Simulating Coastal Processes in the Classroom

Lesson Plan Outline

- **Background**- Coastal processes are important for residents of an island to understand. Changes in the coastline impact the geology, chemistry, and biology (including humans) of Long Island and our bordering marine environments. An excellent earth science resource is the New York Sea Grant publication titled Long Islands Dynamic South Shore: A Primer on the Forces and Trends Shaping Our Coast by Jay Tanski revised in 2012.
- Materials
  - Stream Table or any container of sufficient size to hold some sand and water.
  - Sand
  - Water
  - Some tools to shape the sand and scoop sand
  - A broad instrument to generate wave action
  - Additional accessories- small toy animals, houses, plants, people, ……
- Activities – Stream Table by Gregory W. Beckway and Maurice Schwartz is helpful for ideas
  - Measure and Contour Map you coastline repeatedly to work on contour mapping and record changes during the lab activities.
  - Wave Action on a perpendicular shoreline
  - Wave Action on shorelines with headlands and islands
    - Spit and tombolo formation can be observed
  - Circular motions create longshore currents and show beach drifting
    - Structures designed to reduce erosion can be incorporated such as groins to see the coastal impacts.
  - Demonstrate Turbidity Currents
  - Transverse and Barchan Dune Formation
  - Sea levels can be altered by adding or removing water
    - Demonstrate tidal changes
    - Show the significance of sea level rise or decline
  - SPECIAL FOCUS- Barrier Island Dynamics
    - Create a barrier island
      - Experiment with or without dunes, man made structures, plants, and varying beach widths.
      - Breaching and man-made inlets with jetties can be studied
    - Show information regarding old/new inlet. This is a naturally formed breach in Fire Island National Seashore produced during Super Storm Sandy. The National Parks Service is monitoring natural Processes without using the Army Core of Engineers to fill the breach. Lectures regarding Sandy's impacts will be available at http://longislandnature.org/ .
      - **Coastal Response to Hurricane Sandy at Fire Island, NY**
        Cheryl Hapke, USGS
        The Development of the Old Inlet Breach and its Impacts on Great South Bay
        Charles N. Flagg, SUNY Stony Brook
        How Superstorm Sandy Changed Sunken Meadow Creek
        Ariana Newell, NYS Parks
- Assessments
  - Regular Earth Science Exams including Regents questions can be used for assessment
  - Lab reports generated from these activities are also useful assessments.

Lesson Linkages

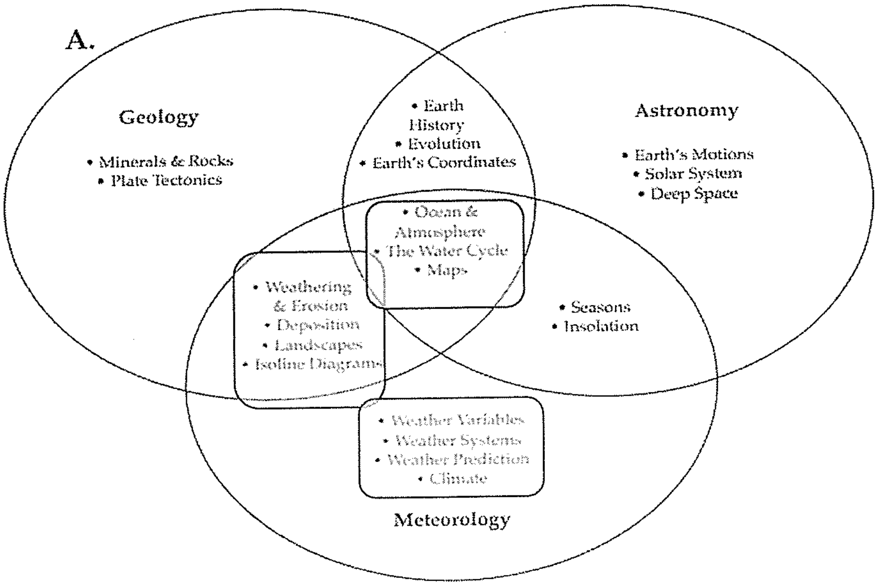
- Winds, Wind Formation, and Wind as a Major Component of Wave Formation
- Climate Change including Sea Level Changes and Weather Variations such as increasing severity of storms in the US
- Tsunami risks and generation could include links to tectonic activity

Coastal Processes Lesson Plan : Initial Instruction or Review Applications Possible

Note: Emphasized and included topics are highlighted

The *Physical Setting/Earth Science Core Curriculum* follows the sequence of Key Ideas and Performance Indicators listed in *Learning Standards for Mathematics, Science, and Technology*. The instructional methods, time allotments, and sequencing of lessons are all decisions that can and should be made at the local level. Local curriculum decisions should be made based on the resources available and with the best interests of the students in mind. The overriding goal should be to cover the material outlined in this Core Curriculum. Some teachers may choose to follow the sequence of topics in the 1970 *New York State Earth Science Syllabus* or the sequence of units in the 1991 *New York State Earth Science Program Modifications*. Many textbooks also present this material in a logical sequence. The diagrams below give two examples of how the material in the Core Curriculum may be organized for curricular and instructional purposes:

A.



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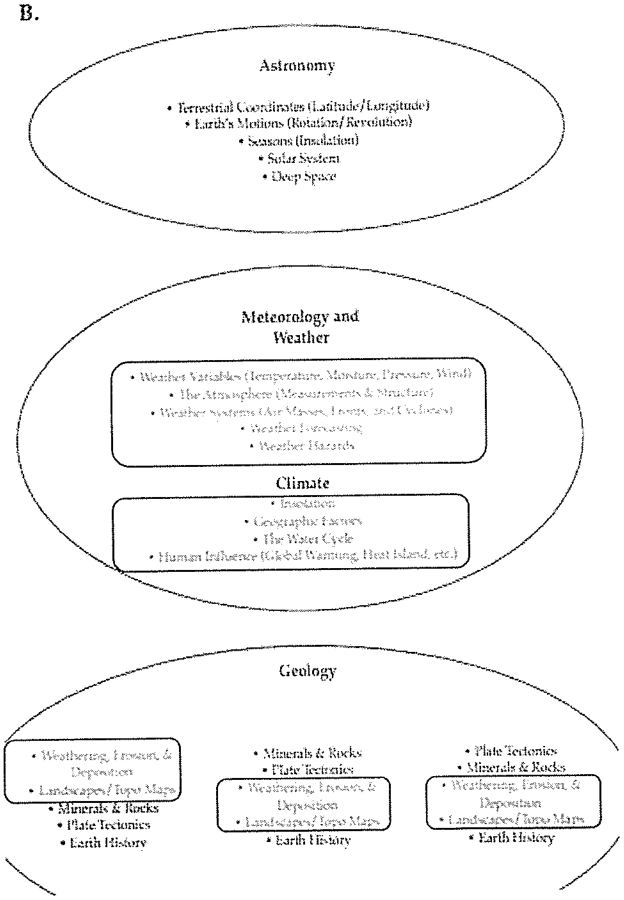


Physical Setting/Earth Science Core Curriculum

Complete List of Standards addressed in this Lesson/Review Activity Plan

*Note: Many standards can be covered or excluded depending on time and depth of lessons and activities performed.

Science process skills should be based on a series of discoveries. Students learn most effectively when they have a central role in the discovery process. To that end, Standards 1, 2, 6, and 7 incorporate in the Physical Setting/Earth Science Core Curriculum *a student-centered, problem-solving approach to Earth Science. The following is a sample of Earth Science process skills. This list is not intended to be an all-inclusive list of the content or skills, but rather a sample of the types of activities that teachers are expected to incorporate into their curriculum. It should be a goal of the instructor to encourage science process skills that will provide students with background and curiosity to investigate important issues in the world around them.*

STANDARD 1—Analysis, Inquiry, and Design

Students will use mathematical analysis, scientific inquiry, and engineering design, as appropriate, to pose questions, seek answers, and develop solutions.

Mathematical Analysis

- ✓ *Key Idea 1:* Abstraction and symbolic representation are used to communicate mathematically.
  - o For example: use eccentricity, rate, gradient, standard error of measurement, and density in context
- ✓ *Key Idea 2:* Deductive and inductive reasoning are used to reach mathematical conclusions.
  - o For example:¥ determine the relationships among: velocity, slope, sediment size, channel shape, and volume of a stream¥ understand the relationships among: the planets' distance from the Sun, gravitational force, period of revolution, and speed of revolution
- ✓ *Key Idea 3:* Critical thinking skills are used in the solution of mathematical problems.
  - o For example:¥ in a field, use isolines to determine a source of pollution

Scientific Inquiry

- ✓ *Key Idea 1:* The central purpose of scientific inquiry is to develop explanations of natural phenomena in a continuing, creative process.
  - o For example:¥ show how our observation of celestial motions supports the idea of stars moving around a stationary Earth (the geocentric model), but further investigation has led scientists to understand that most of these changes are a result of Earth's motion around the Sun (the heliocentric model)
- ✓ *Key Idea 2:* Beyond the use of reasoning and consensus, scientific inquiry involves the testing of
- ✓ proposed explanations involving the use of conventional techniques and procedures and usually requiring considerable ingenuity.
  - o For example:¥ test sediment properties and the rate of deposition
- ✓ *Key Idea 3:* The observations made while testing proposed explanations, when analyzed using conventional and invented methods, provide new insights into phenomena.
  - o For example:¥ determine the changing length of a shadow based on the motion of the Sun

Engineering Design

- ✓ *Key Idea 1:* Engineering design is an iterative process involving modeling and optimization (finding the best solution within given constraints); this process is used to develop technological solutions to problems within given constraints.
  - o For example:¥ after experimenting with conduction of heat (using calorimeters and aluminum bars),make recommendations to create a more efficient system of heat transfer¥ determine patterns of topography and drainage around your school and design solutions to effectively deal with runoff

STANDARD 2

Students will access, generate, process, and transfer information, using appropriate technologies.

Information Systems

- ✓ *Key Idea 1:* Information technology is used to retrieve, process, and communicate information as a tool to enhance learning.
  - o For example:¥ analyze weather maps to predict future weather events¥ use library or electronic references to obtain information to support a laboratory conclusion

- ✓ *Key Idea 2:*Knowledge of the impacts and limitations of information systems is essential to its effective and ethical use.
  - For example:¥ obtain printed or electronic materials which exemplify miscommunication and/or misconceptions of current commonly accepted scientific knowledge
- ✓ *Key Idea 3:*Information technology can have positive and negative impacts on society, depending upon how it is used.
  - For example:¥ discuss how early warning systems can protect society and the environment from natural disasters such as hurricanes, tornadoes, earthquakes, tsunamis, floods, and volcanoes

STANDARD 6—Interconnectedness: Common Themes

Students will understand the relationships and common themes that connect mathematics, science, and technology and apply the themes to these and other areas of learning.

Systems Thinking

- ✓ *Key Idea 1:*Through systems thinking, people can recognize the commonalities that exist among all systems and how parts of a system interrelate and combine to perform specific functions.
  - For example:¥ analyze a depositional-erosional system of a stream

Models

- ✓ *Key Idea 2:*Models are simplified representations of objects, structures, or systems used in analysis, explanation, interpretation, or design.
  - For example:¥ draw a simple contour map of a model landform¥ design a 3-D landscape model from a contour map¥ construct and interpret a profile based on an isoline map¥ use flowcharts to identify rocks and minerals

Magnitude and Scale

- ✓ *Key Idea 3:*The grouping of magnitudes of size, time, frequency, and pressures or other units of measurement into a series of relative order provides a useful way to deal with the immense range and the changes in scale that affect the behavior and design of systems.
  - For example:¥ develop a scale model to represent planet size and/or distance¥ develop a scale model of units of geologic time¥ use topographical maps to determine distances and elevations

Equilibrium and Stability

- ✓ *Key Idea 4:*Equilibrium is a state of stability due either to a lack of change (static equilibrium) or a balance between opposing forces (dynamic equilibrium).
  - For example:¥ analyze the interrelationship between gravity and inertia and its effects on the orbit of planets or satellites

Patterns of Change

- ✓ *Key Idea 5:*Identifying patterns of change is necessary for making predictions about future behavior and conditions.
  - For example:¥ graph and interpret the nature of cyclic change such as sunspots, tides, and atmospheric carbon dioxide¥ based on present data of plate movement, determine past and future positions of landmasses¥ using given weather data, identify the interface between air masses, such as cold fronts, warm fronts, and stationary fronts

Optimization

- ✓ *Key Idea 6:*In order to arrive at the best solution that meets criteria within constraints, it is often necessary to make trade-offs.
  - For example:¥ debate the effect of human activities as they relate to quality of life on Earth systems(global warming, land use, preservation of natural resources, pollution)

STANDARD 7—Interdisciplinary Problem Solving

Students will apply the knowledge and thinking skills of mathematics, science, and technology to address real-life problems and make informed decisions.

Connections

- ✓ *Key Idea 1:*The knowledge and skills of mathematics, science, and technology are used together to make informed decisions and solve problems, especially those relating to issues of science/ technology/society, consumer decision making, design, and inquiry into phenomena.
  - For example:¥ analyze the issues related to local energy needs and develop a viable energy generation plan for the community¥ investigate two similar fossils to determine if they represent a developmental changeover time¥ investigate the political, economic, and environmental impact of

global distribution and use of mineral resources and fossil fuels¥ consider environmental and social implications of various solutions to an environmental Earth resources problem

Strategies

- ✓ *Key Idea 2:* Solving interdisciplinary problems involves a variety of skills and strategies, including effective work habits; gathering and processing information; generating and analyzing ideas; realizing ideas; making connections among the common themes of mathematics, science, and technology; and presenting results.
  - o For example:¥ collect, collate, and process data concerning potential natural disasters (tornadoes, thunderstorms, blizzards, earthquakes, tsunamis, floods, volcanic eruptions, asteroid impacts, etc.) in an area and develop an emergency action plan¥ using a topographic map, determine the safest and most efficient route for rescue purposes

STANDARD 4

Students will understand and apply scientific concepts, principles, and theories pertaining to the physical setting and living environment and recognize the historical development of ideas in science.

Key Idea 2:

Many of the phenomena that we observe on Earth involve interactions among components of air, water, and land.

Earth may be considered a huge machine driven by two engines, one internal and one external. These heat engines convert heat energy into mechanical energy. Earth's external heat engine is powered primarily by solar energy and influenced by gravity. Nearly all the energy for circulating the atmosphere and oceans is supplied by the Sun. As insolation strikes the atmosphere, a small percentage is directly absorbed, especially by gases such as ozone, carbon dioxide, and water vapor. Clouds and Earth's surface reflect some energy back to space, and Earth's surface absorbs some energy. Energy is transferred between Earth's surface and the atmosphere by radiation, conduction, evaporation, and convection. Temperature variations within the atmosphere cause differences in density that cause atmospheric circulation, which is affected by Earth's rotation. The interaction of these processes results in the complex atmospheric occurrence known as weather.

Average temperatures on Earth are the result of the total amount of insolation absorbed by Earth's surface and its atmosphere and the amount of long-wave energy radiated back into space. However, throughout geologic time, ice ages occurred in the middle latitudes. In addition, average temperatures may have been significantly warmer at times in the geologic past. This suggests that Earth had climate changes that were most likely associated with long periods of imbalances of its heat budget.

Earth's internal heat engine is powered by heat from the decay of radioactive materials and residual heat from Earth's formation. Differences in density resulting from heat flow within Earth's interior caused the changes explained by the theory of plate tectonics: movement of the lithospheric plates; earthquakes; volcanoes; and the deformation and metamorphism of rocks during the formation of young mountains.

Precipitation resulting from the external heat engine's weather systems supplies moisture to Earth's surface that contributes to the weathering of rocks. Running water erodes mountains that were originally uplifted by Earth's internal heat engine and transports sediments to other locations, where they are deposited and may undergo the processes that transform them into sedimentary rocks.

Global climate is determined by the interaction of solar energy with Earth's surface and atmosphere. This energy transfer is influenced by dynamic processes such as cloud cover and Earth rotation, and the positions of mountain ranges and oceans.

Performance Indicator 2.1- Use the concepts of density and heat energy to explain observations of weather patterns, seasonal changes, and the movements of Earth's plates.

Major Understandings:

2.1a Earth systems have internal and external sources of energy, both of which create heat.

2.1b The transfer of heat energy within the atmosphere, the hydrosphere, and Earth's interior results in the formation of regions of different densities. These density differences result in motion.

2.1c Weather patterns become evident when weather variables are observed, measured, and recorded. These variables include air temperature, air pressure, moisture (relative humidity and dewpoint), precipitation (rain, snow, hail, sleet, etc.), wind speed and direction, and cloud cover.

2.1d Weather variables are measured using instruments such as thermometers, barometers, psychrometers, precipitation gauges, anemometers, and wind vanes.

2.1e Weather variables are interrelated.

- For example:¥ temperature and humidity affect air pressure and probability of precipitation¥ air pressure gradient controls wind velocity

2.1f Air temperature, dewpoint, cloud formation, and precipitation are affected by the expansion and contraction of air due to vertical atmospheric movement.

2.1g Weather variables can be represented in a variety of formats including radar and satellite images, weather maps (including station models, isobars, and fronts), atmospheric cross-sections, and computer models.

2.1h Atmospheric moisture, temperature and pressure distributions; jet streams, wind; air masses and frontal boundaries; and the movement of cyclonic systems and associated tornadoes, thunderstorms, and hurricanes occur in observable patterns. Loss of property, personal injury, and loss of life can be reduced by effective emergency preparedness.

2.1i Seasonal changes can be explained using concepts of density and heat energy. These changes include the shifting of global temperature zones, the shifting of planetary wind and ocean current patterns, the occurrence of monsoons, hurricanes, flooding, and severe weather.

2.1p Landforms are the result of the interaction of tectonic forces and the processes of weathering, erosion, and deposition.

2.1q Topographic maps represent landforms through the use of contour lines that are isolines connecting points of equal elevation. Gradients and profiles can be determined from changes in elevation over a given distance.

2.1r Climate variations, structure, and characteristics of bedrock influence the development of landscape features including mountains, plateaus, plains, valleys, ridges, escarpments, and stream drainage patterns.

2.1s Weathering is the physical and chemical breakdown of rocks at or near Earth's surface. Soils are the result of weathering and biological activity over long periods of time.

2.1t Natural agents of erosion, generally driven by gravity, remove, transport, and deposit weathered rock particles. Each agent of erosion produces distinctive changes in the material that it transports and creates characteristic surface features and landscapes. In certain erosional situations, loss of property, personal injury, and loss of life can be reduced by effective emergency preparedness.

2.1u The natural agents of erosion include:

- ¥ *Streams (running water):* Gradient, discharge, and channel shape influence a stream's velocity and the erosion and deposition of sediments. Sediments transported by streams tend to become rounded as a result of abrasion. Stream features include V-shaped valleys, deltas, flood plains, and meanders. A watershed is the area drained by a stream and its tributaries.
- ¥ *Glaciers (moving ice):* Glacial erosional processes include the formation of U-shaped valleys, parallel scratches, and grooves in bedrock. Glacial features include moraines, drumlins, kettle lakes, finger lakes, and outwash plains.
- ¥ *Wave Action:* Erosion and deposition cause changes in shoreline features, including beaches, sandbars, and barrier islands. Wave action rounds sediments as a result of abrasion. Waves approaching a shoreline move sand parallel to the shore within the zone of breaking waves.
- ¥ *Wind:* Erosion of sediments by wind is most common in arid climates and along shorelines. Wind-generated features include dunes and sand-blasted bedrock.
- ¥ *Mass Movement:* Earth materials move downslope under the influence of gravity.

2.1v Patterns of deposition result from a loss of energy within the transporting system and are influenced by the size, shape, and density of the transported particles. Sediment deposits may be sorted or unsorted.

LESSON PLAN

Stream Table

By Gregory W. Beckway
Maurice Schwartz

HUBBARD

EARTH SCIENCE
GEOLOGY

INTRODUCTION

The *stream table* provides students with an excellent means of familiarizing themselves with the major processes of earth sculpture. With the help of the *stream table,* it is possible for the students to see landforms, that they would not have a chance to observe in the field. In addition, it gives them the unique opportunity of creating and witnessing the natural geological processes that are too slow to experience in reality. Thus the *stream table* is a valuable laboratory tool in teaching physical geology.

The Lesson Plan gives instructions on the simulation of stream processes, mass wasting, the formation of coastal features, the action of glaciation, and the structural deformation of the earth's crust. It poses many open-end questions that challenge the student to formulate basic concepts through direct observation. The *stream table* may be used for student laboratory experiments as well as teacher demonstrations. It has scope for the performance of innumerable experiments and the exploration of many new subjects.

CORRELATING THE DEMONSTRATIONS

The demonstrations and experiments in this booklet can be correlated wih the Geology/Stream Table film loops, the books on Aerial Stereo Photographs and Aerial Stereo Studies, Stereo Atlas, Geology Transparencies, Geology View Files I & II, Geology Models, and Elementary Geology Models. This complete set of products offered by Hubbard Scientific Company will augment and enhance student observations of the *stream table* investigations.

CONTENTS

INSTRUCTIONS ON USE

INVESTIGATIONS

RUNNING WATER

MASS WASTING

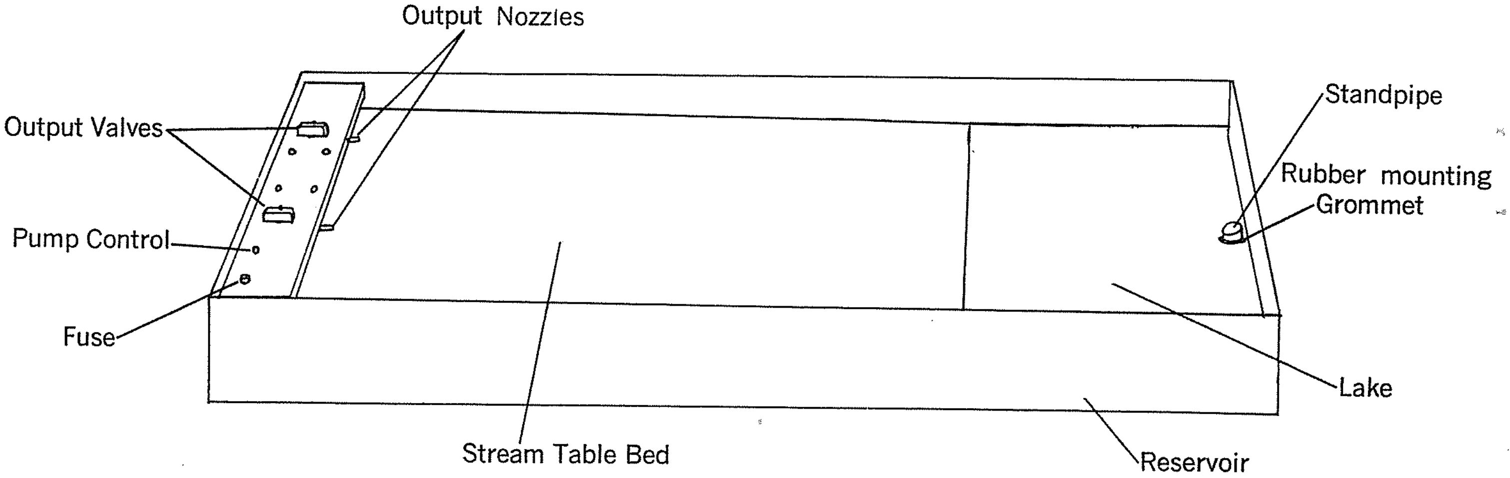
COASTAL PROCESSES

GLACIATION

CONSERVATION

Printed in U.S.A.

The Stream Table



The apparatus consists of a large ***stream table bed*** with an inclined bottom. The bottom levels off, at the lower end, to form a ***lake.*** Water can be filled in the lake and its depth determined by adjusting the height of the ***standpipe*** in its ***rubber mounting grommet.*** The standpipe can be removed completely from the grommet and the water from the lake allowed to drain into the ***reservoir*** under the stream table bed.

At the upper end of the table, is the control panel, with two ***output valves*** that control the flow of water through the ***nozzles.*** The rate of the water flow can be adjusted by turning the output valves. Water flow may be increased without causing turbulence by attaching a piece of plastic tubing to the nozzle and running the water through it.

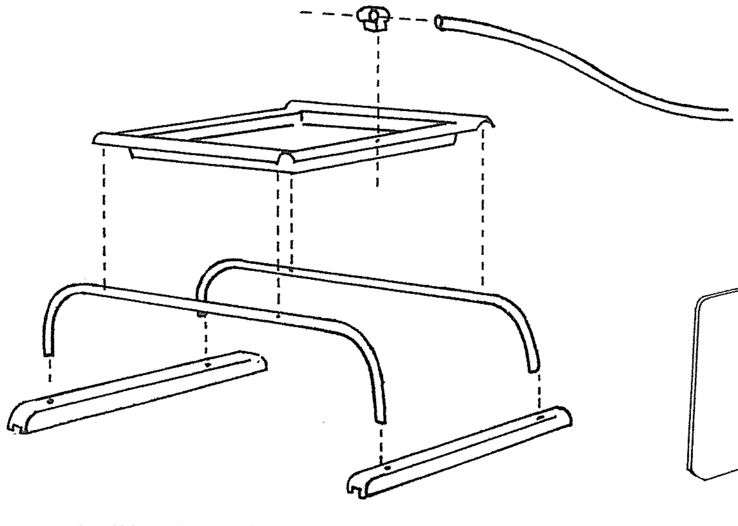
Another control operates the ***pump.*** Water can be pumped from the reservoir, through the nozzles, onto the stream table bed and into the lake. The water may be directed elsewhere, as required, by attaching a piece of tubing to the nozzle.

ACCESSORIES

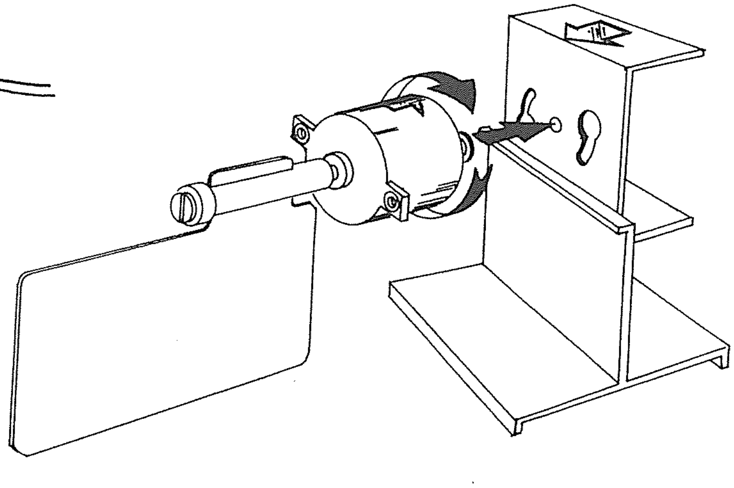
The *rainmaker set-up* may be mounted on the sides of the *stream table.* When filled with water, it causes a rainfall through its perforated bottom. It can be slid along the sides to cause a rainfall anywhere on the table.

The *wave generator set-up* is a self-contained stand and, when operated, creates waves in any direction. It is designed for use **only** with the Hubbard Stream Table.

Other accessories that facilitate experimentation, include an *acrylic marking grid, plastic landform models, stream dividers, colored sand, wire screen* and a *sand trowel.*



RAINMAKER SET-UP



WAVE GENERATOR SET-UP

INSTRUCTIONS ON USE

STREAM TABLE SET-UP

1. After unpacking the unit, place it on top of the *Hubbard Scientific Stream Table Cart,* STC-910, or a surface capable of adequately supporting 200 lbs. The *stream table* must be in a level position to function properly.
2. Remove the standpipe from its rubber mounting grommet, and pour 9 to 10 gallons of water into the reservoir through the standpipe opening. Replace the standpipe.
3. Fill the inclined area of the stream table "bed" with approximately 50 lbs. of fine silica sand. *(Hubbard Scientific* ST-904 *Sand Kit* is available with a reusable storage pail.) Spread the sand to the desired inclination.
4. Turn off both water output valves (handles turned 90° to the outlet nozzle direction.)
5. Plug the power cord into a properly grounded, 115 volt A.C. wall receptacle.

   Note: The power cord is equipped with an integral grounding prong. Do not defeat this grounding provision. If you are not sure that the wall receptacle is grounded, consult a qualified electrician who can check this important function for you.
6. Turn on the system with the toggle switch, and adjust one or both water output valves to the desired flow. Increased water flow with reduced turbulence may be obtained by placing a 2 to 3-inch-long piece of plastic tubing over the water output nozzles. Cut the tubing from the length included with your *stream table.*

MOVING

1. If the unit is to be moved a few feet, and is on a wheeled cart, raise the standpipe and fill the "lake" area to its maximum. This will reduce the possibility of water splashing out through the ventilating louvers on the control panel end of the table.
2. When the *stream table* is to be moved from a stationary support, attach the plastic hose provided to one of the water outlet nozzles. Turn off the other outlet valve, turn on the pump and drain the system into a sink or bucket. (This will take 4 to 5 minutes.)

STORAGE

1. Allow the unit to remain unused for several days to dry the sand.
2. Remove the sand and return it to its storage container.
3. Pump out the reservoir as in No. 2 above.
4. Remove most of the remaining residual water by raising the standpipe end of the unit a few inches, while running the pump.
5. Store the unit horizontally or vertically where it will receive some amount of air circulation.

TROUBLE-SHOOTING

If Pump Will Not Operate

1. Make sure line cord is securely plugged into an operative wall receptacle.
2. Unplug unit, remove fuse cover and check for a faulty fuse. If the fuse is blown, replace with the spare included with the *stream table,* or obtain a 3 AG 1 amp. fuse from a local electronics supply house. Plug in unit and turn on switch. If fuse again blows, consult your Hubbard representative for proper, corrective action.

Pump Output Continues At a Reduced Rate

Should the supply of water to the pump become reduced (from movement of the table, heavy water use by accessories, or evaporation of the water) air will become trapped in the system, causing the pump to "cavitate." To rectify this, turn off the pump, open both water output valves, and wait a few seconds before restarting the pump. Should the problem continue, check the table for level mounting, and be sure that with all water in the reservoir, the depth as measured through the standpipe opening is 1¼" minimum.

Pump Jams or Flow is Reduced by Obstruction

The circulation system is designed to handle large quantities of sand without any danger of damage to itself. If, however, a large foreign object such as a pebble has fallen into the reservoir, and somehow finds its way to the pump, it may cause a jam.

1. Turn off pump and open both valves.
2. Connect the plastic drain hose to one output nozzle.
3. Forcibly blow into the free end of the attached hose.
4. Repeat the above operation with the other nozzle.
5. Restart the pump after disconnecting the hose.

ACCESSORIES

Rainmaker Set-Up

1. Assemble the supporting structure for the perforated rain tray by pressing the ends of the metal tubing into the guide blocks, as shown. "Square up" the assembly so that the grooves in the guide blocks ride on the sides of the *stream table.*

2. Squeeze the hose support, while pushing its tab ends down through the hole in the side flange of the perforated tray.
3. Place the perforated tray over the supporting tubes so that the tray will slide from side to side if desired.
4. Push the plastic hose through the hose support so that the water will pump into the tray and connect the other end of the hose to the nozzle of one water output valve.
5. Be sure that the tray is in a level position.

Operation

1. A new or unused (dry) tray will not produce "rain" in an even manner. To rectify this, put a few drops of liquid detergent into the tray as it fills, or rub the bottom of the tray with the palm of your hand a few times as the drops begin to form.
2. Regulate the intensity of the rain by controlling the depth of the water in the tray with the *stream table* water output valve.

Wave Generator Set-Up

The wave generator has two parts: (1) the paddle/motor assembly and (2) the battery stand.

Caution:

Do not allow water or sand to get into the motor and/or the battery case. Assemble and disassemble the wave generator away from the stream table. Turn off (disassemble) the wave generator when not in use.

Assembly

1. With the battery stand upright and its open case facing you, place two "D-cell" batteries into the case. Place the battery on your left TOP UP, the battery on your right TOP DOWN. The correct position of the batteries is also indicated on the inside of the case.
2. Take the paddle/motor assembly in your left hand with the paddle extending to the left and the arrow on top of the motor case pointing to the right.
3. Take the battery stand in your right hand with the square base flat and the arrow on top of the battery case pointing to the left.
4. Bring the two components together until the center pin on the motor is in the center hole on the battery stand.
5. Rotate the motor assembly one-half inch COUNTERCLOCKWISE. The two motor terminals will slip into the two holes on the battery stand simultaneously.
6. Rotate the motor assembly one-half inch CLOCKWISE until the arrows are facing. The motor terminals will lock into place on the battery stand, starting the motor and turning the paddle.
7. To stop the motor, rotate the motor assembly one-quarter inch COUNTERCLOCKWISE.
8. To remove the motor and paddle, continue turning the assembly COUNTERCLOCKWISE and lift it off.
9. The wave generator can be faced in any direction and placed at any point in the water at depths of up to 2½ inches. Make sure the paddle, when turning, has clearance from any stream table wall. For stronger waves, move the generator closer to the shoreline.

Hubbard Scientific Contour Grid

Mount the *grid* on the *stream table* sides. Be sure that the printed *grid* is on the underside to prevent its erasure during use and cleaning. Do not over-tighten the wingnuts.

The surface of the *grid* will give long and satisfactory service if handled carefully to prevent scratching. Use a grease pencil or felt-tipped marker with washable ink to make the charts. Remove markings with soap and water, and a soft cloth. Alcohol and a soft cloth may also be used.

RUNNING WATER

The most powerful of all agents is running water. Year after year, it sweeps vast quantities of earth materials from the land surface into the oceans. The result of its work, through the ages, stands as vast systems of valleys and canyons, that can be observed in all parts of the world.

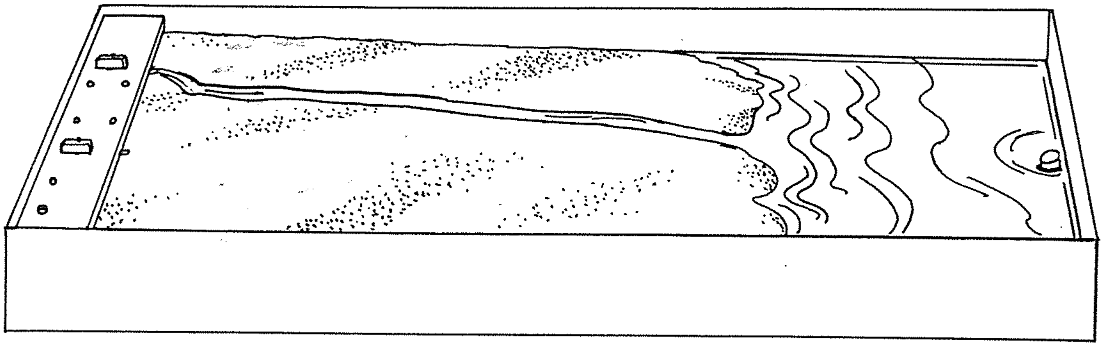
STREAM EROSION CYCLE

Valleys carved by streams pass through three major stages: ***youth***, ***early maturity***, and ***full maturity***. Though it is impossible to draw sharp divisions between the stages, each stage has its own characteristic features.

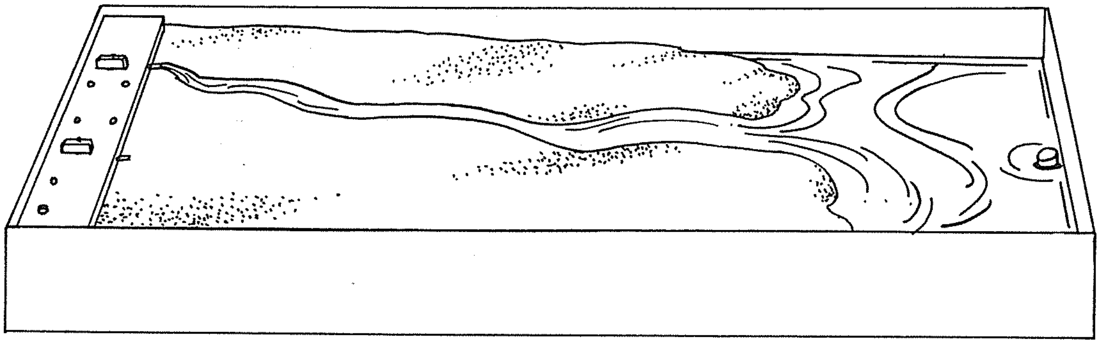
In its youth, a stream usually flows through mountainous terrain. It has a small volume but it has a great velocity, so it cuts mainly downward, and straight ahead. As a result, its valley is usually deep, narrow and straight.

In early maturity the stream emerges from the mountains. It has a larger volume but a slower speed than before. It begins to cut sideways, as well as downward. As a result, it takes a winding course through a wider valley.

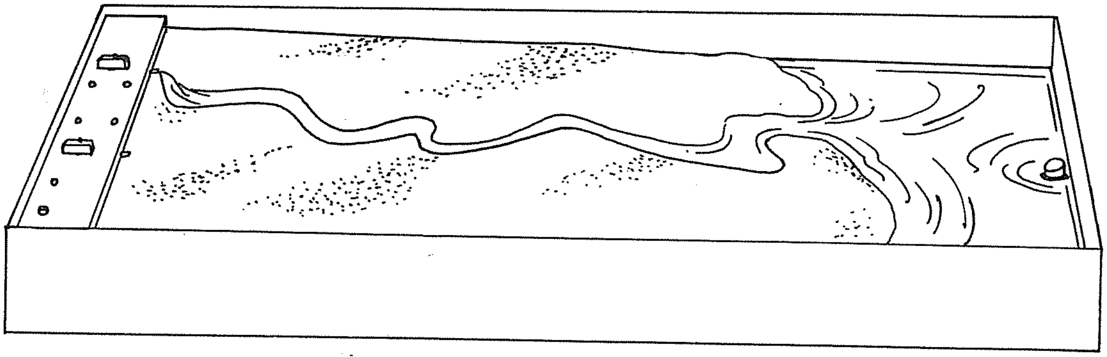
In late maturity, the stream flows over a flat plain. It has a large volume of water but its speed is very slow. Most of its cutting action is lateral and there is much deposition. As a result the stream winds considerably, often doubling back on itself. It has removed its valley walls almost completely, so only a flat, and often swampy, plain remains.



YOUTH



EARLY MATURITY



OLD AGE

PROCEDURE

The fluvial cycle can be recreated on the *stream table.* Moisten the sand and shape it into a smooth surface sloping toward the standpipe. Terminate the slope in a sharp edge. Carve a straight narrow channel from one of the outlet nozzles up to the edge of the slope.

Make sure both water output valves are closed before plugging in the power cord. Place the plastic stream deflector beneath the outlet nozzle at the head of the channel. Fill water in the lake, at the lower end of the *stream table,* to a depth of 1½″. The depth can be determined by adjusting the drainpipe 1½″ above the bottom.

Open the valve and allow the water to flow moderately onto the deflector and drain down the valley. Place the acrylic *grid* over the edges of the table and trace the borders of the stream onto it. Trace the edge of the valley after every 5 minutes using a different colored pencil each time. At frequent intervals sprinkle colored sand into the stream and examine its movement.

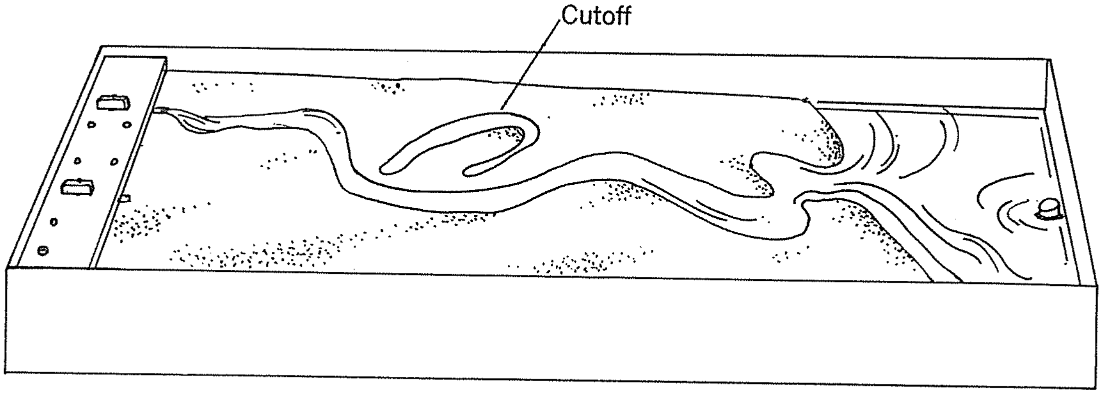
OBSERVATIONS

The observer will notice that the stream changes from its youthful straight course in a narrow, steep-walled valley, to a more mature meandering course, in a wider valley with more gently sloping walls.

These signs of maturity appear first at the mouth of the stream and gradually work their way upstream. The path of the colored sand grains reveals that the water takes an increasingly meandering path. The increase in the velocity of water on the outside of each meander is revealed by the piling up of the colored grains there.

STREAM CUTOFFS

When a stream reaches its last stage in the erosion cycle, commonly referred to as old age, the meanders become so deep, that the channel curves back on itself. The loops continue to deepen, until the water, instead of taking the long curving path along the meander, breaks through the narrow neck of land between its two ends. The stream channel is shortened and the meander, cut off from the course, forms an oxbow lake. If its water supply is replenished by ground water, the oxbow lake may remain. If it dries up, the trace of its channel remains as a meander scar.



PROCEDURE

Shape the moist sand into a smooth slope. At the end of the slope, form a lake one inch deep. Cut a sharply meandering channel leading from one of the outlet nozzles, down the entire length of the slope. Open the outlet valve and allow a gentle flow of water down the channel. Sprinkle colored sand into the stream and observe carefully where the grains move the fastest. Wait until a cutoff occurs. Observe the flow of water through the cutoff.

OBSERVATIONS

The sand will shift to the outside of each meander as it moves downstream, revealing the greater velocity there. After the cutoff occurs, water does not flow into the meander, and sand deposits around its neck.

STREAM PIRACY

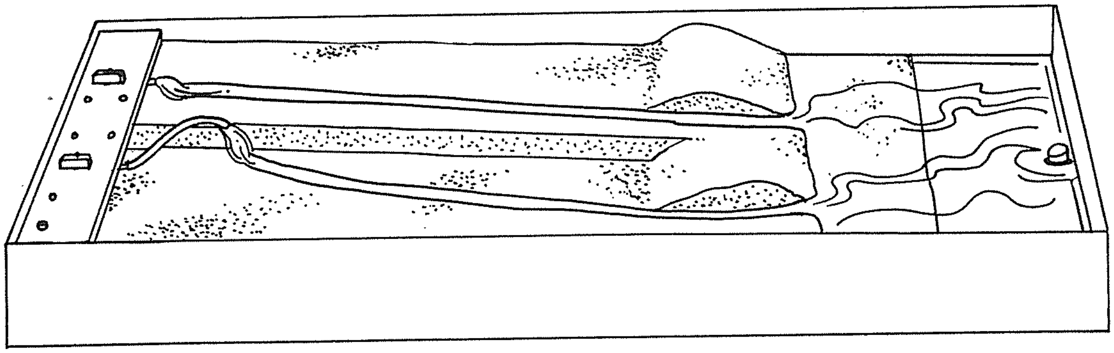
Stream piracy is the capture of the water of one stream by another. It can result from the headward erosion of a stream source or from the lateral erosion of the more mature part of the stream.

The rate of the headward erosion of a stream depends on its gradient. A stream with a high gradient will erode rapidly into the slope behind it until its headwaters come in contact with those of another stream, which has a lower gradient. Since water will take the slope that is the steepest, the water of the stream with the lower gradient will be diverted down the steeper gradient.

The lateral cutting of mature streams causes the valley sides to recede from the stream. The wall between the two adjacent streams becomes narrower and disappears. The two channels then occupy a single valley and a change in the course of one stream may cause the two channels to merge. Thus, streams capture the upper parts of their own tributaries.

Often, streams cut straight through mountain ridges or scarps that run across their course. The V-shaped notches through which they flow, are called water gaps. If a stream is diverted out of the water gap by piracy the dry notch is known as a wind gap.

Part A — Stream Piracy by Headward Erosion



PROCEDURE

Distribute the sand so that there is more on one side of the table than on the other. Shape the sand on both sides to form smooth slopes down to the shoreline. Construct a low ridge of uniform height, parallel to the shoreline, at the lower end of the slopes.

Carve a stream channel down the side of the table that has the higher slope. Pass it through a notch in the ridge to the shoreline. Form another diagonal channel from the shoreline, through a notch in the ridge, diagonally up the lower slope and on to the upper slope until it approaches the other channel. Place the *grid* over the table and sketch the streams on its surface with a water soluble marker.

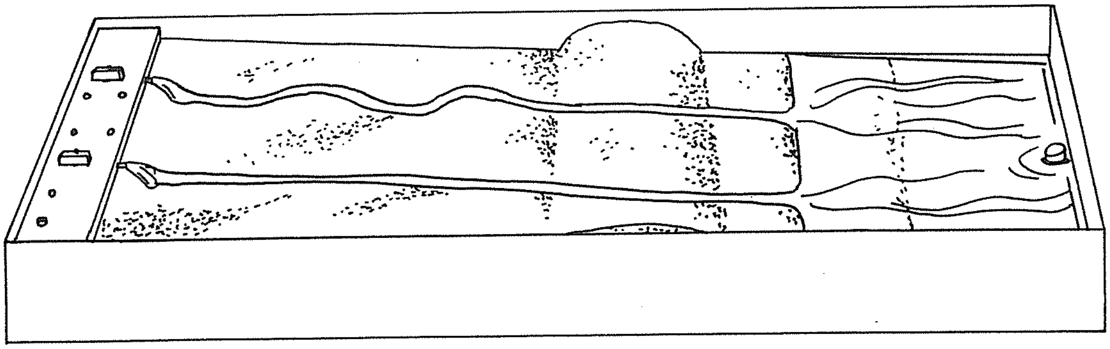
Open the valve nearest the higher slope and direct the flow of water into the source of the channel on higher ground. Fit a piece of plastic tubing onto the outlet nozzle nearest the lower slope and direct the water into the mouth of the diagonal channel. Move the hose upstream until it reaches the first stream. Carefully note the change in the movement of water through the channel and the gaps. Sketch the changes in the drainage on the *grid.*

OBSERVATIONS

In this experiment, headward erosion is simulated by moving the source of water upslope. When the source of the faster stream intersects the slower stream, the water of the slower stream is diverted into the faster stream.

Since the higher stream no longer flows through the water gap in the ridge, the gap becomes a wind gap.

Part B — Stream Piracy by Lateral Planation



PROCEDURE

As before, push most of the sand onto one half of the table, form an upper and lower slope and a low ridge along the shoreline. Carve a straight channel down the upper slope, close to the middle of the table. On the lower slope, form a broadly meandering stream channel with meanders closely approaching the first channel. Pass the channel through a gap in the ridge and to the shoreline. Make an overhead drawing on the *grid.*

Open a valve and let water flow down the channel on higher ground. Direct another flow down the meandering channel. After a few minutes, make a second overhead drawing of the two channels.

OBSERVATIONS

The meandering stream will cut laterally through the divide that separates it from the adjacent stream.

When the two streams meet, the water of the stream on higher ground will be diverted into the stream on lower ground, since the slope toward the lower stream will be greater than the slope of the channel of the stream on higher ground. The former water gap will remain as a wind gap.

WATERFALLS

Waterfalls have long been recognized as one of the most beautiful features of nature's landscape. What brings about the development of these nearly vertical drops in the stream channel?

When the stream bed is made up of hard rock that overlies soft rock, the erosion of the stream bed is slow; until the soft layer is exposed. Once it is subjected to erosion, the soft layer wears away rapidly and the edge of the hard layer stands as a cliff over which the water must fall.

The falling water cuts a basin-like plunge pool in the soft rock at the foot of the fall. It also removes the softer rock under the hard by undercutting and leaves the hard layer without support.

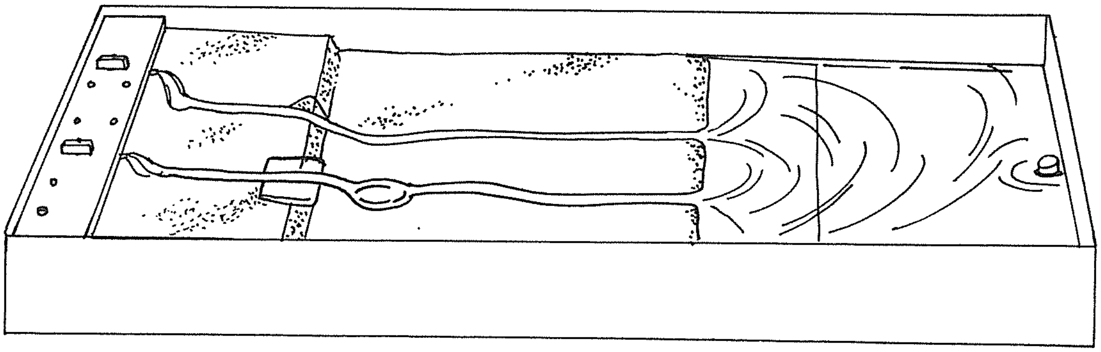
The unsupported portion then breaks off and falls into the channel below, forming a new cliff-edge a few feet upstream from the old edge. Consequently, the waterfall over the new edge is a few feet upstream from its former location.

By repeated undercutting and collapses, the fall migrates upstream. The Niagara Falls are a good example of falls of this nature. They have receded nearly 700 miles upstream since they were formed.

Another reason for the formation of falls is the differential erosion of large streams and their tributaries. Large youthful streams flowing rapidly down steep slopes, cut deep, narrow gorges relatively quickly. Since the tributaries carry less water, they are not able to cut downward at the same rate as the main stream and their channels remain high above the main stream as hanging valleys. To enter the main stream, the tributaries must fall over the edge of the hanging valley. Hanging valleys can also be found where glaciation has scoured the main valley to a level below its tributary valleys.

Waterfalls also develop when stream valleys are crossed by vertical faults. The vertical displacement of a part of the stream bed along the fracture produces a scarp or steep cliff over which water must tumble to the lower reaches of its channel.

Part A — Erosion of Waterfalls



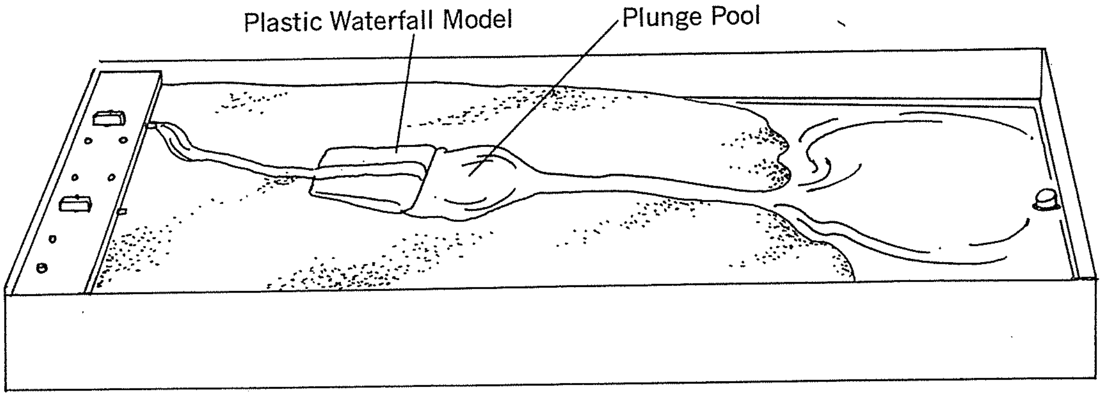
PROCEDURE

Form a steep cliff along the width of the *stream table.* Carve two channels leading from the valves, across the cliffs, to the shoreline. In the path of one of the channels, place the plastic waterfall in the cliff. Open both outlet nozzles and direct a heavy flow of water down each channel for five minutes. Make an overhead drawing of the changes.

OBSERVATIONS

The stream flowing over the sand cliff quickly erodes the cliff into a series of rapids, while the protected cliff preserves its vertical shape. In nature, these capped waterfalls migrate upstream by undercutting.

Part B — Waterfalls Produced by the Varying Hardness of the Underlying Rock



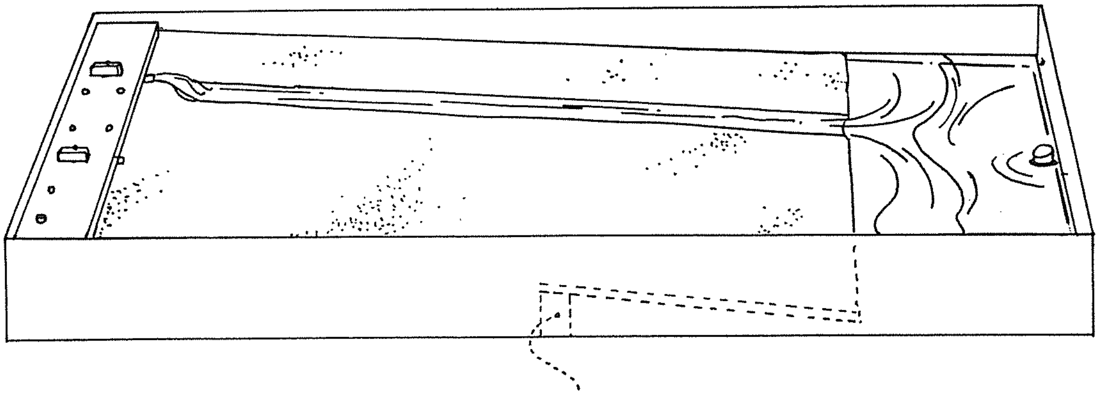
PROCEDURE

Bury the plastic *waterfall* about ¼ inch below the surface of the sand, midway down the *stream table,* and form a smooth slope to the shoreline. Form a channel passing over the buried *waterfall,* and extended along the entire length of the slope. Direct a heavy flow of water down the channel until the *waterfall* is exposed and a plunge pool begins to form at the base of the fall.

OBSERVATIONS

The plastic *waterfall* represents a resistant layer of rock that is uncovered by the stream. Its edge represents the cliff over which the water falls into the plunge pool.

Part C — Waterfalls Produced by Faulting



PROCEDURE

Remove all the sand from the lower half of the table. Place a piece of plywood about 1½ feet long on the floor of the table so that one end lies about 1 foot from the standpipe, and the board extends about half way along the length of the table.

Prop up the end of the plywood near the middle of the table on two-by-four blocks. Smooth the sand over the board forming a uniformly sloping surface from the outlet nozzles to the end of the board.

Carve a channel from one nozzle down the entire length of the slope. Direct a light flow of water down the channel. While the water is still flowing, quickly remove the supporting blocks. The supports may be removed by pulling a string tied to them previously.

OBSERVATIONS

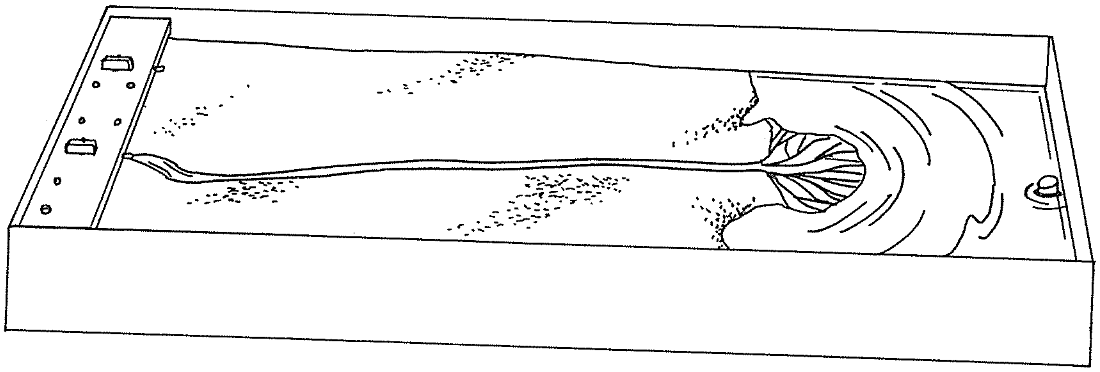
The dropping of the board upon the removal of the supports represents faulting. A small scarp will form in the sand on the upstream side of the fault. Observe that the stream erodes away this scarp quite rapidly. It should be made clear that if the scarp were formed of rock rather than sand, the waterfall would be eroded away less rapidly.

DELTA

When a stream enters an ocean or lake, its velocity is reduced. It can no longer carry its load and the transported material is deposited on the floor of the ocean or lake. The debris blocks the channel, forcing the stream to break up into numerous ill-defined distributaries. The resulting landform is a delta.

The surface of the delta can have different patterns, depending on the distributaries of the stream and the nature of the shoreline. The cross section of a delta reveals three distinct types of beds.

Part A — Growth of a Delta



PROCEDURE

Shape the sand into a smoothly sloping surface down to the shoreline. Carve a narrow channel from one of the nozzles, along the entire length of the sand. Adjust the standpipe to a height of 2 inches and fill the lower end of the table with 2 inches of water.

Direct a heavy flow of water down the channel for 30 seconds, then turn it off. Place the *grid* over the delta that is formed, and make an overhead drawing of it. Trace the stream distributaries if any have formed.

Direct another heavier flow of water down the channel for 2 more minutes and make another overhead drawing. Allow another flow for 5 minutes, then make a final drawing.

OBSERVATIONS

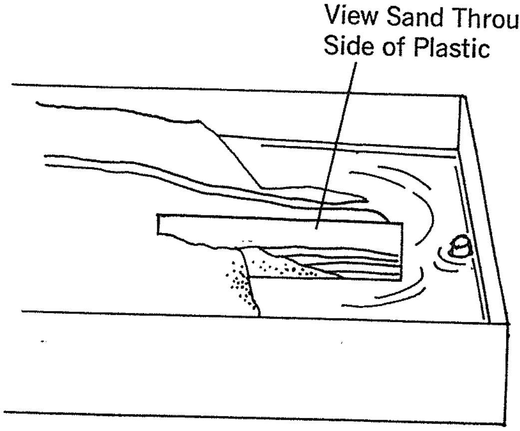
The water body will check the speed of the stream, and its load will be deposited. The channel will extend through the deposits into the water body. After a while, as deposits accumulate, distributaries break through the channel walls.

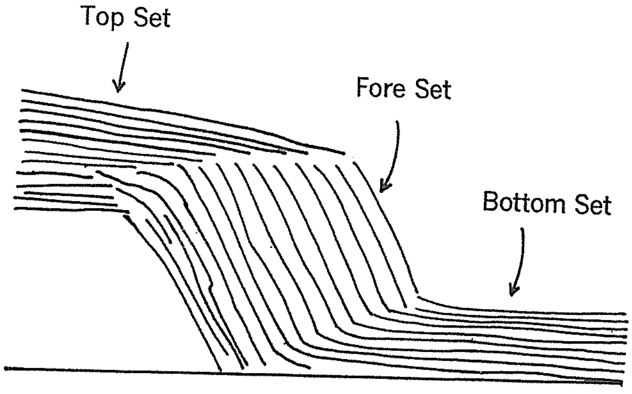
The first drawing should show one small lobe of sand extending into the water.

The second drawing should show a better developed delta, with several overlapping lobes and two or more distributaries, or distributary scars.

The third drawing should show a delta, nearly semicircular in shape, with many distributary scars formerly occupied by the streams.

Part B — Cross-Section of a Delta





Cross Section

PROCEDURE

Reshape the sand as in Part A and carve a narrow channel from one of the outlet nozzles to the shore. Insert the clear plastic *divider* vertically into the sand at the end of the channel so that it extends out into the lake.

Direct a heavy flow of water down the channel, periodically adding sand of different colors into the channel. Allow a well-developed delta to form. Stop the water and remove all the sand on one side of the plastic *divider*. Observe the cross-section as seen through the plastic *divider*.

OBSERVATIONS

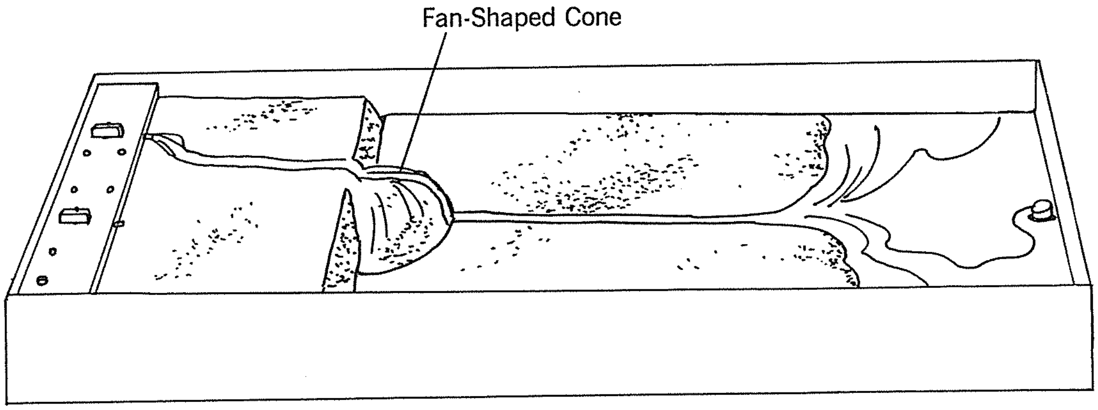
In cross section, the delta reveals three distinct beds: the ***top set, fore set*** and ***bottom set*** beds. The ***top set*** beds are composed of sand deposited on the delta's surface. The ***fore set*** beds consist of sand which has slid or rolled down the front slope of the delta. (The angle of these beds is dependent upon the angle of repose of the materials in water.) The ***bottom set*** beds are the most difficult to see. They consist of finer sand washed out in front of the advancing deltas.

ALLUVIAL FAN

When a debris-laden stream emerges from a highland onto a flat plain, its velocity slackens suddenly, causing the deposition of its load on the flat land. The resulting landform is known as an alluvial fan.

The formation of an alluvial fan is somewhat similar to the formation of a delta. The fan, however, does not form below water level, and the constant aggrading and shifting of the stream channel results in a distinctively different landform.

The alluvial fan is semicircular, and has a constant downward slope in all directions from the point where the stream discharges from the highlands.



PROCEDURE

Construct a steep cliff in the sand across the full width of the table, and form a stream channel leading from one of the outlet nozzles, to the top edge of the cliff.

Direct a heavy rate of flow down the channel for 30 seconds. Turn off the water and make an overhead diagram of the alluvial fan and the stream on the *grid.*

Direct the flow of water down the channel for 2 more minutes and make a second drawing.

Make a final drawing after another flow of 5 minutes.

OBSERVATIONS

The alluvial fan has a semicircular shape because it grows laterally as rapidly as it grows forward. With continued growth the slope of the fan decreases and more distributaries develop. The deposit is similar to a delta, except that it has a uniform slope and the delta does not.

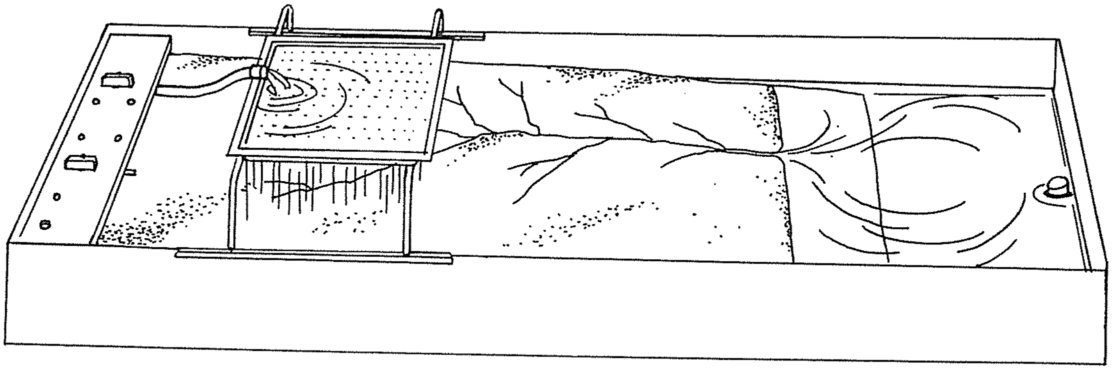
DRAINAGE PATTERNS

Stream patterns established on the land depend on the initial slope of the land, the hardness of underlying rocks, and structural controls such as folds or faults.

Four of the most common types of drainage patterns are ***dendritic, parallel, radial*** and ***trellis.*** The stream pattern in any area can change as different types of rocks or rock structures are exposed by the streams themselves. Massive earth movements such as faulting or uplift may alter the structure, and therefore, the stream pattern in any area.

Part A — Dendritic Pattern

The dendritic pattern looks like the branches of a tree, since the streams approach each other at many different angles. This pattern is most common and develops independently of the structure of the rocks.



PROCEDURE

Pile the sand so it slopes roughly downward to the floor of the *stream table,* but has a slight dip toward the center.

Place the *rainmaker* apparatus over the upper slope of the sand. If possible, tape shut the holes above the lower half of the slope. Fasten one end of plastic tubing to one of the outlet nozzles, and fix the other end in the rainmaker tray.

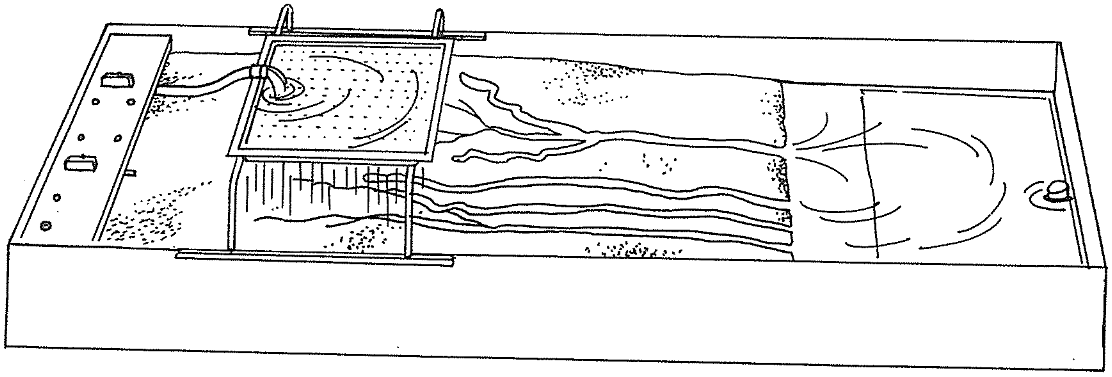
Allow a gentle flow of water into the rainmaker tray. Shake the tray gently to distribute the raindrops evenly. After a few minutes, make an overhead drawing of the newly developed stream pattern. (Since the pattern is very faint, it might be necessary to add dye to the water before beginning).

OBSERVATIONS

The water will flow in the direction where the slope is steepest. Notice the irregular bends in the streams and the irregular angles at their confluences.

Part B — Parallel Pattern

The parallel pattern displays streams that all run in the same general direction. A stream pattern of this nature often develops on coastal plains with uniform rock layers (strata) all sloping gently toward the ocean.



PROCEDURE

Do not change the set-up used in Part A. Reshape the sand into a smooth even slope to the shoreline. Sketch the drainage pattern that develops.

OBSERVATIONS

Notice how all the streams flow in the same direction. Tributaries enter a main stream at small angles.

Part C — Radial Pattern

The radial pattern exhibits streams radiating out from a high central point, like the spokes of a wheel. It can develop on conical mounds such as hills, volcanoes and domes.

PROCEDURE

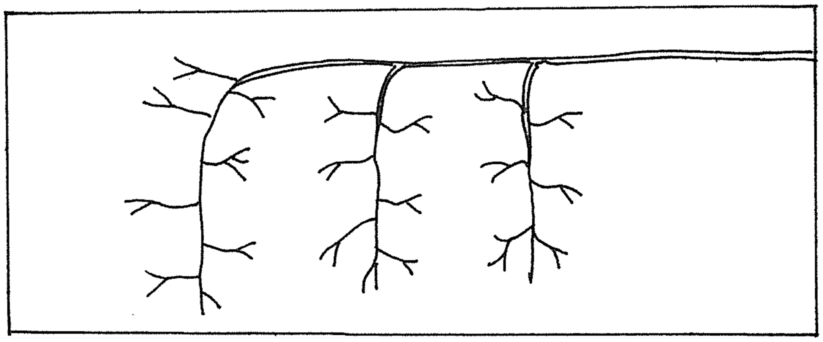
Heap the sand into a large conical mound in the center of the table. Direct a very light flow of water through the *rainmaker* placed on the top of the mound. Sketch the drainage pattern that develops.

OBSERVATIONS

Small streams will radiate outward from the top of the conical pile of sand.

Part D — Trellis Pattern

The trellis pattern has parallel main streams with tributaries that approach the main streams at approximately 90°. This pattern is usually established on parallel structures such as successive ridges formed by folding, or on successive outcrops of strata of varying hardness.



PROCEDURE

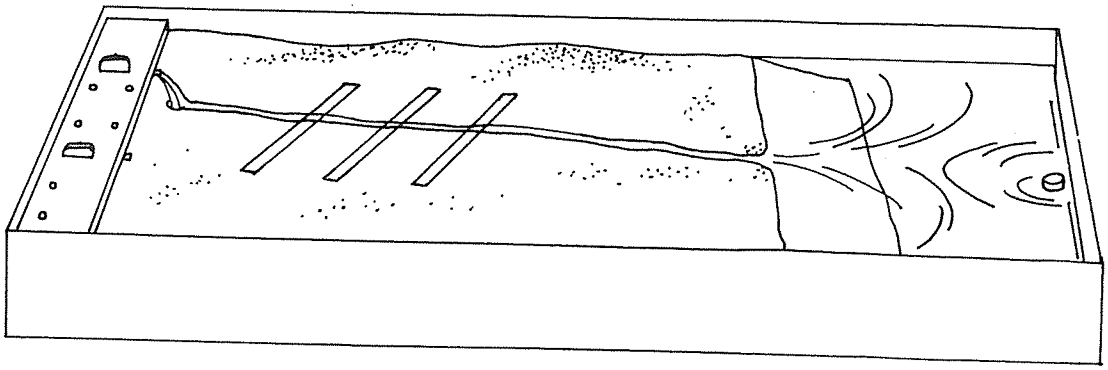
Shape the sand into a slope down to the floor of the table. Form some ridges, approximately two inches wide, along the width of the *stream table*. Place the *rainmaker* over the ridges and add water to the tray. Observe and sketch the resulting pattern.

OBSERVATIONS

The ridges might be thought of as folds of layered rock. These folds govern the rectangular pattern of the streams.

Part E – Changing Patterns

When stream patterns are controlled by underlying rock structures, the drainage pattern is said to exhibit structural control. Radial patterns are one example showing structural control.



PROCEDURE

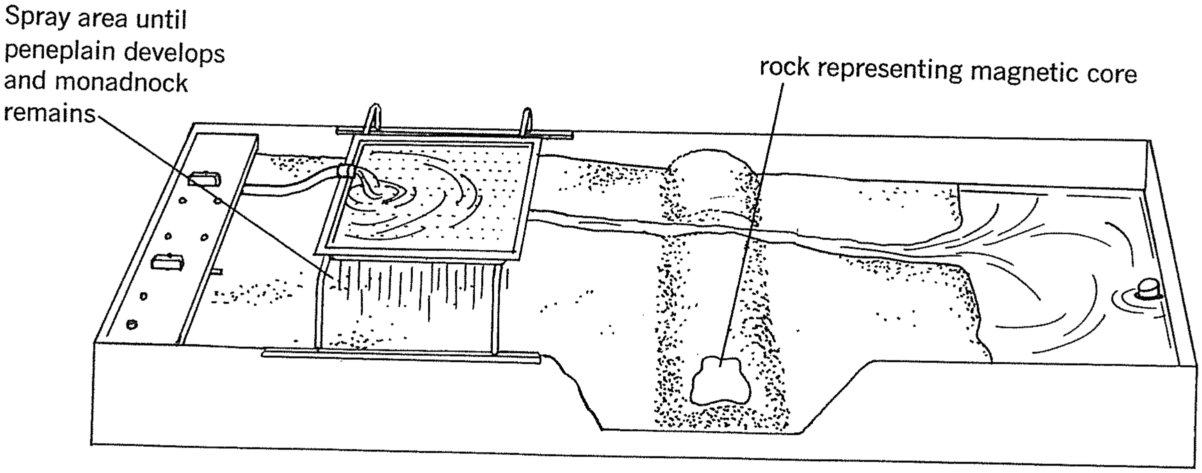
Bury three rulers or pieces of wood diagonally about ½ inch below the surface of the sand. Smooth the sand into a slope over the rulers. From one of the outlet nozzles, form a shallow stream channel with a slight bend. Direct a heavy flow of water down the channel. Allow the water to continue flowing and examine how the stream shifts in position.

OBSERVATIONS

The pieces of wood simulate buried folds, or tilted layers of hard rock. As the stream uncovers the pieces of wood, small waterfalls develop. As more sand is removed, the diagonal pieces block the channel, causing the water to take the easiest route around them. The new path of the stream is structurally controlled, whereas the original was not.

PENEPLAIN AND MONADNOCK

Erosional processes reduce a region to full maturity and finally, to a gently rolling plain closely approximating the base level. The surface thus formed is known as a *peneplain* (from the Latin *paene* meaning "almost," and the English word "plain"). Occasional low hills mark the former presence of relatively resistant rock, or local inefficiencies of erosional processes. These residuals are called monadnocks, after Mount Monadnock in southern New Hampshire.



PROCEDURE

Shape the sand into a mountain chain with an occasional high peak. Bury a piece of rock, about 4 inches in diameter, to simulate a magnetic intrusion. Place the *rainmaker* over the *stream table* and direct a moderate flow of water on the rain tray while sliding the tray back and forth along the length of the table.

OBSERVATIONS

Note that processes of erosion have reduced the former rugged terrain to one of low relief. A monadnock remains where softer rocks were underlain by resistant rock.

GROUND WATER

Water falling to the earth as precipitation may return directly to the atmosphere by evaporation, or it may flow downslope along the surface of the land until it reaches sea level, or it may filter into the ground.

Water that sinks into the ground and remains between the particles of soil due to surface tension, is known as soil water. It can be observed as dampness in subsurface soils even on dry summer days.

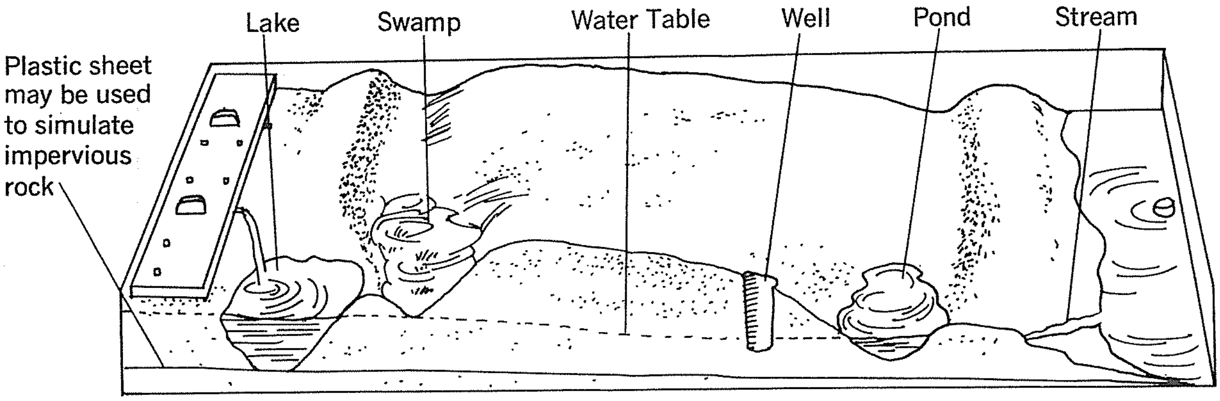
Water that is not held in the soil continues to percolate downward under the force of gravity. When it reaches an impermeable layer of rock its downward movement is blocked, and it accumulates above to form an underground reservoir.

Water held in this manner is known as ***ground water*** and the zone it fills is known as the ***zone of saturation.*** The upper level of the zone of saturation is called the ***ground water table.*** In areas where precipitation is uniform throughout the year, the water table remains at a fixed level, but in areas with alternating wet and dry seasons, its level rises or falls with excess precipitation or drought.

Above the water table, is the ***zone of aeration,*** where the pore spaces are occupied partly by water and partly by air. It usually extends up to the surface.

Ground water flows much like the water at the surface. The chief difference between them is in their speed of flow. Ground water must pass through the tiny rock cavities so it is much slower. Its speed depends on the slope of the water table and the permeability of the rock through which it must pass. The speed can be as low as 50 feet per year or several hundred feet per day. In either case, the speed is strikingly slow when compared to that of surface flow.

The ground water table tends to seek a horizontal level but, due to the extremely slow movement of ground water, it remains roughly parallel to the surface of the land above it. The depth of the water table below the surface can be determined by noting the level of water in the wells. In general, the depth is greater under elevated areas than it is under depressed areas. In depressed areas, such as stream valleys, the water table may intersect the surface, and ground water may issue from the rock as a spring. Sometimes, the low-lying areas fill with water to form swamps, or even lakes.



PROCEDURE

Push the standpipe to its lowest elevation and allow all the water to drain from the lower end of the *stream table.* Moisten the sand and smooth it in a slope to the standpipe. Form a lake bed in the upper part of the slope; a lowland, a hill, and a basin at short distances from each other down the slope. Dig out a small circular column of sand near the base of the hill and insert a plastic tube almost down to the floor of the *stream table.* The tube represents a well. The edge of the sand should terminate in a sharp line on the dry floor of the *stream table.*

Open one inlet nozzle and allow the water to fill the upper lake basin. Be sure not to overflow the basin. Note the time. Keep refilling the lake as its level goes down. Watch for changes in the lowland well and the small basin.

Observe and record the level of water in the well after two-minute intervals by dipping a stick into the well and noting the level on the stick. Note the time when water begins to issue at the edge of the sand.

Measure the distance from the lake basin to the edge of the sand. Calculate the velocity of the water through the sand.

OBSERVATIONS

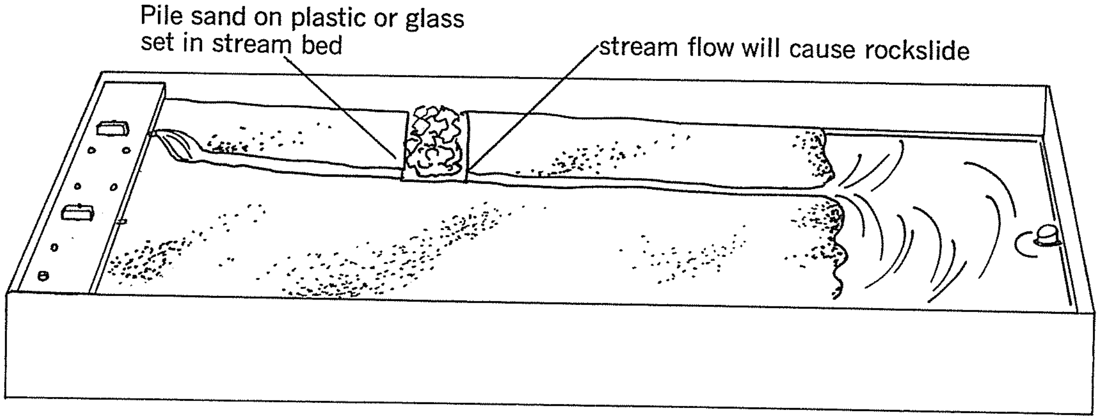
Several minutes after the lake is filled, water will begin filling the lowland and form a swamp. Then, the well will begin to fill. Next, water will seep into the lake basin and, finally, a spring will emerge at the base of the slope. These results will be best if the sand is perfectly sculptured and firmly packed. Unless very coarse sand is used, the velocity of the ground water will be less than one foot per minute.

MASS WASTING

Loose earth materials that lie on a slope move downward under the force of gravity. Sometimes the movement is slow and imperceptible and sometimes, rapid. Ice or water between particles often aid movement.

ROCKSLIDE

A rockslide is a rapid, downhill movement of a large rock mass along a smooth, inclined bedding plane or fault. The rock begins to slide as a consolidated unit, but usually it disintegrates before coming to rest as an accumulation of disordered rock debris. Rockslides can cause devastation if they occur in a populated region.



PROCEDURE

Smooth the sand into a gentle slope and carve a narrow channel from one of the outlet nozzles along the entire length of the sand. Construct a steep hill on one bank of the channel. Place the plastic *waterfall* over the hill with its open end resting in the stream valley. Pile wet sand on the *waterfall* at the steepest possible angle.

Open the outlet nozzle and allow a gentle flow of water down the channel. After some time, a landslide will occur.

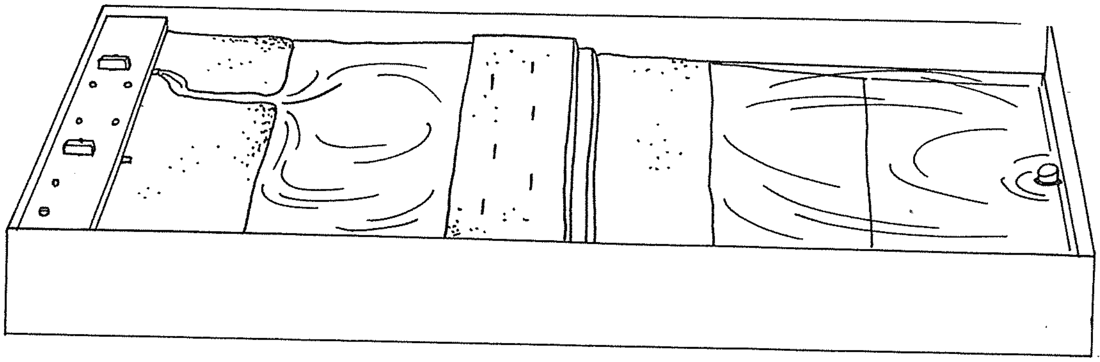
OBSERVATIONS

As the stream removes the sand at the bottom of the slope, the sand above the channel slides down the plastic, which represents a bedrock surface.

If conditions are right, the landslide will dam the stream. Water will accumulate behind the dam as a lake. When the lake rises to a certain level, the stream will shift forming a new channel.

SLUMP

Slumping, sometimes called earthflow, is the collapse of a wet, steep slope in a series of steps, above a basal protruding accumulation of debris or a "toe." When the slope surface is composed of rock, or fairly consolidated earth, whole blocks may slump with a backward rotating motion along a curved slip plane.



PROCEDURE

Construct a broad sand ridge across the *stream table* and terminate it in a steep slope. Level its top and measure its width. Plant tooth picks vertically in the top near the edge. Draw a side view.

Direct a moderate flow of water behind the ridge until the water level nears the top of the ridge. Keep refilling as the water level drops. Be careful not to allow the water to overflow the ridge. After the first slump occurs measure the width of the ridge and make another drawing.

After several more blocks have slumped measure the width of the ridge again and make a third drawing. Are the toothpicks in the slumped blocks still vertical?

OBSERVATIONS

The sand will slump in blocks along planes of stress, and the width of the ridge will decrease. The slumping is accompanied by a backward rotation which causes the toothpicks to slant toward the ridge.

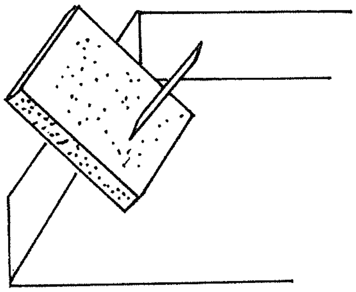
SOLIFLUCTION

Solifluction occurs only in subarctic climates. It is the slow flow of melted surface soil over the permanently frozen permafrost layer below.

PROCEDURE

Fill a large pan with sand to a depth of at least two inches. Saturate the sand completely with water and place a ruler vertically in it at one end. Place the pan in a freezer and allow the mixture to freeze overnight.

Remove the pan and read the depth of the sand as shown on the ruler. Place the container against the side of the *stream table* at an angle of 45°, with the ruler extending into the table. Observe the results as the layer of sand and water mixture at the surface melts. Measure the depth of the sand after approximately one-half of it has melted.

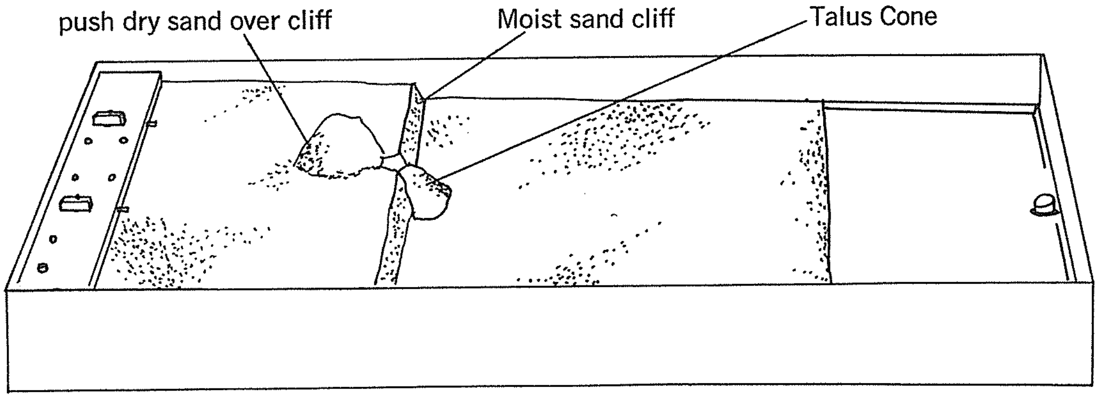


OBSERVATIONS

The melted water cannot soak into the frozen sand beneath so it forms a fluid mixture with the sand, and flows slowly down the slope. This process is called solifluction. After solifluction has continued for some time the depth of the sand will be greater at the foot of the slope than in the middle of the slope.

TALUS CONE

The products of the mass wasting of cliff faces may tumble down to accumulate as talus cones at the foot of the cliff. The larger fragments tend to come to rest at the base, while the smaller ones remain closer to the top of the cone. Cones form at the end of ravines, which channel the rockfalls to a single location.



PROCEDURE

Form a steep cliff with a large notch in the edge. Smooth the sand flat away from the cliff. Mix some small pebbles in a cup of fine dry sand. Pour the mixture down the notched cliff until a well developed cone forms.

OBSERVATIONS

The cone will develop into its characteristic fan shape. It will reveal particle sorting as the pebbles roll to the periphery.

COASTAL PROCESSES

Most of us are aware of the power of the ocean during a storm. The damage caused by high, angry waves that lash the shoreline is obvious. Whole cliffs can be destroyed or entire beaches can be removed. In times of calm, the waves lap gently against the shore and appear to cause no damage. The action of these waves is not as spectacular as that of the storm waves, but never-the-less, it is there.

Waves carry sand and bits of rock and each time they break against the shore they chip away little fragments. Eventually, a ***notch*** appears in the rocks. When the notch becomes deep enough, the rock above it collapses from lack of support and a vertical ***cliff face*** is formed.

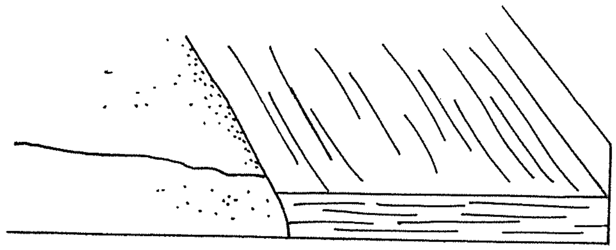
The continuous action of the waves wears another notch in the new cliff and a collapse follows. Each new cliff-face that is formed by this process is a little further inland from the former cliff.

As the rocks above the ocean surface recede inland the rocks beneath the zone of wave action remain as a ***terrace***, or ***wave-cut platform.*** The surface of the platform catches the debris from the collapse of the cliffs.

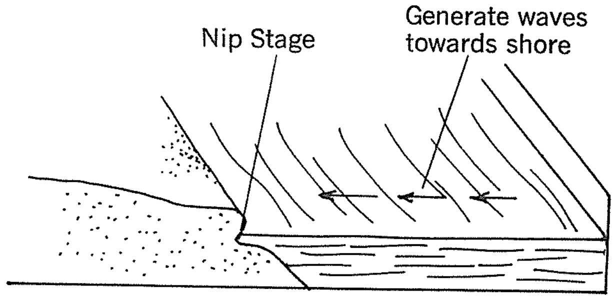
The debris is rolled around by the waves and used as a tool for attacking the cliff. As the debris rubs against the cliff, it is, itself, continuously worn down into smaller and smaller fragments until only the smallest quartz grains remain as sand.

When the sea-cliff recedes to a position where the waves cannot attack it further, the resultant shoreline is said to be ***mature.*** The base of the cliff becomes a resting place for the sand and a ***beach*** forms. The beach continues to grow, until earth movements bring the shoreline in the reach of the waves again.

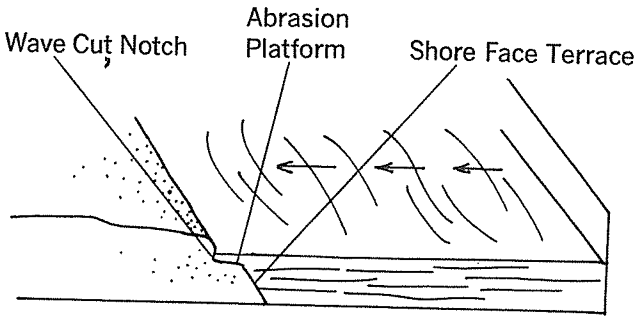
WAVE ACTION ON A SHORELINE



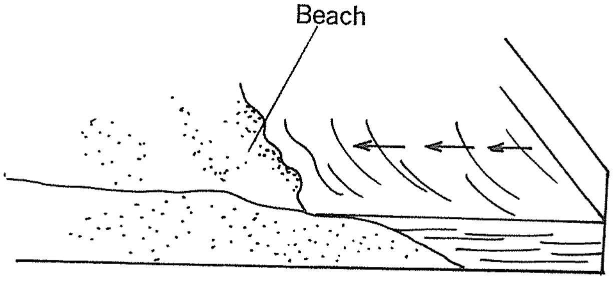
FIRST STAGE



SECOND STAGE



THIRD STAGE



FOURTH STAGE

PROCEDURE

Arrange the sand to form an abrupt slope, at least 4 inches high at the shoreline. Adjust the standpipe to the 2-inch level and add water up to the top of the pipe. Place the *wave generator* directly opposite the sand slope in the center of the *stream table*. Start the motor and observe the development of the shoreline as miniature waves break against the slope.

OBSERVATIONS

Note nip stage in early phase; formation of wave cut notch, abrasion platform and shoreline terrace; and finally a beach. Careful observation during the beach formation will reveal particle sorting and beach drifting of individual sand grains.

TYPES OF SHORELINES

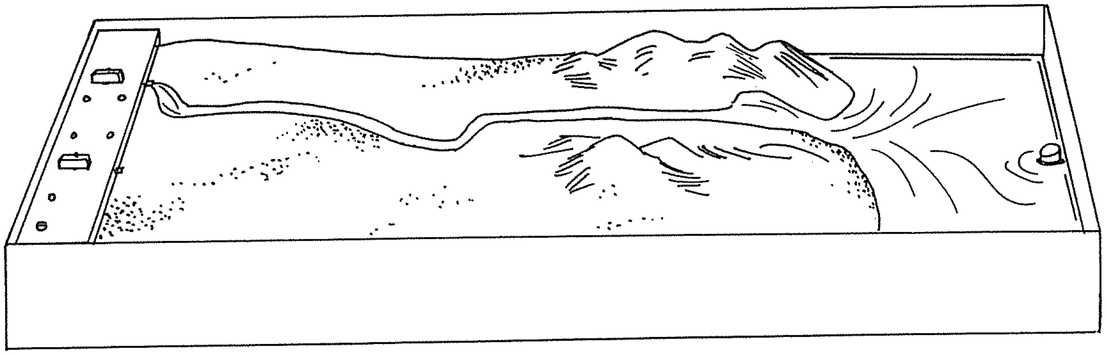
Shorelines are classified as ***shorelines of submergence, shorelines of emergence*** and ***neutral shorelines.***

D. W. Johnson defines shorelines of submergence as "those shorelines produced when the water surface come to rest against a partially submerged land area." Upon submergence, formerly exposed land is flooded by the ocean, and only the higher elevations remain uncovered. This change in the relative levels of land and ocean comes about either by a subsidence of the land or a world-wide rise in sea level.

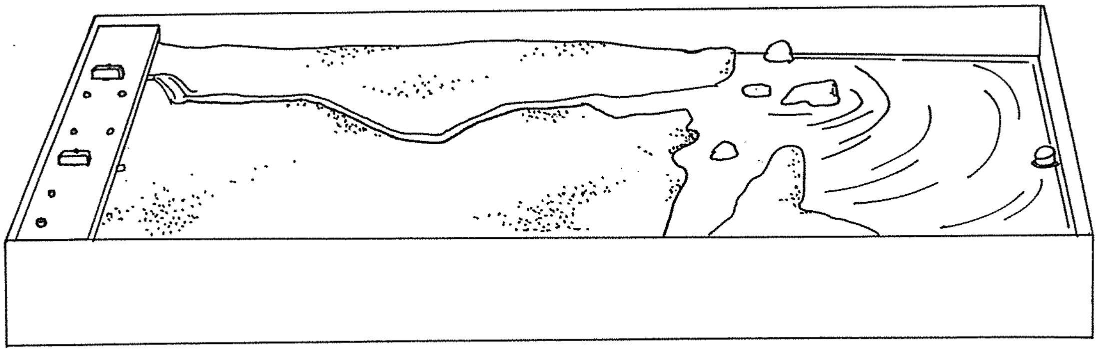
Johnson defines shorelines of emergence as "those resulting when the surface comes to rest against a partially emerged sea floor." Upon emergence, land formerly under water is exposed as a coastal plain by the uplift of continental borders or a drop in sea level.

The rise and fall of sea level have occurred frequently through geologic time and are closely related to the retreat and advance of glaciers. Glaciers advanced as a result of a general cooling of the earth's climate. Most of the precipitation that fell on land was held there in the form of ice. It did not return to the ocean and consequently their level dropped. When a warming trend returned the glaciers melted. When the melt-waters flowed into the oceans, their level rose again.

Part A — Submergence



SHORELINE BEFORE SUBMERGENCE



SHORELINE AFTER SUBMERGENCE

PROCEDURE

Shape the sand into a hilly surface terminating in a steeply sloping beach. Raise the standpipe to the 2-inch level and fill the basin around it. Place the *wave generator* about 18 inches opposite the shoreline. Begin the wave action and observe the changes in the shoreline.

OBSERVATIONS

Note the formation of estuaries, bays, peninsulas and numerous islands.

Part B — Emergence

PROCEDURE

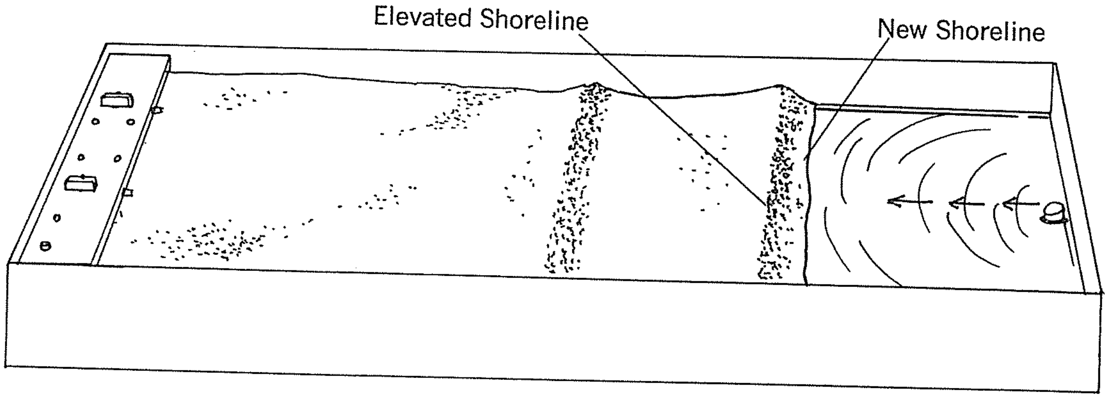
After the shoreline has been worn nearly smooth in the above experiment, shut off the pump and lower the standpipe to the one inch level. Generate waves, as the water level drops.

OBSERVATIONS

Note the gently sloping coastal plain of low relief uncovered by the lowering of the water level.

ELEVATED SHORELINES

When base level is lowered either as a result of the lowering of sea level or the elevation of the land mass, the old shoreline is left many miles inland on dry ground. It is then known as an ***elevated shoreline.***



PROCEDURE

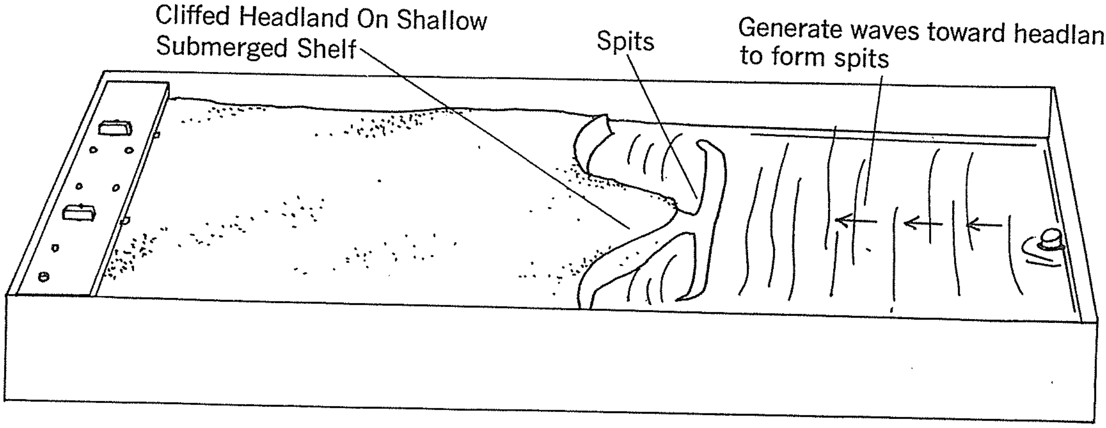
Form the sand into a steep slope near the end of the table. Adjust the standpipe to a high level and fill the lower end of the table with water. Place the *wave generator* opposite the shoreline and generate waves until a well-developed shoreline forms. Turn off the *wave generator* and adjust the standpipe to a much lower level (about 1 inch), allowing some of the water to drain away. Generate waves again to form a new shoreline.

OBSERVATIONS

Two similar shorelines result, both show cliff and beach formations. The first shoreline grades down to a stretch of sand while the second grades down to the water.

SPIT

Beach material, at the base of headland cliffs, is washed out by longshore currents to produce ***sand bars*** extending in the same general direction as the shoreline. Currents swinging round the headland may cause the seaward end of the bar to be curved toward the land. These curved bars are called ***spits.*** The size and direction of growth of all bars depend on the nature and direction of prevailing currents.



PROCEDURE

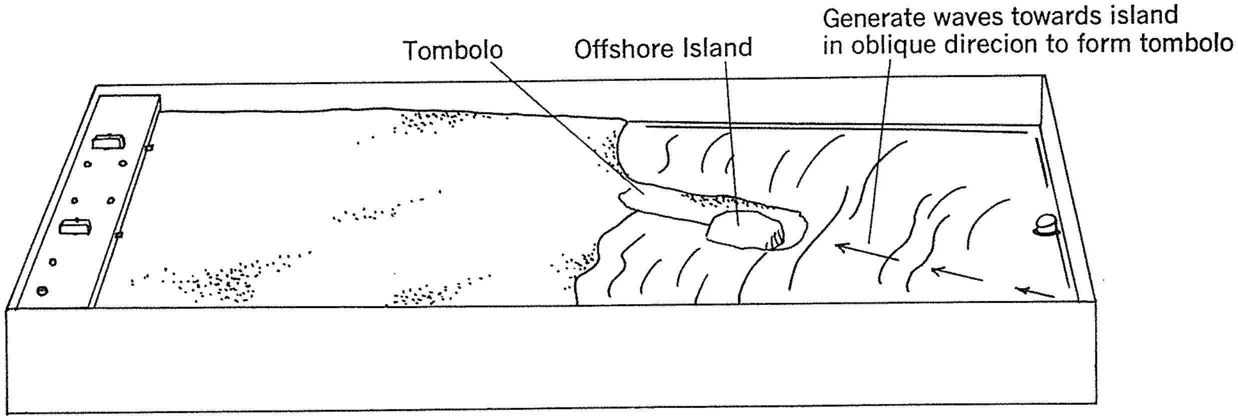
Shape the sand into a cliffed headland. Adjust the standpipe to a height about 1½ inches and fill the basin. Make a low sand beach at the end of the headland. Place the *wave generator* opposite the shoreline and direct waves toward the headland. Sprinkle colored sand on the beach and observe the movement of the grains. Stop the *wave generator* periodically and check the growth of the spits.

OBSERVATIONS

Note the erosion of the headland cliff and the spreading out of the sand particles on both sides of headland to form spits.

TOMBOLO

When a bar connects an island to the mainland it is called a ***tombolo.*** The sand that makes up the tombolo may come from the mainland or the island itself depending on wave and terrain conditions.



PROCEDURE

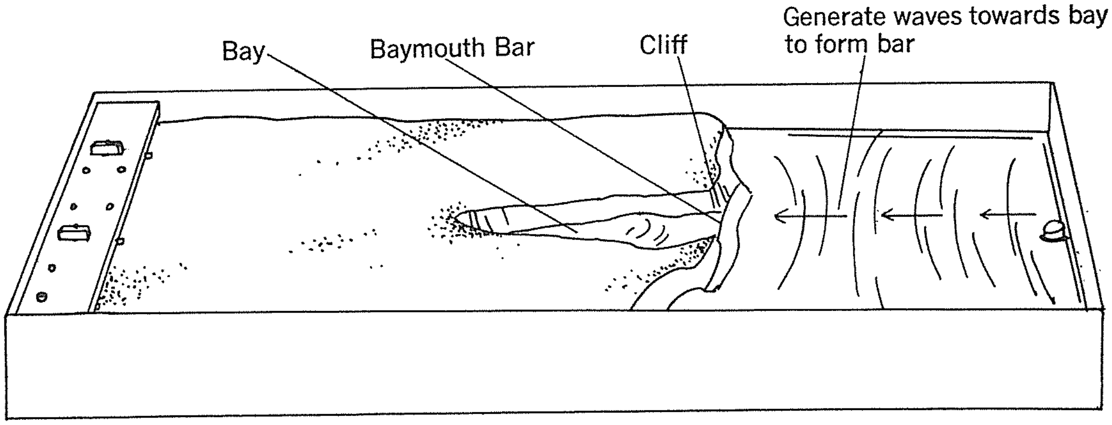
Shape the sand into a smooth slope terminating as a shallow shelf of sand. Form a conical island, several inches from the coast, on the shelf. Adjust the standpipe and raise the water level until the island is separated from the mainland by water. Place the *wave generator* near the corner of the table. Direct waves obliquely toward the shoreline. Stop the *wave generator* at intervals and examine the growth of the tombolo.

OBSERVATIONS

Note the transportation of sediment from island to shore, until a tombolo is formed.

BAYMOUTH BAR

Spits that are connected to land at both ends are called bars. A bar that extends across the entrance of a bay is called a ***baymouth bar.*** The bay may eventually be filled with sediments and become part of the land. The filling of indentations in this manner results in the straightening of the coastline.



PROCEDURE

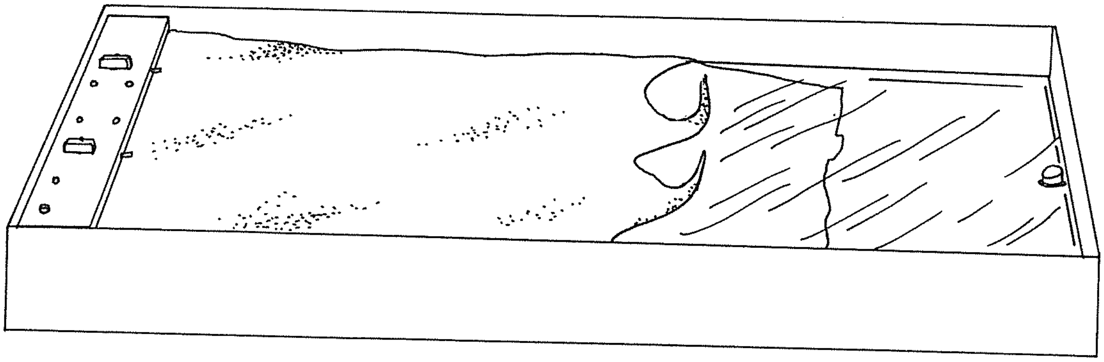
Shape the sand to form a shallow bay flanked by a high steep shoreline, and a shallow shelf. Fill the basin, while adjusting standpipe to a height so that the shelf is completely submerged. Place the *wave generator* opposite the shoreline and generate waves at right angles toward the bay, until a sand bar extends across its mouth. Sprinkle colored sand on the headlands flanking the bay, and observe the motion of the grains.

OBSERVATIONS

Note the progressive development of spits from both sides of the bay until the mouth of the bay is closed off by a baymouth bar. The colored sand grains will show how each swash and backwash of the waves moves the sand "a step" closer to the center of the bay.

BEACH DRIFTING

Waves usually approach a shore at an oblique angle, which depends on the direction of the prevailing winds. They carry the eroded material with them and deposit it in the irregularities of the shoreline.



PROCEDURE

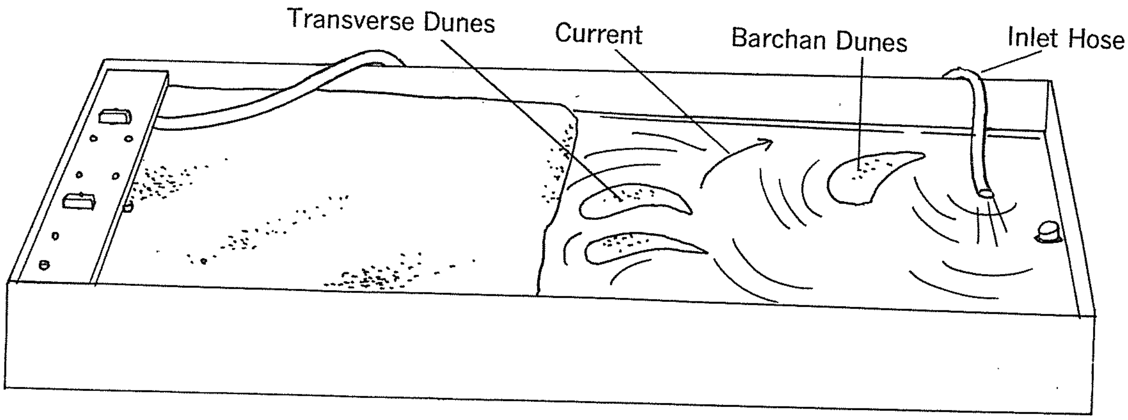
Shape the sand into a steep uneven shoreline with two headlands extending onto a flat shelf. Adjust the standpipe and fill with water to submerge the shelf completely. The edge of the water should be around the headlands. Pour a small amount of colored sand on the tip of each headland. Place the *wave generator* at one corner of the table and direct waves toward the shoreline at an oblique angle. Observe the movement of the colored sand grains and the change in the shape of the shoreline.

OBSERVATIONS

The size of the headlands will be reduced by wave action and the eroded sand will be swept into spits extending in the direction of the waves. Eventually, the shoreline will reach equilibrium when the headlands will be eroded completely, and the bays filled.

SUBMARINE SAND DUNES

Subaqueous currents, particularly those induced by tidal movements, may heap subsurface sands into sanddunes that have many of the characteristics of dunes formed by the wind. Recent research has provided much information about ***subaqueous transverse and barchan dunes*** in the current-scoured regions of the continental shelves and banks.



PROCEDURE

Form a steeply sloping beach leading down to the shoreline. Scrape the basin floor clear of sand. Adjust the standpipe to allow approximately two inches of water in the basin and fill the basin to this level.

Pour some colored sand on the bare basin floor to form two or three small conical mounds under water. Fasten one end of a piece of tubing to one of the outlet nozzles, and submerge the open end in a corner of the basin. Open the outlet valve and direct a current of water around the periphery of the basin. Examine the resulting changes in the sand mounds.

OBSERVATIONS

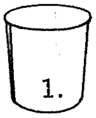
An initial low velocity current rolls and bounces the individual grains over the smooth bottom.

As the current velocity is increased, transverse ridges will form near the shoreline where sand is plentiful, and barchans will develop where sand is scarce. In both cases, the asymmetrical profile of the dunes is a result of the direction of the movement of the sand grains. The grains are swept up the side facing the current. Once they reach the crest they are allowed to fall down the lee side. This action results in a gentler slope facing the current and a steeper leeward slope.

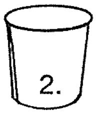
When the velocity of the current is increased further, the dunes break down into a bottom flow of mixed water and sediment.

OCEAN DENSITY CURRENTS

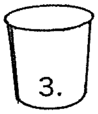
Dense turbid water, set in motion by storms, subsurface earthquakes or landslides, may flow down an ocean slope as a ***turbidity current.*** The particles in the current erode the ocean floor, and may spread over a vast area before they come to rest. Turbidity currents, therefore erode and aggrade the ocean bottom, much as streams do at the earth's surface. Density currents may also occur as ***salinity currents,*** especially in areas of high evaporation. A third form of density current occurs especially in deep water when water is cooled locally. The cooler water is heavier than the surrounding water, so it sinks until it reaches a level where the water density is equal to its own.



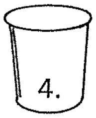
Turbidity
Sand + Water



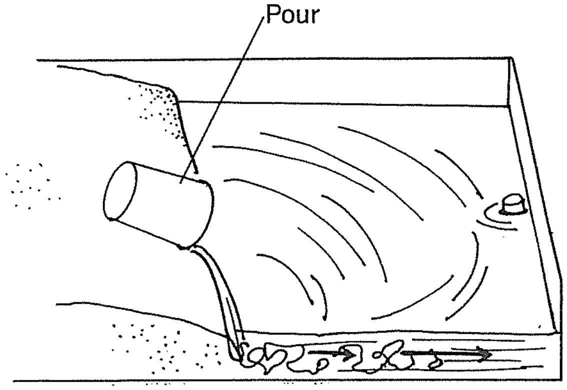
Temperature
Ice + Dye + Water



Salinity
Salt + Dye + Water



Control
Dye + Water



PROCEDURE

Shape the sand into a smooth steep slope down to the shoreline. Clean away all sand from the basin floor and fill the basin to a maximum depth. Fill four cups with mixtures, as shown in the diagram. Pour each mixture separately down a different part of the shoreline and examine its movement.

OBSERVATIONS

The density of the water samples is increased by adding soil or salt, or by cooling. The increased density causes the mixture to slide beneath the less dense fresh water, and flow along the basin floor. As it begins to mix with the water around it, the densities equalize and the speed of the current slackens.

GLACIATION

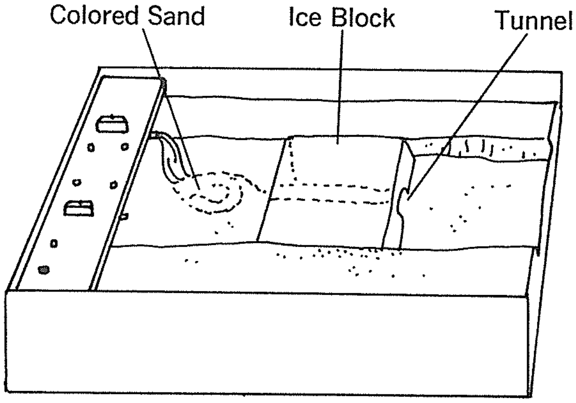
The seas or rivers of moving ice, known as glaciers, once were much more widespread than they are now. As these vast masses of ice moved downslope, they plucked away debris in their path and carved out U-shaped valleys. Although most of these great masses of ice are gone, their evidence remains.

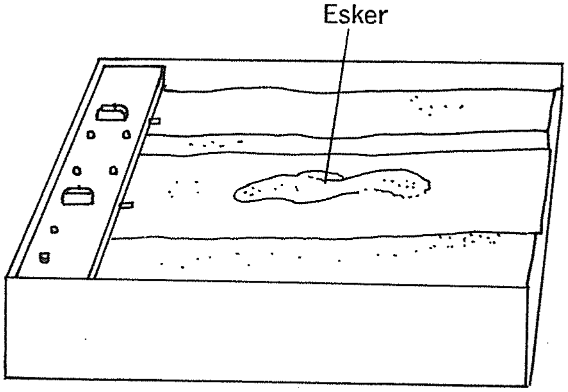
Even when glaciers were at the peak of their advancement they did undergo partial melting. The resulting meltwater flowed through tunnels at the bottom of the ice or through the crevasses of the glacier, or through spaces between the periphery of the glacier and its valley walls.

The meltwater bore along rocks, pebbles and sand, generally known as glacio-fluvial drift. When these meltwater streams dwindled they left behind their deposits as ridges or platforms. Many of these deposits can be observed today unless they have been overrun and destroyed subsequently by a glacier.

ESKERS

As the surface of a glacier melts, melt-waters trickle down to the bottom, where they join to form sub-glacial streams. As these streams flow along the valley floor, they form passageways and tunnels. They may wear away valley floors and pick up debris, which they deposit in other parts of the tunnel. When the glacier melts, this debris filling the tunnels, remains as a sinuous winding ridge called an ***esker.***





PROCEDURE

Advance Preparation: Place a rubber hose on the bottom of a shallow pan, fill the pan with water and freeze.

In the sand of the *stream table*, form a wide, U-shaped valley leading from the nozzles to the lake. Place ice cubes in the reservoir and allow the water to chill. Remove the block of ice from the pan, and the hose from the ice. Place the block of ice, tunnel down, in the valley. Pour colored sand in the valley, between the ice block and the nozzles.

Attach a piece of clear tubing to one of the nozzles and direct a flow of water down the valley and into the tunnel, until some colored sand emerges at the opposite end of the tunnel. Discontinue the flow of water and allow the ice to melt.

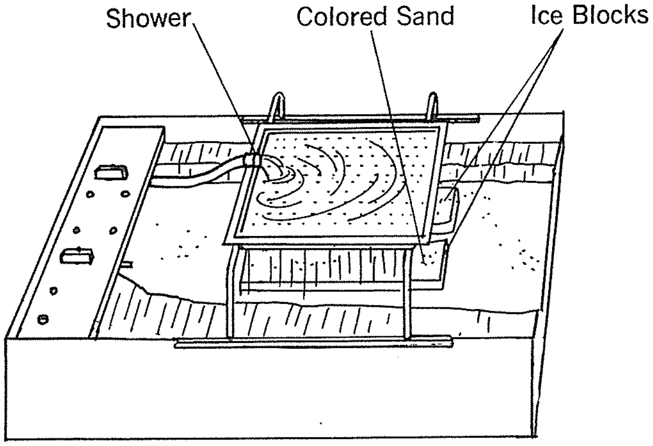
OBSERVATIONS

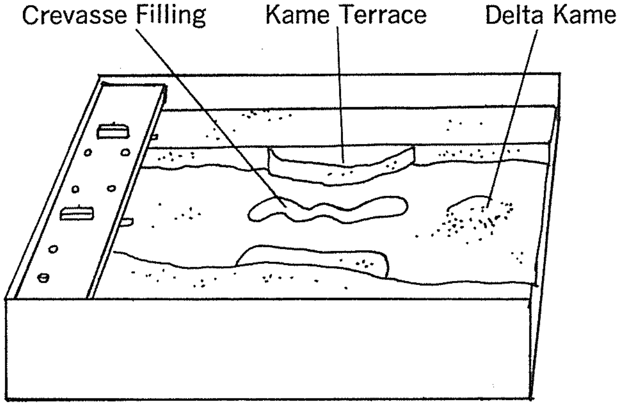
Note the sinuous ridge of aggraded sediments along the course of the stream through the ice tunnel. The free-standing form is a model esker.

CREVASSE FILLINGS AND KAMES

Meltwater streams flowing between a shrinking glacier and its adjacent valley wall deposited stratified platforms of sand and gravel, known as kame terraces. Similar deposits, where melt-water streams entered lakes, are called delta kames.

Melt-water streams also wash debris into a crevasse. When the glacier melts and disappears the crevasse-filling remains.





PROCEDURE

Advance Preparation: Freeze a pan of water in which a flat S-curved metal strip has been placed vertically along the length of the pan. Remove the strip and separate the blocks of ice.

Form a broad U-shaped valley in the sand down the center of the *stream table.* Place the ice blocks in the valley with their corresponding S-curved edges about one inch apart. The outer edge of each block should be close to the valley walls. Cover the ice with a layer of colored sand.

Place the rain tray over the ice blocks. Divert a gentle flow of water from a nozzle into the rain tray, through a tube. When the colored sand has been washed into the crevasse between the ice blocks, and between the ice blocks and valley walls, discontinue the shower and allow the ice to melt. The transported colored sand remains as free-standing forms.

OBSERVATIONS

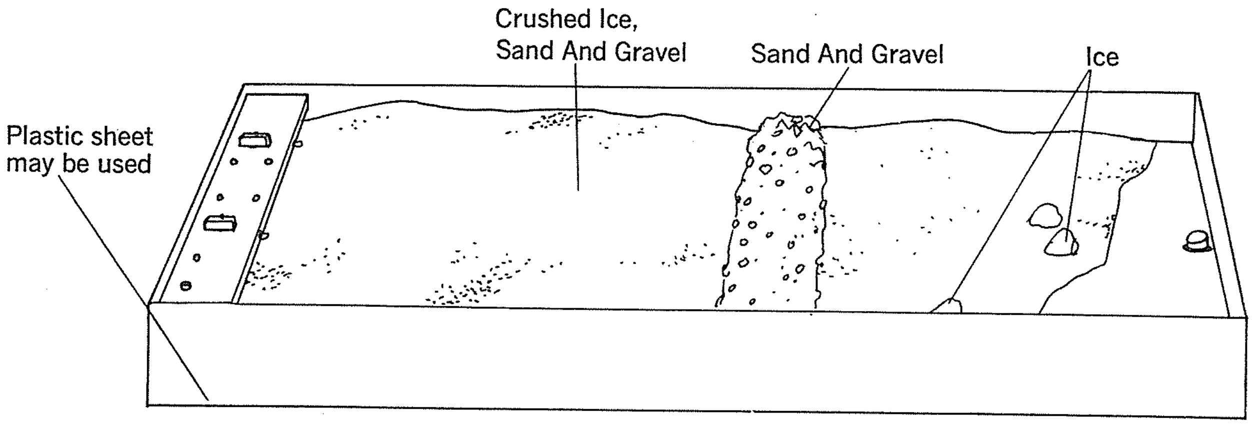
Note the formation and appearance of the crevasse filling, the kame terraces along both valley walls, and the delta kame elevated above the valley floor. At this scale, it is not possible to see the particle sorting, indicative of the transported nature of the sediments.

MORAINES AND OUTWASH PLAINS

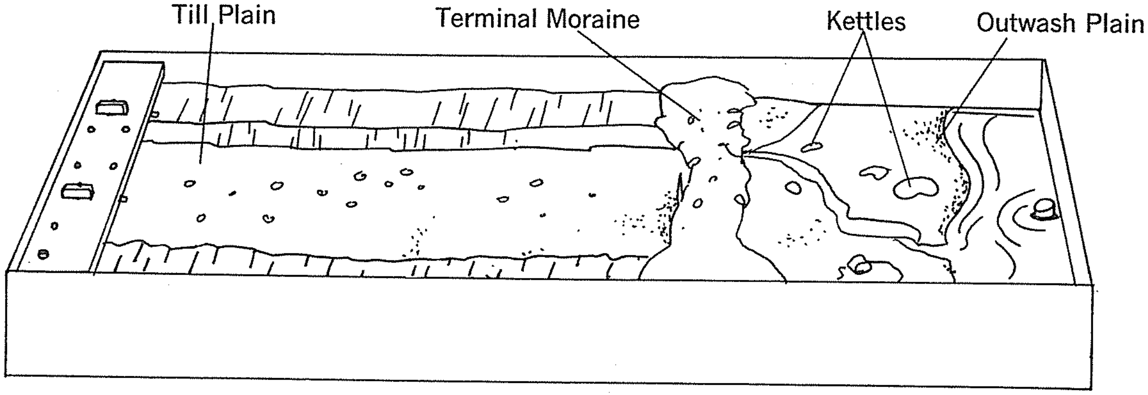
Moraines and outwash plains are features of deposition like kames and eskers, but they are much larger. A ***ground moraine*** or a ***till plain,*** is an unsorted and unstratified deposit that was laid over a surface formerly covered by a glacier.

A ***terminal moraine*** is the deposition of a glacial load that has been deposited as mounds along the front end of a receding glacier. Water from the melting end of the glacier flowed over the terminal moraine, transported the smaller particles and deposited them in a gently sloping, stratified, outwash plain.

Occasionally, blocks of ice detached from the receding glacier were surrounded by till or outwash. When these blocks melted, a pit or depression, remained. This depression is called a ***kettle.*** Many outwash plains are pockmarked with kettles, and are referred to as pitted outwash plains.



BEFORE GLACIER MELTS



AFTER GLACIER MELTS

PROCEDURE

Advance Preparation: Obtain crushed ice, or snow if available.

Form a broad U-shaped valley with its bottom close to the bottom of the *stream table.* Shape a ridge of sand and gravel across one end of the valley. Pile alternate layers of sand and gravel, and crushed ice in the valley behind the ridge. (Use considerably more ice than sand and gravel.) Partially bury chunks of ice in the flat area downgrade from the valley. Allow the ice to melt and note the changes every few minutes. (To speed up the process a light can be directed onto the ice.)

OBSERVATIONS

Note that many small streams emerge from the end of the glacier and deposit their load in a series of alluvial fans that coalesce to form the outwash plain. No sand can be deposited in the spots where the ice blocks were. When the blocks melt, depressions, called kettles, remain. After the model glacier has melted, the uneven gravel deposited as ground morraine, can be seen in the valley.

CONSERVATION

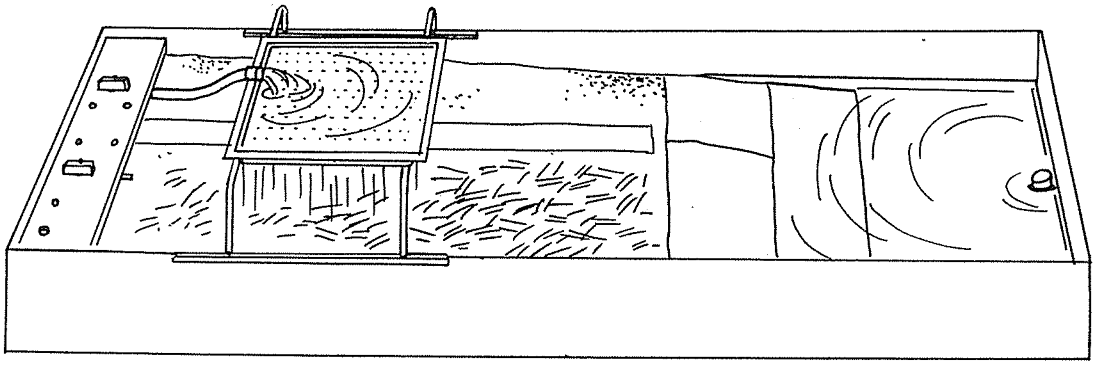
The processes of erosion are constantly altering the face of the land. Rivers erode their banks, winds blow away the soil and ocean waves wear away the shoreline. Man himself has altered the land surface, making it all the more vulnerable to the onslaughts of nature. Often, this land that is constantly under assault from destructive forces, is valuable to man and must be preserved. To counteract the effects of deterioration, man has taken many measures. He has planted barren soils, reinforced river channels and shorelines and tended and replenished exhausted soils.

SOIL PROTECTION—GRASS COVER

Good soils have taken thousands of years to develop but they have been destroyed by man in a matter of a few years. A grass cover is the best protector of soil on sloping land. The grass roots bind loose soil and protect it from the direct effects of erosion.

Grass also slows the rate of flowing water, reducing its erosive action and allowing more of it to soak into the ground. When the grass is removed, as during cropping and grazing, soil is destroyed more rapidly than it can form. Sometimes the entire layer may be completely removed.

The lack of a vegetative cover results in a lack of humus, which means a lack of productivity.



PROCEDURE

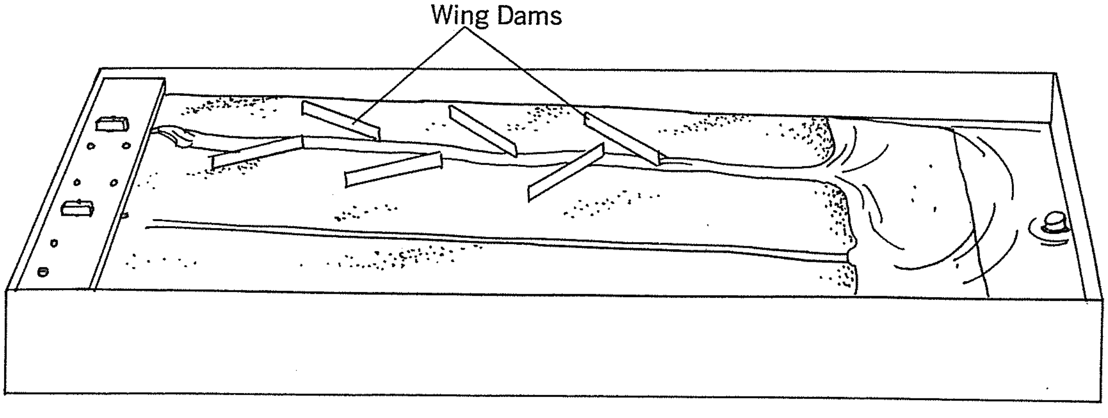
Push the standpipe to its lowest level and allow all the water to drain from the lower end of the table. Form the sand into a smooth slope terminating in a sharp line on the floor of the table. Insert the clear *plastic divider*, lengthwise, down the center of the table. On one side, place a large quantity of grass. (If not available, a wire screen can serve the same purpose.) Place the *rainmaker* over the top of both slopes, and divert a medium flow of water in it. Shake the tray lightly to prevent pooling of the water. Note the amount of erosion on the grassed slope as opposed to the barren slope.

OBSERVATIONS

Note the greater amount of erosion on the barren slope as opposed to the grass covered slope. If the grass were growing on the slope, the rate of erosion would be even less because of the binding effect of the roots.

RIVER CONTROL—WING DAMS

Man has tried to straighten river channels and maintain their depth for purposes of navigation. In flat terrain, channel straightening and dredging are not sufficient to keep a river open for navigation. Meanders and sand bars keep forming continuously. To counteract their formation, river engineers construct short lateral dams on both sides of a river. When located and constructed properly these dams keep the water flowing rapidly and in a straight course, by reducing sedimentation and meandering.



PROCEDURE

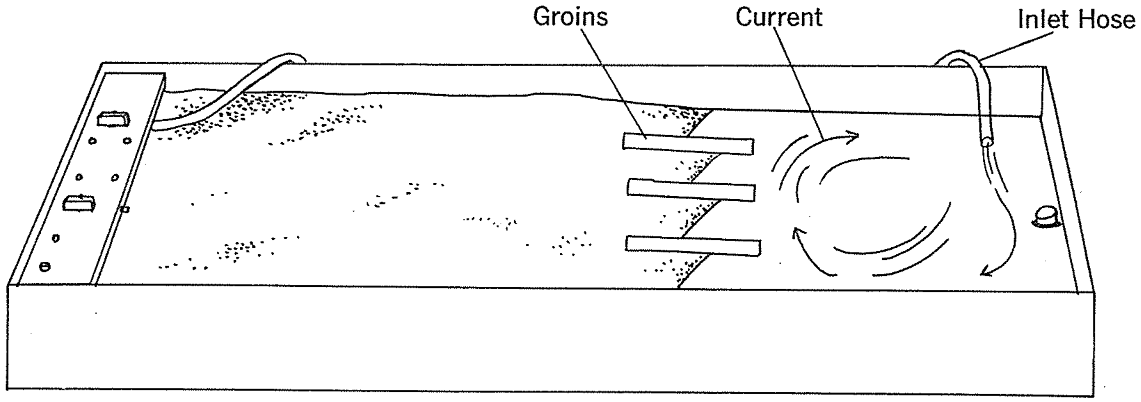
Form the sand into a smooth slope. Carve two narrow channels down the length of this slope away from each outlet nozzle. Allow a moderate flow of water down each channel. Try to keep the flows equal in each channel. When bends begin to form, insert plastic panels in the banks of one of the channels, at the points where the bending proceeds fastest. Each plastic panel should extend from well inside the river bank to the water channel, and be slanted in the downstream direction.

OBSERVATIONS

Notice that the wing dams keep the stream on a straight course, while the other stream is free to develop meanders. Since meanders cut into the stream banks, the protected stream undergoes less erosion, and less material is deposited at the shoreline to form a delta.

BEACH PROTECTION — GROINS

Man has had the need to protect shorelines in order to keep his harbors open and preserve his beaches for recreation. Longshore currents and beach drift, carry enough sand to destroy a beach or block an inlet. In an effort to combat this, coastal engineers erect groins (sturdy wall-like structures) perpendicular to the shore and extending into the water. The groins reduce shifting, stabilize beaches and keep inlets open.



PROCEDURE

Form a straight, steep sloping beach terminating on the floor of the table. Adjust the standpipe to a level which will allow the water to reach half way up the beach slope. Attach a piece of plastic tubing to one of the outlet nozzles and submerge its open end along the back of the basin wall. Place the *grid* over the shoreline and trace its position. Open the outlet valve and generate a strong current along the beach until a noticeable amount of sand has shifted in the direction of the current. Note the line for which the current was allowed to flow. Trace the new shoreline on the *grid.*

Reconstruct the beach to its original position. Insert the plastic panels into the beach at three or four inch intervals. Each panel should be embedded firmly in the sand, extending from the dry sand into the water. Run the same current for the same amount of time. Sketch the change in the shoreline on the contour *grid.*

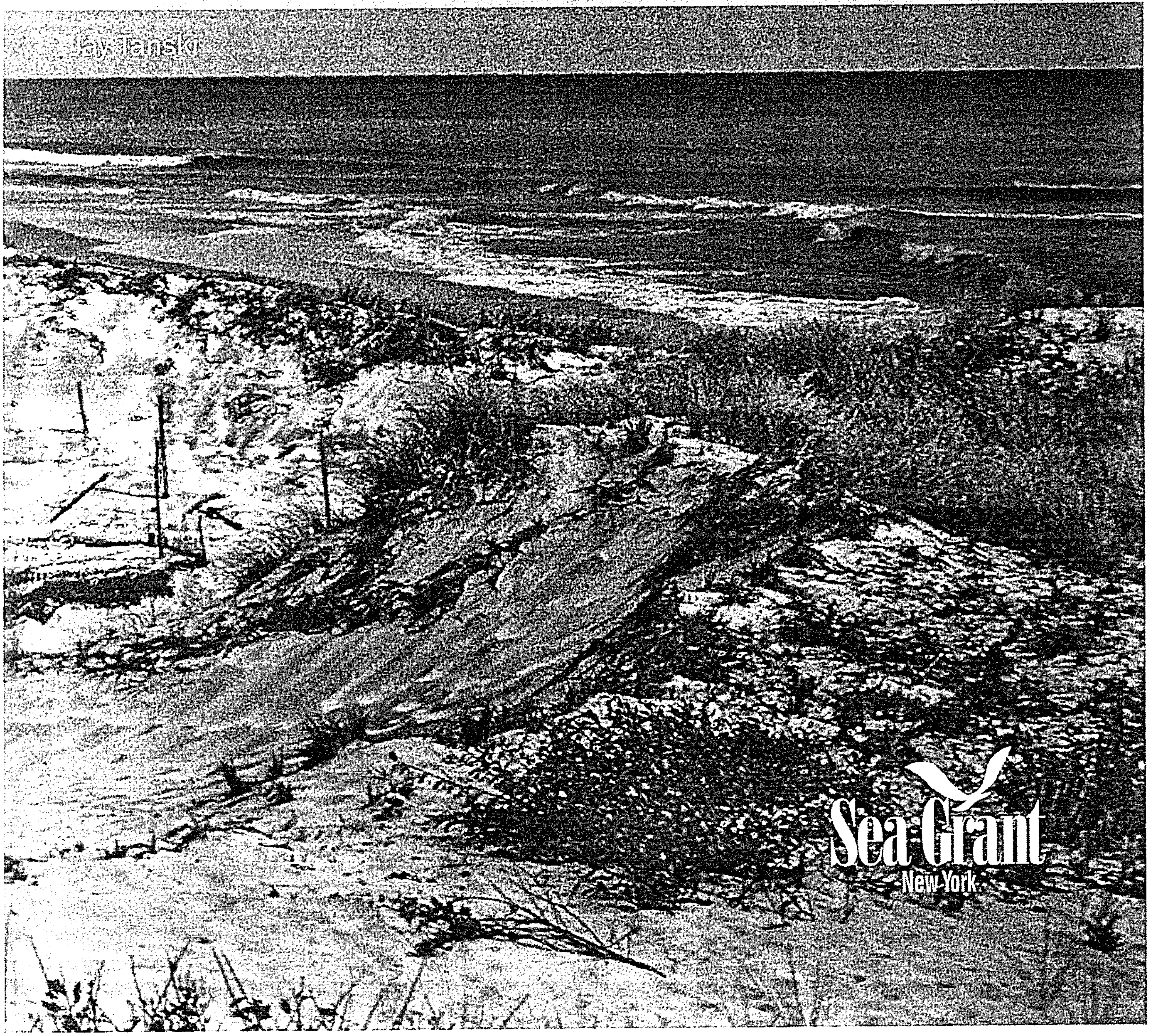
OBSERVATIONS

Note how the current is broken by the groins. This loss in current velocity causes a sand build up on the side of the groin. The result is a beach of greater stability.

Long Island's Dynamic South Shore

A Primer on the Forces and Trends Shaping Our Coast

Jay Tanski



Sea Grant
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Long Island's Dynamic South Shore

A Primer on the Forces and Trends Shaping Our Coast

Introduction

Long Island's Atlantic coastline is a special place for many reasons. The south shore is home to a wide variety of habitats which support a vast array of plants and animals, some threatened or endangered. It is also the place where millions of people live, work, and play. The 120-mile coast stretching between Coney Island and Montauk is remarkably diverse in terms of its physical characteristics, use, and development. This shore contains everything from heavily developed urbanized barrier islands to New York State's only federally-designated wilderness area. Area beaches are a prime recreational resource, attracting millions of visitors every year and serving as the foundation of a multibillion-dollar regional tourism industry.

Long Island's coast is also extremely dynamic, constantly changing in response to natural processes associated with wind, waves, and tides as well as human activities. The dynamic nature of the shoreline coupled with people's desire to use and enjoy the shoreline presents unique challenges in managing this resource. Making decisions that balance conservation of the natural environment with significant demand for use of the shore requires a sound understanding of the processes shaping and impacting the coast.

This primer provides a brief overview of what we know about coastal processes and erosion on Long Island's south shore, based on the best available scientific information. While by no means an extensive treatment of the subject, the information presented here is intended to familiarize the reader with the major shoreline trends and technical issues associated with erosion and erosion management on the south shore.

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Since 1971, New York Sea Grant, a partnership of the State University of New York, Cornell University, and the National Oceanic and Atmospheric Administration (NOAA) has been *"Bringing Science to the Shore"* through research, extension and education to improve the environmental and economic health of New York's marine and Great Lakes coasts.

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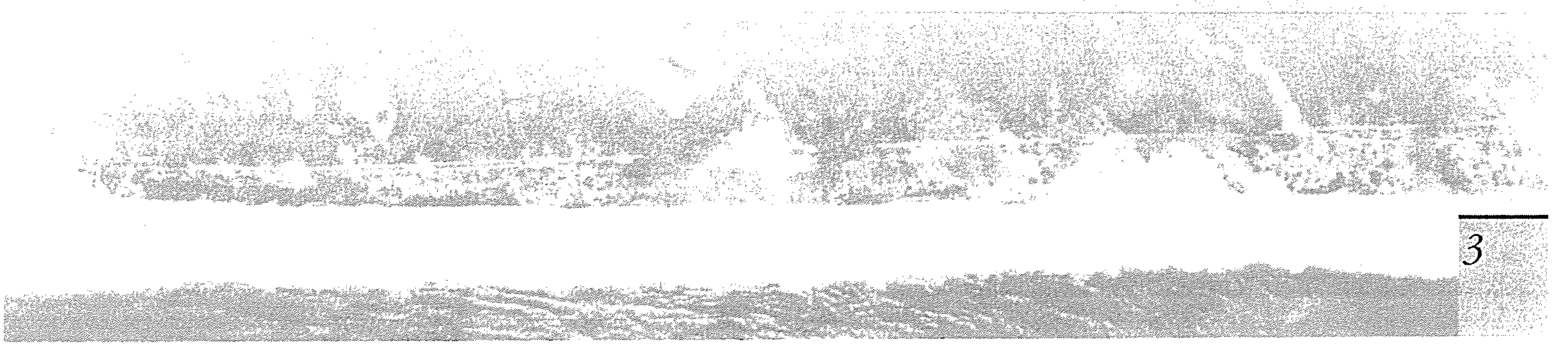

Long Island's South Shore

The south shore of Long Island can be divided into two distinct regions based on the physical characteristics of the coast *(Figure 1)*. Stretching almost 100 miles from Coney Island in New York City to Southampton in the east, the shore is composed of narrow, sandy islands and peninsulas separated from the mainland by shallow bays. These features are called barrier islands and barrier spits because they form a barrier between the ocean and the bays and the mainland. There are five barrier islands (from west to east: Coney, Long Beach, Jones, Fire and Westhampton) and two spits (Rockaway and Southampton). Six openings or tidal inlets separate the barriers and connect the bays with the ocean. All of the inlets are artificially stabilized with structures and are dredged to allow for navigation by commercial and recreational boats.

East of Southampton, the barrier island system gives way to what is known as the headland region. Here, the mainland directly abuts the ocean all the way to Montauk Point. In the western portion of this 30-mile stretch of coast, sandy beaches separate the ocean from a low-lying plain that is made of material laid down by waters melting from glaciers tens of thousands of years ago. To the east, the flat plains are replaced by 40- to 60-foot high bluffs formed when the glaciers stopped their advance southward and dropped the material they were carrying which ranged from large boulders to fine clays.

Development and use of the coast also changes from west to east along the south shore *(Figure 2)*. Heavily urbanized barrier islands and mainland shores are common in the west. Not many people realize it, but Coney Island in New York City is (or was) a barrier island. The western barriers (Coney Island, Rockaway and Long Beach) are home to year-round communities with residences, commercial businesses and industry. Beaches in the eastern and central sections of the south shore are heavily used for recreation due to their proximity to dense population centers. For example, Jones Beach State Park, created in 1929 on Jones Island, receives some six to eight million visitors per year. Fire Island is less densely developed with federal (Fire Island National Seashore), state (Robert Moses) and county (Smith Point) recreational park facilities interspersed with 17 primarily seasonal communities. The Otis Pike Fire Island High Dune Wilderness, the only federally designated wilderness area in New York, occupies seven miles of this island and another 14 miles of the national seashore is undeveloped. From Westhampton to Montauk Point, the shore is characterized by summer resort and residential communities. The well-known "Hamptons" are found here.

Despite the development found along the coast, Long Island's south shore, like many ocean coasts, is subject to change. Sand comes and goes from the beaches. Some areas are lost to the sea while in other areas beaches are actually building seaward. Most people are aware erosion problems exist on Long Island's south shore beaches.
But exactly how is the coast changing and what causes these changes?

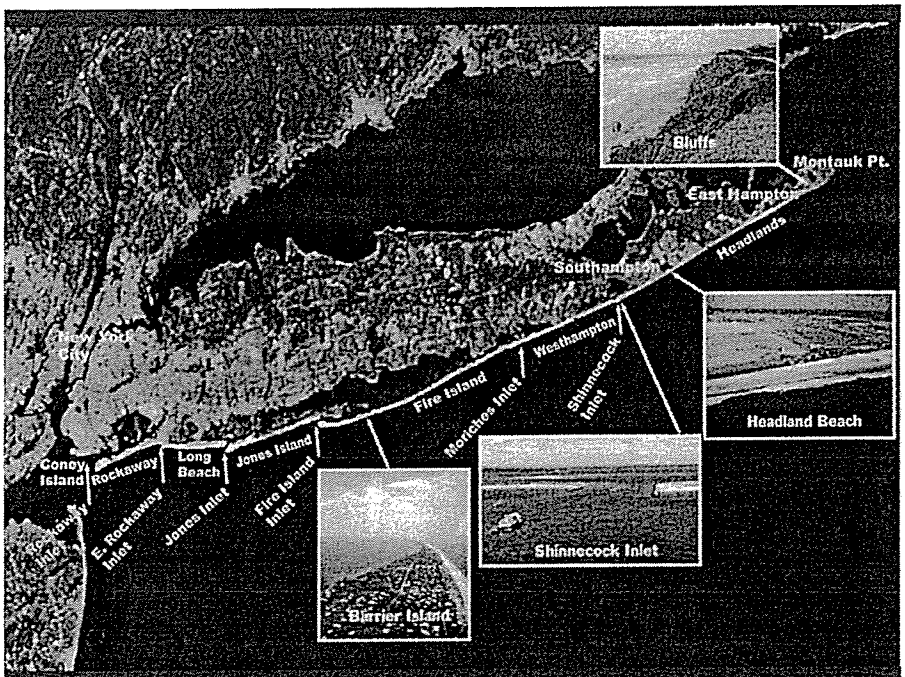

Figure 1. Long Island's south shore includes a variety of different shoreline types including an extensive barrier system with islands separated by tidal inlets in the west and a headlands section with high glacial bluffs in the east. (Satellite photo: NASA Visible Earth *http://visibleearth.nasa.gov/*)

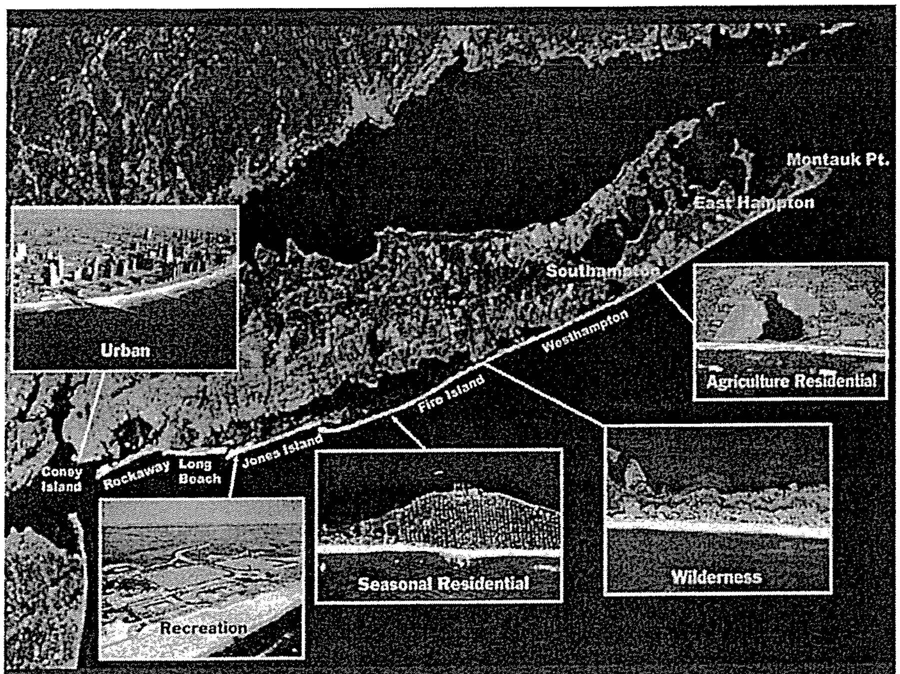

Figure 2. The south shore is characterized by a variety of different land uses. (Jones Beach photo: U.S. Army Corps of Engineers Beach Erosion Board, Satellite photo: NASA Visible Earth *http://visibleearth.nasa.gov/*)

The Dynamic Shore

Although Long Island's coast contains a variety of shore types (barrier islands and spits, mainland beaches and glacial bluffs), they are all primarily composed of small, loose materials such as gravels, sands and clays. Most of these sediments can easily be moved and reworked by wind and water, so the shorelines are inherently unstable and constantly changing in response to natural and human forces. The actual behavior of Long Island's shore is dependent on four major factors:

1) . the amount of wave and current energy striking the coast, which is largely related to storm intensity and frequency;
2) . the supply of sand available for building the beaches or shoreline;
3) . short- and long-term changes in sea level; and
4) . human activities in the coastal zone that alter or disrupt natural processes and movement of sand.

While simple in concept, these factors interact in complex ways and over different time scales. The relative magnitude and importance of each factor in determining shoreline behavior varies depending on the particular stretch of coast being considered and the period of interest, making erosion a deceptively difficult process to fully understand, predict and manage.

The Beach

When many people think of the coast, they automatically visualize the beach since this is where they spend most of their time at the shore. But the beach is not just that sandy strip of land between the waterline and the toe of the dune (or bluff, as the case may be) where you put your towel during the summer. Technically, beaches are usually defined as the accumulation of material (usually sand) moved by the action of waves and currents. Comprised of different parts *(Figure 3)*, the true beach really includes everything from the dune toe seaward to the outermost point where waves begin to break which can be in water 20 to 30 feet deep or deeper in major storms. The breaking waves exert force on the sea floor and create currents which move material on the bottom. Larger waves start breaking in deeper water so the beach extends even further seaward.

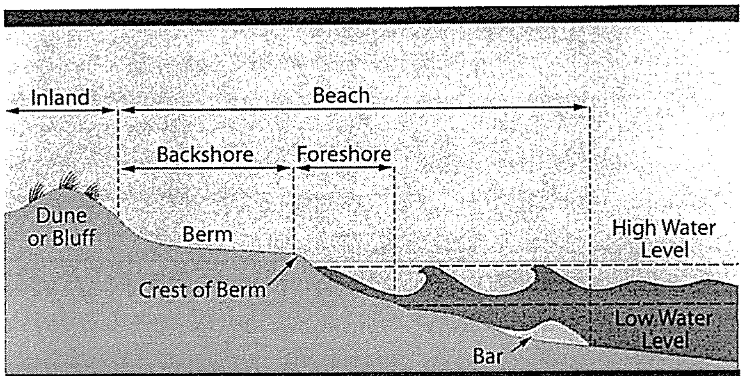

Figure 3. Beach terminology. (Illustration by John Norton)

Although not technically part of the beach, dunes are closely linked with the beach and are often considered as part of the beach system. In natural settings, dunes are the mounds of sand deposited landward of the active beach, usually by the wind. Dunes may be artificially created by either placing sand or creating obstacles (sand fencing or vegetation) to trap sand blown by the wind. Dunes are a common feature along the south shore. They take many forms and can be an important component of the beach system. You will learn more about dunes later in this primer.

Day-to-Day Changes: The beach is constantly changing from day-to-day, week-to-week, month-to-month and year-to-year, primarily in response to the waves. The size and even the presence of any part of the beach at a given time is influenced by a number of factors including the size and direction of the waves, the size and shape of sand grains on the beach, the level of the water at the time the waves strike the shore, and the initial shape of the beach, just to name a few.

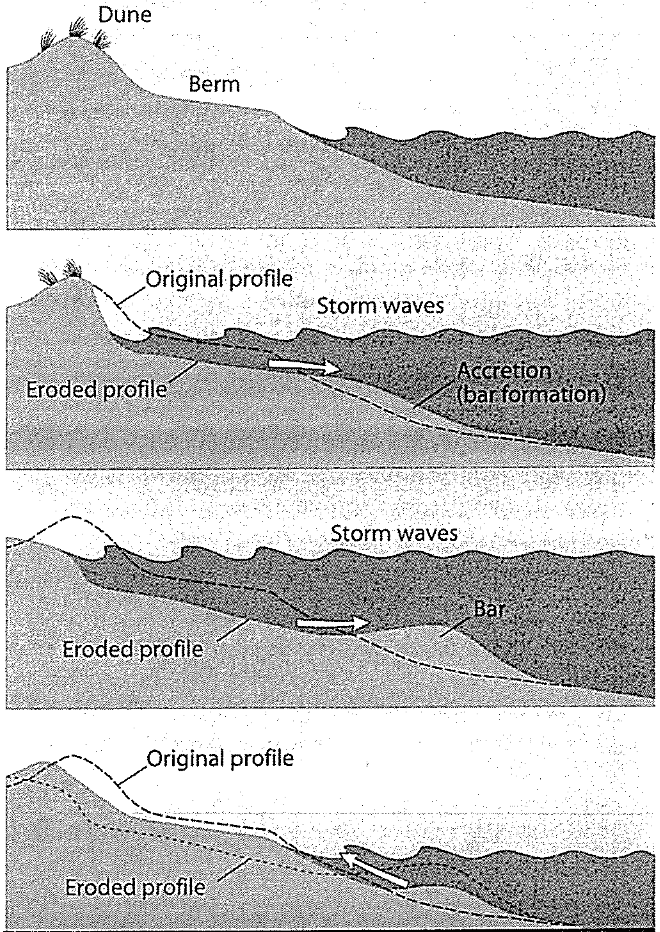

Figure 4. Beach response to storm waves. (Illustration by John Norton)

Waves play a major role in controlling the form, position and size of the beach. They are the primary agents responsible for picking up and moving sand along the coast. The beach responds quickly to changes in wave energy *(Figure 4)*. In general, very large, choppy waves, like those associated with big storms, tend to pick up and remove sand from the beach berm (that relatively flat part of the beach where you sunbathe in the summer) and, if the storm is strong enough, the dunes behind the beach. This lowers the elevation, flattening the beach profile, and causes the berm and shoreline to move landward. (For the purposes of this primer, shoreline is the boundary between the land and the water.) The material picked up by the waves can move in a variety of directions (landward, seaward or along the coast) depending on a number of factors. Frequently, material is moved offshore and is deposited in a bar during storms. As this bar grows, it causes bigger waves to break and dissipate their energy before they reach the landward beach berm. In this way, the beach actually helps protect itself. Although you may not be able to see it standing on the shore, the sand in the bar is still part of the beach and has not been lost from the "system."

In calmer weather, long, gentle waves can actually pick up much of the sand that had been transported to the bar and bring it back onshore, building up the berm, raising the height of the backshore and moving the beach berm and shoreline back seaward.

Thus, there is a cycle where the beach erodes and builds back up in response to wave action. In some coastal areas, this is referred to as the winter/summer seasonal beach cycle, because beaches tend to be narrower in the winter when there are more storms and wider in the summer when weather conditions (and waves) are generally calmer. However, research has shown this seasonal cycle is not as regular for Long Island ocean beaches as it is in some other regions. Here, the width of the beach depends more on the amount of time since the last storm rather than the season. You often find wide beaches in the middle of winter and narrow beaches in the summer depending on recent weather conditions.

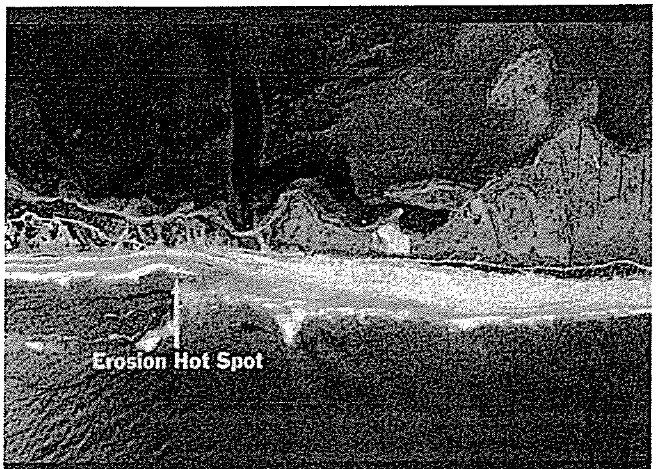

Figure 5. Erosion along the shore can be highly variable, even over short distances, as evidenced by this erosion "hot spot" adjacent to a wide beach. (Photo: Atlantic Coast of New York Monitoring Program, *http://dune.seagrant.sunysb.edu/nycoast*)

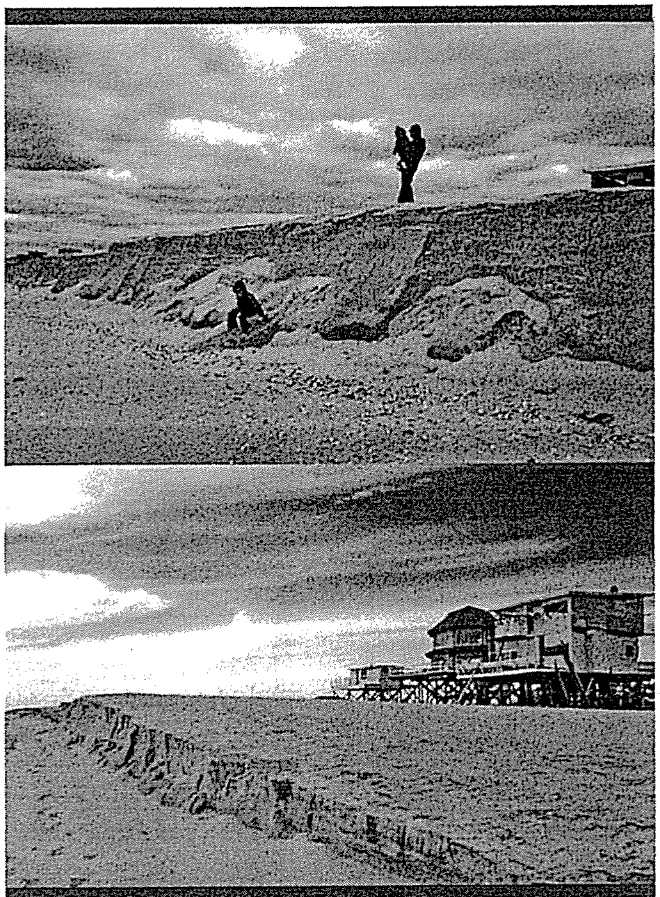

Figure 6. Storms can remove sand from the beach leaving steep scarps (top). In most cases, much of the sand returns to the beach (bottom), usually within a few weeks after the storm.

Year-to-Year Changes: Measurements made along the south shore show the position of the waterline on some ocean beaches may move back and forth by as much as 270 feet over the course of a year as the beach alternately grows and erodes in response to wave action. These changes are largely controlled by the frequency and intensity of storms hitting the coast.

Storms not only generate high waves, they also cause the water level to increase above the elevations expected with the normal tides. This difference in actual or observed water height from the predicted tide level is known as storm surge. Storm surges allow the waves to attack higher up on the beach and cause erosion. As a result, storms can move large amounts of sand from the visible beach very quickly. In some cases, one stretch of the shoreline may be severely eroded while adjacent beaches will have remained stable or even gained sand *(Figure 5).* While these erosion "hot spots" are frequently observed, the underlying causes are not well understood but are thought to have something to do with the presence or absence of the bar offshore.

Even after relatively modest events, beachgoers often see scarps cut by the waves on the beach *(Figure 6).* Much of the sand removed from the beach above the waterline is still in the beach system and may return to the upper portion of the beach under the right conditions. Surveys of some beaches on the south shore show they usually rebuild fairly quickly, generally within a month after most storms.

While the beach may be constantly changing and the waterline moving back and forth, the position of the shoreline fluctuates around an "average" position that won't change very much on a yearly basis as long as the sand is not lost from the beach system. However, this may not be the case if the storms are very severe and sand is being removed from an area without being replaced.

Effects of Storms

Storms play a major role in shaping our shoreline. Long Island experiences both hurricanes and the winter storms known as nor'easters. Hurricanes are usually smaller in size but more intense than nor'easters, with stronger winds and higher storm tides. Hurricane

Figure 7. Damage in Saltaire, Fire Island, caused by the 1938 hurricane. (Photo: U.S.Army Corps of Engineers 1958)

storm surges can increase sea level more than ten feet above the normal tide level. These storms usually pass through this area in a matter of hours but, if they happen to coincide with a high tide, the abnormally high water levels threaten human life and can cause extensive damage to the beach and properties along the shore. The September 1938 hurricane, known as the "Long Island Express," passed over Westhampton and reportedly had winds of 96 miles per hour and a storm surge of nine feet. This storm caused more than 50 fatalities on Long Island and destroyed hundreds of homes on the coast *(Figure 7).*

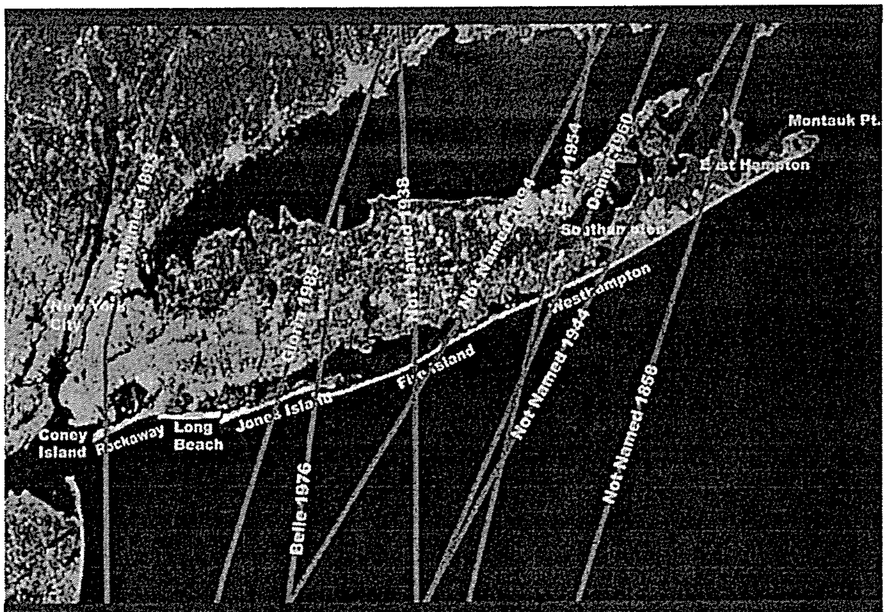

Figure 8. Tracks of hurricanes making landfall in the New York City/Long Island area since 1858. (Storm data from: *http://maps.csc.noaa.gov/hurricanes/*)

More recently, Hurricane Gloria struck our coast in 1985. However, this storm moved very fast and passed quickly over the south shore close to low tide. Although the storm surge was seven feet in some areas, the actual storm tide or water level elevation was only two or three feet above normal high tide levels. As a result, most of the damage from Gloria was caused by the wind rather than the water. The situation could have been considerably different if the storm had hit six hours earlier or later, nearer to high tide. Fortunately, because New York is fairly far north, we have not seen very many hurricanes. Only nine have actually made landfall in the Long Island and New York City area since 1858 *(Figure 8).*

While not as powerful as hurricanes, nor'easters occur much more frequently in this area. Because they cover a bigger area and are slower moving than hurricanes, nor'easters usually affect a larger portion of the coast (hundreds of miles of shoreline as opposed to tens of miles) for a longer period of time (days versus hours). Nor'easters can also produce waves larger than those generated by hurricanes.

During the 1992 December nor'easter, gauges off the south shore of Long Island measured waves over 30 feet high. Storm surges associated with winter storms, while generally lower than those of hurricanes, are still substantial. Measurements taken at the Battery in New York City showed the December 1992 nor'easter caused water levels to rise more than 4.5 feet above normal, allowing waves to reach dunes and bluffs behind the beach. Statistically, storms with similar tide levels have a high probability of occurring over any 30 year period and are sometimes referred to as "30 year storms." (This does not mean that two or more storms of this magnitude could not occur in a shorter time interval.) Because of their long duration, large waves and high storm tides, these intense storms can have a devastating impact on the coast.

The worst hurricanes and nor'easters move vast quantities of sand, rearranging the beach which can have long lasting effects on the

Figure 9. Washover fans and breaches caused by the 1938 hurricane in the Westhampton area. (Photo: U.S.Army Corps of Engineers 1958)

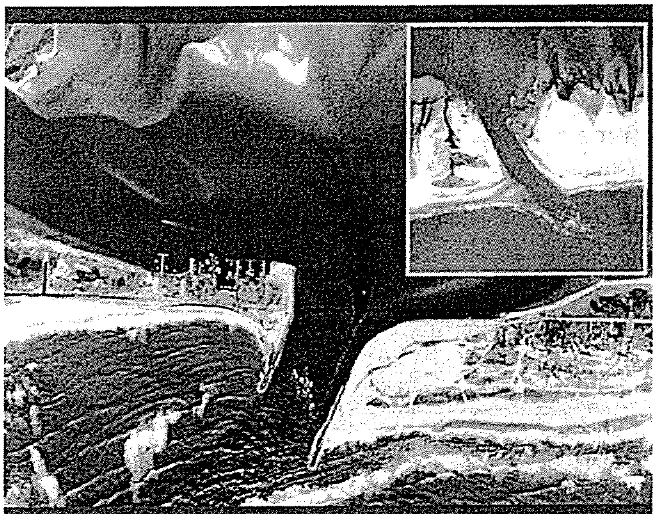

Figure 10. Shinnecock Inlet today and as it looked shortly after it opened during the 1938 hurricane (inset), before it was stabilized. (1938 Photo: U.S. Army Corps of Engineers Beach Erosion Board, Recent Photo: Atlantic Coast of New York Monitoring Program, *http://dune.seagrant.sunysb.edu/nycoast*)

shoreline. During major storms, the elevated water levels and big waves can erode large volumes of sand from the shore and attack the dunes or bluffs behind the beach. The storms move material along the shore to adjacent areas, but some of the sand eroded from the beach and the dune may be carried seaward and deposited in water too deep for it to be brought back by the gentler waves during calmer conditions. This sand is lost from the beach system. If enough sand is transported into deeper water, the beach will not be able to fully recover and the shoreline will move landward resulting in long-term erosion or recession.

If the storm surge is high enough, the waves powerful enough, and the beach and dunes low enough, storms can erode the beach and dunes and cause an overwash. Water carries sand over the beach and through the dune depositing it on the landward side in a feature known as a washover fan *(Figure 9).* The 1962 Ash Wednesday storm reportedly created some 50 such washovers. The material in the washover fan is also lost from the beach system. On the south shore barrier islands or spits, the overwashes can reach the bay. However, studies looking at the impact of storms and the characteristics of the resultant washover fans indicate this rarely happens, except occasionally on the eastern barriers which tend to be lower in elevation. Washover fans do help to increase or maintain the elevation of the barrier island behind the dunes, often burying swales and marshes but providing habitat for shorebirds and other organisms and providing a place for new dunes to form in a more northerly location.

During very extreme events, overwash channels can grow and deepen, eventually forming a breach, or opening in the barrier island or spit, that allows water to flow between the bay and the ocean. Breaches are more frequently formed by hurricanes because they tend to have higher storm tides than nor'easters. The 1938 hurricane reportedly opened nine breaches in the barriers west of Moriches Inlet. Sand moving along the coast usually fills most of these breaches naturally, often during or soon after the storm. However, larger breaches can remain open and grow larger for long periods. Breaches that stay open and that are maintained by normal tidal currents become inlets. Both Moriches and Shinnecock Inlets started out as breaches created by storms that were then kept open artificially for navigation *(Figure 10).*

Inlets and breaches have a tremendous impact on the way sand moves around the coast, which, in turn, exerts a major influence on the behavior of the adjacent shorelines. Currents running through the breaks in the barriers can transport large quantities of sand landward into the bays and seaward into the deeper waters of the ocean. This material usually ends up in large underwater shoals or bars in the bay and in the ocean adjacent to the inlet that are created by the flood and ebb tides, respectively. The shoals on the bay side are known as flood tidal shoals or deltas; ocean shoals are known as ebb tidal shoals or deltas. The amount of sand found in the tidal deltas on the south shore far exceeds the volume of sand moved by the overwash processes. Inlets are a far more important mechanism for moving material in a cross shore direction (that is, perpendicular to the shoreline, rather than parallel to the shoreline) than overwash. Some of the marshes found on the bayside of the barrier islands are actually built on the flood tidal deltas of historical inlets that opened and closed over the last several hundred years *(Figure 11).*

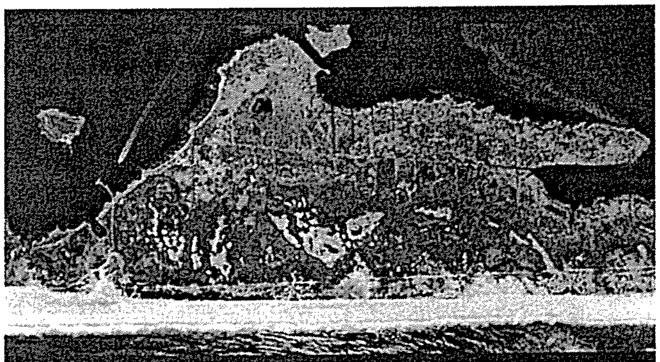

Figure 11. Marsh growing on sediment deposited in the bay by a historical inlet that opened and then closed in the 1800s. (Photo: Atlantic Coast of New York Monitoring Program, *http://dune.seagrant.sunysb.edu/nycoast*)

Long-Term Shoreline Changes

Although major storms are relatively short in duration and do not occur very frequently, they play an important role in shaping how the coast looks and behaves over time. The immediate impact of a single storm is apparent to everyone, but it is the cumulative effects of these storms that determine how the shoreline moves and changes over time scales ranging from tens to hundreds of years.

On these longer time scales, much of the south shore of Long Island is relatively stable compared to many other coastal areas. Estimates of shoreline change over the last 100 years or so show that large portions of the shore have been eroding at average rates of approximately one to two feet per year *(Figure 12).* However, these rates vary widely along the coast. Some areas were actually stable or even moving seaward over the same time span. Averaged erosion rates have to be used with caution. For much of the shore, the long-term changes occurring along the coast are too small to accurately determine with the data and measurement techniques presently available. Part of the problem in making these measurements is that the beach (and shoreline) can move back and forth hundreds of feet on a yearly basis in response to the waves, as described earlier. Yearly fluctuations can be as large, or even larger, than the movement we would expect to see due to longer-term erosion or accretion trends. These large yearly changes make it very difficult to detect long-term shoreline change rates unless the changes are very large. The highest shoreline erosion rates and accretion rates, which may exceed five feet per year, are both usually found near stabilized inlets and other man-made structures and are the result of interruptions in the natural movement of sand along the coast.
(For more information, see section on Longshore Sediment Transport.)

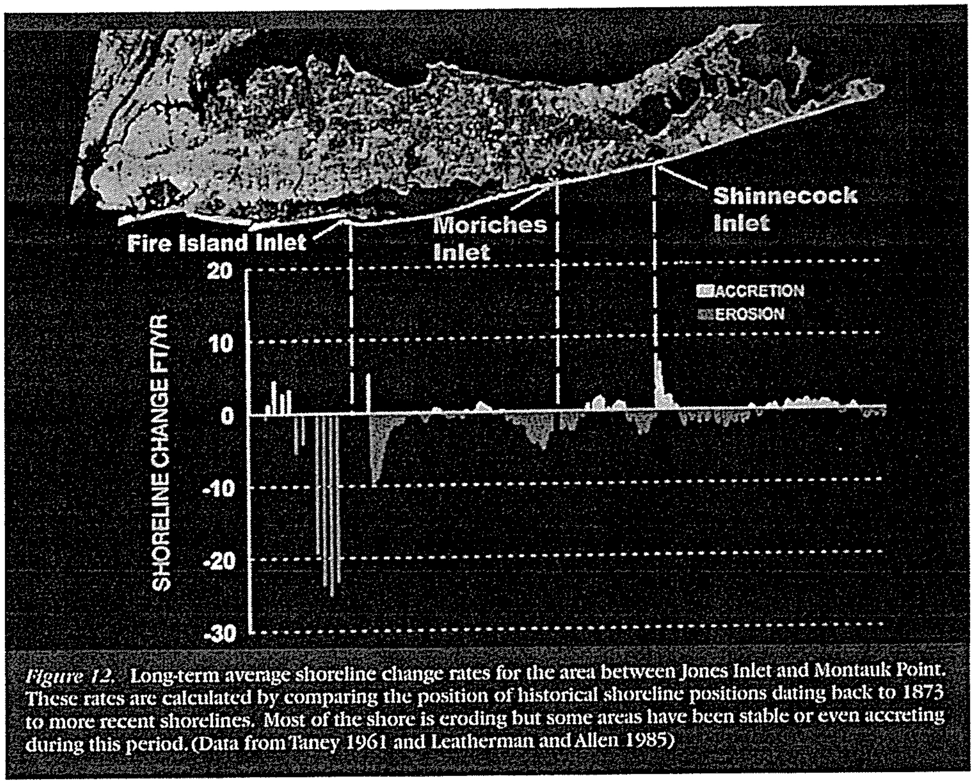

Figure 12. Long-term average shoreline change rates for the area between Jones Inlet and Montauk Point. These rates are calculated by comparing the position of historical shoreline positions dating back to 1873 to more recent shorelines. Most of the shore is eroding but some areas have been stable or even accreting during this period. (Data from Taney 1961 and Leatherman and Allen 1985)

Historical Changes — Sea Level Rise and Barrier Island Migration

A Look at the Past

Shoreline changes over time frames spanning decades to centuries vary considerably ranging from erosion to accretion depending on where you are on the south shore. However, if one considers longer periods of thousands of years, all of Long Island's shorelines have moved landward in response to rising sea level. Twenty thousand years ago, glaciers covered the land and stored a significant amount of the planet's water. With all this water locked up in the glaciers, sea level was some 450 feet lower than it is today and our ocean coastline was more than 80 miles south of its present position
(Figure 13).

As the climate became warmer and ice in the glaciers melted, water poured back into the ocean and sea level rose. The shoreline started migrating landward, moving north up the gently sloping continental shelf. The rate of sea level rise during this time was not constant. Sea level rose very rapidly between 20,000 and about 8,000 years ago and then slowed down to a rate of about three feet every 1,000 years. The origins of the south shore barrier islands are not fully understood but they may have formed when this slowing of sea level rise occurred. There is evidence that barrier islands existed at a location about a mile offshore in water about 50 feet deep.

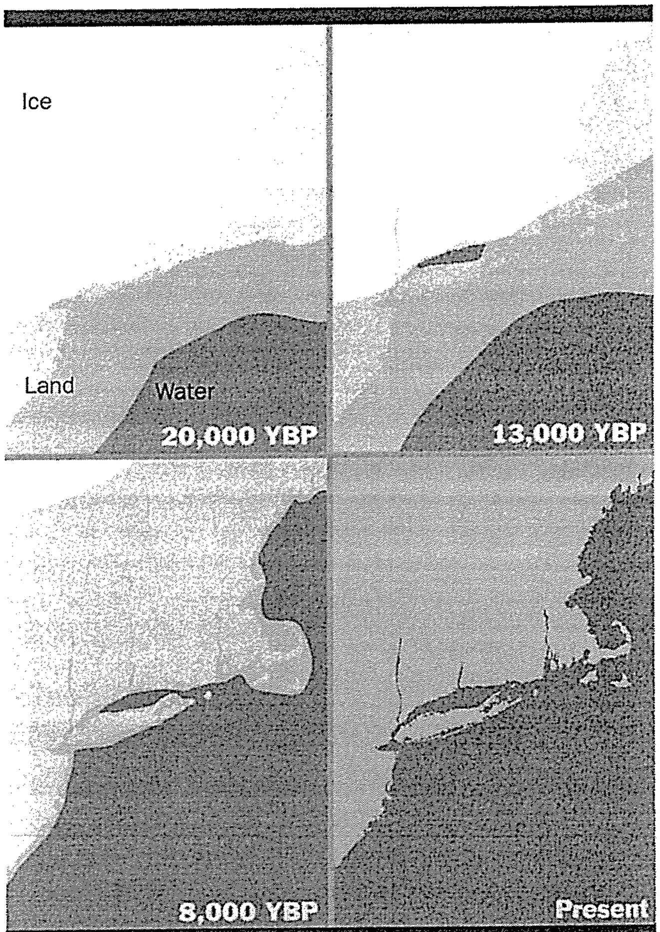

Figure 13. Over geologic time, the shoreline has retreated landward over the last 18-20,000 years as the glaciers melted and sea level rose. YBP = Years Before Present. (Illustration by Loriann Cody)

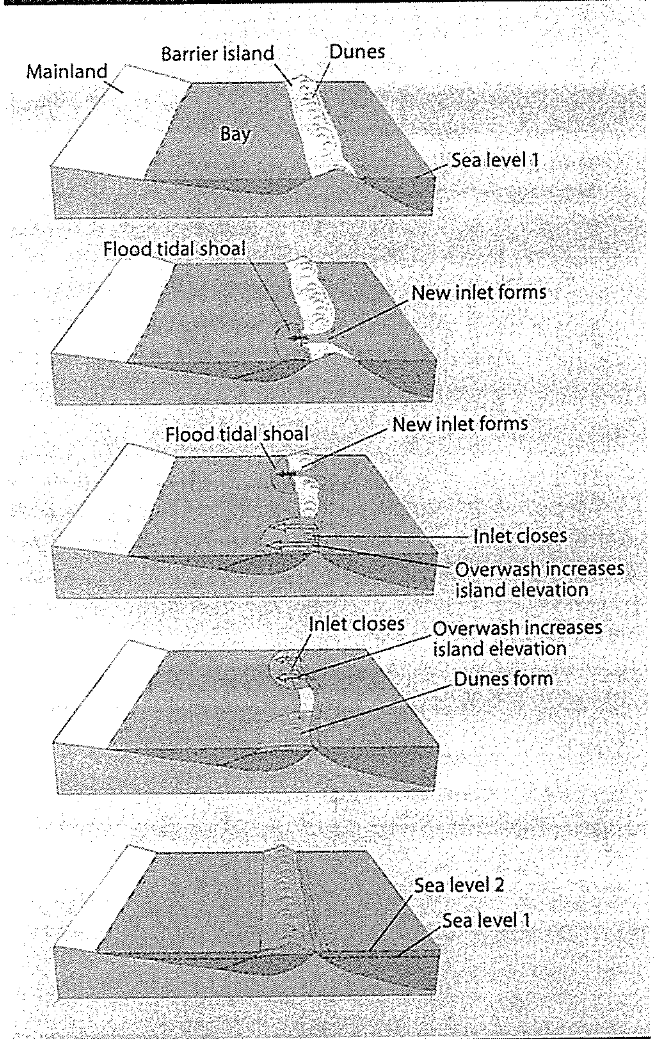

Figure 14. Simplified schematic of barrier island migration on the south shore in response to sea level rise. Inlets transport sand to the bays in the form of flood tidal shoals which provides the platform that allows the island to move landward. Overwash processes then raise the elevation of the island. This migration is a slow process occurring over periods of hundreds to thousands of years. (Illustration by John Norton)

Barrier Island Migration

These barrier islands retreated or migrated northward as the ocean continued rising. There is some debate about how the barriers actually moved. Some research suggests that the barriers slowly drowned in place and then "jumped" or "skipped" landward to a new position coinciding with the new position of the shoreline. More recent studies indicate the islands move in a more continuous process where sand is transported across the island from the ocean to the bay, allowing the island to migrate landward. There are three primary ways that sand can be transported across a barrier island: inlet formation, overwash processes and eolian (or wind) transport. On Long Island's south shore, the inlets are actually far more important than either overwashes or the wind in terms of moving sand landward and driving barrier migration. The flood tidal shoals created by historical inlets provide the platform that allows the island to maintain itself while moving landward over time in response to rising sea level *(Figure 14).* Regardless of the actual mechanisms by which the barriers move in response to the rise in sea level, they have moved landward over the historical time frame of thousands of years.

However, the rate at which the barriers migrate varies along the south shore when one considers shorter time scales on the order of centuries. Geologic evidence indicates that the central portion of Fire Island between Ocean Beach and Watch Hill has not migrated for the last 750 to 1,300 years. This section of the island has experienced erosion on the ocean and bay shorelines, but the position of the island has remained in the same location. Interestingly, there is no evidence of historic inlets in this area over the last several centuries *(Figure 15).* The stable location and absence of historic inlets in this area suggest that barrier migration may not be a continuous process over timescales of a thousand years or less. Further to the east, the barriers are more mobile and one can find evidence of barrier island rollover processes such as old flood shoals in the bay that were associated with inlets that have opened and closed naturally over the last several hundred years.

Sea Level Rise and the Future

Along the New York coast, sea level is not only rising, the land is also slowly sinking, or subsiding due to geologic processes. The rise in the water level in relation to the land surface due to the sinking of the land and the raising of the sea is known as relative sea level rise. In our area, the average rate of relative sea level has been about a tenth of an inch per year, or about one foot per century. As can be seen in Figure 16, there are considerable monthly, yearly and decadal fluctuations in the elevation of the water. Short-term changes in sea level caused by storms are much larger than those associated with the long-term trends. Daily tides change sea level by two to five feet and storms with return periods of 30 years can raise water levels four to six feet above normal elevations in just a few hours.

It is not known exactly how much of the erosion we see on the south shore is directly attributable to the slow rise of relative sea level. Calculations based on measurements of beach changes going back to the 1950s show that the sea level increase might account for less than one foot per year of erosion and even this may be an overestimate. Studies also show that the changes a beach may go through in a single month can be over 200 times more than that expected from relative sea

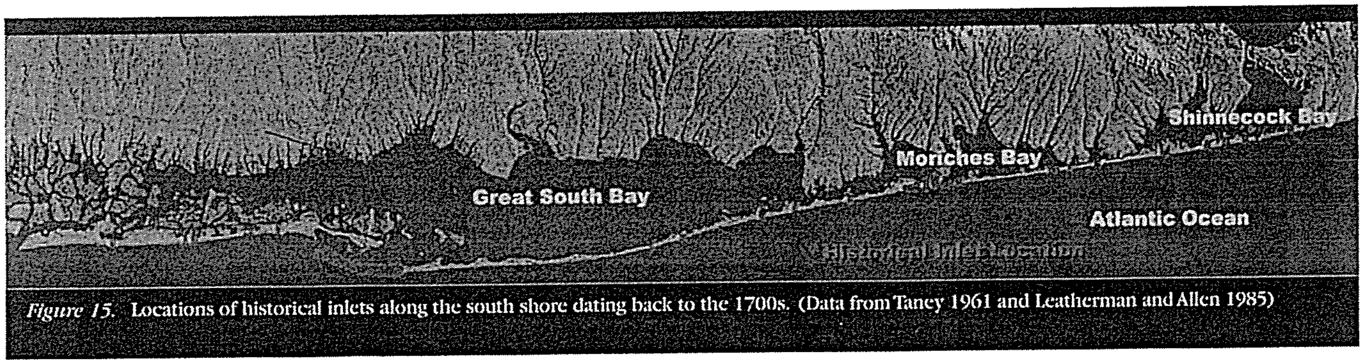

Figure 15. Locations of historical inlets along the south shore dating back to the 1700s. (Data from Taney 1961 and Leatherman and Allen 1985)

level rise alone. In terms of our most severe erosion problems, long-term sea level rise is of secondary importance compared to other factors acting on shorter, decadal time scales.

Long-term relative sea level rise is important, however, in that it ultimately controls the position of the shoreline. An increasing sea level means we will be faced with erosion problems for the foreseeable future. There is a growing consensus that human activities are contributing to global warming, which in turn can increase the rate at which the oceans will rise. While there is considerable uncertainty regarding the magnitude and timing of this increase, the most likely scenarios indicate the rate of sea level rise may double or triple over the next 100 years. In 50 years this could result in water levels that are 1.0 to 1.5 feet higher than present (as compared to 0.5 feet higher if the present rate of rise did not change).

From a planning perspective of 30 to 50 years, the biggest impact of an increased rate of relative sea level rise will be the submergence of the flat, low lying areas around the bays on the south shore. Communities in these areas could be subject to increased flooding. Coastal wetlands may also be affected by long-term sea level rise. Salt marshes, one of the most productive ecosystems on earth, are very sensitive to the position of sea level. Fine-grained material deposited in the marshes raises the surface, keeping it in the same relative position to a rising sea surface. If sea level rises faster than the sediments can be supplied, marshes could be flooded and replaced by open water. If deposition and sea level rise are in balance, some marshes may be able to migrate landward if there is room for them to retreat. Retreat will probably not be possible if the slope of the land behind the marsh is too steep or the path is blocked by structures such as roads, seawalls, or houses.

On time scales of hundreds to thousands of years, increased sea level rise could accelerate the migration of barriers landward or even lead to their disappearance altogether if the rise is very fast. The projected increases in sea level could make sections of the ocean coast more vulnerable to erosion over time. However, over planning time frames of 30 to 50 years, even increased sea level rise would not significantly change the actual observed rates of shoreline change in those areas experiencing the most severe erosion. On these time scales, sea level rise is of secondary importance compared to other factors in controlling what happens on the coast. The frequency and intensity of the storms, discussed above, and the supply of sand in the system available for building the beaches play a far bigger role in shaping the coast. In most cases, our most severe erosion problems are caused by disruptions in the transport of sand, due to either natural processes or human activities.

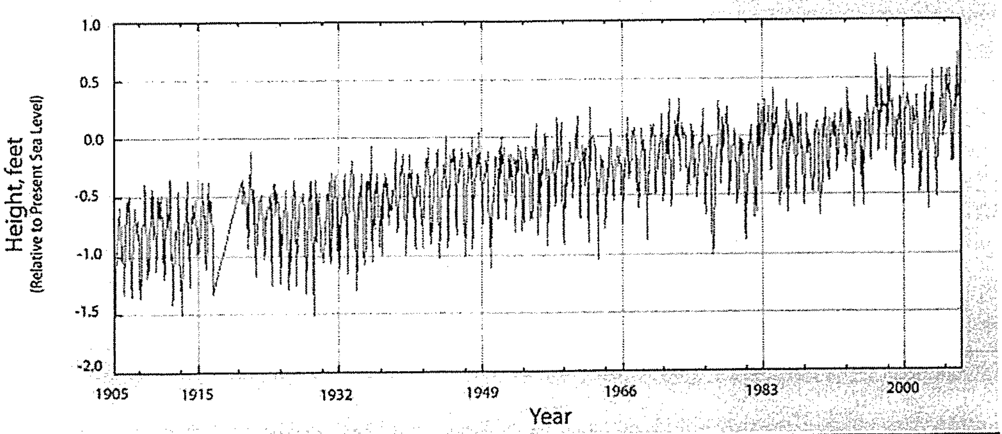

Figure 16. Monthly mean sea level measured by a tide gauge in New York City. Sea level has been rising at a rate of about one foot per century in this area. (Data from: NOAA NOS Battery Tide Gauge, *http://tidesandcurrents.noaa.gov*)

Sand — A Valuable Resource

The south shore is composed of material left by the glaciers that has been reworked by waves and currents to form the coastline we see today. Compared to many other coastal areas, the south shore has a relatively abundant supply of sand for building beaches. The condition of the beaches and position of the shoreline is the result of a balance between the sand lost from an area and new sand brought into the area. Where this balance is positive, beaches can build up and the shoreline can actually move seaward. If more sand is leaving than arriving, the shoreline erodes. For this reason, the way sand moves around in the system and the amounts moved are very important. This "sediment transport" is very complex and not well quantified on the south shore. Even though precise amounts of sand and exact pathways of movement are not known at this time, some general patterns and trends are recognized.

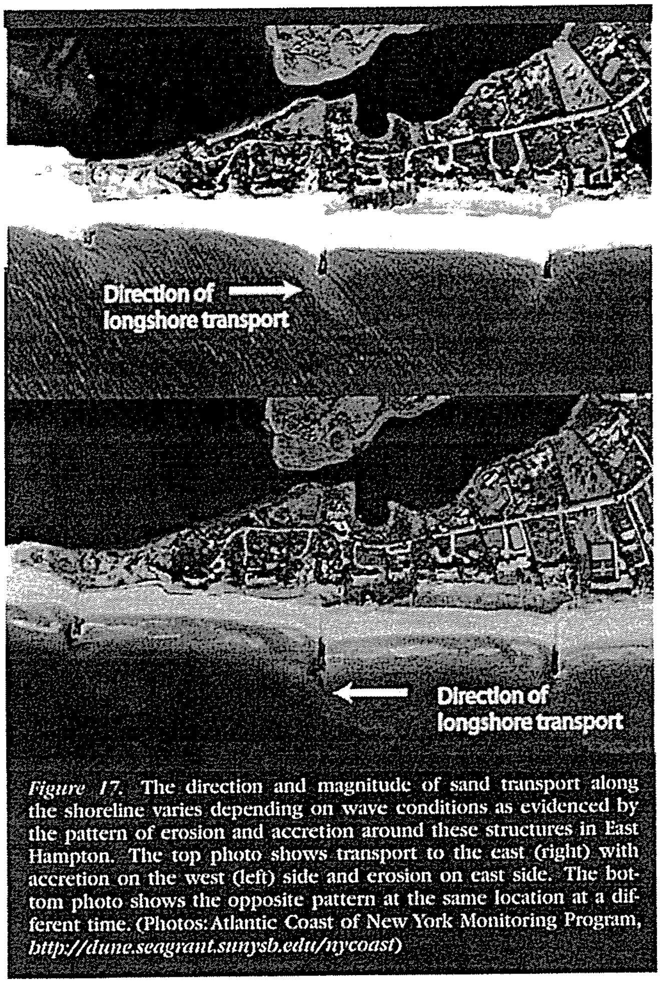

Figure 17. The direction and magnitude of sand transport along the shoreline varies depending on wave conditions as evidenced by the pattern of erosion and accretion around these structures in East Hampton. The top photo shows transport to the east (right) with accretion on the west (left) side and erosion on east side. The bottom photo shows the opposite pattern at the same location at a different time. (Photos: Atlantic Coast of New York Monitoring Program, *http://dune.seagrant.sunysb.edu/nycoast*)

Longshore Sediment Transport: Not Quite a "River of Sand"

As already described, waves hitting the shore can move sand landward or seaward in a cross shore direction. Waves approaching the shore at an angle also create currents which carry sand parallel to the coastline in the surf zone. This movement of sand is called longshore sediment transport (the sand moving in the surf zone is also referred to as longshore or littoral drift). Longshore transport has often been described as a "river of sand" picking up and depositing material on the beach as it moves along the shoreline. This analogy is somewhat misleading for the south shore, however. While a river usually flows in one direction, the longshore transport can be to the east or the west depending on the direction of the waves and even where you are on the shoreline *(Figure 17).*

The amount of sand moved depends on the size and frequency of the waves. Bigger waves move much more sand, which means that storms, with their large waves, are very important in controlling the distribution of sand along the shore. The size of the waves responsible for moving most of the sediment on the south shore is controlled by three variables: the speed of the wind over the water, the distance the wind blows over water (called the fetch), and the length of time the wind blows. The fetch of winds blowing towards the east is limited by the presence of New Jersey. This limits the size of the waves which carry sand east along the New York Atlantic shore. The fetch for winds blowing towards the west is virtually unlimited. As a result, the waves driving longshore transport to the west are generally stronger than the waves moving sand east. Although sand is moved in both directions, more sand tends to be moved to the west resulting in a net transport of sand from east to west in most years. The rate at which sand moves along the coast is usually measured in units of cubic yards per year. To envision a cubic yard, think of a volume of sand about the size of a typical clothes washing machine.

The net longshore transport rate of sand varies along the south shore *(Figure 18).* While there is a good deal of uncertainty regarding the exact numbers, estimates indicate the rate of transport is approximately 100,000 to 300,000 cubic yards per year to the west in the eastern end of Long Island. The rate increases to as much as 600,000 cubic yards to the west at Fire Island Inlet and then decreases to about 450,000 cubic yards nearer New York City. Even given the uncertainties associated with the estimates, there are obviously substantial quantities of sand moving along the coast. This movement of sediment can have a major impact on what happens to the shoreline in an area. To give you an idea of how important it can be, the longshore transport of sand actually allowed the western end of Fire Island to grow or accrete more than four miles between 1825 and 1940 when a jetty was constructed to slow this westward migration of the island and stabilize the inlet. The original Fire Island Lighthouse was constructed in 1826, at what was then the western end of Fire Island, to guide ships through an inlet that existed there at that time. The current structure, constructed in 1857 just to the east of the original light, now sits well east of the new position of the inlet, which moved west as the island grew more than 150 feet per year with sand supplied by longshore transport.

Where does all this sand come from? For a long time, people thought the sand transported along the coast came from erosion of the bluffs at Montauk, but studies of the composition and erosion rates of these features indicate bluff erosion alone can't supply all of the material we see in the system. Some of the sand actually comes from the erosion of the mainland and barrier beaches themselves. More recent studies suggest that a significant portion of the material in the longshore transport system may come from offshore deposits of sand. The relative contributions of these three sources is not known.

The longshore transport of sand ties the south shore together as a system. Although we do not know precisely how much sand is flowing along the shore or exactly where it is flowing at any given time, we do know this flow of sand is critical to maintaining the shoreline. Actions taken in one area can affect adjacent areas. We also know that many of our most troublesome erosion problems are the result of disruptions of this flow either by natural processes or human activities.

Figure 18. Sand moves in both directions along the shore, but generally more sand moves to the west than to the east resulting in a net westerly transport. There is considerable uncertainty in the values shown here due to variability in the rates of movement at different times and places and difficulties associated with trying to measure the amount of sand moving along the coast.

Tidal Inlets — An Important Part of the System

Stabilized Inlets

Inlets exert a dominant influence on the behavior of the shoreline by interrupting the natural longshore transport of sand along the coast and capturing sediment that might otherwise reach adjacent beaches. The stabilized inlets are especially important. Jetties (the long stone structures built at a right angle to the shoreline to fix the navigation channel in place) trap sand moving along the beach, causing the beach on the updrift side (usually the east side on the south shore) to extend seaward *(Figure 19)*. However, the trapping of sand on the beach by the eastern jetty is a very minor impact compared to the problems caused by the formation of shoals associated with the inlets.

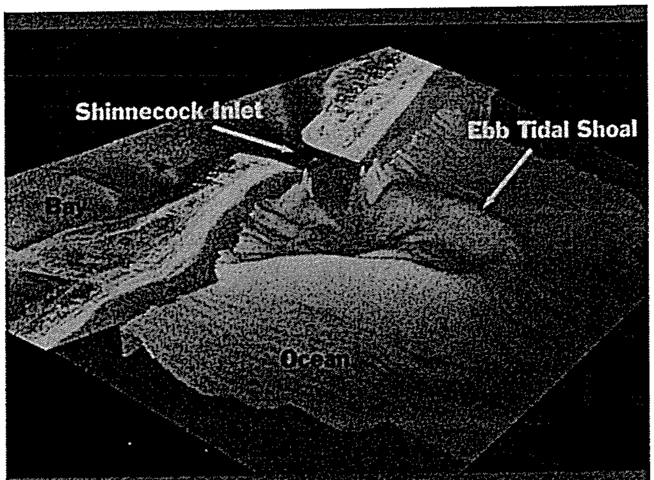

Figure 20. Shinnecock Inlet has trapped approximately 8 million cubic yards of sand from the longshore system in the ebb tidal shoal located seaward of the inlet. This representation of the shoal was constructed from high resolution surveys of the seafloor. (Survey data by R. Flood, GIS integration by B. Batten)

When the tide is flooding or rising, the inlets allow sand to be swept into the bay and deposited where it forms the flood tidal shoals landward of the inlet. During outgoing, or ebbing, tides, currents created by the water flowing out of the bays push sand offshore, depositing it in the ocean where it forms ebb tidal deltas. The ebb tidal deltas are less visible than the flood tidal deltas because they are submerged, but these ebb tidal deltas are more important in terms of their impact on the shoreline because of their sheer size. They are much larger than the flood shoals in the bays. For instance, the ebb tidal delta at Shinnecock Inlet is estimated to hold around 8 million cubic yards of material *(Figure 20)* compared to around 0.5 million for the flood tidal delta. Although very difficult to measure, estimates of the size of the ebb shoals range from about 4 million cubic yards for Moriches Inlet to over 40 million cubic yards for Fire Island Inlet. Imagine a mound of sand the size of 40 million washing machines under water!

Given the size of the inlets and their related shoals, it is easy to see how they can have a major impact on the shoreline. However, these features are actually very complex systems and the full range and magnitude of their impacts are still not entirely understood. What is known is that inlets disrupt the natural flow of sand along the shore and can have a tremendous impact on the adjacent beaches. The vast amount of material stored in associated shoals is essentially lost from the nearshore beach system. Cut off from the natural supply of sand, the beaches immediately downdrift (west) of the inlets experience greatly accelerated erosion. While this erosion helps restore the flow of sand along the shore by replacing material trapped by the inlet, it also causes rapid shoreline recession adjacent to the inlet on the downdrift side. As a result, the inlets on the south shore exhibit a characteristic

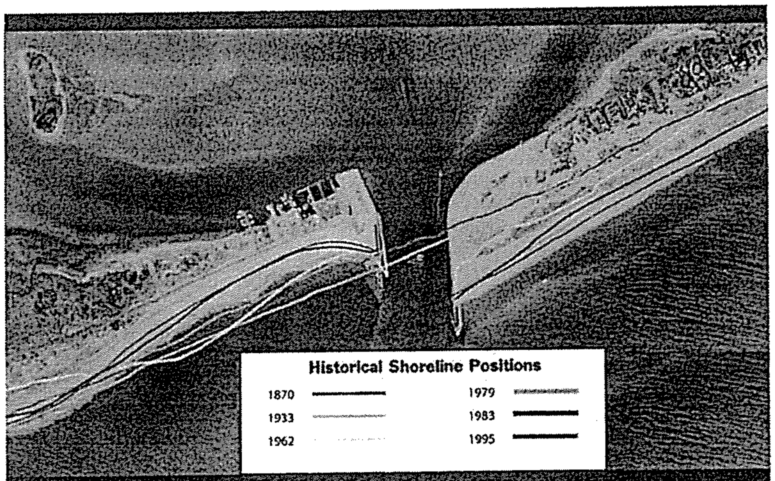

Figure 19. Inlets can have a major impact on adjacent areas as indicated by the historical shoreline positions near Shinnecock Inlet. After the inlet opened in 1938, the eastern or updrift shoreline (to the right) moved seaward while the western shoreline eroded and moved landward. (From: Atlantic Coast of New York Monitoring Program, *http://dune.seagrant.sunysb.edu/nycoast*)

pattern of shoreline accretion on the east and erosion on the west seen in Figure 19. Based on long-term shoreline changes, the impact of each of the individual inlets appears to become more substantial to the west probably because the size of the inlets increases as does the magnitude of the longshore transport of sand. Measured recession rates of over 20 feet per year have been observed on the beaches downdrift of some of the western inlets *(Figure 12).*

The large ebb tidal deltas also interact with the ocean currents and waves. In some cases, these interactions change local conditions around the inlets dramatically. Ebb tidal deltas can change the direction of sand transport by altering the direction of the incoming ocean waves. For example, the ebb tidal delta off of Fire Island actually bends the waves coming from the southeast. Waves striking the coast west of the inlet actually push sand east into the inlet setting up a net longshore transport to the east (opposite of the net westerly movement for the south shore as a whole). The "reversal" of sediment transport results in a situation where sand is moving both to the east and to the west at some point west of the inlet. Areas where the sand is being lost in both directions are known as nodal points and have very high erosion rates. One of these nodal points is thought to be near Gilgo Beach, west of Fire Island Inlet.

Presently, it is not known how long stabilized inlets continue to affect adjacent areas after they are opened or how far along the coast these effects extend. Generally, most experts believe the influence of inlets on shoreline change rates should decrease with time from the formation of the inlets and with distance from the inlet. However, determining where and when the influence of the inlet is overshadowed by the other factors causing shoreline erosion is extremely difficult. Ebb tidal deltas should eventually arrive at an "equilibrium" state where they reach their maximum capacity and stop growing. They no longer trap all the sand moving along the coast and allow some or all of the material to naturally "bypass" the inlet. Unfortunately, there are no universally accepted criteria for determining when an inlet has actually reached this theoretical equilibrium state. It is also not known whether all of the sand "bypassing" the inlet actually makes it to beach on the other side, as it would if the inlet were not present. Smaller inlets, like Shinnecock and Moriches Inlets, should reach this equilibrium state more quickly than the larger inlets to the west. Based on observations of the configuration of the ebb tidal deltas and the behavior of the adjacent shorelines, it appears that both inlets are bypassing sand to some extent. However, detailed surveys of Shinnecock Inlet, which opened in 1938, showed the ebb tidal shoal trapped significant amounts of sand (on the order of hundreds of thousands of cubic yards per year) especially in deeper waters between the years 2000 and 2002. This suggests that the inlet is not bypassing all the sand and is still disrupting the longshore sediment transport. Shinnecock and Moriches Inlets are probably bypassing some sand, but, at this time, no one can say with certainty what portion of the total amount of sand moving along the coast is actually able to flow across the inlets and back onto the beaches to the west. As a result, it is not possible to accurately assess how much of an impact the inlets are having on the shorelines in these areas.

The effects of inlets can be moderated by initiating artificial "bypassing" programs where material is mechanically moved across the inlet to restore the natural longshore sediment transport. But determining how much sand should be moved, where it should be moved and when it should be moved is not a trivial task. In the past, dredging projects at the inlets were designed solely for navigation purposes with safety and cost the primary concerns. In some cases, sand dredged out of the channels was actually disposed of offshore and lost from the beach because it was cheaper than placing it on the downdrift areas. The only inlet on the south shore that has had a regularly scheduled bypassing program is Fire Island Inlet. There, over 800,000 cubic yards are dredged from the inlet every two years, with most of this material being placed on the downdrift beaches of Jones Island.

Breaches and New Inlets

As we have seen, storms, particularly hurricanes, have periodically carved new inlets and breaches through the south shore barriers. Historically, these inlets have been concentrated in the eastern portion of the barrier system *(Figure 15)*. Inlets play an important role in barrier island migration by transferring sediment to the back side of the barrier, allowing the barrier to move landward and providing a platform for marsh creation if the conditions allow. However, an inlet must be open for decades to transport enough sand to the back side of the island to provide the platform necessary for barrier migration.

Short-lived inlets or breaches that are only open for less than a year or two are not as important in terms of barrier island rollover or marsh creation because they do not move enough sand to the back bay. They are, however, a concern from a management perspective because they can cause significant changes in the bay and mainland areas, as well as along the ocean shore. A number of potential impacts associated with new inlets or breaches have been identified.

New inlets or breaches can result in increased tidal ranges and storm water level elevations in the bays under certain conditions. This, in turn, can cause increased flooding and erosion on bay shorelines. Measurements taken when the Little Pike's Inlet *(Figure 21)* opened in Westhampton during the 1992 nor'easter showed the tidal range (the difference in elevation between low tide and high tide) in Moriches Bay increased by 30 percent, from 2.0 to 2.6 feet. There were also reports of increased flooding on the mainland shoreline of the bay. Dredging of new channels in Moriches Inlet in 1958 and 1968 increased the tidal range by about 0.3 feet which also represented an increase of about 30 percent of the tidal range at that time. Studies indicate the effect of new inlets would be greater in smaller bays, like Moriches, than in the larger bays, for the same size opening. It is unlikely an inlet the size of Little Pike's Inlet in Great South Bay would have affected the tidal range to the same extent.

New inlets can also cause changes in the physical and environmental characteristics, such as salinity, temperature, circulation and shoaling patterns in the bays behind the barriers. These changes can, in turn, affect biological resources, including finfish, shellfish and plants. In some cases, certain resources may benefit while others are adversely affected. For instance, a breach may help increase flushing and improve water quality by letting more ocean water into the bay, but it may also allow more predators of shellfish to invade the bay.

Inlets and breaches disrupt the longshore flow of sand on the ocean beaches leading to increased erosion. At the same time, they can supply the bay shoreline with sand. New inlets would also divert some of the tidal flow from existing stabilized inlets, which could cause the channels to fill in more rapidly and adversely affect navigation.

It is clear that inlets and breaches can cause substantial physical and environmental changes in the back bays and these changes could affect some of the important biological resources in these areas. Some these changes may be relatively small, or actually have beneficial impacts. Others may have significant impacts on traditional uses of the south shore bays and mainland coast. There are research efforts underway to identify and, to the extent possible, quantify the impacts of new inlets on the physical characteristics and biological resources of the bays but, presently, we do not have the information necessary to accurately predict the changes that might occur.

Figure 21. The Westhampton barrier breached during the December 1992 northeast storm forming Little Pike's Inlet in Moriches Bay. (Photo: First Coastal Corp)

Impacts of Human Responses to Shore Erosion

As would be expected in an area as densely populated as the New York City and Long Island region, human activity in the coastal zone is substantial and can have a significant impact on the shoreline. In addition to activities related to the stabilization and dredging of the inlets previously discussed, human responses to erosion and flooding problems probably have the greatest potential for affecting coastal processes and the beach. These responses include structural measures, such as groins and seawalls, as well as "soft" erosion control responses that often involve the placement or rearrangement of sand on the shoreline.

Structural Responses

Erosion control structures commonly used on the south shore of Long Island can be divided into two categories: "shore perpendicular" structures and "shore parallel" structures *(Figure 22)*. As the names imply, the shore perpendicular structures are built at a ninety degree angle to the trend of the shore and they extend across the beach toward the water. Groins and jetties are examples of these structures. "Shore parallel" structures are built in line with the shoreline, usually landward of the beach. These structures include bulkheads, seawalls and rock revetments. Because they have the potential to cause considerable damage if used improperly or in the wrong place, erosion control structures require permits from state and local jurisdictions as well as federal permits if they are placed below the spring high waterline.

Shore Perpendicular Structures: Although many people use the terms interchangeably, groins and jetties are not really the same thing. Groins are long, thin structures that extend from the dune to the water. They can be made of rock, steel, wood or concrete. Ideally, they are used in conjunction with sand fill projects and are designed to slow down the rate at which sand placed on the beach is removed by the longshore currents. The structures themselves do not provide any protection. Rather, the beach they create by trapping or holding the sand provides the protection for the landward area. Groins do disrupt the natural transport of sand along the beach and, if they are not designed and built properly, can cause problems.

Jetties, on the other hand, look like groins but are found only at inlets. Their primary function is to hold a navigation channel in one place and prevent it from filling in with sand. Jetties also trap sand moving along the shore. Since they are usually much longer than groins, jetties can have a much larger impact.

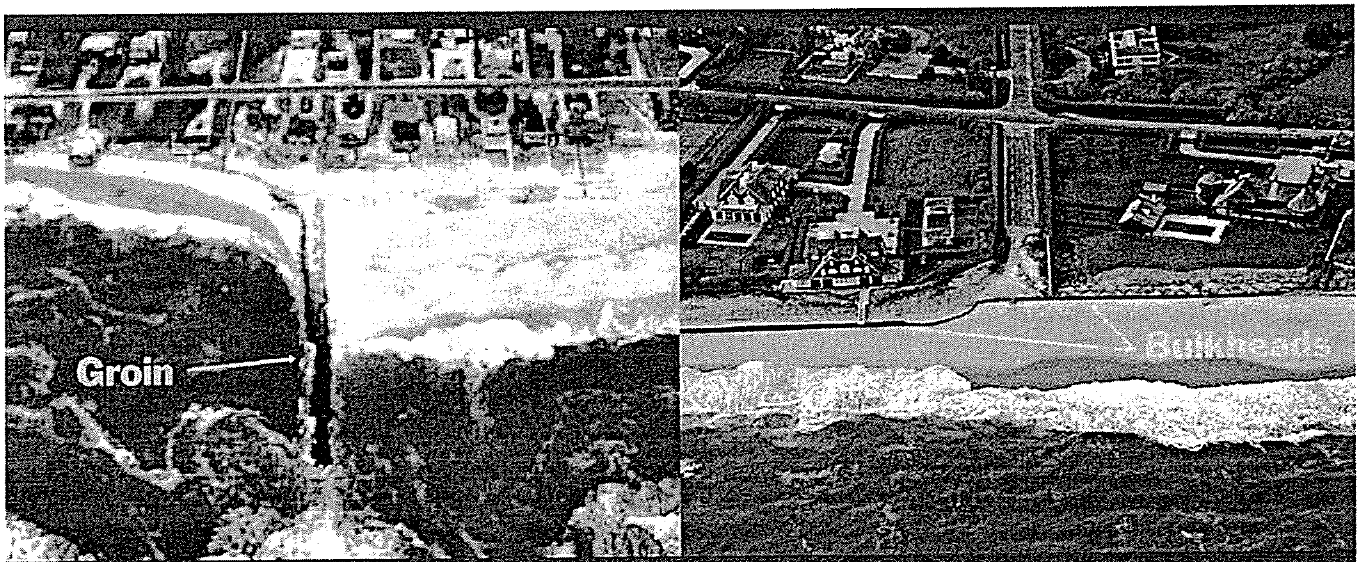

Figure 22. The most commonly used erosion control structures on the south shore are shore perpendicular structures like the groin on left and shore parallel structures like the bulkheads on right. (Bulkhead photo: First Coastal Corp)

Because of the net east to west flow of sand along the south shore, jetties and groins usually tend to trap material on the east side. As with the inlets discussed earlier, these structures interfere with the longshore transport of sand and can cause severe erosion problems on the shores to the west of the structures. The magnitude of the impact increases as the length and height of the structure and the rate of longshore transport increase. To help minimize adverse impacts of these structures, sand should be placed on the east or updrift side of the structure to create a protective beach. This helps minimize the disruption of the flow of sand along the coast (but does not necessarily eliminate all the impacts). The severely eroded area west of the 15 groins at Westhampton that eventually breached during the 1992 December nor'easter is a graphic example of the impact groin projects can have when not properly constructed *(Figure 23 and Figure 21)*. The compartments between the groins were not filled with sand as they should have been. The structures trapped an estimated five million cubic yards of sand that was naturally moving along the shore, depriving the beach to the west of the material it should have received.

In certain situations, however, these structures can help maintain a recreational beach and provide upland protection. There are 69 major groins and jetties along the south shore. The 48 groins at Long Beach, built in the 1920s, have helped slow down erosion and preserve the beach in front of this heavily-developed area for over 80 years *(Figure 23)*.

Shore Parallel or Armoring Structures:

The other type of erosion control device found on Long Island is the shore parallel structure. This category includes bulkheads, seawalls and revetments. These structures can be made of different materials including rock, wood, concrete, and sand-filled bags, but they all function in the same way. They are built parallel to the shore, usually behind the beach. Since they function by hardening or armoring the upland, they are often called shore armoring structures. They are not designed to protect the beach.

Armoring structures built to protect individual private properties probably have minimal impact on the behavior of the shoreline over very long time scales (geologic time) because of their limited area of coverage and relatively short functional lifetime (usually less than 50 years). However, they may cause substantial short-term, localized impacts on the beach if used improperly or in the wrong place. The potential for adverse impacts depends primarily on the conditions at the site, especially longer-term shoreline trends in the area, as well as on the design and location of the structure on the beach. Multi-decadal studies on Long Island have shown that at certain sites

Figure 23. Groins interrupt the natural flow of sand and can increase erosion in adjacent areas (left). However, these structures can be designed to slow down erosion and minimize adverse impacts in certain situations.The 49 groins constructed in the 1920s in Long Beach (right) have helped maintain a recreational beach that protects the developed upland.

these structures can provide protection for the upland during storms without adversely affecting natural beach building processes *(Figure 24)*. Typically, these are areas experiencing episodic damage from storms but that have a shoreline that is stable or accreting on decadal time scales and an adequate supply of sand in the longshore system. In these areas, the structures are often completely covered with sand during calm periods. They are exposed during severe storms, preventing erosion of the upland and then covered again as the beach rebuilds naturally after the storm.

On the other hand, in areas experiencing chronic shoreline recession and a deficit of sand, where these structures are frequently proposed, armoring the shoreline can adversely affect the beach and adjacent areas unless other measures are also taken to mitigate their impacts *(Figure 25)*. These measures might include bringing in additional sand to make up for the sand impounded or retained by the structure. Where you have rapid shoreline retreat, shore armoring structures usually lead to a narrowing or loss of the beach, not because the structures increase erosion but because they prevent the beach from migrating landward. In extreme cases, the structures may end up being surrounded by water as the shoreline recedes on either side. These structures eventually fail because they are not designed to handle the forces found in the surf zone. Before failure, they can block the transport of sand along the shore, essentially acting as groins and causing increased erosion in downdrift areas.

"Soft" Responses

To overcome some of the disadvantages and negative impacts associated with the structural erosion control measures, so-called "soft" erosion control responses are gaining increasing popularity primarily because they are considered more environmentally benign. For the purposes of this primer on coastal processes, these soft solutions are defined as activities that involve adding sand to the system or artificially enhancing the dunes. Other non-structural alternatives such as relocating structures, requiring special building codes

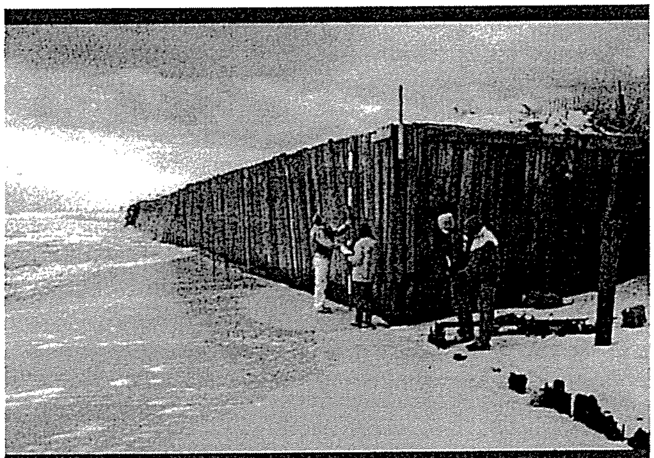

Figure 25. In areas experiencing chronic recession, shore parallel structures like this bulkhead can prevent the landward migration of the shoreline eventually resulting in the loss of the dry beach. (Photo: H. Bokuniewicz)

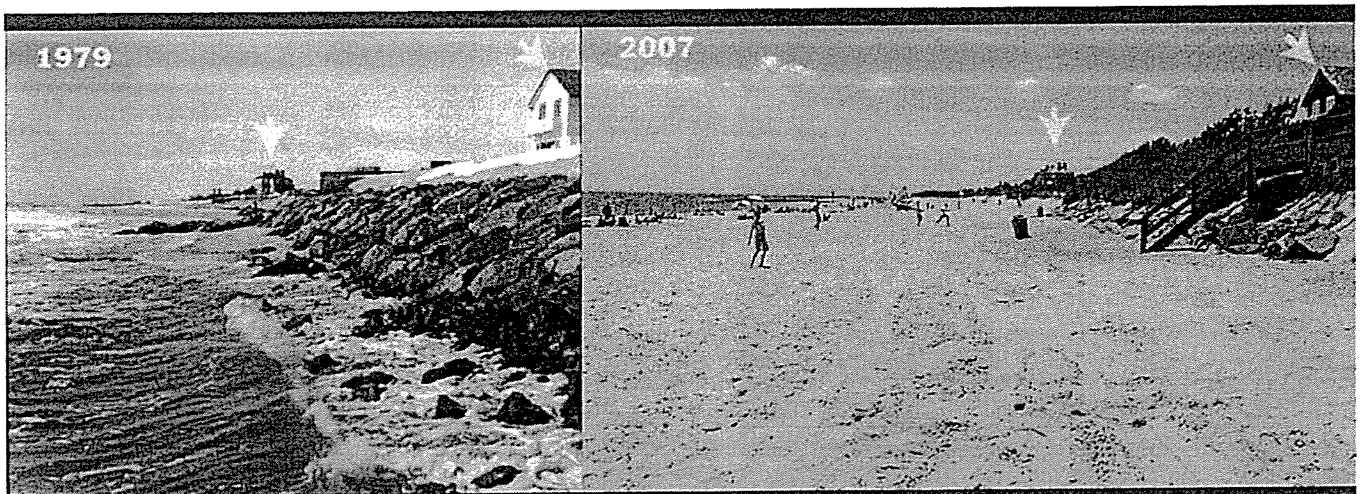

Figure 24. In stable areas with an adequate sand supply, studies over the last thirty years have shown shore parallel structures like this rock revetment can provide erosion protection during severe storms without adversely affecting natural beach building processes. (Arrows indicate the same houses in the two photos for reference.) (2007 Photo: M. Slattery)

for structures in hazard zones and minimizing development in these zones are also often described as "soft" responses. These are management alternatives with limited impact on coastal processes, and therefore are not discussed here.

Beach Nourishment: The most popular soft response to erosion is beach nourishment or replenishment which involves placing sand on the shore to build up the beach, which in turn provides protection for the upland area *(Figure 26)*. New York has a long history of beach nourishment. In fact, the first beach nourishment project in the United States actually took place in Coney Island in 1923 when some 2.5 million cubic yards of sand were added to the shoreline. The objective of this project was not to protect the upland, but to create a wider beach for recreational purposes. Since the 1920s, Long Island beaches have been nourished with an estimated 128 million cubic yards of sand in various projects.

The main advantages of beach nourishment as an erosion management option are that it can create (or maintain) a recreational beach and that it is viewed as more environmentally compatible than some of the structural options because it involves adding sand to the beach. Nourishment doesn't really affect the processes causing erosion. Rather, it simply moves the shoreline seaward. Eventually, the shore will return to its pre-project position if more sand is not added as the beach erodes. Since it is not permanent, beach nourishment is considered somewhat reversible compared to structural alternatives.

Figure 26. Inlet bypassing and beach nourishment project on Jones Beach Island. Sand dredged from Fire Island Inlet (in the background) is piped to the site and deposited on the shoreline to build a beach to protect the Ocean Parkway. (Photo: American Dredging Company)

By the same token, beach nourishment requires a long-term commitment to maintain the project as well as an abundant source of sand. To provide adequate protection, beach nourishment projects must replenish the whole beach, which, as we have seen, can extend out to a depth of 20 to 30 feet below the surface of the water, not just the visible beach. A crude "rule of thumb" in coastal engineering that can be applied to the south shore is that one cubic yard of sand creates approximately one square foot of dry beach. This means a beach nourishment project would require one cubic yard of sand for every one foot of shoreline to move the waterline one foot seaward. To create a new 100-foot wide beach for a mile stretch of shoreline would require over 500,000 cubic yards of sand. This sand has to be similar in grain size (or slightly larger) and composition to the native sand or the restored beach will erode more rapidly. The restored beach also has to be replenished on a regular basis to replace the sand lost as the result of the natural background erosion, if continued protection is needed.

Because of its glacial origins, the area off of Long Island's south shore contains some of the most extensive sand deposits found on the east coast. However, the supply of sand available for beach nourishment is not inexhaustible. Some of the deposits may not be available for nourishment for environmental reasons and some are too far offshore to access practically with today's dredging technology. Others may not contain sufficient material of the right size or composition. In some cases, such as the central portion of Fire Island, recent studies suggest offshore sand may already be feeding the beaches through natural processes. Using this sand for nourishment could disrupt the natural transport of material and accelerate erosion in the future. An important component of any nourishment project is finding a suitable source of sand for the lifetime of the project that can be used without adversely affecting other areas. Since Long Island has significant amounts of sand, it may be feasible to maintain some nourishment projects for time periods on the order of decades depending on the size and the scope of the effort. However, offshore sources of sand are finite so these projects are not sustainable indefinitely. Unfortunately, at the present time, we do not have the necessary information on the total volume of offshore sands that may be available for nourishment to say how long the projects could be carried into the future. Similarly, our limited knowledge of how sand moves offshore does not allow us to quantitatively assess the long-term impacts on the shore that may be associated with using some of these resources for nourishment now.

Oceanfront beach nourishment projects are only practical when implemented on a regional or community scale due to technical constraints and cost considerations. These projects are usually fairly expensive because of the need for periodic maintenance and the large volumes of sand necessary to provide adequate protection. A properly implemented nourishment project can cost millions of dollars per mile of shoreline depending on the erosion rate, conditions of the shoreline, the level of protection required and the proximity of a suitable supply of sand. In most cases, nourishment projects are only economically justified in those areas where there is a high level of development or heavy use of the shoreline being protected.

Beach nourishment projects intended to protect upland areas are usually designed to provide a beach and dune system large enough to prevent wave attack and flooding by overwash and, in the case of barriers, by breaching and inlet formation. Since inlets are the primary mechanisms for transferring sediment landward along Long Island's barrier island systems, nourishment projects that cover large areas and are maintained for very long periods of time could lower the rate of cross shore sand transport and, eventually, affect barrier island migration. The lack of quantitative information on the relationship between barrier island migration and the rate of sand transport across the barrier by new inlets, makes it very difficult to determine exactly how a nourishment project might alter long-term barrier migration rates or how long it would take.

The time frame being considered is an important factor. Most major beach nourishment projects are usually designed to last 50 years or less. In areas where the barrier may not be migrating over periods of hundreds to thousands of years and there is no evidence of historic inlet activity, nourishment may have minimal impact on the cross shore sand transport processes that drive barrier migration processes over the lifetime of such a project. However, there may be more of an impact in those areas where there is evidence of migration, such as historical inlet formation, occurring on time scales closer to the design life of the project. In these areas, more detailed information on the amount of sand actually transported and the rate at which it was carried across the barriers by historic inlets is needed before we can accurately assess how and when beach nourishment projects may affect barrier migration.

Dunes

Dune Characteristics

Dunes are a common coastal landform along the south shore. These features are created when wind carrying sand encounters an obstacle, such as vegetation or a fence, and slows down causing the windborne sand to be deposited. On the south shore, the dominant winds are from the west and northwest so highest rates of wind (also called eolian) sand transport are actually in a west to east direction parallel to the shore. Much less sand is blown in a cross shore direction. Based on measurements of sand transport on the south shore, it is estimated that the amount of sand carried landward across the crest of the dune from beach is about 0.08 cubic yards of sand per foot of dune or less than one cubic yard per year for a 10-foot wide stretch of beach.

Dunes vary greatly in size and form depending on site conditions. In general, the size of the dunes increases from west to east on Long Island. In the urban areas to the west, most of the natural dunes have been heavily impacted by human activities. In some areas, they have been entirely removed or replaced by development along the shoreline *(Figure 27)*. Most of the dunes found along these heavily used areas have been artificially created or maintained, such as the dune fields on Long Beach in the Town of Hempstead. Further to the east, human manipulation of the dune is still common but there are also places, such as the

Figure 27. In some areas, development has replaced the natural dunes. Dunes along many developed shores are artificially created and maintained.

Wilderness Area on Fire Island, where development is less dense and natural dunes can still be found. These dunes can take many forms from low scattered mounds to high continuous ridges *(Figure 28).*

In some areas there are multiple rows of dunes. The seaward dunes adjacent to the beach are called foredunes or primary dunes. These dunes interact with the beach, especially during storms. The dune landward is known as the secondary dune. In essence, these dunes are cut off from the beach and are no longer receiving sand. Some of these secondary dunes are actually the largest dunes in the area. It is thought they might have been created when more sand was available for dune building and became stranded when the beach accreted and a new foredune formed. The larger secondary dunes are often separated by a well-developed swale that may be tens of feet wide.

The volume of sand found in even the largest dunes is relatively small compared to the volume of sand making up the beach. Dunes usually contain less than five to ten percent of the amount of sand found in the beaches (remember, the true beach extends offshore). Because the beach has so much more sand, it actually provides the bulk of protection from erosion during storms. Nevertheless, foredunes do interact with the beach and are an important component of this dynamic system.

Dune Dynamics

As we have seen, high water levels during storms allow waves to attack the dune. Sand in the dunes is removed and redistributed along the beach contributing to the building of the bar and the longshore transport. Essentially the dunes act as a sand storage system that can provide material during storm events. Depending on the size of the dune and the intensity of the storm, high continuous dunes can also provide a barrier to storm surge and overwash, reducing flooding on the landward side.

Natural dune recovery after a storm depends on the severity of the storm and the resultant topography. If the front of the dune is eroded, or scarped, by the waves, the vertical face of the scarp eventually dries out and collapses, moving sand and the beach grass to the toe of the dune *(Figure 29).* Windblown sand from the beach collects at the toe of the dune and the beach grass sends out rhizomes (underground stems and roots). This initiates new plant growth that traps and holds sand, allowing the dune to grow seaward if the beach is wide enough.

Dunes can be completely flattened or overtopped during a storm *(Figure 30).* If the washover deposits are not too deep and the vegetation has not been eroded, new beach grass shoots can emerge and begin the dune building process. Otherwise, dune recovery has to start

Figure 28. Natural dunes can take many forms, from small mounds to high continuous ridges.

Figure 29. Beach grass slides down the face of an eroded dune, taking root at the toe and starting the natural recovery of the dune.

at the landward edge of the washover fan where there is vegetation or, in some cases, where there is a wrack line (the accumulation of vegetation and other natural debris left at the high waterline) that can begin trapping windblown sand. On the south shore, sand can be transported from the inland area towards the beach on these washover fans because dominant winds are from the west and north. As the landward side of the dune becomes vegetated, sand transport from this direction is slowed down and more sand comes from the beach. In response, the dune tends to grow seaward.

The seaward growth of dunes is limited by the width of the beach and distance from the waterline. A wider beach can provide more windblown sand and protection for the dune from the ocean. Since dunes are primarily composed of finer sands, they are very susceptible to damage from even small waves. While dunes can provide some protection from episodic storm events, even the largest dunes are not effective in combating long-term or chronic erosion where they are consistently exposed to wave action. The foredune is dependent on the beach. In a sense, the dune and beach can be thought of as linked components that move together in response to changes in the shoreline position.

Natural dune rebuilding processes operate relatively slowly. Left solely to natural processes, dunes may take years or even decades to recover after a severe storm. Because of the protection they provide and their aesthetic and environmental benefits, maintaining and enhancing dunes are common shoreline management practices.

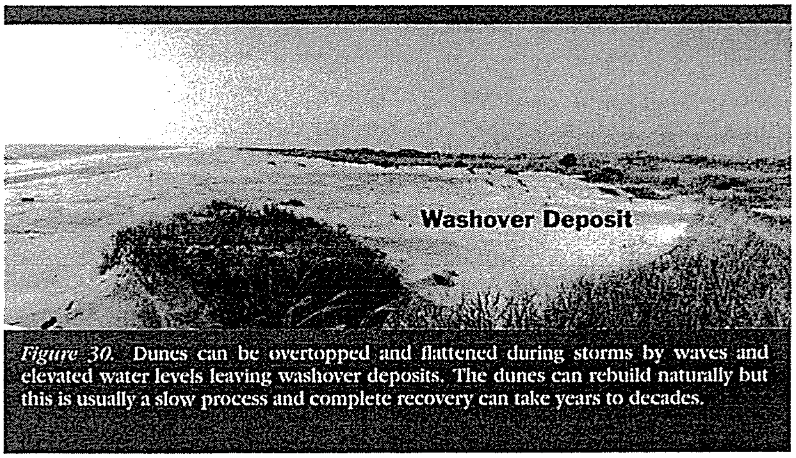

Figure 30. Dunes can be overtopped and flattened during storms by waves and elevated water levels leaving washover deposits. The dunes can rebuild naturally but this is usually a slow process and complete recovery can take years to decades.

Humans and Dunes

Coastal dunes can be affected by human activity especially when it prevents the movement or alters the position of the dunes. The potential impacts of houses on the dunes is of particular concern, but studies looking at dune dynamics on the south shore found that properly built houses that are elevated on piles above the dune height and free of obstructions underneath do not significantly weaken the dune's integrity or its protective capabilities. However, houses built directly on the ground can alter the deposition of windblown sand and, thus, may affect dune building processes. Studies have also suggested that removing these houses without revegetating those areas can create bare sand patches on the back side of the dune which can persist for long periods. Since these bare patches are susceptible to erosion and blowouts from the dominant westerly and northwesterly winds, they also have the potential to weaken the dune. Such complex scenarios illustrate the difficulties associated with trying to manage a resource as dynamic and fragile as the dunes. Management actions may have unintended consequences that can best be identified and rectified through comprehensive monitoring and research efforts.

Dune plantings and fencing: Human activity on the dunes and programs of dune stabilization may play a more important role than elevated structures in controlling what happens to these features. Most people are aware that dune vegetation, especially the beach grass, is very vulnerable to foot traffic. Uncontrolled pedestrian access over the dunes can remove the vegetation and allow wind erosion causing low spots that are more susceptible to overwash. Beach grass spreads by sending rhizomes out underground. The rhizomes can extend 20 feet from the plant. As we have seen, regrowth from rhizomes is an important mechanism in dune recovery after storms. However, the rhizomes are fragile and can be damaged by vehicle traffic even though they are beneath the surface. For this reason, beach vehicle traffic should be discouraged within 20 feet of the dune vegetation line.

Long stretches of sand fencing and artificially planted vegetation used in dune building programs probably have more of an impact on dune processes than either elevated houses or pedestrian traffic. While the amount of windblown sand in the system is not large, these efforts can be extremely efficient at capturing the sand that is available. When not sited, planned, or implemented properly, dune building projects can result in a dune that is much closer to the water than would be found under natural conditions. Dunes built too close to the water will experience more erosion due to more frequent wave action at the toe. These dunes may appear to have a high steep face but they usually will not have as much sand as a dune placed further landward, due to the constant removal of material. Less sand usually means less protection during storms. The high continuous crest of artificial dunes may also interfere with the landward transport of sand and prevent more natural dune formation further inland.

Beach scraping: Beach scraping is a technique that has also been used to build or repair dunes. A thin layer of sand is scraped from the top of the berm and pushed landward in an attempt to restore a dune *(Figure 31)*. These projects are regulated by the state in terms of when the scraping can take place, how much sand can be removed and where it can be placed. The present regulations allow scraping about two cubic yards of sand per foot of beach. While the effects of beach scraping have not been rigorously examined on Long Island, limited studies of this activity elsewhere suggest it has a limited impact, either positive or negative, on coastal processes or protection of the upland area where it occurs.

Basically, scraping simply redistributes the sand within the system and does not change the amount of sand available for dune and beach building. The volume of sand allowed to be moved is very small. Measurements on Fire Island, where many of the beach scraping projects take place, show the average volume of sand contained in the active beach (out to a depth of 24 feet) is about 925 cubic yards per foot of beach This means beach scraping rearranges only about 0.2 percent of the total amount of sand on the beach in those areas where it is permitted. Projects are limited to 60-foot wide lengths of shoreline, further minimizing their impacts.

Beach scraping probably has minimal adverse effects on the beach, but, by the same token, it also provides minimal benefits in terms of protection for the landward area. The small amount of sand added to the dune would provide limited protection against even a small storm. If the scraped sand is placed seaward of the position where the natural dune would normally form, the resultant feature is more susceptible to erosion. Equipment operating within 20 feet of the existing vegetation line could also damage beach grass rhizomes, hindering natural dune recovery. Because of the drawbacks associated with these projects, some experts have suggested efforts might be better spent on bringing in beach-quality sand from an outside source for dune building rather than relying on scraping. However, the difference in cost between these alternatives could vary considerably depending on site access and has to be evaluated on a case by case basis.

Figure 31. Beach scraping projects remove a thin layer of sand from the beach berm and push it landward to form a mound. This redistribution of a relatively small amount of sand on the beach probably has minimal impact, either positive or negative, on coastal processes or protection of the upland.

In Conclusion...

Long Island's south shore ocean coast is a remarkably diverse and complex place. It is this diversity and complexity that provide the many environmental, recreational and economic benefits the coast has to offer. This area is also very dynamic and, in many ways, very fragile. The shoreline we value and enjoy today was created by a variety of forces and processes operating on time scales ranging from hours to millennia. The result is a coastline that is naturally changing all the time. In some cases, human activities have altered or disrupted the natural system, creating some of our most severe erosion problems.

Proper management of this important area requires a solid understanding of the factors affecting a particular stretch of shoreline, the way the shoreline is actually responding to these factors, and the desired uses of the area. It also requires a variety of strategies that can be tailored to match the diverse conditions found along the south shore. In some areas, the best management strategy may be to do nothing and let the natural processes continue unimpeded. In other areas, some form of intervention may be warranted. However, care must be taken to ensure that efforts to mitigate erosion problems work in concert with, and not against, natural processes. Management strategies must be adaptable to changing conditions to ensure future generations can also enjoy this unique resource.

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Selected On-Line Resources

Atlantic Coast of New York Erosion Monitoring Website	*http://dune.seagrant.sunysb.edu/nycoast*
Fire Island National Seashore	*http://www.nps.gov/fiis*
National Park Service Northeast Region Science Website	*http://www.nps.gov/nero/science/*
New York Sea Grant	*http://www.seagrant.sunysb.edu/*
U.S. Geological Survey Studies in the New York Bight	*http://woodshole.er.usgs.gov/project-pages/newyork/index.html*

Metric Conversion Factors

MULTIPLY	BY	TO OBTAIN
inch	2.54	centimeter
foot	0.305	meter (m)
yard (yd)	0.914	meter (m)
mile	1.609	kilometer (km)
cubic yards	0.764	cubic meters

New York Sea Grant Extension Program
(631) 632-8730