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GORDON

CASE STUDIES 2 AND 1

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4.2.2. Lock and Dam 24 (Case Study 2)

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.

In 1996, micro model methodology was used to evaluate dangerous outdraft flows at the downbound navigation approach to Lock and Dam 24. A number of design alternatives and modifications were studied and tested to alleviate these detrimental flow conditions at the Lock. The study area consisted of a 6.5-Mile reach of the Upper Mississippi River, between Miles 277.5 and 271.0 near Clarksville, Missouri.

The study recommended two structural changes for alleviating 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 recommendation was the construction of 4 bendway weirs placed along the left descending bank upstream of the existing dike. 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.

A majority of the project was constructed in 1998 and 2000. However, due to depth constraints, three of the weirs have not been constructed to their full design length. An initial evaluation of the micro model study at has been made although the full design has not been fully implemented.

Figure 1: Lock and Dam 24 on the Upper Mississippi River

4.2.2.1. Problem Description

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 conditions are experienced at all lock chambers on the Mississippi River. The degree and severity of outdraft is different at each location. Generally, it is caused by the lock chamber acting as an obstruction to flow, which causes current patterns to detour around the chamber and head through the adjacent gate openings in the dam.

Severe outdraft at Lock and Dam 24 had existed since the dam was completed in 1940. Downbound tows approaching the Lock usually experienced these detrimental crosscurrent patterns between the upper end of the landwall and the lock chamber. These currents had pulled vessels toward the riverwall and gate openings in the dam. Numerous accidents and near catastrophic events have occurred from this recurring problem. Figure 2 shows the consequences of an outdraft induced accident at Lock and Dam 24.

The flows that cause the outdraft became most prevalent when there is at least 30 feet of total gate opening on the dam. The greater the gate opening, the more severe the outdraft problem became. This normally occurred during high flow and open river conditions when the gates were completely out of the water. Flows equal to or exceeding this condition had occurred approximately 48% of the time.

Figure 2: Barges in the Dam, Aftermath of an Outdraft Induced Accident at Lock and Dam 24

Outdraft at Lock 24 was magnified, and therefore more dangerous, due to a combination of the existing river alignment and localized geology. A rock bluff extends along the right descending bank from the lock chamber to Mile 274.1. River currents subtly strike and deflect off this protruding bluffline and were directed toward the gate openings. The other contributing factor to the severity of outdraft is the fact that the Lock and Dam was built in a moderate river crossing. Currents on the right descending bank generally have a tendency to head away from the lock chamber and toward the thalweg in the crossing.

Downbound tows frequently utilize the services of a helper boat during most river conditions to enter the lock chamber. A helper boat assists the tow by pushing the head of the tow against the landwall while the tow pilot keeps the stern from drifting toward the riverwall. Figure 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 pilot chooses not to use the helper boat, the tow must be aligned or the head of the tow checked into the landwall several times with the help of lock personnel. If the tow drifts and strikes the riverwall, its barges may become separated and carried into the dam.

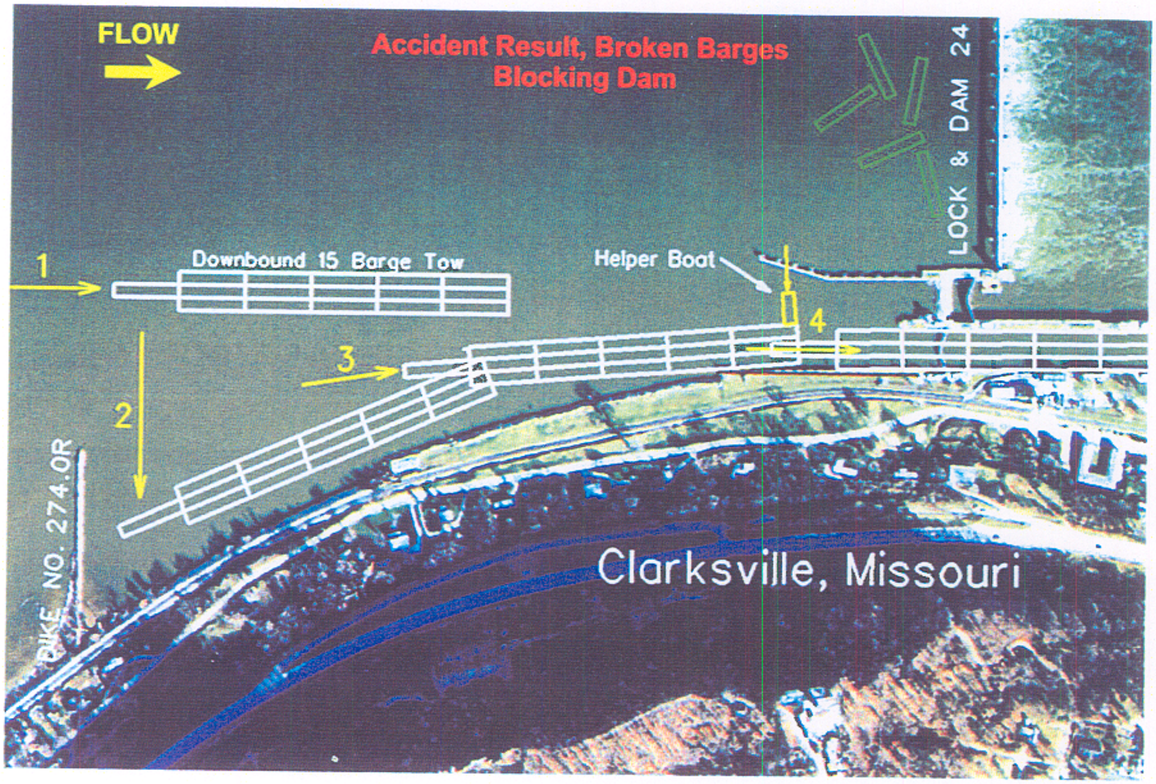

Figure 3: Diagram of the Procedure Most Downbound Tows Use to Navigate into Lock 24

In 1969, a perpendicular stone dike was constructed upstream of the Lock along the right descending bank. 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 formed by the structure maintains a low velocity region. Model test results discussed later indicated that this dike location was crucial in the overall solution to the outdraft problem. Most tows approaching the lock will travel downstream of the dike and then back up into this region 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 stern is positioned in the slack water near the bank, the bow is positioned out in the faster currents, and the entire tow is turned at a skewed angle. The pilot then proceeds toward the lock, usually with the assistance of the help boat.

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. 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. In this report, the impacts of reducing delay times by eliminating outdraft were estimated at approximately $1,020,000 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. 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 million.

4.2.2.2. 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:

1. Further investigate the flow mechanics causing the outdraft problem.
2. 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.
3. Communicate to other engineers, lockmasters, river industry personnel, biologists, and environmentalists the results of the micro model tests and the plans for improvements.

4.2.2.3. Investigation of Outdraft Velocity Patterns

Historically, a somewhat modest amount of velocity data had been collected near the Lock. 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.

Figure 4 show velocity vectors surveyed upstream of the Lock during three consecutive days in April of 1982. Although the density or resolution of the data points was limited, the surveys showed that velocities near 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 that delineated the outdraft problem could not fully be determined from this data alone.

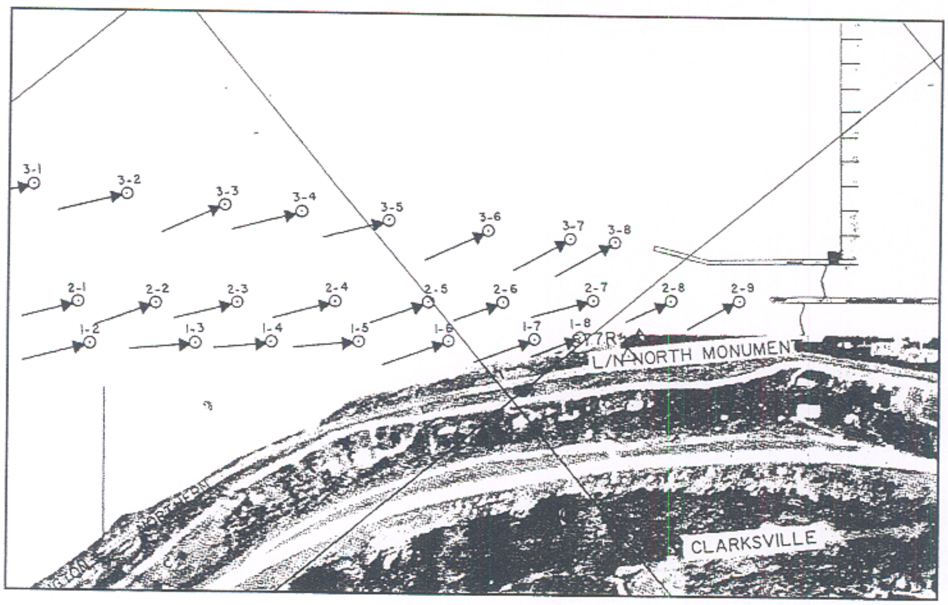

Figure 4: Velocity Vectors at Lock 24, Surveyed in April 1982.

Figure 5 displays velocity vectors that were collected using an ADCP in March of 1997 during open river conditions. Since the resolution of the historical data was limited, this data further characterized the velocity patterns. The data indicated that currents deflected off the right descending bank near the apex of the rock bluff protrusion and approximately 600 feet upstream of the end of the landwall. This discovery served a vital role in the eventual calibration of flow within the micro model.

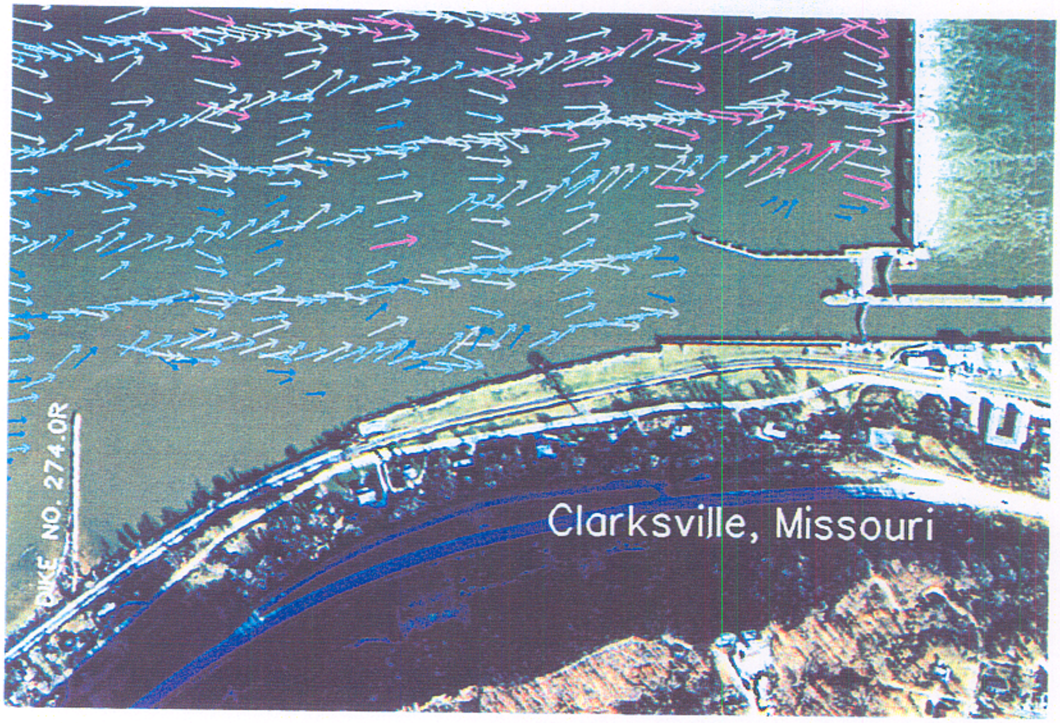

Figure 5: ADCP Velocity Vectors at Lock 24, Surveyed March 1997.

Remote sensing software and standard image processing software was used to analyze aerial photography for current pattern recognition in the vicinity of the Lock. A color aerial photo from December 1993, which contained slight color differences on the water surface, was selected for the application of this technique. The effects of sediment load (turbidity), surface roughness, and turbulence had affected the spectral reflectance characteristics of the water, which lead to an analysis of current patterns on the river. The color variations occurred as a result of a major influx of suspended sediment from an upstream tributary. The Salt River, which enters the Mississippi River approximately 10 Miles upstream of Lock and Dam 24, supplied the study area with a seeding mechanism of suspended sediment that was not thoroughly mixed into the water column before reaching Lock 24. This caused distinct color separation on the water surface, which was used to determine flow patterns. The scanned aerial photo was imported into a multispectral classification scheme and the flow patterns near the lock chamber were then analyzed by enhancing the color variations on the water surface (Figure 6).

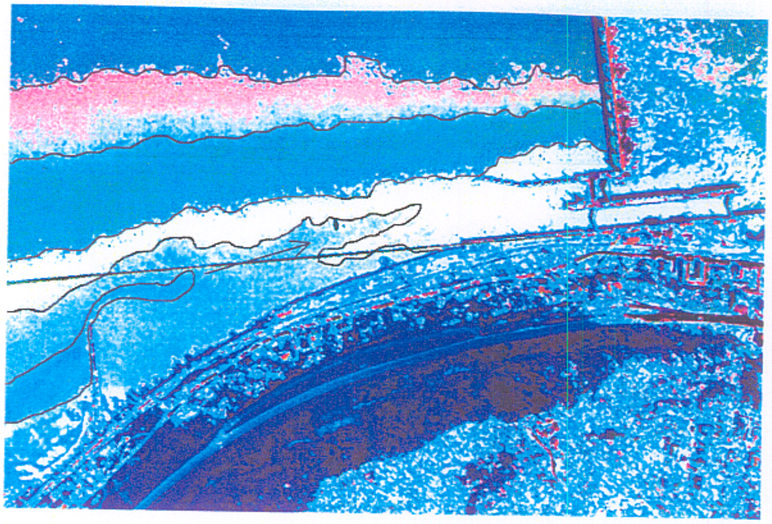

Figure 6: Flow Patterns at Lock 24 in a 1993 Color Enhanced Aerial Photograph.

The remote sensing analysis revealed two important trends. First, the currents were obviously deflected off the tip of Dike 274.0R, as expected. Second, it was shown that 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.

The remote sensing technique, combined with the ADCP data and the historic velocity data, enabled engineers to determine location and reason for outdraft current patterns. 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 shown in the flow visualization of the micro model base test.

4.2.2.4. 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. The model was considered calibrated after it was concluded that the bathymetric patterns of the model were similar to those of the prototype. It was then determined that the flow patterns of the base test (Figure 7) were extremely similar to those shown in the prototype flow data.

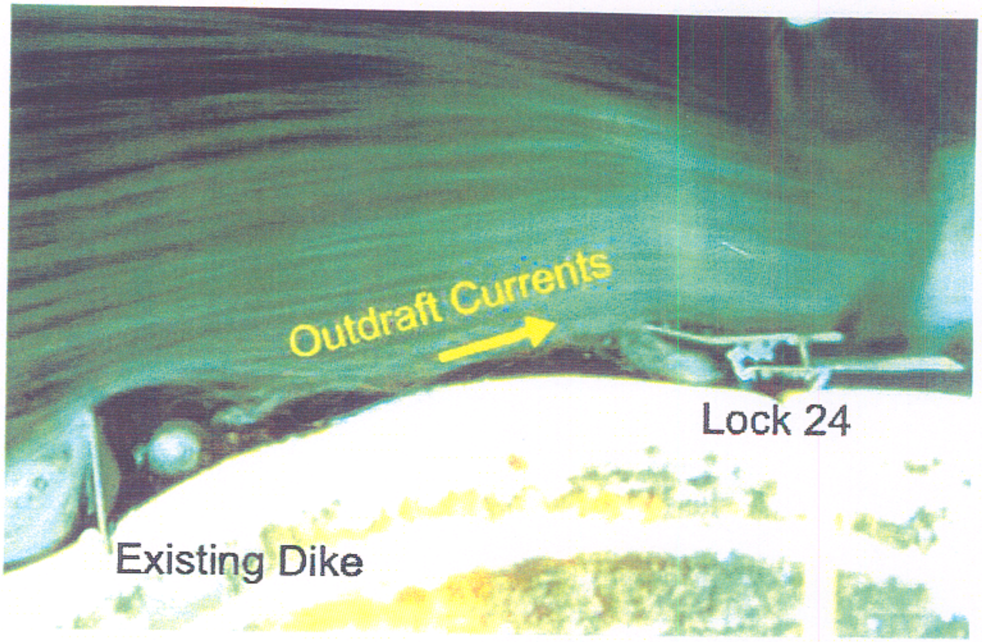

Figure 7: Micro Model Base Test Flow Visualization Showing Dangerous Outdraft Flow Patterns.

Thirty alternative design plans were then 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.

4.2.2.5. Recommended Solution

Using the model study test results as a guide, team representatives from the St. Louis District and river industry determined the most economical and practical solutions to the outdraft problem at the Lock. 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 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 bank near the dike extension. Flow visualization in the model indicated that this design would create increased slack water between the dike and the lock chamber which would reduce the outdraft flow patterns (Figure 8, flow visualization). These patterns would provide favorable flow conditions for both upbound and downbound tows entering and leaving the lock chamber.

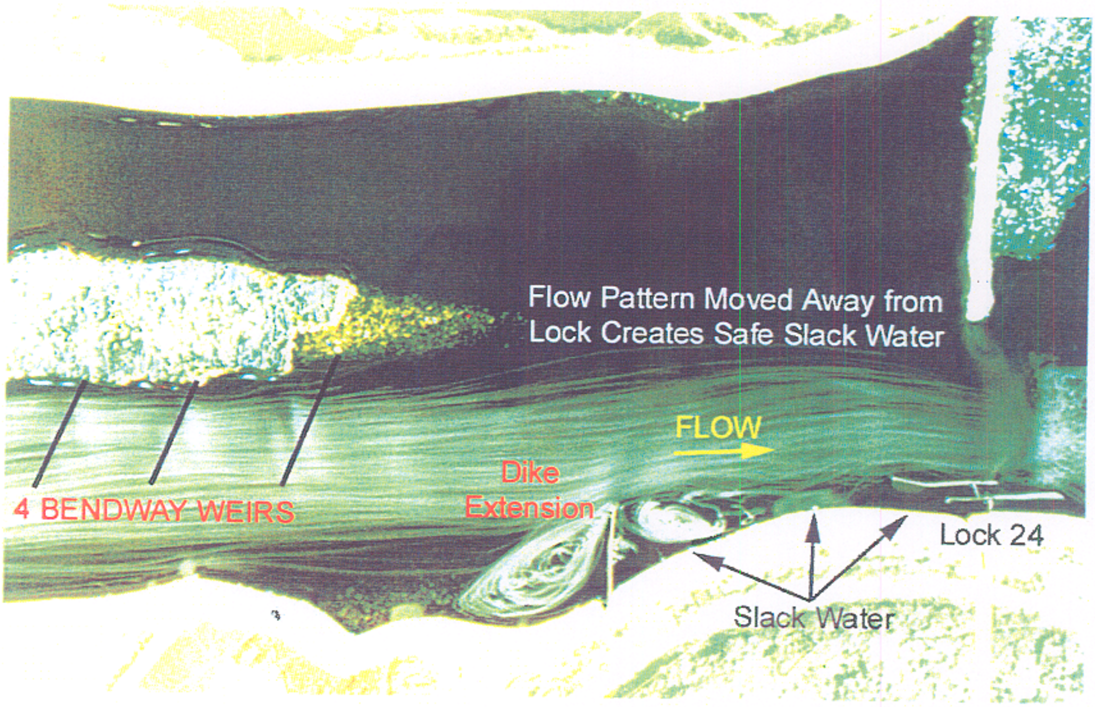

Figure 8: Micro Model Flow Visualization of the Recommended Remedial Design.

4.2.2.6. Results

The dike extension was constructed in 1998 while portions of the 4 bendway weirs were built in 2000 (Figure 1). Unfortunately, the contractor was unable to build the weirs to their designed length due to the lack of depth near the Missouri bank. The insufficient depths in the channel prevented full construction of these three structures. However, after a few high water events, the as-built structures should 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 had 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.

Immediately after the dike extension was constructed, lock personnel and tow pilots reported positive results. The tow pilots have described a noticeable improvement in the flow patterns, which they say 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 may indicate that the higher flows are no longer directed toward the lock chamber. Post construction ADCP velocity data was collected in 2000 and is shown in Figure 9. Additional hydrographic survey data and ADCP data will continue to be collected to monitor the weirs and flow patterns.

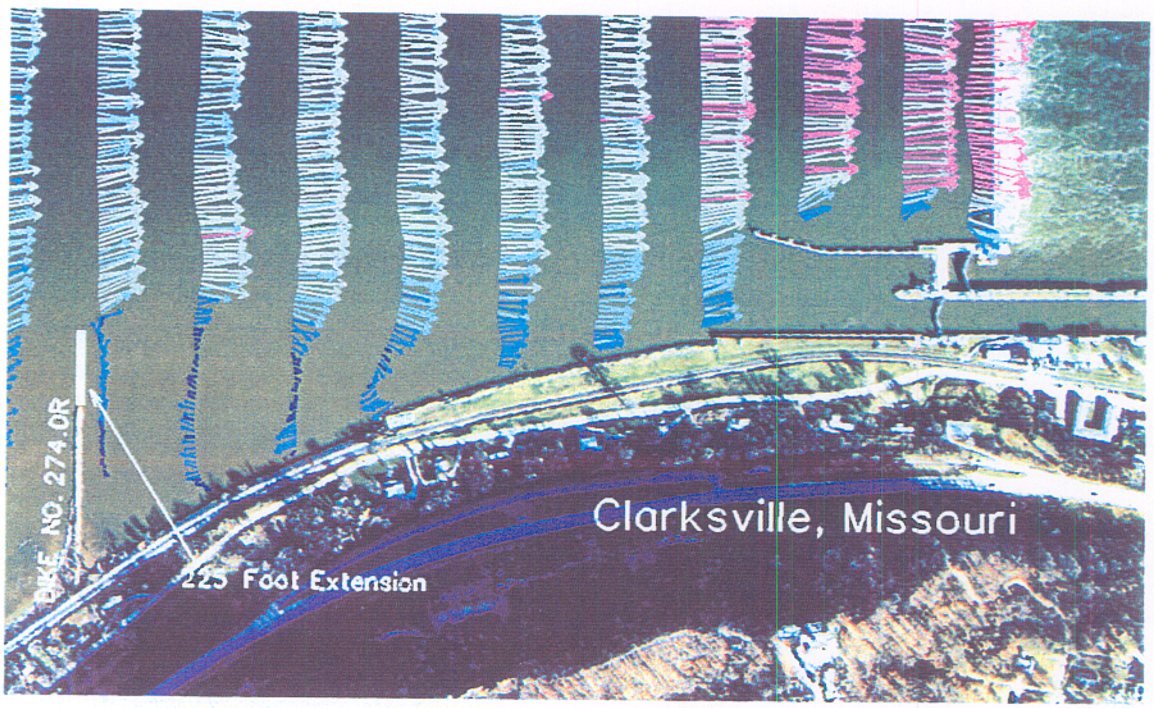

Figure 9: ADCP Velocity Vectors at Lock 24, Post Construction, 2000

4.3.2. Lock and Dam 24 (Case Study 2) Analysis of Results

The flow patterns discerned from the ADCP data collected in 2000 (Figure 9) clearly demonstrates distinctive similarities to those predicted by the micro model flow visualization of the recommended design (Figure 8). This ADCP data compared to the pre construction ADCP data (Figure 5) indicates that the dangerous flow patterns that had caused the outdraft problem have been dissipated. As also shown in the post construction data, the flow patterns in the model displayed a correction to the detrimental currents that had deflected off the right descending bank. The micro model also correctly predicted the position and size of the eddy downstream of the dike. Although these methods of recording flow patterns are different, the similarities between the ADCP velocity vectors and the time elapsed stream lines from the model are clearly shown in these Figures.

qualitative design

Rec'd from Dave
8/17/02

4.2.1. Big Creek (Case Study 1)

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.

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 description 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 southern abutment. Local reports indicated that the stream 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 abutment 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 bank 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.

4.2.1.1 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 ≅ 10 feet
- Average Channel Width at Bankfull Flow ≅ 150 feet
- Average Width to Depth Ratio ≅ 15
- Deepest Channel Depth Encountered ≅ 19 feet

4.2.1.2 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 bank 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 low flow patterns through the bridge opening were orientated in a nearly parallel direction to the bridge crossing (Figure 4-1). Immediately downstream of the bridge opening, flow patterns were directed against the left descending bank.

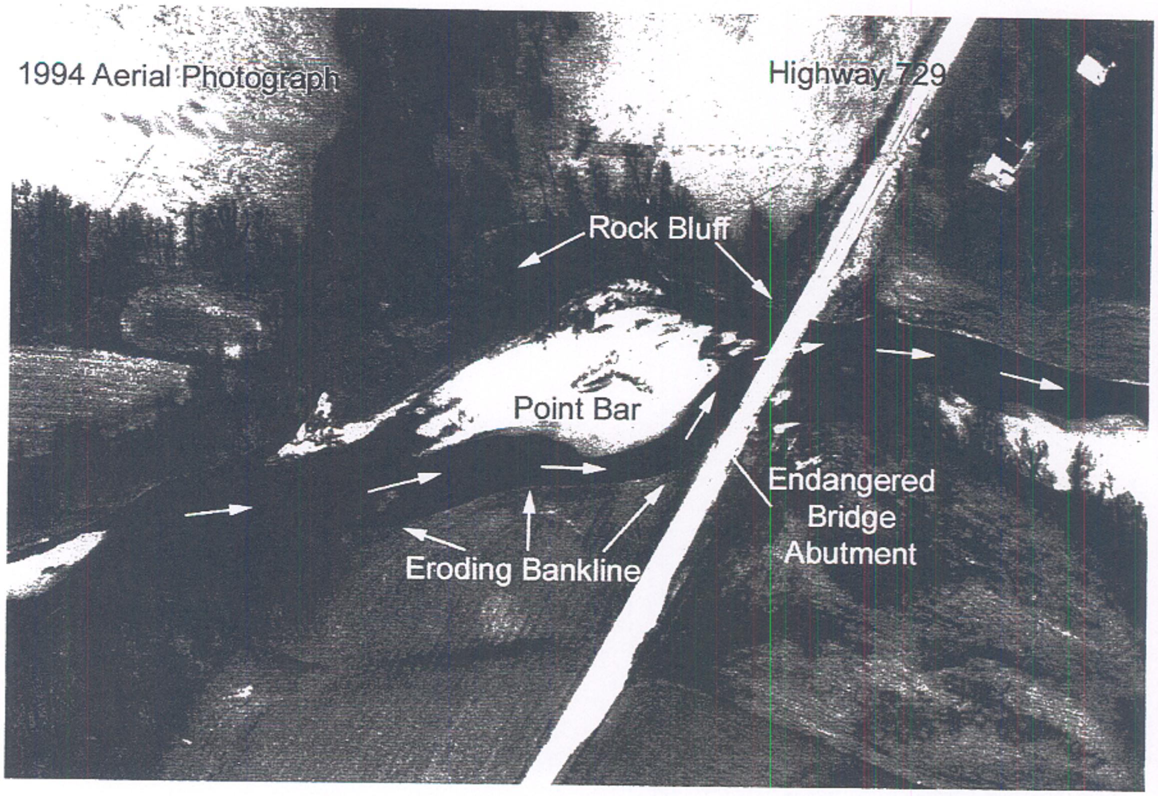

Figure 1: 1994 Aerial Photograph of Big Creek at Lincoln County Highway 729.

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 bank was actively eroding and did not contain any natural vegetation. This feature extended from the bridge abutment to a point 500 feet upstream of the bridge.

- The banks, 500 feet upstream of the bridge, were heavily wooded and stable.
- A large point bar was located along the left descending bank upstream of the bridge. The size and growth of the point bar was directly related to the migration of the right descending bank. This depositional area indicated that the majority of flow was concentrated along the right descending bank.
- The left descending bank immediately upstream of the bridge was a wooded, natural rock bluff line. This condition was evident to a point approximately 400 feet upstream of the bridge.
- The bridge crossing was severely misaligned with the channel thalweg.
- Downstream of the bridge, the right descending bank was heavily vegetated. A small point bar was located along this bank. The majority of flow was concentrated along the left descending bank.
- The left descending bank downstream of the bridge was vertical and devoid of vegetation. This condition was evident from the bridge to approximately 700 feet downstream to a small outcropping of trees.

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 bank 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.

4.2.1.3 Big Creek Micro Model

The model used for this study was constructed according to the high resolution 1994 aerial photograph shown in Figure 4-1. 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, an average design hydrograph was used. Each hydrograph was a repeatable triangular response representing low to high flows.

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. This base test served as the comparison for all future tests, which 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.

4.2.1.4 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. Through these tests, it was determined that the most cost-effective design solution to the 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 bank. 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 bank upstream and downstream of the dike as well as on the left descending bank adjacent to the dike. This measure would ensure bank stability throughout the area of constriction caused by the structure. The left descending vertical bank 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 bank was not addressed.

4.2.1.5 Results

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

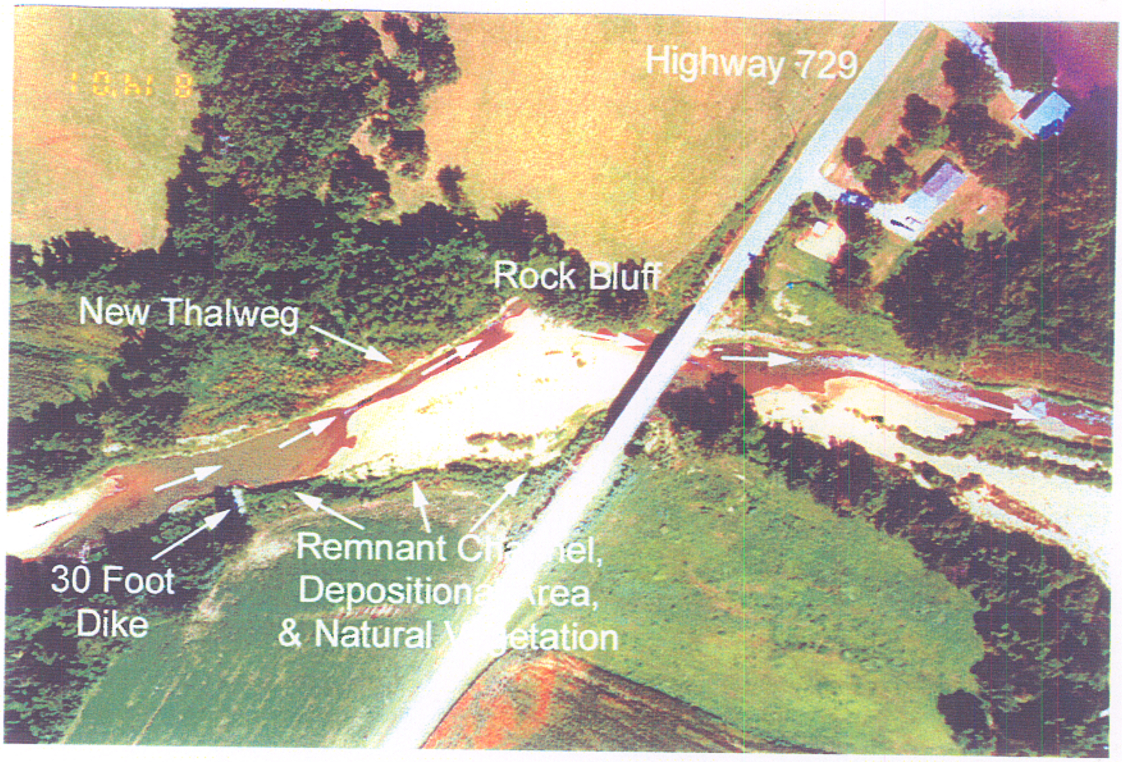

Figure 2: 2001 Aerial Photograph showing Post Construction Response in the Stream

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.

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 intended to deny access to the stream from 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.

Figure 4-3: 1996 Photograph Looking Upstream from the Bridge Crossing.

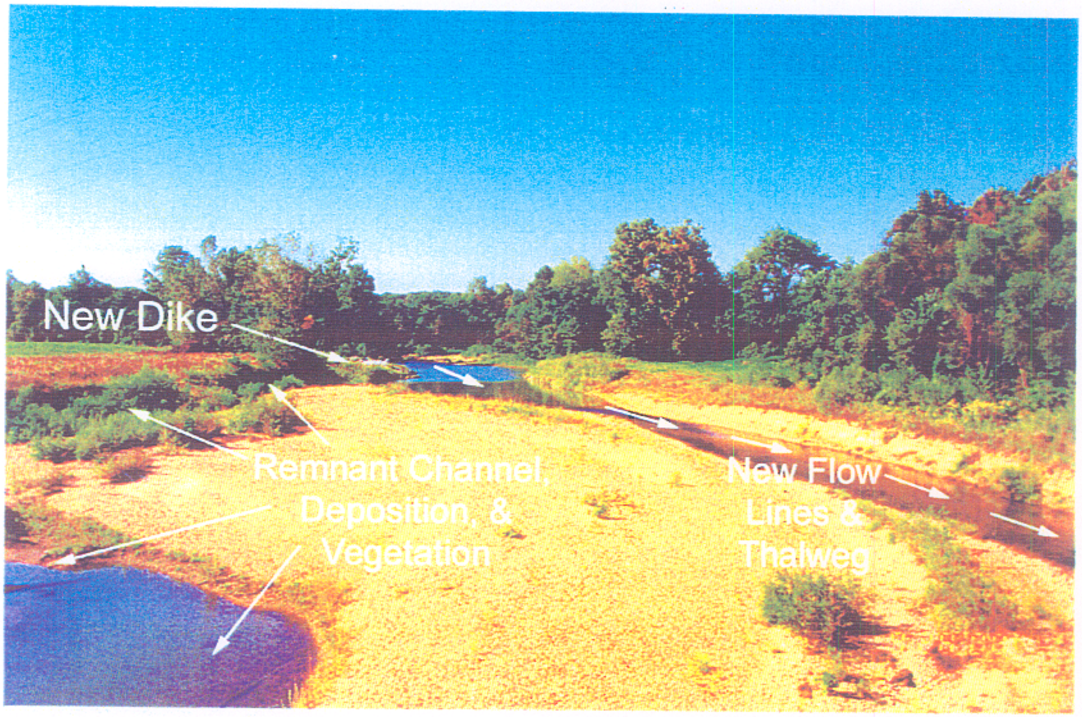

Figure 4-4: 2000 Post Construction Photograph with the Same View as Figure 4-3.

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