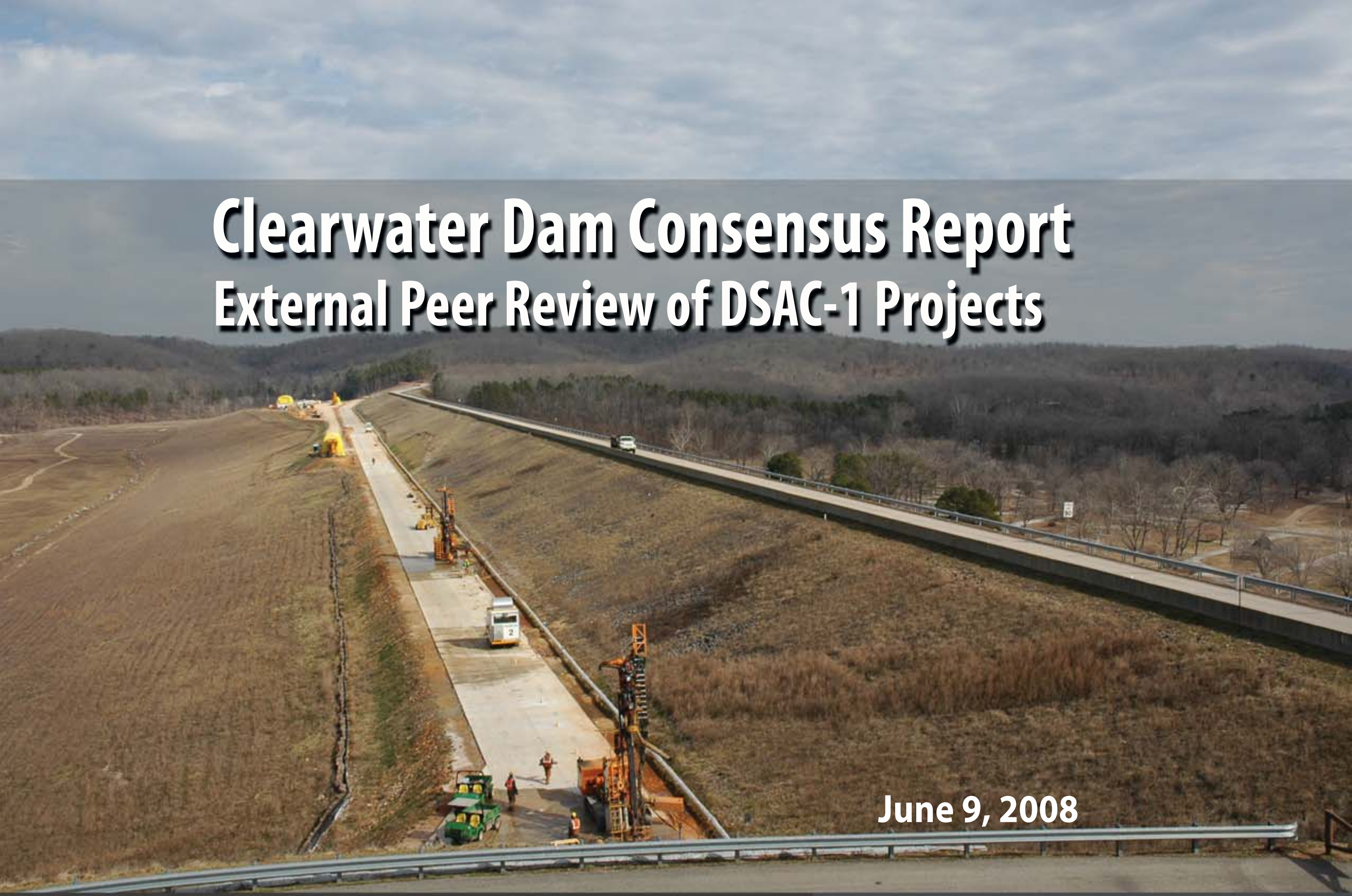
Clearwater Dam Consensus Report
External Peer Review of DSAC-1 Projects



June 9, 2008

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DSAC Class I Dams
Peer Review Panel

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Clearwater Dam (DSAC) Peer Review Team has completed its review in accordance with Contract requirements. All comments, responses, issues and concerns resulting from this Peer Review have been fully addressed.

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Appendices

Executive Summary

The U.S. Army Corps of Engineers (Corps) has designated Clearwater Dam as Class I (Urgent and Compelling) in accordance with the draft EC 1110-2-6064 "INTERIM RISK REDUCTION MEASURES FOR DAM SAFETY." The Dam Safety Action Classification Peer Review Panel, (Panel) concurs with the Corps' designation.

This finding is based on compelling evidence that seepage is occurring at many locations under the embankment since the alluvium under the shells is not filtered against piping into the Karstic dolomite bedrock on which the alluvium was deposited. In addition, the core zone of the dam is not protected against erosion at the bottom of the cutoff trench where it is possibly in contact with open cavities that carry water in the Karst foundation rock. This seepage is likely to create additional sinkholes, similar to the sinkhole in the upstream shell that occurred in 2003, and create conditions that could cause failure of the dam unless remedial measures are implemented. Evidence of increasing seepage with each reservoir filling also indicates that piping may have been initiated at other locations..

Following the occurrence of the pool of record in May 2002, flood storage was evacuated according to the provisions in the approved Clearwater Lake Water Control Manual. If the water level had not been lowered, the dam is likely to have moved rapidly through the progression phase and into the breach formation stage. The Panel believes that there is a reasonable likelihood that similar piping failure modes are developing at other locations under the shells and the cutoff trench. These failure modes are developing slowly under normal pool levels. High pool levels will increase the piping rate at any such locations in proportion to the increase in gradients. If the reservoir is high enough, and if sinkholes develop in the upstream slope, the reservoir is likely to be released through such sinkholes and through the cavities in the Karstic dolomite under the dam. Such events could cause loss of the reservoir and possible breach of the dam. The Panel finds that there is a significant potential for catastrophic failure of Clearwater Dam unless remedial measures are implemented.

Currently the staff at the Little Rock District of the Corps is preparing to install a composite - concrete cutoff wall through the embankment at the center of the core trench, and into the dolomite. The wall will be extended in depth where necessary by grouting on both sides of the concrete wall. Such a cutoff will reduce the probability of failure and extend the life of the dam.

The Panel's conclusions and recommendations are as follows:

1. Immediate Actions

1.1 Update the Emergency Action Plan and Breach Routing Inundation Mapping: A new Emergency Action Plan has been completed as of November 2007. The Little Rock

District is now in the process of updating the surveys and flood routing for the valley downstream from the dam. When these studies are complete, a new set of hydraulic calculations will be made to create inundation maps.

1.2 Reservoir Restrictions: The Little Rock District has established formal pool restrictions based on risk analyses and these restrictions were published in the Interim Risk Reduction Measures Plan dated August 2007. The flood routing on which these pool restrictions were based is being updated. When this update is complete, a new risk analysis will be prepared and the pool restrictions will be changed as needed. The panel concurs with this approach and recommends that, as the measures listed below are implemented, interim risk analyses be prepared to estimate the degree to which the improvements change the risk of failure.

1.3 Instrumentation: Install instrumentation and increase surveillance of all features of the dam that may be deteriorating, especially those due to seepage and piping. The entire existing instrumentation system should be checked to ensure that the readings are reliable. Additional piezometers are needed through the downstream shell with sensing zones in the shell at two or more elevations, in the alluvium, and in the bedrock at a minimum of two elevations. Similarly, piezometers should be installed in the upstream shell to monitor whether the grouting and the proposed cutoff wall reduce the water elevations in the downstream shell. Readings should be taken on a regular basis, during and after any storms or other significant events. Installation of the piezometers should precede the major portion of the grouting described below. The District should consider automation for reading the instrumentation, if automation is practical and provides reliable data.

1.4 Investigation and Grouting: Continue with the ongoing investigation and grouting program to help understand the nature of the Karst dolomite bedrock and to reduce the Lugeon values in that bedrock so that the planned cutoff wall through the dam and bedrock can be installed without downtimes associated with loss of slurry. This grouting will also provide protection against continuation of internal erosion in the solution cavities in the foundation.

2. Short-Term Remedial Actions

2.1 Extend Current Grouting and Exploration Program into Abutments: The left abutment contains significant pervious zones through the epikarst. Pervious zones may exist farther to the left. Seepage has been observed downstream on the left side. Seepage has not been observed downstream of the epikarst in the right abutment. If seepage is occurring on the right side, it may not be observable since the exit point may be underwater. Therefore explorations should be made on the left and right sides of the dam to help judge how far into the abutments the proposed cutoff should extend.

2.2 **Perform a Formal Risk Analysis:** A formal risk analysis has been performed and is recorded in the IRRMP dated August 2007. The panel of consultants for the dam participated in that process. The flood routing on which these pool restrictions were based is being updated by re-surveying the downstream valley and evaluating the population at risk. When this update is complete, a new dambreak flood routing and risk analysis will be prepared and the pool restrictions will be changed as needed. The Panel concurs with this approach and recommends that, as the measures listed herein are implemented, interim risk analyses be prepared to estimate the degree to which the improvements change the risk of failure

2.3 **Design Cutoff Wall:** Design the proposed concrete cutoff wall based on the investigation information from the grouting and exploration program. The longitudinal length and location of the cutoff, as well as its depth, must be selected based on equipment capability, the character of the bedrock, the effectiveness of the grouting and the estimated effect on lowering seepage gradients in the alluvium, in the bedrock, and at the downstream toe.

2.4 **Earthquake-Related Studies**: The earthquake performance for this dam should be evaluated and established as soon as possible so that an integrated solution involving remedial measures needed for earthquake effects and those now ongoing for seepage and piping effects can be developed during design. The earthquake performance of this dam should be evaluated by first carrying out a thorough subsurface investigation of the dam through the upstream and downstream shells and into the alluvium below the shells. Stability and deformations studies may then be made using the new information to determine whether any remediation is needed to mitigate poor performance.

2.5 **Use of Instrumentation Data:** Funding should be included to allow evaluation of the instrumentation data on a regular basis to detect signs of deterioration or the need for action in a timely manner.

3. Long-Term Risk Reduction

3.1 Construct the deep cutoff wall.

3.2 An instrumentation system is being planned to monitor critical aspects of the behavior of the dam throughout its life. Proper evaluation of the data from this program will enable the Corps to take future remedial actions soon after any undesirable conditions.

3.3 The Corps plans to widen the spillway to pass a larger proportion of the PMF flow than is currently possible. The amount of the change in capacity will be dependent on the amount of material that is needed for implementation of the planned remedial measures. When the quantity of material that will be removed from the right side of the spillway is known, the District will evaluate whether the spillway needs to be widened still further. This change will help keep the pool levels lower during a PMF or a near-PMF event. The Panel recommends that an effective concrete sill be installed across the crest line of the spillway. Also, the widened spillway on the right hand side should be protected by a training wall.

3.4 Access to the outlet works controls should be improved so that they can be operated during a large inflow.

1.0 Introduction

1.1 Project Description

Clearwater Dam, in Missouri, is owned and operated by the U.S. Army Corps of Engineers. The main purpose of the dam is flood control. It is also used for fish and wildlife protection and for recreation. Construction was started in 1940 and completed in December 1948. No construction was done from 1943 through 1945 due to World War II.

The location of the dam is shown on Figure 1. The nearest downstream town – Poplar Bluff – is 49.2 river miles from the dam. The town of Piedmont, about 6 miles downstream could be affected by backwaters from the Black River if a major flood occurs. A significant failure will cause loss of life and property in Poplar Bluff and in populated areas in the valley between the dam and Poplar Bluff.

A plan view of the original dam is shown on Figure 2 and a current aerial view is shown on Figure 3. The features of the dam that can be seen on Figure 3 are:

1. The ungated spillway channel far to the right of the right abutment.
2. The outlet channel from the outlet works at the downstream side of the right abutment. A photograph of this channel is shown on Figure 7.
3. The outlet works control tower upstream of the right abutment. A photo of the control tower is shown on Figure 9.
4. The reservoir.
5. The picnic and campground in the area immediately downstream from the toe of the dam.

The original cross section of the highest part of the dam, the valley section, is shown on Figure 4. It shows the shells, the sloping core with a filter zone on the downstream side, and the cutoff trench to the top of bedrock under the bottom of the sloping core. The current cross section of the dam is shown on Figure 5. It shows the alluvium left in place below the upstream and downstream shells. Another plan and a longitudinal profile of the dam are shown on Figure 6. The longitudinal section is vertically exaggerated by a factor of two.

The dam is 4225 feet long at the crest and is an earth fill embankment with a core of clays and silts obtained from the river bed alluvium. From the crest of the dam, the core is sloped in the upstream direction. The upstream slope of the core is 1H:1V (horizontal to vertical) and the downstream slope of the core is 0.5H:1V. The upstream and downstream shell zones of the embankment are compacted pervious gravelly sands obtained from the river bed alluvium. The only description of the filter, to distinguish it from the downstream shell material, is that the filter shall contain not more than 50% larger than 1/4-inch material.

The embankment of the valley section of the dam, shown in profile on Figure 6, is 154 feet high above the top of alluvium in the bed of the Black River near the right abutment. The cutoff trench was constructed through the alluvium from the base of the embankment core to the top of bedrock. The bottom width of the cutoff trench is about 35 feet and the top width is about 155 feet. This 'valley section' of the dam is approximately 2300 feet long.

The left ridge segment of the embankment averages 20 to 25 feet high on the left abutment. It is 1800 feet long. The left abutment itself is composed of residual clays that resulted from decomposition of the dolomite bedrock. Below the residual clays there exists a partially weathered zone of dolomite – referred to as epikarst – which is quite pervious. Below this stratum lies the fresh Karstic dolomite. Pinnacles of partially weathered dolomite extend up from the fresh rock through the epikarst and upper residual clays to heights of 50 feet or more.

Between the valley section and the left ridge section of the dam there is a 150-feet-long transition zone within which the core of the dam was stepped up the left abutment from right to left. The height of the compacted dam on top of the abutment alluvium in this transition zone decreases from 138 feet where the valley section ends to about 25 feet near the top of the left abutment.

The right abutment of the dam is composed of residual soils weathered from the dolomite. A 23-foot diameter, concrete-lined low-level discharge tunnel was constructed through the right abutment. Its alignment on the centerline of the dam, shown on Figure 6, is about 250 feet to the right of the bottom of the right abutment slope.

In 1989, a 3 foot-high parapet wall was constructed on the upstream crest line of the dam to reduce wave overtopping during a potential probable maximum flood event (PMF). The parapet wall can be distinguished on Figure 7 as a dark line on the upstream side of the crest. A guardrail is on the downstream side of the crest.

The downstream slope averages 2.5H:1V. The upstream slope was constructed at an average slope of 3H:1V. In 1989 a berm and an impervious blanket were added on the upstream side to help reduce seepage through the dam that had begun during the first filling in 1950. The average upstream slope is now 4H:1V. The berm extends 600 feet upstream from the original upstream toe of the dam. The top of the blanket is at El. 575. Figure 7 shows the top of this blanket with construction equipment on it.

During construction of the core cutoff trench, two wide joints were found in the bedrock and were treated. The bottom of the core trench was cleaned of loose materials. The soils in the joints were removed and replaced with concrete. Some areas were filled with dental concrete. A concrete slab exists on top of the cleaned bedrock from about Sta. 40+00 to 53+00. The entire core trench extends from Sta. 34+00 to 53+50.

Table 1 shows some vital statistics for the dam.

Table 1
Clearwater Dam Facts and Features

Location: Black River in Wayne and Reynolds Counties, Missouri
Five miles SW of Piedmont, MO
Uses: Flood Control, Recreation and Fish and Wildlife Protection
Datum: 1929 National Geodetic Vertical Datum (NGVD1929)

Feature	Measurement
Maximum Embankment Height	154 ft
Total Crest Length	4225 ft
Spillway Sill Length (uncontrolled)	410 ft
Volume of Embankment	5,500,000 cy
Constructed	
To top of Alluvium	1940-1942
Completion	1946-1948
Embankment Crest Elevation	608 ft
Top Elevation of Parapet Wall on Crest	611 ft
Spillway Crest Elevation	567 ft
Streambed Elevation (top of alluvium)	454 ft
Top Elevation of Seepage Blanket	575 ft
Maximum Design Pool Elevation	607.7 ft
Flood Control Pool Elevation	567 ft
Conservation Pool Elevations	494 ft Oct-May 498 ft Jun-Sep
Record High Pool Elevation (May 20, 2002)	566.7 ft
Pool Elevation at PMF	610.2 ft
Drainage Area	898 sq. mi.
Average Annual Rainfall	46.6 in
Water Surface Area, Top of Conservation Pool	1630 acres at El. 494
Total Storage at Top of Conservation Pool	22,000 acre-feet at El. 494
Total Storage at Top of Flood control Pool	413,700 acre-feet
Top of Pool at PMF	610.2 ft
Gated Outlet Tunnel (Concrete lined)	
Invert Elevation	467 ft
Diameter	23 ft
Length	1177 ft
Flow Rate of Gated Outlet Tunnel	
Conservation Pool at 494 ft	10,350 cfs
Flood Pool at 567 ft	25,000 cfs
Length of Spillway Outlet Channel	
River Miles to Poplar Bluff	49.2 mi.
First downstream town, population	17,000

2.0 Site Visit Observations

2.1 General

Five members of the Peer Review Panel (all except Dr. Poulos) visited the site on February 7, 2007 for the purpose of supporting the development of opinions and recommendations, and preparation of this consensus report. Dr. Poulos visited the site the following day (February 8). The site tour and briefing were conducted by David Howe, Bob Oberle, Leroy Arnold, Mark Brightwell, and Mark Harris of USACE. A summary of the key findings related to our site visit is provided below. Conclusions and Recommendations that are based on the site visit are included in Section 6.

2.2 Pool Level Management

Pool restrictions currently in place are listed in the IRRMP of August 2007 and have been incorporated into the Water Control Action Plan revised December 2007. The staff regulates the pool level at El. 494 in the winter and El. 498 in the summer, although higher levels may be reached during high rainfall periods, since the low level outlet has to be restricted to avoid flooding certain downstream areas. Thus the operation of the reservoir is balanced between the requirement to preserve the safety of the dam while controlling the outflow to prevent loss of life and property damage downstream.

The project staff makes reasonable efforts to operate the release rate to keep the pool level below El. 545 during a flood event, and plans to release the water as fast as possible, without flooding the downstream inhabitants, until the pool is once again down to El. 494 in the winter and El. 498 in the summer. The maximum release rate is 3,800 cfs without flooding the downstream area. Higher release rates will be used to maintain the reservoir elevation at El. 545 or lower. The maximum outlet capacity is 25,000 cfs. The plan of operation is to stay under a release rate of 3,800 cfs unless distress indicators cause concern for the safety of the dam.

2.3 Grouting and Data Collection

The Panel observed an on-going grouting and exploration program. Water pressure testing and grouting operations were being performed from a platform located at El. 575 on the upstream slope of the dam. The program is being performed to fill solution cavities in the foundation, to prepare for installation of a deep concrete wall through the major defects in the foundation, and to investigate geologic conditions. The grouting operations are being performed using state-of-the-art methods for injecting grout and keeping records of conditions found in the foundation as well as grout takes, permeability (Lugeon) measurements and information related to grouting effectiveness. It was reported that some large voids have been found and large grout takes are prevalent at the contact between the base of the embankment and the foundation.

It is the goal of the grouting program to produce information in the following three important areas:

- Investigative information regarding cavities and openings in the rock and filling material or lack thereof.
- Grout takes and permeability (Lugeon) measurements.
- Downstream effects of the grouting on seepage flow based on a comparison of water levels upstream and downstream of the grout curtain.

The Panel was also briefed on an Emergency Action Plan (EAP) that had been developed. The plan is coupled with a comprehensive surveillance plan to have the on site personnel monitor conditions whenever the pool level rises above El. 525. The EAP involving evacuation will be implemented and emergency pool drawdown will be done when signs of distress are observed.

A new plan for Interim Risk Reduction Measures (IRRM), dated August 2007, has been prepared.

2.4 Spillway

The Panel walked over the crest area of the spillway. The spillway is ungated. It is an earth/rock section constructed by making a large excavation into the right abutment. The spillway had been enlarged to approximately double its original width in 1988. That enlargement was carried out because material was required to construct a berm and blanket on the upstream side of the dam. The original spillway contained a reinforced concrete control section with side walls. The enlarged section has only a shallow concrete wall embedded into the spillway crest. There is no right training wall in the spillway. The exit channel is an earth section that discharges into a side canyon downstream from the dam.

3.0 Seepage History and Observations

3.1 Seepage

Seepage flows have been observed at the higher pool levels since the dam was first filled. However, muddy seepage flows have never been observed downstream of the dam. Before drainage systems were installed, seepage began to show up when the pool level reached between Elevations 515 and 520. As the pool rises further, the entire downstream area becomes wet. The greatest concentration of seepage exits near the left abutment.

The Panel notes that the lack of observations of muddy flows needs to be viewed with caution. No direct measurements have been made of the fines that may flow from the exit point downstream of the left embankment or into the French drain systems. To determine whether fines are moving it is necessary to construct a system that will collect the soil particles that may be moved because piping is an intermittent phenomenon. Alternatively, samples can be taken directly from exit points or the French drains (below) on an hourly basis for several days and observed directly, and/or by turbidity testing to help judge the rate of particle removal.

3.2 Installation of French drains

A French drain system was installed along the base of the left abutment in 1972 and in the downstream wet areas. This drainage system collects the seepage below the surface and discharges it downstream. In 1980, an additional French drain system was installed to drain water downstream. This system included a set of vertical drains at the bottom of the French drains that penetrate through the alluvium to bedrock. These vertical drains were filled with coarse sand so that water from the bedrock would flow upward to the 1980 French drain system as needed. After the 1980 French drain system was installed, the downstream area did not become wet or flooded until the pool level rose to El. 525-530.

3.3 Seepage Blanket and Berm

In 1988, a low-permeability seepage berm (clayey blanket) was constructed on the upstream slope of the dam and on the upstream side of the left abutment. After the seepage berm was installed, a pool level of 545 was reached and the downstream area stayed dry, but water was flowing through the drainage system at high rates.

Since 1988, the volume of seepage flowing through the two French drain systems appears to have increased slightly with time, although the measurements made are not sufficient to draw a clear conclusion.

In 2002, the pool level reached a record high elevation of 566.7 feet. During this flood, the historical wet area did not show up until 9 days later. During this 9 day delay, the French drain system was carrying very high flow rates. The USACE concluded that the seepage berm had a pronounced improvement on the seepage indicators downstream.

It is the Panel's judgment that the upstream seepage blanket and berm probably caused a small reduction of the gradients in the upstream shell. Although slightly reduced, these gradients can carry soil from the alluvium and the upstream shell into openings in the bedrock under the alluvium. This process is likely to have caused the sinkhole that was first observed in 2003.

The Panel inspected the historical wet areas downstream and along the base of the left abutment. The reservoir pool level was at El. 494 at the time of the site visit. Although the area was dry on the surface, the downstream French drainage systems were carrying considerable flow. The Panel also observed springs that exit along the base of the left abutment. They were dry during the site visit, although the Panel saw evidence of sediment deposits near the exit points.

Piezometer data have been collected since soon after the first filling of he dam. No significant changes in piezometric levels have been observed. Some instruments have shown increases while others have shown decreases. Settlement monuments are spaced at 100-foot intervals on the crest of the dam, and have shown very little vertical movement over the years.

It was reported to the Panel by Corps personnel that the grouting investigative information has revealed some soft zones in the dam and that the embankment material is not as plastic as anticipated. Soils encountered consisted of silty sand, sandy silts, and silty clays of low plasticity. The softer areas are more prevalent in the lower reaches of the embankment.

3.4 Pool of Record

The pool of record at El. 566.7 feet occurred on May 20, 2002 as a result of a near 60 to70 year storm event, which produced a total average rainfall of 20 inches over the drainage basin. This elevation is just below the spillway crest elevation. The pool was lowered to El. 540 in about 45 days and to El. 500 during the next 30 days. A photograph taken at normal pool is shown on Figure 9 which also shows the outlet control tower. Figure 10 shows the pool at near the maximum level. All shoreline beaches were submerged.

A sinkhole was first observed in January 2003 on the upstream slope at about El. 573, which is above the record pool level, but just below the top of the seepage berm placed in 1988. The hole was near the top of the clay seepage berm and was about 10 feet in diameter and 8 to 10 feet deep. A photograph is shown on Figure 11 of the bottom of the sinkhole after excavation to a depth of 25 feet. At the bottom, the sink hole is about 2 feet in diameter and is filled with the material from above. Figure 12 shows the location of the sinkhole superimposed on two wide joints in the Karst that were found during construction of the cutoff trench. Openings through one or both of these joints are considered to have allowed the sinkhole to form. Photos of the two joints, taken during construction, are shown on Figures 13 and 14. Figure 15 shows one schematic cross section to demonstrate how the sinkhole may have formed.

Repairs were made by filling the sinkhole with compacted clayey fill. The Panel observed the repaired area during the site visit.

4.0 Continuum of Failure Timeline

4.1 Graphic Depiction of Continuum of Failure Timeline

The Panel has developed a graphical depiction of a seepage failure mode continuum and has presented this depiction in a separate memorandum (DSAC Peer Review Panel, December 14, 2006). The failure continuum on Figure 16 summarizes four stages of failure development and three corresponding intervention strategy categories as seepage characteristics progress along the continuum. The various modes of failure are described in Section 5.0.

4.2 Safety in Context of Failure Continuum

The Panel's assessment of the safety of this dam is shown along the Failure Continuum on Figure 17. Our assessment, as shown in this diagram, indicates that a seepage-related failure mode has initiated. Appearance of the sinkhole on the upstream slope of the dam indicates that the continuation phase has been completed and that the dam is entering the progression stage toward failure. During the progression stage the rate of seepage and piping and the corresponding rate of deterioration will significantly increase whenever the pool rises. The heavy red arrow on the right shows that the dam is susceptible to a seepage failure unless remedial measures are taken.

Upon completion of the planned remedial measures for the seepage and piping failure mode, the probability of a seepage and piping failure will be decreased and the life of the dam will be increased. The red arrow to the left on the Failure Continuum is the Panel's current estimate of the improvement. However, instrumentation will be installed in the dam to better judge the actual improvement.

5.0 Dissenting Views

Members of the Panel have been contractually provided a framework to express a dissenting view or views in the form of a "Non-concurrence" report. This report represents the consensus of the entire Panel.

No member of the Panel has provided a dissenting opinion.

Variations in Panel member opinions are represented by the confidence bands presented on Figure 17.

Each Panel member has reviewed this report in its present form.

6.0 Failure Modes and Proposed Risk Reduction Measures

6.1 SPRA Failure Modes

SPRA (Screening Portfolio Risk Assessment) is an internal tool developed by USACE to carry out initial risk characterizations of the USACE dam inventory, and to identify the highest risk projects for risk management decision making.

The Panel concurs that all potential failure modes were identified during the SPRA process completed by the Corps. During the SPRA process the following features of the dam were considered to be inadequate under the conditions listed:

Under Normal, Unusual and Extreme Conditions

- Foundation Seepage and Piping

Seepage and piping or internal erosion of the soil infilling of the Karst features of the foundation was initiated some time ago (likely upon first impoundment). Noticeable increases in seepage occurred as reservoir levels reached higher levels as evidenced by the large wet areas and increased seepage flows downstream. The sinkhole that developed in the upstream slope of the embankment in January 2003 after a reservoir filling is the most significant event indicating that piping is occurring in the solution cavities under the dam.

This sinkhole occurred in one cavity of many that may exist under the dam. It is only a matter of time until additional loss of support under the dam will occur and sinkholes will again form if no intervention is implemented. If sinkholes occur below the reservoir level in the upstream portion of the dam, the reservoir water will be released into the sinkhole and the solution cavities under the dam causing rapid erosion of the embankment material and eventual collapse of the dam into the erosion holes.

- Embankment Seepage and Piping

Investigations into the embankment have shown that the core zone is coarser than anticipated with mainly silty sands with some clay. Initial downstream seepage was very large. A seepage berm consisting of a clay blanket was constructed on the upstream slope of the dam in 1988. This seepage berm reduced the seepage downstream, but the seepage berm did not extend over the contact between the dam and the left abutment. Seepage continues to be observed at high pool levels through the dam in the area of the contact with the left abutment. Gradients during high pool levels will likely be sufficient to cause continuation of piping in the embankment, creating tunnel erosion and eventual loss of the reservoir through piping cavities or through a breach caused by the embankment caving into a large piping cavity.

Under Unusual and Extreme Conditions

- Abutment Seepage and Piping: Evidence indicates that there is considerable seepage in the abutments, particularly at the left abutment. The clay blanket seepage berm is not continuous between the dam and the left abutment. The left abutment is known to contain Karst features. Seepage downstream of the left abutment appears to increase somewhat each time the reservoir rises to levels above El 520 or higher. Seepage through the epikarst could be carrying overburden soils and embankment materials. It is possible that this seepage discharges directly to the river and would be undetectable during routine visual observations. Such seepage could lead to the initiation of a seepage-related failure mode and may cause failure of the dam when the reservoir levels are elevated.

Under Extreme Conditions only

- Erosion of Embankment Toe, Surface and Crest: This condition would occur when the pool levels reach near the crest of the dam. The parapet wall could be undermined by wave action, which may allow flow over the crest that could eventually lead to failure of the dam if the pool remains high long enough.

- Erosion of Spillway and Stilling Basin: This condition would occur during pool levels that exceed the elevation of the invert of the ungated spillway. Erosion of the spillway itself would begin. As the pool rises, the amount of water flowing into the spillway would eventually erode downstream parts of the spillway channel. The existing sill of the spillway probably would be undermined. The outflow from the spillway would cause flood levels in the river downstream that may result in loss of life and property even in the absence of a breach.

- Low Level Outlet Controls: During major floods the controls for the outlet tunnel will be submerged and cannot be operated. Steps need to be taken to enable operation of the outlet works when the pool is in a flood stage.

Due to an Earthquake

- **Foundation Loss of Shear Strength:** The alluvium left in place under the shells of the dam may contain continuous loose deposits of soil which, during an earthquake load could lead to a major undrained shear failure. Insufficient data are available to judge this matter since the alluvium under the shells has not been explored and tested for this purpose and since the appropriate earthquake loads have not been fully established. Personnel of the Little Rock District are preparing to perform the necessary explorations and analyses to better judge the probability of such a failure. The program is expected to be completed during 2008.

- **Deformation due to Earthquake Loads:** An earthquake load may result in deformations of the dam which could result in transverse cracking near the abutment contacts or elsewhere in the dam. Such cracking could lead failure of the dam. Also shear deformations through loose zones in the alluvium could crack the proposed cutoff wall. The effect of deep seated shearing on the cutoff wall should be analyzed prior to installing the wall.

- **Low Level Outlet Controls:** Earthquake loads could cause failure of the tower housing the controls for the outlet works or make them inoperable The operability of the controls should be assessed under varying earthquake loading conditions

6.2 Failure Modes of Primary Concern

The following failure modes have been identified by the Panel to be of primary concern;

- Embankment – Foundation Seepage and Piping. Piping into the Karstic dolomite foundation leading to loss of a major portion of the upstream shell and loss of the pool over a short time. Numerous locations remain, under the alluvium that underlies the upstream and downstream shells, where piping may be occurring at a slow rate under normal pool levels. At high pool levels, the probability of such piping increases and could lead to failure of the dam.

- Embankment – Foundation Stability and/or Strength Loss. An earthquake-induced flow failure (liquefaction) is possible through continuous zone(s) of loose saturated soils in the 35-40 feet thick foundation alluvium. The failure could occur through the downstream or upstream shell and along a roughly horizontal zone in the alluvium. Insufficient data are currently available on the characteristics of the foundation alluvium to judge whether this mode of failure is critical or not.

- Embankment – Abutment Seepage and Piping. Seepage and possible piping has occurred through the epikarst in the left abutment and through an existing gap on the left side of the embankment where the pool is in direct contact with the upstream face of the pervious upstream shell. Seepage has been observed downstream of this location since 1950, when the pool was first filled. There is no significant information available to judge whether piping (internal erosion) is in progress. However, the gradients are high enough that piping is likely to be occurring. The available information indicates that the rate of seepage increases each time the same pool elevation is reached. Therefore the dam may to be deteriorating in this zone and a seepage and piping failure becomes more probable with time.

- Spillway Erosion during Extreme PMF Event. During the lifetime of the dam, the highest pool elevation was 566.6 which occurred on May 20, 2002. This level is 41 feet below the crest and 44 feet below the top of the parapet wall. At 94 percent of the PMF inflow, the pool level would rise to El. 610.9, which is approximately the top of the 3-foot high parapet wall on the crest. Therefore the hydraulic capacity of the existing spillway is inadequate to pass the PMF. This and lesser flows will probably erode parts of the spillway and certainly flood areas downstream resulting in loss of life and property damage Pool levels near these elevations are likely to cause failure of the main embankment.

- Embankment – Erosion. It is anticipated that modest winds will likely topple or overtop some part of the parapet wall during pool levels that may be reached at or near the PMF. A failure of a small portion of the parapet wall could lead to a complete breach of the embankment.

6.3 USACE Proposed Risk Reduction Measures

The Panel has evaluated the proposed risk reduction measures by sorting them into three general categories: 1) immediate, 2) short term, and 3) long-term.

6.3.1 Immediate Risk Reduction Measures

The sinkhole that was first observed in January 2003 was excavated to a depth of 25 feet and filled with compacted soil. The Panel considers that erosion of Karst features is continuing at other locations in the foundation of the dam at the interface with the base of the embankment resulting in the loss of support that could cause additional sinkholes.

The Panel recommends that the pool levels of El. 494 in the winter and El. 498 in the summer be maintained if possible, keeping in mind that rates of release will be governed by their effects on downstream population and properties. The details of the pool restrictions are provided in the Water Control Action Plan of December 2007. This plan should be updated as necessary as the remedial measures are installed. In addition, interim risk analyses at selected stages of completion of remedial measures should be carried out to help understand the effects of the changes. The Little Rock District has engaged a Panel of Consultants to help review the information and to make recommendations for actions that will reduce the risks. The DSAC Panel endorses the use of such a panel to make recommendations on pool restrictions.

The Panel recommends increased surveillance, monitoring and evaluation of the available data. Continual surveillance and evaluation is needed to detect any distress indicators. The instrumentation system should be updated and improved to enable evaluation of critical conditions.

6.3.2 Short-Term Risk Reduction Measures

Grouting of Left Abutment - The Panel notes that an extensive grouting program has been initiated and is progressing during our review. A major effort is under way to reduce the flow rates through the epikarst in the left abutment by grouting it using state-of-the art procedures.

This grouting program is expected to reduce internal erosion in this zone and to help prevent loss of slurry during construction of the concrete cutoff.

Significant Drilling and Grouting in the Bedrock - The purposes of the ongoing drilling and grouting program are to:

- Obtain thorough information about the site geology in the Karstic dolomite under the dam,
- Install two rows of grout, one on each side of the proposed cutoff wall, to help ensure that slurry loss during construction of the cutoff will be small., and
- Make measurements of the Lugeon values in the bedrock, and to evaluate the rippability and the groutability of the bedrock.

During this exploration and grouting program, a cavity about 15 feet wide and about 90 feet in height was found near the location of the sinkhole first observed in January, 2003. The top of the cavity is about 30 feet below the top of rock. Rounded stones covered with what appeared to be residual soil were found near the bottom of the cavity. It is likely that they entered the cavity from soils in the alluvium on top of the bedrock during the current exploration program.

6.3.3 Long-Term Risk Reduction Measures

Construction of a deep concrete cutoff wall has been selected by the Corps for long-term risk reduction. The depth and length of the wall will be finalized when explorations are finished and evaluated. The cutoff wall will be located at the centerline of the cutoff trench beneath the sloping core. It is to be designed to cut off seepage pathways in the foundation and at the contact between the dam and the foundation. This wall will be a composite wall, since grout will be placed at depths greater than the toe of the concrete wall to reduce the gradients for flow through the bedrock.

The design depth of the cutoff wall and the grouting to deeper levels must be carefully evaluated and selected since seepage pathways are likely to remain under the composite wall unless it extends to about 400-600 feet beneath the top of the dolomite foundation rock. Based on the site geology an impervious stratum is thought to exist at that depth although no boring has been drilled to that depth at the site. The deeper the cutoff - the longer the life of this dam. Careful consideration must be given to the seepage through the dolomite and the gradients that will remain at critical locations, such as the downstream toe of the dam, when the wall is in place.

A new thorough instrumentation system is planned to evaluate the dam continually during construction of the cutoff wall and over the long term for observing possible seepage and other events that may cause deterioration or failure of the dam.

Widening of the spillway is planned to allow a larger proportion of the PMF to flow over the spillway. This change would reduce the probability of failure during a PMF event.

The seepage blanket on the upstream side of the dam will be extended to the crest of the dam. The existing seepage blanket currently stops at El. 575 on the upstream face of the dam.

Design and install a new spillway sill with side walls.

Repair the access to the controls in the intake tower for the discharge tunnel so that they are operable during high pool levels.

7.0 Conclusions and Recommendations

7.1 Introduction

The U.S. Army Corps of Engineers (Corps) DSAC (Dam Safety Action Classification) External Peer Review Panel (Panel) has found that the Corps Class I designation (Urgent and Compelling) for Clearwater Dam under EC 1110-2-6064 "INTERIM RISK REDUCTION MEASURES FOR DAM SAFETY" dated May 31, 2007 is appropriate.

A partial piping failure has occurred, which caused a sinkhole high and near the center of the main dam. The sinkhole probably developed over a long period of time, although it was first observed on January 15, 2003 after the pool of record that occurred on May 20, 2002. This sinkhole has been repaired.

The upstream and downstream shells are pervious and overlie the original alluvial deposits that were not removed during construction. The alluvium was penetrated only by the core trench under the sloping core. It is the Panel's opinion that additional sinkholes, similar to the previous sinkhole, could occur at several locations near the known Karstic features in the bedrock. Piping may be occurring at several locations since the alluvium under the shells is not filtered against piping into the Karstic dolomite bedrock and the core zone is not protected against erosion where it may contact the open cavities in the Karst foundation bedrock.

Therefore, the Panel finds that the dam is well into the continuation phase on the continuum to failure. In some locations under the shells, there may be un-observable progression of piping occurring at a slow rate under normal pool elevations. High pool levels will increase the erosion rate at any such locations in proportion to the increase in gradients.

7.2 Panel Recommendations

7.2.1 Immediate Risk Reduction Measures

7.2.1.1 Emergency Action Plan Update: Activate the recently updated EAP, which is included in the IRRMP dated August 2007, to provide warning and/or evacuation of the population at risk downstream of the dam. The EAP has been formulated to keep the interested parties informed of events relating to the safety of the dam, such as reservoir restrictions, changes of release rates, emergency warning system operation, and any events during construction of the proposed cutoff wall that may affect the safety of the dam. At present, the USACE is preparing updated surveys of the valley downstream from the dam. They will then perform new flood routing and dambreak inundation-mapping to evaluate the population and property at risk if the dam were to fail.

7.2.1.2 Reservoir Restrictions: The reservoir restrictions that are currently in place should be maintained until the remedial measures in progress show, based on a revised flood routing and consequences evaluation, that the condition of the dam has been sufficiently improved enough to modify the pool restrictions.

7.2.1.3 Improve Instrumentation: Install instrumentation and increase surveillance of all features of the dam that may be deteriorating. The entire existing instrumentation system should be checked to ensure that the readings are reliable and the instruments repaired as necessary. Additional piezometers must be installed through the downstream shell with sensing zones in the shell at two or more elevations, in the alluvium, and in the bedrock at a minimum of two elevations. Readings should be taken and evaluated on a regular basis and during and after any significant storms as well as after an earthquake or any other event that could affect the safety of the dam. Consideration should be given to automating the instrumentation.

7.2.1.4 Investigation and Grouting: Continue with the ongoing investigation and grouting program to help understand the nature of the Karst dolomite bedrock and to reduce the Lugeon values in the bedrock so that the planned cutoff wall through the dam and bedrock can be installed without downtimes associated with loss of slurry. This grouting will also provide some protection against continuation of internal erosion in the solution cavities in the foundation.

7.2.2 Short-Term Risk Reduction Measures

7.2.2.1 Extend Current Grouting Operations Into Abutments: Previous investigations and seepage observations indicate considerable seepage through the abutments and particularly the left abutment. Extension of the grouting into the abutments will reduce the potential for continuation of internal erosion in the abutments and will provide information for understanding the nature of the Karstic dolomite bedrock in the abutments.

7.2.2.2 Perform a Formal Risk Analysis: A formal risk analysis should be performed considering alternative reservoir restriction levels and downstream consequences to assist with project decision making and evaluation of reservoir operation restrictions.

7.2.2.3 Cutoff Wall: Design the proposed cutoff wall. The longitudinal length and location of the cutoff, as well as its depth, must be selected based on equipment capability, the character of the bedrock, and the effect on lowering seepage gradients in the alluvium, in the bedrock and at the downstream toe.

7.2.2.4 Earthquake-Related Studies: The earthquake performance for this dam should be evaluated and established as soon as possible so that any interaction between remedial measures that could be needed to mitigate poor performance during an earthquake and those now ongoing for seepage and piping effects, can be taken into account during design. The earthquake performance should be evaluated by first carrying out a thorough subsurface investigation of the dam through the upstream and downstream shells and into the alluvium below the shells. Stability and deformations studies may then be made using the new information to determine whether any earthquake-related remedial measures are needed.

7.2.2.5 Use of Instrumentation Data: Funding should be included to allow evaluation of the instrumentation data on a regular basis to detect signs of deterioration or the need to action in a timely manner.

7.2.3 Long-Term Risk Reduction Measures

7.2.3.1 Deep Partial Cutoff: Construction of a cutoff wall has been selected by the Corps and its consultants for long-term risk reduction. The depth of the cutoff wall will be finalized by the Corps as soon as enough information is available from the current intensive exploration and grouting program. The cutoff will be located to pass through the center of the cutoff trench beneath the core. It will need to be designed so that the probability of a seepage-and-piping failure mode – the most critical failure mode for this dam – will be conservatively addressed.

The depth of the cutoff wall is a serious concern since the wall can not be installed deep enough to reach a possible impervious barrier that may exist 400 feet to 600 feet beneath the top of bedrock under the dam. The cutoff wall will therefore be a partial cutoff. Its depth will vary across the dam. Zones below which it is currently practical to install a concrete cutoff wall will be improved by grouting to deeper depths where needed. Thus the cutoff wall will be constructed as a composite concrete and grout curtain wall. When suitably designed and installed, the cutoff is expected to reduce the probability of failure and to increase the useful life of the dam due to a seepage and piping mode of failure

7.2.3.2 An instrumentation system is being planned to monitor critical aspects of the behavior of the dam throughout its life. Proper evaluation of the data from this program will enable the Corps to take future remedial actions soon after any undesirable conditions arise. The instrumentation also will be installed to monitor the expected reduction of risk due the measures during and after they are completed.

7.2.3.3 The Corps plans to widen the spillway to pass a larger proportion of the PMF flow than is currently possible. This change will help keep the pool levels lower during a PMF event. The Panel recommends that the spillway crest be completed with a suitable concrete sill throughout the width of the spillway channel and with a training wall on the right hand side of the spillway. The left side currently has a training wall in place.

7.2.3.4 Improve access to the outlet works controls so that they can be accessed during high pool levels.

Appendix A – Figures

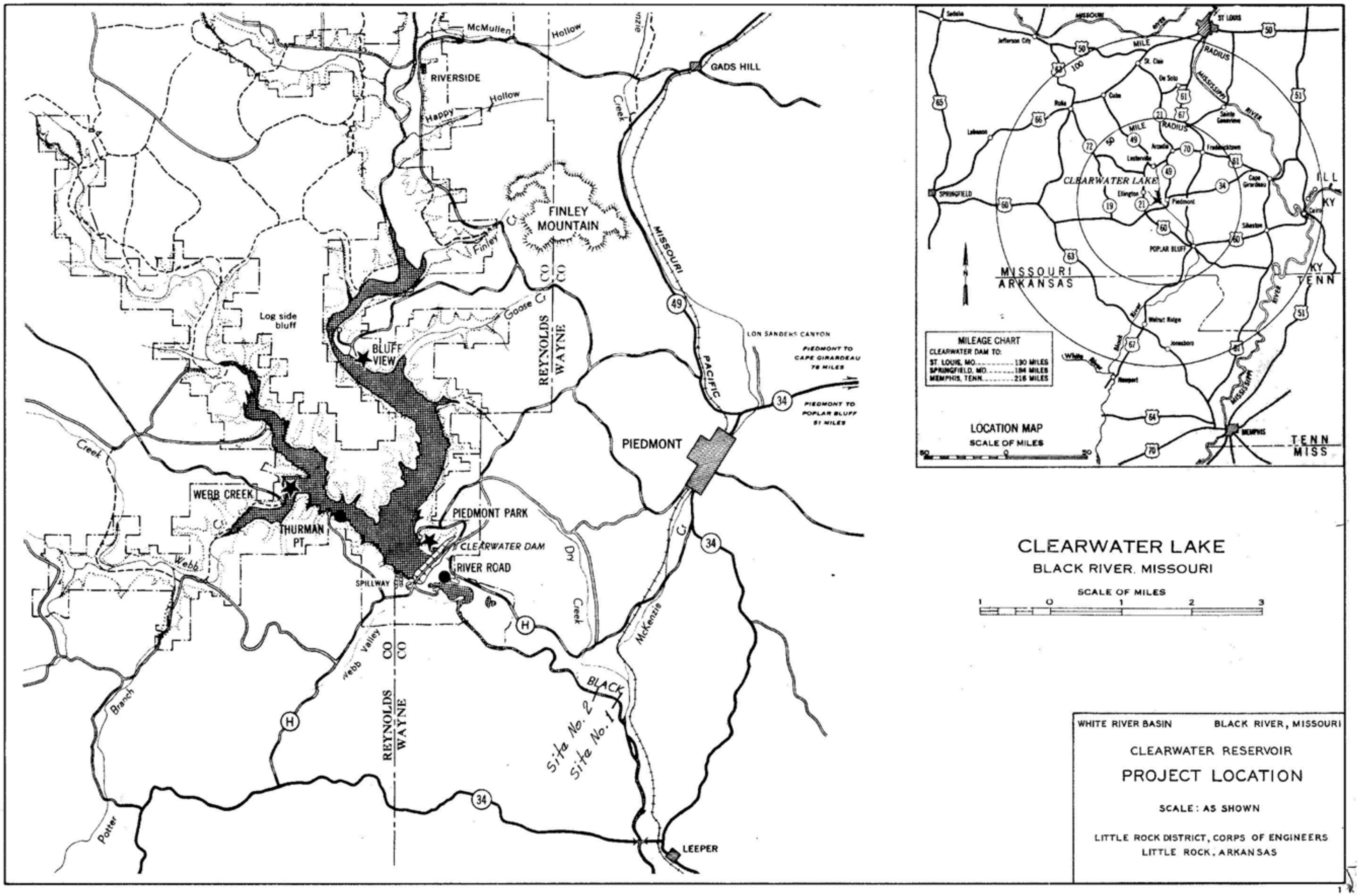


Figure 1. Location Plan

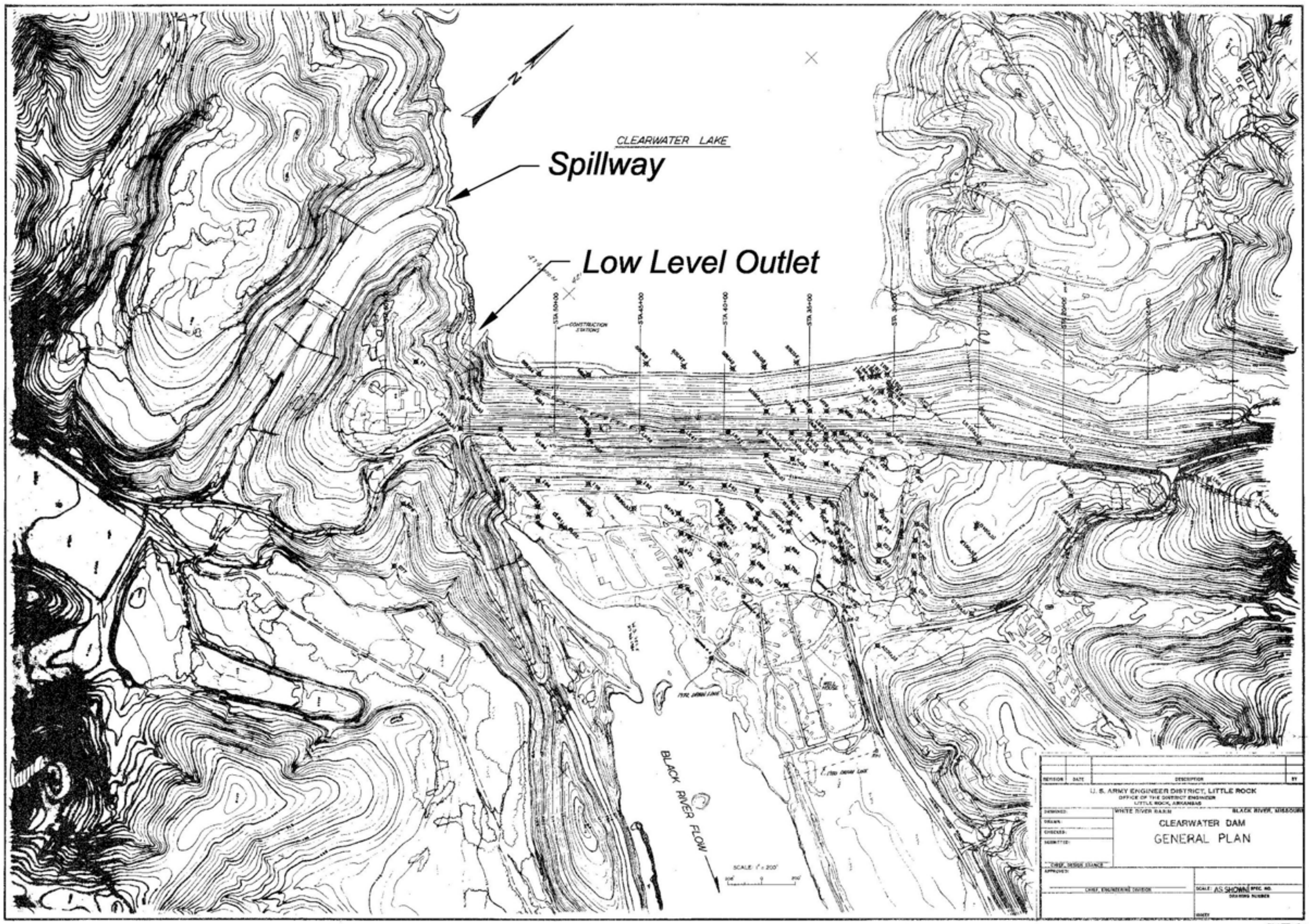


Figure 2. Original Plan View

Figure 3. Current Aerial View

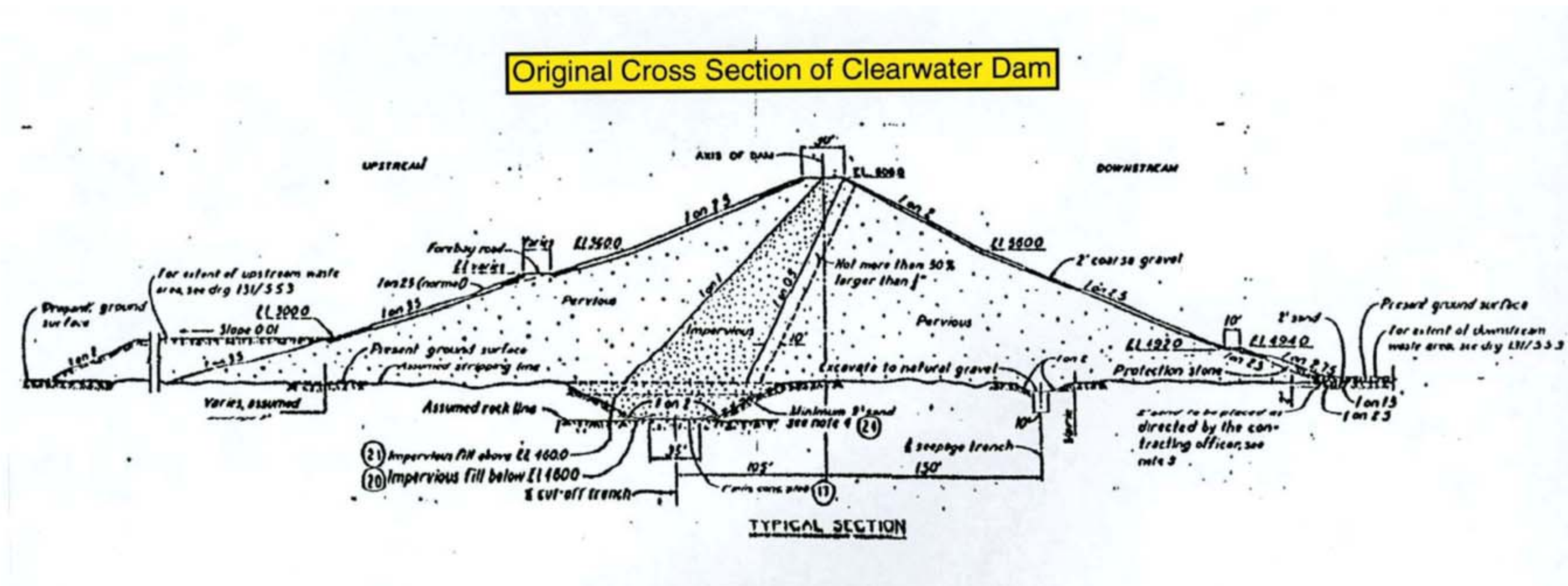


Figure 4. Original Cross Section

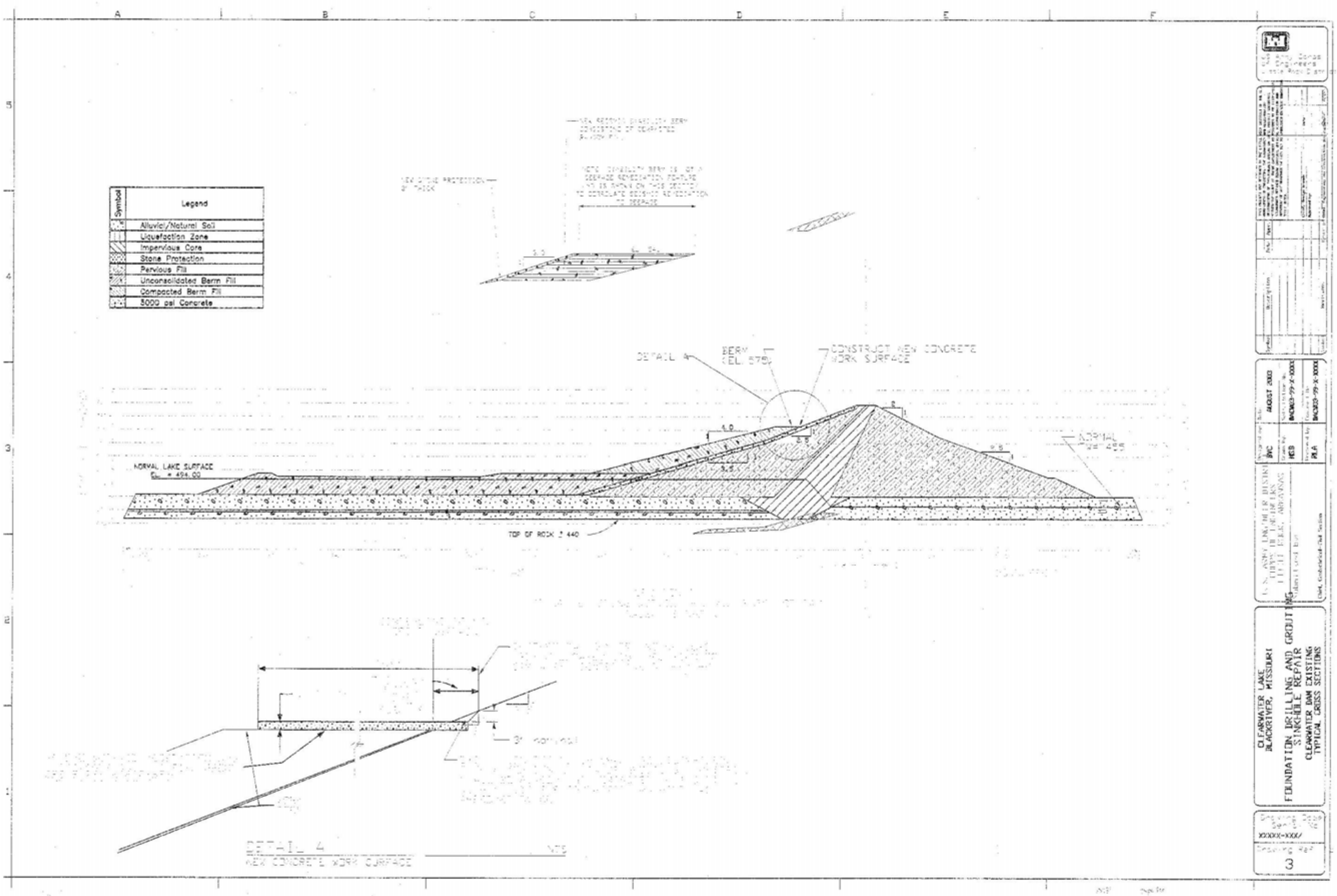


Figure 5. Current Cross Section

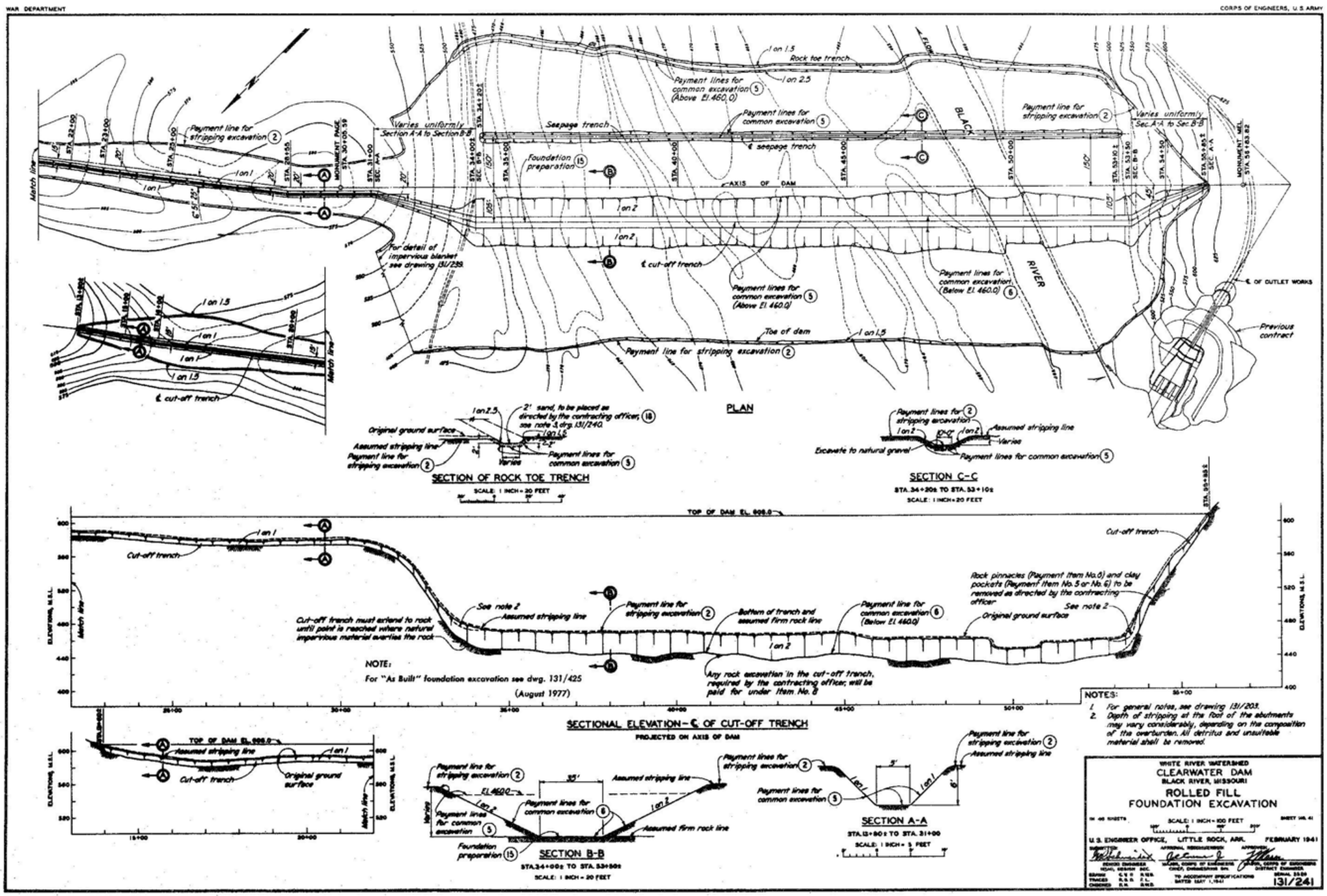


Figure 6. Plan and Profile

Figure 7. Low Level Outlet Channel

Figure 8. Parapet Wall and Berm

Figure 9. Low Level Outlet Control Tower

Figure 10. Record Pool

Figure 11. Sinkhole After Excavation

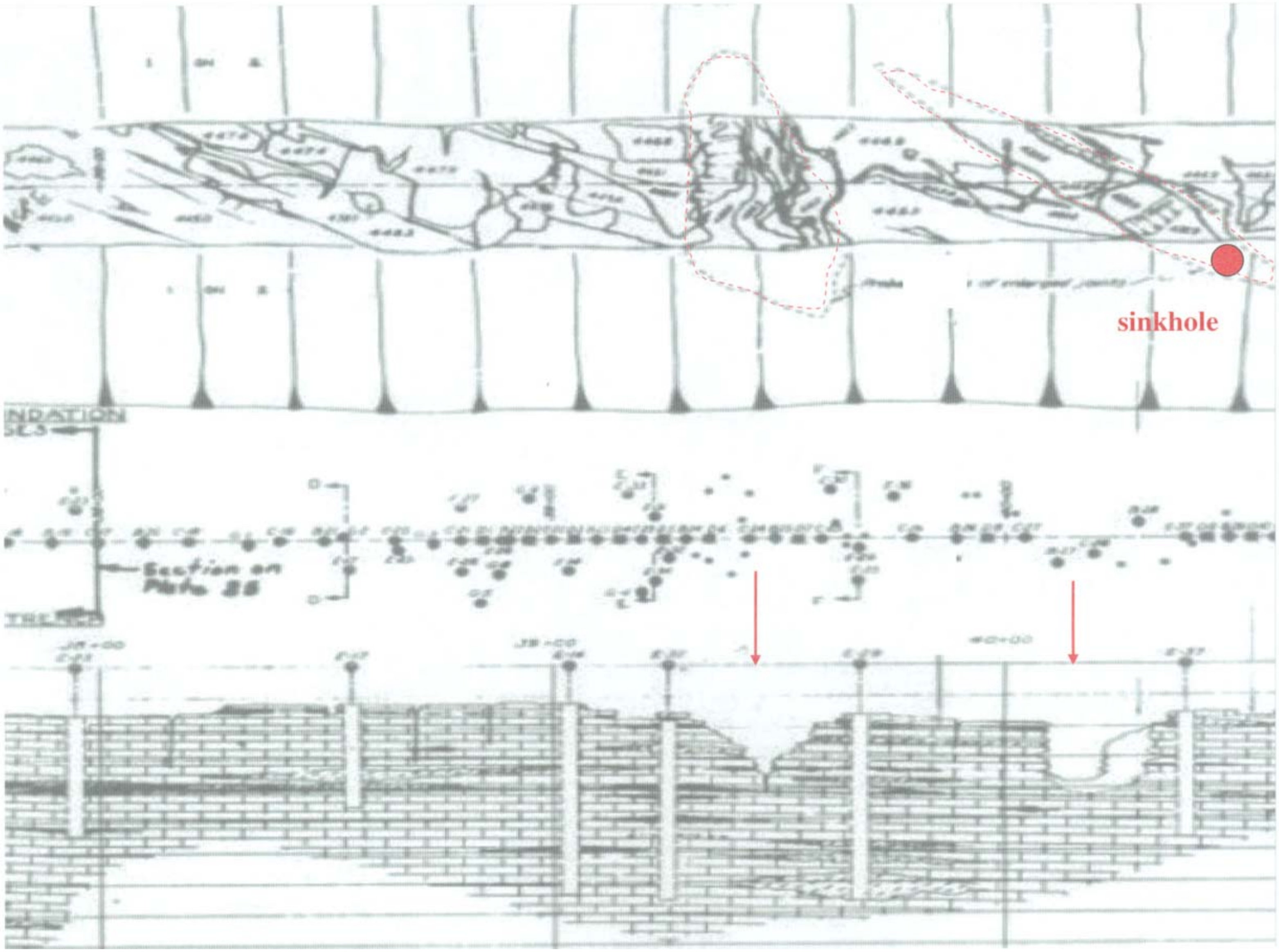
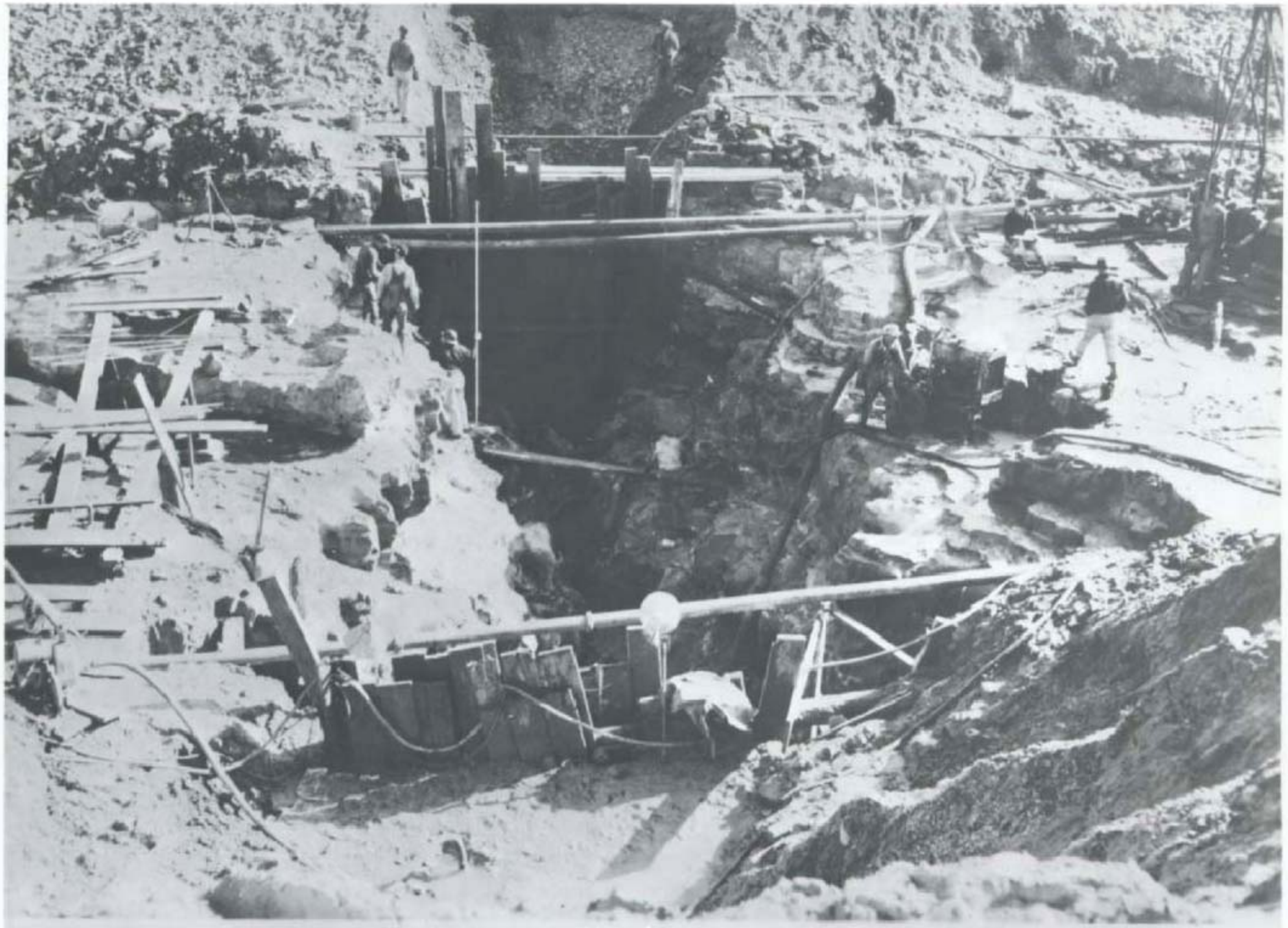


Figure 12. Sinkhole Location Plan



Looking S from 175' US of station 39 + 20: Open joint in cut-off trench foundation.

Figure 13. Joint at Sta. 39+20

Looking NW from 35' U.S. of station 40 + 15: Open joint in cut-off trench foundation.

Figure 14. Joint at Sta. 40+15

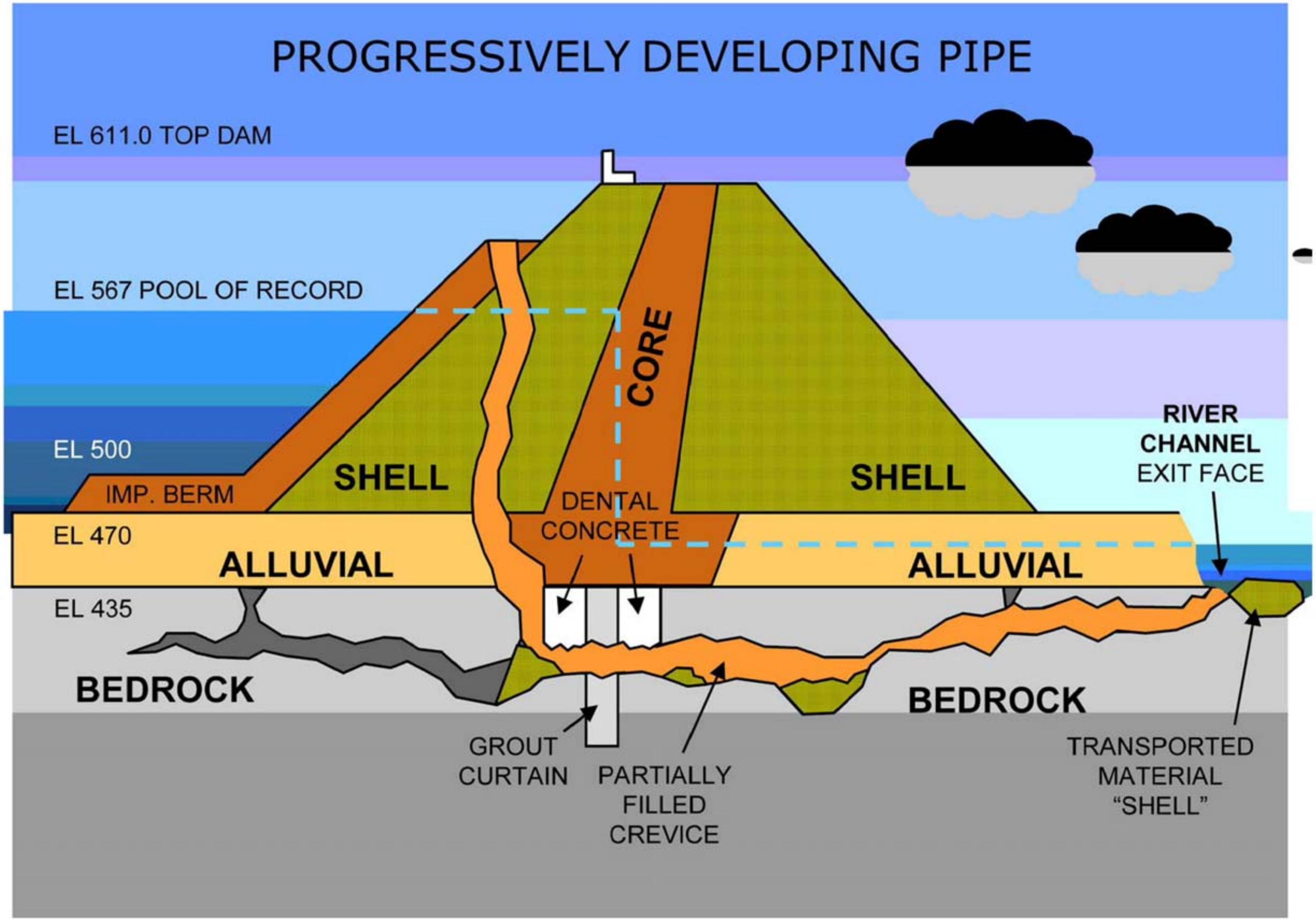


Figure 15. Schematic Section through Sinkhole

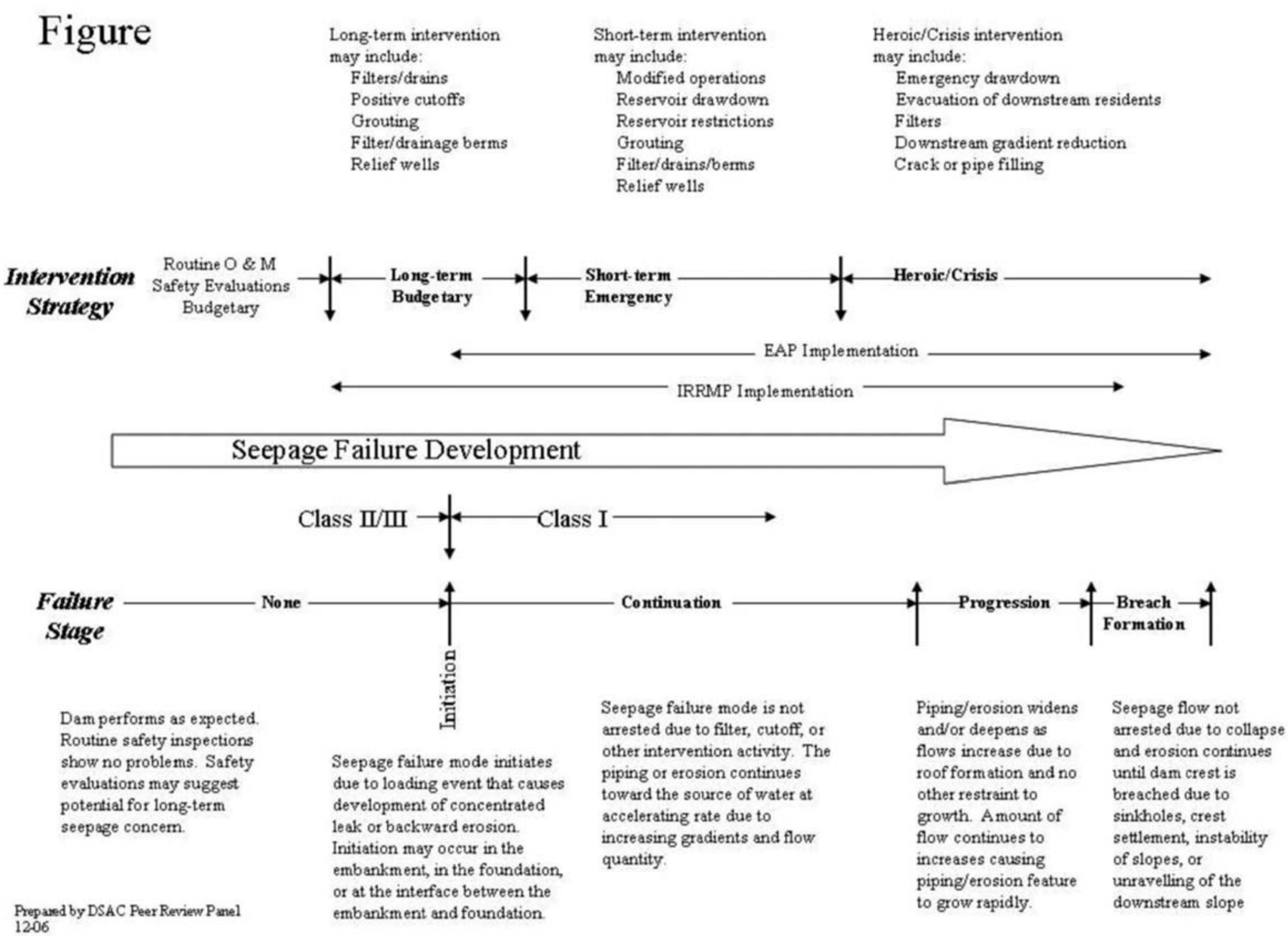


Figure 16. General Continuum to Failure

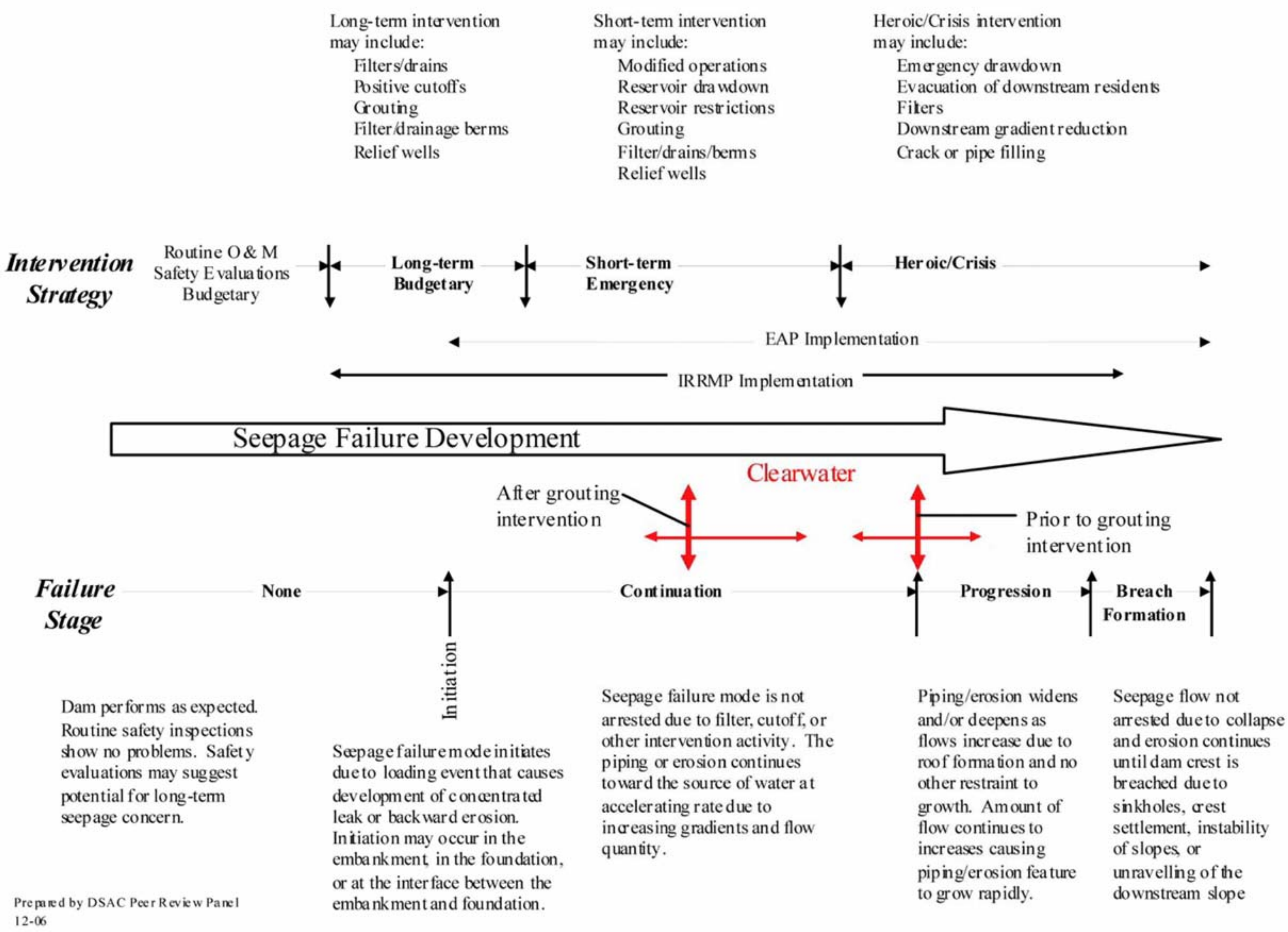


Figure 17. Clearwater Continuum to Failure

Appendix B – References and Sources of Factual Data

The following documents were used to a greater or lesser extent for preparation of this report:

1939 USACE, Little Rock District, Section II – Regional Geology, Clearwater Dam, May.

1941 USACE, Little Rock District, Foundation Completion Report, Vol. II, Plans for Dam and Appurtenant Works.

1979 USACE, Little Rock District, Clearwater Dam, Left Abutment Seepage Study. November

Volume I	Text
Volume II	42 Plates
Volume III	71 Plates
Appendices A	Correspondence
Appendices B	Reports referenced
Appendices C	Boring Logs

1980 – 1982. USACE, Southwestern Division, Laboratory Results of Classification Tests, Clearwater Dam, Little Rock District, SWDED-LL Reports:

13087	May 1, 1980	13220	February 12, 1981
13146	October 8, 1980	13222	February 25, 1981
13190	December 10, 1980	13231	March 16, 1981
13194	December 19, 1980	13240	March 30, 1981
13209	January 26, 1981	13284	July 10, 1981
13220	February 12, 1981	13472	September 7, 1982

1981 USACE Little Rock District, Clearwater Dam. Comprehensive Seepage Analysis and Report 1949 to 1981, August.

1982 USACE, Little Rock District, Clearwater Dam, Seismic Analysis Report, Volume I, August, Volume II – 14 Plates, August 1981, revised October 1982.

1989 USACE, Little Rock District, Clearwater Dam, Grouting Completion Report, Right Abutment Sta. 53+00 to Sta. 56+55, July.

2002-2003 USACE, Little Rock District, Field Office at Clearwater Dam, Record of Reservoir levels for 2002 and 2003.

The following documents were provided on compact discs:

2002 Photographs of May 2002 pool of record.

2003 Photographs of excavation for sinkhole investigation and slides used for presentation.

2003 Geophysical Survey data by U.S. Bureau of Reclamation, Engineering Research and Development Center and Kansas Geological Survey. Sonic drilling photographs. Graphs of piezometer readings.

2003 Clearwater Dam 2003 Annual Report. Photographs during construction circa 1939-1941 and circa 1946–1948, and 1959.

2003 Risk Categorization for Dams, Report of Steering Committee for the Association of State Dam Safety Officials (ASDSO), April.

2003 USACE, Little Rock District, Draft Specification Section 02249 – Foundation Drilling and Grouting, for sinkhole Repair, September, 8 Plates.

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2003 Anderson Engineering Consultants, Gradation Curves for samples of clay core, upstream shell, and natural alluvium, September 22 and 25.

2003 Kansas Geological Survey, BOR, Conclusions on Geophysical Investigations, Clearwater Dam, September 22, 20 Figures.

2003 U.S. Army Engineering Research and Development Center, Draft preliminary Report on Geophysical Investigation of Foundation Conditions, Clearwater Dam by Troy R. Broslen and Julie Kelly, August 11, 20 pp.

2003 Kansas Geological Survey, University of Kansas Center for Research Inc., Seismic Investigation of Sinkhole on Clearwater Dam, Preliminary Report by Richard D. Miller, Julian M. Ivanor, David R. Laflen, and Joe M. Anderson, May 30, 36 pp.

2004 USACE, Little Rock District, Clearwater Dam, DRAFT, Safety Assurance Program Evaluation Report, April 30.

2004 USACE, Little Rock District, Clearwater Dam Major Rehabilitation Report, June.

2005 FMSM Seismic Performance Assessment, Clearwater Dam, Black River, Missouri, June.

2006 Presentation by Corps of Engineers Headquarters personnel on procedures for classification of DSAC dams and for external review of results, Pittsburgh, PA, October.

2006 Presentation by Little Rock District on history of Clearwater Dam, Pittsburgh, PA, October.

2007 Interim Risk Reduction Measures Plan for Clearwater Dam, Corps of Engineers, Little Rock District, August.