CALCULATING THE POTENTIAL ENERGY OF FLOWING WATER

OBJECTIVES

The student will do the following:

1. Measure depths, widths, and velocity (flow rate) for a given stream segment.
2. Calculate the rate of flow of volume of a stream.
3. State streamflow values in terms of mechanical energy.
4. Calculate the potential energy of a stream.
5. Calculate the available power of a stream.
6. State the factors affecting the available power of a stream.

SUBJECTS :
Physics, Advanced Physical Science

TIME:
1 class period plus stream visit

MATERIALS:
metersticks, matchsticks, 30-meter (100-ft) tape measure, stopwatch, topographic map, student sheets(included)

BACKGROUND INFORMATION

Hydroelectric power plants are among the most efficient methods of generating electricity. Large facilities often have efficiencies of 90 percent. Smaller facilities usually maintain efficiencies well over 50 percent.

The power obtained over a period of time cannot exceed the potential energy of the flow. Even if a large reservoir is established, the power available will still be equal to the average potential energy in flowing water.

PROCEDURE

I. Select an appropriate stream site and make the necessary arrangements for a class trip.

II. Prepare the class to do the activity.

   A. Review the conversion of energy forms in the water-powered generation of electricity.

   B. Distribute the student materials and explain each step of the instructions.

   C. It may be more time efficient to divide the class into groups and divide the data collection tasks among them. The information can then be shared.

III. Supervise the activity, following the instructions on the student sheets. The calculations can be done later in the classroom.

IV. Continue with the follow-up below.

FOLLOW-UP

I. Obtain the volume, flow rate, and head data for a large hydroelectric facility and calculate the power generating potential of the plant. Compare the calculated amount to the actual amount generated by the plant. What is the difference? Why?

II. Compare the flow of the stream studied to that of the large hydro plant above. Using the calculations done in the activity, estimate how many people might be served in 1 minute, 1 hour, and1 day. (Use $0.4m^3$/person/day as a typical daily water requirement.)

III. Can small streams such as this one be useful in meeting the Nation's energy needs? How might they be used? What might some innovative uses be?

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Instructions

1. Stake out a measured distance (15 to 30 meters) on the stream bank parallel to the mid-channel line. Record this distance on the data sheet.

2. Drop 3 or 4 matchsticks into the water upstream from the measured distance and determine the time required for them to pass through this distance. Start timing as the first matchstick enters the measured distance and stop when any one leaves the measured distance. Do this procedure at least three times. Find the average time. Record this figure.

3. Measure the width of the stream at three points along the measured distance. Find the average of the three measurements and record.

4. At three places along the measured distance, measure the depths of the stream at three points along a line perpendicular to the bank and crossing the stream. Find the average of the nine measurements and record.

5. Survey the area through which the stream flows. Make an estimate of the change in elevation of the stream over a reasonable distance. For accuracy over longer distances, examine a topographic map of the area through which the stream flows. Record the elevation change, or head, for this section of the stream.

6. Using the measured distance and the average time, calculate stream velocity (flow rate) using the following formula:

   $$\text{Velocity} = \frac{\text{Distance (meters)}}{\text{Time (seconds)}}$$

   Record the flow rate.

7. Knowing the flow rate, average depth, and average width of the stream, calculate the volume of water passing a given point in one second using this equation.

   Rate of flow of volume = Flow rate (m/sec) x Width (m) x Depth (m) = m^3/sec

   Record the calculated figure.

8. Because the density of water is known and the volume of water flowing past a given point is known, it is possible to determine the mass (and weight) of a given volume of water. One cubic meter of water has a mass of 1.00×10^3 kg and a weight of 9.80×10^3 newtons. Calculate each as follows:

   Mass of water = Volume in m^3 x density of water = $m^3 \times (1.00 \times 10^3\ kg/m^3)$

   Weight of water = Volume in m^3 x density of water = $m^3 \times (9.80 \times 10^3\ n/m^3)$ -

   Record the calculated figures.

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(continued)

9. Allow a volume of water for which the weight is calculated above to fall through a distance "h." This height is called the water's head. The product of the weight and this height is the gravitational potential energy (PE) of this volume of water. Use an estimate of elevation change for "h":

   PE (joules) = weight (newtons) x head (meters), where 1 joule = 1 newton-meter
   (Note: The unit is a newton-meter.)

   Record this figure.

10. The rate of doing work is called power. Work and energy are equivalent. If the potential energy of a volume of water is known, the power generated by the falling water may be calculated. The power generated depends on three factors:

    1. Weight of water released (step 8)
    2. Head through which water falls (step 9)
    3. Time over which water flows or is released

    $$\text{Power (watts)} = \frac{\text{Weight (newtons)} \times \text{Head (meters)}}{\text{Time (seconds)}}, \text{ where 1 watt} = \text{1 joule/second}$$

    Record.

11. Check a topographic map for the elevation changes through which your stream flows. Use the map to determine the head for the stream. Calculate the hydropotential for the stream over 1 minute, 1 hour, 1 day, or other durations. If a topographic map is unavailable or inappropriate, use an estimate of the elevation change to calculate figures for these various times. Record the answers.

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DATA SHEET

Measured distance ________ meters

Time required for matchstick to cover measured distance

Trial 1, ________ sec
Trial 2, ________ sec
Trial 3, ________ sec

Average: ______ seconds

Width of stream

Point 1, ________ m
Point 2, ________ m
Point 3, ________ m

Average: ______ meters

Depth of stream

Point 1: Depth 1, ____ m; D2, ____ m; D3, _______m
Point 2: Depth 1, ____ m; D2, ____ m; D3, _______m
Point 3: Depth 1, ____ m; D2, ____ m; D3, _______m

Average: ______ meters

Estimate of elevation change (head) _________ meters

Stream velocity or flow rate (m/sec) ________________________________

Rate of flow of volume (m^3/sec) ________________________________

Mass of water (volume x density) ________________________________

Weight of water (volume x density in newtons) ________________________

Potential energy (weight x head) ________________________________

Power $\left(\frac{\text{weight x head}}{\text{seconds}}\right)$ ________________________________

Hydropotential for the stream

1 minute, ______ watts
1 hour, ________ watts
1 day, ________ watts