STREAM TABLES AND WATERSHED GEOMORPHOLOGY EDUCATION

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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

	Level[1]	Use[2]	Watershed Mention[3]	Agents[4]	Fluvial Processes[5]	Fluvial Factors[6]	Landforms[7]
Lewis (1944)	C	?	No	F, C	E,T,D,H,S,I	O,S,C	M,K,A,T,H, D,T,O,F
Balchin..(1952)	P, S	Demo	No	F, C	E,T,D,H,S,P,R	C,B,S	M,K,T,I,D
Brown (1960)	S	Demo	No	F, M, G, C	?	O	M,D,K
Joseph..(1961)	S	Exer	No	F, T, K, V	E,D	?	D,M,I
Heller (1962)	P, S	Demo	No	F, C, G	E,T,D,S,I	C,S,O	D,C,P,M,I
Hubbell (1964)	P	Exer	No	F	E,T,D,S	C,L	M,B,V
Larsen (1968)	C	Demo	No	F, M	E,T,DH	B	A,D,K
Schwartz (1968)	C	Exer	No	F,T,V,M,C,G	E,T,D,H,I,S,P	I,O,C,B	D,A,S,X
Anderson (1969)	P, S	Demo	No	F	I	B,C,S	M,D,C,K,T
Foster..(1970)	P, S	Exer	No	F	E,T,D	O,L	?
Paull..(1972)	P	Exer	No	F	E	O,C,S	M,H,R
DeSeyn (1973)	P, S	Exer	No	F	E,T,D	?	D,A,K,V
Exline (1975)	S	Exer	No	F, C	E,T,D,I,H,S,P,A	I,O,S,C	V,F,I,K,D,M
Chapman..(1983)	C	Demo	No	F	E,T,D	O,S,C	M,D,P
Yoxall (1983)	C	Exer	No	F, M	E,T,D,S,H,I	C,S,B	K,H,D,T,V, R,C,P,M
Payne..(1983)	P, S	Exer	No	F	E,D,S,R	B,O	I,M,D
Tolman..(1986)	P	Exer	No	F	E	O,L	?
Fletcher..(1987)	C	Exer	Yes	F, C	E,T,D	C,O,B	M,D
Goodrich (1987)	C	Exer	No	F	E,T,D	C,S	D,M,I
Haigh..(1987)	C	Exer	No	F	E,T,D,I	O,L,H	V
Porter (1990)	S	Exer	No	F	?	?	M,K,I,D,L,F
Lasca (1991)	C	Exer	Yes	F	E,T,D,S	B,I,C,H	M,B,R,D,T
Van Cleave (1991)	P	Exer	No	F	E	O,S	M
Wikle..(1997)	C	Ex/De	Yes	F	E,T,D,SH	C,O,B,I	K,H,D,P,F, A,M,C,B
Gough..(2000)	P, S, C	Demo	No	F	E,H	H,B,S	H,P,T
Mars..(no date)	P, S	Exer	No	F	E	H,O,L,B	V
Maine..(no date)	P,S	Exer	No	F	E,T,D	O,S	V,M,D,I

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 (?).**

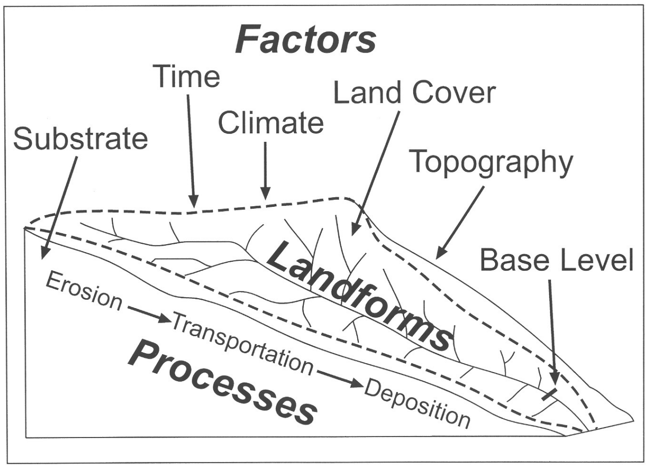

Figure 1. A model watershed and its intertwined fluvial factors, processes, and landforms. The watershed's landforms are largely dictated by the factors (substrate, climate, land cover, topography, time, and base level) and processes (erosion, transportation, and deposition).

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). To gain a view of the stratigraphy of stream table landforms Goodrich (1987) placed a glass window in the side of his wooden stream table. Sediment ranges from "dirt" (VanCleave, 1991) to fine sand (Heller, 1962) to a mixture of "soil", sand, and pebbles (Porter, 1990) to sandy loam (Wikle and Lightfoot, 1997) to ground up plastics and walnut shells (David J. Harbor, written communication, 6 January 1997). Harder substrate may be replicated with ice (Prusok, 1970), clay (Joseph and others, 1961), Plasticine® (Balchin and Richards, 1952), and bricks (Lasca, 1991). Fletcher and Wiswall (1987) advocated the use of dye as a tracer while Schwartz (1968) used different colored sand to illustrate stratigraphy.

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

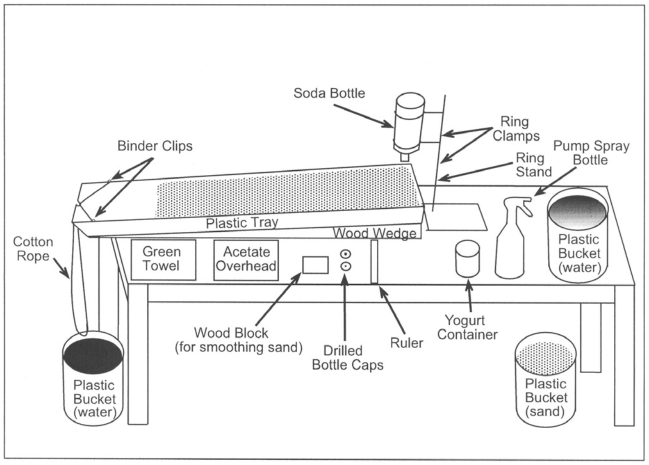

Figure 2. Our stream table and its various components.

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

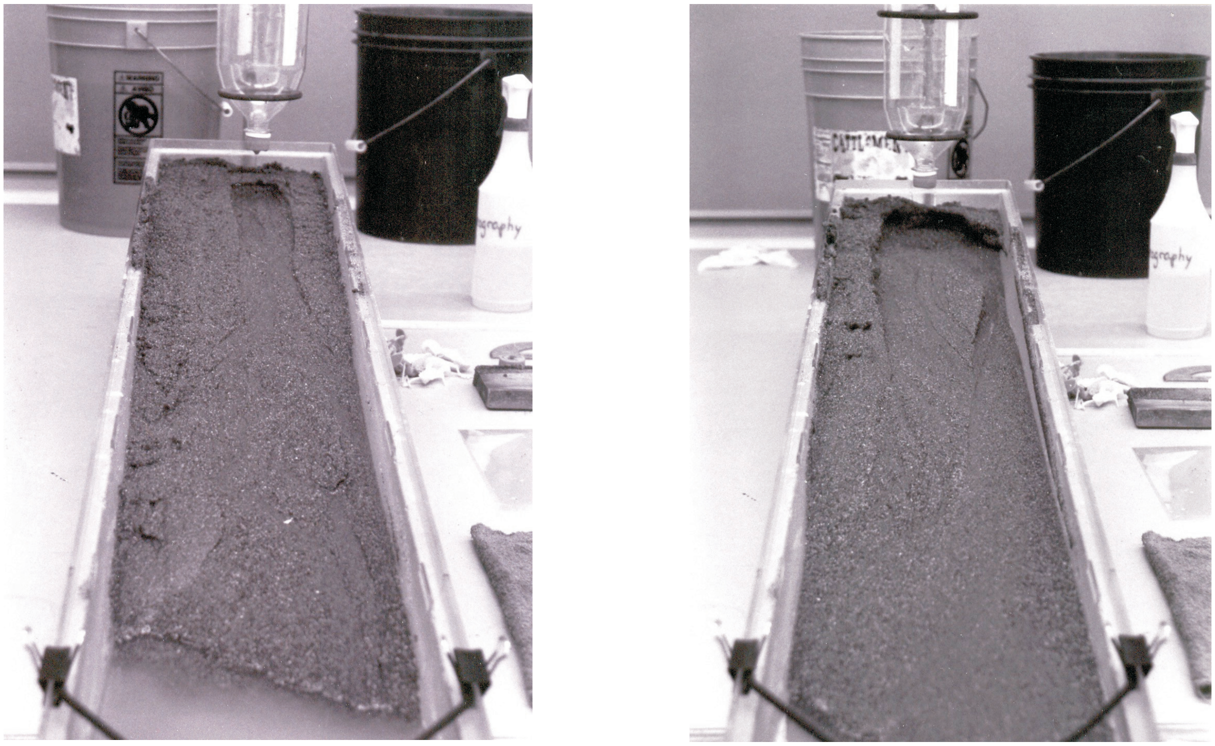

Figure 3. Effects of low (3a) and high (3b) stream discharge. Note the differing degrees of incision, braiding, and fan-delta deposition.

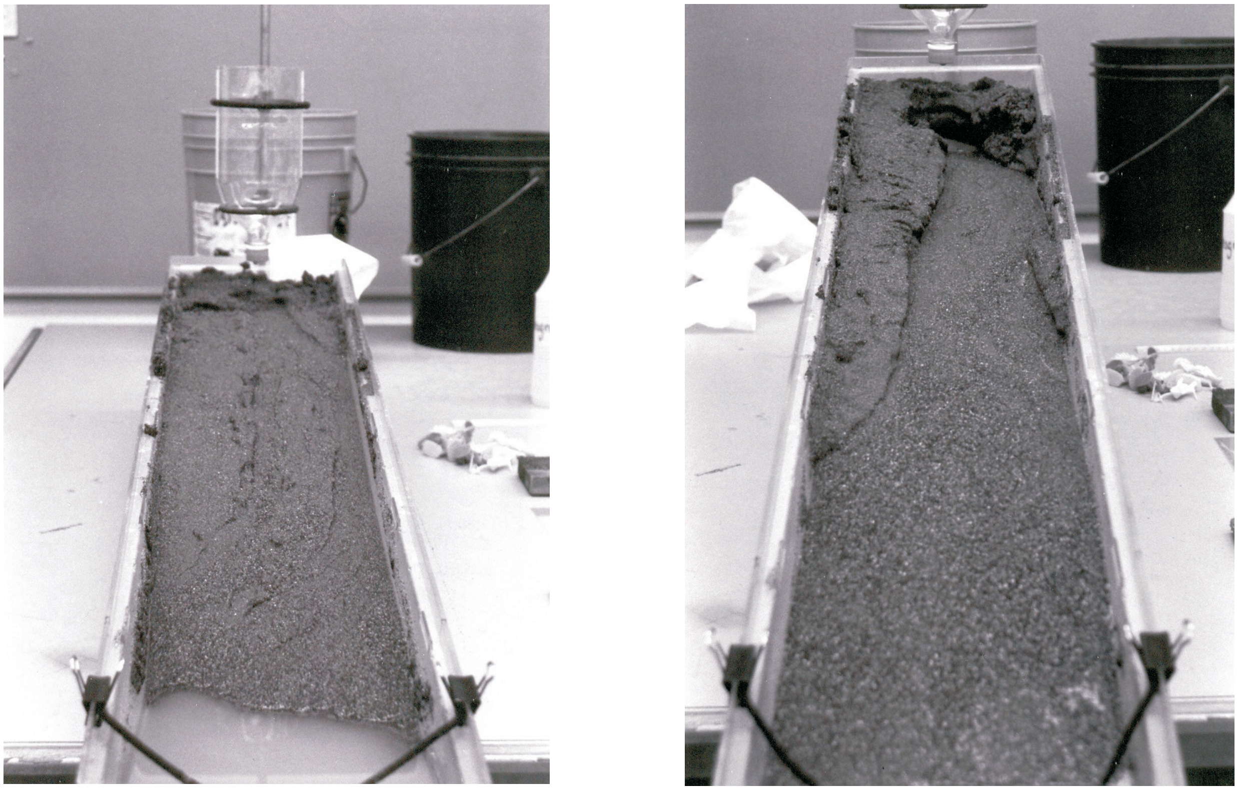

Figure 4. Effects of low (4a) and high (4b) slope angles. Note the differing degrees of incision, braiding, and fan-delta deposition.

Item	Size (lxwxd)	Quantity	Cost[2]
Plastic tray[1]	128 cm x 23.5 cm x 8 cm	1	$45
Sand	fine to medium	~10 l	$5
Low slope angle wood wedge	122 cm x 15 cm x 5 cm	2	$4
High slope angle wood wedge	122 cm x 30 cm x 5 cm	2	$9
Soda bottles w/caps	2 l	3	N/A
Adjustable pump spray bottle	~ 1 l	1	$2
Ring stand	~60 cm hight	1	$20
Ring clamp	9 cm inside diameter	1	$10
Ring clamp	1.5 cm inside diameter	1	$10
Plastic buckets	~20 l	3	N/A
Yogurt containers	~ 1 l	2	N/A
Binder clips	Medium	2	$1
Cotton rope	~125 cm x ~0.6 cm diam	1	$1
Acetate overhead transparencies	~22 cm x ~28 cm	2	$1
Cotton towel	~22 cm x ~28 cm	1	$1
Wood block	~15 cm x ~5 cm x ~10 cm	1	N/A
Toy action figures & houses	< 5 cm tall	10	$1
Protractor	~15 cm	1	$1
Toothpick	~ 6 cm	1	N/A
Ruler	~30 cm	1	$1
TOTAL COST			$112

Table 2. Materials used for stream table demonstrations and exercises within article.

[1] Clear Plastic Lens Diffuser for flourescent light fixture (Item #A-0174) without screw holes drilled in bottom. Send orders/requests to Robert Chism, Executive Vice President of Corporate and Strategic Development, Kenall Manufacturing, 1020 Lakeside Drive, Gurnee, Illinois 60031; fax (847) 360-1781; email bchism@kenall.com. Mention stream table use to get the $45 per fixture price.

[2] In 2000 US currency.

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

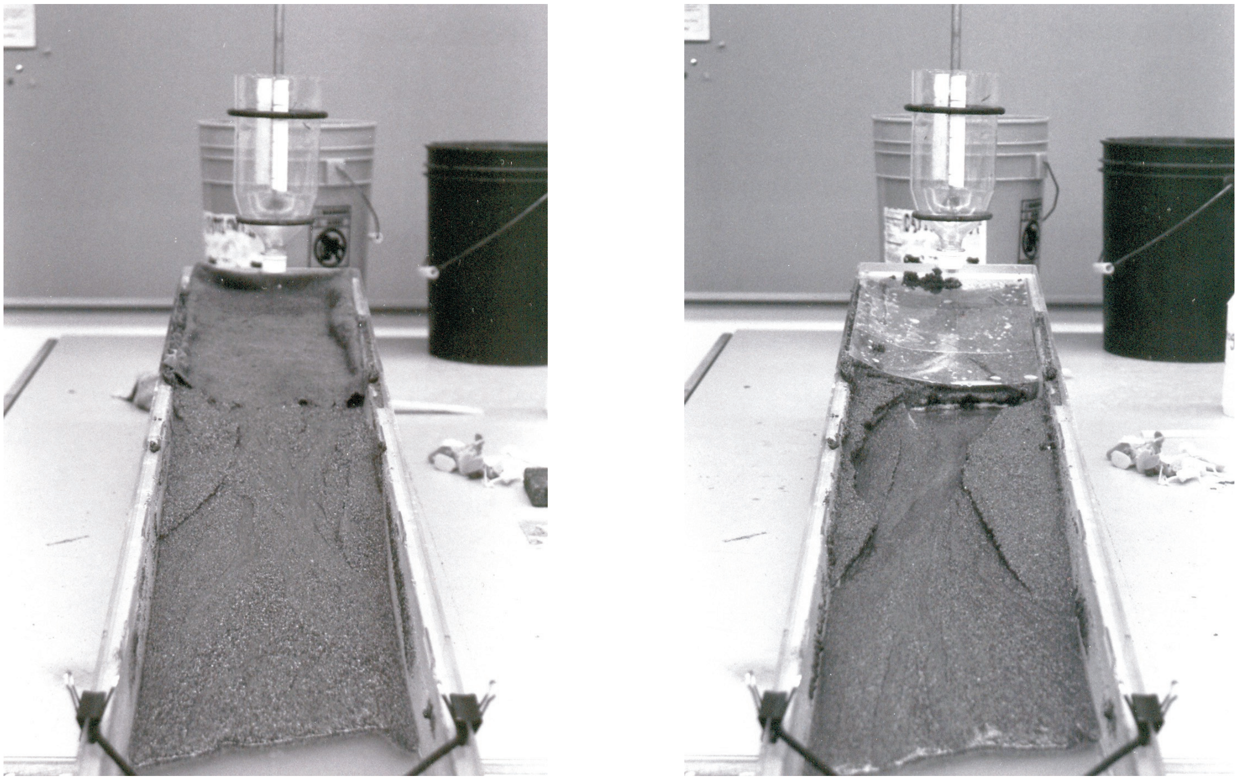

Figure 5. Effects of medium discharge on a partially "vegetated" (5a) and on a partially "urbanized" (5b) watershed. Note the differing degrees of incision (especially at the downstream edge of the cover type),

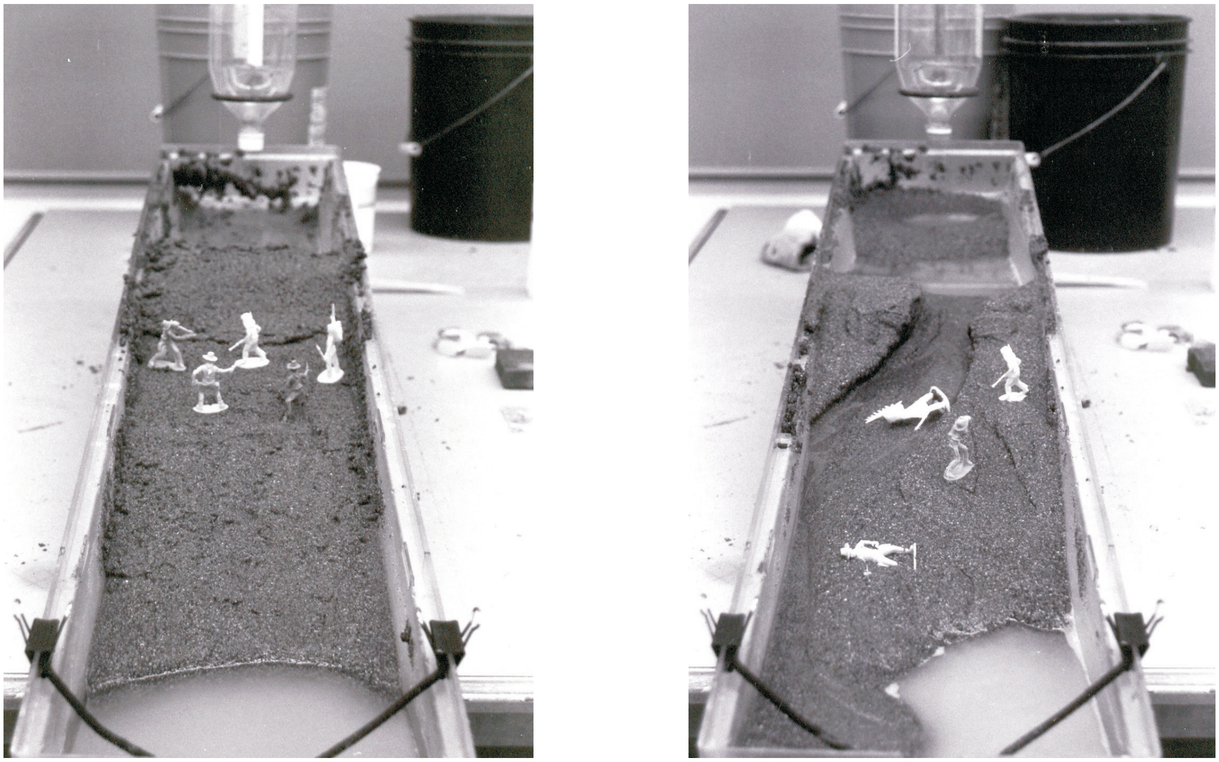

Figure 6. Earthen dam and reservoir pre-breaching (6a) and post-breaching (6b). Note the deep incision in the dam and the well developed fan-delta in the reservoir downstream.

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 (m^3/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. Permeable 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 watersheds 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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