B-3

JOINT VENTURE TEAM/GAINES

PRELIMINARY DRAFT

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INTRODUCTION

Over the years, there has been a large amount of criticism aimed at micro model methodology. Many of the critics have been experts familiar with typical hydraulic models that do not account for sediment transport. Therefore, their critique is directed at similitude criteria and typical parameters used in quantitative hydraulic modeling. However, the focus of all movable bed models is sediment transport and its pattern of formation in an alluvial river channel. These models are always considered qualitative. These same critics also state the micro model is unable to be used to design river training structures. Whether or not this is a true statement, there are no models or other tools and guidance available to the engineer for designing these structures.

The overall knowledge of sediment transport is very limited. There are no equations or models that can accurately predict sediment transport rates or the resultant bathymetry of a river. Therefore, what guidance does the engineer have when designing river training structures? Traditionally, the only tools available were experience, intuition, and the large physical models. Today, the micro model is the only additional tool available.

The micro model is used mainly for qualitatively studying the relative effects on the riverbed imposed by alternative designs. Many other tools are available for studying other types of problems, such at stage-discharge relationships. A complete study of rivers and their morphology require many different tools in which the user must also account for a vast array of interrelated parameters. The micro model is a dedicated tool for the use of studying changes of in channel bathymetry. This model, like all other models, can only be as useful as the knowledge of the modeler. Any problematic reach of river requires the river engineer or designer must be experienced to design the proper solution, whether or not a model is used.

Ettema (in his initial evaluation) states: "Micro-models have their place as a **design aid** for river engineering." He also states "As with all hydraulic models, the bottom line for micro-models is that the limits of their applicability fundamentally depend upon the extents to which they meet similitude considerations and on the level of risk the model user is prepared to assume." This risk is also assumed during the design of river training structures without a model. The risk the modeler takes is considerably less than the risk river engineers normally assume when most river training are designed. These structures are usually designed without the aid of models as well as any other quantitative tools. The design process consists of a team of river engineers using just their experience and intuition along with a limited amount of data to come up with a completed design. There are no equations or specific guidelines to follow.

It should always be considered that in the field of engineering it is better to have a bad tool and good judgment rather than a good tool and bad judgment.

Discuss - Steve's 4 Levels of modeling (in order of increasing complexity)

1. Demonstration
2. River engineering qualitative
3. River engineering quantitative
4. Flow fields and navigation

There are no quantitative sediment transport/river engineering models. Even #4 is qualitative.

TYPICAL RIVER ENGINEERING DESIGN

The design of most river training structures are conducted by experienced river engineers without the use of any sort of model. The data used for design normally includes bathymetry and aerial photography. Sometimes flow data is obtained, such as velocity vectors from ADCP or ice data. However, most designs are initiated without the use of equations or any other quantitative or numerical aids. It is the experience and intuition of a team of river engineers that usually decides upon an initial concept as well as the final design that is eventually constructed in the river. It is estimated that 95% of the river training structures that are constructed in the river contained zero quantitative analysis or model study during the design phase. Most designs originated from empirical analysis by the designers.

USE OF PHYSICAL SEDIMENT TRANSPORT MODELS (PAST & PRESENT)

Traditional movable bed models have always been considered empirical in their operation and design ability. That tradition continues with the use of the micro model.

Discuss Ettema's two model studies.

Many times MBMs are used as a type of insurance to the engineer. They allow the user to first test a design in the protection of a laboratory setting without the risk of failure in the natural river environment. The model can give a design team additional confidence than just using their experience and intuition. For example, the original contract designer of the Big Creek project (discussed later in this report) suggested that a 50-foot dike would solve the problem. However, the model suggested that a 25-foot dike would achieve the desired results and would therefore be the more economical solution.

The micro model, as with all types of models, requires that the operator be experienced in the field of physical sediment transport modeling as well as a qualified river engineer.

Models simply help the river engineer and associated team members formulate plans and conceptual designs through a number of meetings and experiments.

A model provides a means of studying and understanding the morphologic characteristics of a reach of river through the investigation of the data available and through the workings of the model. The model and data tend to complement each other and afford the modeler as well as others a greater clarity of the reach dynamics and characteristics.

Explain the range of uses the micro models have been used for in the past and how the model was utilized to study and design a solution. Provide a detailed description of each model study that MVS has conducted.

Similarity Relationships
Comments

Model Distortion
Typical distortion in the micro model ranges from 6.0 to 20.0. Distortion in the large models ranged from 1.2 to 10.0. Therefore, there exists overlap.

> I was looking in the WES study "Model-Prototype Comparison Study of Dike Systems" and I noticed that the distortion ratios were higher than most of their models because of space limitations. They were 10.83, 10.0, 9.0, 6.0, 8.0, 10.0, and 6.67. Have you included these in your analysis? If not, we need to find a way to fit this in. I believe that these are out of the range of typical large models. This would be great data to include. What are distortions limited to in these models? From Steve's report I assume 6.0 (see page 4, item 2). From 10/22/01 email to Andy

Qualitative or Quantitative
All models are qualitative and are used to make quantitative decisions.
All models are quantitative and are used to make qualitative decisions.

As explained previously, most dikes, weirs and river training structures are designed using the strictly qualitative approach of pure experience and intuition. However, this approach translates into a dimensional design during this process without any quantitative analysis.

Therefore, there exists a gray area between qualitative and quantitative analyses and the subsequent design processes. In the field of river engineering, there exists an undefined and unclear point where a qualitative analysis must become quantitative. All sediment transport modeling overlaps this point. During a model study, the modeler must use quantitative reasoning to make a qualitative analysis. This is the only means of analysis. A completely qualitative or quantitative analysis does not exist. The human mind and model cannot function with one without the other.

In a sense the model is quantitative because exact measurements are recorded and studied. However, the modeler must examine this quantitative data and convert it into qualitative thoughts and analysis. Then the modeler must use this qualitative analysis to convert back to quantitative reasoning with further use of the model. The process is then repeated over and over. At some point during this process, a quantitative design solution must be extracted. Therefore, the points at which reasoning changes from quantitative to qualitative and back to quantitative occurs is blurred. This process not only occurs in the modeling process, but within any river engineering design process.

It is impossible to approach sediment transport and river engineering in a strictly quantitative sense. Every aspect of this field is truly qualitative because of what is currently known about the subject. (This topic could be compared to weather forecasting. A weatherman may tell you to expect strong storms tomorrow but that is only a qualitative prediction. He will also predict when a certain storm cell will reach an area, without any repercussions for incorrect predictions.) Therefore, the model must be considered quantitative. The analysis of the model by the modeler must be both qualitative and quantitative. The final design solution recommended by the modeler must be quantitative. Therefore, the modeler or the designer must be the one to recognize the differences and select the times at which to use each type of analysis.

Model Calibration (to stable bed conditions)
The larger traditional models used at WES were calibrated much differently than the micro model. **ROB TO EXPLAIN**

The micro model is calibrated using simple modeling concepts. The model is calibrated to prototype bed conditions using natural fluvial processes. The bed of the model is not molded what so ever. Therefore, when the modeler determines that the bed conditions formed by the model resemble those of the prototype, then the lateral velocity distribution that created the bed forms in the model should also resemble those of the prototype. It is this velocity distribution that creates and forms the bathymetry of both the model and prototype.

Need a write up on the calibration of the models using only plan view hydrographic surveys of the river and the model (ASCE paper – Andy is including in the report). (All the hydros and base tests will be included in the final report)

It is always better to obtain as much data as possible when modeling or working on any time of river engineering problem. However, it is not required that a certain type or amount of data be obtained due to funding or time constraints that are usually present. Historic data is usually extremely valuable, but depending upon the reach of river, it may not exist in multitude. This historic data is very useful at determining the general bathymetry trends in the river over time. A single hydrographic survey represents only an instant in the history of the riverbed. An analysis of a river using one survey is never recommended. By using numerous surveys collected over time, the engineer is able to detect if any one of surveys contains editing errors or to determine if it shows abnormal bed forms after an unusual hydrologic event. It is only possible to calibrate the model to stable bed conditions.

Average Hydrographs/Sediment Transport (Past & Present)
The models are calibrated to what are considered stable bed conditions. The stable bed condition is determined by studying several years of bathymetry. Under most circumstances, when the boundary conditions of the river remain unchanged, the bathymetry trends through time will be similar. If the river channel is subjected to extreme events, such as 500-year floods, excessive flood duration, drought, etc, an anomalous or unnatural bed condition may develop. However, over time, with fixed

boundary conditions, the general, stable bed forms will return. This is the condition that the model strives to simulate. The model does not try to replicate these extreme events (**this is a limitation**). Although, these events do affect the streambed, the time in which the event uses and the amount of sediment that is transported during these events are minuscule compared to the normal events, which ultimately shape the bed. (sediment graph from Rosgen's book, page 2-3, Figure 2-2.) The river channels studied by the micro models are not impacted or shaped by large flood events. The shape of the channel largely depends upon lesser flows and the dominant discharge.

Dr. Hey's book is a very good reference – pages 56 –63.

From Rosgen, page 2-3:
"A commonly accepted and universally applicable definition of bankfull was provided by Dunne and Leopold (1978): *"The bankfull stage corresponds to the discharge at which channel maintenance is the most effective, that is, the discharge at which moving sediment, forming or removing bars, forming or changing bends and meanders, and generally doing work that results in the average morphologic characteristics of channels."* It is this discharge in concert with the range of flows that make up an annual hydrograph which govern the shape and size of the channel. Bankfull discharge is associated with a momentary maximum flow which, on the average, has a recurrence interval of 1.5 years as determined using a flood frequency analysis (Dunne and Leopold, 1978). Although great erosion and enlargement of steep, incised channels may occur during extreme flood events, it is the modest flow regimes which often transports the greatest quantity of sediment material over time, due to the higher frequency of occurrence for such events (Wolman and Miller, 1960). An example of the relationship between flow magnitude and frequency of flow occurrence is shown in Figure 2-2. The dominant, effective or bankfull discharge is associated with the peak of cumulative sediment transport for a given streamflow magnitude and frequency of occurrence. The majority of work over time is accomplished at moderate flow rates as shown in Figure 2-2. The effectiveness of bankfull discharge and a discussion of dominant or effective discharge theory was presented by Andrews (1980).

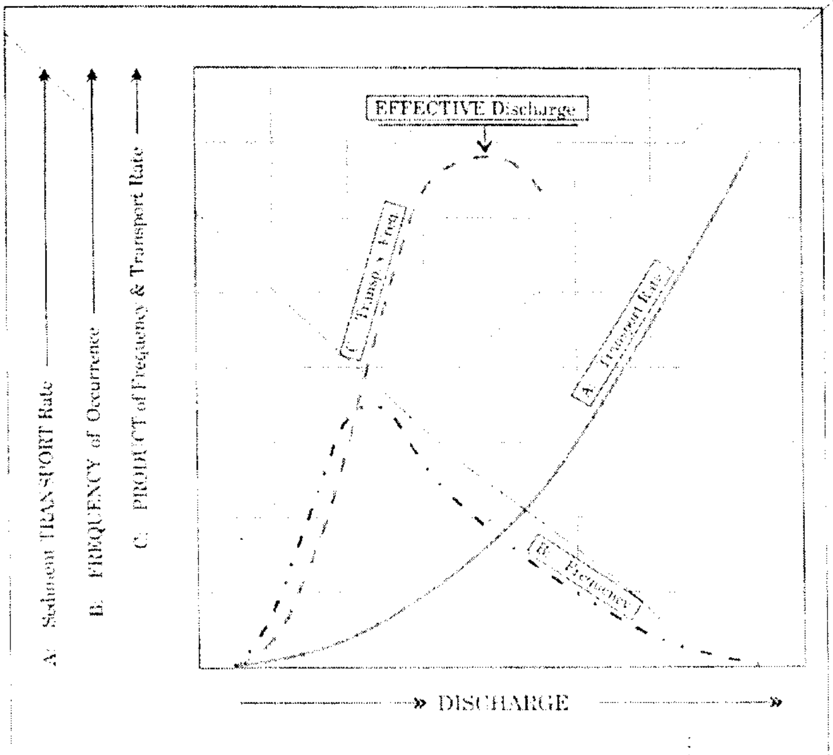


FIGURE 2-2. Relations between DISCHARGE, Sediment TRANSPORT Rate, FREQUENCY of Occurrence, and the PRODUCT of Frequency and Transport Rate. *(After Wolman and Miller 1960)*

Therefore, could any model simulate the sediment transport and abnormal resultant bed forms of a major flood event? Could a model such as the Kate Aubrey WES model simulate the bed forms created by the major floods of the 1970's? Without the knowledge of the sediment transport rates during this event it not possible to simulate the bed formations that developed. If these floods were not channel forming and were only temporary conditions, then the river would have eventually resolved the problematic bed forms naturally and returned the channel to its pre-flood bathymetry. Therefore, the major mid channel shoaling problem created by these floods could have been solved with just a dredge cut. The model should have dealt with the stable bathymetry that was evident before the floods. It may have been detrimental to the design implementation in the reach to have calibrated the model to unstable bed forms that were not representative of normal conditions. Therefore, it could be considered that the model was never even calibrated to the proper conditions.

Constrained Thalweg & Principle Degrees of Freedom

Gaines states: "Three principle freedoms are apparent from observation of most streams: adjustment in channel depth, adjustment in alignment, and adjustment in cross-section shape. The successful prosecution of a physical sediment model entails reproducing these natural adjustment tendencies. However, owing to the high degree of complexity and most unknown processes associated with lateral channel adjustment, such models typically employ a rigid (or nearly so) planform whereby meander migration and bank progression are restricted. Thus, the thalweg is constrained to the confines of the channel banks which limits channel response by one degree of freedom. Where river training structures exist, a further reduction in thalweg positional freedom occurs, and in the extreme case, the channel behaves as a constricted reach with limited potential for adjustment of thalweg position. Distortion of various model parameters (i.e., vertical scale, slope, and roughness) may result in further constricting effects. The consequences of constricting the thalweg's ability to shift in response to water and sediment may pose problems in achieving successful model results. Because thalweg alignment is often a key component of physical sediment model studies, a reduced ability of the thalweg to move may create difficulties in model calibration and in applying model results to the prototype. This is especially true for the small-scale models described by Davinroy (1994, 1999) and Gaines and Maynord (2001) where the primary objective is to estimate the position and number of flow training structures necessary to constrain the channel thalweg alignment and its concomitant depth.

The thalweg position is a factor of the boundary conditions upstream, which if these remain unchanged the thalweg should not adjust. The statements appear to confuse the constraints in thalweg position with a meandering channel. Even in a channel with rigid banks the thalweg is free to shift its position if changes occur in the planform or boundary conditions upstream. Boundary conditions include both banklines and river training structures. The lateral movement of a meandering channel could be considered a fourth degree of freedom. Any model would have extreme difficulty reproducing this fourth degree of freedom. A naturally meandering channel is impossible to model due to differences in the erodibility of the materials in the bankline. However, the micro model has been used successfully to consider thalweg adjustment within the channel planform using river training structures. The thalweg of the Mississippi River, which includes thousands of river training structures, has shown the ability to adjust its position within the current channel planform given a change in a dike field. It is a rare occurrence when a thalweg meanders in a stable channel without the boundaries or banklines changing.

The Big Creek model, discussed in the Case Studies, disputes the previous statements by Gaines. Many other studies also dispute this. Discuss

Velocity Distribution

The flow patterns of any given river would change dramatically and substantially if its bathymetry were converted to a flat bed fixed channel without bed load.
Discuss the Bendway Weir model currently in use at WES.

Discuss Distorted Velocity Distribution – The vertical component is distorted; however the lateral component is not. If it were then the bathymetry would not be correct.
[illegible] consist of [illegible] of [illegible] data for a crossection in the prototype and [illegible] respectively.

Discuss the calibration of many of WES's fixed bed velocity models – the fact that flow data was not used for calibration, only stage discharge relationships.

Comment on UMR and IIHR Flume experiments

Although there are similarities in that the micromodel exhibits several high velocity cells across the channel, the lateral distribution is different in the MM than shown in the prototype data. Davinroy (1999) shows the highest velocity cell at a distance of ~ 250 ft. The highest velocity cell in the P occurred at a distance

Flow Visualization (WES & Micro) (Vicksburg)

Need write up of flow visualization in micro models and WES models – Rob D – Greenville Bridge & St. Louis Harbor (two photos at the same stage show different pathlines). Many of the large model studies state as a purpose the evaluation and improvement of channel alignment and navigation conditions (from Steve's Blue Report). Does this mean that flow patterns were evaluated?

Flow Visualization. Flow visualization of the model is used as a means to qualitatively evaluate the main concentration of flow patterns in the model. It is not used to measure velocity magnitude or detailed velocity information locally, but rather to examine the relative flow paths over a relatively larger area.

The flow patterns in the images captured by flow visualization techniques are never exactly alike, although their trends are similar. A representative picture is usually chosen for the study report after all the pictures are examined for general trends. The general analysis of flow by the modeler includes all the pictures and the identification of trends based on all of the pictures. Ideally, the pictures would be combined if possible for the greatest summary of flow trends.

The model was used in the following manner at Vicksburg, Morgan City, LD 24..anywhere else? Savannah Bay????

Flow visualization was used by WES in movable bed models as well. Figures XX an XX show this.

In the St. Louis Harbor Model, a series of Bendway Weirs were placed

Vicksburg Front Micro Model Flow Evaluation

- 6 foot depth of Droan, is this a factor?
- If GPS accuracy is only 1 meter, then velocities cannot be computed.
- How many droans were tracked? Did any of their flow paths cross? If they did, why? What would happen if a droan were started from the same location repeatedly? Would it follow the same path repeatedly?
- Is there enough data here to make accurate conclusions?
- Are the flow visualization streak lines correctly delineated? Flow visualization images are never exactly alike, although their trends are similar. A representative picture is chosen for the study report after all the pictures are examined for general trends. The general analysis of flow by the modeler includes all the pictures and the identification of trends based on all of the pictures. Ideally, the pictures would be combined if possible for the greatest summary of flow trends.
- Why do the flow visualization patterns and the PIV streamlines not match?
- Are the PIV methods and analysis correct?
- Why are the velocities constant across the channel within the bend as shown by the droans paths? This can't be correct, especially over the middlebar.
- ADCP data at a +20 stage is needed to compare to the velocities from the droans.

- Need to have a write up on the LD24 study before and after dike construction.
- What is the difference in the bathymetry between all the micro model tests and field measurements? It must be constant to make valid conclusions.
- Fig 18, p40 of Ettema's paper shows slight but meaningful differences between the path of the Droan and the PIV streamlines. Why the difference? This must be accounted for.
- What is the point of presenting this at a conference, especially before our final report is published? This is only one small piece or a much larger puzzle. It is only one study and conclusions about the validity of all models cannot be based on this one study – good or bad.
- Why would one Corps entity criticize the study and report of another entity? What would the Vicksburg District think of this criticism?
- If broad conclusions on the validity of flow visualization in the micro model cannot be made using this one study, then why should this analysis be presented in this report or at a conference?

Any study, no matter how detailed or justified, can be dissected and picked apart by a critic.

Dikes in the Model

DIKES, IMPERVIOUS (WES) & POROUS (AREC)

INCLUDE U OF I FLUME EXPERIMENTS

Need a write up on the dikes used in micro models and what their purpose is in relation to the actual river. Compare these structures to the solid dikes used at WES – use picture of dike exaguscour at WES. The model simulates similar scour depths to the prototype through the use of porous dikes. This, combined with a movable bed, minimizes the exagurated scour created by non-porous, solid dikes historically used in large scale models. The porosity of the dikes simulates, or scales proportionally, the roughness created by dikes in the prototype. The dikes also simulate the properties and bed patterns created by the overtopping of dikes in the prototype. The models are meant to study the resultant bed configuration created by a certain set of boundary conditions, including the location of dikes.

The modeler strives to simulate the bathymetry of the prototype within the model to best of his ability using the data that is available (mainly bathymetry). If scour depths and lateral extent of the scour created by dikes is exaggerated in the model, than calibration has not been achieved. It is the modeler's responsibility to control scouring during the calibration phase. If the scour depth, location, and extent are similar to the prototype, the flow fields in the vicinity of the structure should be similar.

Based upon fixed flume work of the University of Iowa, the use of the micro model in reinforced by the observations of impervious and porous structures. The experiments showed that impervious structures distort the near flow field. However, this effect can be dampened by the use of porous structures, which are in use in micro models. At AREC, observations show that the resultant bathymetric response in the model compared to a prototype reach proves that porous structures in the model simulate the effects of structures in the prototype. The porous structures provide a scaled roughness value that allows the bed to react similarly to that of the prototype. The three dimensional response around and over these structures is comparable to the response created by solid rock structures in the prototype.

Using the model, dikes can be designed to an approximate elevation. During calibration, the existing dikes are set in the model according to their actual elevations using the vertical scale and shift. Dikes in the alternative designs are set relative to the other structures in the model. Therefore, an approximate elevation may be attained. If the dikes in the model are not set to their proper elevations, then the model will not respond correctly and will not calibrate.

Whenever a side channel is modeled with a closure structure at its upper end it is imperative that the stage exceeds the height of the closure. These structures are always relatively placed in the model at the elevation they are located at in the prototype. However, this elevation is adjusted during the calibration process when the scale or shift changes. Sometimes, the bed of the side channel partially develops without the closure in place because it is realized that much of the bed in the prototype chute was formed before the closure structure was built. Most of the closure structures on the Middle Mississippi River are lower than an elevation of +20, or 2/3 bankfull. Most of the structures designed using the model have also been lower than this elevation.

Scour Effects on Movable Bed Models (Rob writeup).

One of the most important aspects of the micro model is the ability to make qualitative predictions on the three-dimensional effects of dike structures on the bathymetry or sediment response of a river or stream.

The present methodology of achieving this involves the use of porous structures in the model in the form of steel mesh. The porosity of these mesh structures enables a relative lowering of the hydraulic roughness and conversely a reduction in force and shear stress applied to the model bed. In this way, a favorable scour and depositional response can be achieved on a micro scale.

In the early years of micro modeling development, rock dikes were represented in the model by using non-impervious sheet metal (.01 inch). The use of solid structures in the micro model was based upon observing the use of solid structures used extensively in the movable bed models conducted at WES.

In our experience with the WES models, two types of material were used to represent dikes, sheet metal and a cement-pebble conglomerate (Figures 1 and 2). In many cases, the response of the bed observed around these structures was not representative of what was occurring in the river. Figure one shows excessive scour around sheet metal structures and rock structures tested in the

St. Louis Harbor model. In both cases, scour was so great that the bottom of the concrete flume was exposed. Once the flume bottom was exposed, the end result was armoring of the bed and an additional unrealistic bed response.

For typical dikes, an exaggerated response was observed in many dikes, as the scour hole off the end of the model dikes wrapped around and upstream of the structures. This was exactly opposite of what is observed in the river. Typically, deposition is observed directly upstream of the dikes...got and example, perhaps in Harbor or Dogtooth Bend model?

This was also evident with other structures, including Bendway Weirs. Figure 3 is a close-up of the sediment response around the weirs in the Dogtooth Bend Model. In all tests, the inside scour occurring off the ends of the structures was so exaggerated that the bottom of the concrete flume was exposed. The end result was an unrealistic bathymetric response as compared with the prototype. Figure XX is a comparison of the model bathymetry to the river bathymetry. Notice the unsimilarity of the bed response. The bed is extremely exaggerated in the case of the model.

These type problems were noted early on with the development of the micro models, including the work done at Rolla on the original thesis. At first, as in the case of the WES models, the exaggerated scour of the models was accepted as a limitation of the model, with the underlying philosophy that as long as changes in the thalweg could be observed, one could still make general conclusions about the effectiveness of dikes in the model. Later, however, through flume experimentation, porous structures proved to be much more realistic and effective in mimicking the bed response of solid dike structures observed in the river. Give and example.........what would the bed look like without the change?

ANALYSIS OF CROSS SECTIONAL DATA

Need write up on cross sectional analysis

Prototype Variability

Key Water Surface Elevations & Truncation

Expand upon Andy's write ups: Refer to his excel Kate Aubrey graph

The comparisons of cross sectional area of the river bed calculated extremely low elevations should not be used extensively to analyze the performance of any MBM. Cross sectional areas should always be calculated from a top of bank elevation, which is a standard parameter with which most rivers are studied and compared. This analysis included calculation based upon an elevation that is assumed to be an extreme low water event (0 feet LWRP). The stage elevation that corresponds to a channel forming discharge should be considered the appropriate level at which to calculate cross sectional area (at least +30 feet LWRP for the Mississippi River). From Rosgen, page 2-2: "Stream dimensions, patterns and bed features associated with the longitudinal river profile are generally described as a function of channel width measured at the bankfull stage. Since streams are self-formed and self-maintained, it is important to relate measurable features one can identify in the field to a relatively frequent, bankfull discharge."

By studying differences in area between the model and the prototype using calculations at low elevations results in artificially higher discrepencies. The lower the elevation that is used to calculate differences in cross sectional area, the more inflated the errors become. An example analysis included an area comparison between a hypothetical model and prototype cross section. The sample cross section consisted of a square bottom channel with an overall width of 2000 feet for both model and prototype, a prototype depth of −15 feet LWRP and a model depth of −17 feet LWRP. Calculations of cross sectional area below elevations of 0 feet LWRP (low flow) and +30 feet LWRP (top of bank) was made. The resulting difference in cross sectional area between model and prototype below +30 feet LWRP is 4.4%. By contrast the difference in area between model and prototype below 0 feet LWRP is 13.3%. Presentation of the value of 13.3% difference in cross sectional area between model and prototype to the engineering community would almost certainly cause the perception that the model differs more greatly from the prototype than was actually the case.

The calculation of cross sectional area below an elevation of 0 feet LWRP in the Clarendon reach results in one of highest values of MSE. However, calculating the area from an elevation of +20 feet LWRP results in a near median value of MSE. This is because the reach is in a relatively shallow river where depths are regularly near −10 feet LWRP. Therefore, calculations based upon an elevation of 0 feet LWRP results in extremely exaggerated errors, especially in the shallower areas.

MODEL CONFIDENCE

Confidence in a model comes from the modeler's confidence in understanding the reach of river under study. If the reach is highly variable or if current construction has destabilized the river then the modeler cannot have much confidence in understanding the mechanisms at work in the channel. The model is a tool which helps the modeler understand the dynamics in the reach. This learning process takes place mainly during the calibration phase when the modeler works with the model to achieve bathymetry trends similar to those of the prototype. By modeling the sediment transport and trying to get the model to form the appropriate bed conditions, the model learns dynamics at work in the river. Without first this understanding, the model is useless. The experience the modeler builds while working with and studying a reach of river is priceless. For example, it would not be recommended that one modeler calibrate the model while another modeler tests design alternatives after calibration. The intimate knowledge of a river reach that a modeler gains during calibration builds confidence in the modeler's recommended design alternative. Therefore, it is the modeler that must have the experience and judgment necessary to effectively operate a model. The model is the tool with which the modeler uses to study a reach and recommend a remedial design. If the engineer does not have the tool available than his past experience will have to do to design a solution to a river engineering problem. This is often the case. Therefore, the model is necessary to build his/her confidence.

MODEL RESULT INTERPRETATION

Model results can always be misinterpreted. This goes the same for any data set. It all depends upon the user's experience and judgment.

It has been stated that the results of the model are vulnerable to attack by critics because the study is well documented in a published report. It was further stated that if an accident, possibly resulting in loss of life, occurs in a reach where a model has been used to evaluate design alternatives, that experts from around the country would line up to dispute the models value and worth for such an evaluation. However, most structures on the river are designed with no such tool or method. How the designs were initiated in these cases is never documented (for example: the weirs at the head of the canal). Who or what would be responsible in the case of an accident? Should the results of the study not be documented? If the design of all other river engineering structures is not documented, then why should the designs from the model be documented? Is this a case of too much documentation is negative from a legal point of view?

Comments on Expert Opinions

CASE STUDIES

Unfortunately, there are few examples of designs initiated by the micro model being constructed in the actual river. There are two main reasons for this. First, the technology was just recently developed. Secondly, funding constraints have prevented many of the projects from being started or completed as designed. Therefore, it is difficult to describe the model's accuracy of predicting the bathymetry and flow patterns after a structure that was tested in the model is constructed in the river. Of the 20 model studies conducted by the St. Louis District, only 5 designs have been constructed. However, only one of these designs can be fully evaluated. The four others either have not been fully constructed as designed or have just recently been built. Therefore, a fair evaluation of the model's performance in each of these studies cannot be made. However, a limited evaluation of post construction conditions follows.

Case Study 1: Big Creek Micro Model Study Results

Portions of the following taken from:

Gordon, D.C., Davinroy, R.D., "Bridge Abutment Erosion Problem Solved with a Small Scale Physical Sediment Transport Modeling Approach," 7th Federal Interagency Sedimentation Conference Proceedings, 2001.

Introduction

The Big Creek micro model study was initiated in 1995 and the structure that was designed during the study was constructed in 1997. Therefore, after nearly five years, a reasonable assessment of the project can be made. Unfortunately, due to the lack of prototype data before and after construction, a quantitative assessment is impossible. However, a qualitative assessment is described below through the use of numerous site visits and photographs of the reach.

Big Creek is a gravel bottom stream located in rural Lincoln County, Missouri, approximately 50 miles northwest of St. Louis. Shortly after a new bridge was constructed over the stream, an upstream lateral erosion problem developed that threatened the structure's abutments. Local reports indicated that the stream's bank erosion rate increased severely after the new bridge was built. The misalignment of the bridge opening in respect to the stream planform, and the constriction of the stream caused by the width of the bridge opening, had led to severe bank erosion problems both upstream and downstream of the bridge crossing. County officials worried that further high water events and additional erosion on the bridge abutments could cause a catastrophic failure to the structure.

In 1995, county officials sought the expertise of the U.S Army Corps of Engineers to solve the problem and preserve the structure. To address the problem and design a solution, the Corps of Engineers decided to use a micro model. This modeling technique allowed county officials and local farmers whose land was being affected by the erosion, to view the model and discuss possible remedial actions. The final design was the result of a cooperative engineering effort between the Corps of Engineers, Lincoln County Officials, and local landowners.

Through a cost share program in 1997, the Corps of Engineers and Lincoln County constructed a small rock structure in the stream to reduce the severe abutment erosion and realign the stream's thalweg. Since the construction of the small 30-foot rock dike, strategically located 600 feet upstream of the bridge, the river training structure has caused the thalweg of the stream to adjust and realign. The area of scour along the bridge abutment has been converted to a naturally depositional area. The vertically eroding bankline located upstream of the bridge has experienced a new growth of natural vegetation and begun to revert back to a more natural slope. The stream thalweg now makes a smoother, more natural transition through the bridge opening. Photos taken before and after construction show the dramatic changes in the river regimen.

Background

Big Creek is a typical meandering gravel bed stream found in the central Missouri. The bed material consists of mainly gravels, sands, and silts. Courser gravels and cobbles exist, although their quantity and occurrence is significantly less. The approximate physical stream parameters of Big Creek are as follows:

- Average Slope ≅ 6.4 ft/mile or 0.12 %

- Average Channel Depth at Bankfull Flow $\cong$ 10 feet
- Average Channel Width at Bankfull Flow $\cong$ 150 feet
- Average Width to Depth Ratio $\cong$ 15
- Deepest Channel Depth Encountered $\cong$ 19 feet

Problem Description

In 1995, Lincoln County highway commissioners presented to the U.S. Army Corps of Engineers a very common problem that faces many local governments. Big Creek was rapidly eroding a bridge abutment and the nearby banklines at a bridge crossing for rural County Highway 729. The abutment was in danger of completely failing and threatening the structural integrity of the bridge

Historically, Big Creek had been a somewhat stable stream. However, with increased runoff from land use changes that have occurred in the basin and channel constriction of the stream at the bridge crossing, the tendency for lateral bank erosion had dramatically increased both upstream and downstream of the bridge. The aerial photo in Figure 1 shows the degree of bankline erosion that has occurred. The lateral movement of the stream was more significant where adequate vegetation buffers were not maintained between the crop fields and the stream.

In the early 1990's, a new bridge crossing was constructed across Big Creek on Lincoln County Highway No. 729. The support for the 25 feet wide by 220 feet long concrete bridge consists of three sets of bridge piers and two earthen abutments. Since the new bridge was built, the stream channel upstream of the bridge had moved laterally in a southward direction approximately 100 feet. The lateral movement of the thalweg had caused a majority of the flow to be directed at the right descending bridge abutment. The scour experienced along this abutment had threatened the integrity of both the road and the bridge. Therefore, county road crews had to continuously repair this abutment for the temporary protection of the road and bridge.

The flow patterns through the bridge opening were orientated in a nearly parallel direction to the bridge crossing (Figure 1). Immediately downstream of the bridge opening, flow patterns were directed against the left descending bankline, threatening the left descending bridge abutment as well. Therefore, possible abutment failure existed on both the left and right descending sides of the bridge opening.

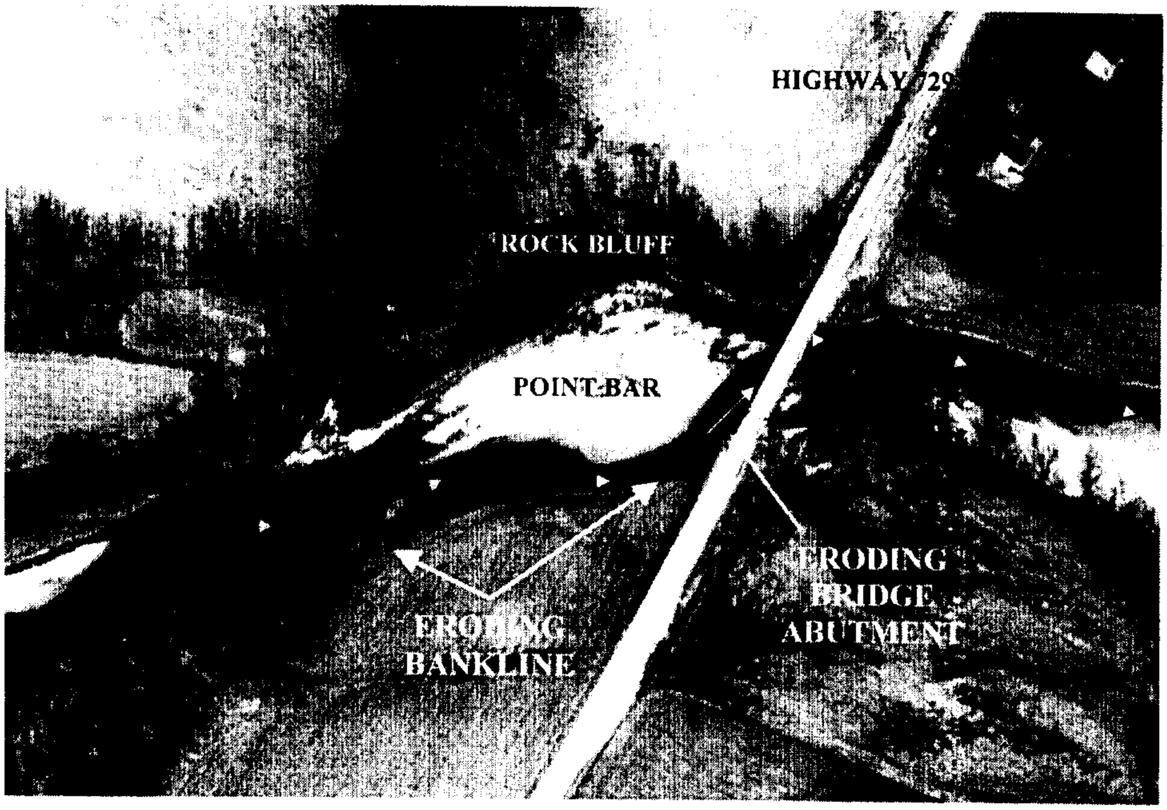


Figure 1 shows a complete overview of the study conditions. Conditions of the stream in the vicinity of the bridge crossing were described as follows:

- The right descending bankline was actively eroding and did not contain any sustained vegetation. This bankline feature extended from the bridge abutment to a point 500 feet upstream of the bridge.
- Both banklines at least 500 feet upstream of this bridge were heavily wooded and stable.
- A large point bar was located along the left descending bankline upstream of the bridge crossing. The size and rapid growth of the point bar was directly related to the migration of the right descending bankline. This depositional area indicated that the majority of flow was concentrated along the right descending bankline.
- The left descending bankline immediately upstream of the bridge was a wooded, natural rock bluff. This condition was evident to a point approximately 400 feet upstream of the bridge.
- The bridge crossing was severely misaligned with the thalweg of the stream channel.
- Downstream of the bridge, the right descending bankline was heavily vegetated. A small point bar was located along this bankline. The majority of flow was concentrated along the left descending bankline.
- The left descending bankline downstream of the bridge was vertical and devoid of any vegetation. This condition was evident from the bridge to approximately 700 feet downstream to a small outcropping of trees.

Approximately 100 feet beyond this bankline was the continuation of the rock bluff described upstream of the bridge.

The study was performed by the Corps of Engineers to address the existing sediment transport response occurring in the vicinity of the bridge crossing. This included investigating the bridge abutment erosion, the detrimental flow alignment through the bridge opening, and the excessive bankline erosion. The goal of the study was to develop improved flow conditions through the bridge opening and protect the bridge abutments through the use of channel regulation structures.

Big Creek Micro Model

The model used for this study was constructed according to the high resolution 1994 aerial photograph shown in Figure 1. The model employed a horizontal scale of 1 inch = 50 feet, or 1:600, and a vertical scale of 1 inch = 10 feet, or 1:120, for a 5 to 1 distortion ratio. This distortion supplied the necessary forces required for the simulation of sediment transport conditions similar to those of the prototype (Davinroy).

The micro model insert was constructed of water-resistant polystyrene and measured 6 feet long by 29 inches wide by 3 inches deep. The bed material used was granular plastic urea with a specific gravity of 1.4. The banks of the stream were formed with sheet metal inserts and the bridge abutments, dikes, and weirs were modeled with oil based clay.

In all model tests, the effective discharge or hydrograph was used. Each hydrograph was a repeatable triangular response representing low to high flows within the channel, with peak flow in the model representing top of bank flows in the prototype. The recurrence interval of bankfull flow in the prototype is approximately 1.5 years (Leopold). Stages in the model were recorded by both a staff gage and a digital electronic micrometer.

The calibration of the model involved the adjustment of water discharge, sediment volume, hydrograph time scale, model slope, and entrance conditions of the model. Several different physical combinations of these variables were tested to develop sediment transport conditions considered to be representative of those experienced in the prototype. Data available from the prototype used for the calibration process included surveyed cross sections, contours surrounding the bridge crossing, aerial photographs, and on-site field inspections. Once the favorable comparison of several surveys of model tests to field survey data was made, the model was considered calibrated. The calibrated bed configuration, or Base Test, served as the comparison for all future tests. This represented the average expected sediment response of the prototype over an extended period of time. Observations and data collected from the base test indicated that the flow lines and sediment transport trends of the model and the prototype were very similar.

Recommended Solution

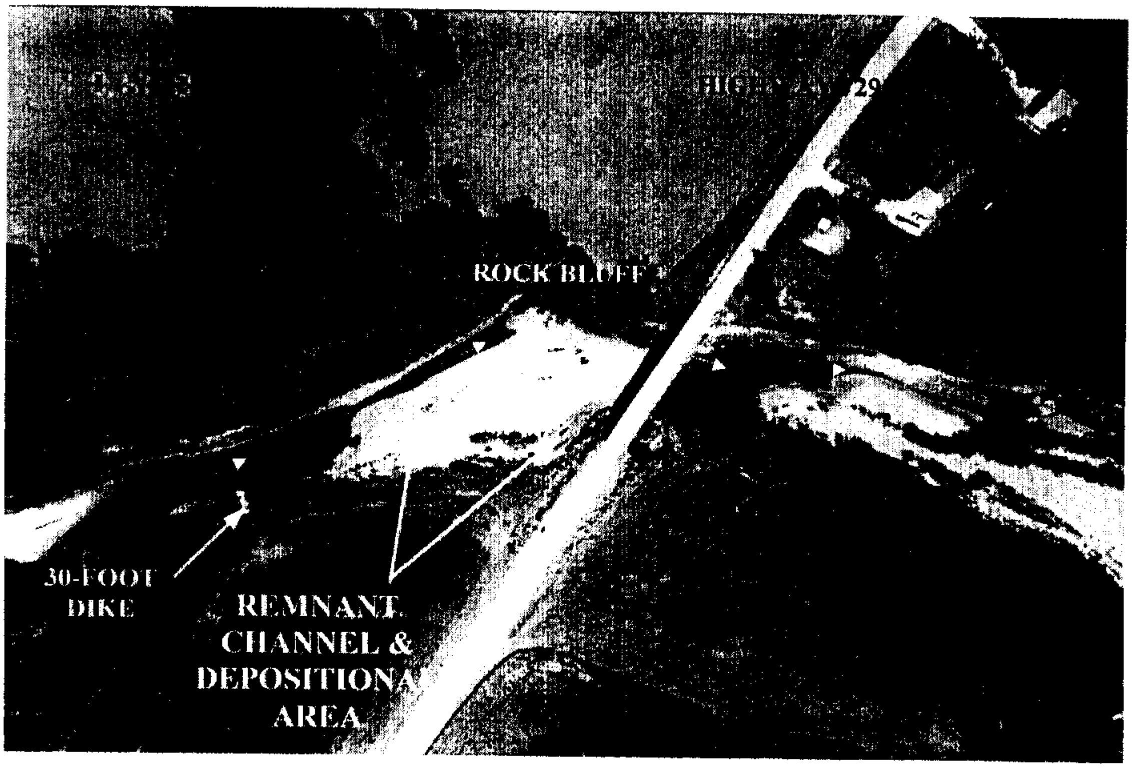
Several alternative design plans were tested in the model. The procedure for analyzing each alternative involved implementing the desired plan, running 5 consecutive design hydrographs, observing the sediment transport through the channel, and surveying the bed of the model. The micro model tests determined that the most cost-effective design solution to the bridge scour problem was the implementation of a level crested 25 foot long dike at elevation top of bank, strategically placed 600 feet upstream of the bridge on the right descending bankline. The model indicated that the structure redirected a majority of flow and shifted the thalweg toward the left descending rock bluff bank. The design also shifted the flow lines and the thalweg to a nearly perpendicular alignment to the bridge crossing which eliminated the scour against the right descending bridge abutment

The designers determined that a 30-foot long dike should be constructed in the river at the location specified by the model design alternative. The additional length was added to account for any stone launching off the end of the structure. The launched material would naturally armor the creek bed near the dike to reduce localized scour. The design also called for revetment to be placed on the right descending bankline upstream and downstream of the dike as well as on the left descending bankline adjacent to the dike. This measure would ensure bankline stability throughout the area of constriction caused by the structure. The left descending vertical bankline just downstream of the bridge would also be stabilized with revetment to protect the north bridge abutment from any back eddies that would develop from the new flow patterns.

The scope of the study focused primarily on reducing scour at the right descending abutment of the bridge crossing. Therefore, the lateral bank erosion problem downstream of the bridge along the left descending bankline was not addressed.

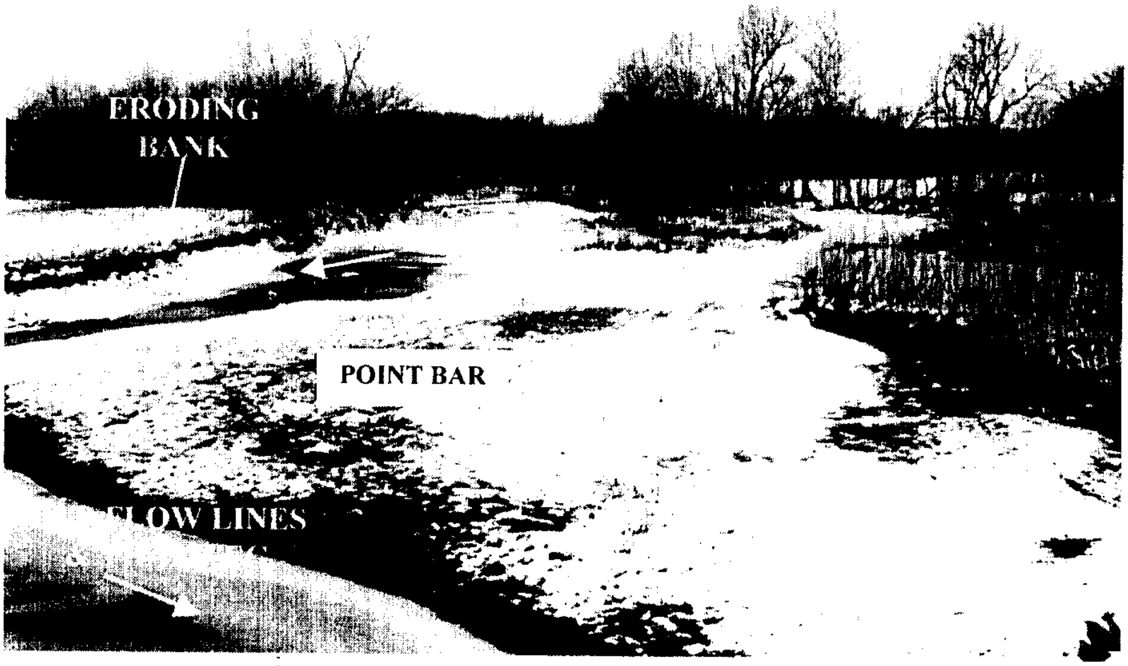
Results

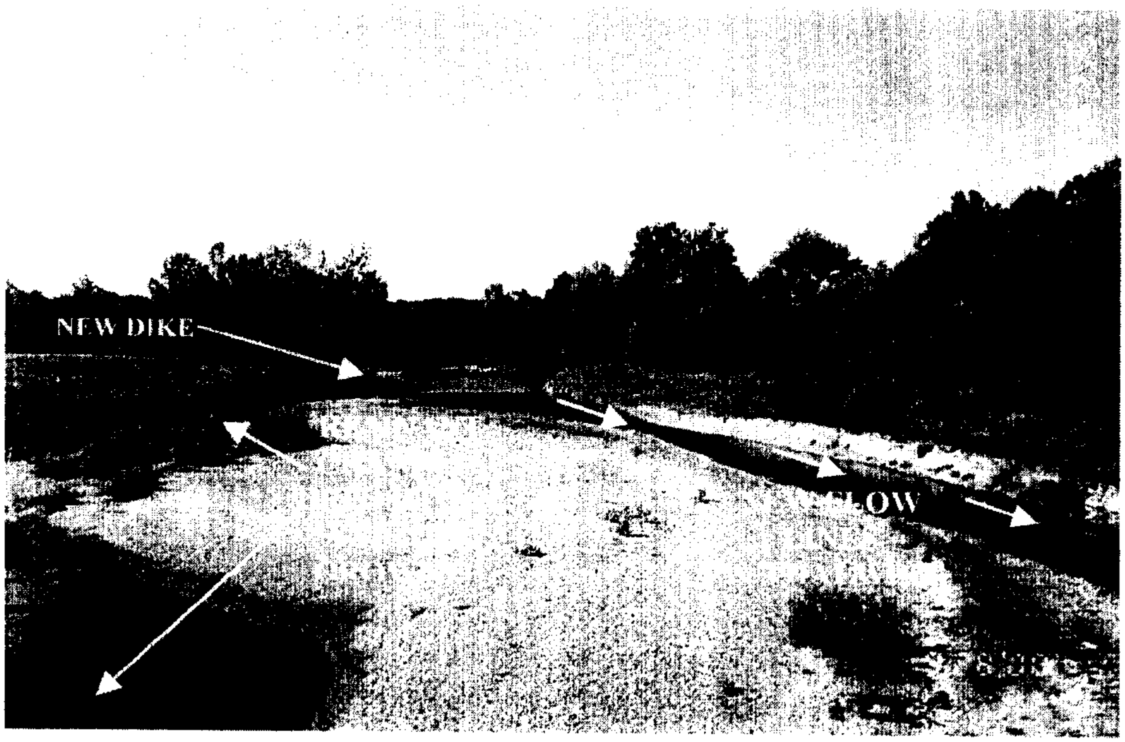
The recommended design was constructed in the summer of 1997. After the first high water event, the streambed demonstrated an immediate positive reaction. With the passing of each event, the bed configuration gradually developed as indicated by the micro model. Figure 2 shows a 2001 aerial photograph of the reach (compare this photo with Figure 1). Figure 3 shows a photograph taken from the top of the bridge facing upstream before the construction of the dike. Figure 4 was taken from the same location 1-½ years after construction. The photos show a dramatic shift of the thalweg from the right descending bank towards the left descending bank. The thalweg has cut a new location through the depositional area, which has isolated the remnants of the old point bar along the right descending bankline. The right descending bankline downstream of the dike has begun to naturally repair itself with vegetation. The area near the endangered bridge abutment has begun to fill with sediment indicating that it is now a depositional area with slower velocities. Additional maintenance to the banklines and bridge abutments after construction has not been required and only periodic monitoring of the streambed has been needed.



This project would not have been possible without the support of the farmers who own the land adjacent to the creek. These landowners had already lost land due to the lateral bank erosion caused by the new bridge and were extremely skeptical of any structure designed to remedy the problem. In fact, they were going to deny access to the stream from their land for construction purposes. Only after engineers enabled the farmers to observe the micro model in action did they accept the design and allow access to the construction site.

Before the project and model study began, a local contractor stated that a 50-foot dike should be built in approximately the same location as the constructed rock dike. A test of this design in the model indicated that it would produce excessive scour in the channel and would not properly realign the channel through the bridge crossing. Therefore, the model was very helpful in guiding the design team toward a more economical solution that ultimately resulted in successful project.





Case Study 2: Lock and Dam 24 Micro Model Study Results
Portions of the following was taken from:

Davinroy, R.D., Gordon, D.C., Hetrick, R.D., "Navigation Study at the Approach to Lock and Dam 24, Upper Mississippi River, Hydraulic Micro Model Investigation," U.S. Army Corps of Engineers, St. Louis District, 1998.

Introduction

An evaluation of the micro model study at Lock and Dam 24 on the Upper Mississippi River can be made although the initial design has not been fully constructed. A majority of the project, which involved the lengthening of a dike and the construction of 4 bendway weirs, was completed in 1998 and 2000. Due to depth constraints, three of the weirs have not been constructed to their full design length. However, a reasonable qualitative assessment of this project is also described below.

The micro model study was conducted in 1996 and 1997 at the Applied River Engineering Center. The study recommended that two structural changes be made on the river to help alleviate the outdraft problem. The design was intended to create a longer and wider area of slack water downstream of the dike to give tows a low velocity area to maneuver and therefore reduce the outdraft problem. The first change involved a 200-foot extension of the existing rock dike structure located upstream from the lock chamber. The second recommended change was the construction of 4 bendway weirs placed along the left descending bank upstream of the existing dike.

Background

A physical hydraulic sedimentation and flow study was initiated in order to evaluate a number of design alternatives and modifications to alleviate outdraft experienced by downbound tows entering the lock chamber at Lock and Dam 24. The study area consisted of a 6.5-Mile reach of the Upper Mississippi River, between Mile 277.5 and Mile 271.0 near Clarksville, Missouri. The micro model methodology was used to evaluate detrimental flow conditions experienced at the downbound navigation approach to Lock and Dam 24, Mile 273.5R, at Clarksville, Missouri.

Problem Description

Outdraft

Outdraft has been defined as the condition whereby natural or man-induced crosscurrents developed in the river adversely affect a vessel while in a low-powered state. Outdraft at Lock and Dam 24 on the Upper Mississippi River has existed since 1940 at the beginning of project operation. Downbound vessels (tows) approaching Lock 24 may experience detrimental crosscurrent patterns near the upper end of the lock chamber. These currents tend to pull boats toward the riverwall and adjacent gate openings. Numerous accidents and near catastrophic events have occurred from this historic problem.

Outdraft becomes prevalent when there is at least 30 feet of total gate opening on the dam. The greater the gate opening, the greater the outdraft. Outdraft becomes most severe during high flow and open river conditions when the gates are completely out of the water. Flows equal to or exceeding this condition have occurred approximately 48 percent of the time.

Outdraft is experienced at all lock chambers on the Mississippi River. The degree and severity of outdraft is different at each project location. Generally, outdraft is caused by the lock chamber acting as an obstruction to flow in the river, causing current patterns to detour around the chamber and head through the adjacent gate openings. However, outdraft at Lock 24 had been more dangerous. As discovered by the findings of this study, outdraft at Lock 24 is magnified due to a combination of the existing river alignment and localized geology. A protruding rock bluff (marked "The Pinnacle" on the USGS Quad) extends along the right descending bankline from the lock chamber to river Mile 274.1 (Plate 1). River currents subtly strike and deflect off this protrusion and are directed toward the gate openings.

Another contributing factor to the severity of the outdraft is the fact that the lock and dam was built in a moderate river crossing. Currents on the right descending bankline generally have a tendency to head away from the lock chamber and toward the thalweg in the crossing.

Downbound tows frequently require the services of a helper boat during most river conditions to enter the lock chamber. A helper boat assists the tow by pushing its "head-of-tow" against the landwall while the tow pilot positions the stern towards the right descending bankline. Plate 3 is a plan view aerial diagram describing the process of a tow entering the lock chamber with the assistance of a helper boat. If the towing company chooses not to use the helper boat, the tow pilot must align or check his "head-of-tow" into the landwall several times with the help of lock personnel. If the tow strikes the riverwall, barges may become separated and carried into the gate openings (Plate7).

In 1969, a perpendicular stone dike was constructed in the Mississippi River on the right descending bank at river Mile 274.0R. This dike was later extended in 1971. The dike was constructed in an attempt to alleviate outdraft conditions and create a waiting or holding area for downbound tows. The downstream eddy or flow shadow of the structure maintains a low velocity region. Most tows approaching the lock will travel downstream of the dike and then back up into the dike before making their final approach into the lock chamber. This allows the pilot to properly align the tow before entering the lock chamber. While within the dike shadow, the next maneuver consists of turning the tow at a skewed angle. The stern is positioned in the slack water near the bankline and the bow is positioned out in the faster current. The pilot then proceeds toward the lock. Model test results discussed later indicate that this dike is crucial in the overall solution to the outdraft problem.

Lock records have indicated that through the period between 1980 and 1991, 55 percent of downbound tows experienced outdraft of which 36 accidents occurred. Of these accidents, 23 involved damage to the lock or dam (1). The economic and safety impacts of this navigation problem are of great concern. In 1993, a detailed economic analysis study was conducted by the St. Louis District as part of the Lock and Dam 24 Major Rehabilitation Report (Appendix B, Economics). In this report, three economic costs were specified as being incurred by the outdraft problem. The first and most important cost was the increased transportation costs imposed by traffic delays on downbound tows waiting to enter the lock. The second was the costs associated with the prevention of tow accidents, while the third was the increased accident costs incurred when outdraft was present relative to the accident costs incurred when outdraft was not present.

The impacts of reducing delay times by eliminating outdraft was estimated at approximately $1,020,000 annually. Cost reductions associated with the prevention of tow accidents were estimated to be $33,500 annually. Total costs associated with the outdraft problem were thus estimated to be $1,053,000 annually. For the twelve-year period in this study, the average cost for the repair of damages to the lock and dam as a result of outdraft was $12,877 per accident, while the cost per accident without outdraft was $1,841.

Another cost associated with the outdraft problem was transportation delays caused by the closure of the lock due to repair of the miter gates from collisions. Plate 7 shows the consequences of an outdraft induced accident at Lock and Dam 24. An unscheduled half-day lock closure for repairing a leaf gate was estimated to increase transportation costs approximately $220,000. A two-day unscheduled lock closure for repair was estimated to increase transportation costs approximately $2,760,000. The greatest cost would result from an accident that causes major damages to the miter or tainter gates, resulting in a loss of pool. The minimum closure due to this occurrence was estimated to be 14 days with navigation delays estimated at approximately $82,163,000.

Study Purpose and Goals

The purpose of this study was to develop possible remedial measures to improve navigation conditions at Lock and Dam 24. This was accomplished by the utilization of a hydraulic micro model.

The goals of this study were to:

- Further investigate the flow mechanics causing the outdraft problem.
- Evaluate a variety of remedial measures in the micro model with the objective of identifying the most positive, economical, and environmentally friendly plan to alleviate the outdraft problem.
- Communicate to other engineers, lockmasters, river industry personnel, biologists, and environmentalists the results of the micro model tests and the plans for improvements.

Investigation of Outdraft Velocity Patterns

Historically, a somewhat modest amount of velocity data had been collected near Lock and Dam 24. Traditional velocity measuring systems were used in an attempt to study outdraft. Unfortunately, the resolution of this data had limited the depiction or visualization of the outdraft flow patterns. With the more recent advancements of data collection and remote sensing methodologies, the opportunity existed in this study to obtain additional velocity data with greater resolution. The following section is a description of the velocity data used for this model study. Observations and conclusions made from this data are then discussed.

Plates 8, 9, and 10 show velocity vectors surveyed upstream of the lock during three consecutive days in April of 1982. The density or resolution of the data points was limited. The surveys tended to show that velocities in front of the lock chamber were directed toward the gate openings. The most severe skewed angles of velocity occurred just upstream of the riverwall. However, reliable velocity patterns describing the outdraft could not fully be determined from this data alone.

Plates 11 and 12 display velocity vectors and velocity contours at the downbound approach to Lock and Dam 24. This data was collected using ADCP equipment in March of 1997 during open river conditions. The data was collected to allow engineers to better visualize the outdraft. Since the resolution of the historical data was limited, this data further enhanced the perception of velocity patterns. Results indicated that currents actually deflected off the right descending bankline (near the apex of the rock bluff protrusion) approximately 600 feet upstream of the end of the landwall. This discovery served a vital role in the eventual calibration of the micro model.

Remote sensing software and standard image processing software was used to analyze aerial photography for river current pattern recognition in the vicinity of Lock and Dam 24. Since there has been a lack of velocity data in the immediate vicinity of the lock chamber, a remote sensing technique was developed at AREC to identify the flow patterns. A color aerial photo from December 1993, which contained color differences on the water surface, was selected for the application of this technique. The effects of sediment load (turbidity), surface roughness, and turbulence were expected to affect the spectral reflectance characteristics of the water, which could possibly lead to an analysis of current patterns on the river. The scanned aerial photo was imported into a standard image processing software package and a multispectral classification scheme. The flow patterns near the lock chamber were then analyzed by enhancing the color variations on the water surface.

Most of the color variations occurred as a result of a major influx of suspended sediment from an upstream tributary (Salt River). The Salt River enters the Mississippi River approximately 10 Miles upstream of Lock and Dam 24. The tributary supplied the study area with a seeding mechanism of suspended sediment that failed to thoroughly mix into the water column before reaching Lock 24. This caused distinct color separation on the water surface which lead to the possibility of determining flow patterns.

Plate 14 shows the original color aerial and the color-enhanced aerial from a standard image processing software package. Visual comparison between the two images showed a distinct variance in color. This represented the effects of surface roughness and suspended sediment. The remote sensing analysis revealed two important trends. First, it could be seen that currents deflected off the tip of dike 274.0R, as expected. Second, it could be visualized that both the deflected currents off the dike tip and the currents within the downstream shadow of the dike were pulled toward and then away from the apex point of the rock bluff protrusion. This visualization of current deflection at the bluff was verified by observations from the ADCP data (Plate 11).

The remote sensing technique, combined with the ADCP data and the historic velocity data, enabled engineers to determine how, why, and where outdraft was occurring in the river. It was apparent that the rock bluff protrusion, located approximately 600 feet above the lock chamber, was the primary influence to the development of exaggerated outdraft conditions upon downbound approaching tows. This observation was later verified by flow visualization of the micro model base test (Plate 26).

Lock and Dam 24 Micro Model

The micro model was constructed according to 1994 aerial photography of the study reach. The scales of the model were 1 inch = 800 feet, or 1:9600 horizontal and 1 inch = 50 feet, or 1:600 vertical for a 16:1 distortion ratio.

Thirty alternative design plans were tested in this study in an attempt to improve flow conditions at Lock and Dam 24. The effectiveness of each plan was compared to the base test conditions. Impacts or changes created by each alternative were evaluated by analyzing both the flow (using flow visualization) and sediment response of the model. A qualitative evaluation of the ramifications of each plan to both downbound and upbound tows was made during team participation meetings at AREC. Engineers and navigation industry port captains and pilots carefully examined and discussed each alternative.

Recommended Solution

Using the model study test results as a guide, team representatives from the St. Louis District and river industry determined the most efficient, economical, and practical solutions to the outdraft at Lock and Dam 24. The team concluded that four bendway weirs upstream of the lock chamber off the left descending bank and a 200-foot extension of the existing dike at Mile 274.0R would result in the best possible measure at reducing or eliminating the outdraft problem. The model showed that extending the dike would create increased slack water between the dike and the lock chamber (Figure xx, flow visualization).

The weirs were designed to push flow towards the existing rock dike, making the elongated structure more effective at creating an area of slack water between the dike and the lock chamber. The resultant bathymetry from the model indicated that the thalweg shifted toward the right descending bankline near the dike extension. Flow visualization showed that this plan generated an area of slack water which reduced the outdraft flow patterns. This effect would provide favorable flow conditions for both upbound and downbound tows entering and leaving the lock chamber.

Results

The dike extension was constructed in 1998 while portions of the 4 bendway weirs were built in 2000. Unfortunately, the contractor was unable to build the weirs to their designed length due to the lack of depth near the Missouri bankline. The insufficient depths in the channel prevented full construction of these three structures. However, after a few high water events, the as-built structures will begin to scour the channel. Once sufficient depths are generated off the ends of the weirs, the remainder of the structures will be constructed. Until recently, Pool 24 has not experienced an extended duration of high flow that would rearrange the bathymetry of the riverbed to generate the proper depths for completion of the weirs.

Positive results were noticed immediately after the dike extension was constructed. These results were further enhanced once the weirs were built. ADCP velocity collected in 2000 showed that compared to pre construction data, the flow patterns that had caused the outdraft problem had been significantly reduced. Tow pilots have also reported a noticeable improvement in the flow patterns, which has significantly eased navigability into the lock chamber. Some pilots have even chosen not to accept assistance from the helper boat. Lock personnel also reported a decrease in drift entering the lock chamber, which indicated that the higher flows were no longer directed toward the lock chamber.

Additional hydrographic survey data and ADCP data will continue to be collected to monitor the weirs and the flow patterns that they create.

Case Study 3: Sante Fe Chute

Portions of the following taken from:
Gordon, D.C., Davinroy, R.D., "River Restoration Measures in Four Secondary Channels of the Mississippi River, An Interagency Success Story," ASCE Wetlands Engineering and River Restoration Conference Proceedings, 1998.

Introduction

In 1996, biologists and engineers from the United States Fish and Wildlife Service, the Illinois Department of Natural Resources, the Missouri Department of Conservation, and the St. Louis District Corps of Engineers, ventured on a joint environmental effort to improve riverine habitat conditions within Sante Fe Chute on the Middle Mississippi River. This effort was made possible by the authority of the St. Louis District Avoid and Minimize Environmental Program.

The agencies assembled a team of experts to formulize ideas and strategies for the purpose of developing aquatic diversity within the side channel at Mile 39 L. Design alternatives were tested by the team in the micro model at the AREC in St. Louis, Missouri. The use of the micro model enabled the team to address the complex sediment transport interaction problem between the side channel and the main navigation channel of the Mississippi River (figure 1). Team members assembled at AREC on numerous occasions to jointly experiment with the micro model.

Various alternatives that displayed promise in the model during team experiments where then studied in greater detail using the established micro modeling methodology. Comparisons were made to a model base condition, whereby the most feasible and cost effective design solution could be selected. Creating bathymetric variance and aquatic diversity was the primary goal of the team. Several different river engineering schemes were ultimately chosen for implementation in the Mississippi River. The team chose those alternative that produced the most positive effects to the flow and streambed of the side channel. Construction costs were a major concern throughout the study. Also, particular attention was directed toward the integrity of the main navigation channel. Once a plan was chosen from model study results, river engineers then developed detailed construction plans and specifications.

Sante Fe Chute is a particular side channel of the Mississippi River (Figure 2) that was of high priority by the restoration team. Various structural modifications to existing river training works as well as other ideas were tested in the model, including closure structure removal/modification, dredging, chevrons, and traditional dikes.

The plan eventually chosen by the team encompassed an alternating dike scheme designed to create sinuosity in both the flow and sediment pattern of the side channel (Figures 3 and 4). Construction of the plan was initiated shortly after the model study in April of 1997 (Figure 5). Recent field monitoring of the plan in the river has demonstrated that positive effects were developed after the first hydrographic event (Figure 6).

Through the use of micro modeling, it was possible for a team of biologists and engineers to develop cost effective, reliable design solutions to the side channel restoration project on the Middle Mississippi River. The delicate balance of flow and sediment between the main channel and the side channels were for the first time visualized by use of the model. Hours spent together on the micro model provided an invaluable dialect and understanding among the interagency team members and set a precedence for future environmental engineering efforts on the river

Case Study 4: Mouth of the White River

Portions of the following was taken from:
Gordon, D.C., Davinroy, R.D., "Sedimentation and Navigation Study of the Lower Mississippi River at the White River Confluence, Miles 603 to 596, Hydraulic Micro Model Investigation," U.S. Army Corps of Engineers, St. Louis District, 1998.

Case Study 5: Dogtooth Bend

Rob to write

Case Study 6: Morgan City/Berwick Bay

Portions of the following was taken from:
Gordon, D.C., Davinroy, R.D., "Sedimentation and Navigation Study of the Lower Atchafalaya River at Morgan City and Berwick, Louisiana, River Miles 124.0 to 118.5, Hydraulic Micro Model Investigation," U.S. Army Corps of Engineers, St. Louis District, 2001.

LIMITATIONS AND CAPABILITIES

Minimal justification required, based on your view point from available information you have. "Based on observations of model response ..." or "Based on observations of flume response... ."

There are no limitations or user requirements for HEC or numeric models. Rob to discuss

Limitations
Obvious (its better to focus on the capabilities)

1. Water Surface Profile Analysis (in channel and floodplain)
2. Floodplain Sedimentation
3. Velocity Magnitudes
4. Quantitative & Near Field Scour and Deposition Analysis
5. Unknown non-erodibles in the prototype
6. Ability to reproduce:
   a. Abnormal or unstable bed forms initiated by extreme hydrologic events
   b. Aggradation or degradation
7. xxxx

Capabilities
Base upon experimentation and experience with past model studies, the following are the general capabilities of micro modeling.
As with all sediment transport models, these capabilities are limited to qualitative analyses.

General

1. Three-dimensional scour and deposition trends in rivers and streams.
2. Changes in thalweg location from imposed training structures.
3. Qualitative velocity trends and patterns: Examination of main flow concentrations and general flow direction. Flow pattern determination in response to bathymetric changes imposed to the streambed.
4. General navigation studies to bathymetric and flow pattern response.
5. Main channel and side channel bathymetric analysis and study. Rearrangement of the bed forms to decrease dredging and to improve or diversify aquatic conditions.
6. Qualitative analysis of the three degrees of translation freedom as described by Ettema in "A Framework for Evaluating Micro-Models."

Specific

1. Flow and sediment response trend studies at multiple entrances (tributaries) and outlets (distributaries). (Mouth of the White River, Memphis Harbor, Morgan City)
2. Analysis and resolution of outdraft at lock approaches and bridge crossings. (LD24, LD25, Mouth of the White River, Morgan City, Vicksburg Front)
3. Implementation of Bendway Weirs; flow and bathymetric response. (LD24, SEMO Port, Mouth of the White River, Morgan City, Vicksburg Front)
4. Innovative design of environmental river engineering structures, i.e. notched dikes, chevrons, hard points, etc. (Copeland Bend, Bolters Bar, JB Bridge, Cottonwood)

5. Channel contraction measures to reduce dredging. (White River, Clarendon and Augusta; Savanna Bay, Copeland Bend, Bolters Bar, JB Bridge, New Madrid, Morgan City)
6. Dike and closure structure modification to increase scour or flow within side channels and off channel areas. (Sante Fe Chute, Marquette Chute, Schenimann Chute, Savanna Bay, Wolf Island, Salt Lake Chute, JB Bridge)
7. Sedimentation patterns within slack water harbors. (SEMO Port, Memphis Harbor)
8. Stream realignment at bridge crossings. (Big Creek)
9. Analysis and study of inflow sedimentation of lakes. (Slagle Creek)
10. Deposition patterns at water intakes. (Highbanks)

RECOMMENDATIONS

Recommendations for further study should be included in the final report. It should be recommended that all types of models be subjected to this type of rigorous analysis (both physical and numerical as well as flow and sediment models)

If this model is required to have a clear set of calibration and validation procedures, then all other models need this as well.