Stream Table Models of Erosion and Deposition
Grade Level 7
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To understand the science of how streams move and shape the landscape, we must know certain terms and measurement methods to describe what we see. Using a scale model is one way a scientist can understand larger, more complex systems. In this lesson, students use a stream table model to learn terms and explore how different stream characteristics and conditions interact. This lesson is for 7th grade and will take approximately two 50-minute class periods.

Goals for Students
By the end of this lesson students will know terms associated with geomorphic processes such as erosion, deposition, entrainment, meanders, ephemeral, perennial, slope (or gradient), discharge, velocity (or speed), gravity, etc. Students will also understand the use of a physical model to represent and understand natural systems. By working through the lesson, students will gain basic ideas about streamflow and how it is affected by the slope of the stream and the amount of water through the channel, and how different features of the stream form. Lastly, depending on which “Extend” lesson is used, students will gain knowledge about how humans affect streams and/or how streams can preserve natural fossil and mineral deposits.

Standards
Science

<table>
<thead>
<tr>
<th>Strand 1</th>
<th>Concept 2: PO5 Keep a record of observations, notes, sketches, questions, and ideas using tools such as written and/or computer logs.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Concept 3: PO2 Form a logical argument about a correlation between variables or sequence of events.</td>
</tr>
<tr>
<td></td>
<td>Concept 3: PO5 Formulate a conclusion based on data analysis.</td>
</tr>
</tbody>
</table>

| Strand 3 | Concept 1:PO1 Analyze environmental risks caused by human interaction with biological and geological systems. |

| Strand 6 | Concept 1:PO3 Explain the following processes involved in the formation of the Earth’s structure: erosion and deposition. |

Standards Justification
This lesson focuses on the stream system and the processes of erosion and deposition (6.1.3) and how different components of the system interact when different conditions are applied to the system (3.1.1). Written observations (text and drawings; 1.2.5) will allow students to understand causational relationships between different variables (1.3.2) and draw conclusions from these relationships (1.3.5).
Materials and Equipment
- Stream Tables (boxes, buckets, string, houses/dinosaurs/army men/etc., transparencies, squirt bottle, bottles, caps with different flow holes)
- Ample room in a classroom or outside to set up stream tables
- Water source close to where stream tables are set up
- Sediment that you want to work with (gravel, cobbles, clay, sand, silt, etc.)
- Worksheet for every student
- Media materials (flood videos)
- Extra materials depending on “extend” activity

Safety
Care needs to be taken around stream tables to not spill water that may cause slippery floor conditions. Do not eat or drink anything around water (depending on if water is potable and where sediment has been collected).

Engage (10 minutes)

Today we’ll be learning about rivers, why might we want to know about rivers?
What jobs are there for people who like to learn about rivers?
River can be dangerous…. FLOODS! (show some flood videos)
What type of rivers do we have in southern AZ? What do they look like?

We need to know about rivers because they are very useful to us as humans and to animals and plants. We use rivers for drinking water, irrigation, waste removal, recreation, transportation, and energy. In the Southwest, our ephemeral rivers can be very dangerous during the winter storms and the summer monsoon storms. Erosion and deposition processes are how rivers are shaped, define erosion and deposition (or have a student define it for you).

Many people study rivers in one way or another. Engineers, teachers, scientists, recreation management, natural resources, health professionals, religious leaders, city officials, government officials, farmers, etc all may study rivers in a way. To get any of these jobs means knowing how a river works as a system and how this system affects other natural and human systems around it.

Explore (40 minutes)

The goal of this investigation is to understand the river system. Leading questions:

What things about a river would be important to measure?
What river characteristics and conditions affect flow?
What river conditions affect the amount of erosion?

Make a list of what they say on the board and go over the key words in the lesson:

Erosion= “the entrainment or picking up of sediment to be moved by water”
Deposition= “the laying down or dropping of sediment from the water”
Entrainment= “picking up of sediment by the water”
Morphology = “the shape of the stream”
Ephemeral = “a stream that does not flow all the time”
Perennial = “a stream that does flow all the time, never goes dry”
Flood = “when streamflow is larger than the normal amount, or when the stream overflows its channel”
Gravity = “the force that moves objects towards the earth”
Slope = Rise/Run “the slope of the land”
Velocity = Distance / Time “the speed of the water moving through the stream”
Discharge = Area x Velocity “amount of water moving through the stream”

Make it a point to say that velocity and discharge will not be measured, but only observed, in this investigation because it is difficult to make measurements accurately on such a small model.

Next let them write their predictions on their worksheet, tell them it’s okay if they don’t know and to write how they think the two variables in each question relate to one another. If they are having a lot of trouble help them by reminding them how water moves through water slides, washed near their houses, hoses, etc.

Introduce the stream tables and their components to the class. Make sure to set any rules that you have in your classroom, for example, “Do not put more than the prescribed amount of water in the table, you will ruin your experiment” or “Do not add more sediment unless you check with a teacher first”. These are important for the experiment, as well as the first step towards minimizing the mess after the class is finished! Break the students up into groups to work at each stream table. Usually somewhere between 3-5 students per table.

Next, have them follow the instructions through the experiment part of the handout. This will lead them through testing discharge vs. erosion, stream gradient vs. velocity and erosion, and morphology vs. erosion and velocity. While they are working ask questions to keep them on task and to make sure they aren’t having too much fun with the water and dirt!

Are you finding actual values or just observing relative similarities and differences?
What do you notice about the stream movement at this velocity, slope, etc.?
Are there any areas along the rivers that are eroded faster? Any areas that deposition occurs more? Is it even throughout the river?

Explain (15 minutes)

As they finish up their experiments and look at their results ask them questions about what they found throughout the different exercises.

When the stream gradient was increased, did erosion change along the stream?
How do you think the velocity would change with different stream gradients?
What would happen if the whole stream channel was in hard rock and not sediments?
What is similar and different between the model and real life rivers?
What kind of material does the Santa Cruz River run through?
Extend (35 minutes)

Now that we understand how a river works, let’s think about how that helps us as humans.

*If you were building a house by a river what would you keep in mind to make sure your house lasted?*
*If you wanted to go on a river rafting/kayaking trip and wanted lots of rapids and fast water and beaches to camp on, where would you need to be on the river?*
*If you wanted to fish, where could you find fish that like the swift water? Where could you find the fish that liked the calm and still water?*

This is a great time to bring out the transparencies and squirt bottles to talk about how pavement and urban areas create large areas of high overland flow and can cause large amounts of water to go into the nearby stream. There are lots of things that can be talked about here; it really depends on what you want to cover in your classroom. Other ideas and insightful observations to include:

- **House and infrastructure placement near streams and flooding problems**
  Have students place their house where they think it is safe, flood the stream and see if their house survives. Have them relate this to what locations they would zone as residential versus farmland only uses.

- **Runoff from urban areas and water harvesting**
  Use transparencies to represent pavement and spray water over the top and watch the runoff concentrate and erode a small channel to the larger river. Have them design a system to move water to the stream or disperse water effectively.

- **Dam placement and breaking**
  Have them design embankment or earth-fill dams (or other dams with play dough) to see how they block up the water or create a large drop for electricity. Let the students destroy the dam with a flood at the end, have them write down observations about how it failed and how they could build the dam better next time.

- **Diversion and flood hazard minimization**
  Have student engineer channels to “save” a neighborhood from floods. Can set up a scene before class for each group. Have them explain the setup, draw to scale, etc. and then test it with a design flood.

- **Delta formation and sedimentation**
  At the end of the stream table (non-filled in area) the sediment will create a delta feature. Talk about features of a delta and relate the ones they make (have them draw them) to real ones on Google Earth or other pictures. Talk about how these systems occur at the mouth of all rivers and can influence trade routes (think Mississippi River).

- **Fossil preservation**
  Use plastic dinosaurs to show how river (or lake) sedimentation covers and preserves dinosaurs after death (or during death like La Brea tar pits).

- **Placer deposits and grain size and density**
  Use different materials in the stream table to show how the different densities group into deposits in specific locations in the river, these are called placer deposits and are mined by people. Also different grain sizes will move to different locations of the stream, have them draw and observe where these occur.
Evaluate

This investigation is used to teach the kids the stream section of a larger design and installation project on hydroelectric dams. The kids will be graded on their worksheet (see accompanying file) and conduct during lab time following the rubric provided.

Stream Table Performance Rubric

<table>
<thead>
<tr>
<th>Element</th>
<th>Excellent (10 pts.)</th>
<th>Good (7.5 pts.)</th>
<th>In Development (5 pts.)</th>
<th>Need Improvement (2.5 pts.)</th>
<th>Not Scorable (0 pts.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Participation (10%)</td>
<td>Student fully participates and works well as a group</td>
<td>Student does their part in the group</td>
<td>Student does their part, but does not work in the group</td>
<td>Student doesn’t put full potential into their part of the group project</td>
<td>Student does not participate in the investigation</td>
</tr>
<tr>
<td>Directions &amp; Prioritizing (20%)</td>
<td>Student follows directions perfectly and is able to prioritize time efficiently</td>
<td>Student follows directions well and is able to finish on time.</td>
<td>Student finishes on time, but does not follow directions.</td>
<td>Student does not follow directions and does not finish on time.</td>
<td>Student does not follow directions and does not use their time well</td>
</tr>
<tr>
<td>Knowledge (50%)</td>
<td>Student goes beyond the correct answer and explains extra ideas and thoughts</td>
<td>Student correctly answers the questions given, understands most concepts.</td>
<td>Student answers most questions correctly but does not understand concepts.</td>
<td>Student answers few questions and does not understand concepts.</td>
<td>Student does not understand and does not answer questions</td>
</tr>
<tr>
<td>Responsibility (20%)</td>
<td>Student is responsible for his or her area and equipment and others equipment</td>
<td>Student responsible with their area and equipment</td>
<td>Student does not show responsibility to all their equipment or all their space</td>
<td>Student does the least work and shows the least amount of responsibility but still finishes the project.</td>
<td>Student shows no responsibility for actions or equipment</td>
</tr>
</tbody>
</table>

Teacher Background Info

Some things that can be seen clearly in the model may not be able to be seen as easily in real-world examples, such as the Santa Cruz River. Have them keep this in mind while looking at this model and make sure the kids understand that a model is used for observation and assumptions here may not be correct for all other models.

Rivers are extremely important in understanding natural systems of an area. Remember that rivers are studied for many different reasons and any or all of these embraced by the students is a step in the right direction.
Stream Table Instructions
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<table>
<thead>
<tr>
<th>Materials</th>
<th>Where to Buy</th>
<th>Price</th>
</tr>
</thead>
<tbody>
<tr>
<td>Table</td>
<td></td>
<td></td>
</tr>
<tr>
<td>41-quart Sterilite under-bed plastic storage Box</td>
<td>Target, Walmart</td>
<td>$9</td>
</tr>
<tr>
<td>Waterproof Silicone Caulking</td>
<td>Home Depot, Lowes</td>
<td>$4</td>
</tr>
<tr>
<td>Nylon Hose Barb (1 per table) ½ in ID, ¾ in NIP</td>
<td>Home Depot, Lowes</td>
<td>$2</td>
</tr>
<tr>
<td>1 in hole saw bit</td>
<td>Home Depot, Lowes</td>
<td>$3</td>
</tr>
<tr>
<td>5/8 inch clear plastic tubing (10 ft, 2.5 ft per table)</td>
<td>Home Depot, Lowes</td>
<td>$5</td>
</tr>
<tr>
<td>Handheld power drill</td>
<td>Borrow or Own</td>
<td></td>
</tr>
<tr>
<td>Accessories</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bricks or other block object</td>
<td>Borrow or Own</td>
<td></td>
</tr>
<tr>
<td>Plastic dinosaurs or houses</td>
<td>Dollar Tree</td>
<td>$1</td>
</tr>
<tr>
<td>Transparency Sheets</td>
<td>School or buy</td>
<td></td>
</tr>
<tr>
<td>Bucket</td>
<td>Home Depot, Lowes</td>
<td>$5</td>
</tr>
<tr>
<td>Plastic pop bottles</td>
<td>Buy anywhere</td>
<td></td>
</tr>
<tr>
<td>Bottle caps (three per table)</td>
<td>Collect from pop bottles</td>
<td></td>
</tr>
<tr>
<td>Dirt, sand, rock, etc.</td>
<td>Collect or go to local quarry</td>
<td></td>
</tr>
</tbody>
</table>

Instructions
Table draining system
1. Mark with a pen/marker a dot about 3-4 inches above bottom of box on one of the small ends. Use this as a guide to drill a hole in that location with a handheld power drill with hole saw bit. Use Exacto knife or fingers to remove any loose material around the edge of the hole. *Power drills can be scary, if you aren’t comfortable have a friend, spouse, coworker, etc. help you out!

2. Screw in threaded end of nylon hose barb into hole just drilled. Screw about half way, and add caulking around hose barb and screw in the rest of the way. Add a thick “bead” around the completely screwed in hose barb and on the back of the barb within the box. Let caulking set at least 3 hours (directions on tube). *The screwing of the hose barb can be difficult, helps to have someone with strong hands help out with this portion!

3. Cut plastic tubing to desired length (I used 2.5 ft.) for drainage and push tubing onto hose barb.

OR
1. If you do not want the tubing, you can also cut a deep notch into the end of the table for drainage and affix a string for the water to follow from the notch to the bucket. *This will compromise the stability of the box, especially when filled with heavy dirt and water!
STREAM MORPHOLOGY

Stream morphology (fluvial geomorphology) is the study of how the watershed and stream channel change over time and space. Today we will use stream tables as a model to learn about rivers and how they behave.

Models are used extensively in science to accurately depict processes and mechanisms that we can not readily observe in the field. Today you will see many fluvial processes that you would not be able to see outside!

Important Stream Variables
Discharge, Velocity, Gradient/Slope, Morphology, Erosion, Deposition

Predictions
Do changes in discharge and velocity change erosion?

Does the slope of the stream affect erosion rates?

Do meanders and straight stretches affect the velocity and or erosion of the stream?

Do different materials change the erosion and deposition along a stream?
**Experiment Procedure**

1. Let’s test three different discharge amounts to see how the stream changes, 1) ½ bottle, 2) 1 bottle, 3) 1 ½ bottle.
2. Set the slope of stream table to 1 block.
3. What natural event are we modeling when we change the discharge?

4. What changes when more discharge is added in each of the 3 trials?

**MAKE SURE TO REBUILD CHANNEL BETWEEN EACH TEST!!!!**

5. Let’s test three different stream gradients (slopes) to see if the velocity of the stream changes, 1) 1 block, 2) 2 blocks, 3) 3 blocks.
6. Set the discharge to be the same each of the three times, ½ bottle.
7. Does the water move faster or slower as the gradient increases?

8. Where would you find streams with steep, medium, and shallow gradients?

**MAKE SURE TO REBUILD CHANNEL BETWEEN EACH TEST!!!!**
9. Let’s test different stream paths to see if velocity and erosion changes along the stream path.
10. Set the stream discharge to ½ bottle and slope to 1 block.
11. In your stream table make two meanders in the stream.
12. Now let’s look at the erosion and deposition along a stream. Where is the sediment being eroded, where is it being deposited? DRAW A PICTURE

13. Use the three different grain sizes and other materials to see which the water erodes away first. Record what you find below. Which material erodes easily and which material is more difficult to erode?
Review
Look back at your predictions, were they correct? Explain in words and/or drawings.
ABSTRACT

Watersheds are basic landscape units that are fundamental to understanding resource and environmental issues. Stream tables may be an effective way to learn about watersheds and the dynamic processes, factors, and landforms within. We review the copious stream table literature, present new ideas for assembling stream tables, and provide a watershed approach to stream table exercises. Our stream table’s compact size and low cost permits the purchase and use of multiple units to maximize active learning. The included stream table modules allow introductory students to experiment and observe the effects of factors—i.e., climate (Module A–Precipitation, Overland Flow, and Channel Initiation and Module B–Stream Discharge and Channel Formation), topography (Module C–Watershed Topography and Channel Formation), land cover (Module D–Watershed Cover Types and Channel Formation), and base level (Module E–Local Base Level Changes via Dams and Reservoirs)—on fluvial processes and landforms in a watershed. Course evaluations and exams show that students enjoy the stream table exercise more, and learn the concepts of fluvial geomorphology better, than via traditional topographic map and aerial photograph interpretation exercises.

Keywords: apparatus–stream table; education–geoscience; education–laboratory; geoscience–teaching and curriculum; surficial geology–geomorphology.

INTRODUCTION

Watersheds (i.e., drainage basins or catchments) are the most basic of landscape-scale units (Sutherland, 1994). Watershed-based environmental issues increasingly impact our daily lives—e.g., witness the recent listings of anadromous fish as threatened and endangered, and the resulting impacts of these listings on land use in the Pacific Northwest of the United States. A clear understanding of the functions of watersheds, and the factors that influence them, is therefore essential to understanding contemporary environmental issues. However, the large areas, often subtle boundaries, and complex interaction of geomorphic factors (substrate, climate, land cover, topography, time, base level, and human activity), geomorphic processes (fluvial erosion, transportation, and deposition), and landforms within make watersheds difficult to comprehend (Figure 1).

Watersheds are commonly addressed in introductory physical geography, environmental science, earth science, and geology courses within sections on the hydrologic cycle and fluvial geomorphology. Instructors in such courses often attempt to link dynamic fluvial factors, processes, and landforms to watersheds with traditional lectures, and with topographic map- and airphoto-based laboratory exercises. Students subsequently may struggle to understand how fluvial landscapes evolve over time and how fluvial processes and factors affect everyday lives. This problem is especially acute when the vast majority of students enrolled in introductory courses are non-science majors. Thus, the question explored here is how may scientists and non-scientists better learn about the interrelated, dynamic fluvial factors, processes, and landforms of watersheds?

A potential solution to these problems is to use stream tables as watershed education tools. Stream tables (also referred to as “earth sculpture tanks” (Balchin and Richards, 1952), “erosion beds” (Haigh and Kilmartin, 1987), “erosion tables” (Hubbell, 1964), “erosion trays” (Tolman and Morton, 1986), “flumes” (Yoxall, 1983), “model rivers” (Chapman and Wilcox, 1983), “sand tables” (Joseph and others, 1964), “sand trays” (Joseph and others, 1964), “sedimentation tanks” (Larsen, 1968), “stream models” (DeSeyn, 1973), “stream tanks” (Anderson, 1969), and “stream troughs” (Lewis, 1944)) are sediment-filled troughs through which water flows to provide a laboratory model of a stream or stream system within a watershed. The dynamic interaction between the stream table’s flowing water and sediment enables students to observe and experiment with the most important of the geomorphic agents in shaping Earth’s surface–fluvial processes (Bloom, 1998). While the use of stream tables is not a new idea, it is one worth revisiting, especially in light of the recent emphasis on “student-centered” (Gold and others, 1991) or “active learning” (Meyers and Jones, 1993) classroom methods. This paper reviews the existing stream table literature and presents new ideas for assembling watershed-emulating stream tables. Additionally, it provides new approaches for watershed-based stream exercises aimed at introductory university-level students but with potential for use by kindergartners to advanced-level college students. The ultimate goal is to encourage educators to further design and use stream tables in their classrooms and laboratories.

PREVIOUS STREAM TABLES AND THEIR USES
<table>
<thead>
<tr>
<th>Education level</th>
<th>Use</th>
<th>Watershed Mention</th>
<th>Agents</th>
<th>Fluvial Processes</th>
<th>Fluvial Factors</th>
<th>Landforms</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hubbell (1964)</td>
<td>P</td>
<td>Exer</td>
<td>No</td>
<td>F</td>
<td>E, T, D, S</td>
<td>C, L</td>
</tr>
<tr>
<td>Larsen (1968)</td>
<td>C</td>
<td>Demo</td>
<td>No</td>
<td>F, M</td>
<td>E, T, D, H</td>
<td>B</td>
</tr>
<tr>
<td>Tolman (1986)</td>
<td>P</td>
<td>Exer</td>
<td>No</td>
<td>F</td>
<td>E</td>
<td>O, L</td>
</tr>
<tr>
<td>Vancleave (1991)</td>
<td>P</td>
<td>Exer</td>
<td>No</td>
<td>F</td>
<td>E</td>
<td>O, S</td>
</tr>
<tr>
<td>Mars (no date)</td>
<td>P, S</td>
<td>Exer</td>
<td>No</td>
<td>F</td>
<td>E</td>
<td>H, O, L, B</td>
</tr>
<tr>
<td>Maine (no date)</td>
<td>P, S</td>
<td>Exer</td>
<td>No</td>
<td>F</td>
<td>E, T, D</td>
<td>O, S</td>
</tr>
</tbody>
</table>

Table 1. Chronology of previous stream table uses extending from Lewis (1944) to Maine Department of Conservation (no date).

Notes:
1. Education levels as primary school (P), secondary school (S) or college (C).
2. Stream tables used for demonstration (Demo), exercises (Exer) or unknown (?).
3. Watershed/drainage basin emphasized—Yes or No.
4. Geomorphic agents include fluvial (F), volcanic (V), tectonic (T), karst (K), mass wasting (M), coastal (C), glacial (G), and eolian (E).
5. Fluvial processes include erosion (E), transportation (T), deposition (D), sidecutting (S), headcutting (H), downcutting (I), differential erosion (A), rejuvenation (R), stream piracy (P) or unknown (?).
6. Fluvial factors include substrate (S), climate (C), topography (O), base level (B), land cover (L), time (I), humans (H) or unknown (?).
7. Fluvial landforms include knickpoints and waterfalls (K), alluvial fans (A), terraces (T), deltas (D), meandering streams (M), braided streams (B), stream channels/valleys (V), antecedent, subsequent, and superimposed streams (S), peneplains and monadnocks (X), badland topography (O), scour holes (H), floodplain (F), cutbanks (C), pointbars (P), floodplain lakes (I), mid-channel bars (R), natural levees (L) or unknown (?).
Educational Uses of Stream Tables - Stream tables have been used as teaching tools at a variety of academic levels since the early 1940's (Debenham, 1942; Lewis, 1944). Simple stream tables have been used by primary and secondary school students (Balchin and Richards, 1952; Hubbell, 1964; Exline, 1975; Payne and Featherston, 1983; VanCleave, 1991) while more complex stream tables have been employed at the college level (Lewis, 1944; Schwartz, 1968; Chapman and Wilcox, 1983; Wikle and Lightfoot, 1997) (Table 1). While most college stream table exercises are aimed at introductory students, Haigh and Kilmartin (1987) and Yoxall (1983) focused their stream table efforts on upper level students (Table 1). Stream tables have been used for demonstrations (Schwartz, 1968) as well as hands-on exercises (Paull and Paull, 1972) (Table 1). Despite abundant stream table literature, few educators mention, or even imply, watersheds when discussing their stream table exercises (Table 1). However, entities such as the Oregon Museum of Science and Industry integrate stream tables with watershed education (http://www.omsi.org/explore/earth/watershed/index.cfm).

Stream Table Design and Construction - Instructional stream tables vary in complexity (Yoxall, 1983; Tolman and Morton, 1986) depending on funds available, space available, and intended use—i.e., lecture demonstrations or hands-on laboratory exercises. Most authors construct stream tables specific to their needs; however, stream tables may also be purchased from scientific supply sources (Porter, 1990).

Stream tables range from square surfaces less than 0.1 m$^2$ (VanCleave, 1991) to 10 m long rectangles (Yoxall, 1983). According to Lasca (1991), an ideal instructional stream table is 1.8 m long by 0.6 m wide by 0.2 m deep. Stream tables may be constructed of wood (Brown, 1960), cardboard (Tolman and Morton, 1986), metal (Paull and Paull, 1972), brick (Balchin and Richards, 1952), plastic (DeSeyn, 1973), and glass (Larsen, 1968). Permeable surfaces of stream tables are typically lined with fiberglass (Wikle and Lightfoot, 1997), plastic sheeting (Yoxall, 1983), waterproof cement (Balchin and Richards, 1952), tarpaper (Foster and Fox, 1957), tar (Goodrich, 1987) or metal (Schwartz, 1968). Most stream tables are flat bottomed and tilted by means of base adjustments while others are hinged (Schwartz, 1968). Water supplies include paper cups (VanCleave, 1991), hoses (Heller, 1962), and elaborate spray systems (Schwartz, 1968). Pumps are sometimes used to recirculate water (Porter, 1990) and wave generators may be added to simulate coastal conditions (Fletcher and Wiswall, 1987).

Stream Table Uses - Past stream table exercises and demonstrations have emphasized one or more of the following terrestrial geomorphic processes: fluvial, volcanic, tectonic, karst, mass wasting, coastal, glacial (Table 1). Stream tables are even used to help students understand Martian landscapes (Mars Team Online, no date).

A variety of fluvial processes are well illustrated with stream tables. These processes include the basic principles of erosion, transportation, and deposition (DeSeyn, 1973), sidecutting (Lewis, 1944), headcutting (Wikle and Lightfoot, 1997), downcutting (Schwartz, 1968), differential erosion (Exline, 1975), and stream piracy (Balchin and Richards, 1952) (Table 1). Stream tables allow students to alter the various factors affecting stream table “streams” to produce different fluvial responses (Wikle and Lightfoot, 1997).

Stream tables have previously been used to address the stream-impacting factors including substrate (Balchin and Richards, 1952), climate (Heller, 1962), topography (Fletcher and Wiswall, 1987), base level (Larsen, 1968), land cover (Maine Department of Conservation, no date), time (Exline, 1975), and humans (Wikle and Lightfoot, 1997) (Table 1). The large size of Chapman...
and Wilcox’s (1983) “Western River” model allows students to isolate the various factors that affect streams at different places along the model. The interaction between the above factors, streams, and humans may also be modeled with a stream table. Foster and Fox (1970) show how a stream table may be used to illustrate the impacts of changing land cover types (i.e., cropped vs. fallow, mulched vs. bare) and topography (contour vs. non-contour cultivation) on soil erosion. Stream tables may be used to assess the impacts of channelization on streams (Gough, Petersen and Turner, 2000). Students commonly enjoy the “mass destruction” of floods, especially when those floods devastate miniature plastic houses and people placed on the floodplain (Michael Folkoff, written communication, 2 July 1996).

Stream tables are commonly used to model the development and evolution of various fluvial landforms including stream valleys (Exline, 1975), braided streams (Lasca, 1991), meandering streams (Exline, 1975), knickpoints, rapids, and waterfalls (Balchin and Richards, 1952), alluvial fans (Larsen, 1968), terraces (Lasca, 1991), deltas (Joseph and others, 1961), scour holes (Wikle and Lightfoot, 1997), antecedent, subsequent, and superimposed streams (Schwartz, 1968), peneplains and monadnocks (Schwartz, 1968), badland topography (Lewis,1944), cutbanks (Heller, 1962), point bars (Heller, 1962), mid-channel bars (Lasca, 1991), and floodplain lakes (Payne and Fetherston, 1983) (Table 1).

Several authors note the advantages of stream tables in compressing the time required for landscape evolution (Exline, 1975). Dilly (1992) and Wikle and Lightfoot (1997) advocate the combined use of stream tables and time lapse videography to show students slowly occurring stream processes over short time periods. Videography also prevents the problem of too few stream tables for too many students (Dilly, 1992).

Stream tables are readily related to the “real world” (Goodrich, 1987) via coinciding lectures, the course textbook (Payne and Fetherston, 1983), slides (Wikle and Lightfoot, 1997), airphotos, and topographic maps (Wikle and Lightfoot, 1997). Porter (1990) even combines fluvial geomorphology with literature by developing an exercise where “river” conditions on the stream table are compared to those of Mark Twain in Life on the Mississippi (1917).

Most of the exercises discussed above are qualitative rather than quantitative. This may reflect the emphases of the various authors or it may be a response to questions regarding the validity of stream table measurements to real-world processes. Morgan (1967) questions the accuracy of stream table measurements because of difficulty in replicating proper relationships between various factors (e.g., substrate size and discharge depth). Chapman and Wilcox (1983) recognize scale issues and their impacts on stream table measurements but argue that the same laws of mechanics and hydraulics apply despite scale differences; therefore, students still learn the processes of good science on a stream table. Anderson (1969) also emphasizes the ideas coming from the stream table are the important result rather than accurate numbers. Stream velocity and discharge, channel dimensions, sediment transportation rates, channel migration distance, scour hole depths, bedload caliber, rates of fan delta growth, and channel dimensions are all ideal for measurement (Exline, 1975; Chapman and Wilcox, 1983; Wikle and Lightfoot, 1997).

Stream table exercises teach the scientific method through observation, experimentation, hypothesis testing, data recording, sketching, and report writing (Paull and Paull, 1972; Payne and Fetherston, 1983; Porter, 1990). Stream table exercises may involve student teams (Wikle and Lightfoot, 1997) thus enhancing interpersonal communication and problem solving skills (Haigh and Kilmartin, 1987). Ultimately, stream table experiments are interesting, exciting, and fun (Paull and Paull, 1972) as evidenced by students often remaining after the lab period to experiment with the stream table (Wikle and Lightfoot, 1997). Indeed, some of the best results occur when students are allowed to experiment (Paull and Paull, 1972).

A SIMPLE STREAM TABLE

We constructed a pedagogically effective, yet transportable and inexpensive stream table from readily available materials (Figure 2, Table 2). Assuming that one is able to obtain the discounted price for the plastic trough and scavenge some of the other components, the cost for one complete stream table is about $110. An initial investment of approximately $550 would thus provide a sufficient number of stream tables for five teams each comprised of four students. These costs
Figure 3. Effects of low (3a) and high (3b) stream discharge. Note the differing degrees of incision, braiding, and fan-delta deposition.

Figure 4. Effects of low (4a) and high (4b) slope angles. Note the differing degrees of incision, braiding, and fan-delta deposition.
could be further reduced by borrowing ring stands and ring clamps from other science departments.

The plastic trough is placed on the wood “slope” wedges so it projects about 15 cm beyond the end of a laboratory table (Figure 2). The trough is partially filled with a mixture of fine and medium sand using one of the yogurt containers. The sand supply is stored in a nearby bucket. This sand represents the substrate of the watershed.

An inverted soda bottle is the primary water source (Figure 2). The bottom is cut out of a plastic soda bottle so it can be readily filled with water poured from one of the yogurt containers. Water is stored in a nearby bucket. A standard chemistry ring stand with two ring clamps holds the soda bottle water supply in place. Thumb screws on the ring clamps allow vertical adjustment for the different watershed slope angles. A protractor is used to measure watershed slope angles while water supply height above the watershed is measured with a ruler. Water flow on the watershed is regulated by the diameter of the hole drilled in each of the soda bottle caps (0.32 cm for low, 0.48 cm for medium, and 0.64 cm for high discharge). Simulated precipitation provided by the adjustable 1 liter pump spray bottle falls on the densely vegetated (i.e., thick cotton towel), bare or urbanized (i.e., acetate transparency) land cover. Water exits the downstream end of the stream table via a precut pushout notch in the plastic trough and into a bucket below the end of the table (Figure 2). A cotton rope attached to each side of the trough by binder clips and leading through the notch to the bucket helps the trough drain more cleanly.

**STREAM TABLE EXERCISE MODULES**
The following stream table exercise modules center around the key factors affecting fluvial processes and landforms in a watershed. One to two hours of
Figure 5. Effects of medium discharge on a partially “vegetated” (5a) and on a partially “urbanized” (5b) watershed. Note the differing degrees of incision (especially at the downstream edge of the cover type).

Figure 6. Earthen dam and reservoir pre-breaching (6a) and post-breaching (6b). Note the deep incision in the dam and the well developed fan-delta in the reservoir downstream.
slide-illustrated fluvial geomorphology lecture typically precedes this exercise. Student teams of two to four maximize active learning and group brainstorming. Modules A-E are completed during a two hour laboratory period while Module F is completed outside of the laboratory. Students read each module and develop hypotheses regarding the potential outcomes of the module before actually undertaking any experiments. Unless otherwise stated, students saturate the sand substrate and smooth the substrate surface into a broad, gently sloping valley atop the “low slope angle” wood wedges before the start of each new experiment. The downstream end (with the notch cutout) is kept sand free in the final ~20 cm stretch of the stream table. The cutoff soda bottle is set so the cap is about 5 cm above the watershed surface and so water draining from it will strike the sand surface about 8-10 cm below the upper end of the stream table.

Module A. Precipitation, Overland Flow, and Channel Initiation - Precipitation falling on a permeable, inclined surface will initially infiltrate and become part of the throughflow until that surface’s pore spaces are filled by water or splash eroded sediments. Once the pore spaces are filled, water striking the watershed surface will become overland flow which will eventually initiate channels. The rate of pore space filling is thus dictated by the size and shape of pore spaces and by the characteristics of the precipitation-type, amount, duration, number of events, and seasonality. Light precipitation is typically associated with warm fronts while downpours are associated with cold fronts, occluded fronts, and convective thunderstorms. Watersheds receiving high intensity precipitation commonly experience rapid rill and gully initiation. In this module, students evaluate the impacts of varying rates of precipitation on overland flow and channel initiation in a watershed. This is accomplished by adjusting the spray bottle pump rate at the fine mist spray setting. An undrilled soda bottle cap is placed on the upper watershed surface to serve as a “rain gauge”. One student in each group aims the spray bottle at the top of the watershed and slowly squeezes the handle once every two seconds for two minutes. One member times the precipitation event while another measures the depth of water in the undrilled soda bottle cap with a toothpick. All members of the group observe the degree to which overland flow and, ultimately, channels form. A student then repeats the procedure by rapidly squeezing the pump spray handle at a rate of once about every 0.5 seconds for the same period of time. Group members again observe the response of the watershed to the precipitation event. At the conclusion of this module students discuss and answer the following questions: what was the rate of precipitation (cm/hr) on the surface in each of the precipitation scenarios; how much time passed before overland flow began to develop in each of the scenarios; why did a lag occur between the onset of precipitation and the initiation of overland flow in the watershed; under which of the scenarios did more overland flow develop; and what are the implications of a warm front-derived light rain as compared to a cold front or convectional downpour on overland flow and channel initiation in the watershed’s headwaters?

Module B. Stream Discharge and Channel Formation  - Once overland flow results in a stream channel, the channelized flow is termed discharge. Stream discharge is a measure of water volume passing a given point in a particular time (m³/sec). Variations in discharge, especially the velocity component, are instrumental in shaping channel cross section, longitudinal, and planimetric form. Significant channel changes associated with erosion, transportation, and deposition typically occur during brief, high discharge events (Leopold, 1994). Arid watersheds characterized by intense precipitation often become incised by rills, gullies, and arroyos. Humid watersheds are commonly characterized by more gentle precipitation events; therefore, streams in these settings tend to aggrade. Oscillations between periods of relative aridity and humidity may be reflected in channel degradation and aggradation cycles (Leopold, 1994). Three general types of channel patterns are recognized—straight, braided, and meandering (Leopold and others, 1964). Truly straight channels are uncommon in nature so we focus on the latter two channel types. Braided streams typically have wider, shallower channels, steeper gradients, and more rapid lateral migration than meandering streams (Leopold and others, 1964). The dominant landforms of the braided stream are mid-channel bars and levees while meandering streams systems are typically comprised of point bars, cutbanks, natural levees, oxbow lakes, and terraces.

In this module, students evaluate the impacts of different stream discharges on watershed channels. Participants use two different soda bottles and their respective drilled caps to simulate low and high discharge events. A student first pours water onto the upper watershed surface through the low discharge cap over a five-minute period. Group members measure stream velocity by timing the movement of a small piece of a toothpick through a measured length of channel while others observe the resulting changes to the watershed over the entire period (Figure 3a). Next, a student repeats the procedure using the high discharge cap. Members of the group again measure stream velocity and observe the water and its impacts on the watershed (Figure 3b). Appropriate follow-up questions include: what was the stream velocity in each of the discharge scenarios; under which discharge scenario did more erosion occur; how did planimetric, cross sectional, and longitudinal channel form change under the different discharge regimes; if high discharge represents a rapid snowmelt event or a thunderstorm, what are the geomorphic implications of such “catastrophic” events on watersheds; and if low discharge represents base
flow, what are the geomorphic implications of such “uniform” events on watersheds?

**Module C: Watershed Topography and Channel Formation** - Watershed topography impacts stream velocity which, in turn, affects erosion, transportation, and deposition (see Module B). Infiltration is also impacted by topography—i.e., steeper slopes are characterized by higher runoff and less infiltration. Assuming all other variables remain constant, mountainous watersheds are characterized by more runoff than are more planar watersheds.

This module involves comparing and contrasting the impacts of watershed topography on streams. A student first pours water through the medium discharge cap onto the low slope angle watershed. Group members measure the slope angle (the angle made by the front base of the trough with the laboratory table) with a protractor while others observe the flowing water's velocity and the resulting changes to the watershed over a five minute period (Figure 4a). Students repeat the procedure on the high slope angle watershed again measuring slope angle, and observing the flowing water's velocity and the resulting changes to the watershed over a five minute period (Figure 4b). Follow up questions include: what was the slope angle in the different scenarios; did more runoff occur on the low or the high angle topography; on which topography was stream velocity greatest; on which topography did more erosion take place; and how did planimetric, cross sectional, and longitudinal channel form change on the different topography?

**Module D: Watershed Cover Types, and Channel Formation** - Watershed cover types may be divided into two general classes—permeable and impermeable. Permeable surfaces are those that readily allow precipitation to infiltrate and percolate into the subsurface thus resulting in less erosion. Impermeable surfaces include bare sediment-covered and vegetation-covered surfaces. Impermeable surfaces don’t permit water to infiltrate. Precipitation striking these bedrock, asphalt, concrete, compacted sediment, or frozen sediment surfaces runs off rather than in. Therefore, more runoff, higher magnitude peak flows, and more frequent peak flows occur downstream of impermeable surfaces than downstream of permeable surfaces. Higher erosion rates result.

This module explores the impact of three cover types—i.e., densely vegetated, bare soil, and urbanized-on watersheds. To assess the impacts of different cover types we use the cotton towel (densely vegetated surface) and the acetate transparencies (urbanized surface). First, a student covers the upper one-third of the watershed with the cotton towel (forested watershed) and pours water onto this surface through the medium discharge cap. Participants observe the forested watershed and the resulting geomorphic changes over a five minute period (Figure 5a) taking care to time the appearance of the first surface runoff. This procedure is repeated using the acetate transparencies (urbanized watershed) (Figure 5b). Finally, students leave the upper portion of the watershed exposed to represent a bare surface (e.g., due to aridity, logging, wildfire, fallow fields, etc.). Again, water is added using the medium discharge cap. Students time the appearance of the first surface runoff in this “arid” watershed and observe the resulting geomorphic changes over a five minute period (Figure 4a). At the culmination of the module students discuss and answer the following questions: how rapidly did runoff develop on each of the three surface types; how do different surface types affect the time required for water to travel the length of the stream table; how do fluvial processes and fluvial landforms vary directly beneath and downstream of the different cover types; and how might different surface types impact a stream hydrograph during a flood event?

**Module E: Local Base Level Changes via Dams and Reservoirs** - Base level is the elevation to which streams erode. Mean sea level is the ultimate base level (Bloom, 1998). Local or temporary base level is dictated by abrupt breaks in slopes known as knickpoints (or “nickpoints”). Knickpoints may be natural (resistant bedrock) or artificial (dams). A rise in water level behind a dam knickpoint will lead to deposition of deltaic sediments in the dam’s reservoir and a lessening of the channel’s gradient. Conversely, a fall in lake or sea level results in a steepening of the channel gradient by downcutting and headcutting to the new level of the lake. These modes of erosion may be aided by piping of saturated sediments (Leopold, 1964). Thus, changes in base level alter stream longitudinal profiles and the spatial patterns of erosion, transportation, and deposition.

This module focuses on dam- and reservoir-induced changes in base level and their resulting impacts on stream channels. Students first build an earthen dam about midway down the stream table by removing most of the sand from the upstream reservoir area. To limit post-laboratory cleanup, students are encouraged to make sure the top of the earthen dam is about one cm below the top of the stream table. Small plastic toy action figures or miniature houses are placed at various points on the dam’s downstream face and in the river valley below the dam (Figure 6a). A student pours water through the high discharge cap into the reservoir behind the dam. Students observe the geomorphic changes occurring upstream and downstream of the dam before and after the water overtops the dam (Figure 6b). Key questions here include: what are the likely geomorphic implications of rising base level (i.e., water filling reservoir) on a watershed’s stream; by what processes does the dam ultimately fail; what is the rate of stream incision in the dam; what are the geomorphic implications of falling base level (i.e., dam breached and reservoir levels dropping) on the watershed’s stream; and what are the impacts of the dam failure on the floodplain and the human settlement downstream?
Module F: General Stream Observations - As a synthetic wrapup to the exercise, students respond to the following questions outside of the laboratory: geomorphically, what process dominates the headwaters of the watershed’s stream, and what landforms are most common there; what is the dominant mode of sand movement in watershed; geomorphically, what process dominates at the mouth of the watershed’s stream, and what landforms are most common there; how do channels evolve over time; and what factor is most significant in altering the watershed’s stream?

DISCUSSION AND CONCLUSIONS

The stream table and modules (or slight variations thereof) described above have been used for four semesters (total of 15 laboratory sections) in an introductory physical geography laboratory at Drake University. The inexpensive stream tables allow teams of two to four students to isolate the various factors affecting watershed streams and observe the resulting geomorphic processes and landforms. The laboratory also requires that students integrate what they learn throughout the physical geography course—i.e., meteorology, climatology, hydrology, biogeography, pedology, and geomorphology. Students are also encouraged to experiment on their own. Indeed, student experimentation resulted in the development of Module E: Base Level via Dams and Reservoirs.

Ultimately, students learn that: watersheds and floodplains are dynamic over space and time; a variety of factors influence these dynamic places; changes in any one of the factors results in different fluvial processes; and different fluvial processes lead to the development of a variety of landforms. The lab experiments and associated questions are successful in helping students tie the “experimental world” of the stream table to the “real world,” an important goal noted by Exline (1975). This goal may be further enhanced by modeling the laboratory watershed after local watersheds that students may visit during a subsequent laboratory session. Maps of the local watershed may be incorporated into the exercise as can questions relating the local watershed to the model watershed.

Student interest and enthusiasm in the stream table laboratory was consistently the highest of any of our laboratories. Student evaluations, while not always a faithful measure of the success of a particular exercise as a learning tool, strongly favored our stream table laboratory. Most students commented that this was their favorite laboratory because of the “hands-on” nature of the modules involving experiments with factors, processes, and resulting landforms. Incidentally, the second most favorite laboratory was the hands-on mass wasting lab, also involving the stream table.

While the stream table laboratory has many positive aspects, it also has drawbacks. First, the stream table laboratory is messy. Water and sand end up everywhere in the laboratory and in adjacent hallways. Second, it is time consuming. Approximately one hour is required for setup and cleanup. Third, a nearby sink and faucet are required. In working with a recent kindergarten class we partially dealt with these issues by setting up in an outdoor park with a nearby lake as a water source. Fourth, as Wikle and Lightfoot (1997) point out, the initial costs of the stream tables may be difficult to justify to cost-conscious administrators. This may be especially difficult if the stream table is used only for one demonstration/exercise per quarter or semester. However, as discussed above, stream tables may be used for other topics as well. Further, our stream table is an excellent community outreach tool that may be readily transported to public schools, Earth Day celebrations, county fairs, etc. The dividends of such outreach should far outweigh the initial costs of the stream tables.

Despite these few negative points, we hope this paper will encourage introductory course instructors to use stream tables as pedagogically effective alternatives to non-dynamic topographic map- and airphoto-based laboratories and logistically demanding field trips. The literature review, stream table, and watershed-oriented laboratory presented within, with modification and experimentation, may serve as a model for the development of exercises to meet the needs of various learning levels. Our recent experiences with kindergarten students suggest that this stream table, and altered versions of the exercise, may also be beneficial for elementary and secondary school students. Further, additional quantitative aspects may be added to better serve the needs of intermediate and advanced college students.

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