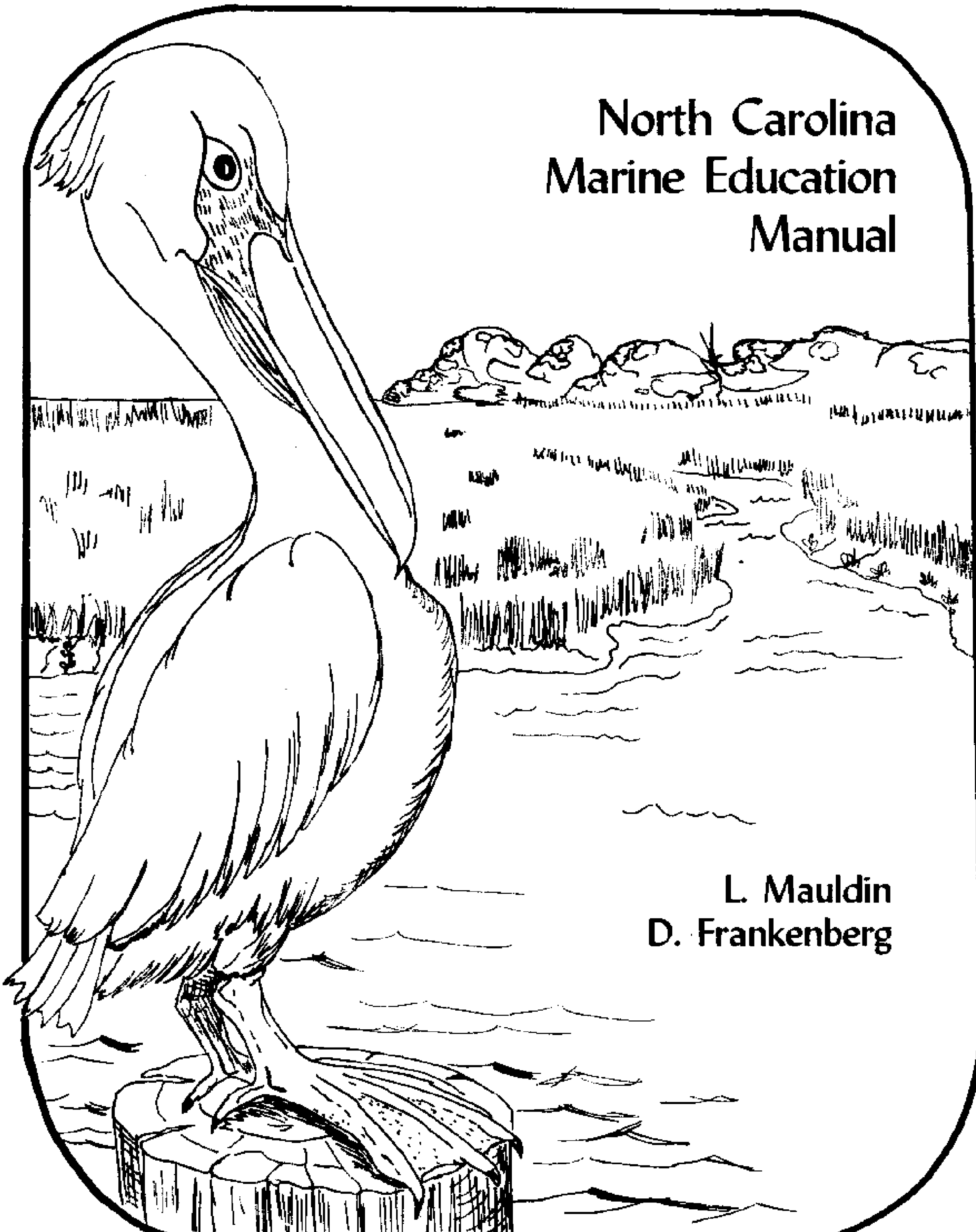
# Unit Two
# Seawater

## North Carolina Marine Education Manual



L. Mauldin
D. Frankenberg

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August, 1978

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# NORTH CAROLINA MARINE EDUCATION MANUAL

## UNIT TWO

## SEAWATER

LUNDIE MAULDIN
UNC Sea Grant College Program

DIRK FRANKENBERG
Marine Science Curriculum
UNC, Chapel Hill

Illustrated by Lundie Mauldin and Johanna Bazzolo

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Unit 2 Seawater

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# ACKNOWLEDGEMENTS


The North Carolina Marine Education Manual is a collection of teaching materials generated by North Carolina public school teachers and university professors under a University of North Carolina Sea Grant College project entitled "Man and the Seacoast." Dr. Dirk Frankenberg is the principle investigator; the Resource Unit Development Committee project directed by Dr. William Rickards of North Carolina State University assisted with material production. The manual is designed to help middle school teachers put marine perspectives into their lessons. The activities can be modified for higher or lower grades.

This manual consists of separate units which cover environmental aspects of the coast such as geology, ecology, and seawater interactions and motions. Additional units cover facets of coastal communities and economics, history, anthropology, art, folklore, and literature. An appendix provides information on keeping aquaria, state and federal agencies, field trip guides, and film company addresses.

We wish to acknowledge the cooperation we have received from other marine education projects, North Carolina Marine Resource Centers, North Carolina Department of Public Instruction, National Marine Education Association, and many people who have contributed suggestions and opinions. Especially we wish to thank those people whose enthusiasm and contributions made this project possible -- the following North Carolina teachers:

1977 "Man and the Seacoast" teachers

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The North Carolina Marine Education Manual developed through the interaction and involvement of people interested in marine education. UNC Sea Grant would like to continue the involvement by inviting your opinions and suggestions for topics and activities. In this way, we can remain responsive to your needs with new additions to the manual.

Please address your comments to: UNC Sea Grant College Program
Marine Education Specialist
North Carolina State University
105-1911 Building
Raleigh, NC 27650

Introduction

Coastal water of North Carolina is no different from other bodies of sea water in physical and chemical aspects. North Carolina experiences tidal changes and waves similar to all coastlines and shares seawater of the world ocean. Consequently, much of the background reading in Unit Two can be supplemented by general oceanography texts of chapters in earth/space science books. Unique to North Carolina is the specific manner in which physical forces like tides and waves act on the coast line. Understanding some oceanographic concepts like longshore current and tidal flow will help citizens make decisions on controversial coastal projects. Quality of coastal water is another aspect dependent on decisions citizens make. We have control over effluent flowing into estuaries and sounds. How we exerise this control will affect coastal economies like commercial fisheries and recreation.

Activities in Unit Two insert easily into Eighth Grade earth/space science curriculum. However, some of the activities would help younger students to understand natural phenomena around them. Table 1 provides a summary of the activities presented in Unit One in relation to the recommended program features of the North Carolina state curriculum guide (Course of Study for Elementary and Secondary Schools K-12, 1977, pages 139-148). Program features include knowledge/content objectives. The objectives have been generalized into broad catagories to simplify the table. Process skills include observing, classifying, using numbers, inferring, interpreting data, controlling variables, experimenting, and formulating models. Manipulative skills include using instruments, calibrating, and constructing. Supplemental skills of organizational, creative, and communicative ability include those which tend to develop an investigation: recording, comparing, planning, inventing, discussing, reporting, writing, graphing, and criticizing. We hope this table will make it easier for you to insert these activities into your lesson plans. Table 2 provides educational goals and behavioral objectives for Unit II.

The activities in this Marine Education Manual are suggestions of ways in which you can transfer information on North Carolina's fascinating coast to your classroom. Only the framework of the activities is described because we feel that each teacher would want to modify the activities to suit his/her particular grade or class level. Specific equipment is minimal leaving maximal need for inventiveness and enthusiasm! We hope these activities will generate an understanding of what is happening on the North Carolina coast.

TABLE 1. Correlation of Activities with Some Skills and Program Features Recommended by the North Carolina Department of Education.

| Activities | Process Skills | Manipulative Skills | Organizational Skills | Creative Skills | Communicative Skills | Measurement Systems |
|---|---|---|---|---|---|---|
| Moon Ring and Tides | | X | | X | | |
| Tides and Magnets | | X | | | X | |
| Sun and Moon on Tides | | X | | X | X | |
| 24-Hour Clock | X | | | | | X |
| Tide Chart | X | | X | | | X |
| Plot of N.C. Tides | X | | | | X | |
| Bay of Fundy Model | X | X | X | X | | |
| Tidal Range | X | | X | | | X |
| Making a Wave | X | X | | X | | |
| Wave Structure | | X | | | | |
| Wind Waves | | X | | | | |
| Particle Movement | | X | | X | | X |
| Wave Period and Speed | X | X | | X | | X |
| The Water Molecule | | X | | | | |
| Surface Tension | | X | X | | X | |
| Dissolving Power | | X | | | X | |
| Freeze/Boil Experiments | X | X | X | X | X | X |
| Hand-Made Hydrometers | X | X | | X | | X |
| Determine Salinity | X | X | X | X | X | X |
| Calculate Salinity | X | | X | | | X |
| Density | X | X | X | | X | |
| More Density | X | X | X | | X | |
| Cartesian Diver | X | X | X | X | X | |
| Buoyancy | X | X | X | | X | |
| Pressure | X | X | | | X | |
| Salinity and Density | X | X | | X | X | |
| Oxygen and Sewage | | X | | X | X | |
| Air in Water | | X | | X | X | |
| Oxygen and Temperature | X | X | X | X | X | X |
| Too Many Nutrients | | X | | X | X | X |

## Goals and Behavioral Objectives

I. To acquaint students with two physical ocean phenomena: tides and waves and their effect on North Carolina's coastline.

Concept 1. Tides are ocean surface phenomena produced from gravitational pulls of sun and moon.

Behavioral Objectives

Upon completion of this concept, the student should be able

a. To describe the effect of sun and moon gravitational pulls on ocean water.

b. To graph a tide chart, indicating neap tides, spring tides, and tidal ranges.

c. To convert regular time to 24-hour time and reverse.

Concept 2. Waves are ocean phenomena that effect the surface water and the shore.

Behavioral Objectives

Upon completion of this concept the student should be able

a. To label parts of a wave.

b. To discribe at least two effects of wave energy on a coastline.

c. To describe how wave induced currents can affect swimmers.

II. To investigate physical properties of seawater, how salinity and density are related and how they affect circulation.

Concept 1. Seawater is salty and salinity affects circulation of coastal waters.

Behavioral Objectives

Upon completion of this concept the student should be able

a. To describe surface tension of water.

b. To estimate the amount of salt in water based on density measurements.

III. To investigate chemical properties of seawater, especially oxygen and nutrients, and their relationship to living organisms.

Concept 2. Seawater contains all known chemicals. Oxygen and nutrients are two chemicals that effect the quality of the marine environment.

Behavioral Objectives

Upon completion of this concept, the student should be able

a. To increase and decrease amounts of dissolved oxygen in water (agitation, temperature, plants, animals, and decay).

b. To show at least one effect of nutrients in water.

Concept 1. Tides are ocean surface phenomena produced from gravitational pulls of sun and moon.

a. Background Reading

Tides are ocean events familiar to anyone who has spent time at the coast. On the North Carolina coast we can observe that the water rises to a peak called high tide and then falls to a low (low tide) about every twelve hours. Tides are actually long waves in which crests of high water and troughs of low water follow each other in regular six hour patterns (note: this pattern is altered by coastal configeration to other factors in other states.) Tides are barely perceptible in the open ocean but can be quite dramatic along the shore. The vertical distance between high and low tide is called the <u>tidal range</u>. Tidal rnages vary from place to place and week to week. For example, the Great Lakes of the United States and Mediterranean Sea have a tidal range of only a few inches, the open ocean varies less than two feet whereas the Bay of Fundy, Nova Scotia, located at the apex of a funnel-shaped coastline; has a tidal range of over 60 feet.

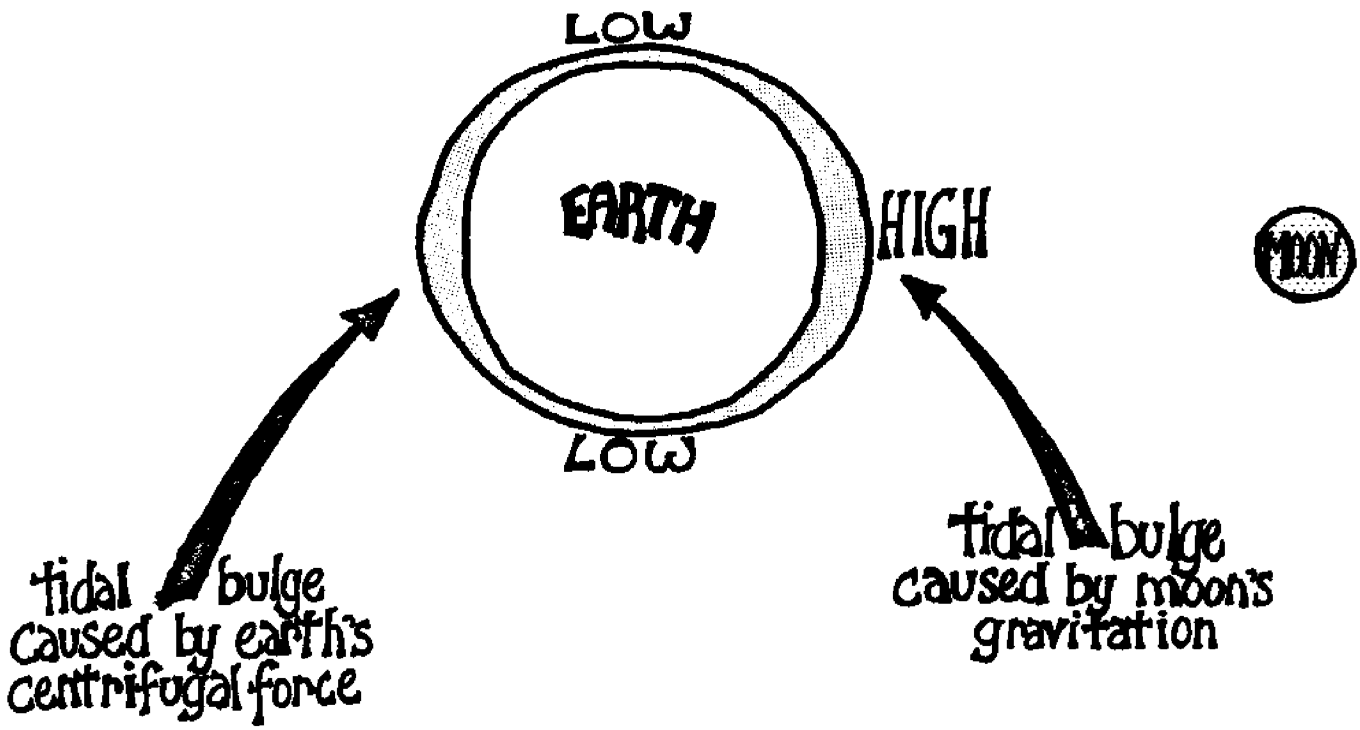
Tides affect the coast by alternately exposing and submerging a strip of land called the <u>intertidal zone</u>. The extent of the intertidal zone depends on the contour of the land. Steep sides of tidal creeks expose only a narrow strip of mud at low tide while shoals on barrier islands expose land for several hundred yards (diagram). In addition to creating the intertidal zone, the ebb and flow of tides cause tidal currents. The ebbing current removes sediments, detritus, and nutrients from marsh backwaters to the estuaries while the flowing tide brings back sea water. Tidal changes are responsible for strong currents which sweep through the inlets between barrier islands. Thus tides create a unique habitat area, the intertidal zone, and also provide important currents that circulate water within the coastal-estuarine system.

Many coastal activities are affected by the tide such as navigation in shallow sounds, fishing, and shoreline activities from beaching boats to beach combing. Today, tides can be predicted years in advance. Tide charts giving predicted tidal heights and times are vital to ship pilots, marine ecologists and also to teachers planning field trips to beach or marsh.

<u>Cause</u>

Tides are the result of complex gravitational forces between earth, sun, and moon. The sun is larger than the moon but since it

FIGURE 1: Affect of the Moon on the tides.



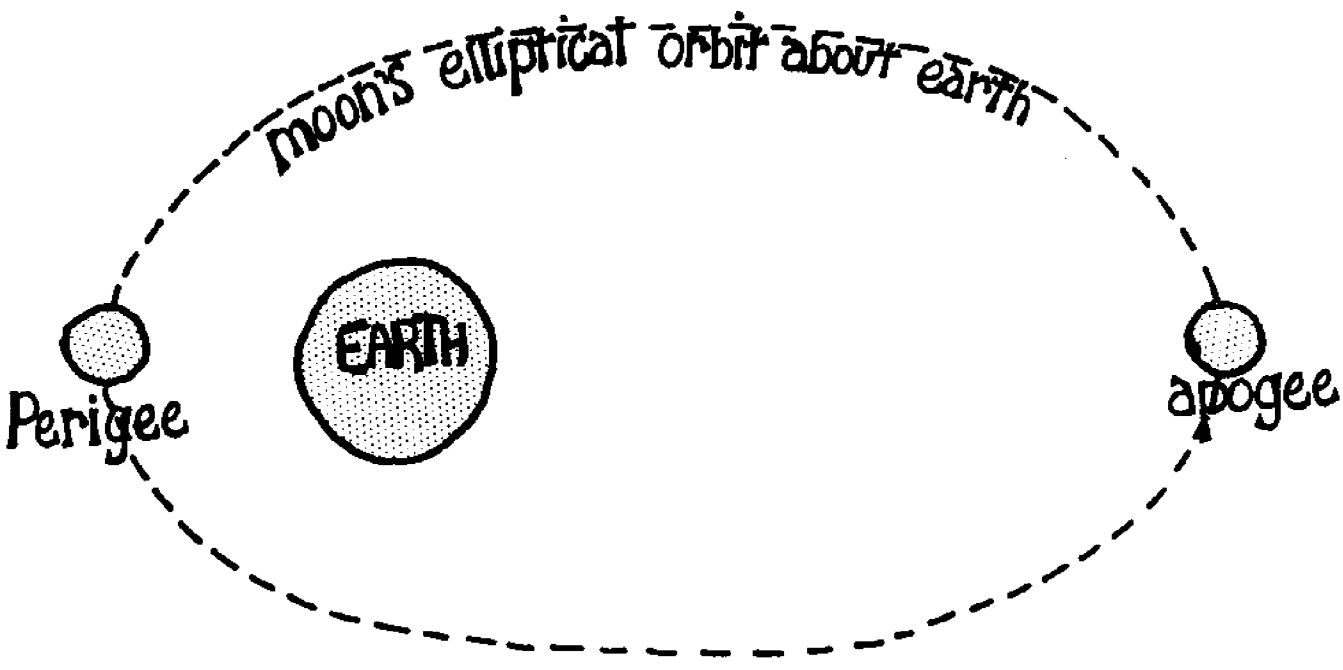
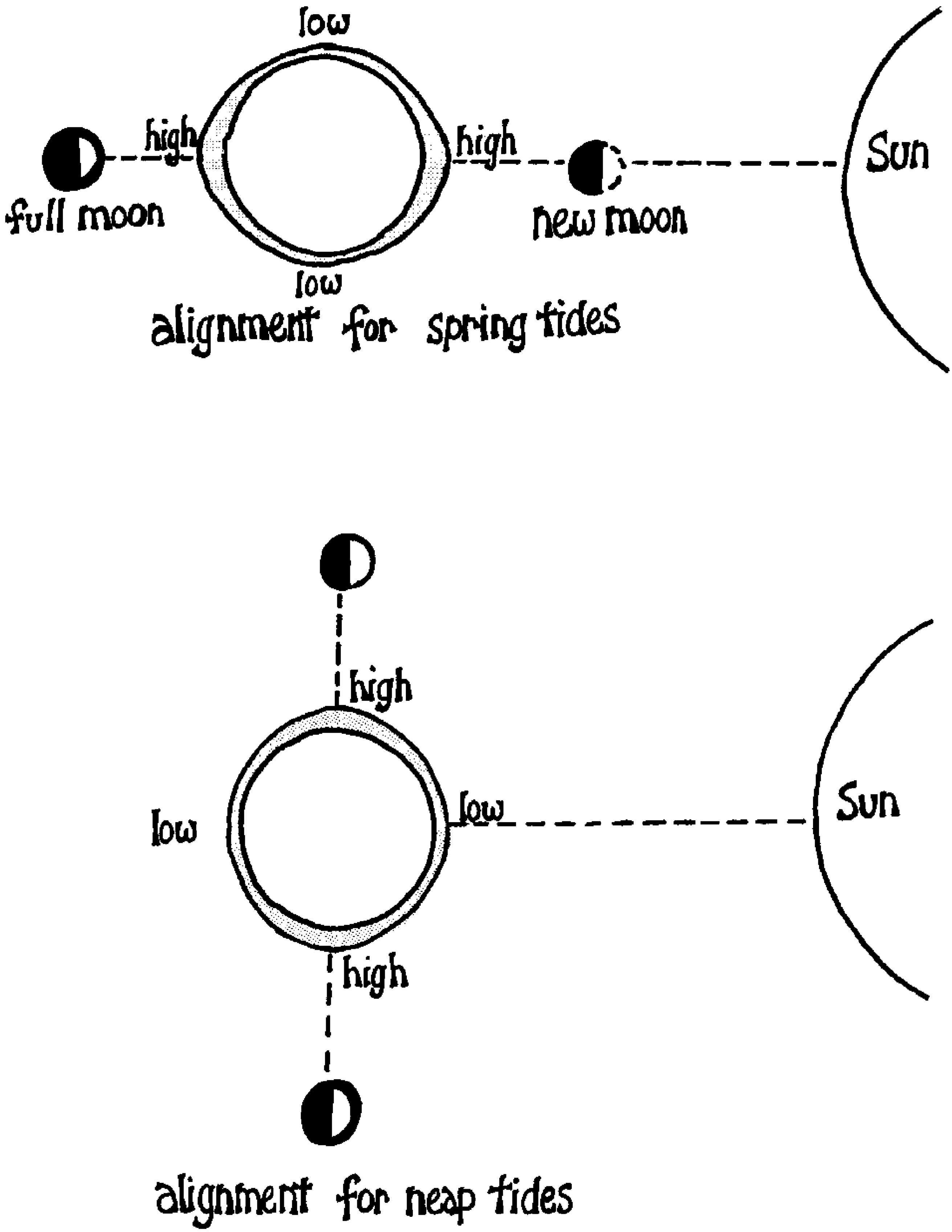



FIGURE 2: Affect of the Sun on the tides.



is much farther from the earth, the moon's gravitational force has a greater pull on the tides.

Tides are formed as sea water reacts to the pull of gravity. Picture the earth as a smooth planet with an even layer of water covering the surface, and with no continents dividing the water into oceans. On such an earth water level reflects a balance between gravity (holding water on the surface) and centrifugal force (pinning water away from the coast). The moon's gravitational attraction influences this balance by pulling water toward the moon and away from the earth, creating a bulge of water, on the moon side of the earth. On the opposite side of the earth, water is being spun away from the earth by centrifugal force thereby creating another bulge of water.

The sun's gravitational pull affects the tides but to a lesser degree than the moon because of its greater distance from the earth. When the sun and moon are in direct line with each other, their gravitational forces pull together. Therefore the bulges of water are greater producing the maximum tide range or the highest and lowest tides, called <u>spring tides</u>. New moons and full moons produce spring tides. However, new moons tend to produce higher tides than full moons because the sun and moon are on the same side of the earth. As the moon rotates around the earth, gravitational forces of the moon and sun gradually pull against each other. When the moon is at first and last quarter, the moon, earth, and sun form a $90^{\circ}$ angle. This produces <u>neap tides</u> which have the least tidal range or the least high and low tides (Figure 2).

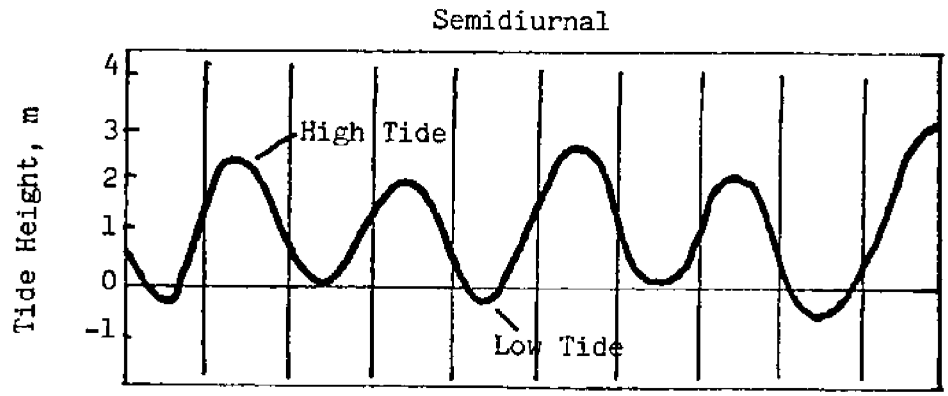
Since the moon rotates around the earth on an elliptical orbit, it is not always the same distance from the earth and is not always directly over the same part of the earth's surface. The point of the orbit closest to earth is the perigee. The point furthest from earth is the apogee. When the moon is in the perigee of its orbit, its gravitational pull affects the earth more and tidal range is greater. The earth has an elliptical orbit around the sun also. Thus, the position of the moon and earth in their orbits affects tidal range.

. On the real earth tides are generated by the processes described above, but are influenced by the shape of ocean basins and other factors, for example, the moon and sun are not always directly over the equator, but vary north and south. The moon varies $28^{\circ}$ north or south each month, and is directly over the equator twice in a 30-day period. The sun also varies in its position over the earth in a year's time, being north of the equator between March 21 and September 23 and south of the equator between September and March. As the sun and moon vary from the northern to the southern hemispheres and back again, the tidal bulges follow their movement, causing the heights of tides to vary in a predictable pattern (Figure 3).

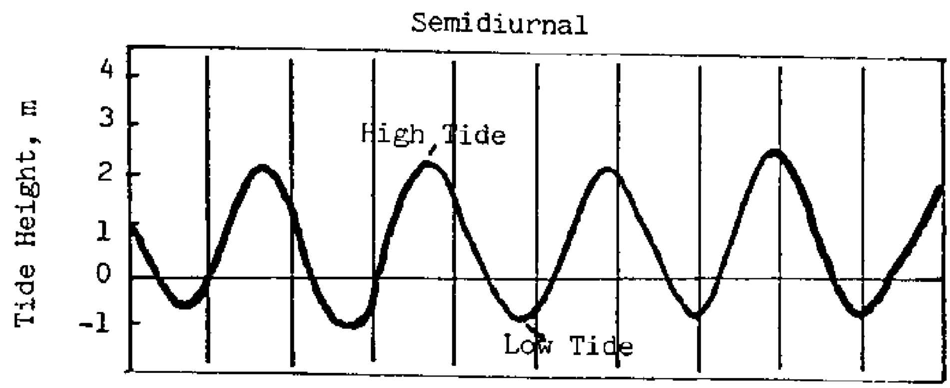
Tides occur 50 minutes later each day due to the rotation pattern of earth and moon. A period of 24 hours 50 minutes is known as a lunar day, while 24 hours is a solar day.

Figure 3

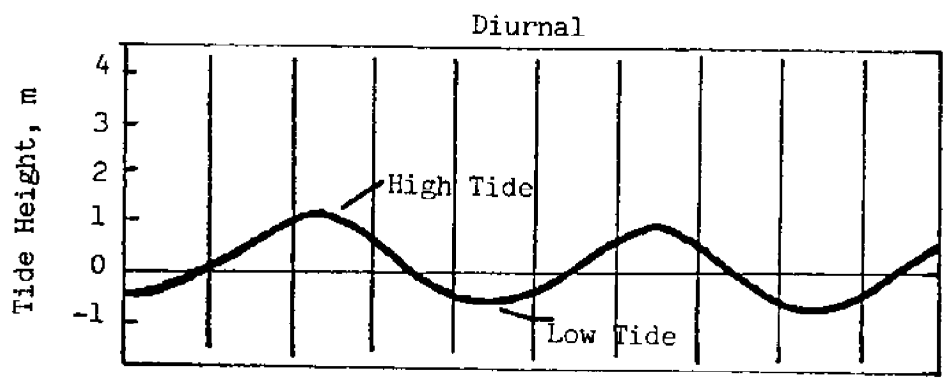
Beaufort,
N.C.




Portland,
Maine




Pensacola,
Florida




San Diego,
California

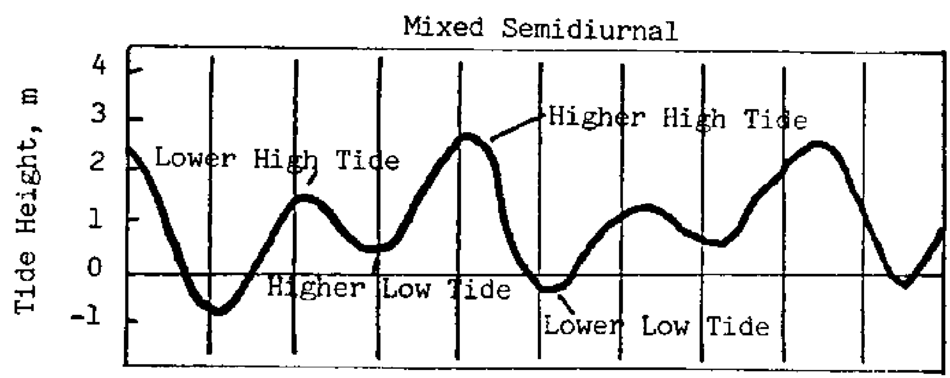
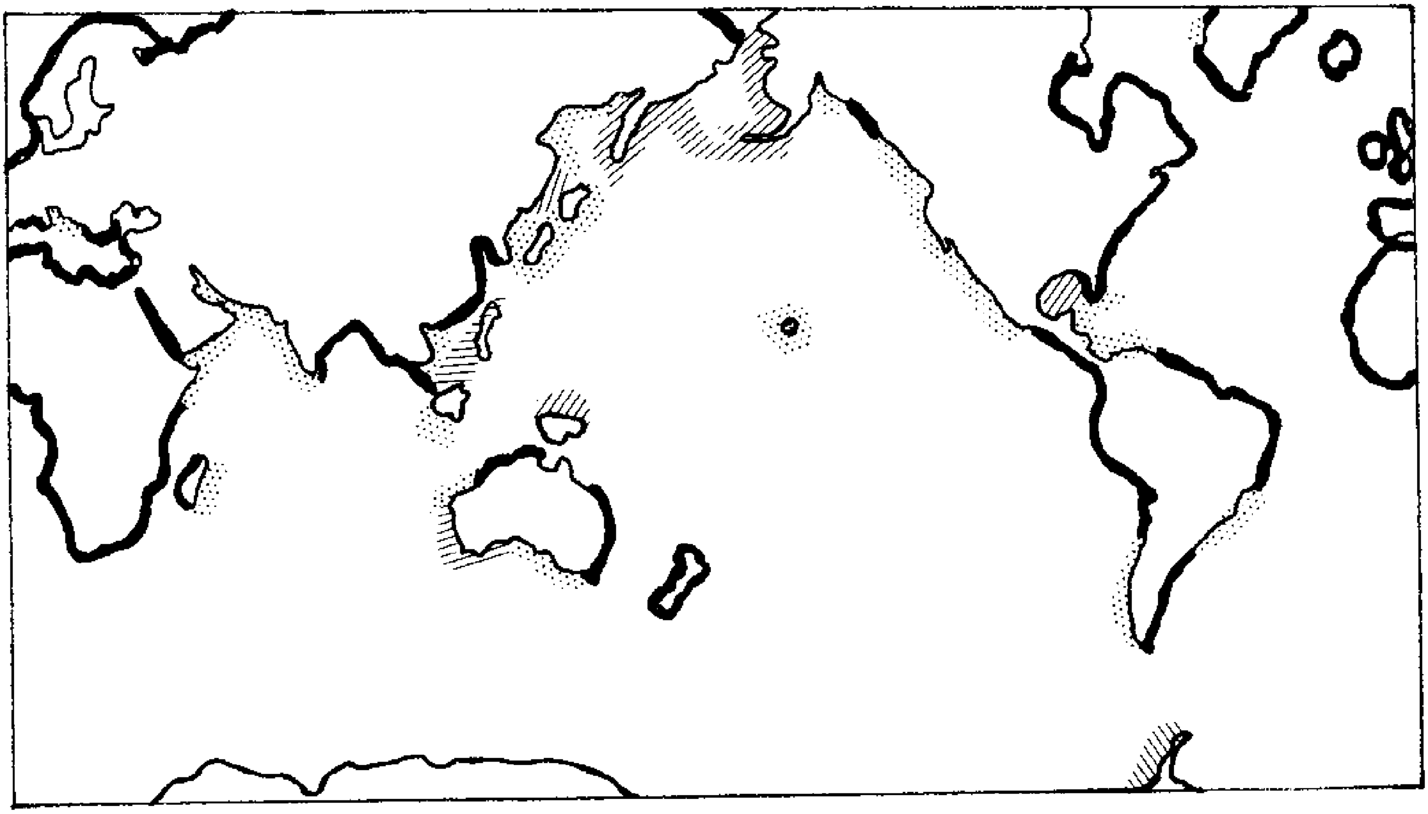


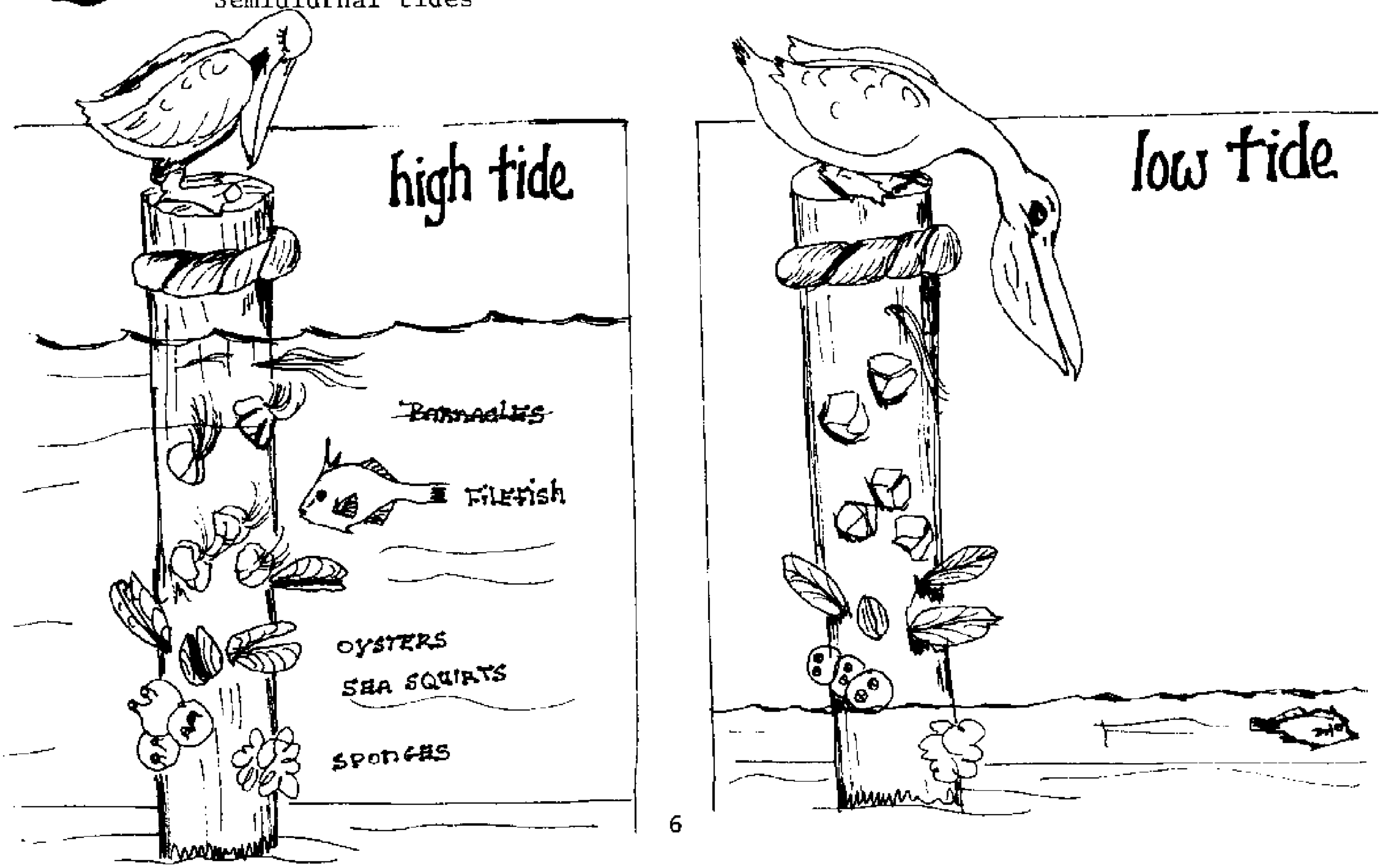
FIGURE 4: Tidal Patterns in the World



||||||||| Diurnal tides

Mixed semidiurnal tides

Semidiurnal tides



## Tidal Patterns

Continents block the westward passage of the tidal bulje and produce complex tidal patterns within each ocean basin. These patterns have been classified into three types. (1) Semidiurnal (semidaily): two high and two low tides each lunar day. Each high and low is similar to the preceeding high or low. This is typical for the Atlantic coast. (2) Diurnal (daily): one high and one low tide each lunar day. This is found at Pensacola, Florida and on the Gulf coast. (3) Mixed: two high and two low tides each day with the successive high tides quite different from each other. This is characteristic of the West coast of the United States. (Figure 4).

## Tide Charts

Tides are predictable because orbit of the earth and moon and slope of ocean basins are predictable. The National Oceanographic and Atmospheric Administration of the United States Department of Commerce publishes tide charts which list predicted time and magnitude of daily tides for many locations on the coast of the United States. These tide tables are available from the United States Government Printing Office in Washington, D.C., and in many nautical shops on the coast.

Tide tables give detailed information on daily tides for specific areas important for shipping. It is possible to calculate tide information for other areas by adding or subtracting correction factors given at the back of the tide book. Hampton Roads (Seawells Pt.), Virginia is a reference point for tide prediction in North Carolina (Table 1a-d, Table 2).

Knowing how to interpret these tables is essential since exact time and magnitude of tides are important for many activities in the coastal regions. Tide tables illustrate the rhythmic nature of tides.

Tide tables give times of high and low tide, as well as the time during which the tide is coming in (flooding tide) or going out (ebbing tide). Heights are measured in reference to a fixed point called "Mean Low Tide." This is the average level of low tides. If a tide height is listed as 2.5, it will be 2.5 feet above mean low tide. The first tide would be high and the second would be low. If a tide is predicted to have a height of -0.3, it will be 0.3 feet below mean low tide. Tide tables are predictions. Natural conditions such as winds and storms can alter heights higher or lower than predicted.

TABLE 1a: HAMPTON ROADS (SEWELLS PT.). VA., 1978
TIMES AND HEIGHTS OF HIGH AND LOW WATERS

### JANUARY

| DAY | TIME h.m. | HT. ft. | DAY | TIME h.m. | HT. ft. |
|---|---|---|---|---|---|
| 1 | 0117 | 2.0 | 16 | 0251 | 2.2 |
| SU | 0722 | 0.0 | M | 0905 | 0.0 |
| | 1332 | 2.1 | | 1505 | 1.9 |
| | 1949 | -0.2 | | 2139 | -0.2 |
| 2 | 0212 | 2.1 | 17 | 0350 | 2.2 |
| M | 0822 | 0.0 | TU | 1007 | 0.1 |
| | 1427 | 2.0 | | 1603 | 1.8 |
| | 2045 | -0.2 | | 2214 | -0.1 |
| 3 | 0313 | 2.2 | 18 | 0447 | 2.2 |
| TU | 0927 | 0.0 | W | 1108 | 0.1 |
| | 1527 | 2.0 | | 1700 | 1.7 |
| | 2145 | -0.3 | | 2308 | -0.1 |
| 4 | 0413 | 2.4 | 19 | 0540 | 2.2 |
| W | 1036 | -0.1 | TH | 1201 | 0.1 |
| | 1634 | 2.0 | | 1756 | 1.8 |
| | 2245 | -0.4 | | | |
| 5 | 0519 | 2.5 | 20 | 0000 | -0.1 |
| TH | 1141 | -0.2 | F | 0630 | 2.3 |
| | 1738 | 2.1 | | 1251 | 0.0 |
| | 2348 | -0.5 | | 1845 | 1.8 |
| 6 | 0620 | 2.7 | 21 | 0046 | -0.2 |
| F | 1243 | -0.4 | SA | 0715 | 2.3 |
| | 1841 | 2.2 | | 1336 | -0.1 |
| | | | | 1931 | 1.9 |
| 7 | 0046 | -0.7 | 22 | 0131 | -0.2 |
| SA | 0718 | 2.9 | SU | 0756 | 2.4 |
| | 1339 | -0.6 | | 1417 | -0.2 |
| | 1939 | 2.3 | | 2013 | 2.0 |
| 8 | 0144 | -0.8 | 23 | 0213 | -0.3 |
| SU | 0811 | 3.0 | M | 0835 | 2.5 |
| | 1435 | -0.7 | | 1456 | -0.3 |
| | 2035 | 2.4 | | 2052 | 2.0 |
| 9 | 0240 | -0.9 | 24 | 0252 | -0.3 |
| M | 0904 | 3.1 | TU | 0911 | 2.5 |
| | 1526 | -0.8 | | 1531 | -0.3 |
| | 2128 | 2.5 | | 2131 | 2.1 |
| 10 | 0333 | -0.9 | 25 | 0330 | -0.3 |
| TU | 0956 | 3.1 | W | 0948 | 2.5 |
| | 1615 | -0.8 | | 1606 | -0.3 |
| | 2219 | 2.6 | | 2205 | 2.1 |
| 11 | 0426 | -0.8 | 26 | 0407 | -0.3 |
| W | 1046 | 2.9 | TH | 1024 | 2.5 |
| | 1704 | -0.8 | | 1640 | -0.3 |
| | 2312 | 2.5 | | 2243 | 2.1 |
| 12 | 0518 | -0.7 | 27 | 0445 | -0.3 |
| TH | 1136 | 2.8 | F | 1057 | 2.4 |
| | 1754 | -0.7 | | 1715 | -0.3 |
| | | | | 2321 | 2.2 |
| 13 | 0003 | 2.5 | 28 | 0525 | -0.2 |
| F | 0613 | -0.5 | SA | 1136 | 2.3 |
| | 1226 | 2.5 | | 1751 | -0.3 |
| | 1842 | -0.5 | | | |
| 14 | 0058 | 2.4 | 29 | 0002 | 2.2 |
| SA | 0709 | -0.3 | SU | 0608 | -0.2 |
| | 1317 | 2.3 | | 1217 | 2.2 |
| | 1932 | -0.4 | | 1832 | -0.3 |
| 15 | 0154 | 2.3 | 30 | 0048 | 2.2 |
| SU | 0805 | -0.1 | M | 0658 | -0.1 |
| | 1409 | 2.1 | | 1303 | 2.1 |
| | 2023 | -0.3 | | 1917 | -0.3 |
| | | | 31 | 0143 | 2.2 |
| | | | TU | 0757 | 0.0 |
| | | | | 1358 | 2.0 |
| | | | | 2012 | -0.3 |

### FEBRUARY

| DAY | TIME h.m. | HT. ft. | DAY | TIME h.m. | HT. ft. |
|---|---|---|---|---|---|
| 1 | 0243 | 2.3 | 16 | 0401 | 2.1 |
| W | 0903 | 0.0 | TH | 1021 | 0.2 |
| | 1502 | 1.9 | | 1617 | 1.7 |
| | 2114 | -0.3 | | 2226 | 0.1 |
| 2 | 0349 | 2.4 | 17 | 0458 | 2.1 |
| TH | 1013 | 0.0 | F | 1121 | 0.2 |
| | 1610 | 1.9 | | 1716 | 1.8 |
| | 2222 | -0.3 | | 2321 | 0.0 |
| 3 | 0458 | 2.5 | 18 | 0553 | 2.2 |
| F | 1123 | -0.1 | SA | 1212 | 0.1 |
| | 1721 | 2.0 | | 1810 | 1.8 |
| | 2329 | -0.4 | | | |
| 4 | 0604 | 2.6 | 19 | 0015 | 0.0 |
| SA | 1226 | -0.3 | SU | 0641 | 2.3 |
| | 1825 | 2.2 | | 1259 | 0.0 |
| | | | | 1859 | 2.0 |
| 5 | 0033 | -0.6 | 20 | 0102 | -0.1 |
| SU | 0703 | 2.8 | M | 0724 | 2.4 |
| | 1324 | -0.5 | | 1344 | -0.1 |
| | 1926 | 2.3 | | 1944 | 2.1 |
| 6 | 0134 | -0.7 | 21 | 0147 | -0.2 |
| M | 0758 | 2.9 | TU | 0806 | 2.5 |
| | 1417 | -0.6 | | 1421 | -0.2 |
| | 2021 | 2.5 | | 2024 | 2.2 |
| 7 | 0229 | -0.8 | 22 | 0227 | -0.3 |
| TU | 0850 | 3.0 | W | 0845 | 2.5 |
| | 1508 | -0.7 | | 1500 | -0.3 |
| | 2114 | 2.6 | | 2102 | 2.3 |
| 8 | 0321 | -0.8 | 23 | 0306 | -0.3 |
| W | 0939 | 2.9 | TH | 0921 | 2.6 |
| | 1555 | -0.7 | | 1534 | -0.3 |
| | 2202 | 2.7 | | 2139 | 2.4 |
| 9 | 0411 | -0.8 | 24 | 0346 | -0.4 |
| TH | 1027 | 2.8 | F | 0959 | 2.5 |
| | 1641 | -0.7 | | 1609 | -0.3 |
| | 2251 | 2.7 | | 2218 | 2.5 |
| 10 | 0502 | -0.7 | 25 | 0427 | -0.4 |
| F | 1112 | 2.7 | SA | 1036 | 2.5 |
| | 1725 | -0.6 | | 1646 | -0.3 |
| | 2339 | 2.6 | | 2257 | 2.5 |
| 11 | 0548 | -0.5 | 26 | 0507 | -0.3 |
| SA | 1157 | 2.5 | SU | 1115 | 2.4 |
| | 1811 | -0.5 | | 1723 | -0.3 |
| | | | | 2339 | 2.5 |
| 12 | 0026 | 2.5 | 27 | 0552 | -0.2 |
| SU | 0639 | -0.3 | M | 1157 | 2.3 |
| | 1244 | 2.3 | | 1805 | -0.3 |
| | 1853 | -0.3 | | | |
| 13 | 0115 | 2.4 | 28 | 0027 | 2.5 |
| M | 0730 | -0.1 | TU | 0642 | -0.1 |
| | 1330 | 2.1 | | 1245 | 2.2 |
| | 1943 | -0.2 | | 1856 | -0.2 |
| 14 | 0207 | 2.2 | | | |
| TU | 0825 | 0.1 | | | |
| | 1422 | 1.9 | | | |
| | 2034 | -0.1 | | | |
| 15 | 0303 | 2.1 | | | |
| W | 0921 | 0.2 | | | |
| | 1518 | 1.8 | | | |
| | 2130 | 0.0 | | | |

### MARCH

| DAY | TIME h.m. | HT. ft. | DAY | TIME h.m. | HT. ft. |
|---|---|---|---|---|---|
| 1 | 0121 | 2.5 | 16 | 0215 | 2.2 |
| W | 0740 | 0.0 | TH | 0833 | 0.3 |
| | 1341 | 2.1 | | 1434 | 1.9 |
| | 1951 | -0.2 | | 2044 | 0.2 |
| 2 | 0223 | 2.5 | 17 | 0310 | 2.1 |
| TH | 0845 | 0.0 | F | 0932 | 0.4 |
| | 1444 | 2.0 | | 1535 | 1.9 |
| | 2057 | -0.1 | | 2143 | 0.3 |
| 3 | 0330 | 2.5 | 18 | 0410 | 2.1 |
| F | 0955 | 0.1 | SA | 1032 | 0.3 |
| | 1557 | 2.0 | | 1634 | 1.9 |
| | 2208 | -0.2 | | 2242 | 0.2 |
| 4 | 0442 | 2.5 | 19 | 0508 | 2.2 |
| SA | 1106 | 0.0 | SU | 1126 | 0.3 |
| | 1708 | 2.1 | | 1732 | 2.0 |
| | 2319 | -0.3 | | 2340 | 0.2 |
| 5 | 0548 | 2.6 | 20 | 0601 | 2.3 |
| SU | 1209 | -0.2 | M | 1217 | 0.2 |
| | 1814 | 2.3 | | 1822 | 2.1 |
| 6 | 0025 | -0.4 | 21 | 0030 | 0.0 |
| M | 0649 | 2.7 | TU | 0649 | 2.4 |
| | 1307 | -0.3 | | 1302 | 0.0 |
| | 1913 | 2.5 | | 1907 | 2.3 |
| 7 | 0123 | -0.5 | 22 | 0116 | -0.1 |
| TU | 0744 | 2.8 | W | 0732 | 2.5 |
| | 1358 | -0.4 | | 1344 | -0.1 |
| | 2005 | 2.7 | | 1950 | 2.5 |
| 8 | 0219 | -0.6 | 23 | 0200 | -0.2 |
| W | 0835 | 2.9 | TH | 0813 | 2.6 |
| | 1446 | -0.5 | | 1422 | -0.2 |
| | 2055 | 2.8 | | 2032 | 2.6 |
| 9 | 0308 | -0.6 | 24 | 0242 | -0.3 |
| TH | 0920 | 2.8 | F | 0853 | 2.6 |
| | 1531 | -0.6 | | 1502 | -0.3 |
| | 2141 | 2.9 | | 2112 | 2.7 |
| 10 | 0355 | -0.6 | 25 | 0325 | -0.4 |
| F | 1005 | 2.8 | SA | 0932 | 2.6 |
| | 1614 | -0.5 | | 1539 | -0.3 |
| | 2226 | 2.8 | | 2153 | 2.8 |
| 11 | 0441 | -0.5 | 26 | 0407 | -0.4 |
| SA | 1049 | 2.6 | SU | 1012 | 2.6 |
| | 1656 | -0.4 | | 1618 | -0.3 |
| | 2310 | 2.8 | | 2235 | 2.9 |
| 12 | 0523 | -0.3 | 27 | 0451 | -0.3 |
| SU | 1130 | 2.5 | M | 1057 | 2.5 |
| | 1736 | -0.3 | | 1701 | -0.3 |
| | 2355 | 2.6 | | 2318 | 2.9 |
| 13 | 0608 | -0.2 | 28 | 0539 | -0.3 |
| M | 1211 | 2.3 | TU | 1142 | 2.4 |
| | 1819 | -0.2 | | 1747 | -0.3 |
| 14 | 0037 | 2.5 | 29 | 0010 | 2.8 |
| TU | 0653 | 0.0 | W | 0629 | -0.1 |
| | 1 55 | 2.1 | | 1232 | 2.3 |
| | 1903 | 0.0 | | 1839 | -0.2 |
| 15 | 0123 | 2.3 | 30 | 0104 | 2.7 |
| W | 0741 | 0.2 | TH | 0727 | 0.0 |
| | 1341 | 2.0 | | 1330 | 2.2 |
| | 1948 | 0.1 | | 1938 | -0.1 |
| | | | 31 | 0207 | 2.6 |
| | | | F | 0831 | 0.1 |
| | | | | 1436 | 2.2 |
| | | | | 2047 | 0.0 |

TABLE 1b: HAMPTON ROADS (SEWELLS PT.), VA., 1978
TIMES AND HEIGHTS OF HIGH AND LOW WATERS

APRIL

| DAY | TIME h.m. | HT. ft. | DAY | TIME h.m. | HT. ft. |
|---|---|---|---|---|---|
| 1 | 0316 | 2.5 | 16 | 0319 | 2.2 |
| SA | 0942 | 0.1 | SU | 0941 | 0.4 |
| | 1548 | 2.2 | | 1551 | 2.0 |
| | 2201 | 0.0 | | 2159 | 0.4 |
| 2 | 0427 | 2.5 | 17 | 0418 | 2.2 |
| SU | 1048 | 0.0 | M | 1037 | 0.3 |
| | 1658 | 2.3 | | 1647 | 2.1 |
| | 2311 | -0.1 | | 2300 | 0.3 |
| 3 | 0533 | 2.6 | 18 | 0514 | 2.3 |
| M | 1150 | -0.1 | TU | 1129 | 0.2 |
| | 1801 | 2.5 | | 1740 | 2.3 |
| | | | | 2353 | 0.1 |
| 4 | 0017 | -0.2 | 19 | 0606 | 2.4 |
| TU | 0633 | 2.6 | W | 1216 | 0.1 |
| | 1246 | -0.2 | | 1830 | 2.5 |
| | 1858 | 2.7 | | | |
| 5 | 0113 | -0.3 | 20 | 0043 | 0.0 |
| W | 0727 | 2.7 | TH | 0652 | 2.5 |
| | 1336 | -0.3 | | 1300 | -0.1 |
| | 1947 | 2.8 | | 1915 | 2.7 |
| 6 | 0205 | -0.4 | 21 | 0132 | -0.2 |
| TH | 0815 | 2.7 | F | 0737 | 2.5 |
| | 1421 | -0.3 | | 1344 | -0.2 |
| | 2035 | 2.9 | | 2000 | 2.9 |
| 7 | 0252 | -0.4 | 22 | 0216 | -0.3 |
| F | 0858 | 2.7 | SA | 0823 | 2.6 |
| | 1503 | -0.3 | | 1427 | -0.3 |
| | 2117 | 3.0 | | 2043 | 3.0 |
| 8 | 0335 | -0.4 | 23 | 0302 | -0.4 |
| SA | 0942 | 2.6 | SU | 0908 | 2.6 |
| | 1544 | -0.3 | | 1510 | -0.4 |
| | 2200 | 2.9 | | 2128 | 3.1 |
| 9 | 0417 | -0.3 | 24 | 0349 | -0.4 |
| SU | 1022 | 2.5 | M | 0951 | 2.6 |
| | 1625 | -0.2 | | 1555 | -0.4 |
| | 2240 | 2.8 | | 2214 | 3.1 |
| 10 | 0458 | -0.2 | 25 | 0437 | -0.4 |
| M | 1102 | 2.4 | TU | 1039 | 2.6 |
| | 1703 | -0.1 | | 1642 | -0.3 |
| | 2321 | 2.7 | | 2303 | 3.1 |
| 11 | 0539 | 0.0 | 26 | 0525 | -0.3 |
| TU | 1140 | 2.3 | W | 1130 | 2.5 |
| | 1742 | 0.0 | | 1733 | -0.3 |
| | | | | 2355 | 3.0 |
| 12 | 0003 | 2.6 | 27 | 0619 | -0.2 |
| W | 0619 | 0.1 | TH | 1224 | 2.4 |
| | 1221 | 2.2 | | 1829 | -0.2 |
| | 1824 | 0.2 | | | |
| 13 | 0044 | 2.4 | 28 | 0053 | 2.8 |
| TH | 0704 | 0.2 | F | 0716 | -0.1 |
| | 1306 | 2.1 | | 1325 | 2.4 |
| | 1909 | 0.3 | | 1932 | 0.0 |
| 14 | 0130 | 2.3 | 29 | 0154 | 2.7 |
| F | 0751 | 0.3 | SA | 0818 | 0.0 |
| | 1357 | 2.0 | | 1430 | 2.4 |
| | 2001 | 0.4 | | 2040 | 0.0 |
| 15 | 0222 | 2.2 | 30 | 0300 | 2.5 |
| SA | 0844 | 0.4 | SU | 0923 | 0.0 |
| | 1453 | 2.0 | | 1538 | 2.4 |
| | 2100 | 0.4 | | 2151 | 0.0 |

MAY

| DAY | TIME h.m. | HT. ft. | DAY | TIME h.m. | HT. ft. |
|---|---|---|---|---|---|
| 1 | 0410 | 2.5 | 16 | 0327 | 2.2 |
| M | 1026 | 0.0 | TU | 0944 | 0.2 |
| | 1644 | 2.5 | | 1603 | 2.2 |
| | 2300 | 0.0 | | 2216 | 0.3 |
| 2 | 0514 | 2.4 | 17 | 0425 | 2.2 |
| TU | 1127 | 0.0 | W | 1039 | 0.1 |
| | 1745 | 2.6 | | 1658 | 2.4 |
| | | | | 2313 | 0.2 |
| 3 | 0004 | -0.1 | 18 | 0521 | 2.3 |
| W | 0614 | 2.5 | TH | 1130 | 0.0 |
| | 1220 | -0.1 | | 1750 | 2.6 |
| | 1838 | 2.8 | | | |
| 4 | 0059 | -0.2 | 19 | 0009 | 0.0 |
| TH | 0705 | 2.5 | F | 0613 | 2.3 |
| | 1310 | -0.2 | | 1219 | -0.1 |
| | 1928 | 2.9 | | 1841 | 2.8 |
| 5 | 0147 | -0.2 | 20 | 0103 | -0.2 |
| F | 0752 | 2.5 | SA | 0705 | 2.4 |
| | 1355 | -0.2 | | 1307 | -0.2 |
| | 2013 | 2.9 | | 1930 | 3.0 |
| 6 | 0233 | -0.3 | 21 | 0152 | -0.3 |
| SA | 0837 | 2.5 | SU | 0754 | 2.5 |
| | 1437 | -0.2 | | 1355 | -0.4 |
| | 2056 | 2.9 | | 2019 | 3.2 |
| 7 | 0315 | -0.2 | 22 | 0241 | -0.4 |
| SU | 0918 | 2.4 | M | 0844 | 2.6 |
| | 1517 | -0.2 | | 1444 | -0.4 |
| | 2134 | 2.9 | | 2107 | 3.2 |
| 8 | 0356 | -0.2 | 23 | 0332 | -0.5 |
| M | 0956 | 2.4 | TU | 0934 | 2.6 |
| | 1556 | -0.1 | | 1535 | -0.5 |
| | 2213 | 2.8 | | 2158 | 3.2 |
| 9 | 0433 | -0.1 | 24 | 0422 | -0.5 |
| TU | 1035 | 2.3 | W | 1025 | 2.6 |
| | 1633 | 0.0 | | 1627 | -0.4 |
| | 2251 | 2.7 | | 2249 | 3.2 |
| 10 | 0512 | 0.0 | 25 | 0513 | -0.5 |
| W | 1115 | 2.2 | TH | 1118 | 2.6 |
| | 1710 | 0.1 | | 1721 | -0.3 |
| | 2328 | 2.6 | | 2342 | 3.0 |
| 11 | 0551 | 0.1 | 26 | 0605 | -0.4 |
| TH | 1155 | 2.2 | F | 1213 | 2.6 |
| | 1752 | 0.2 | | 1819 | -0.2 |
| 12 | 0010 | 2.5 | 27 | 0039 | 2.9 |
| F | 0632 | 0.2 | SA | 0703 | -0.3 |
| | 1237 | 2.1 | | 1314 | 2.5 |
| | 1834 | 0.3 | | 1921 | -0.1 |
| 13 | 0053 | 2.3 | 28 | 0139 | 2.7 |
| SA | 0714 | 0.2 | SU | 0759 | -0.2 |
| | 1322 | 2.1 | | 1417 | 2.5 |
| | 1925 | 0.4 | | 2028 | 0.0 |
| 14 | 0138 | 2.2 | 29 | 0242 | 2.5 |
| SU | 0802 | 0.3 | M | 0900 | -0.1 |
| | 1412 | 2.1 | | 1521 | 2.5 |
| | 2018 | 0.4 | | 2137 | 0.0 |
| 15 | 0230 | 2.2 | 30 | 0346 | 2.4 |
| M | 0852 | 0.3 | TU | 1000 | 0.0 |
| | 1509 | 2.1 | | 1623 | 2.6 |
| | 2116 | 0.4 | | 2244 | 0.0 |
| | | | 31 | 0449 | 2.3 |
| | | | W | 1058 | 0.0 |
| | | | | 1721 | 2.7 |
| | | | | 2345 | 0.0 |

JUNE

| DAY | TIME h.m. | HT. ft. | DAY | TIME h.m. | HT. ft. |
|---|---|---|---|---|---|
| 1 | 0548 | 2.3 | 16 | 0437 | 2.2 |
| TH | 1150 | 0.0 | F | 1044 | 0.0 |
| | 1817 | 2.7 | | 1714 | 2.7 |
| | | | | 2337 | 0.0 |
| 2 | 0040 | 0.0 | 17 | 0537 | 2.2 |
| F | 0641 | 2.3 | SA | 1140 | -0.1 |
| | 1240 | -0.1 | | 1810 | 2.9 |
| | 1904 | 2.8 | | | |
| 3 | 0128 | -0.1 | 18 | 0033 | -0.1 |
| SA | 0727 | 2.3 | SU | 0633 | 2.3 |
| | 1327 | -0.1 | | 1235 | -0.3 |
| | 1950 | 2.8 | | 1905 | 3.1 |
| 4 | 0213 | -0.1 | 19 | 0129 | -0.3 |
| SU | 0813 | 2.3 | M | 0728 | 2.5 |
| | 1408 | -0.1 | | 1331 | -0.4 |
| | 2031 | 2.8 | | 1958 | 3.2 |
| 5 | 0255 | -0.1 | 20 | 0222 | -0.4 |
| M | 0853 | 2.3 | TU | 0824 | 2.6 |
| | 1449 | -0.1 | | 1424 | -0.5 |
| | 2110 | 2.8 | | 2050 | 3.3 |
| 6 | 0332 | -0.1 | 21 | 0315 | -0.5 |
| TU | 0931 | 2.3 | W | 0917 | 2.7 |
| | 1527 | 0.0 | | 1519 | -0.5 |
| | 2148 | 2.7 | | 2141 | 3.3 |
| 7 | 0410 | -0.1 | 22 | 0405 | -0.6 |
| W | 1012 | 2.2 | TH | 1011 | 2.7 |
| | 1606 | 0.0 | | 1613 | -0.5 |
| | 2224 | 2.7 | | 2233 | 3.2 |
| 8 | 0446 | 0.0 | 23 | 0457 | -0.5 |
| TH | 1048 | 2.2 | F | 1104 | 2.7 |
| | 1644 | 0.1 | | 1709 | -0.4 |
| | 2302 | 2.6 | | 2328 | 3.1 |
| 9 | 0523 | 0.0 | 24 | 0549 | -0.5 |
| F | 1128 | 2.2 | SA | 1200 | 2.7 |
| | 1723 | 0.2 | | 1808 | -0.3 |
| | 2339 | 2.5 | | | |
| 10 | 0600 | 0.1 | 25 | 0021 | 2.9 |
| SA | 1207 | 2.2 | SU | 0642 | -0.4 |
| | 1805 | 0.3 | | 1256 | 2.7 |
| | | | | 1908 | -0.2 |
| 11 | 0018 | 2.4 | 26 | 0119 | 2.7 |
| SU | 0640 | 0.1 | M | 0735 | -0.2 |
| | 1249 | 2.1 | | 1356 | 2.7 |
| | 1848 | 0.3 | | 2010 | 0.0 |
| 12 | 0100 | 2.3 | 27 | 0218 | 2.5 |
| M | 0722 | 0.2 | TU | 0831 | -0.1 |
| | 1335 | 2.2 | | 1455 | 2.6 |
| | 1941 | 0.4 | | 2115 | 0.1 |
| 13 | 0148 | 2.2 | 28 | 0318 | 2.3 |
| TU | 0806 | 0.2 | W | 0929 | 0.0 |
| | 1425 | 2.2 | | 1557 | 2.6 |
| | 2037 | 0.3 | | 2220 | 0.1 |
| 14 | 0241 | 2.2 | 29 | 0420 | 2.2 |
| W | 0855 | 0.1 | TH | 1024 | 0.0 |
| | 1523 | 2.3 | | 1655 | 2.6 |
| | 2137 | 0.3 | | 2320 | 0.2 |
| 15 | 0337 | 2.1 | 30 | 0517 | 2.1 |
| TH | 0951 | 0.1 | F | 1120 | 0.1 |
| | 1619 | 2.5 | | 1748 | 2.7 |
| | 2237 | 0.2 | | | |

TABLE 1c: HAMPTON ROADS (SWELLS PT.). VA., 1978
TIMES AND HEIGHTS OF HIGH AND LOW WATERS

## JULY

| DAY | TIME h.m. | HT. ft. | DAY | TIME h.m. | HT. ft. |
|---|---|---|---|---|---|
| 1 | 0015 | 0.1 | 16 | 0505 | 2.2 |
| SA | 0611 | 2.1 | SU | 1113 | -0.1 |
| | 1209 | 0.1 | | 1745 | 3.0 |
| | 1839 | 2.7 | | | |
| 2 | 0105 | 0.1 | 17 | 0012 | 0.0 |
| SU | 0700 | 2.1 | M | 0609 | 2.4 |
| | 1257 | 0.1 | | 1212 | -0.2 |
| | 1923 | 2.7 | | 1843 | 3.1 |
| 3 | 0148 | 0.0 | 18 | 0109 | -0.2 |
| M | 0747 | 2.2 | TU | 0708 | 2.5 |
| | 1342 | 0.0 | | 1313 | -0.3 |
| | 2006 | 2.8 | | 1939 | 3.3 |
| 4 | 0230 | 0.0 | 19 | 0205 | -0.3 |
| TU | 0829 | 2.2 | W | 0805 | 2.7 |
| | 1424 | 0.0 | | 1410 | -0.4 |
| | 2045 | 2.8 | | 2033 | 3.3 |
| 5 | 0309 | 0.0 | 20 | 0256 | -0.5 |
| W | 0908 | 2.3 | TH | 0901 | 2.8 |
| | 1504 | 0.1 | | 1506 | -0.5 |
| | 2123 | 2.7 | | 2126 | 3.3 |
| 6 | 0345 | 0.0 | 21 | 0346 | -0.5 |
| TH | 0947 | 2.3 | F | 0954 | 2.9 |
| | 1543 | 0.1 | | 1601 | -0.5 |
| | 2159 | 2.7 | | 2217 | 3.3 |
| 7 | 0420 | 0.0 | 22 | 0438 | -0.5 |
| F | 1024 | 2.3 | SA | 1047 | 3.0 |
| | 1621 | 0.1 | | 1654 | -0.4 |
| | 2234 | 2.6 | | 2309 | 3.1 |
| 8 | 0454 | 0.0 | 23 | 0526 | -0.4 |
| SA | 1101 | 2.3 | SU | 1139 | 3.0 |
| | 1658 | 0.2 | | 1749 | -0.3 |
| | 2310 | 2.6 | | | |
| 9 | 0530 | 0.0 | 24 | 0001 | 2.9 |
| SU | 1139 | 2.3 | M | 0616 | -0.3 |
| | 1739 | 0.2 | | 1234 | 2.9 |
| | 2346 | 2.5 | | 1847 | -0.1 |
| 10 | 0605 | 0.1 | 25 | 0053 | 2.7 |
| M | 1218 | 2.3 | TU | 0706 | -0.2 |
| | 1821 | 0.3 | | 1327 | 2.8 |
| | | | | 1945 | 0.1 |
| 11 | 0026 | 2.4 | 26 | 0148 | 2.5 |
| TU | 0644 | 0.1 | W | 0759 | 0.0 |
| | 1300 | 2.4 | | 1426 | 2.7 |
| | 1907 | 0.3 | | 2045 | 0.2 |
| 12 | 0112 | 2.3 | 27 | 0245 | 2.3 |
| W | 0725 | 0.1 | TH | 0854 | 0.1 |
| | 1349 | 2.4 | | 1522 | 2.7 |
| | 2002 | 0.3 | | 2146 | 0.3 |
| 13 | 0202 | 2.2 | 28 | 0345 | 2.2 |
| TH | 0814 | 0.1 | F | 0949 | 0.2 |
| | 1444 | 2.5 | | 1623 | 2.6 |
| | 2100 | 0.3 | | 2246 | 0.4 |
| 14 | 0258 | 2.2 | 29 | 0443 | 2.1 |
| F | 0909 | 0.1 | SA | 1045 | 0.3 |
| | 1543 | 2.6 | | 1717 | 2.6 |
| | 2206 | 0.3 | | 2345 | 0.4 |
| 15 | 0400 | 2.2 | 30 | 0540 | 2.1 |
| SA | 1009 | 0.0 | SU | 1140 | 0.3 |
| | 1642 | 2.8 | | 1809 | 2.7 |
| | 2309 | 0.1 | | | |
| | | | 31 | 0035 | 0.3 |
| | | | M | 0631 | 2.2 |
| | | | | 1230 | 0.3 |
| | | | | 1855 | 2.7 |

## AUGUST

| DAY | TIME h.m. | HT. ft. | DAY | TIME h.m. | HT. ft. |
|---|---|---|---|---|---|
| 1 | 0120 | 0.2 | 16 | 0051 | 0.0 |
| TU | 0718 | 2.3 | W | 0654 | 2.7 |
| | 1318 | 0.2 | | 1259 | -0.2 |
| | 1937 | 2.8 | | 1923 | 3.3 |
| 2 | 0200 | 0.2 | 17 | 0145 | -0.2 |
| W | 0800 | 2.3 | TH | 0751 | 2.9 |
| | 1400 | 0.2 | | 1358 | -0.3 |
| | 2019 | 2.8 | | 2017 | 3.4 |
| 3 | 0239 | 0.1 | 18 | 0237 | -0.3 |
| TH | 0841 | 2.4 | F | 0844 | 3.1 |
| | 1440 | 0.2 | | 1453 | -0.4 |
| | 2056 | 2.8 | | 2109 | 3.4 |
| 4 | 0316 | 0.1 | 19 | 0326 | -0.4 |
| F | 0920 | 2.5 | SA | 0936 | 3.2 |
| | 1519 | 0.2 | | 1546 | -0.3 |
| | 2133 | 2.8 | | 2158 | 3.3 |
| 5 | 0351 | 0.0 | 20 | 0413 | -0.4 |
| SA | 0956 | 2.5 | SU | 1027 | 3.3 |
| | 1556 | 0.2 | | 1638 | -0.3 |
| | 2208 | 2.8 | | 2247 | 3.1 |
| 6 | 0424 | 0.1 | 21 | 0459 | -0.3 |
| SU | 1032 | 2.6 | M | 1115 | 3.2 |
| | 1633 | 0.2 | | 1728 | -0.1 |
| | 2242 | 2.7 | | 2334 | 3.0 |
| 7 | 0457 | 0.1 | 22 | 0547 | -0.2 |
| M | 1107 | 2.6 | TU | 1206 | 3.1 |
| | 1712 | 0.2 | | 1820 | 0.1 |
| | 2319 | 2.6 | | | |
| 8 | 0531 | 0.1 | 23 | 0024 | 2.7 |
| TU | 1146 | 2.6 | W | 0632 | 0.0 |
| | 1754 | 0.3 | | 1256 | 3.0 |
| | 2357 | 2.5 | | 1914 | 0.2 |
| 9 | 0608 | 0.1 | 24 | 0114 | 2.5 |
| W | 1228 | 2.7 | TH | 0722 | 0.2 |
| | 1840 | 0.4 | | 1348 | 2.8 |
| | | | | 2010 | 0.4 |
| 10 | 0040 | 2.4 | 25 | 0209 | 2.3 |
| TH | 0651 | 0.2 | F | 0815 | 0.3 |
| | 1317 | 2.7 | | 1443 | 2.7 |
| | 1933 | 0.4 | | 2108 | 0.5 |
| 11 | 0130 | 2.3 | 26 | 0305 | 2.2 |
| F | 0740 | 0.2 | SA | 0910 | 0.5 |
| | 1412 | 2.7 | | 1542 | 2.7 |
| | 2033 | 0.4 | | 2207 | 0.6 |
| 12 | 0228 | 2.3 | 27 | 0407 | 2.2 |
| SA | 0838 | 0.2 | SU | 1009 | 0.5 |
| | 1515 | 2.8 | | 1639 | 2.6 |
| | 2140 | 0.4 | | 2306 | 0.6 |
| 13 | 0335 | 2.3 | 28 | 0505 | 2.2 |
| SU | 0943 | 0.2 | M | 1105 | 0.5 |
| | 1620 | 2.9 | | 1733 | 2.7 |
| | 2248 | 0.3 | | 2358 | 0.5 |
| 14 | 0445 | 2.3 | 29 | 0558 | 2.3 |
| M | 1052 | 0.1 | TU | 1201 | 0.5 |
| | 1724 | 3.0 | | 1822 | 2.7 |
| | 2352 | 0.1 | | | |
| 15 | 0553 | 2.5 | 30 | 0046 | 0.4 |
| TU | 1158 | 0.0 | W | 0649 | 2.4 |
| | 1826 | 3.2 | | 1249 | 0.4 |
| | | | | 1907 | 2.8 |
| | | | 31 | 0126 | 0.3 |
| | | | TH | 0731 | 2.5 |
| | | | | 1332 | 0.3 |
| | | | | 1947 | 2.9 |

## SEPTEMBER

| DAY | TIME h.m. | HT. ft. | DAY | TIME h.m. | HT. ft. |
|---|---|---|---|---|---|
| 1 | 0205 | 0.2 | 16 | 0216 | -0.2 |
| F | 0811 | 2.7 | SA | 0827 | 3.3 |
| | 1413 | 0.3 | | 1441 | -0.2 |
| | 2026 | 2.9 | | 2051 | 3.3 |
| 2 | 0242 | 0.1 | 17 | 0302 | -0.2 |
| SA | 0849 | 2.8 | SU | 0917 | 3.4 |
| | 1454 | 0.2 | | 1531 | -0.2 |
| | 2104 | 2.9 | | 2139 | 3.2 |
| 3 | 0317 | 0.1 | 18 | 0347 | -0.2 |
| SU | 0926 | 2.8 | M | 1003 | 3.4 |
| | 1532 | 0.2 | | 1618 | -0.1 |
| | 2140 | 2.9 | | 2224 | 3.1 |
| 4 | 0350 | 0.1 | 19 | 0430 | -0.2 |
| M | 1003 | 2.9 | TU | 1049 | 3.3 |
| | 1609 | 0.2 | | 1707 | 0.0 |
| | 2215 | 2.8 | | 2308 | 2.9 |
| 5 | 0425 | 0.1 | 20 | 0513 | 0.0 |
| TU | 1038 | 2.9 | W | 1136 | 3.2 |
| | 1649 | 0.2 | | 1754 | 0.2 |
| | 2254 | 2.7 | | 2354 | 2.7 |
| 6 | 0459 | 0.1 | 21 | 0559 | 0.2 |
| W | 1118 | 3.0 | TH | 1221 | 3.0 |
| | 1732 | 0.3 | | 1841 | 0.4 |
| | 2331 | 2.6 | | | |
| 7 | 0539 | 0.2 | 22 | 0040 | 2.5 |
| TH | 1203 | 3.0 | F | 0645 | 0.3 |
| | 1818 | 0.4 | | 1309 | 2.9 |
| | | | | 1932 | 0.5 |
| 8 | 0017 | 2.5 | 23 | 0130 | 2.4 |
| F | 0623 | 0.2 | SA | 0733 | 0.5 |
| | 1252 | 2.9 | | 1402 | 2.7 |
| | 1912 | 0.4 | | 2026 | 0.6 |
| 9 | 0109 | 2.4 | 24 | 0226 | 2.3 |
| SA | 0717 | 0.3 | SU | 0831 | 0.6 |
| | 1349 | 2.9 | | 1457 | 2.6 |
| | 2014 | 0.5 | | 2123 | 0.7 |
| 10 | 0210 | 2.4 | 25 | 0326 | 2.2 |
| SU | 0818 | 0.3 | M | 0927 | 0.7 |
| | 1454 | 2.9 | | 1555 | 2.6 |
| | 2121 | 0.5 | | 2222 | 0.7 |
| 11 | 0321 | 2.4 | 26 | 0426 | 2.3 |
| M | 0927 | 0.3 | TU | 1029 | 0.7 |
| | 1602 | 2.9 | | 1651 | 2.6 |
| | 2231 | 0.4 | | 2316 | 0.6 |
| 12 | 0433 | 2.5 | 27 | 0522 | 2.4 |
| TU | 1039 | 0.3 | W | 1124 | 0.6 |
| | 1709 | 3.0 | | 1743 | 2.7 |
| | 2335 | 0.3 | | | |
| 13 | 0541 | 2.7 | 28 | 0004 | 0.5 |
| W | 1148 | 0.1 | TH | 0612 | 2.5 |
| | 1812 | 3.1 | | 1217 | 0.5 |
| | | | | 1830 | 2.7 |
| 14 | 0033 | 0.1 | 29 | 0047 | 0.3 |
| TH | 0641 | 2.9 | F | 0657 | 2.7 |
| | 1251 | 0.0 | | 1303 | 0.4 |
| | 1909 | 3.2 | | 1913 | 2.8 |
| 15 | 0126 | -0.1 | 30 | 0126 | 0.2 |
| F | 0736 | 3.1 | SA | 0738 | 2.8 |
| | 1347 | -0.1 | | 1347 | 0.3 |
| | 2002 | 3.3 | | 1953 | 2.9 |

TABLE 1d; HAMPTON ROADS (SWELLS PT.), VA., 1978
TIMES AND HEIGHTS OF HIGH AND LOW WATERS

## OCTOBER

| DAY | TIME h.m. | HT. ft. | DAY | TIME h.m. | HT. ft. |
|---|---|---|---|---|---|
| 1 SU | 0205 | 0.1 | 16 M | 0237 | -0.2 |
| | 0816 | 2.9 | | 0857 | 3.4 |
| | 1427 | 0.2 | | 1514 | -0.2 |
| | 2033 | 2.9 | | 2116 | 2.9 |
| 2 M | 0240 | 0.1 | 17 TU | 0320 | -0.2 |
| | 0855 | 3.1 | | 0941 | 3.3 |
| | 1507 | 0.1 | | 1601 | -0.1 |
| | 2110 | 2.9 | | 2200 | 2.8 |
| 3 TU | 0317 | 0.0 | 18 W | 0402 | -0.1 |
| | 0934 | 3.1 | | 1024 | 3.2 |
| | 1548 | 0.1 | | 1643 | 0.0 |
| | 2149 | 2.8 | | 2242 | 2.7 |
| 4 W | 0354 | 0.0 | 19 TH | 0443 | 0.0 |
| | 1012 | 3.2 | | 1106 | 3.1 |
| | 1630 | 0.1 | | 1725 | 0.2 |
| | 2230 | 2.8 | | 2324 | 2.5 |
| 5 TH | 0433 | 0.0 | 20 F | 0525 | 0.2 |
| | 1056 | 3.2 | | 1147 | 2.9 |
| | 1715 | 0.2 | | 1809 | 0.3 |
| | 2312 | 2.7 | | | |
| 6 F | 0515 | 0.1 | 21 SA | 0007 | 2.4 |
| | 1142 | 3.1 | | 0608 | 0.3 |
| | 1803 | 0.2 | | 1232 | 2.8 |
| | | | | 1856 | 0.4 |
| 7 SA | 0002 | 2.6 | 22 SU | 0056 | 2.3 |
| | 0605 | 0.2 | | 0656 | 0.5 |
| | 1233 | 3.1 | | 1319 | 2.6 |
| | 1858 | 0.3 | | 1943 | 0.5 |
| 8 SU | 0056 | 2.5 | 23 M | 0146 | 2.2 |
| | 0701 | 0.3 | | 0746 | 0.6 |
| | 1330 | 3.0 | | 1410 | 2.5 |
| | 1959 | 0.4 | | 2038 | 0.5 |
| 9 M | 0201 | 2.4 | 24 TU | 0244 | 2.2 |
| | 0806 | 0.3 | | 0844 | 0.7 |
| | 1438 | 2.9 | | 1505 | 2.4 |
| | 2105 | 0.4 | | 2131 | 0.5 |
| 10 TU | 0311 | 2.4 | 25 W | 0343 | 2.2 |
| | 0919 | 0.4 | | 0946 | 0.6 |
| | 1547 | 2.9 | | 1602 | 2.4 |
| | 2214 | 0.3 | | 2226 | 0.5 |
| 11 W | 0423 | 2.6 | 26 TH | 0439 | 2.3 |
| | 1033 | 0.3 | | 1045 | 0.6 |
| | 1656 | 2.9 | | 1655 | 2.4 |
| | 2316 | 0.2 | | 2316 | 0.4 |
| 12 TH | 0529 | 2.8 | 27 F | 0532 | 2.4 |
| | 1141 | 0.2 | | 1138 | 0.4 |
| | 1756 | 2.9 | | 1746 | 2.5 |
| 13 F | 0014 | 0.1 | 28 SA | 0003 | 0.2 |
| | 0628 | 3.0 | | 0620 | 2.6 |
| | 1243 | 0.0 | | 1228 | 0.3 |
| | 1852 | 3.0 | | 1833 | 2.6 |
| 14 SA | 0105 | -0.1 | 29 SU | 0045 | 0.1 |
| | 0721 | 3.2 | | 0702 | 2.8 |
| | 1336 | -0.1 | | 1315 | 0.2 |
| | 1944 | 3.0 | | 1918 | 2.6 |
| 15 SU | 0153 | -0.2 | 30 M | 0126 | 0.0 |
| | 0810 | 3.3 | | 0745 | 3.0 |
| | 1427 | -0.2 | | 1400 | 0.0 |
| | 2032 | 3.0 | | 2000 | 2.7 |
| | | | 31 TU | 0205 | -0.1 |
| | | | | 0827 | 3.1 |
| | | | | 1443 | -0.1 |
| | | | | 2043 | 2.7 |

## NOVEMBER

| DAY | TIME h.m. | HT. ft. | DAY | TIME h.m. | HT. ft. |
|---|---|---|---|---|---|
| 1 W | 0247 | -0.2 | 16 TH | 0337 | -0.2 |
| | 0908 | 3.2 | | 1000 | 3.0 |
| | 1527 | -0.1 | | 1619 | -0.1 |
| | 2127 | 2.7 | | 2217 | 2.4 |
| 2 TH | 0329 | -0.2 | 17 F | 0417 | -0.1 |
| | 0951 | 3.3 | | 1037 | 2.9 |
| | 1613 | -0.1 | | 1659 | 0.0 |
| | 2211 | 2.6 | | 2257 | 2.3 |
| 3 F | 0413 | -0.2 | 18 SA | 0457 | 0.0 |
| | 1037 | 3.2 | | 1118 | 2.7 |
| | 1659 | -0.1 | | 1740 | 0.1 |
| | 2258 | 2.6 | | 2339 | 2.2 |
| 4 SA | 0459 | -0.1 | 19 SU | 0536 | 0.2 |
| | 1126 | 3.1 | | 1157 | 2.6 |
| | 1750 | 0.0 | | 1821 | 0.2 |
| | 2351 | 2.5 | | | |
| 5 SU | 0552 | 0.0 | 20 M | 0021 | 2.1 |
| | 1219 | 3.0 | | 0619 | 0.3 |
| | 1845 | 0.0 | | 1239 | 2.4 |
| | | | | 1904 | 0.2 |
| 6 M | 0048 | 2.4 | 21 TU | 0109 | 2.0 |
| | 0652 | 0.1 | | 0706 | 0.4 |
| | 1318 | 2.9 | | 1325 | 2.3 |
| | 1945 | 0.1 | | 1950 | 0.3 |
| 7 TU | 0152 | 2.4 | 22 W | 0202 | 2.0 |
| | 0758 | 0.2 | | 0759 | 0.4 |
| | 1422 | 2.7 | | 1414 | 2.2 |
| | 2049 | 0.1 | | 2041 | 0.3 |
| 8 W | 0303 | 2.4 | 23 TH | 0256 | 2.0 |
| | 0911 | 0.2 | | 0858 | 0.5 |
| | 1529 | 2.6 | | 1509 | 2.2 |
| | 2153 | 0.1 | | 2131 | 0.2 |
| 9 TH | 0411 | 2.5 | 24 F | 0352 | 2.1 |
| | 1023 | 0.2 | | 0957 | 0.4 |
| | 1637 | 2.6 | | 1606 | 2.2 |
| | 2255 | 0.0 | | 2224 | 0.2 |
| 10 F | 0514 | 2.7 | 25 SA | 0445 | 2.3 |
| | 1129 | 0.1 | | 1057 | 0.3 |
| | 1738 | 2.6 | | 1700 | 2.2 |
| | 2350 | -0.1 | | 2313 | 0.0 |
| 11 SA | 0612 | 2.9 | 26 SU | 0537 | 2.5 |
| | 1230 | 0.0 | | 1153 | 0.2 |
| | 1835 | 2.6 | | 1753 | 2.2 |
| 12 SU | 0043 | -0.2 | 27 M | 0002 | -0.1 |
| | 0705 | 3.0 | | 0625 | 2.7 |
| | 1325 | -0.1 | | 1243 | 0.0 |
| | 1924 | 2.6 | | 1843 | 2.3 |
| 13 M | 0128 | -0.2 | 28 TU | 0048 | -0.2 |
| | 0752 | 3.1 | | 0711 | 2.9 |
| | 1413 | -0.2 | | 1331 | -0.2 |
| | 2011 | 2.6 | | 1929 | 2.4 |
| 14 TU | 0214 | -0.3 | 29 W | 0134 | -0.4 |
| | 0836 | 3.1 | | 0800 | 3.0 |
| | 1458 | -0.2 | | 1420 | -0.3 |
| | 2055 | 2.5 | | 2016 | 2.5 |
| 15 W | 0255 | -0.2 | 30 TH | 0220 | -0.5 |
| | 0918 | 3.1 | | 0845 | 3.1 |
| | 1540 | -0.2 | | 1508 | -0.4 |
| | 2137 | 2.5 | | 2106 | 2.5 |

## DECEMBER

| DAY | TIME h.m. | HT. ft. | DAY | TIME h.m. | HT. ft. |
|---|---|---|---|---|---|
| 1 F | 0307 | -0.5 | 16 SA | 0353 | -0.2 |
| | 0933 | 3.2 | | 1014 | 2.6 |
| | 1557 | -0.5 | | 1635 | -0.2 |
| | 2155 | 2.5 | | 2233 | 2.1 |
| 2 SA | 0356 | -0.5 | 17 SU | 0430 | -0.2 |
| | 1022 | 3.2 | | 1049 | 2.5 |
| | 1646 | -0.5 | | 1712 | -0.2 |
| | 2246 | 2.5 | | 2311 | 2.0 |
| 3 SU | 0448 | -0.5 | 18 M | 0509 | -0.1 |
| | 1112 | 3.1 | | 1126 | 2.4 |
| | 1736 | -0.4 | | 1749 | -0.1 |
| | 2339 | 2.4 | | 2352 | 2.0 |
| 4 M | 0544 | -0.4 | 19 TU | 0549 | 0.0 |
| | 1207 | 2.9 | | 1203 | 2.3 |
| | 1831 | -0.3 | | 1827 | -0.1 |
| 5 TU | 0037 | 2.4 | 20 W | 0034 | 2.0 |
| | 0642 | -0.2 | | 0631 | 0.1 |
| | 1304 | 2.7 | | 1245 | 2.2 |
| | 1927 | -0.3 | | 1906 | 0.0 |
| 6 W | 0140 | 2.4 | 21 TH | 0117 | 1.9 |
| | 0748 | -0.1 | | 0717 | 0.2 |
| | 1404 | 2.5 | | 1328 | 2.1 |
| | 2026 | -0.2 | | 1951 | 0.0 |
| 7 TH | 0244 | 2.4 | 22 F | 0208 | 2.0 |
| | 0857 | 0.0 | | 0810 | 0.2 |
| | 1509 | 2.4 | | 1417 | 2.0 |
| | 2129 | -0.2 | | 2039 | 0.0 |
| 8 F | 0352 | 2.4 | 23 SA | 0300 | 2.0 |
| | 1007 | 0.0 | | 0909 | 0.2 |
| | 1615 | 2.2 | | 1513 | 1.9 |
| | 2228 | -0.2 | | 2131 | -0.1 |
| 9 SA | 0455 | 2.5 | 24 SU | 0359 | 2.1 |
| | 1114 | 0.0 | | 1013 | 0.1 |
| | 1716 | 2.2 | | 1611 | 1.9 |
| | 2325 | -0.2 | | 2224 | -0.2 |
| 10 SU | 0553 | 2.6 | 25 M | 0455 | 2.3 |
| | 1214 | -0.1 | | 1113 | 0.0 |
| | 1812 | 2.2 | | 1710 | 2.0 |
| | | | | 2319 | -0.3 |
| 11 M | 0018 | -0.3 | 26 TU | 0550 | 2.5 |
| | 0646 | 2.7 | | 1212 | -0.1 |
| | 1307 | -0.2 | | 1806 | 2.1 |
| | 1903 | 2.2 | | | |
| 12 TU | 0107 | -0.3 | 27 W | 0014 | -0.4 |
| | 0734 | 2.8 | | 0643 | 2.7 |
| | 1354 | -0.2 | | 1305 | -0.3 |
| | 1952 | 2.2 | | 1902 | 2.2 |
| 13 W | 0153 | -0.3 | 28 TH | 0107 | -0.6 |
| | 0817 | 2.8 | | 0737 | 2.9 |
| | 1439 | -0.2 | | 1400 | -0.5 |
| | 2035 | 2.2 | | 1955 | 2.3 |
| 14 TH | 0235 | -0.3 | 29 F | 0200 | -0.7 |
| | 0858 | 2.8 | | 0827 | 3.0 |
| | 1520 | -0.3 | | 1451 | -0.6 |
| | 2115 | 2.2 | | 2048 | 2.4 |
| 15 F | 0314 | -0.3 | 30 SA | 0251 | -0.8 |
| | 0937 | 2.7 | | 0917 | 3.1 |
| | 1558 | -0.2 | | 1539 | -0.7 |
| | 2155 | 2.1 | | 2140 | 2.5 |
| | | | 31 SU | 0344 | -0.8 |
| | | | | 1009 | 3.1 |
| | | | | 1630 | -0.7 |
| | | | | 2233 | 2.5 |

## Table 2 - TIDAL DIFFERENCES AND OTHER CONSTANTS

Use this table to adjust the times and heights of the Hampton Roads to locations in North Carolina.

| PLACE | POSITION | | DIFFERENCES | | | | RANGES | | Mean Tide Level |
|---|---|---|---|---|---|---|---|---|---|
| | Lat. | Long. | Time | | Height | | Mean | Spring | |
| | | | High water | Low water | High water | Low water | | | |
| | ° ′ | ° ′ | h. m. | h. m. | feet | feet | feet | feet | feet |
| **NORTH CAROLINA, Outer Coast** | | | | | | | | | |
| Currituck Beach Light | 36 23 | 75 50 | -1 50 | -1 50 | +1.1 | 0.0 | 3.6 | 4.3 | 1.8 |
| Albemarle and Pamlico Sounds† | ----- | ----- | ----- | ----- | ----- | ----- | ---- | ---- | ---- |
| Kitty Hawk (Ocean) | 36 06 | 75 43 | -1 54 | -1 54 | +0.7 | 0.0 | 3.2 | 3.8 | 1.6 |
| Oregon Inlet | 35 46 | 75 32 | -1 17 | -1 12 | -0.5 | 0.0 | 2.0 | 2.4 | 1.0 |
| Cape Hatteras | 35 14 | 75 31 | -1 58 | -2 10 | +1.1 | 0.0 | 3.6 | 4.3 | 1.8 |
| Hatteras (Ocean) | 35 12 | 75 42 | -2 06 | -2 10 | +0.9 | 0.0 | 3.4 | 4.1 | 1.7 |
| Hatteras Inlet | 35 12 | 75 44 | -1 43 | -1 44 | -0.5 | 0.0 | 2.0 | 2.4 | 1.0 |
| Ocracoke Inlet | 35 04 | 76 01 | -1 42 | -1 46 | -0.6 | 0.0 | 1.9 | 2.3 | 0.9 |
| Ocracoke, Ocracoke Inlet | 35 07 | 75 59 | -1 27 | -1 05 | *0.40 | *0.40 | 1.0 | 1.2 | 0.5 |
| Cape Lookout | 34 37 | 76 32 | -2 08 | -2 18 | +1.2 | 0.0 | 3.7 | 4.4 | 1.9 |
| Shell Point, Harkers Island | 34 41 | 76 32 | +0 08 | +0 40 | -1.2 | 0.0 | 1.3 | 1.6 | 0.6 |
| Beaufort (Pivers Island) | 34 43 | 76 40 | -1 05 | -1 14 | +0.5 | 0.0 | 3.0 | 3.6 | 1.5 |
| Morehead City | 34 43 | 76 42 | -1 02 | -1 10 | +0.4 | 0.0 | 2.9 | 3.5 | 1.4 |
| Atlantic Beach | 34 42 | 76 43 | -2 06 | -2 08 | +1.1 | 0.0 | 3.6 | 4.3 | 1.8 |
| Bogue Inlet | 34 39 | 77 06 | -1 38 | -1 42 | -0.3 | 0.0 | 2.2 | 2.6 | 1.1 |
| New River Inlet | 34 32 | 77 20 | -1 35 | -1 40 | +0.5 | 0.0 | 3.0 | 3.6 | 1.5 |
| New Topsail Inlet | 34 22 | 77 38 | -1 31 | -0 57 | +0.5 | 0.0 | 3.0 | 3.5 | 1.5 |
| | | | on CHARLESTON, p.96 | | | | | | |
| Masonboro Inlet | 34 11 | 77 49 | -0 14 | +0 05 | -1.4 | 0.0 | 3.8 | 4.5 | 1.9 |
| Wilmington Beach | 34 02 | 77 54 | -0 48 | -0 38 | -1.2 | 0.0 | 4.0 | 4.7 | 2.0 |
| Cape Fear | 33 51 | 77 58 | -0 33 | -0 28 | -0.7 | 0.0 | 4.5 | 5.1 | 2.2 |
| *Cape Fear River* | | | | | | | | | |
| Bald Head | 33 52 | 78 00 | -0 17 | -0 11 | -0.9 | 0.0 | 4.3 | 4.9 | 2.2 |
| Fort Caswell | 33 54 | 78 01 | -0 12 | -0 05 | -1.0 | 0.0 | 4.2 | 4.8 | 2.1 |
| Southport | 33 55 | 78 01 | 0 00 | +0 11 | -1.1 | 0.0 | 4.1 | 4.6 | 2.0 |
| Reaves Point | 34 00 | 77 57 | +0 15 | +0 45 | -1.3 | 0.0 | 3.9 | 4.3 | 2.0 |
| | | | on WILMINGTON, p.92 | | | | | | |
| Campbell Island | 34 07 | 77 56 | -0 49 | -0 44 | -0.4 | 0.0 | 3.8 | 4.0 | 1.9 |
| WILMINGTON | 34 14 | 77 57 | Daily predictions | | | | 4.2 | 4.5 | 2.1 |
| Castle Hayne, Northeast River | 34 21 | 77 56 | +2 40 | +2 55 | *0.40 | *0.40 | 1.7 | 1.9 | 0.8 |
| Bannermans Br., Northeast River | 34 35 | 77 46 | +5 54 | +6 09 | *0.31 | *0.31 | 1.3 | 1.4 | 0.6 |
| Yaupon Beach | 33 54 | 78 05 | -0 39 | -0 49 | -0.3 | 0.0 | 4.9 | 5.8 | 2.4 |
| Lockwoods Folly Inlet | 33 55 | 78 14 | -0 29 | -0 12 | -1.0 | 0.0 | 4.2 | 4.8 | 2.1 |
| Shallotte Inlet (Bowen Point) | 33 55 | 78 22 | +0 10 | +0 26 | -0.6 | 0.0 | 4.6 | 5.4 | 2.3 |
| Tubbs Inlet | 33 53 | 78 29 | -0 19 | -0 12 | -0.7 | 0.0 | 4.5 | 5.1 | 2.2 |

*Ratio.

†In Albemarle and Pamlico Sounds, except near the inlets, the periodic tide has a mean range less than one-half foot.

b. Vocabulary

Apogee - the point in an elliptical orbit where the orbiting object is at the greatest distance from the object being orbited.

Contrifugal force - outward force exerted by a revolving body away from the center of revolution.

Diurnal tides - a tidal cycle of one high and one low tide about every 24 hours and 50 minutes, one lunar day.

Ebb tide - the tide associated with the decreasing height of the tidal cycle, the outgoing tide.

Flood tide - the tide associated with the increasing height of the tidal cycle, the incoming tide.

Gravity - the attractive force which masses exert on each other.

Lunar day - the amount of time it takes the earth to rotate so that the same spot on the earth is lined up with the moon before and after the rotation, about 24 hours and 50 minutes.

Mean low tide - the average height of the water at low tide.

Neap tides - tides that have the least variation of water level between high and low. Neap tides occur when the sun, earth and moon form a right (90 degree) angle with each other i.e. when the moon is in its quarters.

Perigee - the point in an elliptical orbit where the orbiting object is at the least distance from the object being orbited.

Semidiurnal tides - a tidal cycle of two high and two low tides about every 24 hours and fifty (50) minutes, a lunar day. There is little difference in the magnitude of two successive high and low tides.

Slack tide - the state of the tide when tidal current velocity is near zero.

Spring tides - tides that have the greatest variation of water level. Spring tides occur when the sun, moon, and earth form a straight line, with a full or new moon.

Tidal currents - movements of water in response to the tides.

Intertidal zone - that part of a coastline that is underwater at high tide and exposed at low tide.

Mixed tides - semidiurnal tides that have a difference in the magnitude of successive high and low tides.

c. Things to Do

How Does the Moon Affect the Water

1. Objective: To demonstrate the pull of the moon on the waters of the earth.

2. Teacher Preparation: Choose students to represent the earth, the moon, and about 7-10 to represent the world ocean.

3. Procedure:

1. Place student "earth" in the middle of the circle of hand-holding students representing the world ocean.

2. Student "moon" is to move slowly about the outside of the circle. As he moves, the circular ring of students should become ellipical with "earth" and one side moving to him, leaving opposite children away from "earth" The teacher may try to point out that the students at the sides of the ring are the closest and that the students at the part of the ring away from moon have been separated from the earth, as the earth is also being pulled by the moon and its centrefugal force is spinning water away from its surface. Thus high tides at opposite sides and low tides at opposite sides.)

3. Have the students not involved in the action explain where low and high tide would be.

4. Discussion:

1. Discuss the ways that the moon affects the waters. Could the pull of the moon affect animals or plants? (Yes, egg laying of turtles and grunions relate to spring tides of full moon.)

2. Discuss how the amount of pull would change if the moon were further from the earth. (Much less pull, therefore tidal range would be less.)

c. Things to Do

## Demonstration of How Tides are Formed

1. Objective: To demonstrate how the pull of gravity of the moon and sun cause the tides in the ocean basins of earth.

2. Teacher Preparation: Collect small glass jar with top; iron filings; two magnets (one preferable larger than the other)

3. Procedure: Place iron filings in glass jar and screw on the top. Place the two magnets in different positions around the jar to simulate the moon and sun. The larger magnet should represent the sun, but should be farther away. As the magnets are rotated about, the iron filings (representing sea water) should respond to the pull of gravity and should move accordingly in the glass jar. Be sure to point out the connection between magnets and filings and the tidal cycle.

4. Discussion:
   1. What do the iron filings represent? (water)
   2. What does the pull of the magnets represent? (gravitational pull of moon and sun)
   3. Why does the smaller magnet cause more attraction of iron filings? (closer)
   4. What happens when the magnets are in line on the same side of the jar? What happens on the opposite side. (more pull -- again, more pull)

c. Things To Do

## How the Sun and Moon Affect Tides

1. Objective: To demonstrate the pull of the sun and the moon on the earth's waters.

2. Teacher Preparation: For each group, have the following things: small world globe (the earth); small ball (the moon); large ball (the sun); two pieces of string, one long and one short; a large rubber band.

3. Procedure:

   1. Tie the pieces of string to the opposite ends of the rubber band. Tie the short piece of string to the small ball. Put the rubber band around the globe. Tie the long string around the large ball.

   2. Have one student hold the small ball and another student hold the large ball. First pull the small ball (moon) away from the globe. Observe what happens.

   3. Now pull the large ball (sun) away from the globe. Observe what happens.

4. Discussion:

   1. What do the strings represent? (gravitational pull)

   2. What does the rubber band represent? (water)

   3. What happens to the ocean when the moon is pulled away? (bulges)

   4. How many high and low tides are there? (2 of each)

   5. What causes low tides? (reduction of water as it is being pulled to high tide direction)

   6. Which tide is higher, the one on the side of the moon or the one on the side of the sun? Why? (moon, more pull)

   7. Which has the least effect on ocean water, the moon or the sun? (sun, further away)

   8. Can the sun cause tides? (yes, but much less, 1/12, attraction of moon)

c. Things To Do

## The 24-Hour Clock

1. Objective: 1. To be able to understand time using the 24-hour clock and read tide table times.

   2. To be able to express time in 24-hour and 12-hour clock time.

2. Teacher Preparation: Present the information given below to the class. The exercises for expressing time could be written on the board or on separate sheets.

   Times on tide charts are given in four digits and are based on the 24-hour clock. This way of telling time is slightly different from the one you are used to but it is as easy to use once you become familiar with it. The exercises below will help you become familiar with the 24-hour clock.

   The 24-hour clock begins with midnight which is 0000 (zero hundred hours) and runs through noon which is written 1200 (twelve hundred hours) and continues until the next midnight when it begins again. Below is a table which shows our clock on the left and the same time on the 24-hour clock on the right.

3. Procedure: 1. Review the information on 24-hour time, also called military or nautical time.

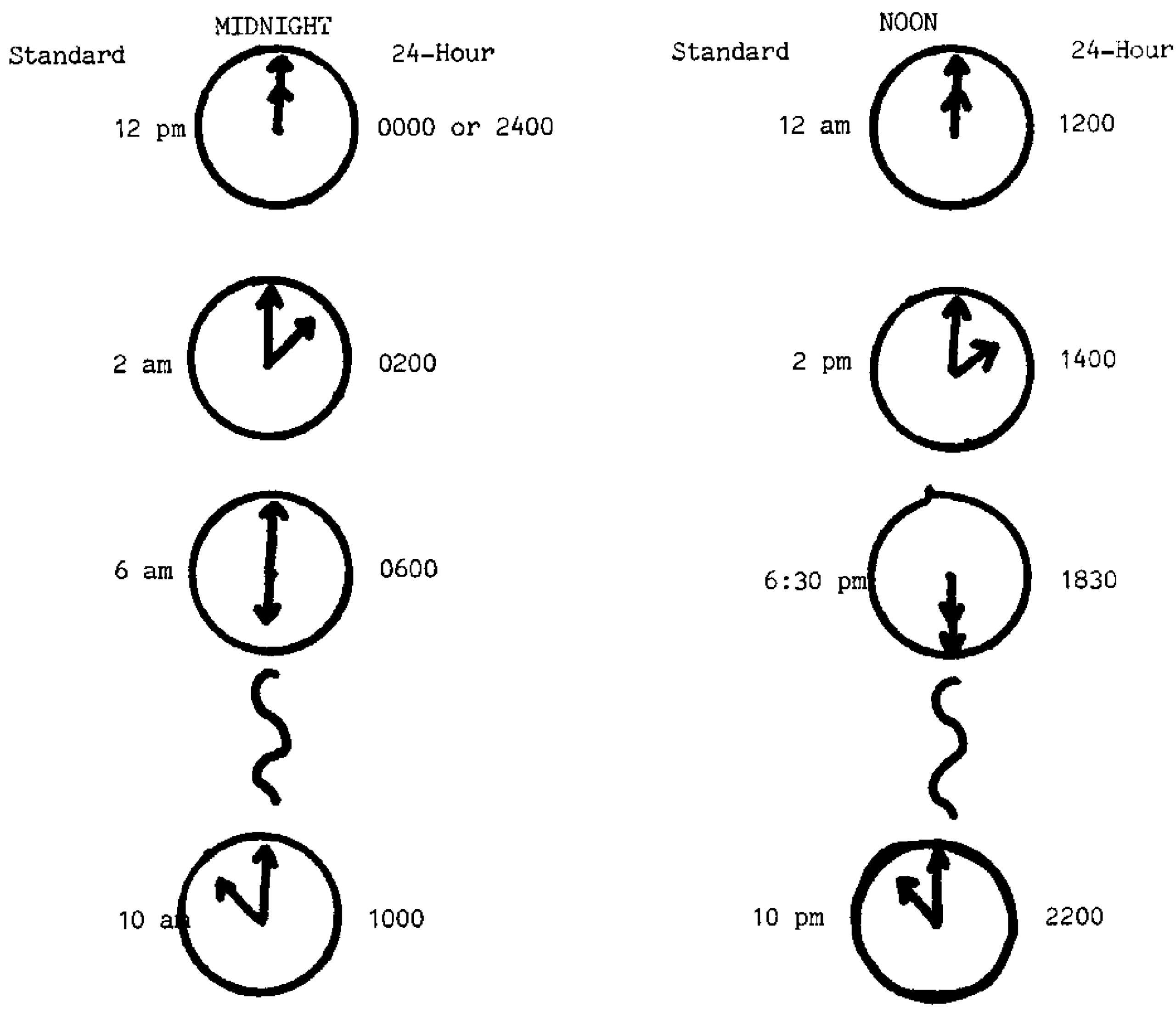
   2. Fill in the following times:

| Change to Standard 12-hour time | Change to Military Time |
|---|---|
| a. 0035 | a. 12:06 p.m. |
| b. 1812 | b. 6:30 a.m. |
| c. 0303 | c. 9:00 p.m. |
| d. 2323 | d. 11:30 a.m. |
| e. 0000 | e. Midnight |

4. Discussion: 1. Discuss the advantages of using the 24-hour clock at sea or in scientific experiments. (no confusing times over 24 hour basis)

   2. What types of work could use the 24-hour clock to advantage? (shift work in factories, military, navigation, international communication)

COMPARISON OF THE 24-HOUR CLOCK AND THE STANDARD CLOCK TIMES



c. Things To Do

## Making a Tide Chart

1. Objectives: 1. To read a tide table, to identify three tidal curves, to determine tidal range, and to plot a tidal curve.

2. Teacher Preparation: Prepare sufficient tide charts (Figure 5) for each student

3. Procedure: 1. Using the tide table, plot tidal highs and lows for four days (the first day is completed)

   2. Answer the following questions after having connected consecutive points to form a tidal curve.

      a. When does the highest tide occur and how high is it? (Day 3, 7 ft.)

      b. When does the lowest tide occur and how high is it? (Day 3, 0 ft.)

      c. Which would be the better time to look for drift wood on the beach - Monday morning or Monday afternoon? Why? (afternoon at low tide; more drift left behind)

      d. Which would be a better time to go surfing - Monday afternoon or Wednesday afternoon? Why? (Wednesday afternoon; usually higher waves on an incoming (flooding) tide)

      e. During which day is the tide diurnal? (Day 3)

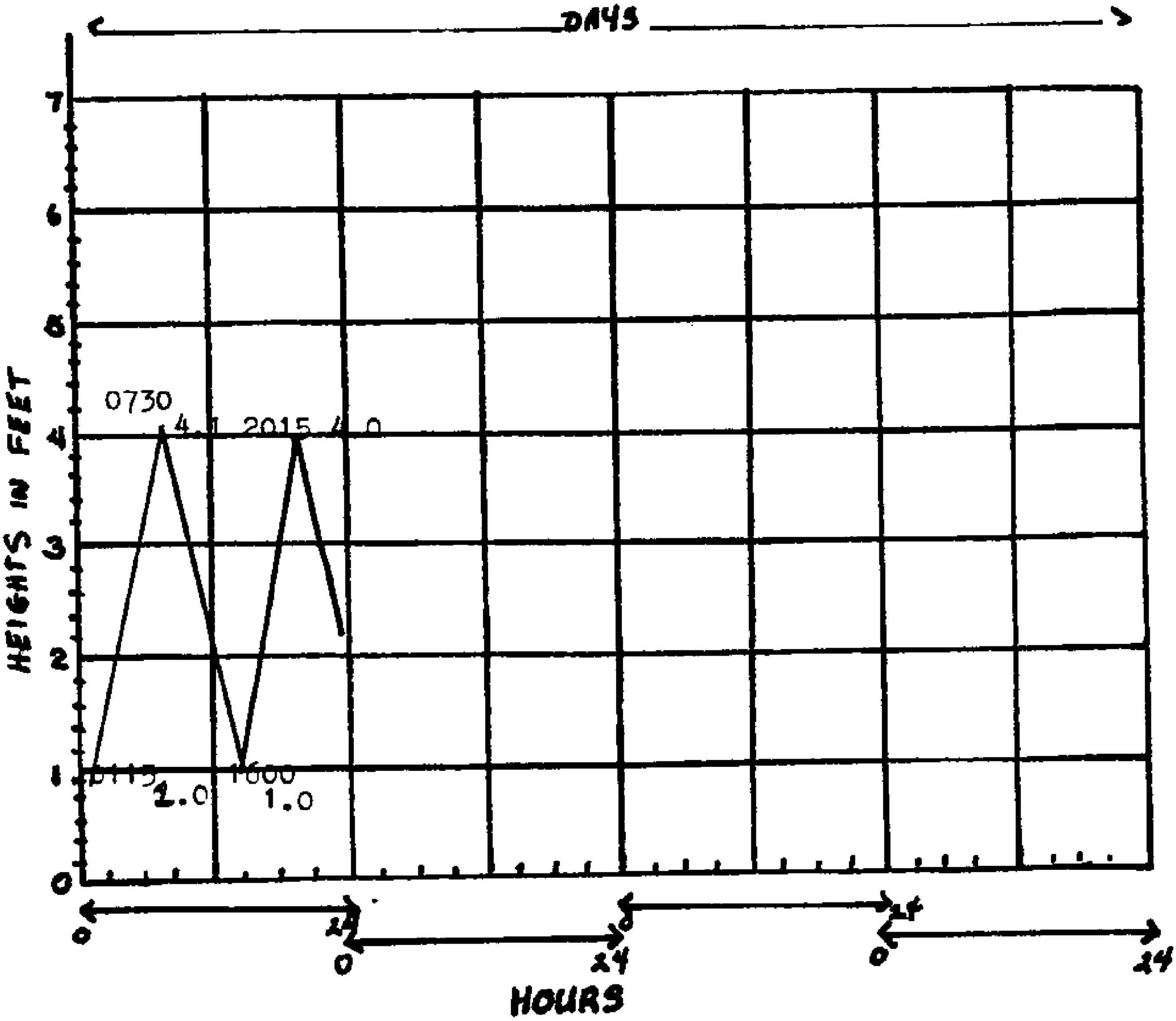
      f. During which day is the tide semidiurnal? (Day 1, Day 4)

      g. During which day is the tide mixed? (Day 2)

      h. During which day is the range the greatest? the smallest? (Day 3, 7 ft.; Day 4, 1.9 ft.)

      i. During which day is the largest diurnal inequality (difference between consecutive high or low tides)? How much is it? (Tuesday, Day 2, 1.5 ft. at high tides)

FIGURE 5:




| Day | Time | | Height |
|---|---|---|---|
| | Hours | Minutes | Feet |
| Mon. | 01 | 15 | 1.0 |
| 1 | 07 | 30 | 4.1 |
| | 16 | 00 | 1.0 |
| | 20 | 15 | 4.0 |
| Tue. | 02 | 00 | 1.0 |
| 2 | 08 | 30 | 6.5 |
| | 14 | 15 | 2.0 |
| | 21 | 00 | 5.0 |
| Wed. | 04 | 15 | 0.0 |
| 3 | 16 | 00 | 7.0 |
| Thur. | 04 | 30 | 1.0 |
| 4 | 10 | 00 | 3.0 |
| | 16 | 00 | 1.0 |
| | 22 | 00 | 2.9 |

C. Things To Do

Plotting Tidal Curves for North Carolina

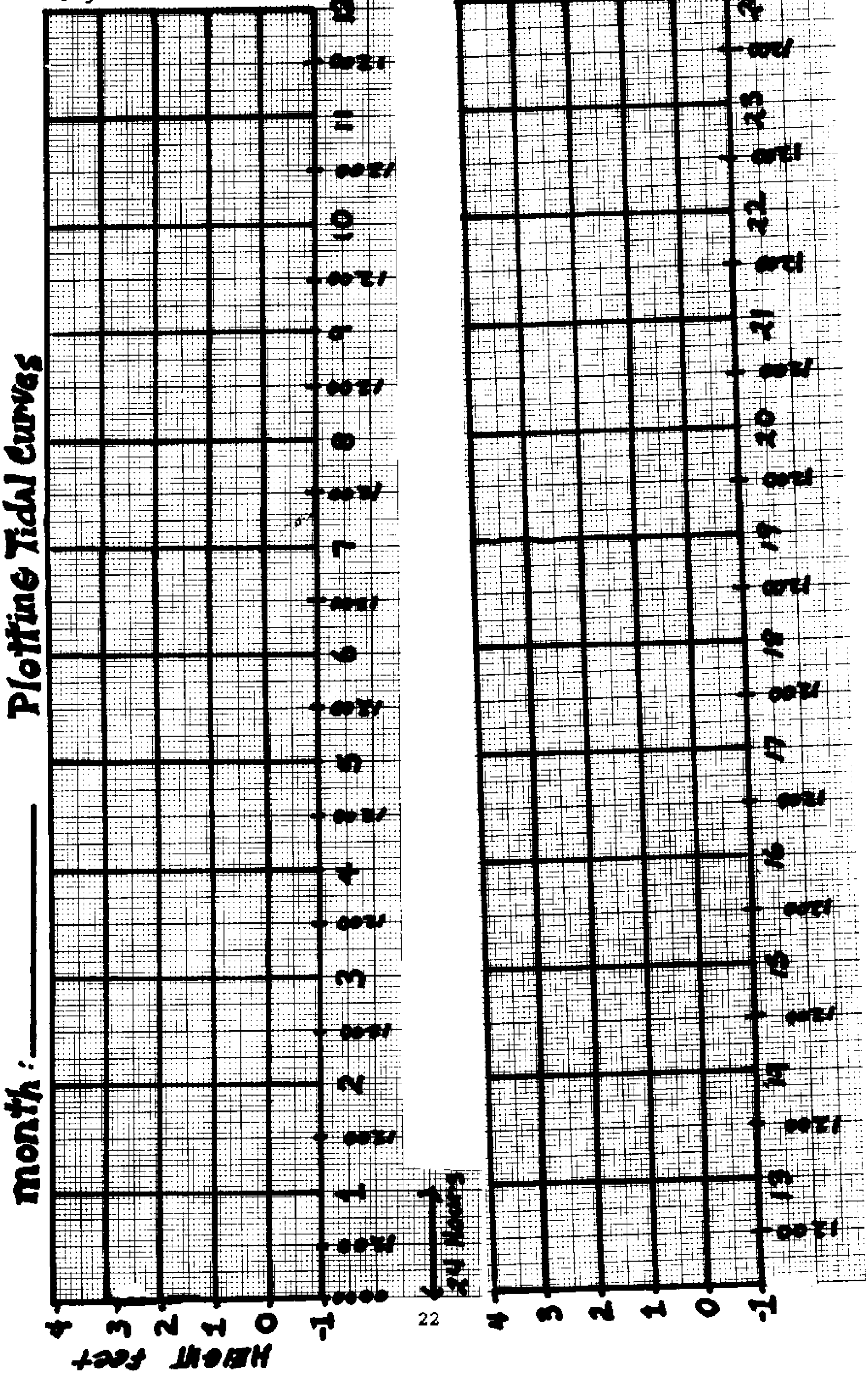
1. Objectives:
   1. To be able to plot tidal curves from a tide chart, to determine tidal ranges, to identify spring and neap tides, and to identify the type of tidal curves.

2. Teacher Preparation:
   1. Each student should have a tide chart of North Carolina's coast (Table 1. 1978). Use the Hampton Road chart for brevity or you could calculate for NC locations. Specific times and heights can be calculated from the table.
   2. Either prepare a graph on graph paper or provide each student with a graph in Figure 6.

3. Procedure:
   1. Choose one month (preferable a winter month) and plot the tidal high and low point for each day for at least 20 days.
   2. When the chart is completed, draw lines connecting the high and low tides (Figure 3). You should now be able to answer the following questions:
      a. What is the greatest tidal range (widest space)?
      b. What is the smallest tidal range (narrowest space)?
      c. During which time of the month is there neap tide?
      d. During which time of the month is there spring tide?

4. Discussion:
   1. From the graph, what type of tide does North Carolina have?
   2. Compare North Carolina to other locations given in the curves below. Discuss what factors might cause tidal ranges to increase. Locate Savannah on a map, note that it is in the middle of a great cusp or curve. How might this affect the incoming tidal bulge? (funnel-effect, greater tidal range)

Fig. 6 Student Chart



c. Things To Do

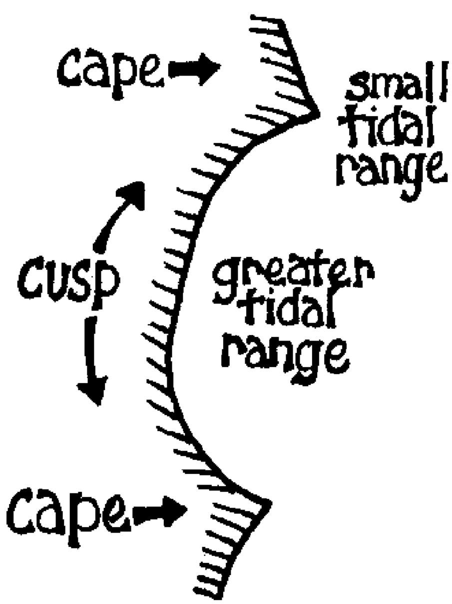
<u>What Makes the Tides at the Bay of Fundy so Great?</u>

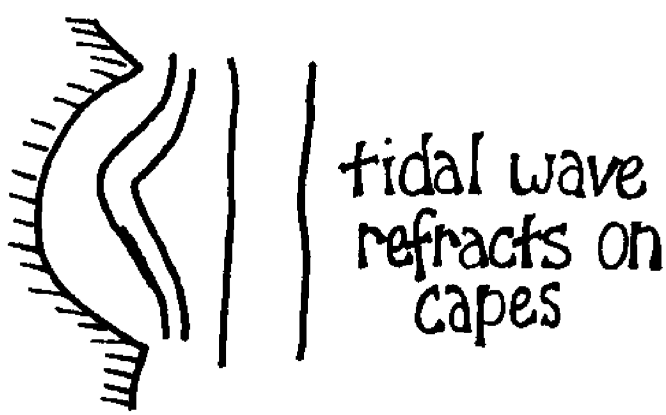
1. Objective: To simulate the land forms which tend to accentuate the tidal range.

2. Teacher Preparation:
   1. Read about tides in Bay of Fundy, Nova Scotia or see movie "Ocean Tides -- Bay of Fundy" NOAA
   2. Stream table or pan with sides,
   3. Rocks or clay to form the shorelines,
   4. Board to act as a wave maker, and
   5. Centimeter ruler or 6" ruler

3. Procedure:
   1. Set up wave tank or stream as shown in the diagram
   2. Use colored water (ink dyed) to facilitate reading the heights of the waves.
   3. Make a slow series of waves (tidal bulges). Record the height of the waves at the entrance of the funnel shoreline and at the end of the funnel.
   4. Try to determine the bending of the waves to understand the change in wave height.

4. Discussion: To apply this simulation, look at the coastline of the eastern USA. Look at the curved cusps, with horns or capes at the points. Predict what the tidal ranges might be at the capes and at the center of the cusps. Look at the tidal ranges in a Tide Table. Discuss the reasons for the differences in tidal ranges.



c. Things To Do

## Determining Tidal Range

1. Objectives: To be able to read a tide graph, to determine tidal ranges, and recognize spring and neap tides.

2. Teacher Preparation: Reproduce figure 7 showing tidal curves for different locations. Review definitions, tide curves, and ranges.

3. Procedure: 1. Name the type of tide (semi-diurnal, diurnal, mixed) for each city.

| Location | Type | Range | Day Neap Tide | Day Spring Tide |
|---|---|---|---|---|
| Boston | | | | |
| New York | | | | |
| Hampton Roads | | | | |
| Savannah River | | | | |
| Pensacola | | | | |
| Galveston | | | | |

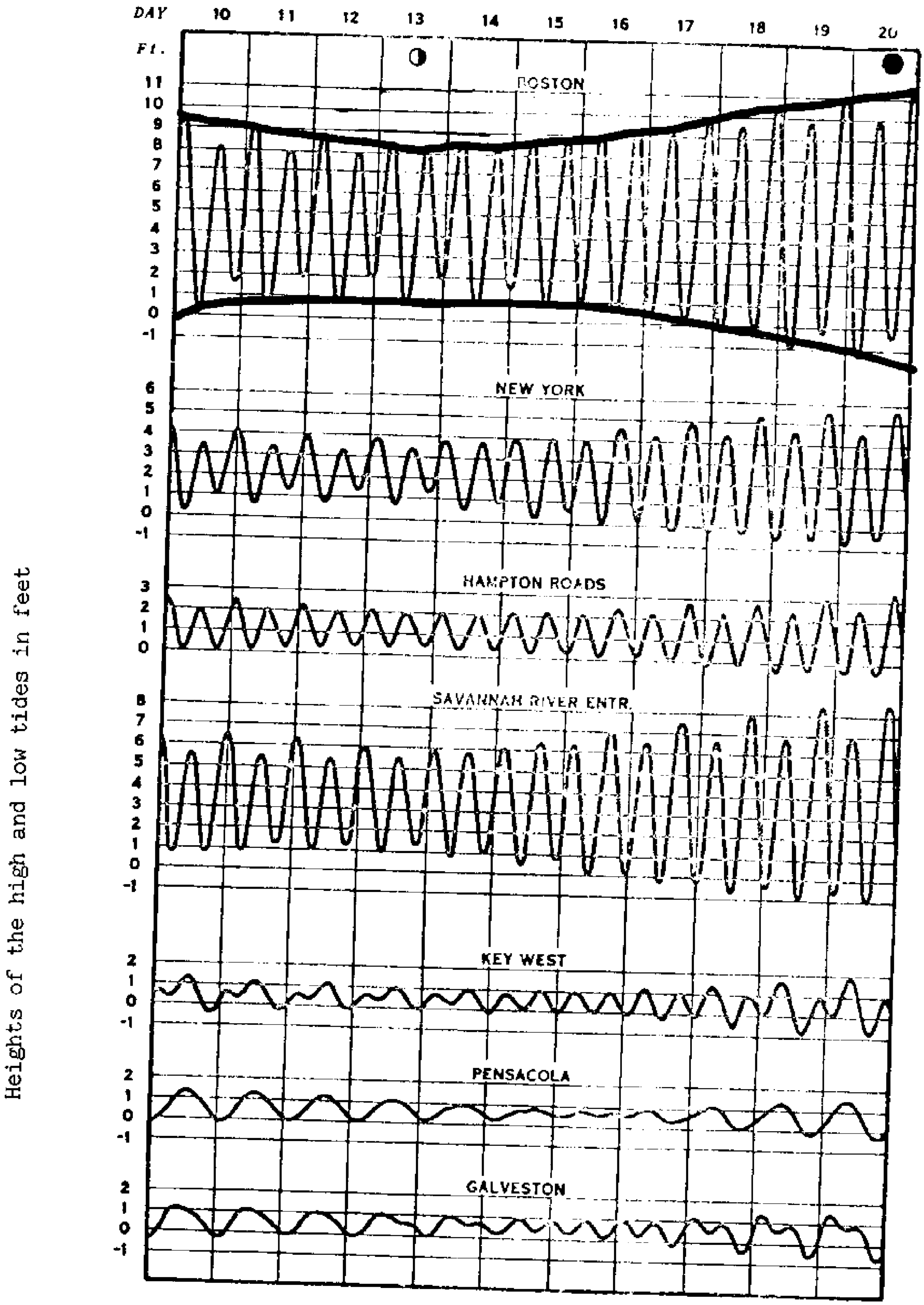
2. Give the greatest tidal range difference between consecutive high and low tides.

3. Using your pencil, connect the highest high tides and the lowest tides for each graph. Give the days for the neap (narrow) and spring (wide) for each location.

4. Discussion: 1. Which location has the greatest tidal range? (Boston)

2. What is the relation between neap/spring tides and phase of the moon? (Spring tides at full and new moon; neap tides at 1st and 3rd quarter)

## COMPARISON OF TIDAL CURVES IN ATLANTIC AND GULF OF MEXICO LOCATIONS




SYMBOL

◐ Moon in last quarter

● Moon --new

d. Resources to Use

Printed Material

1. Coker, R.E. 1954. This Great and Wide Sea. Harper and Row, New York. Ch. 11, Sea Water in Motion: Tides and Other Movements., pp. 146-159.

2. Gross, M.G. 1972. Oceanography - A View of the Earth. Prentice-Hall, Inc., Englewood, NJ. Ch. 10, Tides and Tidal Currents, pp. 207-293.

3. Chapman, F. The Sea and its Boundaries. Carteret Regional Marine Science Project, pp. 3-14.

4. Engel, L. 1969. The Sea. Time-Life Books, NY. Ch. 5, Waves and Tides, pp. 87-92.

5. Dean, A. 1970. Exploring and Understanding Oceanography. Benefic Press, 96 pp (lower and upper intermediate).

6. Epstein, S. and B. Epstein. 1961. The First Book of the Ocean. Franklin Watts, Inc., 70 pp (upper intermediate).

7. Brindze, R. 1964. The Rise and Fall of the Seas: The Study of Tides. Harcourt, Brace and World, Inc., 91 pp. (upper intermediate - middle school).

8. Tide Tables. 1978. East Coast of North and South America. National Ocean Survey, Rockville, Maryland 20852. $2.00.

9. Our Restless Tides. NOAA. Nat. Ocean Survey. Free pamphlet.

10. Project COAST. The Moon, the Sun and Tides. #214, $1.30.

Films

1. "Tides of the Ocean." Movie, 16½ min., color, Paramount-Oxford. Explains causes of tides, phenomena associated with tides. Good.

2. "Oceanography - Understanding our Deep Frontier." 8 sound filmstrips. National Academy of Science, D.C. Physical Oceanography.

3. "Understanding Oceanography" 5 sound filmstrips. Society for Visual Education, Inc., "Currents, Waves and Tides".

4. "Ocean Tides - Bay of Fundy" 20 min., NOAA. Outdated, but interesting.

5. <u>Sea Patterns, Sea Cycles</u>, "Rhythm of Tides", Cypress Publishing Co., 1763 Gardens Ave., Glendale, CA 91204.

Unit II. Physical and Chemical Effects on the Marine Environment
Waves

Concept 2. Waves are ocean phenomena and affect the surface and the shore.

a. Introduction

The rhythmic pounding of the surf against the beach, the gentle lapping of ripples in a tidal creek, and the rolling of swells in the open ocean are waves. Most of the waves we experience on North Carolina's shores are wind waves, i.e., they are generated by friction created by wind blowing over the water surface. Other types of waves are the tsunamis - very long waves produced by seismic disturbance, and internal waves - waves which occur within the sea rather than at the surface. Waves are obvious features of the ocean which can affect the shape of the shoreline, the organisms living there, and man in his relation to the sea.

Wind waves, tsunamis, and internal waves are all considered to be progressive waves, i.e., they appear to progress in a definite direction. The other major wave type is called a standing wave because it appears to oscillate without forward movement. All progressive waves have similar characteristics in form and motion. They have <u>crests</u> and <u>troughs</u> with the vertical distance between the two called the <u>wave height</u> and the horizontal distance between crests called the <u>wave length</u>. The <u>wave period</u> is the time it takes for two consecutive wave crests to pass a given point. If you know the wavelength and period of any wave, the speed of travel can be calculated with this formula:


$$\text{Wave Speed} = \frac{\text{Wavelength}}{\text{Period}}$$

Seismic waves or tsunamis (often referred to as "tidal waves" although they have nothing to do with tides) originate from several possible geologic phenomena: submarine volcanic explosions, submarine landslides, or earth movements such as faulting. Tsunamis have a very long wavelength between 120 and 720 km and their speed is determined by the water depth. The formula for this is $C = gd$; where C is the wave speed; g, the acceleration of gravity; and d, the water depth. Consequently, in the open ocean with an average depth of 10,500 ft., they can travel at about 400 nautical miles per hour. (To calculate the speed using the formula:
$32\ ft/sec^2 \times 10,500\ ft = 336,000\ ft^2/sec^2 = 580\ ft/sec = 395$ miles/hour.) In the open ocean their height is insignificant, perhaps 30 cm with a period of 10-60 minutes. However, as it approaches shore, such a wave can attain heights up to 35 m (ca 100 ft.). Tsunamis are generated in seismically active areas such as earthquake zones in the Pacific Ocean. North Carolina and the East Coast have been relatively free of tsunamis but the West Coast, especially Hawaii, has experienced them. If tsunamis arrive without warning, they cause much loss of life and property. Since 1946

tsunami warning systems have been established in the Pacific which have helped to notify islands and countries of impending tsunamis.

Internal waves are similar to ordinary sea waves except they occur within the water and not at the surface. They exist between layers of water with different densities. Slicks (oily looking, smooth surface areas) sometimes indicate the presence of internal waves underneath the surface. Internal waves may affect ships when layers occur near the depth of the ship's draft (where some of the energy of propulsion is absorbed in generating internal waves). Ship captains call this phenomenon "dead water". The cause of internal waves is varied - storms, tides, surface waves - and their effect is still under study.

Wind waves, the most important type of wave on the North Carolina coast, are formed by wind blowing over the water surface. Wind waves begin as ripples or capillary waves formed as the water surface is deformed by variation in wind pressure. Thus ripples provide surface roughness necessary for the wind to push the water into larger waves. Ripples disappear almost immediately if the wind dies. However, with continued wind, ripples grow into larger, steeper crested waves. As long as energy is supplied, the wave will continue to develop. Once formed, waves persist even after the wind ceases, but the steepness decreases and the waves become "swells". Swells can travel thousands of miles without losing much energy. Thus, some waves breaking on North Carolina beaches represent energy derived from storms thousands of miles away.

The size of waves is dependent on three major factors: the speed of the wind that formed them; the duration that the wind blew; and the fetch (the length of water surface over which the wind blows in a constant direction). For example, if the wind is blowing across a barrier island toward the mainland at a constant speed, the water in the lee of the island will be relatively free of waves while that on the opposite side of the sound will have large waves because the winds will have acted across a greater distance of water surface, i.e. the fetch is greater. Given the wind speed, duration, and fetch, it is possible to predict the size of the waves generated by a given storm. Conversely, wind speed at sea can be estimated by the wave conditions produced. This relationship is presented in the Beaufort scale (Table 3).

Two types of motion are associated with waves - that of the wave form and that of the water particles. It is important to realize that waves transport only energy, not water. Thus, the wave form moves across miles of sea, but the water does not. Individual water particles in a wave travel in circular orbits with diameters (at the surface) equal to the wave height. These water particle orbits get smaller with depth but are still measurable at depths of about one half the wavelength.

In deep water, surface waves with long wavelengths travel faster than those with shorter wavelengths. Storms make waves of different

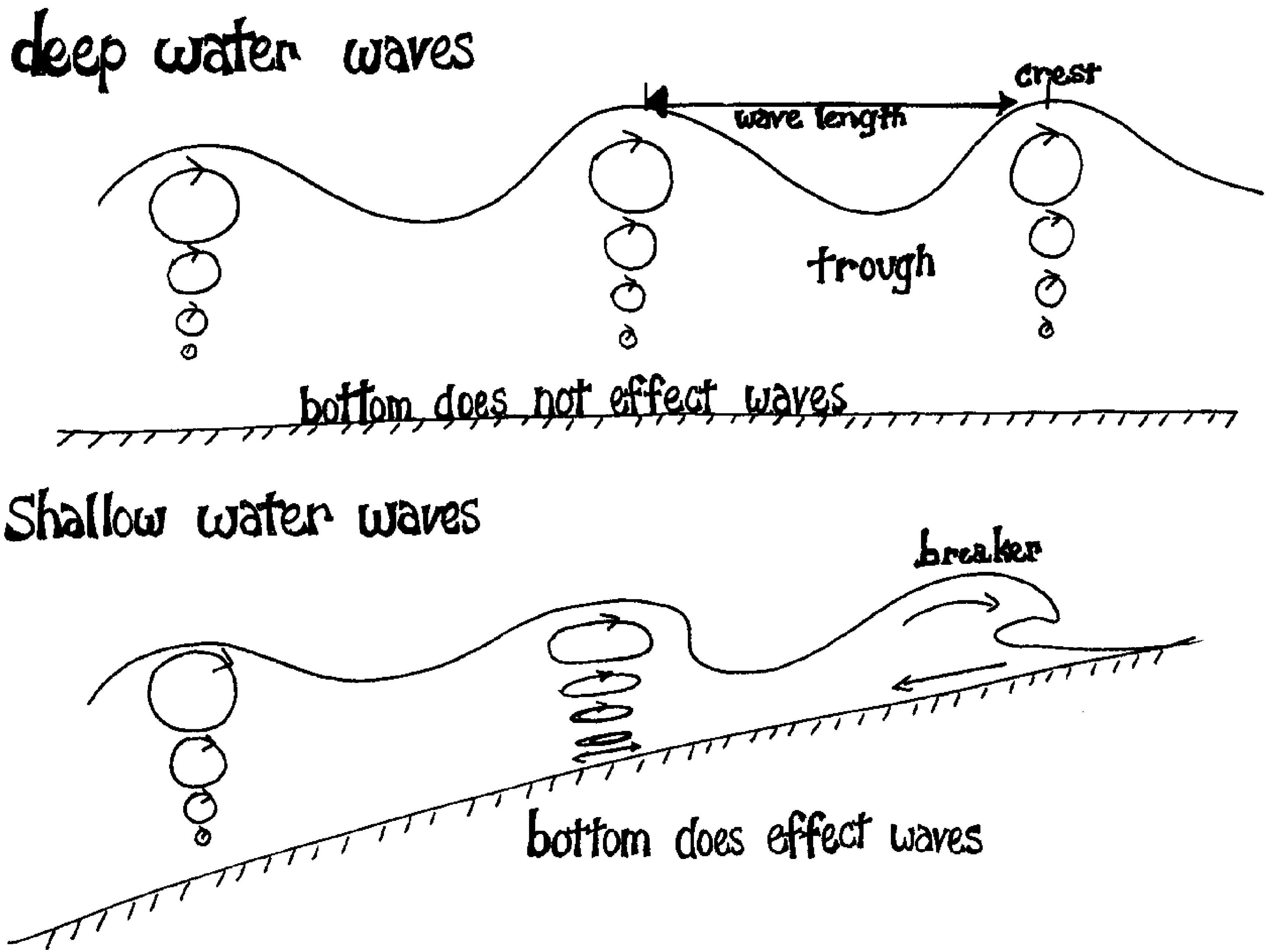
Table 3

Beaufort Scale Numbers and the Sea's Appearance

| Beaufort Number | Wind Speed km/hour | Seaman's Term | Effects Observed at Sea |
|---|---|---|---|
| 0 | under 1 | calm | sea is mirror-like |
| 1 | 1- 5 | light air | ripples, scale-like; no foam crests |
| 2 | 6- 11 | light breeze | small wavelets; crests glassy, not breaking |
| 3 | 12- 19 | gentle breeze | large wavelets; crests begin to break; scattered whitecaps |
| 4 | 20- 28 | moderate breeze | small waves, becoming longer; more whitecaps |
| 5 | 29- 38 | fresh breeze | moderate waves, taking longer form; many whitecaps, some spray |
| 6 | 39- 49 | strong breeze | larger waves, whitecaps everywhere; more spray |
| 7 | 50- 61 | moderate gale | sea heaps up; white foam from breaking waves blowing in streaks |
| 8 | 62- 74 | fresh gale | moderately high waves of greater length; edges of crests begin to break into spindrift; foam is blown in streaks. |
| 9 | 75- 88 | strong gale | high waves, sea begins to roll; dense streaks of foam, spray very heavy |
| 10 | 89-102 | whole gale | very high waves with overhanging crests, sea looks white from foam; heavy rolling; low visibility. |
| 11 | 103-117 | storm | exceptionally high waves; sea covered with foam patches; less visibility |
| 12-17 | 118-220 | hurricane | air filled with foam; sea completely white with driving spray; visibility greatly reduced |

(Reproduced by Courtesy of the Defense Mapping Agency, Hydrographic Center, Washington, D.C.)

FIGURE 8:


deep water waves
crest
wave length
trough
bottom does not effect waves
Shallow water waves
breaker
bottom does effect waves

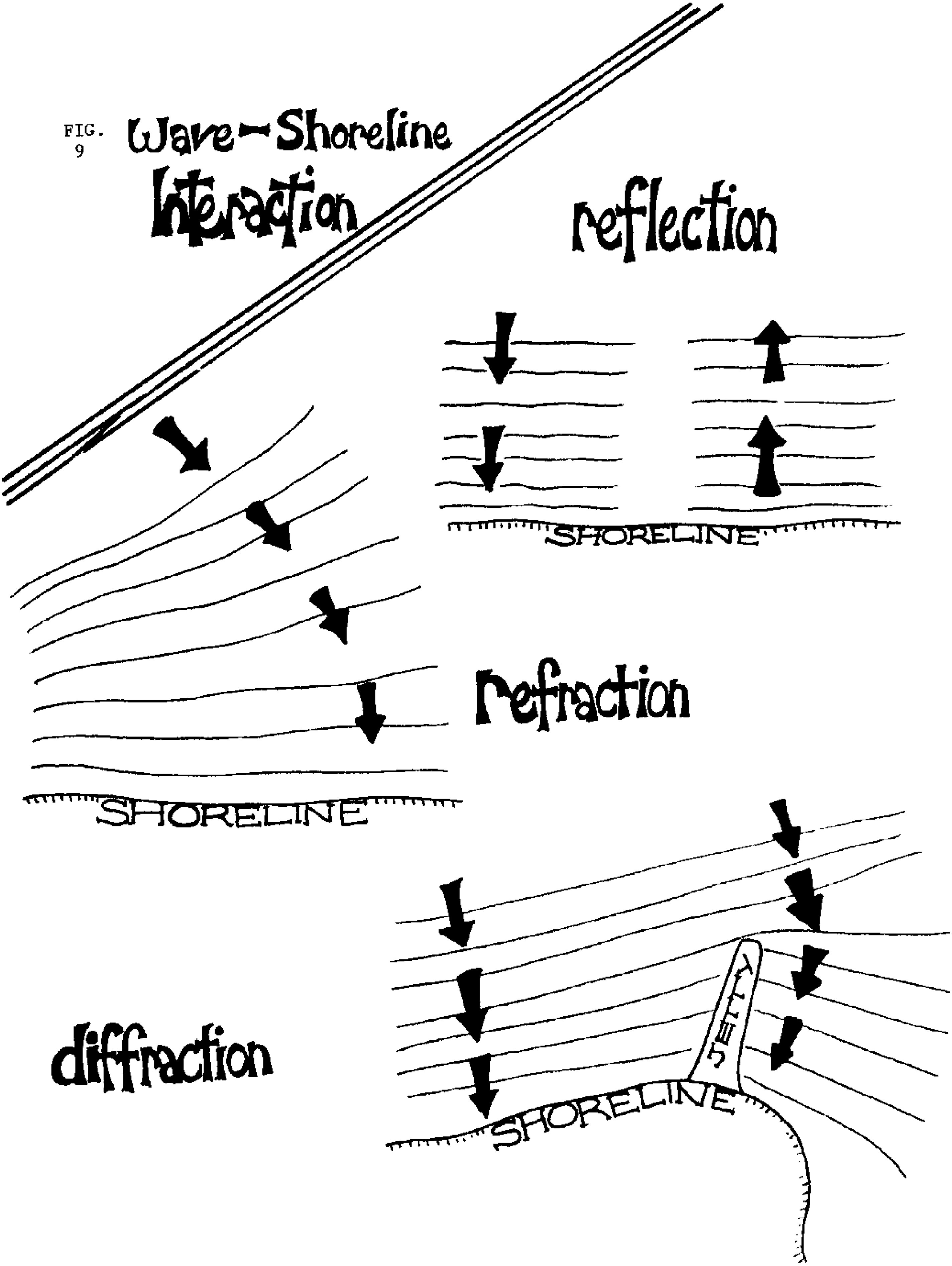



FIG. 9 Wave–Shoreline Interaction

wavelenghts. Since waves travel at different speeds, the longer waves move out ahead of the shorter waves. Long waves may even run ahead of the storm itself. Tans long, low waves crashing on a beach often warn of approaching storms.

In water shallower than half the wavelength waves begin to drag along the bottom. The circular motion of the water particles becomes flattened. The bottom of the wave moves more slowly than the top causing the wave to steepen, become unstable and eventually "break" on the beach. Water from a breaking wave running up a beach is known as "swash". After dissipating its energy on the beach, the swash runs back down the beach and under the next breaker producing a flow often called "undertow". This back and forth motion of the swash stirs up sand and seidment (Figure 8).

Breakers occur as several types. Spilling breakers are over-steepened waves in which the unstable top spills down the front of the wave as it travels toward the beach. Spilling breakers occur on relatively flat beaches, and are good for surfing. Plunging breakers are more spectacular. The wave crest curls over, forming a large air pocket as illustrated in the background for the credits on TV's Hawaii 5-0. When the wave breaks, there is usually a large splash of water and foam. These waves are even better for surfing, and occur on steeper beaches.

In shallow water, long waves travel at the same speed as short waves, but the speed of all waves slows as water depth decreases. If one part of a wave is in deeper water than another part, the shallow water section will slow down and the wave crest will bend. Although most waves approach the beach at an angle, the influence of the bottom causes waves to refract toward the beach. Refraction results in waves with crests almost parallel to the shoreline. Wave refraction causes wave energy to be concentrated on a headland because the crests on either side bend so that the energy of the wave is dissipated along a greater distance of the coast as illustrated (Figure 9).

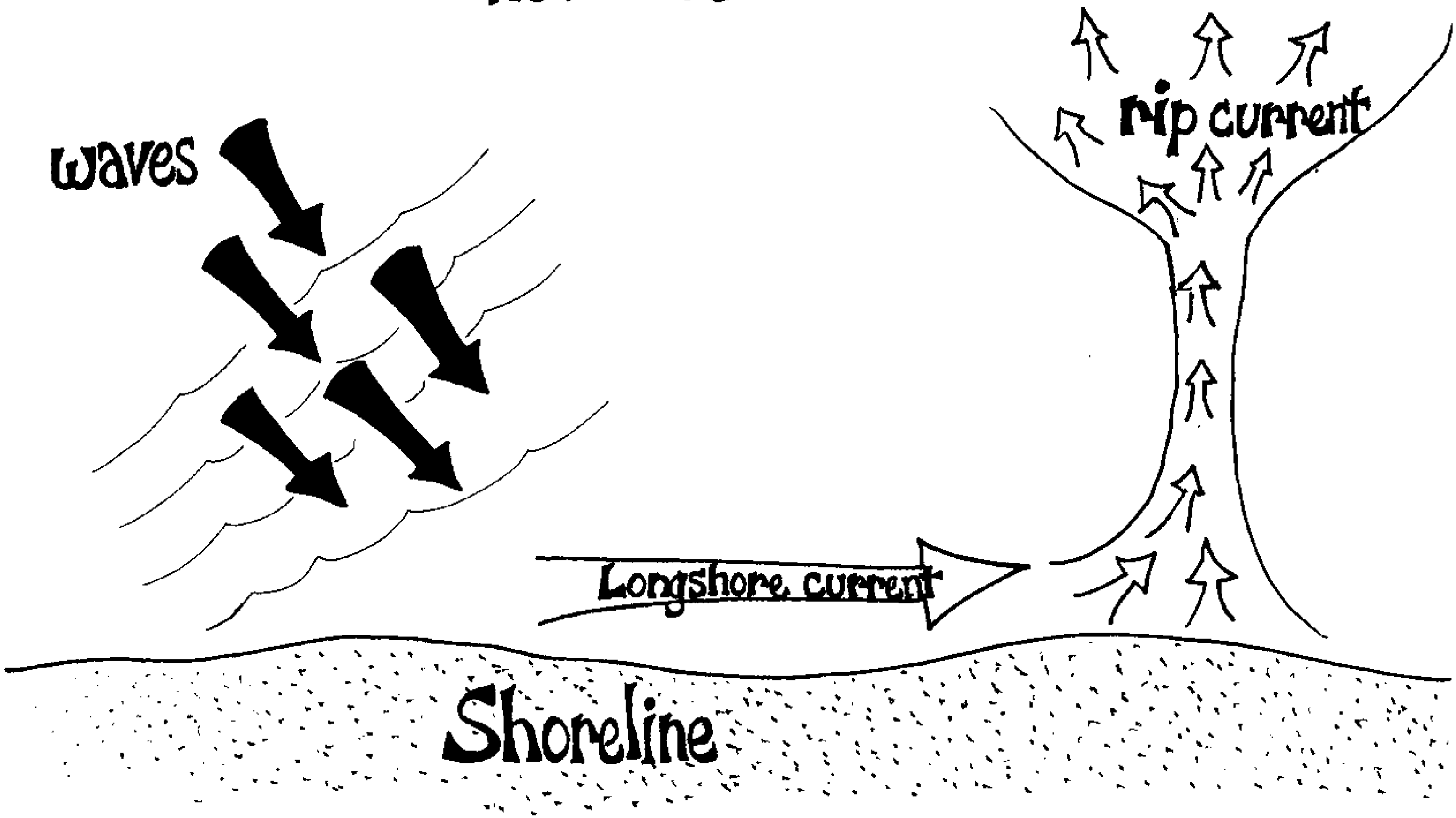
Wave effect on the shoreline varies between winter and summer resulting in "winter and summer beaches". Winter storms cause large steep waves that break on beaches and remove sediments to offshore sand bars. Such waves erode the beach to become narrower and steeper. Single storms can remove many feet of beach in a single night as occured at Wrightsville Beach on November 3, 1977. In summer the waves become less steep and sand from the offshore bar is pushed back up onto the beach. Thus summer beaches are wider and not as steep as winter beaches.

Waves are also the originators of two types of currents - the longshore current and the rip current. The longshore current is caused by waves which approach the shore at an angle. As these waves break they move water and sand grains along the beach in the direction of their travel. This longshore transport exists in the surf zone where waves are breaking. Longshore current is responsible for much of the erosion on barrier islands. Attempts to stop longshore sand transport such as with jetties and groins usually result in deposition in one area coupled with increased erosion in another. Rip currents are localized seaward flows of water from the surf zone. They occur when wave action forces more water into the surf zone than can escape by normal swash run back. As a result the excess water accumulates and eventually flows seaward in a strong localized current. Such rip currents occur when longshore currents converge in a bay, where water builds up as breakers coming across an underwater sand bar, or where some barrier obstructs longshore currents. Swimmers should learn to recognize rip currents to avoid being caught in them and carried seaward. Discolored water due to suspended sand, premature steepening of the waves, accumulation of foam at the head of the rip are signs to watch for. Once caught in a rip current, the swimmer should not try to swim straight back to shore, but should swim parallel to the beach for a few yards (less than 100), then angle back to the beach. (see figure 10).

Table 4 . The wave climate along the North Carolina coast varies depending on the shoreline orientation and degree of open sea exposure. Based on wave gauge records from U.S. Corps of Engineers at four points along the North Carolina coast, the following average wave characteristics have been observed:

| Location | Avg. Wave height (ft) | Avg. Wave period (secs) |
|---|---|---|
| Nags Head | 3.00 | 8.84 |
| Atlantic Beach | 2.19 | 7.16 |
| Wrightsville Beach | 2.56 | 7.74 |
| Holden Beach | 2.02 | 7.40 |

FIGURE 10: Nearshore Circulation



b. Vocabulary

Beaufort scale - a scale of numbers that relates the speed of the wind to the size of waves observed on the open ocean.

breaker - a wave in which the crest has fallen off.

crest - the uppermost part of a wave.

feeling bottom - when waves move into water shallower than ½ their wave length causing the lower part of the circular motion of the water particles to slow down due to friction with the bottom.

fetch - the distance of water over which the wind can blow. One of three factors that determine the size of wind waves.

littoral drift - the movement of sand along a beach because of long-shore current.

longshore current - current of water that moves along a beach caused by waves breaking at an angle with the shoreline.

plunging breaker - a breaker in which the crest is thrown off into the trough ahead.

rip current - water current formed when water moves to sea through a break in an offshore bar.

spilling breaker - a breaker in which the crest slides down itself into the trough ahead.

surging breaker - a breaker in which the crest does not fall over into the trough ahead.

swell - a wave that has moved out from under the wind that formed it.

trough - the low area of a wave between two crests.

tsunami - a seismic wave that may reach great heights. Giant sea waves caused by earthquakes, volcanic explosions, and other disturbances of the sea floor.

wave height - the vertical distance between a wave trough and a wave crest.

wave length - the horizontal distance between two crests.

wave period - the time that elapses between the passing of two wave crests.

wave refraction - the bouncing of waves off the shore or other obstructions. The angle of reflected waves depends on the angle of the approaching waves.

wave diffraction - the curving of waves when they pass between obstacles.

Unit II.

B. Waves

Concept 2

b. Things to Do

"Making a Wave"

1. Objective: To create and observe a model of an ocean wave.

2. Teacher Preparation: Have available the following materials:
    1. A plastic bottle such as shampoo or baby oil comes in.
    2. A measuring cup.
    3. Turpentine (how much depends on the size of the bottle).
    4. Alcohol (how much depends on the size of the bottle).
    5. Green and blue food coloring (about 2 drops blue, 1 drop green)
    6. Some kind of tape to seal the cap on so your wave can't leak

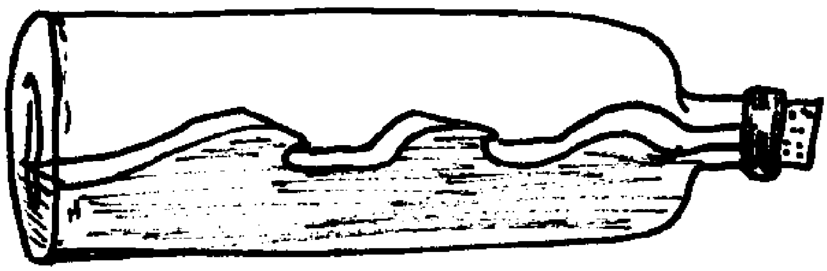
3. Procedure: Mimeograph the following directions for the class.

    STEPS IN MAKING THE WAVE:
    1. Get all the things that you need together.
    2. Fill the bottle with water, all the way to the top.
    3. Pour this water into the measuring cup and measure it exactly.
    4. Put the bottle somewhere to dry out completely. You won't want any water droplets in the bottle when you put the wave in.
    5. Measure half of amount of the total liquid in your bottle. Put this amount of alcohol in. An equal amount should be turpentine. Use your division skill in math and figure it out carefully. You don't want any air bubbles in your bottle when the wave goes in, so you'll need enough liquid to fill it completely.
    6. Put the food coloring into the bottle. When your wave is the color you want it to be, you will know that's enough food coloring.
    7. Fill the bottle with the two fluids. Squeeze the plastic bottle gently to get the air out. Be sure your bottle is full all the way to the top.
    8. Put your bottle cap on as tightly as you can and tape it shut. Masking tape or electrical tape will both work.
    9. Wash and put away your supplies and tools.
    10. Enjoy your wave.

Problems that you may have.

1. You could overdo the color and have to start over.
2. You might find it hard to get all the air out of the bottle.
3. Your bottle may not make a pretty wave if the shape is wrong.
4. Your bottle may give you trouble about the sealing shut.

One wave bottle melted. We think the turpentine dissolved it. What do you think?



c. Things To Do

## Wave Structure and Motion

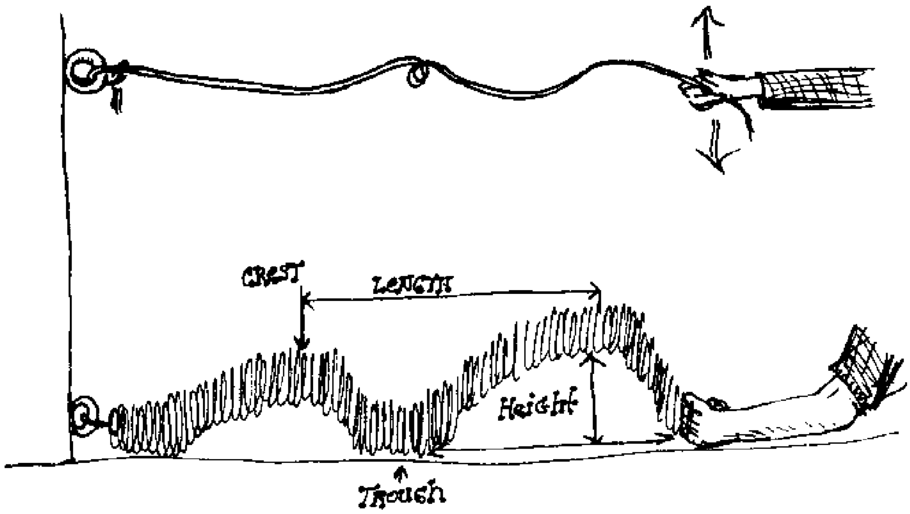
1. Objective: To show that the form of the wave moves as energy, not water particles.

   To learn the parts of a wave.

2. Teacher Preparation: Obtain several pieces of rope or a wire slinkie.

3. Procedure:
   1. Tie a knot in the middle of the rope and tie one end of the rope to a chair or desk.
   2. Whip the rope to achieve a wave-like motion. Observe that the wave will travel along the rope but the knot remains in the same spot.
   3. "Slinkies" provide a similar demonstration of wave motion.

4. Discussion:
   1. Label a sketch of a wave with crest, trough, wave length, and wave height. See if someone can measure height and length of the rope waves.
   2. Discuss how waves move the water in orbits which would effect mixing and location of some animals.



C. Things To Do

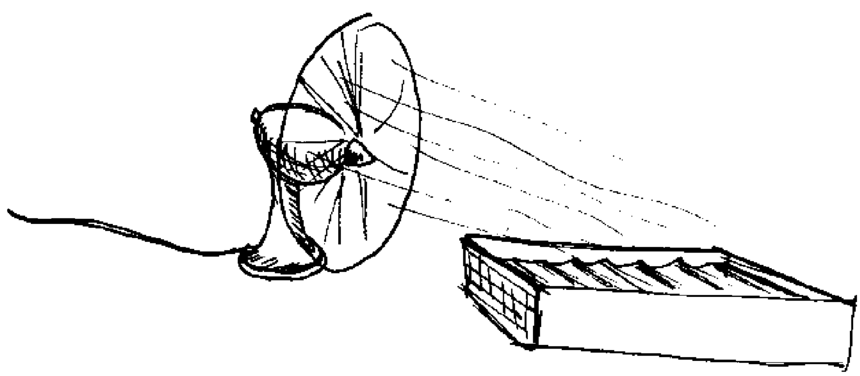
## Waves Caused By Wind

1. Objective: To make wind waves.

2. Teacher Preparation: Obtain a large bowl or large rectangular baking dish, electric fan with multiple speeds (optional), and water.

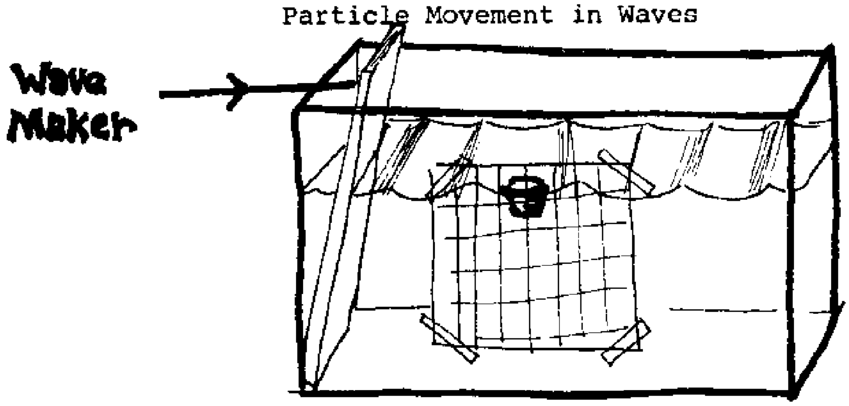
3. Procedure:
   1. Fill the bowl or dish with water. Blow across the water's surface. If using a fan, use the lowest speed. Observe the water's surface.
   2. Now try blowing the water very hard (preferably near a sink) and keep blowing as long as you can. If using a fan, use the next fastest speed. Observe the surface water now.

4. Discussion:
   1. Describe the changes in the water's surface from when you first start the wind, after several minutes, and at different wind strengths.
   2. Where do the waves or ripples reach their greatest height in the dish? (Far end of dish)
   3. In what three ways could you increase the size of the waves? (Increase wind speed, length of dish, or duration of wind)



c. Things To Do

Particle Movement in Waves




1. Objectives: The students will observe an object floating in the water under the influence of waves and then try to determine the path of movement in the water. The major objectives of this activity are for students to be able to develop an understanding of the causes, structure, and behavior of waves.

2. Teacher Preparation: Obtain the following materials: aquarium or other transparent container, 1 cm grid transparency, float (cork), flat board.

3. Procedure: Fill the container with water and tape the grid to the side of the container so that the water surface appears as a line through the center of the grid. Before generating any waves, ask students to predict the path of movement of the cork. Have one student trace the movement of the cork on the grid using a wax pen. Have another student draw the path of movement on the blackboard for all to see.

   Find a float that will remain at different depths below the water surface (use a dropper slightly filled with water). Trace the movement of the object at different depths and record the results. Compare the movement of the float at different depths. What is the relationship of particle movement within a wave to depth? (Particles are definitely affected by waves up to the depth of one-half the wave length)

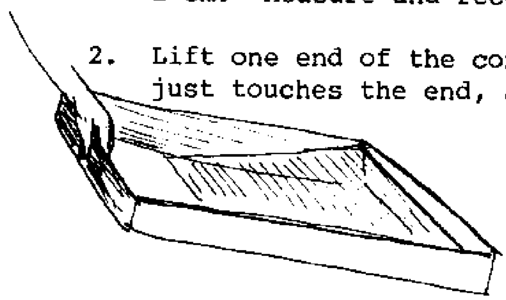
C. Things To Do

## Wave Period and Speed

1. Objective: To determine wave speed and investigate the relationship between wave speed and water depth.

2. Teacher Preparation: Obtain transparent rectangular container (such as a fish tank or deep baking dish), water, meter stick, and stop watch.

3. Procedure:
   1. Pour water in the container to a depth of 1 or 2 cm. Measure and record the depth.
   2. Lift one end of the container so that the water just touches the end, as shown here.



   Quickly set the end back down on the table and note the wave action; identify the crest and trough of the wave. Repeat lifting if necessary.

   3. Use a stop watch to find the time required for the crest of the wave to move across the container and return to its original position. This is the period of the wave. If the wave is visible for more than one trip across and back, two or three oscillations may be timed and the average period determined. Record this in the chart.
   4. Measure the total distance the wave crest moves (across and back is twice the length of the container). Using wave speed = wave length/ period. Record this data in a chart.
   5. Increase the depth another centimeter or so. Measure and record this depth. Repeat steps 2, 3, 4 to find the period and speed of the wave at the new depth.
   6. Continue to increase the depth a few cm at a time. Measure and record the depth whenever you change it. Find the period and speed at each new depth.

4. Discussion:
   1. How did the depth of the water affect the speed of the wave?
   2. Would you expect a wave to speed up or slow down as it moves from deep water toward shore? (slow down)

d. Resources To Use

## Waves

1. References


Coker, R.E. 1954. This Great and Wide Sea. Harper and Row, New York, NY. Ch. 10, Sea Water in Motion: Water Moved by the Wind, pp. 138-145.

Gross, M.G. 1972. Oceanography - A view of the Earth. Prentice-Hall, Inc. Englewood, NJ. Ch. 9, Waves, p. 239-265 (good information)

Chapman, F. The sea and its boundaries. Carteret Regional Marine Science Project, pp. 15-24.

Readings from Scientific American - Oceanography. W.H. Freeman and Co., San Francisco, CA. Bascom, W., Aug. 1959. Ocean Waves. Bernstein, J. Aug. 1954. Tsunamis. Bascom, W. Aug. 1960. Beaches.

Epstein, S. and B. Epstein. 1961. The First Book of the Ocean. Franklin Watts, Inc., 10 pp. (upper intermediate)

Zim, H. 1967. The Waves. Wm. Morrow and Co., 63 pp. (upper intermediate)


2. Audio Visuals

The Beach - A River of Sand. Movie, Encyclopedia Britannica, 1965, 20 min., color. Waves, beach processes, long shore current; an excellent film.

Waves on Water. Movie, Encyclopedia Britannica, 16 min., color. Wind waves, experiments with wave tank; excellent film.

Tsunami. Movie, NOAA, 1965, 28 min., black and white.

Oceanography - Understanding our Deep Frontier. 8 sound filmstrips, National Academy of Science. "Physical Oceanography" - waves, tides, ocean currents.

"Understand Oceanography" 5 sound filmstrips, Society for Visual Education, Inc. "Currents, Waves and Tides" - waves caused by winds, tsunamis.

Sea Patterns, Sea Cycles. "Waves, Waves, Waves." "Ocean Currents" sound filmstrips Cypress Publishing Co., 1763 Gardena Avenue, Glendale, CA 91204.

To Love the Sea - "Ocean Motion" 5 sound filmstrips. Cypress Publishing Company.

Unit II.

## Seawater

### Concept 3. Seawater is salty and salinity affects the circulation in coastal waters.

#### a. Introduction

That sea water is salty is probably the best known fact about the ocean. The most obvious implication of the ocean's saltiness is that the salt must have come from someplace. Thus, the question "Why is the sea salty?" is totally reasonable. The answer to the question involves phenomena from molecular chemistry to global paleogeochemistry and thereby provides an educationally useful base to analyze the various chemicals in the sea.

Henry Bryant Bigelow, the first Director of the Woods Hole Oceanographic Institution, has been quoted as saying, "The most important thing about the ocean is that it is full of water". This simple statement is really quite profound as it focuses attention on the importance of water in sea water. Water is the most common substance on the surface of the earth; however, it is an unusual compound and consequently has some unique properties: high surface tension, high heat capacity, high dissolving power, high heat conductivity, high latent heats of fusion and evaporation, and an abnormal thermal expansion (pure liquid water reaches its greatest density at temperatures of 4°C rather than just above freezing as in the case of other compounds). Molecular chemists have different theories concerning the cause of these abnormalities, but all theories place considerable emphasis on the shape, and resultant electrical polarity, of the water molecule. The water molecule has two atoms of hydrogen bounded through shared electrons (covalent bonding) to one atom of oxygen. This arrangement forms a molecule that can be envisioned as having the two-dimensional shape of a silhouette of Mickey Mouse's head, i.e. with the "face" being the oxygen and the "ears" being the two hydrogens. The angle between the two "ears" is about 106° and, since the hydrogens are positively charged, the eared end of the molecule carries a positive charge in comparison to the "chin" end of the molecule. As a result, water molecules can link up "ears to chin" to form multimolecular groups.

These groups can form closed crystalline structures as in ice or looser orientations as found in liquid water. Crystals occupy more space than a fluid mixture of smaller components which explains water's unusual thermal expansion properties. "Ear to chin" linkages (hydrogen bounds) between water molecules prevent the molecules from moving as rapidly as they would without such bonds, hence the high specific heat of water. It takes heat to break the hydrogen bonds between water molecules thus accounting for water's high heat of fusion (the heat required to convert ice at 0°C to liquid water at

$0^{o}C$ is 80 cal/gram) and high heat of vaporization (heat required to convert liquid water at $100^{o}C$ to gas at $100^{o}C$ is 540 cal/gram).

The polarity of the water molecule also accounts for water's high surface tension because molecules tend to form a hydrogen bonded "skin" over freer moving molecules within the liquid. From the standpoint of salinity, water's high dissolving power explains the saltiness of the sea. The polar water molecules cluster around charged particles keeping them from interacting directly with one another and thereby keeping them in the dissolved state. Thus, basic marine chemistry rests on understanding rudiments of the molecular structure of water.

Understanding how water might dissolve a wide array of chemicals leads one to consider the chemicals available for dissolution. If one explores the salt content of the world ocean, such considerations lead directly into the territory of global paleogeochemistry. A thorough analysis of the mechanisms postulated to be involved in the geochemistry of sea salt is beyond the scope of these materials (the interested reader should read MacIntre, Ferren, 1970, "Why the Sea is Salt", Scientific American, November, pgs. 104-115), but dissolution of crustal rocks, significant additions of volatile material from volcanos, and complex reactions between sea floor clays and newly dissolved and newly formed materials appear to be involved. The result of these processes is that the ocean contains some of every known chemical. These chemicals constitute the salt content of the sea with salinity defined as the total weight in grams of these chemicals in a kilogram of sea water.

Sea water from the open sea contains about 35 grams of salt per kilogram. This weight to weight relationship can be expressed as a percent, i.e. sea water is 3.5% salt; but, for ease of calculation, sea water salinities are expressed on a parts per thousand scale, e.g. average sea water has a salinity of $35^{o}/00$ ($^{o}/00$ = parts per thousand). The major and minor constituents of sea water of $35^{o}/00$ are listed in Table 1 from Sumich, James L., 1976, An Introduction to the Biology of Marine Life, p. 11.

Table 1. Major and minor ions in seawater of 35 $^{o}/00$ salinity

| Ion | Chemical Symbol | Concentration $^{o}/00$ | |
|---|---|---|---|
| Chloride | $Cl^-$ | 19.3 | |
| Soduim | $Na^+$ | 10.6 | |
| Sulfate | $SO_4^{-2}$ | 2.7 | |
| Magnesium | $Mg^{+2}$ | 1.3 | Major |
| Calcium | $Ca^{+2}$ | 0.4 | |
| Potassium | $K^+$ | 0.4 | |
| Biocarbonate | $HCO_3^-$ | 0.1 | |

Table 1 continued.

| ION | Chemical Symbol | Concentration $^{o}/oo$ | |
|---|---|---|---|
| Bromide | $Br^-$ | 0.066 | |
| Borate | $H_3BO_3$ | 0.027 | |
| Strontium | $Sr^{+2}$ | 0.013 | Minor |
| Fluoride | $F^-$ | 0.001 | |
| Silica | $Si(OH)_4$ | 0.001 | |
| and traces of other naturally occurring elements | | | |

Dilution from rain and river lower salinity while evaporation and freezing increase salinity. North Carolina estuaries which contain sea and river water have intermediate salinities ranging from 10-25 $^{o}/oo$ depending on the direction of the tide flow.

The role of the sea's salt content can provide educationally useful examples of physico-chemical principles. Examples of such principles involve the role of salt content in nearshore water circulation, and the environmental role of gases, nutrients and organic matter dissolved in sea water.

Water with salt dissolved in it weighs more than the same water without dissolved salt. Therefore, wherever rivers empty into the sea, fresh water from the river tends to flow out over the salty sea water to form a two-layered system. With strong tidal or wind-driven currents, the two layers mix to form a homogeneous water mass of intermediate salinity; but where currents are weak, the two layers remain separate. North Carolina has examples of both layered (stratified) and mixed coastal waters. The Cape Fear River is North Carolina's best example of a stratified coastal water body. The large open sounds (Pamlico, Albemarle, Core, Bogue, etc.) are usually mixed but may become stratified depending on the relationship between mixing processes and freshwater runoff (Figure 11).

Salinity layering influences the nature of water circulation in the coastal water. When layers occur, dissolved substances tend to stay in one layer or the other. In addition, materials flowing downstream in the fresh water layer may be recycled and virtually trapped in the two-layered system when they sink into the saltier layer and then move back upstream with seawater used in the initial mixing process. This circulation is one based on a salinity concentration mechanism. This vertical circulation is diagrammed as follows:

b. Vocabulary

Density - mass per unit volume (grams per milliliter), the density increases as more atoms are packed into the same space.

Hydrogen bonding - a weak chemical bond between a hydrogen atom in one polar molecule and the negative atom in a second polar molecule of the same substance.

Hydrometer - a calibrated floating device to measure the density of water which relates to salinity at a given temperature.

Mixed estuary - the river and sea water have been stirred and mixed to have a uniform salinity intermediate between that of the river and the sea.

Parts per thousand (°/00) - unit used in measuring the saltiness of water; expression of salinity; number of grams of solids dissolved in one kilogram of water.

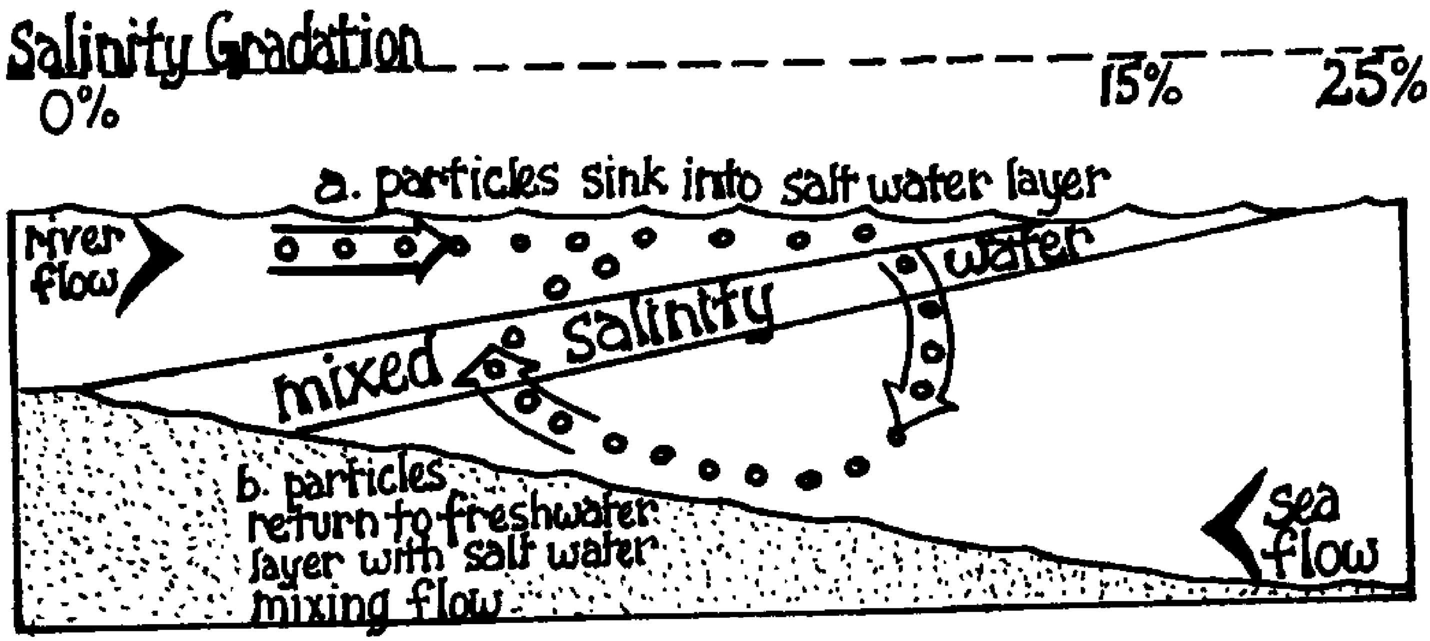
Polar molecule - a molecule that has slight negatively and positively charged ends.

Salinity - the total amount of solids dissolved in a kilogram of sea water.

Stratified estuary - a layered estuary with river water on top and sea water on the bottom.

Surface tension - the skin of hydrogen bonded molecules at the surface over the freer moving molecules within the liquid.

FIGURE 11:



c. Things To Do

## Water is a Special Molecule

1. Objective: 1. To construct a water molecule and label the polarity.

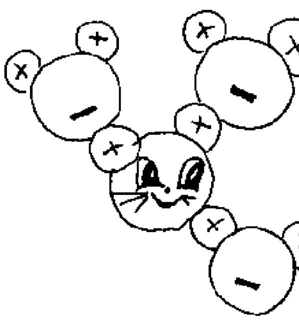
2. To apply the concept of polarity and demonstrate some resulting properties of water: water tension, freezing and boiling points, dissolving power.

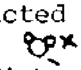
2. Teacher Preparation: 1. The following are a group of activities which can be modified for several age levels. The group can be accomplished with construction paper, plain paper and crayons, and scissors.

2. For demonstration or investigations, water tension lab needs a large can with 5 holes punched near the base about 5 mm apart. Freezing and boiling points need access to a freezer, heat source, thermometers. Solution investigation needs a solute such as salt, sugar.

### Part A. The Molecule - "Mickey Mouse"

3. Procedure: 1. A molecule of water consists of two atoms of hydrogen and one atom of oxygen. Cut out a large circle, label it O for oxygen; cut out two smaller circles, label them H for hydrogen. Due to their atomic structures, these atoms are attracted to each other. Move them about and see in what positions the three could be arranged. Sketch your arrangements.



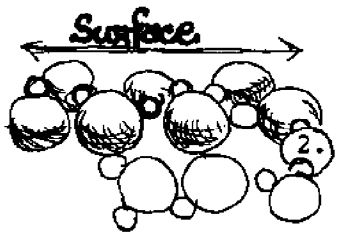
2. Assume that the two hydrogens are both attracted to the oxygen and also are slightly attracted to themselves. Place the circles like this,  , so that you have a figure somewhat like Mickey Mouse's head and his two ears. Because of this funny, and very important, arrangement, this molecule is polar; it is like a magnet with a positive and negative end. Label the oxygen end negative (-) and the hydrogen end positive (+).

3. Investigate with several other people how water molecules could fit together. (If you have some bar magnets, you can experiment with these to see how the positive and negative ends affect the various fits.) These hydrogen bonds between

molecules caused by attracting positive and negative ends mean that the molecules stay together better than other molecules. This would affect properties like boiling, freezing, and surface tension. Draw how you think water exists as liquid, solid and gas. Use your "Mickey Mouse" models to help.

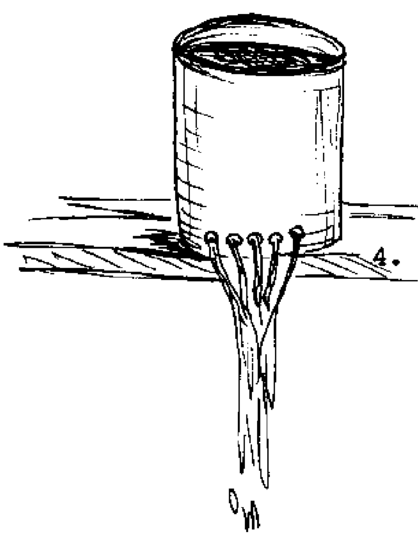
<u>Part B. Surface Tension</u>

Procedure: 1. You have read how the water molecules are polar molecules and therefore have an attraction for each other. This attraction shows when you investigate the surface of water in a bowl. Place a needle or razor blade or thin strip of metal carefully on the surface. What is keeping it afloat? Touch the metal with your finger. The metal strip will sink, so you have to eliminate the idea of buoyancy or floatation. One little demonstration may help -- have a friend put a book on your outstretched fingers -- hard to hold up, right? Now take both your hands and interlock your fingers. Again, ask your friend to put the book back on your fingers. This time it is easy to hold. Now think back to the water molecule. The little attraction between the molecules is very similar to the interlocking of your fingers. The molecules have formed a thin surface film.




2. Another place to look for surface tension is the edge of the bowl or glass. Notice how the water is creeping up the side. If you use a graduated cylinder to measure milliliters of water, avoid measuring the creep up the side, but eye the water straight across the meniscus.

3. Another place to find surface tension is in filling a test tube. Fill the tube to the top, then slowly drop by drop, keep adding water until you have built a mound of water. What is keeping the water from falling over the side? You know that answer now. If you continue to add water, the weight becomes so great that the hydrogen bonding is broken and the water spills.



4. One last investigation on water tension. Take a tin can and punch five little holes near the base about 5 mm apart. Fill the can with water holding the holes closed with your hand. Let the water drain from the can. It will either come in 5 little streams or if you brush your hand past the streams, they will form a single stream. What holds the five streams together? (Water tension)

Part C. Dissolving Power

Procedure: 1. Take a test tube or jar of water, add a little salt to the water and shake. The salt particles disappear. What happens to them? Taste the water. Did you find the salt? Salt is made up of two elements, sodium (Na) and chloride (Cl). Na has a positive charge and chloride has a negative charge when the two are separated as ions. Together they make a nice couple - neutral. What do you think happens to this couple when it is put into water? Think about the polar molecule. Sketch the polar molecule and show where the Na and Cl end up.

2. Keep adding salt and shaking the tube. What keeps the excess salt from dissolving? (All available ions used) From this experiment, define what the word "dissolve" means. (A molecule is split into ions by attraction to polar ends of water molecule)

Part D. Freezing and Boiling Points in Water

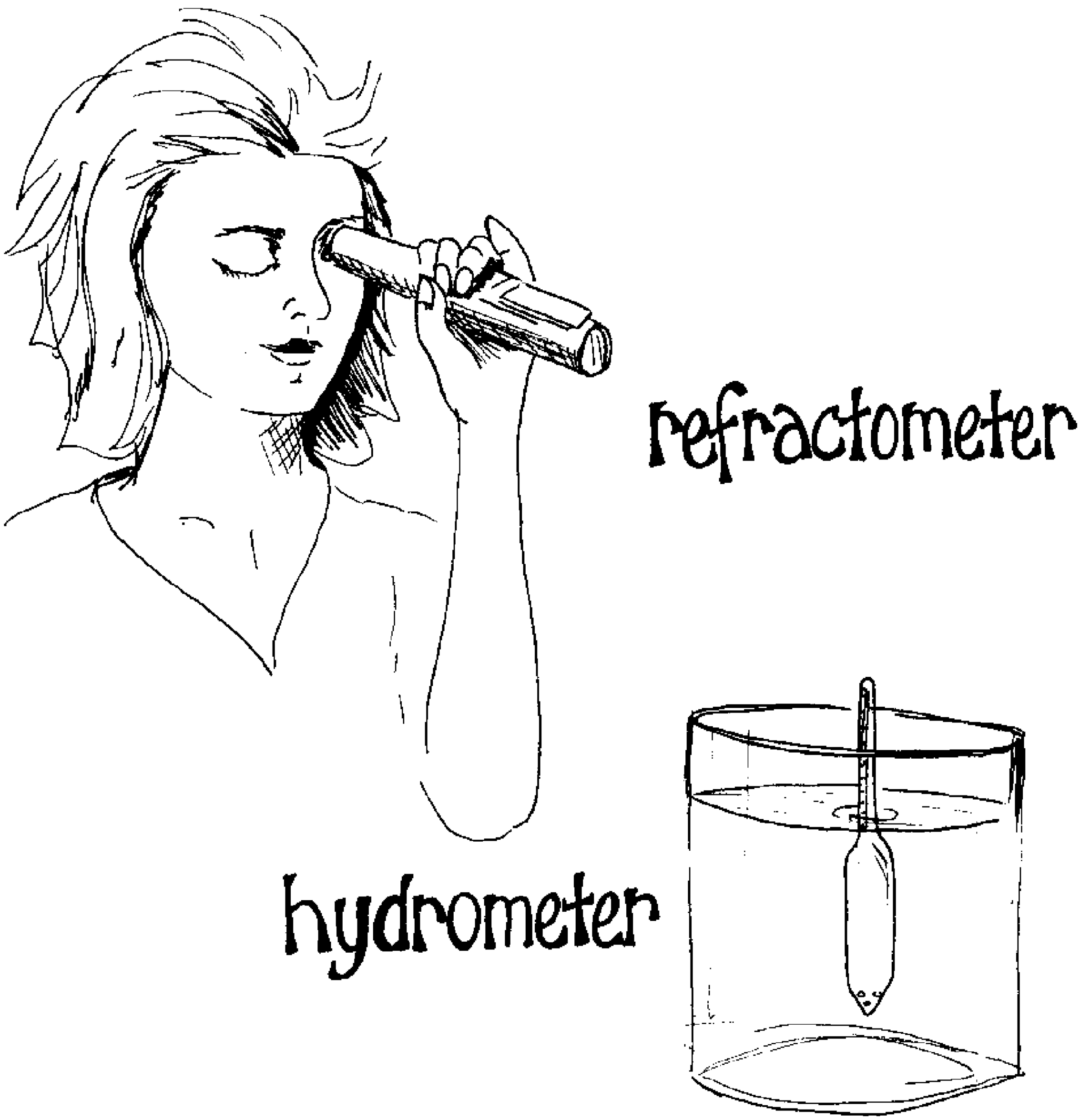
Procedure: 1. If you heat a liquid the particles or molecules in it will eventually get enough energy to leave the liquid state and become a vapor. Water has to get enough energy to break the hydrogen bonds before it can boil into vapor. If water did not have this bonding, do you think it would boil at a higher or lower temperature?

2. However, water does have bonding and it boils at 100$^{o}$C or 212$^{o}$F. Investigate what happens to this boiling point if you add salt water. You will need to set up a ring stand and flame (or heater), and a beaker of water. Bring the water to a rolling boil and measure the temperature of the water. Don't put the thermometer too close to the bottom or you will measure the heat from the flame. Now let the water cool, add salt, and repeat. Did you notice a difference?

3. Try to explain the reason why there was a difference by using your model of water molecules bonding together. (Hint: Did the water have more or less bonds with the salt?)

4. For variation, you can investigate the effect of freezing points on pure water and salt water. In order for water to freeze, the water molecules line up in a lattice framework with positive and negative parts joined. (In liquids, this arrangement is very loose, in solids, the arrangement is more rigid). How would the addition of salt to water affect the difficulty of making the framework? (More difficult) Do you think salt water would freeze at

a lower or higher temperature than pure water which freezes at 0°C or 32°F? (Lower temperature)



c. Activity

## Hand-Made Hydrometers

Teacher Preparation: Simple hydrometers can be fashioned from plastic straws or glass tubes. The straws will need to be stoppered, clay is sufficient, and the test tube will need a cork. Both will need to be weighted by paper clips, lead bee-bees, toothpicks, etc. Water-proof markers or grease pencils. Container of salt water with a known concentration of salt.

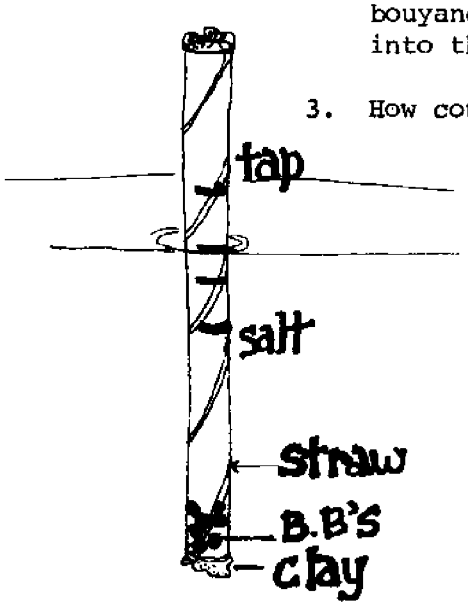
Procedure: Stopper one end of the straw and add some bee-bees, then stopper the top with a little bit of clay. (If using test tube, put in some bee-bees). The object is to add enough weight so that the straw or test tube floats vertically in salt water. Mark the water level on the straw or tube. Dilute the salt water by ¼, and again mark the level of water on the tube. Repeat regular dilusions and subsequent marking on the tube. These markings represent your salinity scale and you should be able to drop this "hydrometer" into an unknown solution and estimate the actual salinity.

Discussion:

1. What causes the "hydrometer" to float higher in water with more salt? (More salt increases density and thus the "hydrometer's" bouyancy)

2. What would happen to the "hydrometer" if put in fresh water? (Less density, therefore less bouyancy, and the hydrometer would sink deeper into the water)

3. How could you make your "hydrometer" more accurate?



c. Activity

How to Determine Salinity

1. Objective: To investigate different ways to determine salinity of sea water.

2. Background Information: Determining salinity for oceanographers is a precise analysis utilizing sophisticated equipment. However, you can get approximate salinities in the classroom, depending on the equipment you have and the involvement of the students. There are four basic methods to establish the concentration of the solution: (1) titration which involves making a compound which will change color by addition of drops of the titrating solution. LaMotte Chemical Company has an inexpensive portable kit for $16.00. (2) Conductivity, which measures the resistance of an electrical current through sea water which decreases with increasing salinity. These are expensive instruments which cost approximately $1,500. (3) Optical refraction is used in a hand-held instrument called a refractometer which measures the bending of light rays - the higher the salinity, the greater the bend. This instrument is very useful on field trips and costs about $200 from American Optical Corporation. (4) Water density varies with amount of salt dissolved in it. Density can therefore buoy up an instrument called a hydrometer. The greater the salinity, the higher the hydrometer floats. Hydrometers can be purchased from aquarium supply stores inexpensively (about $2.00) or can be made. Another simple, although usually the less accurate method is to evaporate a known quantity of sea water and weigh the residue salt.

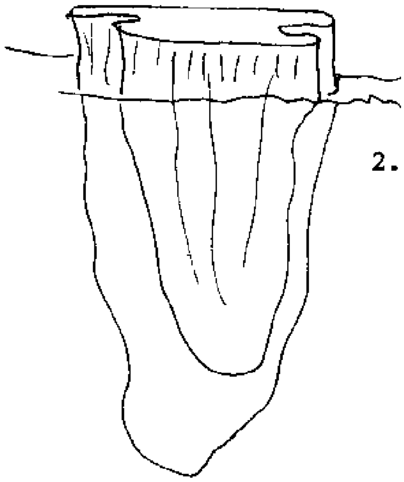
For information on instruments or chemical lists, write to LaMotte Chemical Products Co.
P.O. Box 329
Chestertown, MD 21620

American Optical Corporation
Scientific Instrument Division
Buffalo, NY 14215

c. Activity

Objective: To determine salinity.

1. Once you decide how your class can determine salinity, there are several activities to use this skill. For many students, it is hard to see clear water and conceptualize that a lot of salt is dissolved there. So, make up some solutions with different amounts of salt and then determine relative salinity of each by some method. (Evaporation and weighing, tasting, or the hydrometer can accomplish this.



2. Another activity which involves both determining salinity and world news is making icebergs. The idea of bringing fresh water to desert countries via icebergs from the poles is not new, but recently the idea has undergone some rigorous engineering and may actually be done. Discuss importance of this idea with your students. If the question is not brought up naturally in class, ask how can an iceberg be made of fresh water when it was formed in the sea. The following activity illustrates this question nicely.

3. Obtain the following materials: salt water about 35 °/oo (35 grams of salt in 1,000 ml of water), a plastic container which holds 1 liter, thermometer, method of measuring salinity, and refrigerator with freezer.

3. Procedure:
   1. Place 500 ml of the salt water in the container. Measure the salinity of the sample.
   2. Place a thermometer in the container and place the container in a freezer; check the sample until it is about half frozen. Measure the salinity of the liquid water. Remove the piece of ice, let it thaw in a separate container and measure the salinity of the thawed ice. Record the results. It is interesting to measure the temperature of the freezing salt water.

4. Discussion:
   1. How did the salinity of the liquid water compare with the thawed ice? (Ice has less salt in it)
   2. From this information, what are ice bergs made of and how would this affect the salinity of the water near the surface at the North Pole when ice is forming? (Icebergs are mostly made of fresh water; water is saltier)
   3. Discuss any differences between the temperature of fresh water and salt water freezing points. (Fresh water freezes near $0^{o}C$, salt water freezes $1-2^{o}$ lower)

c. Things To Do

## Salinity in Parts Per Thousand

1. Objective: To calculate salinity given amount of salt and water in parts per thousand.

2. Teacher Preparation:
   1. The following exercise reviews the math procedure needed to determine salinity and thus is a good activity to preceed the "Float an Egg" lab.
   2. A few samples should be done as a group and then some problems given to the students. A few examples are given here.

3. Procedure:
   1. The actual math set-up for calculating salinity is a proportion relating the salt in grams and water in ml used to 1,000 ml of water and X grams of salt. For example: 6 grams of salt dissolved in 240 ml of water:

      $$\frac{6g}{240\text{ ml}} = \frac{X}{1{,}000\text{ ml}} \qquad X = 25\ {}^{0}/00$$

      $^{0}/00$ is a symbol meaning "parts per thousand". It is similar to % meaning "parts per hundred". Literally, salinity is the amount of salt in 1,000 parts of water.

   2. For slower math students, it is easy to calculate salinity by using the following formula: divide the water into the salt, move the decimal in the answer three places to the right for $^{0}/00$. For example: the problem above becomes: $240\overline{)6.000}$ = .0250 = (move decimal 3 places) = 25 $^{o}/00$

   3. 

| Amount of Salt grams | Amount of Water milliliters | Salinity $^{o}/oo$ |
|---|---|---|
| 10 | 100 | -- |
| 35 | 1000 | -- |
| 18 | 500 | -- |
| 70 | 2000 | -- |
| 20 | 160 | -- |
| -- | 250 | 10 $^{o}/00$ |

C. Things To Do

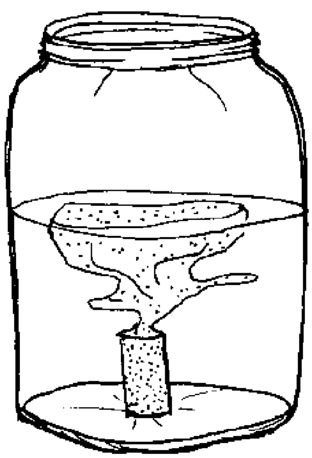
## Concepts of Density

1. Objectives:
   1. To be able to predict the density of water in relation to temperature.
   2. To be able to relate differences in density to water currents.

2. Teacher Preparation: Each group has a gallon jar or beaker and a small medicine vial with a square bottom. Food coloring and availability of hot water are needed.

3. Procedure:
   1. Fill the large jar with cold water and the small vial with hot water. To the small vial add a few drops of food coloring so that you can see the movement of the water. Stopper the vial lightly.
   2. Very carefully, set the small vial on the bottom of the large jar and remove the stopper. Withdraw your hand very slowly so that you don't stir up the water.
   3. Record the results.

4. Discussion:
   1. What causes the water in the small vial to move? Where did it go? (Difference in density, less dense floated up)



   2. Think about the individual water molecules in both the vial and the jar. In which container would the molecules be moving more rapidly and thus be spread further apart? (Warmer water)
   3. Density can be defined as the number of particles or molecules in a given space or volume. The more molecules in a space, the denser and heavier that space. Given this information, which would have the most molecules in the space, warm or cold water? (Cold) Therefore, which would be denser? (Cold) Which less dense and therefore able to rise? (Warm)
   4. Now, with this information, discuss what happens to ocean water when the surface layer gets colder than the layers beneath it. (Sinks)

c. Things To Do

Activities with Density, Salinity and Temperature

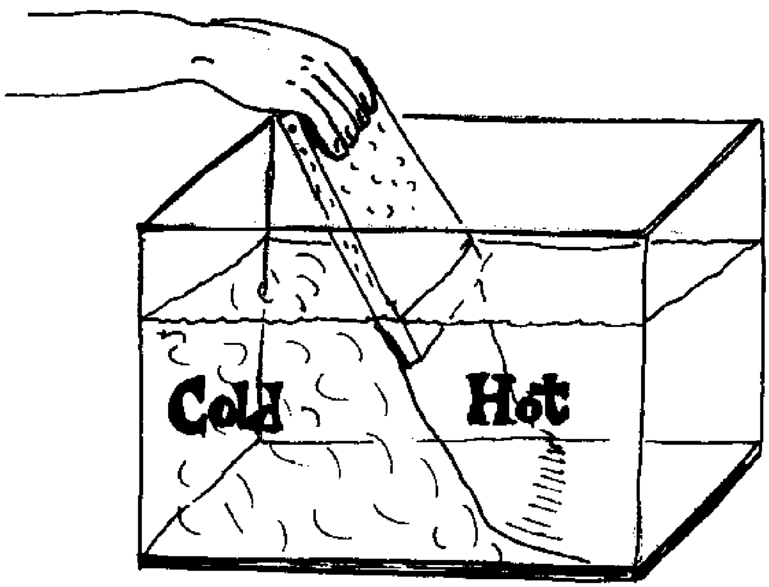
1. Objectives:
   1. To investigate the relationship between density and salinity.
   2. To relate changes in densities to some oceanic motions.

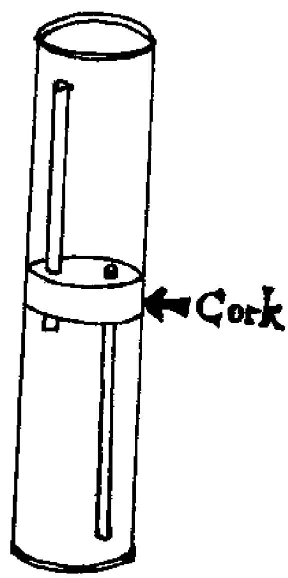
2. Teacher Preparation: These activities make good demonstrations and are effective when you ask for predictions before the demonstration and explanations later. Small glass aquarium or pyrex baking dish, dye, some type of partition to divide the container in half (piece of styrofoam, cardboard), hot and cold water, and salt are needed. (If you have a graduated cylinder, stopper, borer and some glass tubing, you can follow the diagram and construct a more sophisticated piece of equipment.)

3. Procedure:
   1. To investigate density and temperature, fill one container (an old milk carton) with hot water and color it with a few drops of dye; fill a second container with cold, uncolored water.
   2. Place the partition in the aquarium.
   3. Slowly pour the hot, colored water into one half of the aquarium and pour the cold, uncolored water into the other half.
   4. Carefully withdraw the partition and observe the movement of the two types of water.
   5. To investigate density and salinity, fill one container with very salty water and color it with a few drops of dye; fill a second container with fresh water.
   6. Repeat steps 2-4.

4. Discussion:
   1. What was in common between the two types of water which ended up as the bottom layer each time? (Density)
   2. What two factors could cause water to become denser (heavier)? (More salt, colder temperature)
   3. To relate these experiments with situations in the sea, where would the sea water be located in an estuary where the river meets the ocean water? (Near bottom)

4. If the surface water in a still body of water got very cold, but did not freeze, what might happen to it? (Answer: surface water could sink producing a vertical current. In lakes and coastal water, this happens in the spring and fall and is called an overturn, as bottom water full of nutrients replaces the sinking surface water.)



c. Things To Do

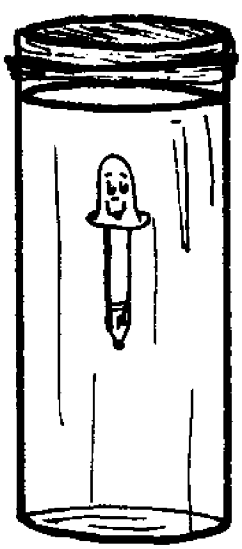
## The Cartesian Diver

1. Objectives: To investigate how salinity and pressure affect density, and how this affects objects floating in water.

2. Teacher Preparation: A 30 x 3½ cm test tube, graduated cylinder or jar, medicine dropper or very small test tube, piece of thin rubber (balloon), rubber band, and salt are required.

3. Procedure:
   1. Fill the test tube or jar nearly full of fresh water and suspend a medicine dropper in it. The dropper can be suspended by having a few drops of water in it.
   2. Stretch a piece of rubber (balloon) over the mouth of the test tube so it is air tight by using a rubber band.
   3. Press on the rubber cover and note what happens to the dropper. Release the pressure on the rubber cover. What happens to the dropper then?
   4. Take off the rubber cover. Add some salt to the water in the test tube (about 2 teaspoons). Replace the rubber cover and repeat step 3.
   5. Record your observation of the Cartesian Diver in fresh and salt water.

4. Discussion:
   1. In which case does the Cartesian Diver submerge easier? (Fresh)
   2. How does the Cartesian Diver work? (Changes in water pressure)
   3. Discuss the relationship among density, salinity and pressure.



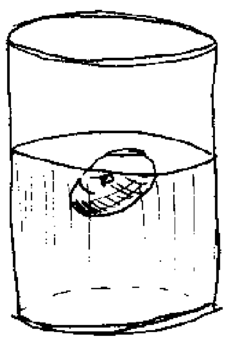
c. Things To Do

Seawater and Buoyancy - Can Chickens Swim?

1. Objectives:
   1. To investigate the increasing density (buoyancy) of water as salinity increases.
   2. To calculate the salinity of water in parts per thousand (for some classes, this could be ignored).

2. Teacher Preparation:
   1. Discuss floating in fresh and salt water with the class. Some discussion about how objects float would help but is not vital in this activity.
   2. Provide each team with a boiled egg, container, graduated cylinder or some way to measure water in milliliters, salt, and access to scales.

3. Procedure:
   1. Fill the container with 250 ml of water. Add the egg to the water. Does it sink or float?
   2. Weigh out 10 grams of salt and add it to the water, stir to dissolve.
   3. Continue adding units of 10 grams to the container until the egg floats off the bottom. It is fun to see which team can float its egg with the least amount of salt (if chickens can't swim, they can float!)



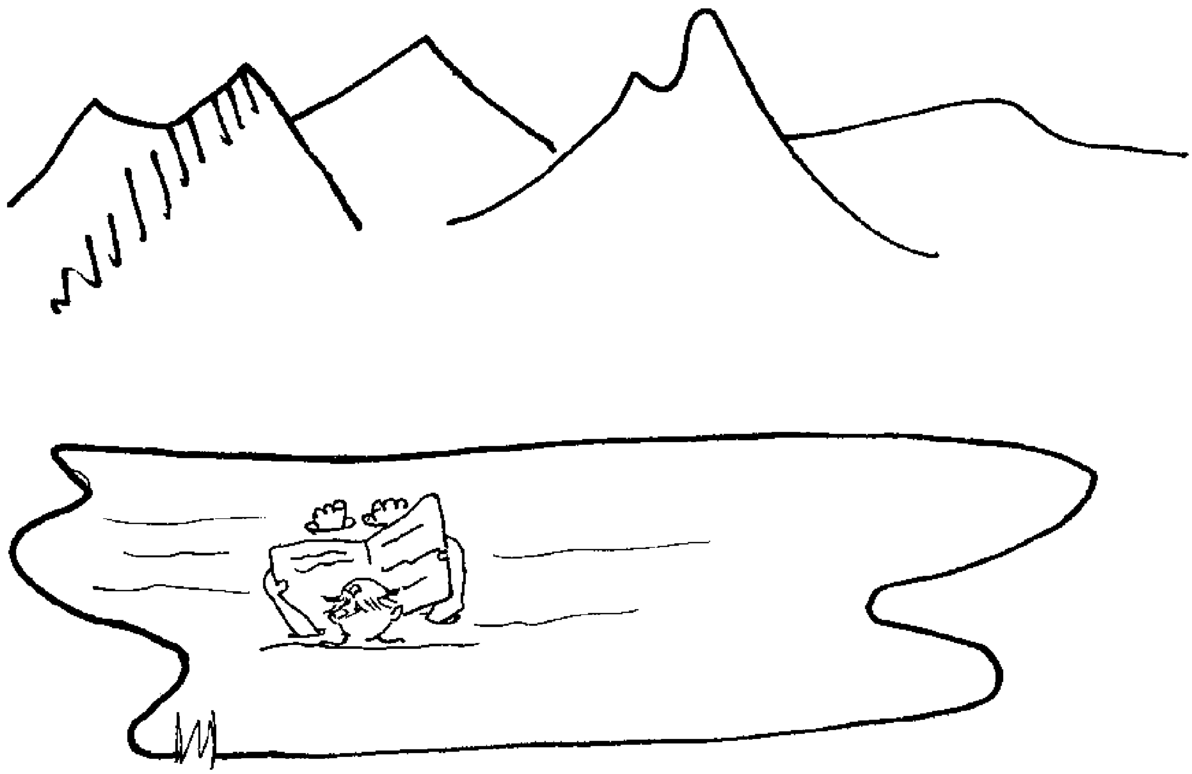
   4. Once the egg floats, determine the salinity of the water by using this formula:

$$\frac{\text{Amount of salt}}{\text{Amount of water}} \times 1{,}000 = \underline{\hspace{3cm}}\ ^{0}/_{00}$$

   For ease, just divide and move decimal three places to right. Salinity strong enough to float an egg is called "brine" and people use this solution to pickle cucumbers.

4. Discussion:
   1. If average seawater has salinity of 35 $^{0}/_{00}$, how does "brine" compare? Is there any natural water that you can think of which would have very high salinity? (Great Salt Lake in Utah)
   2. How does increasing salinity affect the density? (Increases density)

3. Would it be easier for you to float in a fresh water lake or the ocean? Why? (Ocean, denser, therefore, more bouyant)



Floating is easy in salt lake!!

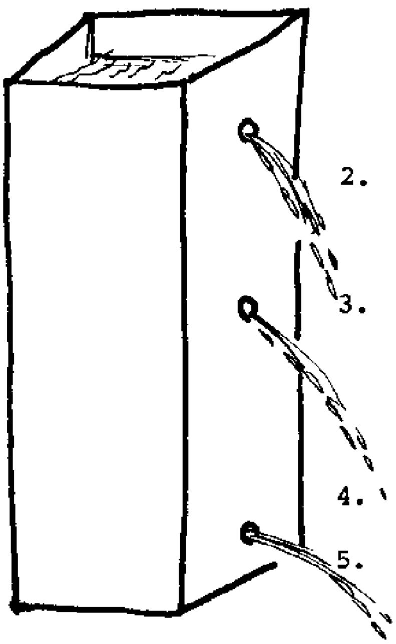
c. Things To Do

## Seawater and Pressure

1. Objective: To observe that with increasing water depth, there is increasing water pressure or weight pressing down at that level.

2. Teacher Preparation: Provide each team with a quart milk carton, water, and a nail or pick.

3. Procedure:



   1. Discuss the effects of pressure on a SCUBA diver as he descends into deeper water. He feels more and more water pressure which presses against his ear drums until he "equilizes" them, i.e., builds up pressure inside the ear to equal the external pressure. We experience the opposite effect when we drive up a mountain and thus have less pressure outside our ears.

   2. Hold up the milk carton. Where would the class predict the greatest water pressure would be -- near the top or bottom?

   3. To test their hypothesis, punch 3 small holes in the sides of the carton, one near the bottom, one near the middle, and one near the top. Put tape or fingers on the holes while another person fills the carton with water.

   4. Release the holes; what happens to the water?

   5. For some classes, it would be a good exercise to record the length the pressure pushes the water stream out and also the depth of the hole and graph the results.

4. Discussion:

   1. Why doesn't the water all stream out the same distance? (Differences in pressure)

   2. What do you predict would happen if you could have a taller carton with more water and had a hole near the bottom? What would happen if you had a larger carton, the same height, with a hole near the bottom?

c. Things To Do

## Concepts of Density - Salinity

1. Objectives:
   1. To be able to predict the density of water in relation to salinity.
   2. To be able to understand the reason for layers in some estuaries and one reason for different layers in the ocean.

2. Teacher Preparation: This can be done as a demonstration or on a group basis. A small aquarium, stiff piece of cardboard, quantity of salt and water, and food coloring are needed.

3. Procedure:
   1. Mix up a gallon of tap water with about a cup of salt. Have another gallon of water with no salt, but add enough food coloring so that it is relatively dark.
   2. Place the piece of cardboard wedged tightly against the sides in the middle of the aquarium. Pour slowly one gallon of water on one side and the other gallon of dyed water on the other.
   3. Slowly withdraw the cardboard. Predict what will happen with the two volumes of water.

4. Discussion:
   1. Which water is denser, the salty water or the fresh water? (Salty)
   2. Discuss what happened with the two volumes of water in the aquarium. (Denser, salt water flows to bottom)
   3. In estuaries where would you expect to find the water from the river and where would you expect to find the water from the ocean? (Surface river water and bottom ocean water)
   4. If you were an oceanographer and took water samples from the surface to the bottom, where would you predict the saltiest water? (Closest to bottom)

d. Resources to Use

1. References

Anderson, Norman D., 1978. Investigating Science in the Swimming Pool and Ocean. McGraw-Hill, NY $7.95.

Coker, R.E. 1954. This Great and Wide Sea. Harper and Row, Publishers, New York. Ch. 6, The Sea as a Solution, pp. 77-93. Ch. 7, Some Physical Properties of Sea Water, pp. 94-111.

James, D.E. 1975. Carolina Marine Aquaria. Carolina Biological Supply Co., Burlington, NC (write to ask for copy of articles)

"Why the Sea is Salty". U.S. Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. Free pamphlet.

Readings from Scientific American - Oceanography. W.H. Freeman and Co., San Francisco, CA. MacIntyre, F., Nov. 1970. "Why the Sea is Salt".

2. Audio Visuals

How Level is Sea Level? Movie, Encyclopedia Britannica, 1970, 13 min., color. Factors affecting sea level - salinity, temperature, air pressure and winds.

Nature of Sea Water. Movie, Dept. of the Navy, 1967, 29 min., color. Temperature, pressure, salinity, density.

Oceanography - Understanding our Deep Frontier. 8 sound filmstrips, National Academy of Science. Chemical Oceanography. Currents, density, salinity, salts as nutrients for plants, origin of salts, etc.

"Understanding Oceanography". 5 sound filmstrips, Society for Visual Education, Inc. "Characteristics of Sea Water". Composition, salinity, temperature, etc.

## Oxygen and Nutrients

Concept 4. Seawater contains all known chemicals. Oxygen and nutrients are two examples which affect the quality of the marine environment.

a. Background Reading

Oxygen is another physio-chemical factor of environmental importance to the coastal waters. Oxygen is very abundant, comprising about 30% of the atmosphere, but the solubility of gases is so low in water that oxygen concentrations are measured in parts per million rather than parts per hundred (per cent). Not much oxygen can dissolve in natural waters under the best of circumstances. Increasing temperature and salinity reduce the amount of oxygen that can be dissolved still further as illustrated in Table 2.

Table 2. Oxygen dissolved in sea water in equilibrium with a normal atmosphere (760 mm) of air saturated with water vapor*

| | Parts per million | | | |
|---|---|---|---|---|
| Salinity % | 0 | 10 | 20 | 30 |
| Temperature °C | | | | |
| 0 | 14.16 | 13.32 | 12.48 | 11.64 |
| 5 | 12.37 | 11.65 | 10.93 | 10.20 |
| 10 | 10.92 | 10.30 | 9.68 | 9.05 |
| 15 | 9.76 | 9.22 | 8.68 | 8.14 |
| 20 | 8.84 | 8.36 | 7.88 | 7.40 |
| 25 | 8.11 | 7.68 | 7.25 | 6.82 |
| 30 | 7.53 | 7.12 | 6.71 | 6.30 |

*Truesdale, G.A., Downing, A.L., and Lowden, G.F., The Solubility of Oxygen in pure Water and Sea Water. Journal of Applied Chemistry, Vol. 5, pp. 53-63, 1955.

These inverse relationships are biologically significant because "cold-blooded" organisms use more oxygen in warm weather than in cold, and thus have the least oxygen available when they need it most. Often these animals respire all the oxygen in a body of warm water, and may die unless more oxygen is supplied. Some fish kills in North Carolina's coastal waters are caused by oxygen depletion, and concern over increasing the number of such fish kills underlies many environmentalists' objections to development plans that would add oxygen demanding materials to coastal waters.

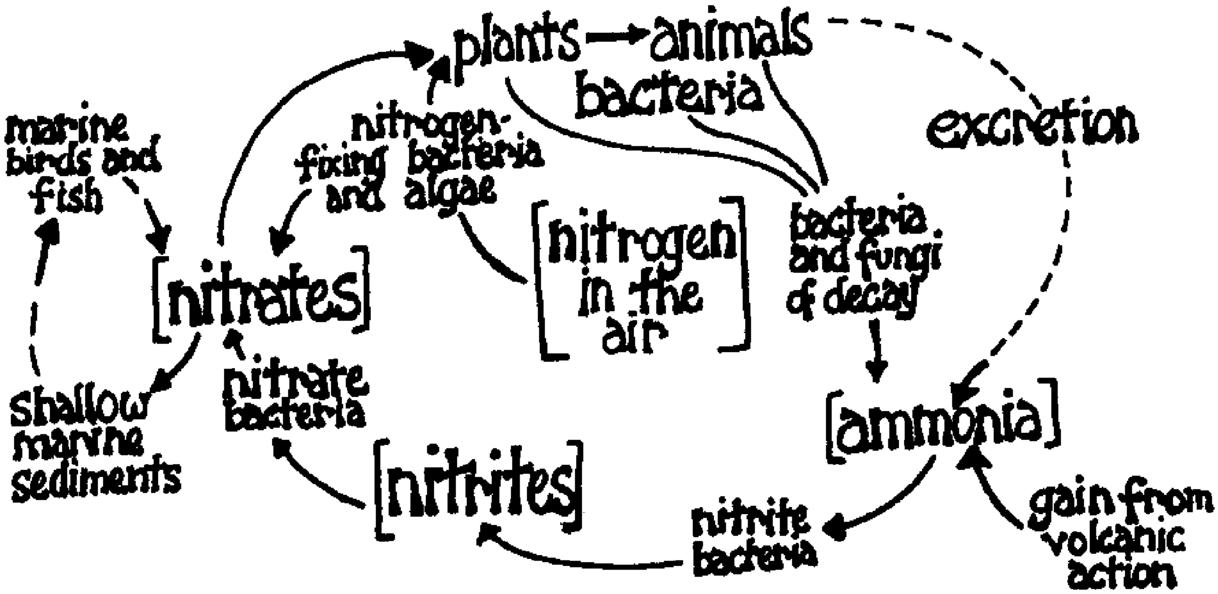
Other environmentally important constituents of coastal waters include nutrients and organic matter. Nutrients are substances needed for plant growth and include nitrogen, phosphorous, silicon, and other elements needed in smaller amounts. Organic matter in coastal waters results from metabolic growth and activity and includes an array of substances ranging from highly reactive sugars like glucose to biochemically refractive compounds like cellulose, lignin, and tannic acid.

Nutrients cycle between inorganic and organic components of ecological systems. Some cycles, like that of phosphorous, are relatively simple; others, like that of nitrogen, are complicated by involving chemical reactions that both cycle elements and transfer energy. Diagrams of general features of these cycles are presented in Figures 12 and 13.

In North Carolina's coastal waters, nutrients come from rivers, from the ocean, and are regenerated by biotic activity within the waters. River input of nutrients is an important and increasing nutrient source. Runoff from heavily fertilized agricultural lands contributes nutrients to coastal waters and rivers. Human nutrient sources add to natural sources to produce a superabundance of phosphorous in many coastal water bodies. Addition of nitrogen to such systems can stimulate plant growth to produce quantities of organic matter that result in an overwhelming oxygen demand that causes such problems as oxygen depletion, fish kills, and smelly masses of decomposing organic matter. North Carolina has largely avoided such problems in the past, but the slow circulation of many of its coastal waters, its high summertime temperatures, and the increasing nutrient loading of its streams causes concern for the future.

Organic matter in North Carolina's coastal waters comes from an array of sources, but the most abundant source is the freshwater swamps that dominate the lower reaches of coastal plain rivers. These swamps, and the decomposing leaves they contain, generate large quantities of biologically inactive compounds such as tannic acids and lignins. These compounds impart a tea-colored appearance to coastal fresh waters, and the color can be traced some distance offshore by the rise of sensitive oceanographic instruments (spectrophotometers). The environmental role of these organic compounds is an active area of current research, so we may soon know more about the role of this characteristic feature of North Carolina's coastal waters.

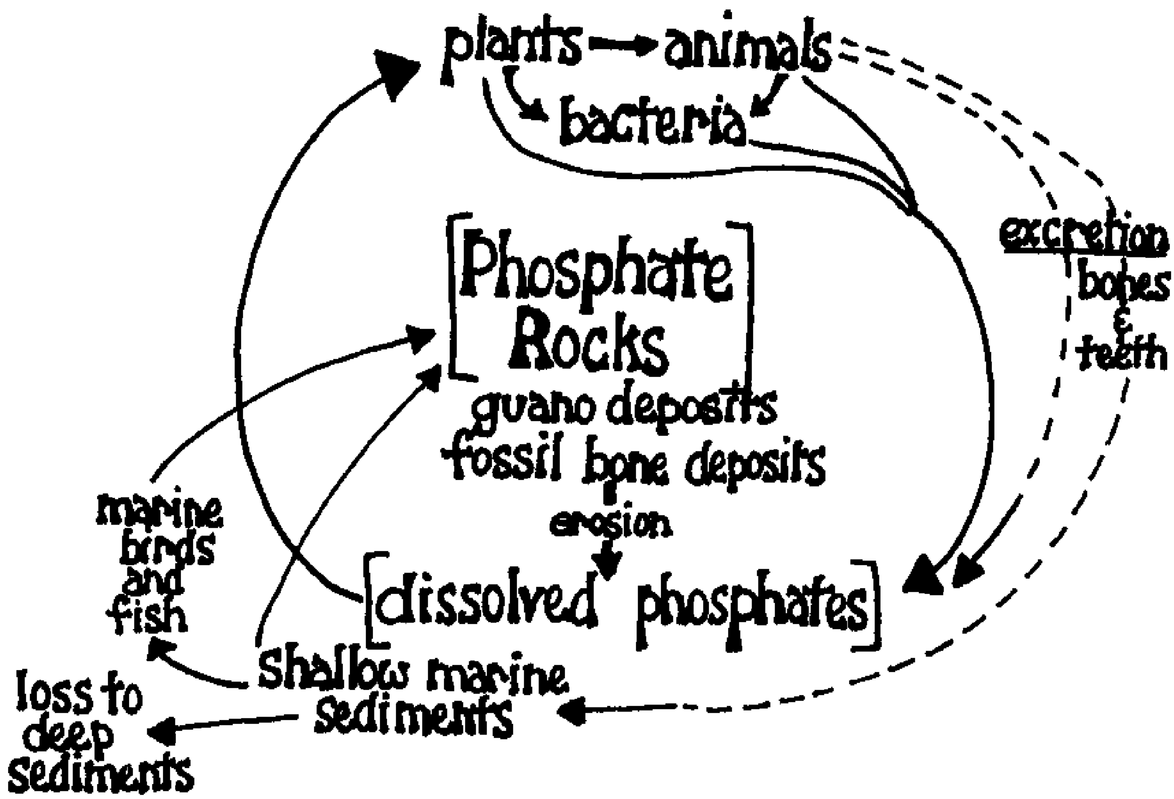
Figure 12: General Features of the Nitrogen Cycle




A. This is a simplified diagram of the nitrogen biogeochemical cycle, an example of a self-regulating cycle with a large reservoir of nitrogen gas. Nitrogen circulates through the system in several forms, changed through the action of living organisms.

From Odum, E. P. 1971. <u>Fundamentals of Ecology</u>. 3rd edition, W. B. Saunders, Philadelphia: p. 88.

Figure 13: General Features of the Phosphorous Cycle




B. The Phosphorous Cycle. Phosphorous is a rare element compared with nitrogen. The ratio of phosphorous to nitrogen in natural waters is about 1/23. Research has shown that the return of phosphate to land has not been keeping up with the loss to the ocean.

From Odum, E. P. 1971. Fundamentals of Ecology. 3rd edition, W. B. Saunders, Philadelphia: p. 88.

b. Vocabulary

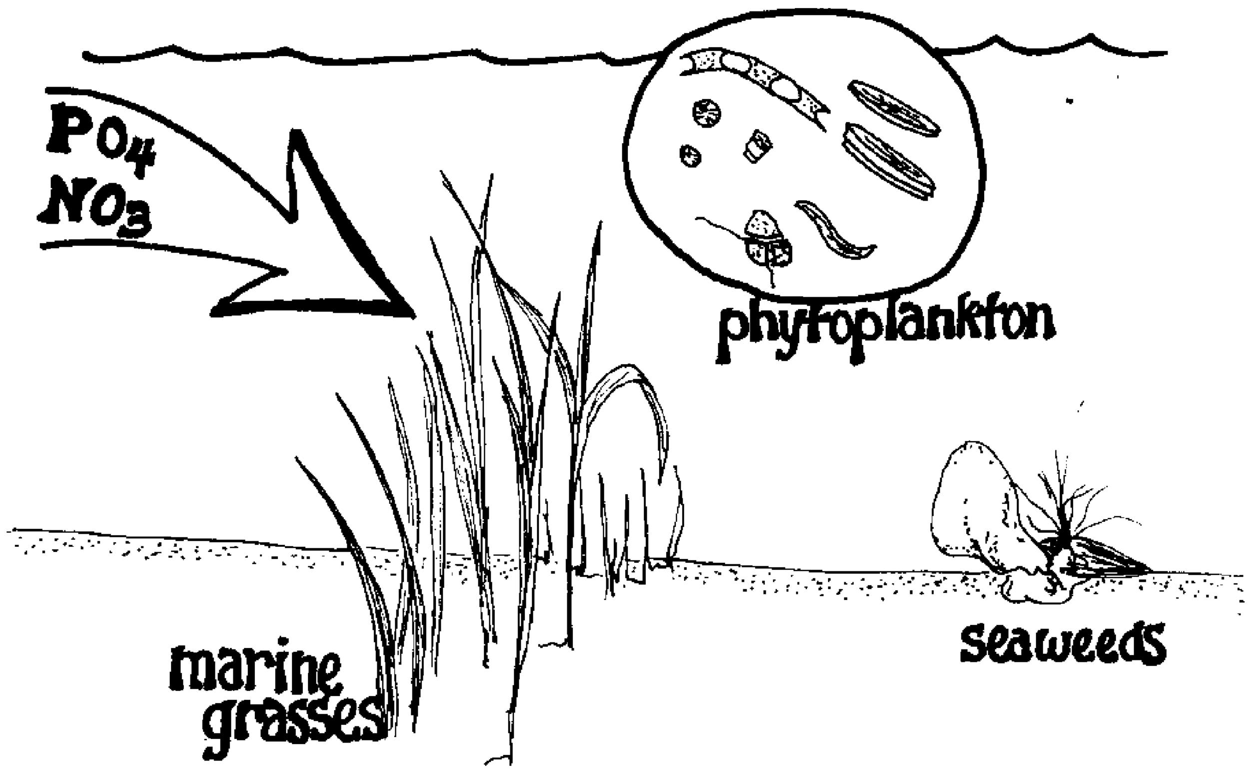
Humic acid (tannic acid) - organic leakages from swamp plants and trees which color the streams brown

Nutrients - fertilizers, mainly nitrates and phosphates, which are necessary for plant growth including phytoplankton and marine grasses and seaweeds

Oxygen depletion - the state in which the amount of oxygen is less than normal. Caused by heating, decay, respiration, or chemical oxidation

Parts per million - unit of measurement for trace elements and gases dissolved in water in the concentration of 1 part of element to one million parts of water

Saturation (oxygen) - the situation when water has dissolved all the oxygen gas possible at a given temperature



C. Things To Do

Oxygen and Water - Sewage in the Sound

1. Objective: To investigate the effects of organic matter on the oxygen level.

2. Teacher Preparation: This activity was designed as a demonstration (Driscoll, J.A., Environment. The Science Teacher. February, pg. 56-57) to show how "sewage" can cause a body of water to have little/no oxygen in it. With a little alteration, the design can become an investigation into how much sewage is too much. Obtain 1% solution of methylene blue, dissolve 20 grams sodium hydroxide in ½ liter of water and add 6 drops of methylene blue solution. Dissolve 20 grams of glucose in ½ liter of water (These measurements do not have to be exact). Have 2 one-quart jars with lids for each group. Smaller samples can be made and then use baby food jars.

3. Procedure:

   1. The jar containing the blue solution is supposed to simulate the blue of a lake or sound. Add the jar of glucose which is like dumping sewage into the lake. Wait about 2 minutes to observe the reaction.

   2. While you wait, pretend that bugs (bacteria) and plants (algae) in the water are "eating" (digesting or absorbing) the "sewage". As long as the blue color exists, the water has oxygen in it.

   3. The organisms use up all the oxygen in the water and the blue solution turns colorless. No fish or other normal life could live in the water now.

   4. How to get oxygen back into the water? One way is to build machines to pump air back in. So, put the lid on the jar and shake the colorless solution. What happens?

   5. Wait and watch what happens again. Repeat. (When all the glucose is consumed, the solution will stay blue.)

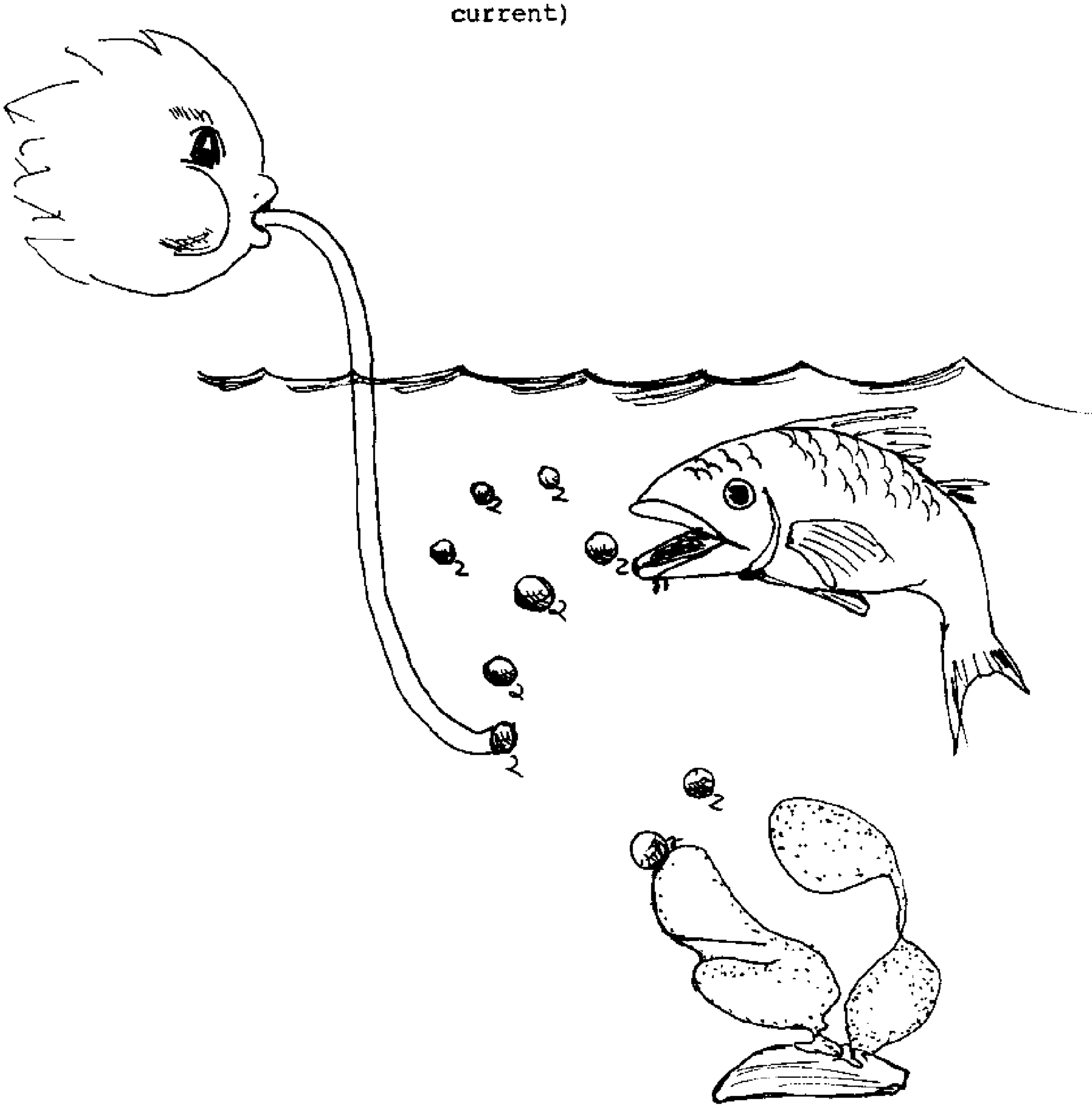
4. Discussion:

   1. How does air (oxygen) get into water? (Dissolved from the atmosphere and produced by photosynthesis)

   2. How does dumping organic matter (leaves, sewage, fats, wood products, glucose) cause the oxygen

to be depleted? (Microorganisms use up oxygen when they decay and break down the organic matter.

3. Discuss how you would solve the problems of water with too much organic matter being dumped into it. (Aerate water to add oxygen and speed up decay by bacteria; flush area with stronger current)



c. Things To Do

How Do We Know There is Air in Water?

1. Objectives:
   1. To have students realize that the oxygen (air) fish breathe is dissolved in water (not a part of the water molecule).
   2. To investigate how increasing temperature will deplete the water of oxygen.

2. Teacher Preparation: This is a very simple demonstration which requires only a jar or beaker, some water, and a heat source (burner, sunshine, school radiator).

3. Procedure: Fill the jar with water; let the students observe it before you put it on some heat source. After a few minutes heating, the sides of the jar will have air bubbles forming and some will pop off to the surface. This is oxygen gas being released from the water. If the water is heated enough, all the oxygen will leave.

4. Discussion:
   1. How did oxygen (air) get into water in the first place? (Diffusion from aeration or plants)
   2. What would have happened to fish if you had them in the jar? (Die from lack of oxygen)

c. Things To Do

Oxygen In Water - One Effect of Thermal Pollution

1. Objective: To investigate the effect of temperature on oxygen.

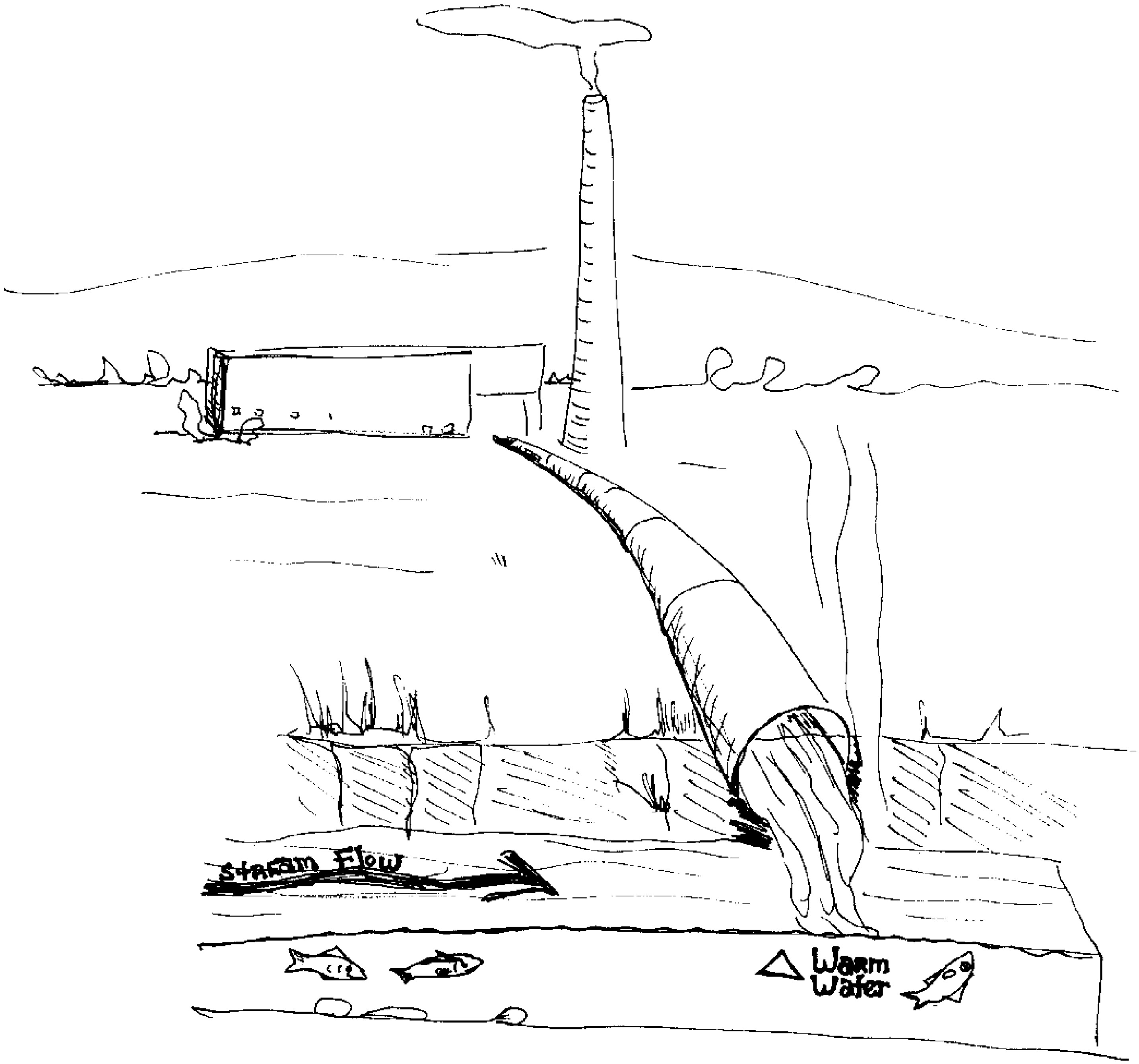
2. Teacher Preparation: Methylene blue solution (1%) is easily obtainable and is a qualitative testing chemical for the presence of oxygen. (With available oxygen, the solution stays blue; without oxygen, the solution turns white.) Dry yeast represents living organisms (bacteria) and powdered milk represents food (sewage). You need each team to have dropper bottle of methylene blue solution, 3 test tubes, heater, thermometer, and syringes without needles (excellent measuring devices for liquids).

3. Procedure:
    1. Prepare solution of milk, adding ½ tsp. of powdered milk to ¼ cup water. Prepare solution of yeast by adding ½ tsp. of yeast to ¼ cup of water.
    2. Warm a beaker half filled with water to 40°C.
    3. Take 3 test tubes, label them 1, 2 and 3. In test tubes 1 and 2, add 3 ml milk solution, add 5 ml of tap water to test tube 3. Add 20 drops of methylene blue indicator to each test tube and stir.
    4. Add 2 ml yeast solution to test tube 1 and 2. Quickly put test tube 2 and 3 into the warmed water of the beaker. Record the time the test tubes were put in water.
    5. Observe each tube carefully. Watch for a complete color change in all three tubes. If it occurs, record the time. Place all the data on a chart in order to compare results.

4. Discussion:
    1. In which test tube did the color change occur the fastest? Why? (#2, yeast developed quicker and used up dissolved oxygen)
    2. What was using up oxygen in test tube 1 and 2? What was the purpose of the third test tube? (Yeast; control)
    3. What two things reduced the amount of oxygen in the water? (Living things and heat)

4. If a fish required a lot of oxygen, would it prefer warm or cold water? Why? (Cold; more dissolved oxygen)

5. If heat builds up in water, e.g. from the discharge of water from a power generating plant, how can this affect the organisms living in the water? (Reduces dissolved oxygen and causes organisms to move or die)



C. Things To Do

### Too Many Nutrients?

1. Objective: To investigate one of the harmful side effects of sewage or organic matter being put into water.

2. Teacher Preparation: This can be a demonstration or team investigation. Two large gallon glass jars are needed in order to compare effects of sewage as a fertilizer on water. Sewage is broken down by bacteria into nitrates and phosphates which can then be absorbed by plants which grow. Single-celled algae "bloom" under high nutrient conditions which cause "eutrophication" - a green farm pond is an excellent natural example. One of the problems with excessive growth is eventually excessive decay and oxygen depletion. Also, the bloom of some plant species prevent the growth of other, more useful, plants.

3. Procedure:
    1. Fill each of the two gallon jars with aged tap water. In each, place a little mat of straw, hay, grass, or scrape a little algae off the sides of an aquarium so as to start a culture of plant algae.
    2. To the experimental jar add a teaspoon of plant fertilizer. Add nothing to the other jar which acts as a control.
    3. Place both jars so they receive equal sunlight.
    4. Keep a record of observations of the jars. (The experimental jar will eventually grow more algae on the sides and in the water.) This, in turn, will support a population of grazing protozoans. These algae and protozoans can be easily seen under low power microscope.
    5. Add additional small amounts of fertilizers every two weeks to the experimental jars.

4. Discussion:
    1. Some rivers and estuaries receive too many nutrients and become eutrophicated (too much plant growth). What would be some sources for these nutrients? (Inefficient septic tanks, sewage effluent, agricultural run-off)
    2. How could septic tanks on islands and estuaries contribute to the problems of eutrophication? What are some alternatives for taking care of

human waste? (Septic systems can seep nitrate- and phosphate-rich water into rivers and sounds. This is particularly true in over-loaded facilities, during wet weather, and in some sandy soils. Some alternatives are self-contained "dry toilets", sewage treatment facilities, ocean outfalls)

d. Resources to Use

References

Environmental Science - Probing the Natural World III. ISCS. Silver Burdett, Morristown, NJ. $5.85. (good chapter on oxygen and eutrophication)

Bolin, Bert. 1970. The Carbon Cycle. Scientific American 223(3):124.

Cloud, Preston and Akaron Gifor. 1970. The Oxygen Cycle. Scientific American 223(3):170.

Deevey, Edward S., Jr. 1970. Mineral Cycles. Scientific American 223(3):148.

Delwicke, C.C. 1970. The Nitrogen Cycle. Scientific American 223(3):736.

Project COAST Materials:
#222 Dissolved Oxygen Measured Qualitatively. Cost $2.50
#223 Air and Life. Cost $2.50

Films

The Breath of Life. 12 min., color, (MacMillan)

Deterioration of Water. 20 min., color.

Learning Corporation of America.