C-6

POKREFKE

SECTION REVIEW 1.1.1 TO 1.2

August 20, 2002

SUBJECT: Review of Sections 1.1.1 and 1.2 of the Micro-Model Report

At the request of Dr. Steve Maynord, I reviewed the subject sections relative to WES movable-bed modeling and a comparison of micro-model and WES model methodologies. This document includes my general comments. Specific comments are in the margins of the document Steve provided me.

I was appalled, agitated, and insulted that **anyone**, other than a WES physical, movable-bed modeler wrote Section 1.1.1. **No one** outside of WES knows how we ran our models and why we did what we did. Mr. John Franco and many others before me and myself for more than the last 30 years spent virtually our entire careers performing physical, movable-bed models. This is a procedure that is as much an art as it is a science, but then I read in various portions of the report why we did what we did and the impacts of those actions. So many of those points were so far from reality that I almost wanted to laugh, if I had not been so angry over it.

It has been my impression all along that the micro-model evaluation being performed under the auspices of the Navigation Hydraulics Research Program was to be an unbiased, non-parochial, fair and impartial review of the micro-model techniques to include applicability and possible limitations. By the end of the first paragraph of the two sections I reviewed, I could sense the writer's agenda and purpose in the presentation. Throughout the entire document WES physical, movable-bed models were degraded to the betterment of micro-models. I had to ask myself several times the question – if the models and we were so far from reality and the science of modeling, how come the Corps built so many successful projects based on physical, movable-bed models? I'm talking major Corps projects, like the Old River Control Structures, Locks and Dam No. 26 (Melvin Price) Replacement, Smithland Locks and Dam, the vast majority of the McClellan Kerr (Arkansas River) Navigation System, the majority of the Red River (Louisiana) Navigation System, and numerous Mississippi River site-specific studies. These are just the studies WES has conducted in the last 40 years or so.

It can be said that I am just "venting" my "sour-grapes" about micro-models, but I have **always** thought, believed, and stated that micro-models have a place in the field of river engineering that the Corps addresses. It is just a sad day when Corps employee(s) put such a loop-sided tilt on others, strictly to make themselves look good to others.

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Hydraulic Engineer
Coastal and Hydraulics Laboratory

1967 G. Fenwick Ch. 5
Report No. 7 Channel/Stab. Committee
Solid Red Cover
Stat. of Knowledge in Channel Stab. in Alluvial Rivers

1.1.1. Basic Methodology of WES Movable Bed Models

The large movable bed models employed by the Corps of Engineers at the Waterways Experiment Station (WES) in Vicksburg, Mississippi, as stated previously, were classified as loose-bed models that used an empirical modeling approach. The models utilized relatively large horizontal scales (typically 1:120 to 1:600) and vertical distortion (typically 5 to 10). The models did not utilize established similitude criteria during the design or operation of a model. Warnock (1949) stated that the primary step in the development of a movable bed model involved the selection of suitable scales and bed material which would result in two phase flow similar to the prototype. To accomplish this, a thorough knowledge of the characteristics of the prototype based upon hydraulic and hydrographic survey data was required. In addition, experience in the field of river mechanics and movable bed hydraulic models was needed for proper model calibration. Figure 2-1 is a typical movable bed model used at WES.

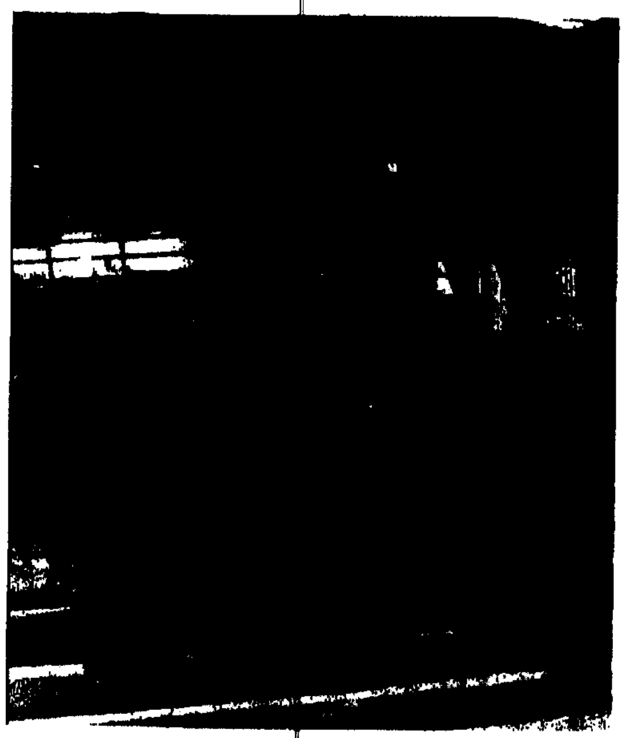


Figure 2-1: Large Movable Bed Model at WES, Middle Mississippi River at Dogtooth Bend, Miles 39.2 to 20.2, Scales 1:400 Horizontal & 1:100 Vertical

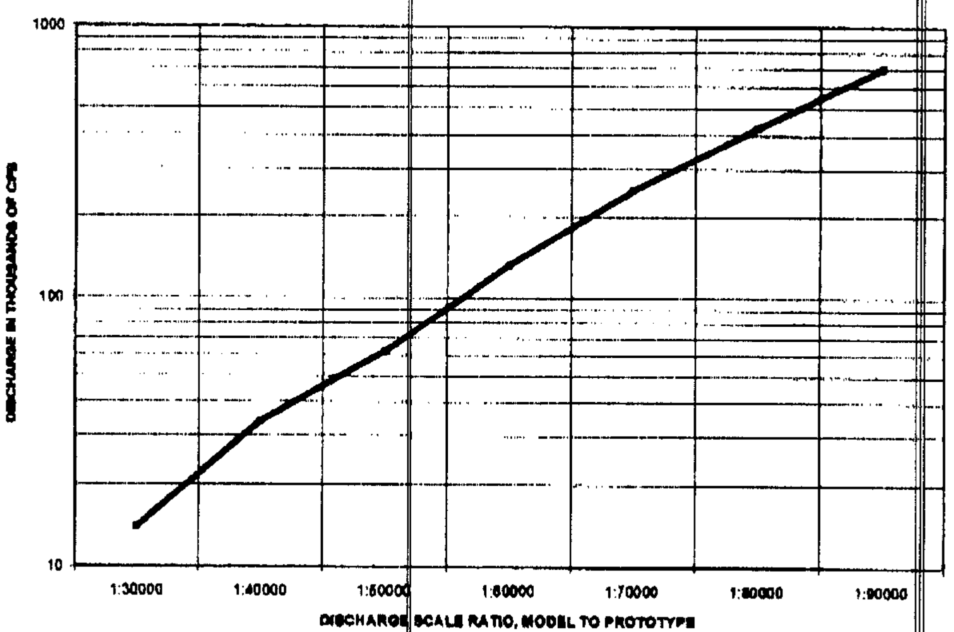


Figure 2-33: Discharge Relation Curve, WES Coal Bed Model, Scale 1:120 - 1:80

discharge of the model increased, the scale discharge ratios applied to represent the prototype increased exponentially. According to Franco, the discharge scale relation must be such that movement of model bed material is similar to prototype bed movement for the range of flows in the simulated hydrograph. Models are generally too small to develop the forces required to move typical model bed materials, especially at lower flows. The additional forces needed to move the sediment must be provided through discharge scale relations that are greater than the theoretical scale derived from the model horizontal and vertical scales.

Due to this exponential discharge scale, the water stages in the model would not correspond to the appropriate stages in the prototype. As a result, the smaller discharges in the model would result in reduced stages. To compensate for these discrepancies, the model stages were manipulated via a movable tailbay weir at the end of the model. This tailbay, in combination with the changing scale discharge releases at the upper end of the model, was moved upwards or downwards to create a distorted water surface profile. By artificially raising the stage, this operational procedure compensated for the fact that a exponential discharge scale relationship was being utilized. Figure 2-4 from Franco (1978) shows the discharge scale ratio versus stage from a sand bed model with a distortion of 7. The graph shows that as stages increased, the discharge scale ratio conversion to the prototype increased exponentially.

Do not know where this statement come from. Simple English - the purpose of the downstream tailgate is to control stages in the model. The tailgate is a physical item which replaces the natural channel downstream of the modelled reach.

Stage was not artificially raised. We reproduced prototype stages at at least one location on the model

Typically a model operates very near the critical tractive force while the prototype operates considerably above the critical level. Vertical distortion is an adaptation to increase tractive force in a model. However, in most loose bed models supplementary slope is also required to develop the necessary forces for bed movement.

5. **Entrance and Exit Conditions.** The entrance condition was constructed and modified so as to dissipate excessive energy and bed scour resulting from the discharge introduction point at the upstream portion of the model. In addition, modifications were made to ensure the proper direction of flow into the model. Baffles, concrete, screen, and other materials were used to accomplish this. The exit condition was constructed far enough downstream from the area of interest in the model study to ensure minimal negative model influence.

? these are materials used to construct a baffle

6. **Bank Alignment and Overbank Roughness.** The accurate alignment of the banks in the model, or channel planform, was critical to the proper development of the resultant bed configuration. For this reason, it was necessary to acquire accurate maps, drawings, or photos of the prototype for accurate horizontal boundary conditions in the model. In addition, overbank roughness in the form of concrete and screen and other materials were incorporated in the models to simulate overbank prototype roughness associated with vegetation, etc. In most WES models, a small, parallel portion of the floodplain or overbank was usually included in the model.

7. **Erosion Resistant Boundaries.** There are many erosion resistant materials that occur in the prototype in the form of gravel and cobble bars, clay plugs, rock strata, sunken vessels, debris, etc. The WES models utilized several different materials in the model to simulate resistance to erosion including haydite, screen, gravel, and concrete. Figures 2-5 and 2-6 are photos illustrating some of the different materials used. In Figure 2-5, concrete was used to simulate both a rock feature and dikes in the model. In Figure 2-6, haydite was used to simulate an erosion resistant bar (Boston Bar). The determination of erosion resistant boundaries in the model was usually made during model verification based upon either information obtained from the prototype or upon judgment made by the modeler.

In addition, pile dikes and rock structures of the prototype were represented in the model by a variety of materials, including pervious thin-walled metal screen and impervious material in the form of thin-walled sheet metal, concrete, and pea gravel. Figures 2-7 and 2-8 illustrate impervious structures used in the WES models.

I never saw any. Pile dikes were represented with cylindrical rods.

8. **Regulating Structure Elevation and Condition.** Critical to the performance of the WES models was the amount of available information describing the condition of existing channel regulating structures in the prototype. This included basic information on dike elevation and dike length, dike type, pile

Figure 2-77: Pea Gravel-Concrete Conglomerate Representing Bendway Weirs in the Dogtooth Bend Model

Figure 2-88: Thin-Walled Metal Representing Chevrons in the St. Louis Harbor Model

Refererence datum was never changed. The rails contained the model supple-mental slope and that was all. The top of the rail was based on a fixed elevation and only changed in value to match the prototype LWRP.

9 **Adjustments of Rails.** Localized adjustments in the reference datum along the models were employed in the WES Models. A series of adjustable rails were placed on either side of the model banks. By raising or lowering the rails, the datum of selected areas of the model bed were shifted (either

decreased or increased in elevation), depending upon the requirements of the particular model. In this manner, localized areas of the model where bed movement was either too great or too low were adjusted by either raising or lowering the molding template in that area. Conversely, the elevations of the model bed would then increase or decrease. The rail adjustments were made during the verification process and then held constant throughout the duration of the model study. Figure 2-9 is a photo showing the location of rails for datum elevation adjustments.

...s approach was able to be used because specific stages were maintained in the models and areas of excessive or limited movement could be identified during verification. The rails would then be adjusted correspondingly up or down from the pivot point (center of the model length) to obtain acceptable bed material movement.

Figure 2-29: Mississippi River, Boston Bar Model. The Photo Illustrates the Use of an Adjustable Rail System for Localized Control of a Variable Datum.

Once the bed was molded, the model was ready for testing. The procedure at WES for the initial adjustment or calibration of the model bed behavior was termed "model verification" (Franco 1968). Each of the above 9 parameters were adjusted during the verification phase of the model study. Franco (1968) states that the normal verification is an intricate process of adjusting the various hydraulic forces and model operating technique until the model demonstrates its ability to reproduce with acceptable accuracy the changes in bed formations that are known to have occurred in the prototype during a given period. Franco (1978) adds that the "principal considerations in the design of movable-bed models should be that the hydraulic forces developed be sufficient to move the material forming the bed in simulation of prototype sediment movement and that the model is capable of defining the problem at hand." With this as the focal objective, sediment movement was guided by the following considerations:

1. Model bed movement should occur during all flows that produce prototype bed movement.
2. Movement should be mostly in crossings with little or no movement in deep channels during low flows.
3. Sediment movement should be fairly general throughout, but bends and deeper channel areas will be greater than elsewhere during high flows.
4. Resultant bed conditions are dependent on the point of time in the hydrograph cycle when a survey is made (surveys made at the end of a high-flow period indicate deeper channels in bends and shallower crossings while surveys made at the end of a low-flow period indicate shallower channels in bends and deeper crossings).

During the verification a non-linear scaled historical hydrograph was run through the model over a starting bed configuration that was molded to represent the actual prototype bathymetry that existed at the beginning of the hydrograph. The planform or bankline alignment of the model associated with this bed was constructed from available historical information as close to the era of time that the starting bed configuration was based upon. After the hydrograph was run, the model bed configuration was surveyed. The resultant bathymetry was visually compared in planform to a hydrographic prototype survey representative of prototype conditions occurring at the end of the historical hydrograph. The time duration of the historical hydrograph was kept relatively short, which was usually one year. This was due to the fact that if the time period was too long, major changes in the bankline occurring in the prototype would have to be incorporated into the model in order for the proper bed response to occur. Longer time durations were consider impractical from both a model operation and economic perspective (Derrick 2002).

It was really due to the premise that the model should be capable of reproducing prototype trends that were documented between annual surveys. In fact, on Bolles Bend-Ajax Bar study we did address the reoccurring bankline issue.

After the hydrograph was run through the model and the ending bed configuration was compared to the prototype survey, the model was re-molded to the starting bed configuration and adjustments were then made as discussed earlier. The hydrograph was then again simulated and the process repeated as necessary until the modeler felt that similarity was achieved with the ending prototype survey. Special attention was given to the input and output of sediment to ensure model bed stability.

After the previous process was complete, the model was considered verified. At this point, an "average annual design hydrograph" was developed and used for all subsequent model runs. This hydrograph was based upon the particular problem at hand and was empirically determined usually by averaging a set of historical data. The average annual design hydrograph was then used to establish a base test condition in the model.

The model bed configuration at the end of verification served as the starting bed configuration for the base test. Usually, multiple average annual hydrographs would be run through the model bed until bed stability was achieved (sediment equilibrium). Once this occurred, the resultant model bed configuration formed the base test template bed. This base test bed configuration was the bed used for the starting bed configuration of all design alternative tests. When a particular design was installed in the model, two to three hydrographs were usually simulated, depending upon the sediment response observed in the model. At the end of each hydrograph, the model was usually surveyed and then compared to the starting base test bed configuration. Sometimes additional hydrographs were simulated in a particular design alternative until model stability was achieved. When a new design was to be incorporated into the model, the bed was usually re-molded back to the starting base test bed configuration and the procedure repeated.

It was in the above manner that general conclusions were made on the effectiveness of particular design alternatives. Designs were always compared to the base test and not directly to the prototype. The river engineer then took these bed response indications from the model to assist in design and construction decisions for the prototype.

Flow visualization was also used in many movable bed model studies at WES. Using time exposure or time lapse photography, confetti streaks or lighted drones were captured under certain flow conditions in the model usually during the base test and comparative design alternative tests. In the model study results, the flow visualization was used for a general indication of the relative effects of the main concentration of flow for a particular design as compared to the base test. Figures 2-10 thru 2-13 illustrate flow visualization used in some of the WES models.

This flow visualization provided the modelers with information, but was not used in design of testing plans. We ~~only~~ used this to a very limited degree to see the plan effects

Figure 2-10~~10~~: Flow Visualization of the Greenville Bridge Model, Lower Mississippi River, Vertical Scale Distortion of 3.6

Figure 2-11~~11~~: Flow Visualization of the St. Louis Harbor Model to Assess Flow Patterns through Multiple Bridge Crossings, Vertical Scale Distortion of 2.5

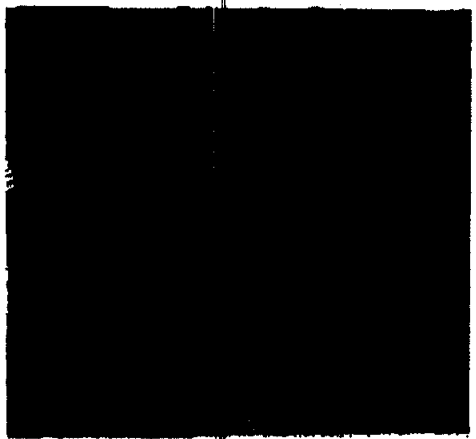


Figure 2-12~~12~~: Flow Visualization of the Arkansas River Model, Vertical Scale Distortion of 4

Figure 2-13~~13~~: Flow Visualization of the Grand Tower Model, Middle Mississippi River, Vertical Scale Distortion of 4

1.2 Micromodel Methodology Compared With WES Model Methodology.

The development of the micromodel was based upon observation and experience with many of the same operational considerations established in the WES models. Both models have historically been used for studying similar river dynamics and for designing solutions to similar types of problems. Similarities and differences in methodology are as follows.

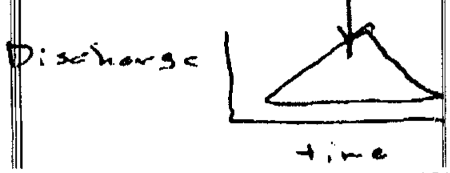
1. **Size.** Typically, the horizontal scales of micromodels are approximately one to two orders of magnitude smaller than most WES models. Horizontal scales in the micromodel have normally ranged between 1:3600 to 1:12000. Horizontal scales in the WES models normally ranged between 1:100 to

1:600. Volumetrically, the WES models are approximately 16 million times smaller than the prototype and approximately 3000 times larger than the typical micromodel.

2 **Vertical Scale Distortion.** Both models rely upon distortion of the vertical scale. In the micromodels, the distortion has ranged between 5 and 20. In the WES models, distortions have ranged between 2 and 10.

3 **Determination of the Vertical Scale and Datum.** In the micromodel, the vertical scale is determined during the calibration phase of the model study. The vertical scale is estimated by the modeler and applied mathematically by multiplying a single scale factor to all model bed elevations. A parallel datum is then shifted up or down in an attempt to match model and prototype elevations. Varying scale factors and shifts are applied to the model bed configuration in order to determine which combination of vertical scale and shift results in a bed configuration that most resembles the prototype. This is a trial and error procedure that is used in the calibration process to study bed forms and to adjust the heights of existing river training structures. Once the model is determined to be calibrated, the resulting vertical scale and shift are then used for the duration of the model study. The vertical scale is held constant throughout all lengths of the model. Likewise, the shift in reference plane or datum is held constant throughout the length of the model. In the WES models, an initial vertical scale and datum is established during initial model design. This vertical scale is then used to mold of the model bed. However, during verification, localized datum changes are made at locations along the model, whereby the datum is either increased or decreased in elevation using rail adjustments. The end result is a model that contains a non-parallel datum which varies over the length of the model.

4 **Correspondence of Discharge and Stage to the Prototype.** The discharge and stage in the micromodel does not correspond directly to the prototype. Because the primary purpose of the micromodel is to obtain a representative sediment response of the model bed, the non-linear graphical relationship is not included in the procedure. In the WES models, a graphical non-linear relationship was prepared for model operation and prototype comparison purposes. However, this non-linear discharge scale reduced flows in the WES models at the higher points in the hydrograph. This would have effectively created disproportionate stages without the use of a varying tailbay located at the end of the model which was used to manipulate the stages to higher elevations. This effect combined with localized datum adjustments with rails created stages that only superficially corresponded to the prototype. Both models employed a standard design hydrograph used during the base test and all design alternative testing. Simulation of a low flow to high flow energy



response was necessary in both models for the proper development of the model bed. Typically, stages in the micromodel approach 2/3 bankfull. These lower stages in the micromodel reduce the energy of the model associated with the distortion effects. Without the use of the variable tailbay, lower stages would result in the WES models as compared to the prototype.

5. **Water Surface Profile.** The micromodel does not use a changing tailbay, therefore the water surface profile stays relatively constant as the flow and stage varies. Due to the changing tailbay in the WES models, the water surface profile had a tendency to flatten out at higher points on the hydrograph.

6. **Maximum Water Stages.** In the micromodel, maximum water stages are contained within the confines of the river channel. In the WES models, maximum water stages were sometimes run higher than the top of bank of the channel over designated narrow strips of the overbank on either side of the channel. Many of these areas contained steel mesh that arbitrarily represented roughness induced by vegetation (Figure 2-14).

7. **Calibration and Verification.** In the micromodel, calibration and verification are used synonymously. However, in the WES models, verification represents reproduction of a specific period of time in the prototype by the model. Yet both models end up arriving at a similar base test condition. In the micromodel the calibrated bed is naturally developed without molding through a series of flow responses. In the WES model, a molded bed is formed from a previous historical hydrographic survey and is the starting condition for the natural development of a given ending condition. Both models are adjusted during a series of flow responses in order to develop

Figure 2-1414: Steel Mesh Roughness in Overbank Areas (Flow Patterns are Shown in the Main Channel.)

bathymetry consistent with the most recent hydrographic survey information at the time of the model study. However, while the WES model must be continually remolded, the micromodel bed forms are allowed to re-adjust naturally. In both models a comparison is made of the resultant ending model bed versus the prototype bed, and by observation, if the beds are similar, the model is declared verified or calibrated. The WES model methodology contains an additional step whereby a base test is established by running successive average annual hydrographs (based on prototype information) until bed stability is reached. This is accomplished in the micromodel during model calibration. In both models, the bed configuration at the end of these tests then serve as the base test and is representative of the general trends that can be expected to occur in the prototype from no imposed future changes, including dike construction or changes in bankline alignment. This base test then serves as the comparison for all future design alternative tests.

to what? How do you know the starting point?

How is stability determined in the micro-model?

8 **Model Sediment.** If scaled to prototype dimensions, the average size of the sediment used in the micromodels and WES models would translate into approximate diameters of 2 to 4 feet in the micromodel and approximately 1.5 to 9 inches in the WES Models. The plastic bed material used in the micromodels, with a SG = 1.47, has resulted in average slopes to be about 0.01 ft/ft. The crushed coal used in most WES models had a SG = 1.3, but the slopes use for these models are unknown.

See Table B2 in Franco (1978). Total slopes varied .0003 to 0.0008

9 **Similarity of Friction.** The micromodel and the WES models include no provision for providing similarity in prototype friction (or roughness). This should be explained further for both the micromodel and WES model.

TP 44, pg 27 of Franco (1978). Operated WES models near critical tractive force or critical velocity. Accomplished using scaled slope & discharge relationship

10 **Composition of Model Dikes.** In the micromodel, dikes, weirs, and other rock structures were initially represented by thin-walled sheet metal. From flume experiments conducted in 1998, porous thin-walled steel mesh structures were eventually used to minimize scour to simulate more realistic depositional patterns around structures. These porous structures solve the problem of exaggerated scour around dikes that occur in most distorted models (Figure 2-15). One of the most important aspects of the micromodel is the ability to make qualitative predictions on the effects of training structures on the bathymetry or sediment response of a river or stream. The present methodology of achieving this response involves the use of porous structures in the model in the form of steel mesh. The porosity of these mesh structures is critical for reducing turbulent effects and provides a corresponding reduction in shear stress at the model bed.

In the WES models, solid, non-porous structures in the form of concrete, pea-gravel, or thin sheet metal were predominantly used. No information has been found on the study of these type structures on the model bed response.

See TP 25 in Franco (1978). Also TP's 85 & 86.

Excessive, local scour at the streamward end of dikes was not uncommon due to inability to reproduce size distribution, particularly coarser-grained material in bed. See Nickles (Loosahatchie - Memphis study, 1990) pg. 5 on verification.

Figure 2-15~~16~~: Exaggerated Scour Pattern Around a Non-Porous Dike in a WES Model

11. **Time Scales and Sequencing.** In the micromodel, hydrograph duration is usually on the order of 5 to 15 minutes. Hydrographs are usually run in succession until bed stability is observed. Thus, one particular model test may employ 4 or 5 successive hydrographs equaling 1 hour in total duration based upon whether the model bed response has completely or fully developed. In the WES model, durations of individual hydrographs were as long as 40 hours and were sometimes run multiple times without re-molding the bed. Equilibrium of sediment transport (the amount of sediment placed in the upper end of the model should be equal to the amount of sediment discharged out of the lower end of the model) is a key factor in both modeling methodologies. In either method, the time in the model was not used for the purpose of predicting the bed response time in the prototype.

12. **Relative Depth of Model Bed Within Flume.** In the micromodel, the bed is allowed to move freely in the vertical direction because of adequate vertical flume dimensions relative to model scale. In the WES Models, the bed was restricted in its vertical movement because of the minimal vertical dimensions provided by the flume. The unrestricted depth was based upon space considerations and the cost of constructing a deeper concrete flume. Many times the modelers would have to contend with scour patterns that extended onto the concrete floor of the flume. This would sometimes cause other problems to the model study in the downstream direction.

Gross exaggeration. In reality this was a very unusual case. In model design we reviewed prototype data, took the deepest prototype elevation and set the model such that the flume or model bottom 6-12 inches below this.

13. **Erosion Resistant Materials.** In the both the micromodels and the WES models, various materials have been used to represent erosion resistant material in the prototype, including clay, screen, and pea gravel. In the WES

models, a variety of non-porous materials were used to represent rock structures including concrete, sheet metal, and pea gravel. Knowledge of where these areas exist in the prototype and to what extent has always been a major challenge to the modeler. Most of the time, reliable data depicting erosion resistant materials in the prototype does not exist and is too expensive to collect. Therefore, it is usually the modelers judgment that determines where to locate such material within the model.

14. **Details in Design Alternative Effects in Dikes called out in the Model.** In both the micromodels and the WES models, various details in the relative effects of dike alternative plans as compared to the base test were called out in the model study. Details such as incremental changes in length, height, and angle were tested, and the relative effect of these measures on the bed and sometimes the flow response as compared to the base test were described in both models.

15. **Flow Visualization.** As discussed previously, time-exposure or time-elapsed photography to capture and examine general surface flow trends has been used in both modeling methodologies.

1.2. MICROMODELS CONTRASTED WITH OTHER LOOSE-BED MODELS

At this point, if the team decides to contrast the micromodels with other loose-bed models beyond the WES models, we should be specific about what type models we are contrasting them with. This means documenting how these models operate and what kind of problems they are attempting to solve. Since these models apparently are individually different, do all of them deserve to be generically lumped together? In addition, how extensive are each of these models being used…hundreds of time per year, once per year?, ….for example, if a particular model in Canada followed strict similitude criteria, but was used only once in the last 5 years, this should be called out…..please be more specific. Reading the thesis, only the relative theory of the methodology is discussed, but a description of the operations of the models and how they were used is lacking. The contrasting of other models is also needed. This section will be much reduced if the suggested section (MM contrasted with WES) is added, but there are other differences for the non-WES large-scale models as well.

1:600. Volumetrically, the WES models are approximately 16 million times smaller than the prototype and approximately 3000 times larger than the typical micromodel.

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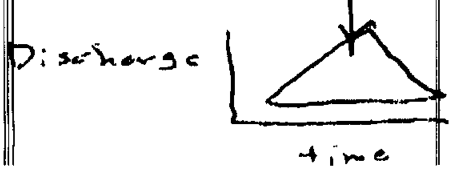

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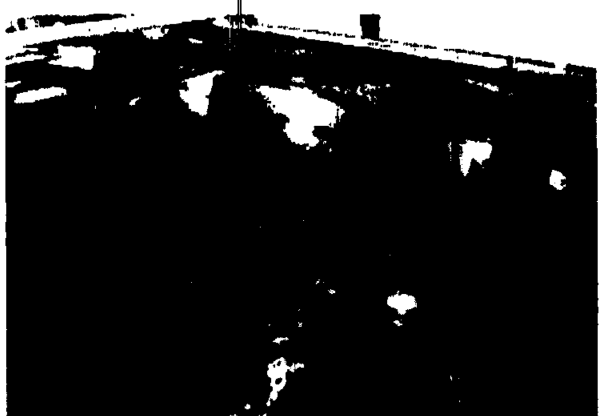

Figure 2-1414: Steel Mesh Roughness in Overbank Areas (Flow Patterns are Shown in the Main Channel.)

bathymetry consistent with the most recent hydrographic survey information at the time of the model study. However, while the WES model must be continually remolded, the micromodel bed forms are allowed to re-adjust naturally. In both models a comparison is made of the resultant ending model bed versus the prototype bed, and by observation, if the beds are similar, the model is declared verified or calibrated. The WES model methodology contains an additional step whereby a base test is established by running successive average annual hydrographs until bed stability is reached. This is accomplished in the micromodel during model calibration. In both models, the bed configuration at the end of these tests then serve as the base test and is representative of the general trends that can be expected to occur in the prototype from no imposed future changes, including dike construction or changes in bankline alignment. This base test then serves as the comparison for all future design alternative tests.

8. **Model Sediment.** If scaled to prototype dimensions, the average size of the sediment used in the micromodels and WES models would translate into approximate diameters of 2 to 4 feet in the micromodel and approximately 1.5 to 9 inches in the WES Models. The plastic bed material used in the micromodels, with a SG = 1.47, has resulted in average slopes to be about 0.01 ft/ft. The crushed coal used in most WES models had a SG = 1.3, but the slopes use for these models are unknown.

9. **Similarity of Friction.** The micromodel and the WES models include no provision for providing similarity in prototype friction (or roughness). This should be explained further for both the micromodel and WES model.

10. **Composition of Model Dikes.** In the micromodel, dikes, weirs, and other rock structures were initially represented by thin-walled sheet metal. From flume experiments conducted in 1998, porous thin-walled steel mesh structures were eventually used to minimize scour to simulate more realistic depositional patterns around structures. These porous structures solve the problem of exaggerated scour around dikes that occur in most distorted models (Figure 2-15). One of the most important aspects of the micromodel is the ability to make qualitative predictions on the effects of training structures on the bathymetry or sediment response of a river or stream. The present methodology of achieving this response involves the use of porous structures in the model in the form of steel mesh. The porosity of these mesh structures is critical for reducing turbulent effects and provides a corresponding reduction in shear stress at the model bed.

In the WES models, solid, non-porous structures in the form of concrete, pea-gravel, or thin sheet metal were predominantly used. No information has been found on the study of these type structures on the model bed response.

Figure 2-15~~16~~: Exaggerated Scour Pattern Around a Non-Porous Dike in a WES Model

11. **Time Scales and Sequencing.** In the micromodel, hydrograph duration is usually on the order of 5 to 15 minutes. Hydrographs are usually run in succession until bed stability is observed. Thus, one particular model test may employ 4 or 5 successive hydrographs equaling 1 hour in total duration based upon whether the model bed response has completely or fully developed. In the WES model, durations of individual hydrographs were as long as 40 hours and were sometimes run multiple times without re-molding the bed. Equilibrium of sediment transport (the amount of sediment placed in the upper end of the model should be equal to the amount of sediment discharged out of the lower end of the model) is a key factor in both modeling methodologies. In either method, the time in the model was not used for the purpose of predicting the bed response time in the prototype.

12. **Relative Depth of Model Bed Within Flume.** In the micromodel, the bed is allowed to move freely in the vertical direction because of adequate vertical flume dimensions relative to model scale. In the WES Models, the bed was restricted in its vertical movement because of the minimal vertical dimensions provided by the flume. The unrestricted depth was based upon space considerations and the cost of constructing a deeper concrete flume. Many times the modelers would have to contend with scour patterns that extended onto the concrete floor of the flume. This would sometimes cause other problems to the model study in the downstream direction.

Gross exaggeration. In reality this was a very unusual case. In model design we reviewed prototype data, took the deepest prototype elevation and set the model such that the flume or model bottom 6-12 inches [illegible] this.

13. **Erosion Resistant Materials.** In the both the micromodels and the WES models, various materials have been used to represent erosion resistant material in the prototype, including clay, screen, and pea gravel. In the WES

models, a variety of non-porous materials were used to represent rock structures including concrete, sheet metal, and pea gravel. Knowledge of where these areas exist in the prototype and to what extent has always been a major challenge to the modeler. Most of the time, reliable data depicting erosion resistant materials in the prototype does not exist and is too expensive to collect. Therefore, it is usually the modelers judgment that determines where to locate such material within the model.

14. **Details in Design Alternative Effects in Dikes called out in the Model.** In both the micromodels and the WES models, various details in the relative effects of dike alternative plans as compared to the base test were called out in the model study. Details such as incremental changes in length, height, and angle were tested, and the relative effect of these measures on the bed and sometimes the flow response as compared to the base test were described in both models.

15. **Flow Visualization.** As discussed previously, time-exposure or time-elapsed photography to capture and examine general surface flow trends has been used in both modeling methodologies.

1.2. MICROMODELS CONTRASTED WITH OTHER LOOSE-BED MODELS

At this point, if the team decides to contrast the micromodels with other loose-bed models beyond the WES models, we should be specific about what type models we are contrasting them with. This means documenting how these models operate and what kind of problems they are attempting to solve. Since these models apparently are individually different, do all of them deserve to be generically lumped together? In addition, how extensive are each of these models being used…hundreds of time per year, once per year?, ….for example, if a particular model in Canada followed strict similitude criteria, but was used only once in the last 5 years, this should be called out…..please be more specific. Reading the thesis, only the relative theory of the methodology is discussed, but a description of the operations of the models and how they were used is lacking. The contrasting of other models is also needed. This section will be much reduced if the suggested section (MM contrasted with WES) is added, but there are other differences for the non-WES large-scale models as well.