# RECONSTRUCTING RIVER RESERVOIR NO. 3 – FROM EMERGENCY ACTION TO BREACH TO SAFE OPERATION IN 21 MONTHS

Del Shannon, P.E.[1] James R. Swaisgood, P.E.[2]
Michael Johnson, Ph.D., P.E[3]

## ABSTRACT

River Reservoir #3 is located in east central Arizona near the town of Greer. The zoned embankment dam was originally constructed in 1896 and has been modified at least 4 times. Currently the dam is approximately 1,100-feet-long and has a maximum height of about 70 ft.

During the last two weeks of March 2004 the water surface at River Reservoir #3 was at higher than normal levels and began spilling through the spillway on March 22nd. On March 28th, the Round Valley Water Users Association (RVWUA), who own and operate the facility, reported that the left abutment drain was discharging more than 120 gallons per minute (gpm), a rate 10 times the normal amount. On April 1st, sediment was observed in the weir box located at the end of the left abutment drain. This material was mainly sand with some clay, and was assumed to be originating from the sandy clay core of the embankment. In the first week of April, the Arizona Department of Water Resources (ADWR) requested instigation of the emergency action plan, the Governor of Arizona declared an emergency situation, and Apache County emergency responders began 24-hour-hour surveillance of the dam.

Simultaneously, TCB was contracted by the ADWR to begin emergency engineering services in close cooperation with their office. The scope of work of these services included:

- Continued observation and monitoring of the behavior of the River Reservoir #3 dam until a safe situation existed
- Performed investigations of the dam to establish an understanding of the conditions within the embankment and the causes of the internal erosion. Besides conventional drilling and sampling, the investigation included dye tracing and a magnetic-based groundwater mapping survey
- Development of preliminary and final designs for a repair that eliminated the present problem and allowed the reservoir to operate in a safe manner.

[1] Senior Project Manager, Black & Veatch Corporation, 6300 S. Syracuse Way, Suite 300, Centennial, Colorado, 80111; 720-834-4243; fax 720-834-4285; ShannonDA@bv.com
[2] President, Swaisgood Consulting, P.O. Box 1083, Conifer, Colorado 80433, 303-838-8774, j.swaisgood@att.net
[3] Section Manager, Dam Safety Section, Arizona Department of Water Resources, Office of Water Engineering, 3550 N. Central Avenue, Phoenix, Arizona 85012, (602) 771-8659, mjjohnson@azwater.gov

This paper describes the results of the monitoring, evaluation and repair of the River Reservoir #3 dam. The reconstructed dam is currently operating as designed and began providing water to the Round Valley Water Users Association less than two years after nearly failing.

## INTRODUCTION

The River Reservoir dam is a zoned earthen dam, has a slightly curving footprint, is approximately 70-feet-high at its maximum section and is approximately 1,100 foot long. Since its original construction in 1896 it has experienced numerous modifications in form of raises and repairs in response to upstream slope instability issues and near failures. The most recent of these near failures occurred during the last two weeks of March of 2004. During this time the water surface at River Reservoir No. 3 Dam was several feet higher than normal levels and began spilling through the spillway (crest elevation 8,219 feet) on March 22nd. On March 28th, the Round Valley Water Users Association (RVWUA), who own and operate the facility, reported the drain at the left abutment was

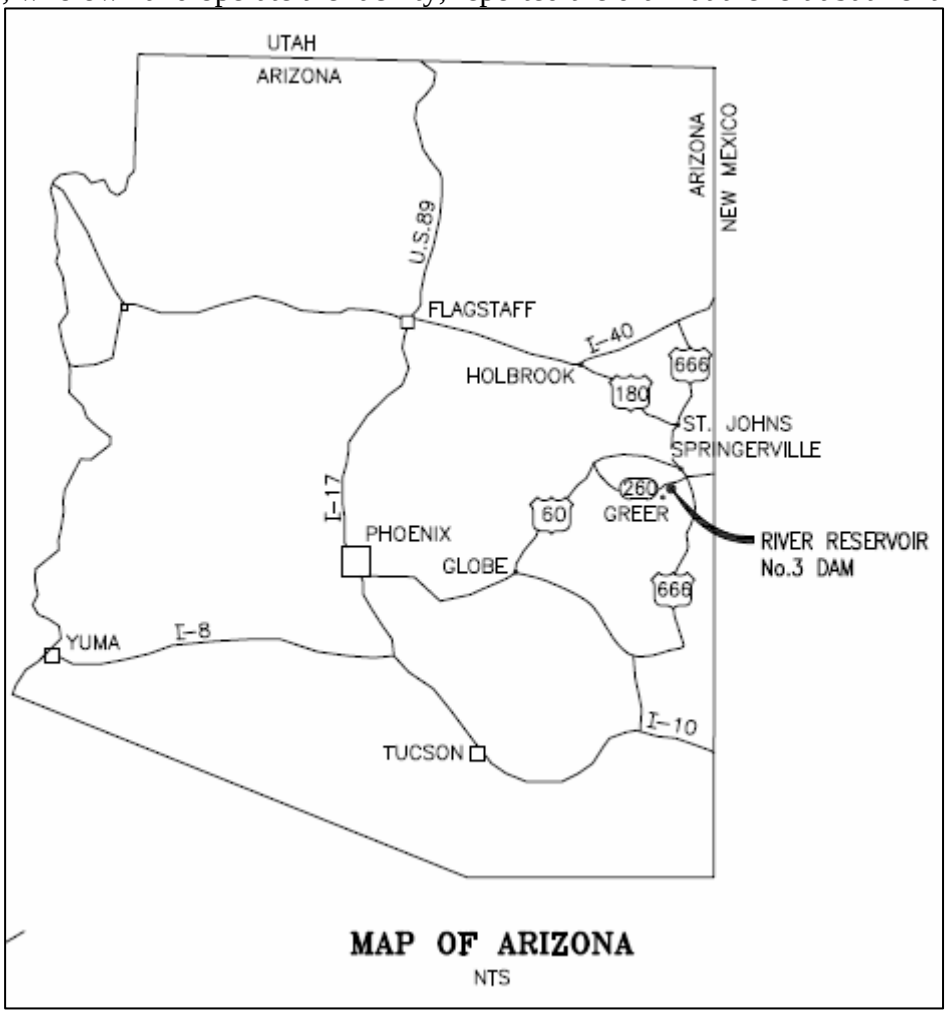


Figure 1 – River Reservoir No. 3 Dam Location

discharging more than 120 gallons per minute (gpm), 10 times the normal amount. The Arizona Department of Water Resources Office of Water Engineering (ADWR) was notified of the abnormality and on March 29th regular monitoring of the left abutment drain, the toe drain, and the reservoir water level began.

On April 1st, sediment was observed inside of the weir box located near the downstream toe on the left abutment drain (left drain). The material observed consisted primarily of sand with some clay. Based on the understanding of the dams zonation, it was assumed that the sand originated from the sandy clay core and that most of the clay remained suspended in the discharge water and was conveyed through the weir faster than the time needed for the clay to settle out. The flow rate in the toe drain (right drain) also increased. However, the discharge remained clear and without any sign of sediment. Therefore, the direct observation of sediment in the left drain was the primary indication that internal erosion was occurring somewhere along the embankment cross section at the left abutment.

During the first week of April, ADWR informed TCB (the design engineering firm for the last modification of the dam in 1996) of the situation. On April 11th ADWR authorized ECI to initiate emergency engineering services in close cooperation with their office. The scope of work included:

- Continuing observation and monitoring activities in order to document the behavior of the River Reservoir No. 3 Dam until a safe situation exists.
- Performing investigations of the dam to establish an understanding of the conditions within the embankment and the causes of the internal erosion.
- Developing a preliminary design for repairing the dam that will eliminate the present problem and allow the reservoir to operate in a safe manner in the future. The preliminary design will serve as a basis for the final design package for the future repair construction.

Based on the results of these studies a design to repair the dam was selected and construction was completed in December 2005.

## EMERGENCY MONITORING

Seepage flows from the drains, sediment discharges, and reservoir water levels were measured and monitored twice a day beginning April 11th. On April 13th large pulses of sediment were observed in the left drain. It was determined that the sediment was a sign of impending instability and the reservoir was drawn down as rapidly as possible with the outlet gate opened fully. On April 15th, an emergency situation was declared by Apache County and the Sheriff's Department began 24 hour surveillance. On April 19th, the State of Arizona declared a state of emergency.

On May 4th, water was observed flowing into the upstream face of the dam in a slightly depressed "sinkhole" area at elevation 8,205 feet. On May 10th, ADWR notified Apache County that the dam no longer constituted an immediate elevated threat to persons and

property downstream and recommended that continuous emergency observation was no longer necessary. By the end of May, the reservoir level was drawn down to Elevation 8,187 feet and both the left drain and right drain discharge rates dropped to less than 1 gpm. No additional sediment was observed in the left drain. Monitoring was discontinued on June 14th.

## EMERGENCY INVESTIGATIONS

Several investigative tasks were undertaken to identify the character and extent of the seepage flows and damage to the embankment. The investigative tasks included:

- Tracer dye studies and chemical analyses of water.
- Electromagnetic geophysical surveys.
- Exploration drilling and test pit excavation.
- Laboratory testing of selected samples.

### TRACER DYE AND CHEMICAL ANALYSES OF WATER

In order to determine the time it took for the water to flow from the upstream face to the downstream toe of the dam, tracer dyes were introduced into the reservoir and the travel time for the dye to emerge at the weirs was recorded. The tracer dye study was performed by Ozark Underground Laboratory on April 29th and April 30th when the level of the reservoir was at Elevation 8,210 feet and again on May 20th when the level of the reservoir was at Elevation 8,192 feet.

Figure 2 – Dye Test Results: Inserted dye into reservoir and dye discharging from toe drain weirs.

An analysis of the chemical makeup of water in the reservoir from the outlet and from the left abutment drain was performed on the samples collected on April 22nd when discharge rates at the drains ranged between 50 and 70 gpm. An additional analysis was performed on samples collected on June 7th, when the flows from the drains were less than 1 gpm.

### GEOPHYSICAL SURVEYS

Electromagnetic geophysical surveys were performed to estimate the location of seepage of the flow paths. These surveys (known by the trade name of AquaTrack) were performed by Sunrise Engineering, Inc., on April 29th and 30th. The major features of the seepage pattern detected by these surveys are shown in Figure 4 and 5.

### DRILLING AND TEST TRENCH

A total of six exploration bore holes were drilled (3 into the crest and 3 into the upstream face of the dam at the locations shown on Figure 5) during the period between June 28th and July 9th. Each drill hole was logged and representative soil samples and rock cores were collected for future laboratory testing.

A large 50-foot by 50-foot area was excavated to a depth of 4 feet in the upstream face where noticeable water was observed entering the dam during earlier observation activities. A 14-foot deep trench was excavated and logged in the central portion of the larger excavation. The trench was backfilled with excavated clayey soils. The backfilled soils were placed in one-foot lifts and compacted by track hoe bucket to densities approximating the surrounding materials. A composite bentonite geotextile liner was then placed over the entire 50-foot by 50-foot area at the depth of 4 feet. The intent of this liner is to serve as a temporary improvement to safety in the event of uncontrolled short duration impoundments above the elevation of the major flow entrance prior to the permanent repair being performed. A 2-foot layer of clayey soils was compacted over the liner and capped with 2 feet of riprap. This work was performed between July 12th and July 16th.

## SUMMARY OF FINDINGS

### GENERAL

Based on the results of the investigation, it was determined the majority of the seepage through River Reservoir dam flowed through an old slide area near the upstream slope and concentrates in the soil surrounding an old stone drain at the contact between the embankment and the rock foundation on the left abutment. Little if any of the seepage flowed through the foundation.

### FLOW THROUGH SLIDE ZONE IN UPSTREAM FACE

Based on a review of the inspection records available in ADWR's files, the upstream face was originally constructed at a somewhat steep slope of 2H to 1V. The records also

indicate that numerous slide failures have occurred at the maximum section nearly continuously on an annual basis between the years of 1920 and 1949. The reports indicate that additional soils as well as brush and tree branches were placed in the slide areas throughout the years to stabilize the slope to an acceptable condition. A major repair of the dam was completed in 1949 by the U.S. Soil Conservation Service when a major slide due to drawdown occurred earlier in the year. The slide left an 8 ½ foot deep scarp in the crest and was approximately 200 feet wide.

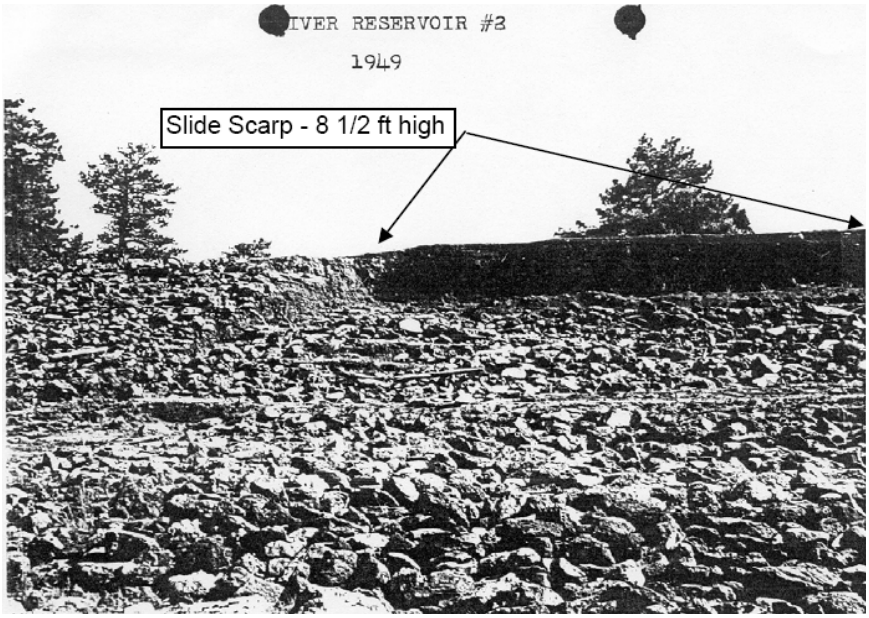


Figure 3 – Historical Upstream Slide (1949)

The repair work completed in 1949 included removing some of the brush and regrading the upstream slope to a 4H to 1V. Apparently none of the slide mass was removed. The drill holes and test pit completed during this investigation confirm this condition. The drill holes (EM-4, 5, and 6) that penetrated the slide mass soils appeared variable with some softer zones interfaced with firmer sections. Small pieces of wood were observed in some of the samples collected from the drill holes. Erratic soil patterns were also observed in the test pit and pieces of wood up to 3 inches in diameter and 18 inches long were uncovered in the excavation.

Although no major slides have occurred since the repair work completed in 1949, there have been recorded incidents of sink holes or depressions redeveloping on the upstream face near the center of the old slide mass. The depressions were observed and the locations surveyed during the years of 1951, 1983, and 1987. Each time the depressions were backfilled with clayey soils. The sink hole and seepage entrance on the upstream face documented during the emergency investigations correlates to the same locations as the depressions reported in earlier years.

The AquaTrack geophysical surveys indicated that there were two broad flow channels where most of the water entered the upstream face (see Figure 4). These flow channels are located within the boundaries of the 1949 slide. The tracer dye studies also confirmed that there were various flow routes where water entered the embankment within the old slide mass.

## CONCENTRATED FLOW ALONG STONE DRAIN

Review of the early inspection reports revealed that the left abutment drain was constructed by placing tabular rocks to form a box shaped opening on the rock foundation having approximate dimensions of 2 feet high by 1 ½ feet wide. Grouting and/or sealing of the rocks were not performed. Conflicting reports state that the drain originally was constructed to relieve water from springs in the left abutment, or for use as a temporary outlet continuing through the dam to the reservoir.

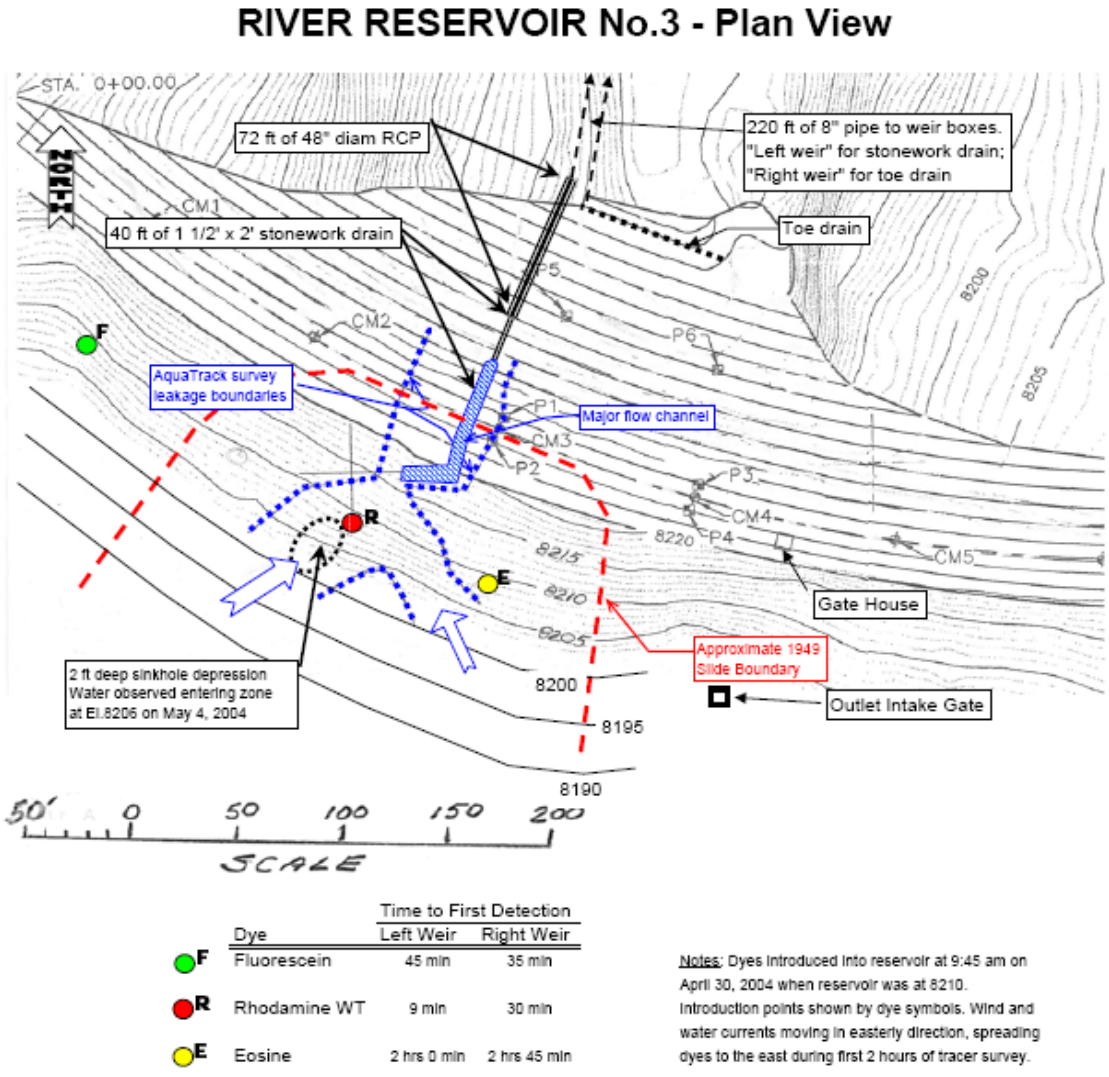


Figure 4 – Results of Investigations and Pre-Repair Features

It was not determined which of these reports was the reason for the drain construction. In 1987, the drain was probed from the downstream dam toe (now about 70 feet upstream from the current toe of the dam) with a half-inch diameter flexible pvc pipe and observed to be open for at least 40 feet. A similar probe was performed during the emergency investigations with the same results. The AquaTrack geophysical surveys indicated a concentrated seepage flow path that coincides with the orientation and elevation with the stone drain. The seepage path continues another 40 feet upstream from the probed end of the drain to a point near the projected base of the slide mass near the upstream face. At this location the concentrated flow path appears to turn west at nearly a right angle.

The drilling program confirmed the AquaTrack surveys. Drill holes EM-2, 4, and 5 were positioned to intercept the concentrated flow path and drill holes EM-1, 3, and 6 were located to penetrate to the outside limits of the flow path. During the rock coring operations, drill holes EM-2, 4, and 5 lost all circulation at the contact between the embankment and the foundation. This is at the approximate level identified by AquaTrack as being the elevation of the concentrated flow channel. The drilling fluid lost in these holes emerged in the weirs several minutes later. The drill holes EM-1, 3, and 6 did not lose any water circulation at this elevation.

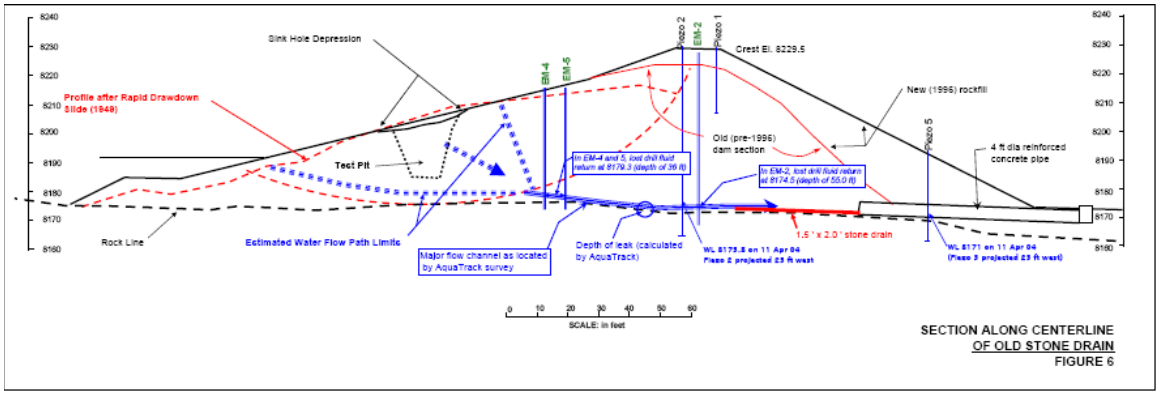


Figure 5 – Results of Investigations (Section View)

# EVALUATION OF POTENTIAL REPAIR METHODS

## INITIAL SCREENING OF OPTIONS

Several methods for the repair of seepage areas were evaluated. These repairs included:

- Complete removal and replacement of the dam.
- Excavation of a “slot” of material in the left abutment, removal of the stone drain, and reconstruction of the removed section.
- Construction of a slurry trench or soil-mix curtain through the embankment into the foundation forming a positive cutoff barrier.
- Placement of a thick clay blanket on the upstream slope in the seepage area.
- Grouting through vertical drill holes in the eroded zone.

- Grouting the entire length of the stone drain.
- Filling the stone drain with a gravel-sand filter drain material
- A combination of two or more of the above options.

Based on our knowledge of the conditions at River Reservoir No. 3 Dam and on our experience in designing economically feasible repairs for leakage problems on other projects, three options were selected for further consideration. These options were:

- Injection grouting through drill holes.
- Construction of a cement-bentonite slurry cut-off wall.
- Excavation of a V-notch cut in the dam down to the stone drain, removal of the drain and reconstruction of the embankment to current day standards.

After additional considerations, the first option of grouting was eliminated, primarily because of several known cases where this method was not successful in stopping severe seepage and piping similar to that experienced at River Reservoir No. 3 Dam.

### SELECTED ALTERNATIVE

Based on the results of the site investigations, historical behavior of the embankment, our understanding of the piping mechanism and findings of the independent reviewers, it was recommendation that the V-Notch Cut be adopted and implemented for the repair of River Reservoir No. 3 Dam. The V-Notch Cut repair alternative addressed the immediate problem of piping and also eliminated the chronic instability of the upstream slope at River Reservoir #3 Dam.

The V-notch was designed to be excavated at 2H to 1V side slopes down to the stone drain. Riprap, rockfill, and clay soils excavated from the cut would be stockpiled in the reservoir area and placed back in controlled lifts after the stone drain was removed. It was assumed that a portion of the excavated clay core would be lost or contaminated. Any shortfall in the clay core would be made up with either clayey soils or rockfill (using a redesigned section) from within the reservoir boundaries, or from an off site source.

## CONSTRUCTION

The repair of the dam consisted of excavating a V notch cut and stockpiling the removed clay, rock fill, and riprap in separate areas. After foundation cleanup, slush grouting and dental concrete the V notch was refilled with the previously excavated clay, rock fill and riprap. All of the stockpiled material was located upstream of the dam in the reservoir.

### Construction Methods and Foundation Treatment

The contractor Stronghold Contracting Inc. started mobilizing equipment the last week in July, 2005 and continued to bring equipment to the site as it was needed. The contractor performed prep work of clearing stockpile areas, safety fencing, and erosion control and started the excavation of the V notch on August 4, 2005. The contractor used a one cubic

yard excavator and 30 ton off-road trucks to remove the material and haul to the stockpiles. A small dozer was used to maintain the haul roads and a front end loader was used to maintain the stockpiles. Approximately 65,000 cubic yards (loose volume) of rock fill, clay and riprap were removed from the dam. The excavation of the V notch was completed the first week of October, 2005.

The Contractor removed 72 lineal feet of 48-inch reinforced concrete pipe, one concrete vault approximately 6 feet 4-inches square and about 125 lineal feet of masonry tunnel and head wall. Numerous logs, tree branches, stumps and rock clusters were remove from the upstream part of the dam. The contractor prepared the foundation bedrock by washing with a high pressure water jet and by hand removal of clay pockets and loose rock. A number of high points were jack hammered off to remove overhangs, steep surfaces and sharp irregularities.


Figure 6 – Excavation of V-Notch

The foundation was given a final high pressure wash and then dental concrete was placed to remove offsets and provide a rounded smooth surface for the embankment. Where the foundation rock was reasonably flat slush grouting was used.

Dewatering was preformed using electric sump pumps and gasoline powered trash pumps. Two sumps were constructed in the upstream side of the dam, one in south east corner of the excavation and the other in the south west corner. Stronghold Contracting, Inc started replacing the fill during the third week of October, 2005. The clay and rock fill lifts were brought up together and the riprap was placed after the fill was topped out. The contractor used a 6 cubic yard front end loader to load material from the stockpiles into off road trucks to transport to the fill. The material was spread with a small dozer. The clay was compacted by wheel rolling and then finishing with a vibratory sheep foot roller. The rock fill was compacted using the vibratory roller. The riprap was hauled to

the upstream side of the dam and then placed using the Excavator. The road grader was used to level and smooth the crest of the dam and to dress the stockpile areas.

**Monitoring system modifications**

The monitoring system includes four new replacement piezometers and three control monuments. They will be used to monitor the continued safe performance of the dam.

**Piezometers**

Four new replacement piezometers were installed in the crest of the dam. These piezometers will allow measurement of the phreatic surface within the dam at the axis and slightly downstream of the axis. The standpipes have 5 feet of screen and the bottoms are capped. They were gravel packed with ¼ inch pea gravel and a bentonite seal was installed above the gravel pack. An inspection frame and lid, locking cap and concrete backfill were installed on the surface.

**Survey Monuments**

Three new replacement control monuments were constructed along the crest of the dam to allow for determining settlement or other movement of the embankment. The monuments were constructed by drilling a 6 inch+/- diameter hole, 6 feet deep and casing it with a 6 inch diameter PVC pipe. A #8 reinforcing bar 6 feet long was installed and backfilled with concrete.

## PERFORMANCE

Since the breach and reconstruction of River Reservoir No. 3 Dam in 2005, has successfully performed through the 2006 irrigation season without incident. Seepage rates have returned to acceptable levels and no instability concerns have been noted.

This positive performance was the result of proactive measures taken early when problems were noted, a design that addressed the root cause of the problem and didn't just attempt to find a cheaper 'Band-Aid' short-term solution, and an aggressive construction schedule that completed the construction in one season.