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ARTICLES

WHAT IS MICROMODELING?
(GAINES/GORDON/MAX)

OPERATION AND CALIBRATON PROCEDURES FOR MICRO-MODELS

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INTRODUCTION

Micro modeling is the application of a physical, moveable-bed sediment model using table-size models with very small scales. The overall objective of a micro model study is to evaluate as many alternatives as feasible, while keeping the time and cost to a minimum. In order to achieve the objective of the study the micro model must be properly constructed, setup, calibrated and operated. A fundamental premise of micro modeling methodology is that the bed slope will adjust to an equilibrium condition given a specified channel alignment, sediment size, sediment size distribution and discharge. A second premise is that micro model behavior will closely approximate the bathymetry of the prototype.

The first requirement of a micro model study, as with any study, is to complete a search of the background of the reach under investigation. This search includes gathering historical materials including photographs, hydrographic surveys, geological data and any other pertinent information, which may be available. Particular attention should be given to any anomalies that may be present such as rock outcroppings or other tertiary limitations, either vertical or horizontal, which may affect the characteristic of the reach being studied. The model itself consists of several major components: (1) the insert that simulates the bed of the river, (2)

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the flume base that holds the insert and houses the water reservoir, submersible pump and control valve, and (3) the computerized flow controller which provides communication between the computer and the control valve.

MODEL INSERT LAYOUT

Once the background research has been completed, appropriate Computer Aided Drafting and Design (CADD) files and recent aerial photographs of the reach are compiled. Using this information, a reasonable horizontal scale can be chosen so that a river reach of 5 km to 15 km (depending on channel width) can be represented in the model. The model horizontal scale is determined by trial until the required reach fits within the flume base. The maximum horizontal dimensions of the flume are approximately 200 cm long by 90 cm wide. Therefore, in choosing a scale, consideration must be given to the minimum channel width acceptable for evaluating the particular problem to be studied. The minimum main-channel width used in micro models is typically around 35 mm to 40 mm. Side channels are sometimes smaller than this; however, most problems studied are in the main channel and measurement of the bathymetric changes in the side channels is normally, although not always, of secondary importance.

After determining the limits of the study reach and establishing a workable scale, the channel bank lines of the river are digitized from the aerial photographs. These lines are typically located at the vegetation line or, where sufficient information exists, at the recognized top bank location. Bank lines are sometimes modified to permit adjustment of the model banks if channel realignment is to be considered during the study. The modified bank may consist of either a removable section in the insert or just a setback in the bank line that can be adjusted using oil-based modeling clay. A reference plane and grid is established on the insert using an appropriate coordinate system such as the Universal Transverse Mercator (UTM). The UTM grid is added to the CADD file describing the model limits.

Three identical scaled plots of the model insert are used to manufacture the physical insert shown in Figure 1. These plots have existing stream boundaries and other model features such as islands, grid lines, head gates, and tailgates clearly marked. Two of the aerial photographs are laminated and glued to two pieces of acrylic sheeting. The acrylic sheets are then glued to the upper and lower sides of a piece of 76 mm thick high-density polystyrene foam. The foam layer and upper acrylic layer are cut along the stream bank and island lines to form an open trough or channel. The manufacturer uses the third plot during construction of the insert. The head gate and tailgate structures are then constructed and placed within 100 mm to 300 mm from the beginning and end of the model, respectively. The sides of the model channel are painted black to reduce the capture of extraneous data when surveying the model bed.

MODEL FLUME AND SETUP

The completed insert is placed within a table-size flume base that measures approximately 204 cm x 90 cm x 104 cm (see Figure 2). Woodworker's clamps are used to secure the insert to the flume to prevent movement during model operation. Rotational jacks located within the flume base control the slope of the model in both the longitudinal and transverse directions. A 75 liter reservoir (see Figure 3) with a small sedimentation chamber and submersible pump is located within the flume base along with an electronic control valve (see Figure 4) that controls flow to the model insert. Another reservoir is located outside and above the flume base to provide a constant head for flow. A magnetic flow meter is placed on the inlet line to monitor flow during operation of the model. The slope of the flume base is initially adjusted to approximately 0.01 mm per mm in the longitudinal direction and zero in the transverse direction. The head gate and tailgate assemblies are adjusted to near mid-depth of the insert to control bed elevations, and existing prototype structures, simulated by galvanized steel mesh, are placed within the insert at the proper locations, lengths and elevations. Sediment, consisting of a plastic Urea Type II is then added to the insert to about one-half the channel depth or approximately 38 mm. Several different sizes of urea can be combined to represent the bed material of the stream under investigation.

MODEL OPERATION

The model is operated using a customized computer control system that simulates a hydrographic cycle. The cycle chosen can be either constant flow, sine wave, triangular or user defined. During these cycles sediment is introduced into the head-bay by a submersible pump and then transported along the bed of the model until it exits the tailgate and is discharged into the sediment chamber below. The submersible pump collects the sediment and again discharges it into the head-bay and the process is repeated. Through the use of the customized software, control valves and centrifugal pumps, the hydraulic processes of a river or stream can be replicated. The moving water and sediment are allowed to develop bed forms similar to those in the river according to natural hydraulic principals. Once the process has begun, the hydrographic cycle continues until equilibrium conditions are reached. The process is depicted pictorially in Figure 4.

MODEL CALIBRATION

Calibration of the model usually begins by introducing a constant discharge to the head-bay of the insert. This flow begins to form the bathymetry of the bed given the channel alignment, the amount of sediment in the model and the tilt of the flume. After equilibrium conditions have been reached and the model bed has stabilized, the slope is adjusted by adding or removing sediment, increasing or decreasing the tilt of the flume, adjusting the tailgate elevation or a combination thereof. These adjustments are continued until the water surface is parallel to the reference plane established on the surface of the insert. Water surface elevations are measured using a mechanical three-dimensional digitizer as shown in Figure 5. During the adjustment process guide vanes, roughness, non-erodible material and baffles are added, as necessary, until a reasonable inlet flow distribution is achieved.

The constant discharge is run at a high flow of approximately 9 l/min. to 12 l/min. to establish a high flow limit on the hydrographic cycle. The discharge is then changed to a flow of around 3 l/min. to 4 l/min. to ascertain a low flow limit on the cycle. High and low flow limits are determined when a desired level of sediment movement is observed in the model. The desired state of sediment mobility is based on the modeler's experience and judgment.

After establishing high and low flow conditions, unsteady flow is introduced in the form of either a sinusoidal or triangular wave. The sinusoidal mode opens and closes the control valve in a stepped sequence, which simulates a sine wave cycle, while the triangular mode does the same resulting in a linear opening and closing of the valve. The cyclic operation provides a mechanism for simulating the effects of the hydrographic cycle of the prototype.

The vertical scale of the model is determined through a trial and error process during the calibration phase. The vertical scale determines the spread of the model data when it is converted to prototype coordinates. All data is referenced to the coordinate plane on the surface of the insert. This plane must be shifted vertically toward the surface of the sediment bed so that the reference plane matches the prototype reference plane. The vertical offset between the model reference plane on the insert surface and the model's equivalent Low Water Reference Plane (LWRP) is called the shift factor. The LWRP on the Mississippi River is based on a statistical analysis of historical river stages and is defined as the stage that is exceeded 97% of the time. Adjusting the shift moves all model elevation data vertically toward the model LWRP. Refinements to the shift and vertical scale continue until the model data approximates the prototype data and the model is considered to have geomorphologic similarity. After shift and vertical scales are determined, water surface elevations are checked during constant discharges at low and high flow limits to determine the prototype stage conditions being modeled. Typically the maximum model flows represent +5.0 m to +6.0 m LWRP in the prototype; however, higher stages have been used on some models. Minimum model flows tend to be at the LWRP. Higher flows in the micro model produce a greater energy level and result in excessive sediment movement. Entrance and exit conditions may be modified slightly, if necessary, to improve the ability of the model to reproduce prototype conditions.

After final adjustments are made to slope, sediment, vertical scale, and shift, the model is operated for several timed hydrographs to ensure that the model is in equilibrium. Equilibrium generally refers to a state where the bed sediments move in a uniform manner throughout the cycle of operation and no sediment waves are observed in the model. When it is established that equilibrium conditions exist, the model bed is surveyed using a three-dimensional laser scanner as seen in Figure 6. Data collected are processed through a customized computer program that converts the model data to prototype coordinates. The data are then converted to hydrographic maps using CADD software and compared to prototype surveys to determine general bathymetric trends. Thalweg location, deep pools, crossings and sandbar locations are some of the parameters currently used as a basis of comparison. When comparison reveals disagreement between the model survey and the prototype surveys, small adjustments are made by changing model tilt, entrance and exit conditions, and boundary conditions. This process is repeated until morphologic similarity between the model survey and the prototype surveys is such that the model is considered to be calibrated and baseline conditions exist. Consistency between repeated model surveys and their comparison to prototype surveys indicates when model baseline conditions have been attained. The actual measure of how well the model data replicates the prototype data depends on the modeler's interpretation of the survey results. It is generally evaluated on how well the converted model data visually reproduces the prototype survey data in both general elevation and location.

In reaches where prototype data are available, flow visualization provides a method of comparing surface flow conditions in the micro model to prototype flow conditions. Prototype data, which may be available, consists of aerial photography containing ice floes (Figure 7) or float data obtained through surface velocity and path measurements. Flow visualization utilizes timed exposures during a constant flow to record the path of surface confetti. The method currently in use employs seeding the model with plastic urea, the same material used to compose the bed. When dry, the urea will float providing an excellent method of tracking surface flow patterns (see Figure 8). The added sediment must be captured at the tailgate or removed from the model to avoid increasing the model slope and energy. Flow visualization serves as a mechanism for comparing flow paths, resulting from alternative designs, with baseline data.

DESIGN ALTERNATIVES

Once baseline data have been established and the model is considered calibrated design alternatives may be applied to the model. The modeler prepares alternative design strategies and confers with pertinent technical personnel, as necessary, to reach stated study objectives. Proposed designs consist of possible structure locations, alignments, lengths and elevations. Each proposed design is placed within the model, and the model is operated through several hydrograph cycles until the bed is stabilized. The actual number of cycles depends on the relative magnitude of the changes induced by the alternative structures. Typically five or six five-minute cycles will bring the bed to equilibrium conditions. Slight changes may require less time for the model to re-stabilize the bed while more drastic changes may require more time. Bed re-stabilization occurs when the model bathymetry obtains a new equilibrium condition. The new equilibrium condition exists when bed material transport remains relatively consistent over several hydrograph cycles and no sediment waves are observed in the model. The resultant bathymetry is surveyed using the laser scanner, and the data are compared to baseline conditions. The effectiveness of the alternative is evaluated, a new alternative introduced into the model, and the process repeated.

CONCLUSION

In this day of limited resources, tabletop models are a distinctive new tool that can be used to assist river engineers in making intelligent decisions during the design of river training structures. While they are not a panacea, these models can provide very useful information to add to the decision-making matrix when solving complex riverine problems. However, caution must be exercised when conducting a micro model study to insure that the model is properly designed, constructed and operated. As with other models, physical or numerical, the old adage "garbage in garbage out" is applicable to small-scale models. The modeler must therefore use judgment and experience in choosing a horizontal scale that will provide a practical model length, while, at the same time, produce a reasonable channel width. He/She must also establish the model slope as flat as possible that will, along with realistic high and low flow rates, provide viable sediment movement. Care should be exercised in placing training structures in the model to insure that they are of the proper length and elevation. Micro modeling is an exciting new tool, which is challenging the paradigm that only large-scale models can provide useful information for the design process.

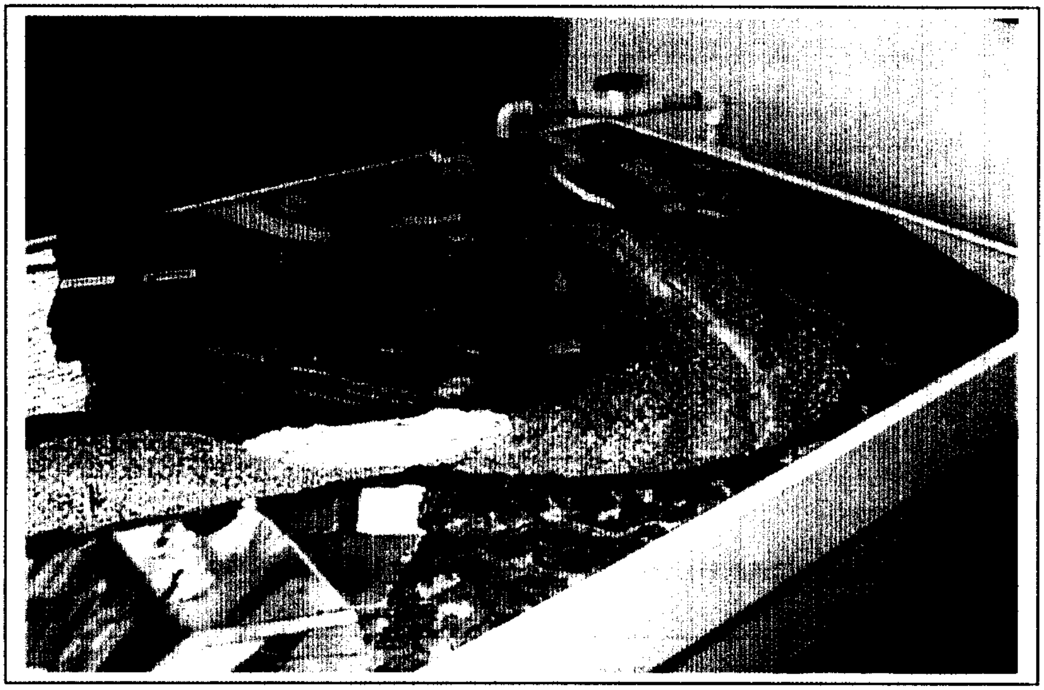

Figure 1. Micro Model Insert

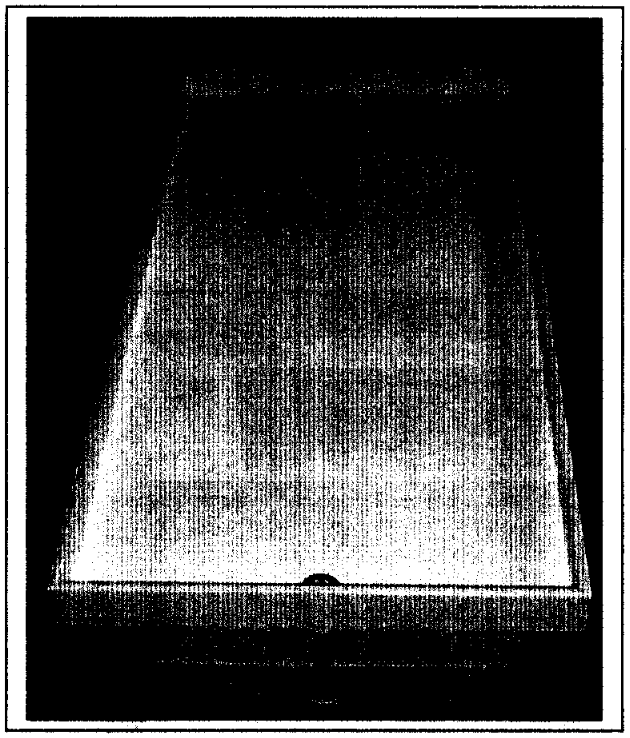

Figure 2. Micro Model Flume

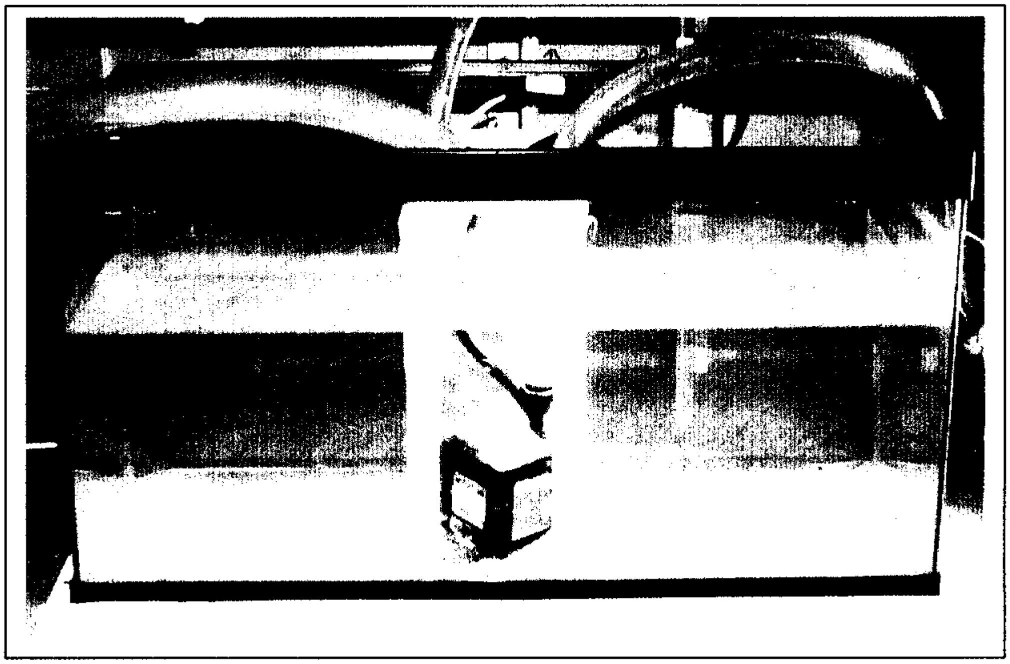

Figure 3. Reservoir and Sediment Chamber

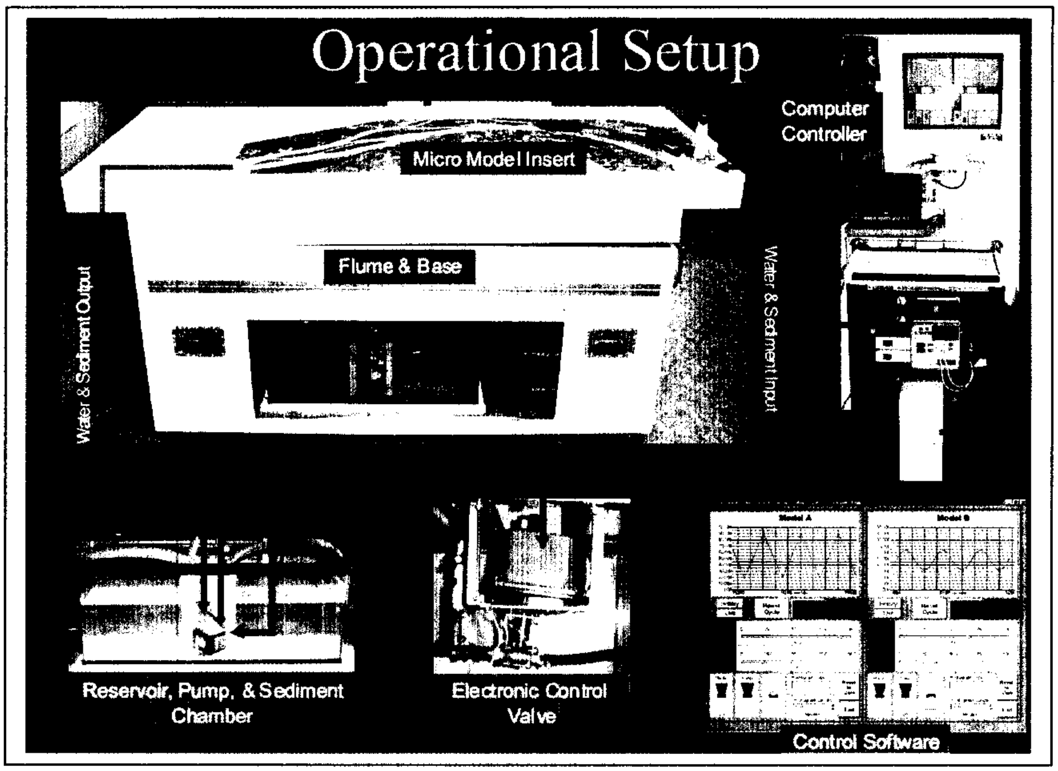

Figure 4. Operational Setup

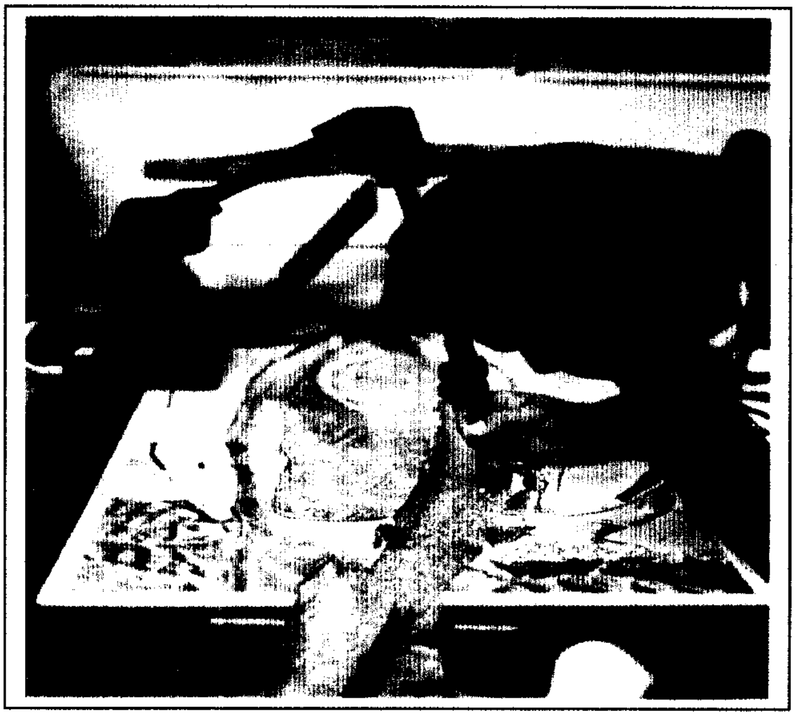

Figure 5. Mechanical Digitizer

Figure 6. Laser Scanner

Figure 7. Mouth of White River, Prototype Ice Floe

Figure 8. Mouth of White River, Base Test Flow Visualization