given high or low tide occurs will vary at different sites along the shore.

Vocabulary

high tide
low tide
tide table

Introduction

The tides are cyclic and thus predictable. Tide tables are published by organizations concerned with navigation. Information about times of high and low tides is vital to work and play on the Hudson River. In addition to the practical value of learning to read tide tables, teaching this skill provides an excellent lesson in interpretation of information presented in the form of tables and charts.

In this activity students will interpret the times of high and low tides from tide tables using the 24 hour clock. The lesson can reinforce knowledge gained through the model-building exercise of the lesson "What Causes the Tides?" Students will be required to exercise their arithmetic skills in completing the worksheets. The lesson will also prepare students for a graphing exercise in the lesson "Graphing the Tides."

While the lesson is intended primarily to teach how to read tide tables, that skill may be learned relatively easily compared to learning how to deal with the 24-hour clock and adding clock times. With that in mind, the lesson is arranged in two sections. The first is suitable for fourth grade, assuming familiarity with or some preparation in reading clock times. The second section, under Table 2, does require particular proficiency at addition, and is better suited to students at fifth grade level or above.

Expect the lesson to take approximately 20-30 minutes of class time.

Materials

Each student should have:

- ☐ 1 copy of the student worksheet "Reading the Tide Tables"
- ☐ a pencil

Procedure

Begin by discussing the need for tide tables, their uses, and the information they contain. The teacher can then lead the class through the lesson, or allow students to work on their own. In the latter case, it would be helpful to first explain a few examples modelled on the initial questions in each section.

Such explanations would be particularly helpful in the section of the worksheet dealing with **Table 2 — Tidal Differences. Many students tend to add clock times — hours and minutes — as though they were in base 10.** This can cause problems when adding or subtracting times starting with different hours, or when addition of minutes comes to more than 60. Most questions under Table 1 are written to avoid having to deal with addition or subtraction outside a given hour period. Such complications were unavoidable in the section under Table 2. Questions there have been designed to lead students through that particular addition process.

Should you use your own examples in dealing with tidal differences, note that adjustments for upriver stations can lead to a tide prediction for the following date. For example, the evening high tide at the Battery on November 8 occurs at 2010. Given the 9 hours it takes to reach Albany, that tide will occur there at 0510 on November 9. The additional computation could overwhelm some pupils or provide a healthy challenge to others. All questions on the worksheet use tide times which avoid this complication.

Look over Questions 10 and 22 before assigning them to your students. These might best be treated as extra credit questions, or answered as a class exercise.

Discussion

At the end of the lesson students can discuss their answers. **In particular they should know that high tides are approximately twelve hours apart due to the two tidal bulges caused by the gravitational effect of the moon** (see "What Causes the Tides?" lesson). To make that more understandable to students, ask students to recall how long it takes the earth to rotate around its axis — 24 hours. Suggest that they imagine themselves standing in one spot directly under the moon and in its high tide bulge. Where will they be 12 hours later? Most students should be able to imagine themselves on the opposite side of the earth, directly opposite the moon and in its second tidal bulge.

Continue the analogy with the students. Shouldn't you be back under the moon 24 hours later? Not quite. The moon is moving too, orbiting around the earth, so it takes a little more than 24 hours to catch up to it. That's why a given tide at a particular spot will occur approximately fifty minutes later each day. That figure is an average. The actual change from one day to the next can vary from thirty minutes to over an hour.

It should be obvious from the worksheets that the time at which a certain tide occurs is not the same at all spots. It takes time for the tide to move upstream; thus predictions in a given table must be corrected to determine when high and low tides will occur elsewhere on the River.

Keep in mind that times given in tide tables are predictions, not fact. Variations from the predicted times are possible and even likely. On the Hudson, sustained north or south winds and heavy rains are among the factors that can change the timing and/or heights of tides.

Further explorations

1. A classroom daily almanac

Many teachers post the date and a schedule on the board each day. When studying the Hudson, it would be appropriate to post daily tide predictions as well. Such predictions can be found in the tide tables referenced below, or in many daily Hudson Valley newspapers, generally with the detailed weather report. One student might be assigned to look up the information each day and write it on the board.

2. Tidal currents

This lesson plan deals only with the tide — the rise and fall in water level. You might also want to cover tidal currents; they're very important to vessels travelling on the Hudson.

The current in the Hudson reverses itself approximately every six hours. A rising tide is accompanied by a current flowing upriver, called the **flood current** or **flood tide.** A falling tide is accompanied by a downriver current — the **ebb current** or **ebb tide.** Current speed varies greatly from place to place and time to time. On the Hudson, ebb currents are generally swifter than floods.

Tidal current tables are readily available (see **Resources** section below). Using such tables it is easy to set up student exercises similar to those for tides. Current tables list the times of maximum current, both ebbs and floods, and the times of minimum current, known as slack water, before the onset of a given ebb or flood.

There are two details worth noting here. First, current speeds are given in units of nautical miles per hour. A nautical mile is equal to about 1.2 land miles. Second, don't expect the times of slack water to coincide with the times of highest or lowest tides. For example, in Newburgh on June 22, 1986, a low tide occurred at 7:12 a.m. Though the water level started rising after that time, the current didn't slack and switch direction from ebb to flood till 9:08 a.m., almost two hours later. The reasons for this take more explaining than we have room for here. Contact Clearwater if you'd like the details.

Resources

Tide and tidal current tables

Tide tables are available from many publishers. Most thorough are those published annually by the National Ocean Service (NOS). The volume *Tide Tables — East Coast of North & South America* includes thirty Hudson River stations, giving the predicted times of high and low tides for every day of the year, the heights of these tides, and the range between high and low. Currently it costs about $9 (price is subject to change) at selected boating and marine supply stores or by mail from: **Distribution Branch (N/CG33), National Ocean Service, Riverdale, Maryland 20737**; their phone number is (301) 436-6990.

Also available from NOS is the volume *Tidal Current Tables — Atlantic Coast of North America*, which lists predicted times for the onset of ebb and flood currents along with data on the speeds of those currents. It covers the same stations on the Hudson and costs about the same as the NOS tide table volume.

Along the Hudson a more convenient reference is *Hudson River Tide & Current Data*, put out in early spring each year by Sea Explorer Ship 182 in New Hamburg and LaGrangeville. This volume omits a few stations and covers only the boating season April 1 to November 30, but otherwise combines all the Hudson River tide and current information given in the two NOS tables and presents it in more readily understandable fashion. This volume costs $3.50 and is available at selected Hudson Valley boating supply stores and from Clearwater.

Answer Key

1. 2:00 p.m. 3:30 p.m.
   8:15 p.m. 12:15 a.m.
2. 2
3. 2
4. 10:09 p.m.
5. 10:54 p.m.
6. later, 45 minutes
7. Nov. 25 — 8:50 a.m., Nov. 26 — 9:51 a.m., 61 minutes later
8. 4:12 a.m., about 5:00 a.m.
9. six hours plus ten to fifteen minutes
10. the moon's orbit; see discussion
11. answer varies
12. answer varies
13. 44 minutes
14. 5 hours
15. 5:44 a.m.
16. 74 minutes
17. 74 — 60 = 14 minutes
18. 8 hours
19. 8:14 a.m.
20. answer varies
21. answer varies
22. no — the tide will be high at 11:00 a.m., covering the rocks; best time to search for scuds would be at low tide, 5:54 p.m.

GRAPHING THE TIDES

Concepts

1. Interpreting height on tide tables.
2. Plotting data on a graph.
3. Calculating tidal range.
4. The cycle of spring and neap tides.

Introduction

Many students (and not a few adults!) are confused and rather daunted by complex-looking tables and graphs. This is a pity as they often contain useful information. This lesson should help students visualize the lunar cycles of the tides. In doing so, it should illustrate how graphs can highlight information that's obscured in lengthy tables.

This activity is designed for students at sixth grade level or older. Fifth grade students who have worked on graphing might take it on late in the school year. Expect it to take 40-50 minutes of class time.

Materials

Each **student** will need:

- ☐ a student's copy of "Graphing the Tides" lesson
- ☐ a copy of the New York tide tables for October 1986
- ☐ a sheet of graph paper, preferably 10 squares to the inch or ten squares to the centimeter
- ☐ a pencil

Procedure

Introduce the lesson by reviewing the results of the modelling exercise "What Causes the Tides?" or going over the following with the students. It is important that they understand the concept of spring and neap tides.

What causes the tides? The gravitational pull of the moon draws the sea into a bulge on the side of the earth closest to it. The other side of the earth also has a high tide because the moon attracts the earth more strongly than it does the water on that far side. This causes a bulge in the sea on that side. The rise and fall of the tides is caused by the earth's rotation on its axis, which changes the seas' position relative to the moon.

The sun also has an effect. When the sun and moon are lined up with the earth, their gravitational attractions work together to produce a higher tidal bulge. This creates very high and correspondingly very low tides, called spring tides, at the times of full moon and new moon. During a first or third quarter moon, the gravitational attractions of the sun and moon work at right angles to one another. As a result the tidal bulge is reduced; high tides are lower and low tides are higher. These less extreme tides are called neap tides.

The students may then work directly through the work sheet.

To simplify and shorten the lesson, the teacher could draw and number the axes in advance and make copies on which students would then plot the data.

Questions may arise as to the meaning of "Heights are referred to mean low water". This explains that the heights of many low tides are averaged and then assigned a value of 0. Differences between this average and the actual height are given on the table. Tide heights lower than the mean will have negative values.

Discussion

This activity can be used both as a math exercise and as a river studies lesson. It demonstrates that math techniques have very practical uses in displaying data.

To round out the discussion of the relationship between tides and lunar cycles, you might want to mention the dates of full and new moons in October. The new moon occurred on the evening of October 3, the full moon on October 17 — dates which roughly correspond to dates of spring tides. You might then ask the students to use the graph to estimate the date of the first quarter moon (October 10) and the last quarter (October 25). These would be the occasion of neap tides. There isn't an exact correspondence of new moon with the highest spring tide or the first quarter with the neap; additional factors do come into play here. However, the moon's position is the most important influence.

In the sample graph attached, note that there are two irregularities in the low tide plot for October 14 and 30. These result from choosing to plot the highest and lowest tides on each day. We felt that students would find this task easier than following a single tide as it advances from morning to evening and then skips a calendar date to become a morning tide again. Plotting highest highs and lowest lows also produces the most extreme tidal range figures. If you'd rather have them plot a single tide throughout the month, we'd suggest following the high tide that starts in the evening October 1 and skips October 8, and the low tide that starts in the morning October 1 and skips October 30. Plotting in this manner will reinforce the fact that the tides occur roughly 50 minutes later each day. Should you choose to do this, the answers to the worksheet questions will differ from those in the key.

Further explorations

Field Trip Activity

When everyone arrives at the site, place a marked stick in the water's edge. Place another one further out in case the tide is still going out. Assign students to note the time and height periodically. Draw a graph showing relationship of time to height.

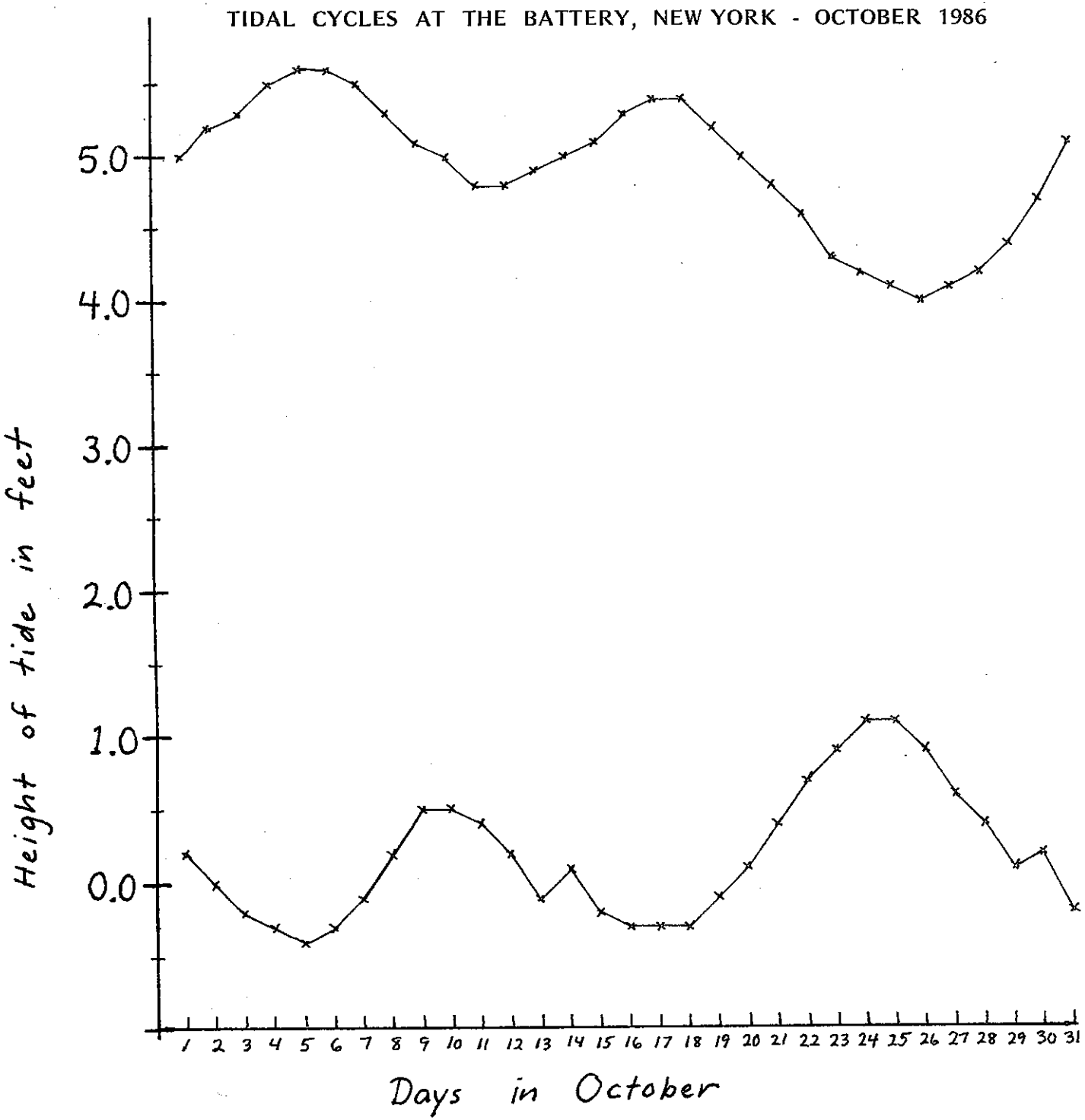
Afterwards the students can draw some conclusions about the tidal action. For instance: how much does it rise in an hour? Does it rise at the same rate each hour?

Resources

Anderson, Norman D. *Investigating Science in the Swimming Pool and Ocean.* McGraw-Hill Book Company, New York: 1978. Many activities exploring water, its properties, and its living organisms; of particular relevance is a section on measuring the height and range of the tide, using graphing skills in the process.

Answer key

1. times of high & low tides, height of each tide in feet & meters
2. 2, 2
3. no, no
4. all low tides do not have the same height; a mean (average) figure is determined from many low tides and assigned a height of 0; all tide heights are then figured against this average
5. about 6 hours
6. 0951 (9:51 a.m.), 2233 (10:33 p.m.)
7. -0.2, low, height is below mean low water
8. lowest low -0.4, highest high 5.6
9. 6.0
10. October 5, range 6.0, October 17 & 18, range 5.7
11. October 11, range 3.4, October 25, range 3.0
12. 9 days
13. 1 day


TIDAL CYCLES AT THE BATTERY, NEW YORK - OCTOBER 1986
5.0
4.0
3.0
2.0
1.0
0.0
Height of tide in feet
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31
Days in October