Development of a Sustainable Migrating Meandering Channel Using a Small-Scale Stream Table

Brandon M. Rasaka, Cody MacCabe, Rachel McCullough, Jason Dayley (Mentor), William W. Little (Mentor)
Department of Geology, Brigham Young University – Idaho, Rexburg, Idaho

Abstract

To date, generating an artificial sustainable and migrating meandering channel has been accomplished only on large-scale stream tables, such as that at the University of California - Berkley (>100 m²). However, using a new, smaller (~2 m²) table, designed by the BYU-Idaho Department of Geology and constructed in conjunction with the Department of Mechanical Engineering, that permits controlled changes in load type, load amount, discharge volume, channel gradient, and base level, we successfully accomplished this objective. Two equilibrium relationships were considered through ten experiments: 1) A stream adjusts its gradient to barely transport introduced load to available discharge, and 2) a channel adjusts its cross-sectional area to barely handle its annual high discharge.

Objective

To generate a single sustainable and migrating meandering channel that traversed the length of a 1.5-meter long stream table.

General Setup

- The stream table consists of a 1.25 m wide by 1.55 m long box for "alluvial" sediment.
- Discharge is fed through a small rubber hose and sediment is fed by auger to a point at the head of the alluvial box.
- Base-level is controlled by an adjustable drain pipe.
- The alluvial box was filled with fine-grained (0.70 mesh) quartz sand for initial experiments. Later experiments added kaolinite and/or bentonite.
- Box fill thickness ranged from ~4 cm in earlier experiments to ~8 cm in later experiments.
- Surface gradient was maintained at ~1° throughout the experiments.
- Base level was varied somewhat between experiments but was maintained mostly about mid-channel in elevation.
- Accurate recording of discharge volume proved difficult and is known only in relation to its channel depth. Most experiments maintained discharge at bankfull stage.
- Accurate recording of the sediment feed rate also proved to be difficult. Numbers in mL/min should be considered only in a relative sense.
- A channel, typically ~4 cm wide and 1 cm deep, was carved to facilitate development of an initial meander near the head of the table. Size and shape of the bend varied somewhat from one experiment to another. In most cases it consisted of a short, straight extension from the discharge/sediment feed entry point directed at an angle to the alluvial box wall, then curved to parallel with the wall, running the remaining length of the alluvial box.

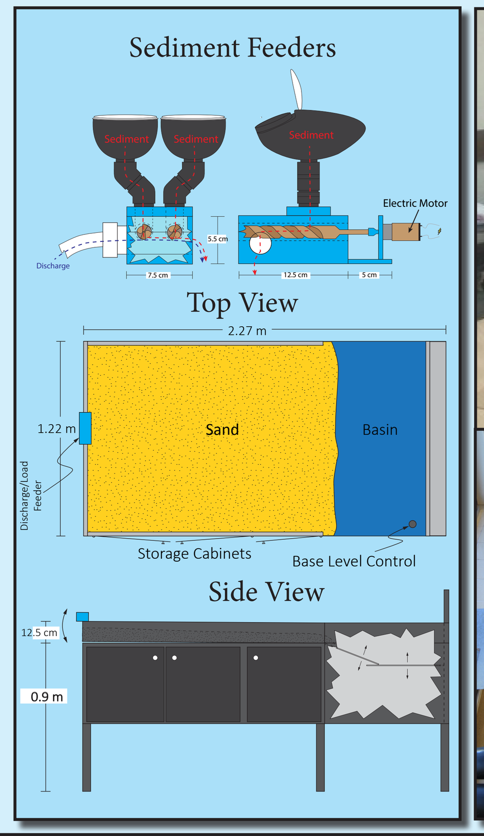

Figure 1 (Table Design):
- 2.4 m long (1.5 m stream bed, 0.9 m basin)
- 1.2 m wide
- Variable discharge and sediment feed
- Variable base level
- Adjustable gradient

Experiments 1 - 7: Unconsolidated Sand Bed

Objective: Generate a sustainable migrating meandering channel on a bed of fine-grained quartz sand.

Hypothesis: Discharge and load can be adjusted to find a balance between cutbank erosion and point bar deposition, so as to maintain a consistent channel width, leading to a migrating meandering channel.

Procedure: Other than Experiment 1, which began with a flat surface, each started with an initial carved channel. Discharge and sediment load were varied from one experiment to another to try and achieve a balance between deposition and erosion.

Observations:
- Without an initial channel, discharge flowed as a sheet across the surface.
- Increases in discharge or decreases in load resulted in cutbank erosion without concurrent point bar deposition, leading to channel widening and formation of a braided pattern.
- Decreases in discharge or increases in load resulted in-channel filling, leading to alluvial fan formation that radiated from the discharge/sediment point source.
- Though each experiment concluded in an equilibrium state between gradient, load, and discharge, a balance between rapid cutbank erosion and in-channel filling was not found.

Interpretation: Because of the lack of cohesion in unconsolidated sand, it is difficult to find a balance between overwhelming a channel with sediment and starving it of sediment, leading either to bank erosion to obtain additional sediment (Fig. 2) or formation of alluvial fans to increase gradient (Fig. 3).

A balance must be reached between discharge velocity and sediment load.

Figure 2 (Bank Erosion): A sediment supply below discharge capacity leads to bank erosion, channel widening, and a braided pattern.

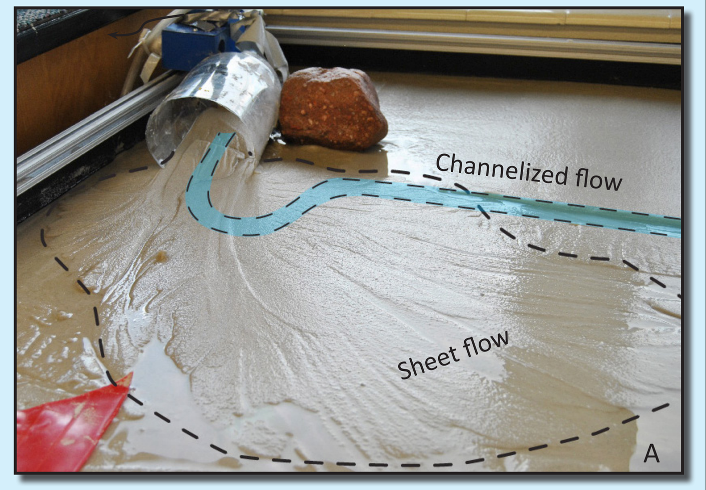

Figure 3A (Alluvial Fan Formation): If sediment entering the system cannot be transported by the discharge, it deposits within the channel, forming an alluvial fan.

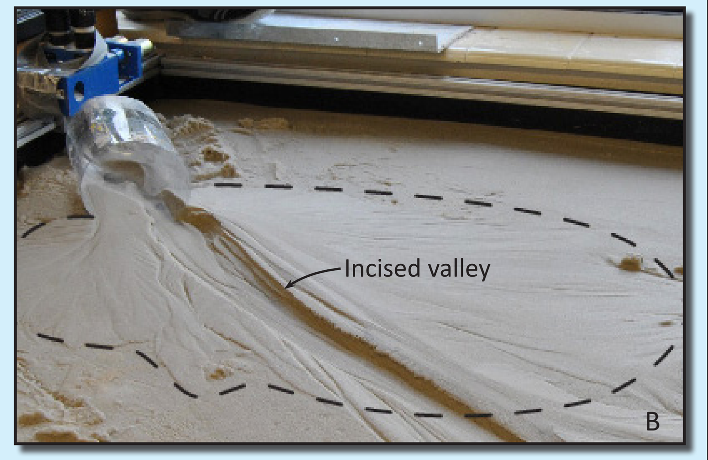

Figure 3B (Alluvial Fan Incision): A decrease in sediment supply leads to fan incision.

Experiments 8 - 9: Bed of Interbedded Sand & Clay

Objective: Increase bank cohesion by adding a layer of clay to the alluvial box surface.

Hypothesis: Adding clay to the surface of the alluvial box will increase cohesion, slowing the rate of cutbank erosion, which will allow point bar deposition to occur and keep pace, resulting in a constant channel width and meandering channel pattern.

Procedure: Experiment 8 had a very thin dusting of kaolinite powder applied as a strip several cm wide along both sides of the channel. Experiment 9 involved an ~2 cm-thick bed of clay (kaolinite and bentonite) on top of the sand. Otherwise, the procedure was the same as before.

Observations:
- The thin dusting of Experiment 8 had little effect, and the channel behaved in much the same manner as Experiments 1 through 7 (Fig. 4).
- The thicker clay cap of Experiment 9 led to formation of a well-defined, weakly-meandering channel in which cutbank erosion was accomplished through undercutting of the clay and sand removal, leading to subsequent collapse of the overlying clay layers. Clay blocks clogged the channel and needed to be artificially removed (Fig. 5).
- Increases in discharge or decreases in sediment supply had little impact on enhancing the meandering pattern.

Interpretation: Thick clay layers placed above sand layers increased cohesion above capacity of the system to erode cutbanks beyond the formation of a slightly meandering pattern. Because of its high capacity for swelling, bentonite is a less suitable bank material than kaolinite.

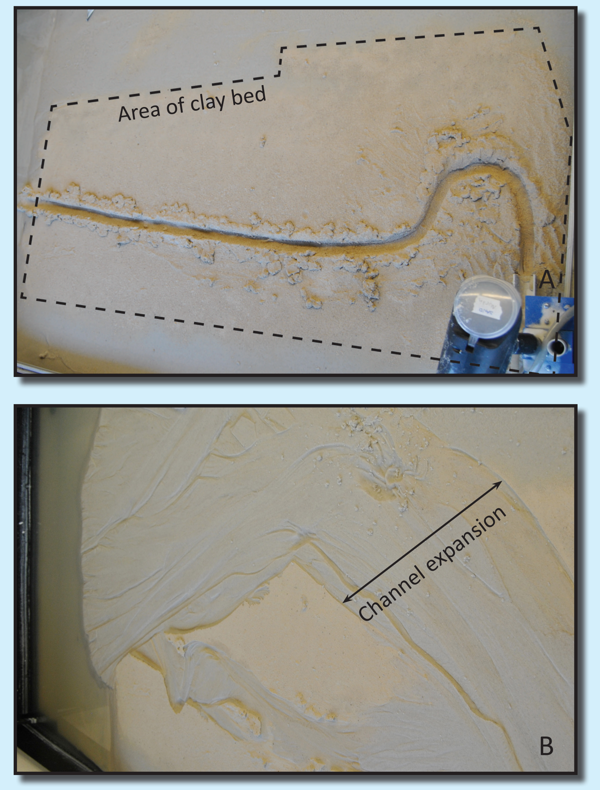

Figure 4 (Thin Kaolinite Layer): A thin layer of kaolinite in a narrow strip slightly decreased the rate of erosion, having no impact once the clay was removed.

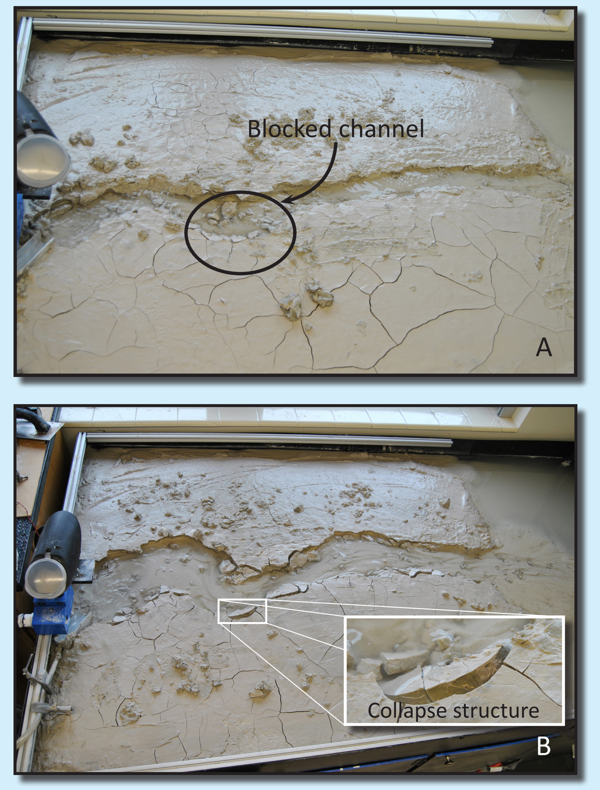

Figure 5 (Thick Bentonite & Kaolinite Layer): A thick layer of highly expansive clay (bentonite) increased cohesion. As sand was removed, overlying clay collapsed, forming a protective barrier that prevented further bank erosion.

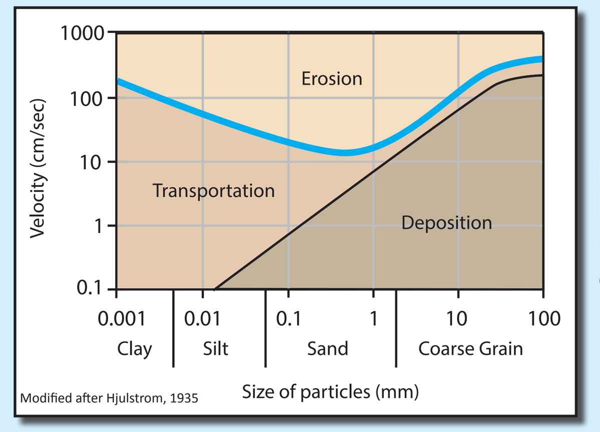

Figure 6 (Sediment Cohesion): As demonstrated by Hjulstrom (1935), clay is more cohesive than unconsolidated sand and is, therefore, less easily eroded.

Experiment 10: Bed of Mixed Sand & Clay

Objective: Find a bank cohesion that is higher than that of unconsolidated sand but lower than that of saturated kaolinite and bentonite.

Hypothesis: A mixture of unconsolidated sand and kaolinite can be found that will allow cutbank erosion and point bar deposition to occur at the same rate, leading to the formation and sustainability of a meandering channel pattern. Addition of kaolinite to the sediment feed will help stabilize point bars, decreasing the tendency for channels to cut across the bars.

Procedure: Three parts quartz sand was thoroughly mixed with one part kaolinite clay for both the alluvial box fill and sediment fed to the table. Otherwise, the procedure was the same as before.

Observations:
- Both cutbank erosion and point bar deposition began soon after initiation of the experiment (Fig. 7A).
- With adjustment to discharge and load, rates of erosion and deposition closely matched, maintaining a constant channel width.
- Cutbanks migrated both laterally and downstream (Figs. 7A - 7D).
- Eventually, three meanders were produced with the channel thalweg crossing from bank to bank between adjacent meanders (Fig. 7C).

Interpretations: The mixture of clay and sand in bed material provided sufficient cohesion to slow bank erosion to where sand deposition on point bars could keep pace. Deposition of clay on point bars prevented formation of chute channels across the bars, helping to confine flow to a single channel thalweg.

Note: The experiment was prematurely terminated because of an unauthorized drop in base level that led to deep incision and development of a straight channel.

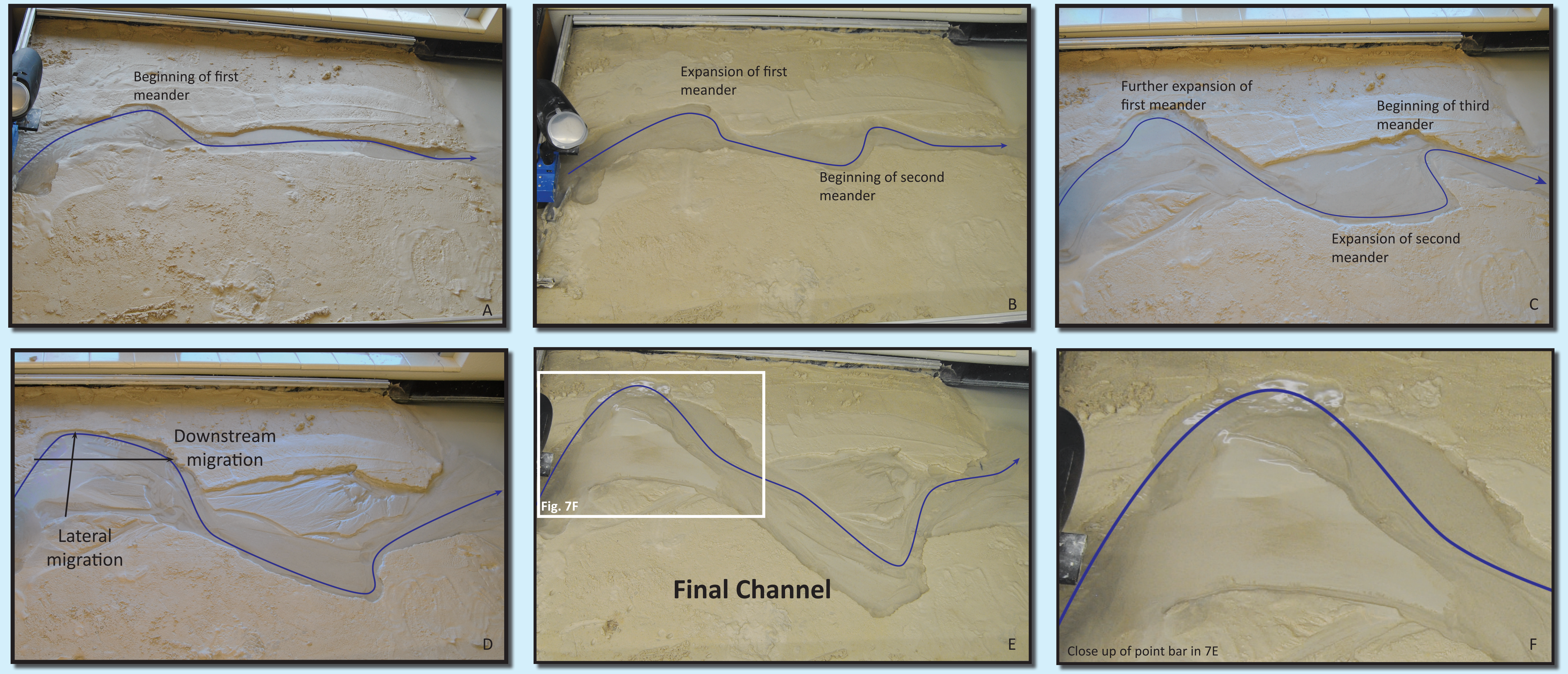

Figure 7 (Meander Development): This series of photos demonstrates the evolution from an initial bend followed by a straight channel to the development of two, then three meander bends that migrated both laterally and downstream.

Conclusions

A sustainable migrating meandering channel can be created on a small-scale stream table. The challenge is finding a balance between cut bank erosion and point bar deposition, which, though conceptually simple, proves difficult to replicate in an artificial setting. This was eventually accomplished by independently adjusting stream gradient, caliber and amount of load, flow velocity, discharge volume, base level, and cohesion of bank materials. The key turned out to be a mixture of sand and clay, both as the initial box-fill material and as sediment fed into the system. Clay in the box fill decreased the rate at which cut banks eroded. Sand in the sediment feed allowed deposition of the initial point bar. Clay in the sediment feed added cohesion to the point bar, decreasing likelihood of channel straightening through chute cutoff across the bar.

Acknowledgements

- BYU-Idaho 2009 Geomorphology class (Tyson Forbush, Barry Miller, Staci Place, and Robert Wheelright) for initial small stream table experiments pertaining to development of meandering systems.
- BYU-Idaho 2011 Geomorphology class (Candace Bradbury, Jason Dayley, Alisha Jensen, David Little, Quincy Nickens, Sarah Nieuwenhuis, Martell Strong, Danielle Worthen) for continuing research and helping design the "Dream Table."
- BYU-Idaho Department of Mechanical Engineering for building the stream table and Department of Geology for providing space and funding