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## Phase 1 Inspection Report: National Dam Safety Program. Mississippi - Kaskaskia - St. Louis Basin. Cadet Mine Tailings Dam, Washington County, Missouri

International Engineering Company, Inc. Consulting Engineers, San Francisco, California

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# MISSISSIPPI-KASKASKIA-ST. LOUIS BASIN

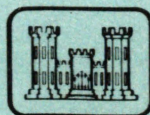
CADET MINE TAILINGS DAM  
WASHINGTON COUNTY, MISSOURI  
MO 30715

*Non-Depository Item*

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## PHASE 1 INSPECTION REPORT NATIONAL DAM SAFETY PROGRAM



**United States Army  
Corps of Engineers**

*... Serving the Army  
... Serving the Nation*

### **St. Louis District**

PREPARED BY: U. S. ARMY ENGINEER DISTRICT, ST. LOUIS

FOR: STATE OF MISSOURI

FEBRUARY 1980

*Incl 1*



DEPARTMENT OF THE ARMY  
ST. LOUIS DISTRICT, CORPS OF ENGINEERS  
210 NORTH 12TH STREET  
ST. LOUIS, MISSOURI 63101

IN REPLY REFER TO

SUBJECT: Cadet Mine Tailings Dam (MO 30715)

This report presents the results of field inspection and evaluation of the Cadet Mine Tailings Dam. It was prepared under the National Program of Inspection of Non-Federal Dams.

SUBMITTED BY:

*Paul R. Liani*  
Chief, Engineering Division

29 April 80  
Date

APPROVED BY:

*Robert J. Lacey*  
Colonel, CE, District Engineer

1 May 80  
Date

CADET MINE TAILINGS DAM  
WASHINGTON COUNTY, MISSOURI

MISSOURI INVENTORY NO. 30715

PHASE I INSPECTION REPORT  
NATIONAL DAM SAFETY PROGRAM

PREPARED BY  
INTERNATIONAL ENGINEERING COMPANY, INC.  
CONSULTING ENGINEERS  
SAN FRANCISCO, CALIFORNIA

UNDER DIRECTION OF  
ST. LOUIS DISTRICT, CORPS OF ENGINEERS  
FOR  
GOVERNOR OF MISSOURI

FEBRUARY 1980

PHASE I REPORT  
NATIONAL DAM SAFETY PROGRAM

|                    |                                 |
|--------------------|---------------------------------|
| Name of Dam        | Cadet Mine Tailings Dam         |
| State              | Missouri                        |
| County             | Washington                      |
| Stream             | Unnamed Tributary to Mill Creek |
| Date of Inspection | 27 August 1979                  |

Cadet Mine Tailings Dam, I.D. No. 30715, was inspected by two civil engineers from International Engineering Company, Inc. of San Francisco, California. The dam is owned by Hornsey Brothers Mining Company of Potosi, Missouri. The purpose of the inspection was to assess the general condition of the dam with respect to safety. The assessment was based on an evaluation of the available data, a visual inspection, and an evaluation of the hydrology and hydraulics of the site to determine if the dam poses hazards to human life or property. The purpose of the dam is to impound tailings from a barite separation and beneficiation operation.

Cadet Mine Tailings Dam was inspected using the "Recommended Guidelines for Safety Inspection of Dams" furnished by the Department of the Army, Office of the Chief of Engineers. Based on these Guidelines, this dam is classified as intermediate size. The St. Louis District Corps of Engineers has classified this dam as having a high downstream hazard potential to indicate that failure of this dam could threaten life and property. The estimated damage zone provided by the St. Louis District Corps of Engineers extends approximately five miles downstream of the dam. Information provided by the Corps of Engineers indicates that eight dwellings and two railroad bridges are within this damage zone.

The results of the inspection indicate an absence of facilities for discharging flood water, inadequate freeboard, and that the dam does not meet the criteria given in the Guidelines for a structure with the size and hazard potential of Cadet Mine Tailings Dam. As an intermediate size dam with a high hazard potential, the Guidelines specify that the discharge capacity and/or storage capacity should be capable of safely handling the Probable Maximum Flood (PMF) without overtopping the crest. The PMF is the flood that may be expected from the most severe combination of critical meteorologic and hydrologic conditions that are reasonably possible in the region. It was calculated that the impoundment can retain the 100-year flood (a flood having a one percent chance of being equalled or exceeded in any one year) without overtopping the dam. It was also estimated that the impoundment can retain 75 percent of the PMF without overtopping the crest. However, the impoundment cannot retain the PMF without overtopping the embankment.


Adequate overflow facilities and/or freeboard should be provided so that the impoundment can handle the PMF without overtopping the crest and without significant erosion of the embankment.

Seepage observed at the dam toe should be drained to reduce the possibility of weakening foundation materials by saturation.

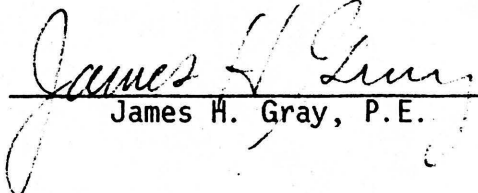
Seepage and stability analyses of this dam comparable to the requirements of the "Recommended Guidelines for Safety Inspection of Dams" are not available. These studies should be performed by a professional engineer experienced in the design and construction of tailings dams and should be made a matter of record. The necessary data for these analyses would be obtained from additional investigations. The investigation would consist of field exploration and soil sampling, a laboratory testing program, and an engineering study to evaluate the stability of the dam. Based on the results of these analyses, remedial measures may become necessary. Remedial work should be performed under the direction of an engineer experienced in the design and construction of tailings dams.

An inspection and maintenance program should be initiated. Periodic inspections should be made and documented by qualified personnel to observe the performance of the dam.

It is recommended that the owner take action to correct the deficiencies described.

  
Kenneth B. King, P.E.

  
Stanley H. Kline, P.E.

  
James H. Gray, P.E.



OVERVIEW OF CADET MINE TAILINGS DAM - I.D. NO. 30715  
FROM CREST OF EAST LEG TOWARD NORTH LEG

PHASE I INSPECTION REPORT  
NATIONAL DAM SAFETY PROGRAM  
CADET MINE TAILINGS DAM  
ID NO. 30715

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PHASE I INSPECTION REPORT  
NATIONAL DAM SAFETY PROGRAM  
CADET MINE TAILINGS DAM - ID NO. 30715

SECTION 1 - PROJECT INFORMATION

1.1 GENERAL

a. Authority. The National Dam Inspection Act, Public Law 92-367, authorized the Secretary of the Army, through the Corps of Engineers, to initiate a program of safety inspection of dams throughout the United States. Pursuant to the above, the St. Louis District, Corps of Engineers, District Engineer directed that a safety inspection of the Cadet Mine Tailings Dam be made and authorized International Engineering Company, Inc. to make the inspection.

b. Purpose of the Inspection. The purpose of the inspection was to assess the general condition of the dam with respect to safety, based on available data and visual inspection, to determine if the dam poses hazards to human life or property.

c. Evaluation Criteria. Criteria used to evaluate the dam were furnished by the Department of the Army, Office of the Chief of Engineers, in "Recommended Guidelines for Safety Inspection of Dams". These Guidelines were developed with the help of several Federal agencies and many state agencies, professional engineering organizations, and private engineers.

1.2 DESCRIPTION OF PROJECT

a. Description of Dam and Appurtenances.

- (1) Cadet Mine Tailings Dam is an L-shaped earthfill dam that is used to impound tailings from a barite separation and beneficiation operation. The north leg of the dam is a cross-valley embankment and the east leg is constructed on the eastern ridge of the drainage. The dam has not been in operation since October 1978. The tailings consist of reddish-brown soft silty clay, which were deposited as a slurry in a water environment.
- (2) The dam has no spillway or regulating outlets. Overflow would pass over the dam crest low point at Station 8+00 (Plates 3 and 4).

b. Location. The dam is located in the northeastern portion of Washington County, Missouri, as shown on Plate 1. The dam, shown on Plate 2, is located in Section 26, Township 38 North, Range 3 East.

c. Size Classification. Cadet Mine Tailings Dam is greater than 40 feet but less than 100 feet high, and the impoundment storage is less than 50,000 acre-feet; therefore, this dam is classified as an intermediate size dam in accordance with the "Recommended Guidelines for Safety Inspection of Dams".

d. Hazard Classification. This dam is classified as having a high hazard potential by the St. Louis District Corps of Engineers. The estimated damage zone, as provided by the St. Louis District Corps of Engineers, extends approximately five miles downstream of the dam. Information provided by the Corps of Engineers indicates that eight dwellings and two railroad bridges are within this damage zone.

e. Ownership. This dam is owned by:

Hornsey Brothers Mining Company  
P.O. Box 309  
Potosi, MO 63664

f. Purpose of Dam. The purpose of the dam is to impound the tailings from a barite separation and beneficiation operation.

g. Design and Construction History. No written design or construction data were available. Information obtained from John, Lewis, and Walter Hornsey, partners of Hornsey Brothers Mining Company, indicated that construction of a starter dam began in 1964. After construction of the starter dam, sand and angular gravels, finer than 3/4-inch, from the mill operation were used to raise the dam. The tailings impoundment operation was shut down by the U.S. Department of the Interior, Mining Enforcement and Safety Administration (MESA) on 5 October 1978. No further dam construction or conveyance of tailings to the impoundment has occurred since that date.

h. Normal Operating Procedures. Prior to the shutdown of the tailings impoundment operation, fine barite tailings were discharged in a slurry form from the mill and desposited by gravity flow into the impoundment near the left abutment. Tailings flowed across the drainage adjacent to the north leg of the dam, and then upstream along to the east leg of the dam. Water collected at the upstream end of the impoundment was recycled back to the mill. Water collected in a pond below the east leg of the dam was pumped into the impoundment through a 10-inch diameter steel inflow pipe located at Station 21+93 (Plate 3). The water was used in the milling operation. No tailings have been conveyed to the impoundment since October 1978. The outflow of surface runoff, if great enough, would pass over the dam crest low point at Station 8+00 (Plates 3 and 4A). The inflow pipe would not function as an outlet pipe because of the presence of a pump in the pipeline. No operating records for this dam are known to exist.

### 1.3 PERTINENT DATA

Field surveys were made by Booker Associates, Inc. of St. Louis, Missouri, on 11 September 1979. Field measurements are valid as of the dates of inspection and survey. The survey data is presented on Plates 3 through 5.

a. Drainage Area. 47 acres (Surdex aerial photograph, scale: 1 inch = 1000 feet, 14 June 1978).

b. Discharge at Damsite.

- (1) Outlet pipe - There is no outlet pipe at this dam. Not applicable.
- (2) Spillway - There is no spillway at this dam. Not applicable.
- (3) Maximum experienced outflow at damsite - No available information.

c. Elevation (Feet above M.S.L.)<sup>1/</sup>

- (1) Top of dam - Varies from El. 834.2 to El. 844.7.
- (2) Streambed at downstream toe of dam - El. 743.6.
- (3) Maximum pool (PMF) - El. 834.7.
- (4) Operating pool (pool level on the date of survey) - El. 829.6 on 11 September 1979.
- (5) Tailings surface adjacent to dam - Varies from El. 829.8 to El. 832.9.

d. Reservoir.

- (1) Length of maximum pool (PMF) - 2000 + feet (Surdex aerial photograph, scale: 1 inch = 1000 feet, 14 June 1978).
- (2) Length of operating pool (pool on date of survey) - 500 + feet (Surdex aerial photograph, scale: 1 inch = 1000 feet, 14 June 1978).
- (3) Length of impounded tailings - 1900 + feet (Surdex aerial photograph, scale: 1 inch = 1000 feet, 14 June 1978).

e. Storage Above Tailings Surface.

- (1) Top of dam (El. 834.2 feet) - 103 acre-feet.

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<sup>1/</sup> Elevations are based on a reference elevation of 840.00 feet M.S.L. estimated from the Mineral Point, Mo., 1954, 7.5 minute series, topographic quadrangle. A temporary bench mark at El. 853.63 feet was established from this reference (Plate 3).

- (2) Operating pool (El. 829.6 feet on 11 September 1979) - 1 acre-foot.

f. Reservoir Surface Area.

- (1) Top of dam (El. 834.2 feet) - 36 acres.
- (2) Operating pool (El. 829.6 feet on 11 September 1979) - 2 acres.

g. Dam.

- (1) Type - Earthfill.
- (2) Crest length - 3800+ feet.
- (3) Height (maximum above streambed) - 96 feet at Station 29+00.
- (4) Crest width - 10 to 20 feet.
- (5) Side slopes -
  - (a) Downstream slope - Variable from 1.4(H) to 1.0(V) to 1.7(H) to 1.0(V).
  - (b) Upstream slope - Unknown.
- (6) Zoning - The zoning of the dam consists of a clay starter dam, which is overlain by sands, angular gravels, and larger rock. The sands, gravels, and rock result from the barite ore milling process. The gravels are generally finer than 3/4-inch, and the larger rock consists of what is referred to as screen rock, between 3/4-inch and 4-inch size, and bull rock, greater than 4-inch size. It appears that a majority of the dam consists of the 3/4-inch minus material.
- (7) Cutoff - No written information is known to exist to indicate that a cutoff was designed or constructed.

h. Spillway. None.

i. Regulating Outlets. None.

j. Diversion Ditches. Some diversion of runoff would occur around the mill access roads at the upstream end of the impoundment. A small ditch would carry runoff around the toe of the embankment between Station 4+00 and 7+00 at the south end of the impoundment adjacent to the paved road (Plate 3). This roadside ditch is a V-shaped ditch typically three feet wide and one foot deep, and is overgrown with grasses, shrubs, and small trees. The ditch is two feet deep at most and disappears where the embankment slope encroaches onto the road.

## SECTION 2 - ENGINEERING DATA

### 2.1 DESIGN

No design drawings or data are known to exist.

### 2.2 CONSTRUCTION

No construction records were available. Information concerning construction of the dam was provided verbally by John, Lewis, and Walter Hornsey, partners of Hornsey Brothers Mining Company. Construction of an earthfill starter dam began in 1964. No drawings or sketches of the starter dam are known to exist, however, the Hornsey Brothers stated that the dam had a downstream slope of 2(H) to 1(V), an upstream slope of 3(H) to 1(V), a 20-foot crest width, and was 30 to 35 feet high. It is not known if a cutoff beneath the starter dam was constructed.

According to the Hornsey Brothers, during subsequent operation of the impoundment following construction of the starter dam, waste material from the barite ore milling process consisting of bull rock, greater than 4-inch size, screen rock, between 3/4-inch and 4-inch size, and sand and angular gravels finer than 3/4-inch were used to raise the dam to provide additional tailings storage capacity. It appears that a majority of the dam consists of the 3/4-inch minus material. In general, no effort was made to clear trees and brush and strip the foundation as the dam was raised, with the exception of the east leg of the dam. A road parallels the eastern ridge embankment at its toe, and as the dam was raised, new roads were cleared adjacent to the toe and stepped down the ridge. The Hornsey Brothers stated that most of the rock was dumped over the downstream side of the crest, that the finer 3/4-inch minus material was dumped near the upstream side of the crest to help seal the upstream zone of the dam, and that the dam was built by somewhat of a downstream method of construction. Material was end-dumped over the downstream face of the dam to widen the crest, and then the crest was raised. The sands, gravels, and larger rock placed in this manner are in a loose state and are at or near their natural angle of repose on the downstream face. Material on the crest was compacted by construction equipment. According to Lewis Hornsey, the dam was raised very little during the last five years of mill operation.

The tailings impoundment operation was shut down by the U.S. Department of the Interior, Mining Enforcement and Safety Administration (MESA) on 5 October 1978. No tailings have been conveyed to the impoundment, and no further dam construction has taken place since that date. Three inspections by various MESA personnel were made of the Cadet Mine Tailings Dam on 10 September 1975, 20 August 1977, and 20 September 1978. The reports of these investigations dated 10 September 1975, 25 August 1977, and 28 September 1978, respectively, are presented in Appendix B. These

reports state that the dam has been raised by the upstream method of construction. It was not evident at the time of this inspection which method of construction has been used since no construction was in progress.

The third inspection report, which recommended the closure of the tailings disposal site because of questionable embankment stability, indicated that a stability analysis was made by the Denver Technical Support Center of MESA. The results of this analysis, which was based on soil parameters obtained in laboratory tests of similar materials from a different site and on assumed dam cross sections, are presented in Appendix B. Also included in Appendix B is a report to the Hornsey Brothers Mining Company from MESA outlining the requirements which must be met before the tailings impoundment could be placed in operation again.

A report by J. H. Williams of the Missouri Geological Survey dated 12 September 1975 and entitled "Engineering Geologic Report on the Hornsey Brothers Tailings Dam" indicates that although the dam was high and had significant seepage, no signs of failure were evident. An addendum to this report dated 1 September 1977 indicated that seepage rates were higher and gravel slumping had occurred along portions of the dam. This report and addendum are presented in Appendix B.

No spillway exists at the Cadet Mine Tailings Dam. The Hornsey Brothers stated that larger screen and bull rock was used to widen the dam crest at its low point to provide an area that could safely conduct water over the dam when required. This low point is located near the southeast corner of the impoundment at Station 8+00, and the crest width in this area at the time of inspection was about 50 feet.

### 2.3 OPERATION

No operating records are known to exist. Tailings have not been conveyed to the impoundment since October 1978 when the tailings disposal operation was shut down by MESA. The outflow of surface runoff, if great enough, would pass over a widened portion of the dam crest at its low point near the southeast corner of the impoundment at Station 8+00. The inflow pipe located at Station 21+93 would not function as an outlet pipe because of the presence of a pump in the pipeline.

### 2.4 EVALUATION

a. Availability. No design or construction records were available. The only design and construction information available to the inspection team was that obtained through verbal communication with John, Lewis, and Walter Hornsey, partners of Hornsey Brothers Mining Company and that contained in inspection reports by MESA.

b. Adequacy. No written records exist to substantiate the cross sections used in the stability analysis done by the Denver Technical Support

Center of MESA. Therefore, conclusions concerning the safety of the dam should not be based on this information. The field surveys and visual inspections presented herein are considered adequate to support the conclusions of this report. Seepage and stability analyses comparable to the requirements of the "Recommended Guidelines for Safety Inspection of Dams" were not available, and this lack of information is considered a deficiency. These seepage and stability analyses should be performed for appropriate loading conditions, including earthquake loads, and made a matter of record.

c. Validity. The dam may not have been constructed as shown on the cross sections used in the stability analysis done by MESA and conditions of seepage and stability have probably changed since the impoundment operation was shut down in October 1978. No design or quality control records are known to exist.



## SECTION 3 - VISUAL INSPECTION

### 3.1 FINDINGS

a. General. The dam was inspected by two civil engineers from International Engineering Company, Inc. on 27 August 1979. John, Lewis, and Walter Hornsey, partners of Hornsey Brothers Mining Company met with the inspection team prior to the inspection, and provided information about the construction and operating history of the impoundment and the shutdown by MESA. The impoundment created by Cadet Mine Tailings Dam contains barite tailings. Tailings have not been conveyed to the impoundment since October 1978. Photographs taken during the inspection are included in this report. The field locations of the photographs are shown on Plate 6.

b. Project Geology. The impoundment watershed is covered by a residual reddish-brown clay containing gravel, rock fragments, and boulders of barite, chert, and quartz druse. Soil cover is estimated to be as much as 30 feet thick. The underlying bedrock is mapped as gray dolomite of the Cambrian age, Potosi Formation. Bedrock was not observed in the reservoir area.

c. Dam. The plan of the dam is shown on Plate 3. The profile and cross sections of the dam are shown on Plates 4 and 5.

The dam embankment itself is practically free of vegetation. Some small trees and brush were observed to be growing out of the embankment at a few locations on the downstream slope. Some brush and trees were growing out of the embankment at the south end of the impoundment adjacent to the paved road and appeared to be rooted in the foundation. A few dead tree snags were observed protruding through the embankment slope along the east leg of the dam. Some vegetation was noted to be buried at the downstream toe during dam enlargements, and dense forest exists immediately downstream of the north leg of the dam. Grasses are growing on the tailings surface.

No detrimental settlement, depressions, cracks, sinkholes, erosion, piping, or animal burrows were observed in or near the dam. Some minor surface ravelling was evident at a few locations along the downstream face of the dam.

Seepage was evident at many locations along the east leg of the embankment at the contact between the dam and foundation. No seepage issuing from the dam face itself was observed. All the seeps observed were flowing at less than 1/2 gpm, and the flow from all the seeps was clear. Many seeps were too small to estimate a flow, and other areas along the toe were wet but had no detectable seepage.

It appeared that a ditch had been cut along the base of the north leg of dam. The ground below the brush and dead leaves in this ditch was wet, but no seepage was visible. A small seep, less than 1/4 gpm, was observed

flowing clear at the base of the north leg, cross-valley dam at its maximum section, Station 29+00. The only other seepage noticed along the north leg of the dam was toward the left abutment at the base of a widened portion of the embankment where screen and bull rock had been dumped. The flow was about 1/2 gpm and clear.

A spring emerging from the natural ground was found approximately 600 feet downslope of the east ridge embankment in the area of Station 18+00. Boiling sand was observed at the spring. Flow was clear and estimated to be in the range of 2 to 3 cfs. The water temperature was estimated at about 50°F. Discharge from the spring flows into a small pond impounded by a small earth embankment about 200 feet long and having a maximum height of 20 feet. The pond is located approximately 500 feet downslope of the east ridge embankment at Station 22+00. During operation of the tailings disposal site, water was pumped from this pond into the impoundment and used in the milling process. The Hornsey Brothers stated that water from the tailings impoundment was being transmitted through bedrock to the spring, and that there has been a history of problems with the pollution of the spring and a well installed by the previous downstream property owner. The Hornsey Brothers reported that sometime between 1970 and 1971 a state geologist put dye into the tailings impoundment to check seepage into the downstream spring and claimed that the spring was fed by the tailings impoundment.

The elevation difference between the dam crest and the tailings surface adjacent to the dam ranged from about 6 to 13 feet. There is no slope protection on the upstream slope which is composed of sands and angular gravels, finer than 3/4-inch. The only slope protection on the downstream slope is provided by the larger screen and bull rock. These materials were dumped at the dam low point at Station 8+00 and near the left abutment to widen the crest and at a few other locations along the downstream face. They do not blanket the entire face of the dam.

No evidence of instability was observed at either abutment. Both abutments are covered with residual reddish-brown clayey soil with gravel and rock fragments. There was no evidence of clearing or stripping of the foundation at either abutment.

d. Appurtenant Structures. The only appurtenant structure at this dam is a 10-inch diameter steel inflow pipe located at Station 21+93. This pipe would not function as an outlet because of the presence of a pump in the pipeline.

e. Reservoir Area. The watershed area is defined by the mine service and access roads connecting the dam crest. No evidence of landsliding was observed in the reservoir area. Some erosion was noted on mine service and access roads around the mill area. There are no upstream structures within the watershed of this dam that would be subjected to backwater flooding. The tailings in the impoundment consist of soft silty clay that have been deposited by hydraulic methods. Grasses are growing on the tailings surface, and dead tree snags protrude through the tailings along the

west side of the tailings deposit near the mill. Although no tailings have been deposited since October 1978, minimal consolidation of the tailings has probably taken place.

f. Downstream Channels. The natural downstream channel below the north leg of the dam is an unnamed tributary to Mill Creek and is undeveloped and heavily forested. This drainage joins Mill Creek about 2500 feet downstream of the dam. A small channel or ditch along the south end of the impoundment adjacent to the paved road would carry diverted runoff around the toe of the embankment between Station 4+00 and 7+00. This ditch has been described in Section 1.3.j. Diversion Ditches.

### 3.2 EVALUATION

Although no tailings have been deposited behind the dam since October 1978, minimal consolidation of the silty clay tailings has probably taken place. Therefore, the dam is effectively retaining a material with very low strength. The tailings exert a high pressure that the dam must resist.

The embankment is a relatively porous granular structure above the tailings surface. If the water level were to rise above the tailings surface adjacent to the dam due to flood runoff, there could be significant seepage through the embankment which could adversely affect the stability of the dam.

Seepage and wet foundation soils were observed along a considerable portion of the embankment toe which could adversely affect the stability of the dam. Although no slope instability other than minor surface ravelling was observed, the downstream embankment slope is at or near the angle of repose of the gravels and rock comprising the dam. The long-term stability of the dam can not be evaluated until seepage and stability analyses are performed.

This dam has no outlet or spillway. Overflow would pass over the dam crest low point at Station 8+00. Although the dam crest is wider at this location and larger screen and bull rock has been dumped in the downstream portion of the dam at this location, flood discharges could cause erosion of the embankment materials and could threaten the stability of the dam during overtopping. As stated earlier, the embankment is a relatively porous granular structure, and flow would be passing through the embankment as well as over its top during overtopping.

The embankment has encroached onto the paved road at the south end of the impoundment. The roadside drainage ditch has been blocked and runoff in this ditch could cause erosion of the embankment toe in this area.

## SECTION 4 - OPERATIONAL PROCEDURES

### 4.1 PROCEDURES

No regulating procedures are known to exist for this dam. The tailings impoundment operation was shut down in October 1978. The outflow of surface runoff, if great enough, would pass over the dam crest low point at Station 8+00.

### 4.2 MAINTENANCE OF DAM

Information available to the inspection team indicates that the dam is not regularly maintained.

### 4.3 MAINTENANCE OF OPERATING FACILITIES

There are no operating facilities at this dam. Not applicable.

### 4.4 DESCRIPTION OF WARNING SYSTEM IN EFFECT

Information available to the inspection team indicates that there is no warning system for this dam.

### 4.5 EVALUATION

The behavior of the dam should be monitored periodically to observe any indications of instability, such as cracks in the dam, sloughing, sudden settlement, erosion of the dam or an increase in the volume or turbidity of emerging seepage. A maintenance program should be initiated for the dam.

## SECTION 5 - HYDRAULIC AND HYDROLOGIC ANALYSES

### 5.1 EVALUATION OF FEATURES

a. Design Data. The significant dimensions of the dam are presented in Section 1 - Project Information, and in the accompanying field survey drawings, Plates 3 through 5B. No hydrologic or hydraulic design information is available.

For this evaluation, the watershed drainage area and reservoir area-elevation data were obtained from a Surdex aerial photograph, scale: 1 inch = 1000 feet, 14 June 1978, and from survey data. The watershed drainage area was checked against an area obtained from the USGS Mineral Point, Mo., 1958, 7.5 minute-series, 1:24,000 scale, topographic quadrangle, and was found to be the same.

The total drainage area including the tailings impoundment at Cadet Mine Tailings Dam, I.D. No. 30715 is primarily enclosed by the embankment and is approximately 47 acres (0.073 square miles). The watershed location and drainage boundary are shown on Plate 2. In order to obtain the active storage capacity, spot surveys of the tailings elevation were transferred to an aerial photograph and used as a guide to develop contours on the tailings surface.

Most of the drainage area is covered by disposed tailings resulting from barite mining. For computations of "basin" characteristics, a lag time of 0.1 hour and a runoff curve number (CN) of 100 were assumed for the computations of flood runoff for the tailings and water within the impoundment.

The input data and computed parameters, such as basin lag time, unit hydrograph, probable maximum precipitation, and the reservoir elevation-area-capacity data are presented in Appendix A. As shown in the computer print-outs, the reservoir surface areas are actual surface areas corresponding to the elevations shown. The capacities, computed in the computer program by the Conic Method, are the active capacities at the given elevations above the tailings.

No spillway is present at the dam. The 10-inch diameter inflow pipe running through the embankment at Station 21+93 would not function as an outlet pipe because of the presence of a pump in the pipeline. Single gravel windrows along the edges of the dam crest were neglected in selecting crest elevations. The low point of the dam at the center of the crest is located at Station 8+00 and is El. 834.2 feet.

Computations of the discharge rating curve for flows over the dam crest were made by using the weir flow formula with a weir coefficient of  $C = 2.7$  for the dam crest. The discharge rating curve for flows over the dam crest is shown in Appendix A, under the input data listing as Y4 and Y5 cards. The overtopping analysis was based on the effective crest elevations as surveyed on the dam crest.

b. Experience Data. Rainfall, streamflow, and flood data for the entire watershed are not available. There is no evidence of historic dam overtopping.

c. Visual Observations. Visual observations are discussed in Section 3 - Visual Observations.

During the field inspection, it was observed that the low points of the tailings were submerged in water. The pond water surface elevation was El. 829.6 feet on the date of survey (see Plate 3).

d. Overtopping Potential. The 100-year flood, probable maximum flood (PMF), and floods expressed as percentages of the PMF were computed and routed through the reservoir. The probable maximum flood is defined as the hypothetical flood event that would result from the most severe combination of critical meteorologic and hydrologic conditions that are reasonably possible at a particular location or region.

The computed floods were routed through the reservoir using the Modified Puls Method of flood routing. For all cases of the reservoir flood routing, the starting water surface elevation was set at El. 829.6 feet, the observed water surface elevation behind the embankment.

Results of the overtopping analyses indicate that the dam is able to retain the 100-year flood. The studies indicate that the dam can retain about 75 percent of the PMF without overtopping the minimum dam crest at El. 834.2 feet.

Results of the overtopping analyses are reported in Appendix A and summarized below:

| <u>Flood</u> | <u>Peak Inflow (cfs)</u> | <u>Peak Outflow (cfs)</u> | <u>Max WS Elev. (ft)</u> | <u>Max Depth Over Min. Dam Crest (ft)</u> | <u>Duration Overtopped (hrs)</u> |
|--------------|--------------------------|---------------------------|--------------------------|---|----------------------------------|
| 50% PMF      | 509                      | 0                         | 833.2                    | 0   | -                                |
| 75% PMF      | 763                      | 0                         | 834.1                    | 0   | -                                |
| PMF          | 1017                     | 44                        | 834.7*                   | 0.5                                       | 31.8                             |

\* Dam overtopped (Minimum dam crest El. 834.2 feet).

Note: Water surface elevations and depths over the minimum dam crest include the velocity heads corresponding to the velocities computed for the various flow depths for the overtopping section.

## SECTION 6 - STRUCTURAL STABILITY

### 6.1 EVALUATION OF STRUCTURAL STABILITY

- a. Visual Observations. Conditions that may adversely affect the structural stability of the dam are discussed in Section 3.
- b. Design and Construction Data. No design or construction data pertaining to the structural stability of the dam were available. Seepage and stability analyses comparable to the requirements of the "Recommended Guidelines for Safety Inspection of Dams" were not available, and lack of this information is considered a deficiency. These seepage and stability analyses should be performed for appropriate loading conditions, including earthquake loads, and made a matter of record.
- c. Operating Records. No operating records for the pump and inflow pipe are known to exist.
- d. Post-Construction Changes. No post-construction changes were apparent.
- e. Seismic Stability. The dam is located in Seismic Zone 2, as defined in the Uniform Building Code. There appears to be a potential for instability caused by ground shaking during earthquakes where the dam overlies soft saturated clay foundation soil. Some crest settlement and raveling of the embankment gravels could also occur during seismic shaking, because the gravels are in a loose state and are at or near their natural angle of repose on the downstream slope.

## SECTION 7 - ASSESSMENT/REMEDIAL MEASURES

### 7.1 DAM ASSESSMENT

a. Safety. The Cadet Mine Tailings Dam has several deficiencies that should be corrected. (1) The seepage occurring along a considerable portion of the embankment toe and the associated soft saturated soil conditions could adversely affect the stability of the dam. (2) The toe of the embankment encroaches onto the paved road along the south end of the impoundment and blocks the roadside drainage ditch. (3) Seepage and stability analyses comparable to the requirements of the "Recommended Guidelines for Safety Inspection of Dams" were not available, and they should be performed and made a matter of record. (4) The dam has no outlet or spillway to remove storm runoff. It was computed that the dam can retain about 75 percent of the Probable Maximum Flood (PMF) without overtopping. The PMF is the flood that may be expected from the most severe combination of critical meteorologic and hydrologic conditions that is reasonably possible in the region. The "Recommended Guidelines for Safety Inspection of Dams" specifies that the spillway design flood for this dam should be the PMF. Although the hydrologic analysis shows the dam capable of retaining 75 percent of the PMF without overtopping, there could be significant seepage through the embankment when the water level rises above the tailings level adjacent to the dam, because the embankment is a relatively porous granular structure above the tailings surface. This seepage could adversely affect the stability of the dam.

b. Adequacy of Information. No detailed design or construction data were available. Three inspection reports of the Cadet Mine Tailings Dam by the U.S. Department of the Interior, Mining Enforcement and Safety Administration (MESA) and results of a stability analysis made by the Denver Technical Support Center of MESA were available and are presented in Appendix B. No written records exist to substantiate the assumed cross sections used in the stability analysis, and conclusions concerning the safety of the dam are not based on this information. The field surveys and visual inspections presented herein are considered adequate to support the conclusions of this report. Seepage and stability analyses comparable to the requirements of the "Recommended Guidelines for Safety Inspection of Dams" were not available, and this lack of data is considered a deficiency.

The only available topographic map at the time of this inspection is the USGS Mineral Point, Mo., 1958, 7.5 minute series, 1:24,000 scale, topographic quadrangle with contour intervals of 20 feet. Results of the hydrologic studies could be changed if larger scale and more up to date topographic maps with smaller contour intervals were used. The maps would also show the mining and dam construction which has occurred subsequent to the publication of the quadrangle map. The watershed drainage area and reservoir areas were measured from a Surdex aerial photograph, scale: 1 inch = 1000 feet, 14 June 1978. Reservoir area-capacity data was developed using survey measurements and constructing topographic contours on the aerial photograph. This data is considered



to be adequate for the Phase I inspection; however, the use of the USGS quadrangle and the aerial photograph for the hydrologic studies results in an approximate evaluation of the embankment overtopping potential.

c. Urgency. The Phase I inspection indicated apparent deficiencies in the condition of the dam. Seepage and stability analyses, and initiation of measures to increase the storage capacity of the dam to safely retain the PMF, or to provide an outlet or spillway with adequate erosion protection to safely pass the PMF should be given priority.

d. Necessity for Phase II. No Phase II investigation is recommended; however, additional investigations are recommended as outlined in Section 7.2.e.

## 7.2 REMEDIAL MEASURES

The following remedial measures are recommended:

a. Control of Seepage. Specific remedial work should be addressed to controlling seepage and safely conducting it away from the toe of the dam to prevent ponding and saturation of foundation soils. This remedial work should be based on appropriate analyses of this condition and should be performed under the direction of a professional engineer experienced in the design and construction of tailings dams.

b. Removal of Trees and Brush. An engineer experienced in the design and construction of tailings dams should direct the removal of trees, dead tree snags, and brush from the dam that could cause a potential seepage hazard.

c. Overflow Provisions. The existing dam was calculated to be capable of retaining 75 percent of the PMF without overtopping at its minimum dam crest El. 834.2 feet at Station 8+00. To comply with the "Recommended Guidelines for Safety Inspection of Dams" for a dam of this size and hazard potential, freeboard should be increased to provide greater storage capacity so that the dam is capable of safely retaining the PMF, or an outlet or a spillway should be constructed so that the PMF can be passed without overtopping the dam crest and without significant erosion of the spillway or embankment. The decision to increase freeboard or provide an outlet or spillway may be dictated by any intentions to reactivate the tailings disposal operation. An increase in freeboard must be considered in seepage and stability analyses as described in Section 7.2.e.

d. Embankment Realignment. The roadside drainage ditch at the south end of the impoundment where the exterior embankment slope encroaches onto the paved road should be cleared. Realignment of the embankment at this area between Station 4+00 and 7+00 should be accomplished if there are any intentions by the owner to reactivate the tailings disposal operation. This area is at the upstream end of the impoundment, and the tailings depth behind the embankment here is shallow enough that this realignment could be accomplished without too much

difficulty. This work should be performed under the direction of a professional engineer experienced in the design and construction of tailings dams.

e. Seepage and Stability Analyses. Seepage and stability analyses should be performed by a professional engineer experienced in the design and construction of tailings dams. The embankment is a relatively porous granular structure above the tailings surface. If the water level were to rise above the tailings surface adjacent to the dam, there could be significant seepage through the embankment which could adversely affect the stability of the dam. Included in these analyses, therefore, seepage and stability computations should be performed with the reservoir water surface set at the top of the dam. If freeboard will be increased so that the dam will retain the PMF without overtopping, the analyses should be performed with the reservoir water surface set at the maximum pool (PMF) level, and the added embankment height should be considered in the stability analysis.

The necessary data for these analyses would be obtained from additional investigations. The investigations should consist of subsurface exploration and soil sampling and a laboratory testing program to obtain the necessary engineering parameters of the dam and foundation materials. These parameters should be used in an engineering study to evaluate the stability of the dam. Concurrent with the exploratory work, groundwater monitoring wells should be installed in the drill holes to obtain water level data that would be used in the stability studies. Remedial measures to the dam should be based on the results of the stability studies and should be done under the direction of a professional engineer experienced in tailings dam design and construction.

f. Inspection and Maintenance Program. An inspection and maintenance program should be initiated. Periodic inspections should be made by qualified personnel to observe the performance of the dam. Observations should include indications of instability, such as cracks in the embankment, sloughing, erosion, sudden settlement, or an increase in the volume or turbidity of seepage. Records of these inspections should be maintained, and all maintenance and remedial measures made to the dam should be documented.

## APPENDIX A

### HYDROLOGIC AND HYDRAULIC ANALYSES

The hydrologic and hydraulic analyses were accomplished by using the computer program "Flood Hydrograph Package, HEC-1, Dam Safety Investigations Version, July 1978". This program was developed by the Hydrologic Engineering Center, U.S. Army Corps of Engineers, Davis, California. The criteria and methodology used are briefly discussed below:

- Probable Maximum Precipitation (PMP) - The 24-hour PMP was obtained from Hydrometeorological Report No. 33. The 6-hour and the 1-hour depth-duration distributions followed Corps of Engineers EM 1110-2-1411 criteria.
- 100-year and/or 10-year storms - The 24-hour storm amounts and distributions were supplied by Corps of Engineers, St. Louis District, Missouri.
- Reservoir Area-Capacity - Areas were measured from U.S.G.S. topographic maps and/or from aerial photographs. Reservoir elevations and corresponding surface areas were input in the computer program, which determined the reservoir capacities by the Conic Method.
- Flood Routing - The Modified Puls Method was used for all flood routing and dam overtopping analyses.

The following pages present the input data listing, the computer program version and its last modification date, together with pertinent computer printouts of results. Definitions of all input and output variable names are presented in the September 1978 computer program "Users Manual", and are not explained herein.

|     |   |        |       |     |       |      |       |        |      |
|-----|---|--------|-------|-----|-------|------|-------|--------|------|
| A1  | CADET MINE TAILING DAM MO. ID. 30715    |        |       |     |       |      |       |        |      |
| A2  | HEC-1 PHASE 1 DAM SAFETY INVESTIGATIONS |        |       |     |       |      |       |        |      |
| A3  | RATIOS OF PMF                           |        |       |     |       |      |       |        |      |
| B   | 288                                     |        | 10    |     |       |      |       |        | 2    |
| B1  | 5                                       |        |       |     |       |      |       |        |      |
| J   | 1                                       | 3      | 1     |     |       |      |       |        |      |
| J1  | .5                                      | .75    | 1.0   |     |       |      |       |        |      |
| K   | 0                                       | INFLOW |       |     |       |      |       | 1      |      |
| K1  | PMF INFLOW TO CLOSED SYSTEM             |        |       |     |       |      |       |        |      |
| M   | 1                                       | 2      | .074  |     |       | 1    |       |        | 1    |
| P   |   | 25.9   | 102   | 120 | 130   |      |       |        |      |
| T   |   |        |       |     |       |      |       | -1     | -100 |
| W2  |   | .1     |       |     |       |      |       |        |      |
| X   | -.0001                                  | -.0001 | 2.5   |     |       |      |       |        |      |
| K   | 1                                       | POND   |       |     |       |      |       | 1      |      |
| K1  | PMF ROUTING THROUGH CLOSED SYSTEM       |        |       |     |       |      |       |        |      |
| Y   |   |        |       | 1   |       |      |       |        |      |
| Y1  | 1                                       |        |       |     |       |      |       | -829.6 | -1   |
| Y4  | 834.2                                   | 834.8  | 835.1 | 836 | 836.4 | 837  | 837.4 |        |      |
| Y5  | 0                                       | 50     | 121   | 670 | 1200  | 2600 | 3950  |        |      |
| \$A | 0                                       | 2      | 11    | 30  | 34    | 36   | 40    |        | 44   |
| \$E | 828                                     | 829.6  | 831   | 832 | 833   | 834  | 838   |        | 845  |
| \$S | 834.2                                   |        |       |     |       |      |       |        |      |
| \$D | 834.2                                   |        |       |     |       |      |       |        |      |
| K   | 99                                      |        |       |     |       |      |       |        |      |
| A   |   |        |       |     |       |      |       |        |      |
| A   |   |        |       |     |       |      |       |        |      |
| A   |   |        |       |     |       |      |       |        |      |
| A   |   |        |       |     |       |      |       |        |      |
| A   |   |        |       |     |       |      |       |        |      |

\*\*\*\*\*  
 FLOOD HYDROGRAPH PACKAGE (HEC-1)  
 DAM SAFETY VERSION JULY 1978  
 LAST MODIFICATION 26 FEB 79  
 \*\*\*\*\*

RUN DATE\* 79/11/16.  
 TIME\* 16.37.20.

CADET MINE TAILING DAM NO. 10, 30715  
 HEC-1 PHASE 1 DAM SAFETY INVESTIGATIONS  
 RATIOS OF PMF

| JOB SPECIFICATION |     |      |       |     |       |       |      |      |       |  |
|-------------------|-----|------|-------|-----|-------|-------|------|------|-------|--|
| NO                | NHR | NMIN | IDAY  | IHR | IMIN  | METRC | IPLT | IPRT | NSTAN |  |
| 288               | 0   | 10   | 0     | 0   | 0     | 0     | 0    | 2    | 0     |  |
|                   |     |      | JOPER | NWT | LROPT | TRACE |      |      |       |  |
|                   |     |      | 5     | 0   | 0     | 0     |      |      |       |  |

MULTI-PLAN ANALYSES TO BE PERFORMED  
 NPLAN= 1 NRTIO= 3 LRTIO= 1

RTIOS= .50 .75 1.00

\*\*\*\*\*

SUB-AREA RUNOFF COMPUTATION

PMF INFLOW TO CLOSED SYSTEM

| ISTAG  | ICOMP | IECON | ITAPE | JPLT | JPRT | INAME | ISTAGE | IAUTO |
|--------|-------|-------|-------|------|------|-------|--------|-------|
| INFLOW | 0     | 0     | 0     | 0    | 0    | 1     | 0      | 0     |

HYDROGRAPH DATA

| IHYDG | IUHG | TAREA | SNAP | TRSDA | TRSPC | RATIO | ISNOW | ISAME | LOCAL |
|-------|------|-------|------|-------|-------|-------|-------|-------|-------|
| 1     | 2    | .07   | 0.00 | .07   | 1.00  | 0.000 | 0     | 1     | 0     |

PRECIP DATA

| SPFE | PMS   | R6     | R12    | R24    | R48  | R72  | R96  |
|------|-------|--------|--------|--------|------|------|------|
| 0.00 | 25.90 | 102.00 | 120.00 | 130.00 | 0.00 | 0.00 | 0.00 |

LOSS DATA

| LROPT | STRKR | DLTKR | RTIOL | ERAIN | STRKS | RTIOK | STRTL | CNSTL   | ALSMX | RTIMP |
|-------|-------|-------|-------|-------|-------|-------|-------|---------|-------|-------|
| 0     | 0.00  | 0.00  | 1.00  | 0.00  | 0.00  | 1.00  | -1.00 | -100.00 | 0.00  | 0.00  |

CURVE NO = -100.00 WETNESS = -1.00 EFFECT CN = 100.00

UNIT HYDROGRAPH DATA

TC= 0.00 LAG= .10

RECESSION DATA

STRTQ= -.00 GRCSN= -.00 RTIOR= 2.50

TIME INCREMENT TOO LARGE--(NHQ IS GT LAG/2)

UNIT HYDROGRAPH 5 END OF PERIOD ORDINATES, TC= 0.00 HOURS, LAG= .10 VOL= 1.00

|       |       | 191.   | 73.  | 17.  | 4.   | 1.     | END-OF-PERIOD FLOW |       |        |      |      |      |        |
|-------|-------|--------|------|------|------|--------|--------------------|-------|--------|------|------|------|--------|
| 0     |       |        |      |      |      | COMP Q | HO.DA              | HR.MN | PERIOD | RAIN | EXCS | LOSS | COMP Q |
| MO.DA | HR.MN | PEP10D | RAIN | EXCS | LOSS |        |                    |       |        |      |      |      |        |
| 1.01  | .10   | 1      | .03  | .03  | 0.00 | 6.     | 1.02               | .10   | 145    | 0.00 | 0.00 | 0.00 | 4.     |
| 1.01  | .20   | 2      | .03  | .03  | .00  | 8.     | 1.02               | .20   | 146    | 0.00 | 0.00 | 0.00 | 1.     |
| 1.01  | .30   | 3      | .03  | .03  | .00  | 8.     | 1.02               | .30   | 147    | 0.00 | 0.00 | 0.00 | 0.     |
| 1.01  | .40   | 4      | .03  | .03  | .00  | 8.     | 1.02               | .40   | 148    | 0.00 | 0.00 | 0.00 | 0.     |
| 1.01  | .50   | 5      | .03  | .03  | .00  | 8.     | 1.02               | .50   | 149    | 0.00 | 0.00 | 0.00 | 0.     |
| 1.01  | 1.00  | 6      | .03  | .03  | .00  | 8.     | 1.02               | 1.00  | 150    | 0.00 | 0.00 | 0.00 | 0.     |
| 1.01  | 1.10  | 7      | .03  | .03  | .00  | 8.     | 1.02               | 1.10  | 151    | 0.00 | 0.00 | 0.00 | 0.     |
| 1.01  | 1.20  | 8      | .03  | .03  | .00  | 8.     | 1.02               | 1.20  | 152    | 0.00 | 0.00 | 0.00 | 0.     |
| 1.01  | 1.30  | 9      | .03  | .03  | .00  | 8.     | 1.02               | 1.30  | 153    | 0.00 | 0.00 | 0.00 | 0.     |
| 1.01  | 1.40  | 10     | .03  | .03  | .00  | 8.     | 1.02               | 1.40  | 154    | 0.00 | 0.00 | 0.00 | 0.     |
| 1.01  | 1.50  | 11     | .03  | .03  | .00  | 8.     | 1.02               | 1.50  | 155    | 0.00 | 0.00 | 0.00 | 0.     |
| 1.01  | 2.00  | 12     | .03  | .03  | .00  | 8.     | 1.02               | 2.00  | 156    | 0.00 | 0.00 | 0.00 | 0.     |
| 1.01  | 2.10  | 13     | .03  | .03  | .00  | 8.     | 1.02               | 2.10  | 157    | 0.00 | 0.00 | 0.00 | 0.     |
| 1.01  | 2.20  | 14     | .03  | .03  | .00  | 8.     | 1.02               | 2.20  | 158    | 0.00 | 0.00 | 0.00 | 0.     |
| 1.01  | 2.30  | 15     | .03  | .03  | .00  | 8.     | 1.02               | 2.30  | 159    | 0.00 | 0.00 | 0.00 | 0.     |
| 1.01  | 2.40  | 16     | .03  | .03  | .00  | 8.     | 1.02               | 2.40  | 160    | 0.00 | 0.00 | 0.00 | 0.     |
| 1.01  | 2.50  | 17     | .03  | .03  | .00  | 8.     | 1.02               | 2.50  | 161    | 0.00 | 0.00 | 0.00 | 0.     |
| 1.01  | 3.00  | 18     | .03  | .03  | .00  | 8.     | 1.02               | 3.00  | 162    | 0.00 | 0.00 | 0.00 | 0.     |
| 1.01  | 3.10  | 19     | .03  | .03  | .00  | 8.     | 1.02               | 3.10  | 163    | 0.00 | 0.00 | 0.00 | 0.     |
| 1.01  | 3.20  | 20     | .03  | .03  | .00  | 8.     | 1.02               | 3.20  | 164    | 0.00 | 0.00 | 0.00 | 0.     |
| 1.01  | 3.30  | 21     | .03  | .03  | .00  | 8.     | 1.02               | 3.30  | 165    | 0.00 | 0.00 | 0.00 | 0.     |
| 1.01  | 3.40  | 22     | .03  | .03  | .00  | 8.     | 1.02               | 3.40  | 166    | 0.00 | 0.00 | 0.00 | 0.     |
| 1.01  | 3.50  | 23     | .03  | .03  | .00  | 8.     | 1.02               | 3.50  | 167    | 0.00 | 0.00 | 0.00 | 0.     |
| 1.01  | 4.00  | 24     | .03  | .03  | .00  | 8.     | 1.02               | 4.00  | 168    | 0.00 | 0.00 | 0.00 | 0.     |
| 1.01  | 4.10  | 25     | .03  | .03  | .00  | 8.     | 1.02               | 4.10  | 169    | 0.00 | 0.00 | 0.00 | 0.     |
| 1.01  | 4.20  | 26     | .03  | .03  | .00  | 8.     | 1.02               | 4.20  | 170    | 0.00 | 0.00 | 0.00 | 0.     |
| 1.01  | 4.30  | 27     | .03  | .03  | .00  | 8.     | 1.02               | 4.30  | 171    | 0.00 | 0.00 | 0.00 | 0.     |
| 1.01  | 4.40  | 28     | .03  | .03  | .00  | 8.     | 1.02               | 4.40  | 172    | 0.00 | 0.00 | 0.00 | 0.     |
| 1.01  | 4.50  | 29     | .03  | .03  | .00  | 8.     | 1.02               | 4.50  | 173    | 0.00 | 0.00 | 0.00 | 0.     |
| 1.01  | 5.00  | 30     | .03  | .03  | .00  | 8.     | 1.02               | 5.00  | 174    | 0.00 | 0.00 | 0.00 | 0.     |
| 1.01  | 5.10  | 31     | .03  | .03  | .00  | 8.     | 1.02               | 5.10  | 175    | 0.00 | 0.00 | 0.00 | 0.     |
| 1.01  | 5.20  | 32     | .03  | .03  | .00  | 8.     | 1.02               | 5.20  | 176    | 0.00 | 0.00 | 0.00 | 0.     |
| 1.01  | 5.30  | 33     | .03  | .03  | .00  | 8.     | 1.02               | 5.30  | 177    | 0.00 | 0.00 | 0.00 | 0.     |
| 1.01  | 5.40  | 34     | .03  | .03  | .00  | 8.     | 1.02               | 5.40  | 178    | 0.00 | 0.00 | 0.00 | 0.     |
| 1.01  | 5.50  | 35     | .03  | .03  | .00  | 8.     | 1.02               | 5.50  | 179    | 0.00 | 0.00 | 0.00 | 0.     |
| 1.01  | 6.00  | 36     | .03  | .03  | .00  | 8.     | 1.02               | 6.00  | 180    | 0.00 | 0.00 | 0.00 | 0.     |
| 1.01  | 6.10  | 37     | .13  | .13  | .00  | 28.    | 1.02               | 6.10  | 181    | 0.00 | 0.00 | 0.00 | 0.     |
| 1.01  | 6.20  | 38     | .13  | .13  | .00  | 35.    | 1.02               | 6.20  | 182    | 0.00 | 0.00 | 0.00 | 0.     |
| 1.01  | 6.30  | 39     | .13  | .13  | .00  | 37.    | 1.02               | 6.30  | 183    | 0.00 | 0.00 | 0.00 | 0.     |
| 1.01  | 6.40  | 40     | .13  | .13  | .00  | 37.    | 1.02               | 6.40  | 184    | 0.00 | 0.00 | 0.00 | 0.     |
| 1.01  | 6.50  | 41     | .13  | .13  | .00  | 37.    | 1.02               | 6.50  | 185    | 0.00 | 0.00 | 0.00 | 0.     |
| 1.01  | 7.00  | 42     | .13  | .13  | .00  | 37.    | 1.02               | 7.00  | 186    | 0.00 | 0.00 | 0.00 | 0.     |
| 1.01  | 7.10  | 43     | .13  | .13  | .00  | 37.    | 1.02               | 7.10  | 187    | 0.00 | 0.00 | 0.00 | 0.     |
| 1.01  | 7.20  | 44     | .13  | .13  | .00  | 37.    | 1.02               | 7.20  | 188    | 0.00 | 0.00 | 0.00 | 0.     |
| 1.01  | 7.30  | 45     | .13  | .13  | .00  | 37.    | 1.02               | 7.30  | 189    | 0.00 | 0.00 | 0.00 | 0.     |
| 1.01  | 7.40  | 46     | .13  | .13  | .00  | 37.    | 1.02               | 7.40  | 190    | 0.00 | 0.00 | 0.00 | 0.     |
| 1.01  | 7.50  | 47     | .13  | .13  | .00  | 37.    | 1.02               | 7.50  | 191    | 0.00 | 0.00 | 0.00 | 0.     |
| 1.01  | 8.00  | 48     | .13  | .13  | .00  | 37.    | 1.02               | 8.00  | 192    | 0.00 | 0.00 | 0.00 | 0.     |
| 1.01  | 8.10  | 49     | .13  | .13  | .00  | 37.    | 1.02               | 8.10  | 193    | 0.00 | 0.00 | 0.00 | 0.     |
| 1.01  | 8.20  | 50     | .13  | .13  | .00  | 37.    | 1.02               | 8.20  | 194    | 0.00 | 0.00 | 0.00 | 0.     |
| 1.01  | 8.30  | 51     | .13  | .13  | .00  | 37.    | 1.02               | 8.30  | 195    | 0.00 | 0.00 | 0.00 | 0.     |
| 1.01  | 8.40  | 52     | .13  | .13  | .00  | 37.    | 1.02               | 8.40  | 196    | 0.00 | 0.00 | 0.00 | 0.     |
| 1.01  | 8.50  | 53     | .13  | .13  | .00  | 37.    | 1.02               | 8.50  | 197    | 0.00 | 0.00 | 0.00 | 0.     |
| 1.01  | 9.00  | 54     | .13  | .13  | .00  | 37.    | 1.02               | 9.00  | 198    | 0.00 | 0.00 | 0.00 | 0.     |
| 1.01  | 9.10  | 55     | .13  | .13  | .00  | 37.    | 1.02               | 9.10  | 199    | 0.00 | 0.00 | 0.00 | 0.     |

|      |       |     |      |      |      |       |      |       |     |      |      |      |    |
|------|-------|-----|------|------|------|-------|------|-------|-----|------|------|------|----|
| 1.01 | 9.20  | 56  | .13  | .13  | .00  | 37.   | 1.02 | 9.20  | 200 | 0.00 | 0.00 | 0.00 | 0. |
| 1.01 | 9.30  | 57  | .13  | .13  | .00  | 37.   | 1.02 | 9.30  | 201 | 0.00 | 0.00 | 0.00 | 0. |
| 1.01 | 9.40  | 58  | .13  | .13  | -.00 | 37.   | 1.02 | 9.40  | 202 | 0.00 | 0.00 | 0.00 | 0. |
| 1.01 | 9.50  | 59  | .13  | .13  | .00  | 37.   | 1.02 | 9.50  | 203 | 0.00 | 0.00 | 0.00 | 0. |
| 1.01 | 10.00 | 60  | .13  | .13  | -.00 | 37.   | 1.02 | 10.00 | 204 | 0.00 | 0.00 | 0.00 | 0. |
| 1.01 | 10.10 | 61  | .13  | .13  | -.00 | 37.   | 1.02 | 10.10 | 205 | 0.00 | 0.00 | 0.00 | 0. |
| 1.01 | 10.20 | 62  | .13  | .13  | -.00 | 37.   | 1.02 | 10.20 | 206 | 0.00 | 0.00 | 0.00 | 0. |
| 1.01 | 10.30 | 63  | .13  | .13  | .00  | 37.   | 1.02 | 10.30 | 207 | 0.00 | 0.00 | 0.00 | 0. |
| 1.01 | 10.40 | 64  | .13  | .13  | -.00 | 37.   | 1.02 | 10.40 | 208 | 0.00 | 0.00 | 0.00 | 0. |
| 1.01 | 10.50 | 65  | .13  | .13  | -.00 | 37.   | 1.02 | 10.50 | 209 | 0.00 | 0.00 | 0.00 | 0. |
| 1.01 | 11.00 | 66  | .13  | .13  | -.00 | 37.   | 1.02 | 11.00 | 210 | 0.00 | 0.00 | 0.00 | 0. |
| 1.01 | 11.10 | 67  | .13  | .13  | -.00 | 37.   | 1.02 | 11.10 | 211 | 0.00 | 0.00 | 0.00 | 0. |
| 1.01 | 11.20 | 68  | .13  | .13  | -.00 | 37.   | 1.02 | 11.20 | 212 | 0.00 | 0.00 | 0.00 | 0. |
| 1.01 | 11.30 | 69  | .13  | .13  | -.00 | 37.   | 1.02 | 11.30 | 213 | 0.00 | 0.00 | 0.00 | 0. |
| 1.01 | 11.40 | 70  | .13  | .13  | -.00 | 37.   | 1.02 | 11.40 | 214 | 0.00 | 0.00 | 0.00 | 0. |
| 1.01 | 11.50 | 71  | .13  | .13  | -.00 | 37.   | 1.02 | 11.50 | 215 | 0.00 | 0.00 | 0.00 | 0. |
| 1.01 | 12.00 | 72  | .13  | .13  | .00  | 37.   | 1.02 | 12.00 | 216 | 0.00 | 0.00 | 0.00 | 0. |
| 1.01 | 12.10 | 73  | .44  | .44  | -.00 | 97.   | 1.02 | 12.10 | 217 | 0.00 | 0.00 | 0.00 | 0. |
| 1.01 | 12.20 | 74  | .44  | .44  | -.00 | 119.  | 1.02 | 12.20 | 218 | 0.00 | 0.00 | 0.00 | 0. |
| 1.01 | 12.30 | 75  | .44  | .44  | .00  | 125.  | 1.02 | 12.30 | 219 | 0.00 | 0.00 | 0.00 | 0. |
| 1.01 | 12.40 | 76  | .44  | .44  | -.00 | 126.  | 1.02 | 12.40 | 220 | 0.00 | 0.00 | 0.00 | 0. |
| 1.01 | 12.50 | 77  | .44  | .44  | -.00 | 126.  | 1.02 | 12.50 | 221 | 0.00 | 0.00 | 0.00 | 0. |
| 1.01 | 13.00 | 78  | .44  | .44  | .00  | 126.  | 1.02 | 13.00 | 222 | 0.00 | 0.00 | 0.00 | 0. |
| 1.01 | 13.10 | 79  | .53  | .53  | .00  | 143.  | 1.02 | 13.10 | 223 | 0.00 | 0.00 | 0.00 | 0. |
| 1.01 | 13.20 | 80  | .53  | .53  | -.00 | 149.  | 1.02 | 13.20 | 224 | 0.00 | 0.00 | 0.00 | 0. |
| 1.01 | 13.30 | 81  | .53  | .53  | -.00 | 151.  | 1.02 | 13.30 | 225 | 0.00 | 0.00 | 0.00 | 0. |
| 1.01 | 13.40 | 82  | .53  | .53  | -.00 | 151.  | 1.02 | 13.40 | 226 | 0.00 | 0.00 | 0.00 | 0. |
| 1.01 | 13.50 | 83  | .53  | .53  | .00  | 151.  | 1.02 | 13.50 | 227 | 0.00 | 0.00 | 0.00 | 0. |
| 1.01 | 14.00 | 84  | .53  | .53  | -.00 | 151.  | 1.02 | 14.00 | 228 | 0.00 | 0.00 | 0.00 | 0. |
| 1.01 | 14.10 | 85  | .66  | .66  | -.00 | 177.  | 1.02 | 14.10 | 229 | 0.00 | 0.00 | 0.00 | 0. |
| 1.01 | 14.20 | 86  | .66  | .66  | -.00 | 186.  | 1.02 | 14.20 | 230 | 0.00 | 0.00 | 0.00 | 0. |
| 1.01 | 14.30 | 87  | .66  | .66  | -.00 | 189.  | 1.02 | 14.30 | 231 | 0.00 | 0.00 | 0.00 | 0. |
| 1.01 | 14.40 | 88  | .66  | .66  | .00  | 189.  | 1.02 | 14.40 | 232 | 0.00 | 0.00 | 0.00 | 0. |
| 1.01 | 14.50 | 89  | .66  | .66  | -.00 | 189.  | 1.02 | 14.50 | 233 | 0.00 | 0.00 | 0.00 | 0. |
| 1.01 | 15.00 | 90  | .66  | .66  | -.00 | 189.  | 1.02 | 15.00 | 234 | 0.00 | 0.00 | 0.00 | 0. |
| 1.01 | 15.10 | 91  | .60  | .60  | .00  | 178.  | 1.02 | 15.10 | 235 | 0.00 | 0.00 | 0.00 | 0. |
| 1.01 | 15.20 | 92  | 1.00 | 1.00 | -.00 | 251.  | 1.02 | 15.20 | 236 | 0.00 | 0.00 | 0.00 | 0. |
| 1.01 | 15.30 | 93  | 1.81 | 1.81 | .00  | 433.  | 1.02 | 15.30 | 237 | 0.00 | 0.00 | 0.00 | 0. |
| 1.01 | 15.40 | 94  | 4.52 | 4.52 | .00  | 1017. | 1.02 | 15.40 | 238 | 0.00 | 0.00 | 0.00 | 0. |
| 1.01 | 15.50 | 95  | 1.31 | 1.31 | .00  | 616.  | 1.02 | 15.50 | 239 | 0.00 | 0.00 | 0.00 | 0. |
| 1.01 | 16.00 | 96  | .80  | .80  | .00  | 334.  | 1.02 | 16.00 | 240 | 0.00 | 0.00 | 0.00 | 0. |
| 1.01 | 16.10 | 97  | .62  | .62  | -.00 | 218.  | 1.02 | 16.10 | 241 | 0.00 | 0.00 | 0.00 | 0. |
| 1.01 | 16.20 | 98  | .62  | .62  | .00  | 186.  | 1.02 | 16.20 | 242 | 0.00 | 0.00 | 0.00 | 0. |
| 1.01 | 16.30 | 99  | .62  | .62  | .00  | 178.  | 1.02 | 16.30 | 243 | 0.00 | 0.00 | 0.00 | 0. |
| 1.01 | 16.40 | 100 | .62  | .62  | .00  | 177.  | 1.02 | 16.40 | 244 | 0.00 | 0.00 | 0.00 | 0. |
| 1.01 | 16.50 | 101 | .62  | .62  | -.00 | 177.  | 1.02 | 16.50 | 245 | 0.00 | 0.00 | 0.00 | 0. |
| 1.01 | 17.00 | 102 | .62  | .62  | .00  | 177.  | 1.02 | 17.00 | 246 | 0.00 | 0.00 | 0.00 | 0. |
| 1.01 | 17.10 | 103 | .48  | .48  | -.00 | 151.  | 1.02 | 17.10 | 247 | 0.00 | 0.00 | 0.00 | 0. |
| 1.01 | 17.20 | 104 | .48  | .48  | -.00 | 142.  | 1.02 | 17.20 | 248 | 0.00 | 0.00 | 0.00 | 0. |
| 1.01 | 17.30 | 105 | .48  | .48  | -.00 | 139.  | 1.02 | 17.30 | 249 | 0.00 | 0.00 | 0.00 | 0. |
| 1.01 | 17.40 | 106 | .48  | .48  | .00  | 139.  | 1.02 | 17.40 | 250 | 0.00 | 0.00 | 0.00 | 0. |
| 1.01 | 17.50 | 107 | .48  | .48  | -.00 | 139.  | 1.02 | 17.50 | 251 | 0.00 | 0.00 | 0.00 | 0. |
| 1.01 | 18.00 | 108 | .48  | .48  | .00  | 139.  | 1.02 | 18.00 | 252 | 0.00 | 0.00 | 0.00 | 0. |
| 1.01 | 18.10 | 109 | .04  | .04  | .00  | 54.   | 1.02 | 18.10 | 253 | 0.00 | 0.00 | 0.00 | 0. |
| 1.01 | 18.20 | 110 | .04  | .04  | .00  | 22.   | 1.02 | 18.20 | 254 | 0.00 | 0.00 | 0.00 | 0. |
| 1.01 | 18.30 | 111 | .04  | .04  | .00  | 14.   | 1.02 | 18.30 | 255 | 0.00 | 0.00 | 0.00 | 0. |
| 1.01 | 18.40 | 112 | .04  | .04  | -.00 | 13.   | 1.02 | 18.40 | 256 | 0.00 | 0.00 | 0.00 | 0. |
| 1.01 | 18.50 | 113 | .04  | .04  | -.00 | 12.   | 1.02 | 18.50 | 257 | 0.00 | 0.00 | 0.00 | 0. |
| 1.01 | 19.00 | 114 | .04  | .04  | -.00 | 12.   | 1.02 | 19.00 | 258 | 0.00 | 0.00 | 0.00 | 0. |
| 1.01 | 19.10 | 115 | .04  | .04  | .00  | 12.   | 1.02 | 19.10 | 259 | 0.00 | 0.00 | 0.00 | 0. |

|      |       |     |     |     |      |     |      |       |     |      |         |         |       |           |
|------|-------|-----|-----|-----|------|-----|------|-------|-----|------|---------|---------|-------|-----------|
| 1.01 | 19.20 | 116 | .04 | .04 | .00  | 12. | 1.02 | 19.20 | 260 | 0.00 | 0.00    | 0.00    | 0.    |           |
| 1.01 | 19.30 | 117 | .04 | .04 | -.00 | 12. | 1.02 | 19.30 | 261 | 0.00 | 0.00    | 0.00    | 0.    |           |
| 1.01 | 19.40 | 118 | .04 | .04 | .00  | 12. | 1.02 | 19.40 | 262 | 0.00 | 0.00    | 0.00    | 0.    |           |
| 1.01 | 19.50 | 119 | .04 | .04 | .00  | 12. | 1.02 | 19.50 | 263 | 0.00 | 0.00    | 0.00    | 0.    |           |
| 1.01 | 20.00 | 120 | .04 | .04 | -.00 | 12. | 1.02 | 20.00 | 264 | 0.00 | 0.00    | 0.00    | 0.    |           |
| 1.01 | 20.10 | 121 | .04 | .04 | .00  | 12. | 1.02 | 20.10 | 265 | 0.00 | 0.00    | 0.00    | 0.    |           |
| 1.01 | 20.20 | 122 | .04 | .04 | .00  | 12. | 1.02 | 20.20 | 266 | 0.00 | 0.00    | 0.00    | 0.    |           |
| 1.01 | 20.30 | 123 | .04 | .04 | .00  | 12. | 1.02 | 20.30 | 267 | 0.00 | 0.00    | 0.00    | 0.    |           |
| 1.01 | 20.40 | 124 | .04 | .04 | .00  | 12. | 1.02 | 20.40 | 268 | 0.00 | 0.00    | 0.00    | 0.    |           |
| 1.01 | 20.50 | 125 | .04 | .04 | -.00 | 12. | 1.02 | 20.50 | 269 | 0.00 | 0.00    | 0.00    | 0.    |           |
| 1.01 | 21.00 | 126 | .04 | .04 | .00  | 12. | 1.02 | 21.00 | 270 | 0.00 | 0.00    | 0.00    | 0.    |           |
| 1.01 | 21.10 | 127 | .04 | .04 | .00  | 12. | 1.02 | 21.10 | 271 | 0.00 | 0.00    | 0.00    | 0.    |           |
| 1.01 | 21.20 | 128 | .04 | .04 | .00  | 12. | 1.02 | 21.20 | 272 | 0.00 | 0.00    | 0.00    | 0.    |           |
| 1.01 | 21.30 | 129 | .04 | .04 | .00  | 12. | 1.02 | 21.30 | 273 | 0.00 | 0.00    | 0.00    | 0.    |           |
| 1.01 | 21.40 | 130 | .04 | .04 | .00  | 12. | 1.02 | 21.40 | 274 | 0.00 | 0.00    | 0.00    | 0.    |           |
| 1.01 | 21.50 | 131 | .04 | .04 | .00  | 12. | 1.02 | 21.50 | 275 | 0.00 | 0.00    | 0.00    | 0.    |           |
| 1.01 | 22.00 | 132 | .04 | .04 | -.00 | 12. | 1.02 | 22.00 | 276 | 0.00 | 0.00    | 0.00    | 0.    |           |
| 1.01 | 22.10 | 133 | .04 | .04 | .00  | 12. | 1.02 | 22.10 | 277 | 0.00 | 0.00    | 0.00    | 0.    |           |
| 1.01 | 22.20 | 134 | .04 | .04 | -.00 | 12. | 1.02 | 22.20 | 278 | 0.00 | 0.00    | 0.00    | 0.    |           |
| 1.01 | 22.30 | 135 | .04 | .04 | .00  | 12. | 1.02 | 22.30 | 279 | 0.00 | 0.00    | 0.00    | 0.    |           |
| 1.01 | 22.40 | 136 | .04 | .04 | .00  | 12. | 1.02 | 22.40 | 280 | 0.00 | 0.00    | 0.00    | 0.    |           |
| 1.01 | 22.50 | 137 | .04 | .04 | .00  | 12. | 1.02 | 22.50 | 281 | 0.00 | 0.00    | 0.00    | 0.    |           |
| 1.01 | 23.00 | 138 | .04 | .04 | .00  | 12. | 1.02 | 23.00 | 282 | 0.00 | 0.00    | 0.00    | 0.    |           |
| 1.01 | 23.10 | 139 | .04 | .04 | -.00 | 12. | 1.02 | 23.10 | 283 | 0.00 | 0.00    | 0.00    | 0.    |           |
| 1.01 | 23.20 | 140 | .04 | .04 | .00  | 12. | 1.02 | 23.20 | 284 | 0.00 | 0.00    | 0.00    | 0.    |           |
| 1.01 | 23.30 | 141 | .04 | .04 | .00  | 12. | 1.02 | 23.30 | 285 | 0.00 | 0.00    | 0.00    | 0.    |           |
| 1.01 | 23.40 | 142 | .04 | .04 | .00  | 12. | 1.02 | 23.40 | 286 | 0.00 | 0.00    | 0.00    | 0.    |           |
| 1.01 | 23.50 | 143 | .04 | .04 | .00  | 12. | 1.02 | 23.50 | 287 | 0.00 | 0.00    | 0.00    | 0.    |           |
| 1.02 | 0.00  | 144 | .04 | .04 | .00  | 12. | 1.03 | 0.00  | 288 | 0.00 | 0.00    | 0.00    | 0.    |           |
|      |       |     |     |     |      |     |      |       |     | SUM  | 33.67   | 33.67   | .00   | 9624.     |
|      |       |     |     |     |      |     |      |       |     |      | ( 855.) | ( 855.) | ( 0.) | ( 272.52) |

|            | PEAK  | 6-HOUR | 24-HOUR | 72-HOUR | TOTAL VOLUME |
|------------|-------|--------|---------|---------|--------------|
| CFS        | 1017. | 208.   | 67.     | 33.     | 9641.        |
| CMS        | 29.   | 6.     | 2.      | 1.      | 273.         |
| INCHES     |       | 26.19  | 33.65   | 33.66   | 33.66        |
| MM         |       | 665.29 | 854.69  | 855.07  | 855.07       |
| AC-FT      |       | 103.   | 133.    | 133.    | 133.         |
| THOUS CU M |       | 127.   | 164.    | 164.    | 164.         |



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HYDROGRAPH ROUTING

PMF ROUTING THROUGH CLOSED SYSTEM

|               | ISTAQ        | ICOMP  | IECON  | ITAPE  | JPLT    | JPRT    | INAME   | ISTAGE | IAUTO |
|---------------|--------------|--------|--------|--------|---------|---------|---------|--------|-------|
|               | POND         | 1      | 0      | 0      | 0       | 0       | 1       | 0      | 0     |
|               | ROUTING DATA |        |        |        |         |         |         |        |       |
|               | QLOSS        | CLOSS  | AVG    | IRES   | ISAME   | IOPT    | IPMP    | LSTR   |       |
|               | 0.0          | 0.000  | 0.00   | 1      | 0       | 0       | 0       | 0      |       |
|               | NSTPS        | NSTD   | LAG    | AMSK   | X       | TSK     | STOR    | ISPRAT |       |
|               | 1            | 0      | 0      | 0.000  | 0.000   | 0.000   | -830.   | -1     |       |
| STAGE         | 834.20       | 834.80 | 835.10 | 836.00 | 836.40  | 837.00  | 837.40  |        |       |
| FLOW          | 0.00         | 50.00  | 121.00 | 670.00 | 1200.00 | 2600.00 | 3950.00 |        |       |
| SURFACE AREA= | 0.           | 2.     | 11.    | 30.    | 34.     | 36.     | 40.     | 44.    |       |
| CAPACITY=     | 0.           | 1.     | 9.     | 29.    | 61.     | 96.     | 248.    | 542.   |       |
| ELEVATION=    | 828.         | 830.   | 831.   | 832.   | 833.    | 834.    | 838.    | 845.   |       |
|               | CREL         | SPWID  | COOW   | EXPW   | ELEVL   | COOL    | CAREA   | EXPL   |       |
|               | 834.2        | 0.0    | 0.0    | 0.0    | 0.0     | 0.0     | 0.0     | 0.0    |       |
|               | DAM DATA     |        |        |        |         |         |         |        |       |
|               | TOPEL        | COOD   | EXPD   | DAMWID |         |         |         |        |       |
|               | 834.2        | 0.0    | 0.0    | 0.     |         |         |         |        |       |

STATION POND, PLAN 1, RATIO 3  
 END-OF-PERIOD HYDROGRAPH ORDINATES

| OUTFLOW |     |     |     |     |     |     |     |     |     |
|---------|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| 0.      | 0.  | 0.  | 0.  | 0.  | 0.  | 0.  | 0.  | 0.  | 0.  |
| 0.      | 0.  | 0.  | 0.  | 0.  | 0.  | 0.  | 0.  | 0.  | 0.  |
| 0.      | 0.  | 0.  | 0.  | 0.  | 0.  | 0.  | 0.  | 0.  | 0.  |
| 0.      | 0.  | 0.  | 0.  | 0.  | 0.  | 0.  | 0.  | 0.  | 0.  |
| 0.      | 0.  | 0.  | 0.  | 0.  | 0.  | 0.  | 0.  | 0.  | 0.  |
| 0.      | 0.  | 0.  | 0.  | 0.  | 0.  | 0.  | 0.  | 0.  | 0.  |
| 0.      | 0.  | 0.  | 0.  | 0.  | 0.  | 0.  | 0.  | 0.  | 0.  |
| 0.      | 0.  | 0.  | 0.  | 0.  | 0.  | 0.  | 0.  | 0.  | 0.  |
| 0.      | 0.  | 0.  | 0.  | 0.  | 0.  | 0.  | 0.  | 0.  | 0.  |
| 0.      | 0.  | 0.  | 0.  | 0.  | 0.  | 0.  | 0.  | 0.  | 0.  |
| 0.      | 0.  | 0.  | 0.  | 0.  | 0.  | 0.  | 0.  | 0.  | 0.  |
| 0.      | 0.  | 0.  | 0.  | 0.  | 0.  | 0.  | 0.  | 0.  | 0.  |
| 0.      | 0.  | 0.  | 0.  | 0.  | 0.  | 0.  | 0.  | 0.  | 0.  |
| 0.      | 0.  | 0.  | 0.  | 0.  | 0.  | 0.  | 0.  | 0.  | 0.  |
| 0.      | 0.  | 0.  | 0.  | 0.  | 0.  | 0.  | 0.  | 0.  | 0.  |
| 0.      | 0.  | 0.  | 0.  | 0.  | 0.  | 0.  | 0.  | 0.  | 0.  |
| 0.      | 0.  | 0.  | 0.  | 0.  | 0.  | 0.  | 0.  | 0.  | 0.  |
| 0.      | 0.  | 0.  | 0.  | 0.  | 0.  | 0.  | 0.  | 0.  | 0.  |
| 0.      | 0.  | 0.  | 0.  | 0.  | 0.  | 0.  | 0.  | 0.  | 0.  |
| 0.      | 0.  | 0.  | 0.  | 0.  | 0.  | 0.  | 0.  | 0.  | 0.  |
| 0.      | 0.  | 0.  | 0.  | 0.  | 0.  | 0.  | 0.  | 0.  | 0.  |
| 17.     | 22. | 26. | 30. | 33. | 37. | 40. | 43. | 44. | 44. |
| 43.     | 43. | 42. | 41. | 40. | 39. | 38. | 37. | 37. | 36. |
| 35.     | 34. | 34. | 33. | 33. | 32. | 31. | 31. | 30. | 30. |
| 29.     | 29. | 28. | 28. | 27. | 27. | 26. | 26. | 25. | 25. |
| 25.     | 24. | 24. | 23. | 23. | 22. | 22. | 21. | 20. | 20. |
| 19.     | 19. | 18. | 17. | 17. | 16. | 16. | 15. | 15. | 14. |
| 14.     | 14. | 13. | 13. | 12. | 12. | 12. | 11. | 11. | 11. |
| 10.     | 10. | 10. | 9.  | 9.  | 9.  | 8.  | 8.  | 8.  | 8.  |
| 7.      | 7.  | 7.  | 7.  | 7.  | 6.  | 6.  | 6.  | 6.  | 6.  |
| 5.      | 5.  | 5.  | 5.  | 5.  | 5.  | 4.  | 4.  | 4.  | 4.  |
| 4.      | 4.  | 4.  | 4.  | 3.  | 3.  | 3.  | 3.  | 3.  | 3.  |
| 3.      | 3.  | 3.  | 3.  | 3.  | 2.  | 2.  | 2.  | 2.  | 2.  |
| 2.      | 2.  | 2.  | 2.  | 2.  | 2.  | 2.  | 2.  | 2.  | 2.  |
| 2.      | 1.  | 1.  | 1.  | 1.  | 1.  | 1.  | 1.  | 1.  | 1.  |
| 1.      | 1.  | 1.  | 1.  | 1.  | 1.  | 1.  | 1.  | 1.  | 1.  |
| 1.      | 1.  | 1.  | 1.  | 1.  | 1.  | 0.  | 0.  | 0.  | 0.  |
| 0.      | 0.  | 0.  | 0.  | 0.  | 0.  | 0.  | 0.  | 0.  | 0.  |
| 0.      | 0.  | 0.  | 0.  | 0.  | 0.  | 0.  | 0.  | 0.  | 0.  |

PEAK FLOW AND STORAGE (END OF PERIOD) SUMMARY FOR MULTIPLE PLAN-RATIO ECONOMIC COMPUTATIONS  
 FLOWS IN CUBIC FEET PER SECOND (CUBIC METERS PER SECOND)  
 AREA IN SQUARE MILES (SQUARE KILOMETERS)

| OPERATION     | STATION | AREA | PLAN | RATIOS APPLIED TO FLOWS |                |                 |
|---------------|---------|------|------|-------------------------|----------------|-----------------|
|               |         |      |      | RATIO 1<br>.50          | RATIO 2<br>.75 | RATIO 3<br>1.00 |
| HYDROGRAPH AT | INFLOW  | .07  | 1    | 509.                    | 763.           | 1017.           |
|               | (       | .19) | (    | 14.40)(                 | 21.60)(        | 28.80)(         |
| ROUTED TO     | POND    | .07  | 1    | 0.                      | 0.             | 44.             |
|               | (       | .19) | (    | 0.00)(                  | 0.00)(         | 1.26)(          |

SUMMARY OF DAM SAFETY ANALYSIS

| PLAN 1 ..... | ELEVATION                  | INITIAL VALUE          | SPILLWAY CHEST        | TOP OF DAM          |                         |                           |                       |
|--------------|----------------------------|------------------------|-----------------------|---------------------|-------------------------|---------------------------|-----------------------|
|              | STORAGE                    | 829.60                 | 834.20                | 834.20              |                         |                           |                       |
|              | OUTFLOW                    | 1.                     | 103.                  | 103.                |                         |                           |                       |
|              |                            | 0.                     | 0.                    | 0.                  |                         |                           |                       |
| RATIO OF PMF | MAXIMUM RESERVOIR N.S.ELEV | MAXIMUM DEPTH OVER DAM | MAXIMUM STORAGE AC-FT | MAXIMUM OUTFLOW CFS | DURATION OVER TOP HOURS | TIME OF MAX OUTFLOW HOURS | TIME OF FAILURE HOURS |
| .50          | 833.17                     | 0.00                   | 67.                   | 0.                  | 0.00                    | 0.00                      | 0.00                  |
| .75          | 834.11                     | 0.00                   | 100.                  | 0.                  | 0.00                    | 0.00                      | 0.00                  |
| 1.00         | 834.73                     | .53                    | 123.                  | 44.                 | 31.83                   | 18.17                     | 0.00                  |

APPENDIX B  
INFORMATION SUPPLIED BY OTHERS

| <u>Item</u>  | <u>Page No.</u> |
|--|-----------------|
| Evaluation of the Hornsey Brothers Impoundment Site near Cadet, Missouri - transmittal letter from MESA to IECO  | B-1             |
| Report of 10 September 1975 Inspection and Evaluation of the Cadet Mine Tailings Dam by MESA   | B-2             |
| Report of 20 August 1977 Inspection and Evaluation of the Cadet Mine Tailings Dam by MESA  | B-6             |
| Report of 20 September 1978 Inspection and Evaluation of the Cadet Mine Tailings Dam by MESA   | B-9             |
| Letter to Mr. Lewis Hornsey from MESA Outlining Requirements for Tailings Impoundment Reactivation including MESA Design Guidelines for Mine Waste Piles and Tailings Dams | B-11            |
| Stability Analysis of Cadet Mine Tailings Dam by MESA Denver Technical Support Center  | B-21            |
| Engineering Geology Report and Addendum on the Hornsey Brothers Tailings Dam by J. H. Williams   | B-23            |

U.S. DEPARTMENT OF LABOR  
MINE SAFETY AND HEALTH ADMINISTRATION  
Box 1156  
900 Pine Street  
Rolla, Missouri 65401



Metal and Nonmetal Mine  
Health and Safety  
South Central Subdistrict

RECEIVED

SEP 21

September 18, 1979

Mr. Jim Gray  
International Engineering Company  
220 Montgomery  
San Francisco, California 94104

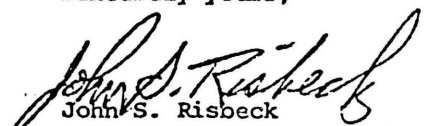
Subject: Evaluation of the Hornsey Brothers Impoundment Site near Cadet, Missouri

Dear Mr. Gray:

Enclosed are the reports you requested concerning the stability of the Hornsey impoundment structure. You will note that these reports span a number of years. In that time, the impoundment structure increased in height significantly. Construction method was observed by both our Rolla people and engineers from our technical support Mine Waste Branch in Denver, Colorado. Construction by the upstream method was observed as I discussed with you by phone.

I hope this information will be of some help to you.

Sincerely yours,

  
John S. Risbeck  
Supervisory Mining Engineer

Enclosures



# United States Department of the Interior

MINING ENFORCEMENT AND SAFETY ADMINISTRATION

P.O. BOX 25367, DENVER FEDERAL CENTER  
DENVER, COLORADO 80225

November 13, 1975

D821 - W560

DENVER TECHNICAL SUPPORT CENTER  
Waste Impoundment Group

## Memorandum

To: District Manager, South Central District, Metal  
and Nonmetal Mine Health and Safety, Dallas, Texas

From: Chief, Waste Impoundment Group, Denver Technical  
Support Center

Subject: Site Inspection and Evaluation of the Tailings  
Embankment and Impoundment at Hornsey Pit at  
Cadet, Hornsey Brothers Mining Company, I.D.  
No. 23-00552, Washington County, Missouri

The enclosed report is based on a visual inspection of  
Hornsey Brothers tailings disposal site on September 10, 1975,  
as requested by your subdistrict office at Rolla, Missouri.  
The company should be encouraged to comply with the rec-  
ommendations contained within the report.

*Robert I. Fujimoto*  
Robert I. Fujimoto

Enclosure w/ attachment

cc: Assistant Administrator, Metal/Nonmetal Mine H&S  
Subdistrict Manager, Rolla, Missouri  
S. A. Stanin, Technical Support  
A. Z. Dimitroff, Denver Technical Support  
S. G. Sawyer, Pittsburgh Technical Support



UNITED STATES  
DEPARTMENT OF THE INTERIOR  
MINING ENFORCEMENT AND SAFETY ADMINISTRATION  
HEALTH AND SAFETY TECHNICAL SUPPORT

Inspection and Evaluation  
of  
Tailings Embankment and Impoundment  
Hornsey Pit at Cadet  
Hornsey Brothers Mining Company  
Washington County, Missouri

September 10, 1975

by

G. W. Center  
Civil Engineer, DTSC  
and  
S. W. Dmytriw  
Civil Engineer, DTSC

DENVER TECHNICAL SUPPORT CENTER

A. Z. Dimitroff, Chief

Originating Office  
Denver Federal Center, Building 55  
Denver, Colorado, 80225  
Robert I. Fujimoto  
Chief, Waste Impoundment Group

Pursuant to a request by your subdistrict office at Rolla, Missouri, a visual inspection of the Hornsey Brothers tailings embankment and impoundment was made on September 10, 1975, by G. W. Center, and S. W. Dmytriw, Denver Technical Support Center; H. J. Lucas, Metal and Nonmetal Mine Health and Safety, Rolla, Missouri; and J. H. Williams, Missouri Geological Survey. No mining company representative was present during the inspection. However, following the inspection, a discussion was held with John Hornsey, co-owner.

Location:

The Hornsey Brothers tailings embankment and impoundment is located in an unnamed drainage on the left of Mill Creek of Big River about 1.5 miles east of Cadet, Washington County, Missouri. Tiff, Missouri is about 2.6 miles downstream. The geographic location is N 37°55'27", W 90°40'00".

Description:

The embankment is L-shaped, with the short leg a cross-valley type about 800 feet long at the north end, and the long leg a ridge embankment about 2100 feet long forming the right (east) side of the impoundment. The embankment is being constructed of gravel-size waste dumped along the crest and then pushed over the edge onto both slopes. The slopes vary from 32° to 36°, which is near the angle of repose. The crest is about 16 feet wide and the height increases from 30 to 45 feet northward along the eastern leg and reaches a maximum of 76 feet near the midpoint of the cross-valley portion. No foundation preparations were noted. Seepage was noted all along the toe of the embankment. There is no other outlet except for a low spot in the haul road at the abutment near the northeastern corner of the impoundment which could serve as a "spillway."

The tailings enter the impoundment in a ditch in natural ground near the left abutment of the cross-valley part of the embankment. Clear water is pumped back to the plant from the upstream end of the impoundment. This procedure results in the coarser tailings settling out near the left side of the impoundment while the slimes and water flow against the embankment. A make-up water line discharges into the impoundment immediately inside the eastern embankment near the northerly 1/3 point. The clean water is pumped from a pond immediately below the eastern embankment which collects water seeping through the dam. The impoundment has a surface area of about 25 acres and a minimum freeboard of about 2.5 feet from the water surface to the embankment crest at the "spillway". Generally, the freeboard is approximately 5.5 feet.



Conclusions:

The Hornsey Brothers tailings embankment and impoundment is a potential hazard. The embankment is of questionable stability because of the large amount of seepage, steep slope, and manner of tailings discharge that places the slimes and water against the embankment. As the embankment height is increased the safety factor will decrease.

Recommendations:

These recommendations are based upon engineering criteria established for coal refuse embankments by Federal Regulations. It is expected that similar criteria for metal/nonmetal tailings disposal operations will be established at a future date.

1. The tailings should discharge into the pond so that the coarse tailings settle out against the embankment and the slimes and free water are as far from the embankment as is practical.

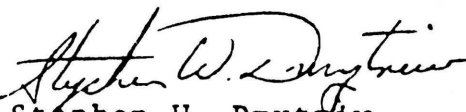
2. A stability analysis of the embankment should be made. A minimum safety factor of 1.5 static and 1.2 dynamic, under full anticipated design capacity, is normally considered a safe design value. If the embankment does not meet the minimum factors of safety, remedial measures should be undertaken to increase embankment stability.

3. Since there is no adequate spillway or outlet, the embankment should be maintained high enough to contain the runoff from a probable maximum precipitation with a freeboard of at least three feet.

4. The make-up water line discharge should be moved further into the pond to reduce erosion of the embankment.

Acceptable hydrologic and hydraulic considerations are included in the copy of the Design Guidelines attached to this report.

  
Gustavus W. Center  
Civil Engineer, DTSC

  
Stephen W. Dmytriw  
Civil Engineer, DTSC



# United States Department of the Interior

MINING ENFORCEMENT AND SAFETY ADMINISTRATION

P.O. BOX 25067, DENVER FEDERAL CENTER 25067  
DENVER, COLORADO 80225

DENVER TECHNICAL SUPPORT CENTER  
Mine Waste Branch

August 25, 1977

D1433 - W910

## Memorandum

To: District Manager, South Central District, Metal and Nonmetal Mine Health and Safety, Dallas, Texas

Through: Chief, Mine Waste Branch *WJ*

From: Civil Engineer, Mine Waste Branch

Subject: Site Inspection and Evaluation of the Tailings Embankment and Impoundment at Hornsey Pit, I.D. No. 23-00552 at Cadet, Washington County, Missouri, Hornsey Brothers Mining Company

At the request of the Subdistrict Manager, Rolla, Missouri, the Hornsey Brothers tailings embankment and impoundment was inspected on August 20, 1977. The inspection was made by Wayne D. Kanack and Howard J. Lucas, Metal and Nonmetal Mine Health and Safety, and Gustavus W. Center, Denver Technical Support Center. No mining company representative was present during the inspection.

The condition of the tailings embankment and impoundment is essentially as described in report dated September 10, 1975, by the Denver Technical Support Center, except that the embankment has been raised about 10 feet by the upstream method of construction, and less surface water was present due to reduced operating days.

The upstream method of constructing a tailings embankment is probably the most unsafe method. As the height of the embankment increases, the potential failure surface is located farther from the downstream face and into the slimes. The outside shell contributes less to the stability as the height increases.

It was noted that the embankment has blocked the roadside ditch at the south end of the site. Depending upon the height of the embankment at the time, runoff from the drainage area south of the road due to a severe storm could enter the impoundment and possibly breach the embankment.

The rear wheels of a truck dumping embankment material left deep impressions in the embankment crest surface indicating a weak structural fill.

### Conclusions

The Hornsey Brothers tailings embankment and impoundment remains a potential hazard. The possibility of an embankment breach exists. In addition, the stability of the embankment is questionable and believed to be marginal because of the narrow (about 16 feet) shell of coarse waste containing the saturated fine tailings. The method of embankment placement is also a hazard to personnel working on the crest. The vibrations from equipment working on the narrow shell of coarse waste supported by the slimes could lead to a local slope failure. Therefore, it is necessary that operating restrictions be placed on the site during operation.

### Recommendations

1. The roadside ditch at the south end of the site should be cleared so that runoff will not enter the impoundment and cause an overtopping of the embankment.

2. A spillway should be provided near the southern abutment of the embankment to discharge into the cleared roadside ditch. This is the low point of the fine tailings within the impoundment.

3. The tailings should discharge into the pond so that the coarse tailings settle out against the embankment and the slimes and free water are as far from the embankment as is practical. In no case should free water be allowed to stand against the embankment face. This procedure develops stronger support for the shell of coarse waste as well as lowering the phreatic level. No trucking of materials should be allowed along the crest until correction of the tailings discharge location. If a higher embankment is needed before movement of the discharge, it should be done after the impoundment has been allowed to drain away from the embankment face.

4. Due to the questionable integrity of the embankment, a stability analysis should be made. A minimum safety factor of 1.5 static and 1.2 dynamic, under full anticipated design capacity, is normally considered a safe design value. If the embankment does not meet the minimum factors of safety,

remedial measures should be undertaken to increase the embankment's stability. The analysis should be completed within 6 months or the site should be closed as the degree of hazard will increase with time.

*Gustavus W. Center*  
Gustavus W. Center

cc: Asst. Admin., M/NMH&S  
Subdistrict Mgr., Rolla, MO  
SAStanin  
DHutchinson

U.S. DEPARTMENT OF LABOR  
MINE SAFETY AND HEALTH ADMINISTRATION

Mailing Address:  
P.O. Box 25367, DFC  
Denver, Colorado 80225

Street Address:  
730 Simms  
Lakewood, Colorado



DENVER TECHNICAL SUPPORT CENTER  
Mine Waste Branch

SEP 28 1978

Report No. D1746-W1081  
File: HLS-5

MEMORANDUM FOR: WAYNE D. KANACK  
District Manager, South Central District  
Metal and Nonmetal Mine Safety and Health  
Dallas, Texas

THROUGH: ROBERT I. FUJIMOTO  
Chief, Mine Waste Branch

FROM: GUSTAVUS W. CENTER AND ROBERT L. FERRITER  
Civil Engineers, Mine Waste Branch

SUBJECT: Site Investigation and Evaluation of the  
Tailings Embankment and Impoundment at  
Hornsey Pit, I.D. No. 23-00552 near Cadit,  
Washington County, Missouri, Hornsey  
Brothers Mining Company

At the request of John S. Risbeck, Mining Engineer, Rolla, Missouri, the Hornsey Brothers' tailings disposal site was investigated on September 20, 1978. The investigation was made by Howard J. Lucas, Michael Ryan, and Dennis Dati, Rolla Subdistrict Office, Metal and Nonmetal Mine Safety and Health, and Gustavus W. Center and Robert L. Ferriter, Denver Technical Support Center. No mining company representative accompanied us during the investigation.

The site is essentially as described in a report dated September 10, 1977, by Denver Technical Support Center, except that the embankment has been raised about 15 feet by the upstream method of construction, and the freeboard has been increased to about 9 feet. The tailings are still discharged into the pond in a manner that places the slimes and water against the embankment. This procedure results in a very poor foundation for construction in the upstream method.

A stability analysis was made by DTSC using soil parameters obtained in laboratory tests of similar material and a cross-section of the structure developed from on site measurements and an assumed boundary between the tailings and coarse waste. The analysis indicated the embankment has a very low factor of safety.

#### CONCLUSIONS

The stability of the Hornsey Brothers' tailings embankment is marginal and therefore remains a potential hazard. The method of material placement is a hazard to personnel. The rear wheels of a truck left deep impressions in the embankment near the upstream edge of the crest as a load was being dumped. It is believed that the embankment is too large for any significant improvement in stability to be obtained by changing the discharge of the tailings to along the embankment crest at this time. Increased stability could be developed by adding a buttress fill of coarse waste to the downstream side of the embankment. The buttress fill would need to be placed on an adequately prepared foundation.

#### RECOMMENDATIONS

It is recommended that the disposal site be closed because of the questionable stability of the embankment. Remedial measures should be undertaken to increase the embankment's stability before disposal operations are resumed.

cc: Administrator, M/NMS&H  
S. A. Stanin  
K. K. Wu  
D. Hutchinson

**U.S. DEPARTMENT OF LABOR  
MINE SAFETY AND HEALTH ADMINISTRATION  
Room 4C50, 1100 Commerce Street  
Dallas, Texas 75242**



**February 6, 1979**

**Mr. Lewis E. Hornsey  
Hornsey Brothers  
P. O. Box 309  
Potosi, Missouri 65401**

**Dear Mr. Hornsey:**

**As per your letter request to Terry Phillips, we are sending you recommendations defining requirements which must be met before tailings impoundments can be placed in operation.**

**We are also enclosing a copy of design guidelines for mine waste piles and tailing dams. These guidelines have been compiled by our Denver Technical Support Center and serve as recommendations to our enforcement staff.**

**If you wish to discuss either of these two reports in detail, please feel free to contact Terry Phillips, subdistrict manager at Rolla, Missouri, 314/364-8282, or myself at Dallas, Texas, 214/749-1241.**

**If we can be of any further help please call on us anytime.**

**Sincerely,**

**Wayne D. Kanack  
District Manager  
South Central District  
Metal and Nonmetal**

**Enclosures**

U.S. DEPARTMENT OF LABOR  
MINE SAFETY AND HEALTH ADMINISTRATION  
Mailing Address: P.O. Box 25367, DFC  
Denver, Colorado 80225  
Street Address: 730 Simms  
Lakewood, Colorado



DENVER TECHNICAL SUPPORT CENTER  
Mine Waste Branch

JAN 31 1979

Report No. D1848-W1139  
File: HLS-5

MEMORANDUM FOR: WAYNE D. KANACK  
District Manager, South Central District  
Metal and Nonmetal Safety and Health

FROM:

*Robert I. Fujimoto*  
ROBERT I. FUJIMOTO  
Chief, Mine Waste Branch

SUBJECT: Hornsey Pit, I.D. No. 23-00552 near Cadet, Washington  
County, Missouri, Hornsey Brothers Mining Company

A memorandum from Terry E. Phillips, Subdistrict Manager, Rolla, Missouri, was received in this office on January 23, 1979. Mr. Phillips sought assistance in replying to a Hornsey Brothers' letter which requested a written statement clearly defining the requirements which must be met before their tailings impoundment could be placed in operation.

After thoroughly reviewing our files, the following recommendations are offered:

1. It is the opinion of our professional staff that the stability of the present retaining embankment is inadequate. As stated in DTSC's memorandum of August 25, 1977, a minimum factor of safety of 1.5 static and 1.2 dynamic, under full anticipated design capacity, is normally considered a safe design value for the hazard rating as associated with the impoundment. Trail stability calculations performed in this office (see DTSC's memorandum of September 28, 1978) have indicated a safety factor considerably less than that mentioned above.
2. It appears that two alternatives are available to the operators, either Hornsey Brothers, or their prospective buyer. The first would be to abandon the current pond by providing drainage control or capping the impounding area to prevent the impoundment of water, and seeking another site for tailings disposal. The second alternative would be to stabilize the existing embankment. This alternative would entail a thorough



investigation of the existing embankment including:

- a. A determination of the phreatic conditions within the embankment;
- b. Foundation investigations;
- c. Testing of embankment and foundation materials to determine soil strength parameters; and
- d. Perform stability analyses along critical embankment sections.

After this investigation is complete, a buttressing fill with a drainage blanket will probably be required to increase the stability of the existing embankment to an acceptable level. Hydrologic calculations should be performed to ensure that sufficient freeboard is maintained to control the runoff from a probable maximum storm. Consideration should also be given to constructing an adequately designed emergency spillway or decant system.

3. Without the stability investigation discussed above, design and proper sizing of a stabilizing buttress is not possible. Also, to achieve the required increase in stability will require remedial construction in accordance with design-determined specifications such as material gradation, compaction, etc.

4. For DTSC to recommend reopening of the site, a properly prepared engineering investigation, including sufficient soil testing to gain confidence in the test results, and proposed modifications to increase the stability of the embankment must be presented. After review, construction in accordance with the approved modifications should be accomplished prior to reopening the site.

Since the extent of remedial work required at the site is yet to be determined, it would be extremely difficult to estimate either the cost or time required to perform the work. However, the St. Louis area has many geotechnical engineering firms who would probably be able to provide the Hornsey Brothers with both design and construction estimates. A copy of MSHA's Design Guidelines for Mine Waste Piles and Tailings Dams is attached to this report for the Hornsey Brothers' use in establishing design objectives. All designs submitted to MSHA for review should conform to the guidelines.

If you require any additional information, please call.

Enclosure

cc: Administrator, M/NMS&H  
 S. A. Stanin  
 Roy Bernard  
 Terry Phillips  
 K. K. Wu  
 D. Hutchinson

DESIGN GUIDELINES FOR MINE WASTE PILES  
AND TAILINGS DAMS

BY

MESA - TECHNICAL SUPPORT CENTER  
DENVER, COLORADO

JANUARY 10, 1978

These DESIGN GUIDELINES are generally employed by the Denver Technical Support Center in its review of plans submitted to MESA. These guidelines will be continually updated as the state-of-art for the safe and orderly deposition of mined waste is advanced.

## Hydrologic and Hydraulic Considerations

1. Current, prudent engineering practices require a conservative approach to provide maximum flood protection for water-retention structures located where failure may cause loss of life or serious property damage. Therefore, designs of water, sediment, or tailings impoundments should be based on the probable maximum precipitation of 6-hour duration. A 20 percent reduction in the probable maximum precipitation (PMP) is allowed for impoundments east of the 105th meridian which have drainage area less than 10 square miles. For areas west of the 105th meridian, inflow design floods should be prepared, using both the probable maximum thunderstorm 1-hour rainfall and the probable maximum 6-hour general-type storm rainfall. The more critical of the two inflow design floods should be used in the design of the structure. If it can be shown that the failure of an impounding structure would not cause loss of life or property damage, then a lesser design criteria may be used if information substantiating such a decision is submitted by the operating companies. A 100-year frequency storm of 6-hour duration (one percent probability) is the minimum storm permitted in the design of any impoundment.

2. The design freeboard distance between the low point on the upstream side of crest of an impounding structure and the maximum water elevation for the anticipated design capacity should be at least three feet. However, in situations where sufficient documentation is provided indicating that adequate freeboard is assured so that there is no possibility of the embankment being overtopped, a lesser freeboard may be acceptable. Many factors are involved in the determination of freeboard requirements. Items that should be considered include; duration of high water level in pond, effective wind fetch, water depth, potential wave runup on embankment slope, and the ability of the embankment to resist erosion. The crest should slope to force all drainage to the upstream side of the embankment.

The design freeboard distance between the top of bank of any spillway or diversion channel and the maximum water surface in the channel must be at least  $1.0' + .025 v(d)^{.33}$  where  $v$  = velocity in ft/sec and  $d$  = depth in feet, if a design flood based on less than 100 percent of probable maximum precipitation is employed.

3. Under normal conditions, diversion ditches around an impoundment should be designed in accordance with the appropriate State regulations. Diversion ditches around embankments that cannot impound water are generally required to pass the runoff from a 100-year frequency storm of 6-hour duration.

4. When any emergency outlet structure for an impounding facility is being checked, any diversion ditches should normally be neglected as a part of the outlet structure. If a diversion ditch is being considered to pass runoff water in lieu of a spillway around an impoundment, the ditch should be designed and constructed under the same design specification as a spillway.

5. The tailings should be distributed around the periphery of embankments constructed of waste materials, and the pool should be kept as far from the embankment crest as is practical.

6. The SCS Handbook, NEH Notice 4-102, August 1972, is an acceptable reference for hydrology design considerations for mined waste structures. Another suitable reference is the Bureau of Reclamation's publication entitled, "Design of Small Dams", Revised Reprint, 1974.

7. Pipes and conduits should be properly designed and constructed with provisions to prevent clogging. A suitable reference on prevention of clogging is "Debris-Control Structures", Bureau of Public Roads, Hydraulic Engineering Circular No. 9, February 1964. Pipes and conduits through the embankment should have several seep rings to prevent piping along the line and ultimate failure. The length of the line of seepage along the line of contact between the embankment, the barrel, and the anti-seep collars should be about 20 percent longer than the length of pipe or conduit lying within the zone of saturation. The line should be constructed with a material which will not deteriorate and create a void through the embankment.

8. Impoundments in which part or all of the inflow from the design storm is to be stored shall be subject to a drawdown criteria. The drawdown criteria is met if 90 percent of the volume of water stored during the design storm can be evacuated, within 10 days, from the facility.

9. Surfaces of channels and diversion ditches should be capable of withstanding the expected maximum velocity of the design flow without undue erosion or scour. A good reference for the sizing of riprap for open channels is "Use of Riprap for Bank Protection", Bureau of Public Roads, Hydraulic Engineering Circular No. 11, June 1967.

#### Geotechnical Considerations

1. The stability of an impounding structure should have minimum, static and dynamic factors of safety of 1.5 and 1.2, respectively, under full anticipated design capacity.

2. For dry embankments that do not and cannot impound water, tailings, and/or silt, the mined waste should be designed to minimum static and dynamic safety factors of 1.5 and 1.2, respectively.
3. Foundations for embankments and impoundments must be properly prepared by removing all vegetation and undesirable material in order to achieve a firm foundation.
4. Filters, drainage blankers, etc., that are so thin that contamination may occur during construction, are not considered adequate. Normally, a blanket of well-graded material five feet thick is preferred; three feet is the minimum and will require special construction consideration to be acceptable. If, in general, the proposed construction requires close field control to assure that the facility is properly constructed, then careful consideration must be given to all elements of the design prior to approval. A good reference on filter design requirements is, "Design of Small Dams."
5. When an operating company has requested approval to raise the height of an impoundment by upstream construction over tailings sediment, the following is recommended:
  - a. The operating company perform suitable tests on the tailings (subsurface investigation) to prove that the tailings have sufficient strength for stability and support of the added material. The construction of the dam addition must be engineer controlled and suitably compacted in layers. The beneficial effect on stability of compaction outweighs the decreased permeability produced by the compaction.
  - b. The dumping of material over the freeboard area of the dam crest to extend and raise the embankment is not allowed unless it is in accordance with an approved plan.
6. A starter dike which is to be the downstream toe should be constructed of coarse rock, gravel, and sand mixture with a gradation to sand on the upstream side to prevent piping of tailings.

APPENDIX - Plan Review Checklist

## APPENDIX

### PLAN REVIEW CHECKLIST

The following is a list of items generally required to make a comprehensive plan and specification review.

#### A. SITE DESCRIPTION

1. Name of site.
2. Ownership of property.
3. Active or inactive site.
4. General description of site, including downstream development.
5. Detailed location.
6. Construction history.
7. Other.

#### B. DRAWINGS OF SITE

Drawings showing the existing conditions and the proposed improvements in sufficient detail that specifications can be prepared and construction accomplished. The drawings should include the following as a minimum:

1. Plan view, including elevations and dimensions, at a scale large enough to show all details such as the location of (a) tailings embankment, (b) impoundment, (c) diversion ditches, (d) spillway, (e) slurry inlet, (f) pumping and decant system, and (g) access road.
2. One or more sections through the tailings embankment showing all dimensions, grades, slopes and material.
3. Sections for the diversion ditches, decant, and spillway, showing all dimensions, grades, slopes and material.
4. Original topography.
5. Time schedule for completion of each phase of work.
6. Other.

#### C. FUTURE PLANS

1. Ultimate size of embankment and impoundment.
2. Method of removing water from impoundment during life of site.
3. Plans to change type of mill or grinding circuits.
4. Other.

D. MINED WASTE EMBANKMENT

1. Type - sidehill, cross-valley, inactive, active, etc.
2. Method of construction and compaction.
3. Seepage - areas and amounts.
4. Stability analysis of embankment and foundation.
5. Classification and mechanical tests of embankment materials and foundation.
6. Other.

E. TAILINGS IMPOUNDMENT

1. Description, including area and depths of water and tailings.
2. History of impoundment.
3. Tailings inlet - location and volume.
4. Description of terrain.
5. Hydrology study of watershed area.
6. Diversion ditches - location, size, slopes, foundation, grade.
7. Method of removing water from impoundment.
8. Decant - type, wall dimensions, location, size, length, grade, discharge channel.
9. Freeboard from slurry level to decant entrance.
10. Spillway - type, location, size, length, grade, discharge channel.
11. Freeboard from slurry level to spillway invert and to low point on embankment.
12. Other.

F. ABANDONMENT PLANS

1. Plans for abandonment, including an anticipated date of abandonment and reclamation of the mined waste embankment and impoundment.
2. Method of removing water from the site after abandonment.
3. Thickness and type of sealer.
4. Preparation, physical and chemical, of embankment of sealer.
5. Type of vegetation.
6. Other.

G. DESIGN CALCULATIONS

1. Hydrologic data and methods of calculations used to determine inflow, outflow, and storage.
2. Hydraulic data and method of calculations used to determine channel sizes of spillways, decants, and diversion structures.
3. Soil data and methods of calculations used to determine stability of structure under varying conditions.
4. When computer facilities are used for engineering calculations, a copy of the input data and computer output listing shall be submitted for verification and checking purposes. The consultant should also provide a listing of the program used in the computer analysis. If the program is used in a subsequent plan submission, the results should be accompanied by a statement that the program has not been altered since its initial submission to MESA, or a new program listing should be provided.



**XXHORNSEYXX**

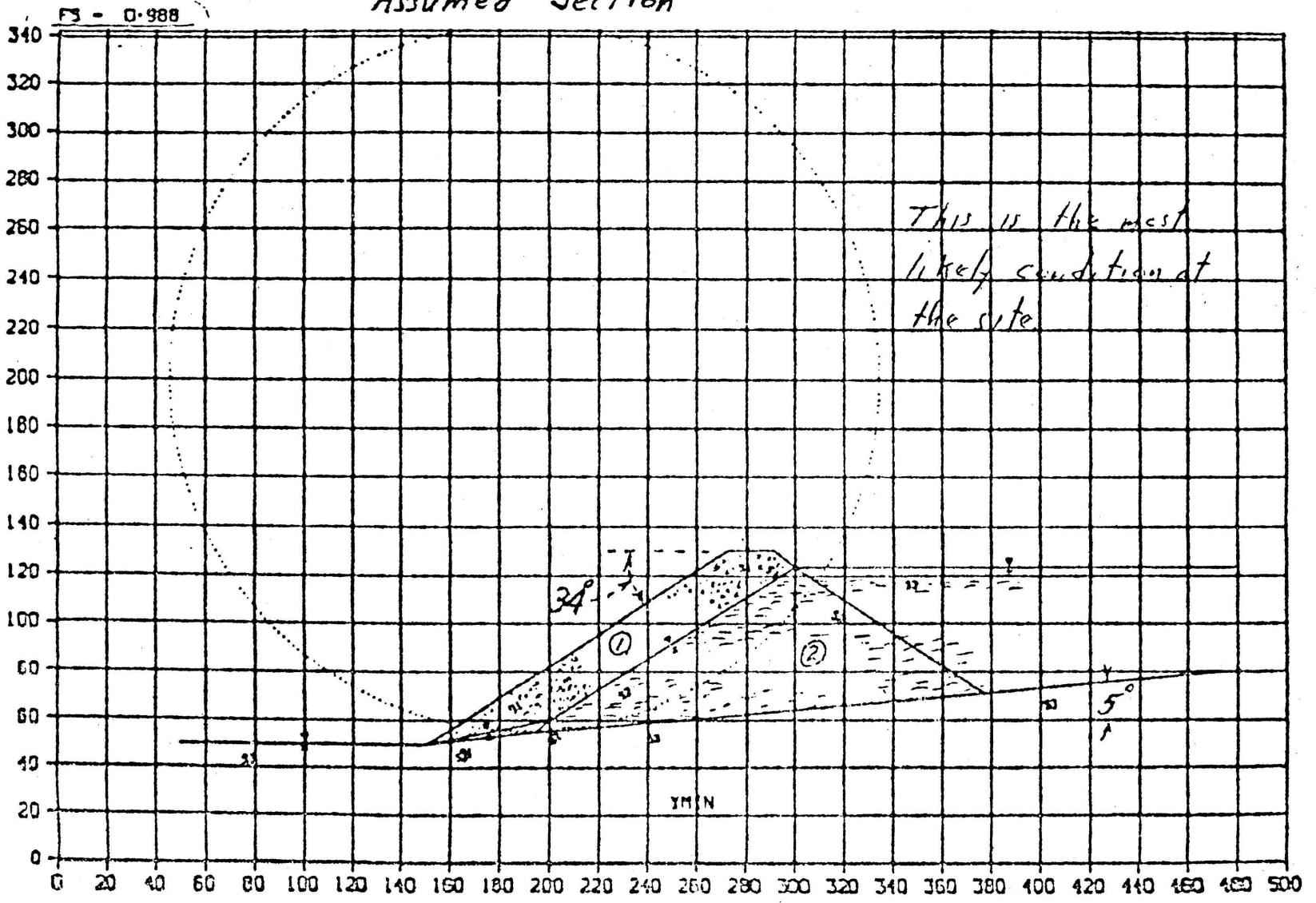
Values based on tests of materials at Dresser #4.

Static condition

①  $W = 90^\circ$   $\phi = 38^\circ$   $C = 0$

②  $W = 68^\circ$   $\phi = 21^\circ$   $C = 1 \text{ psi}$

Assumed Section



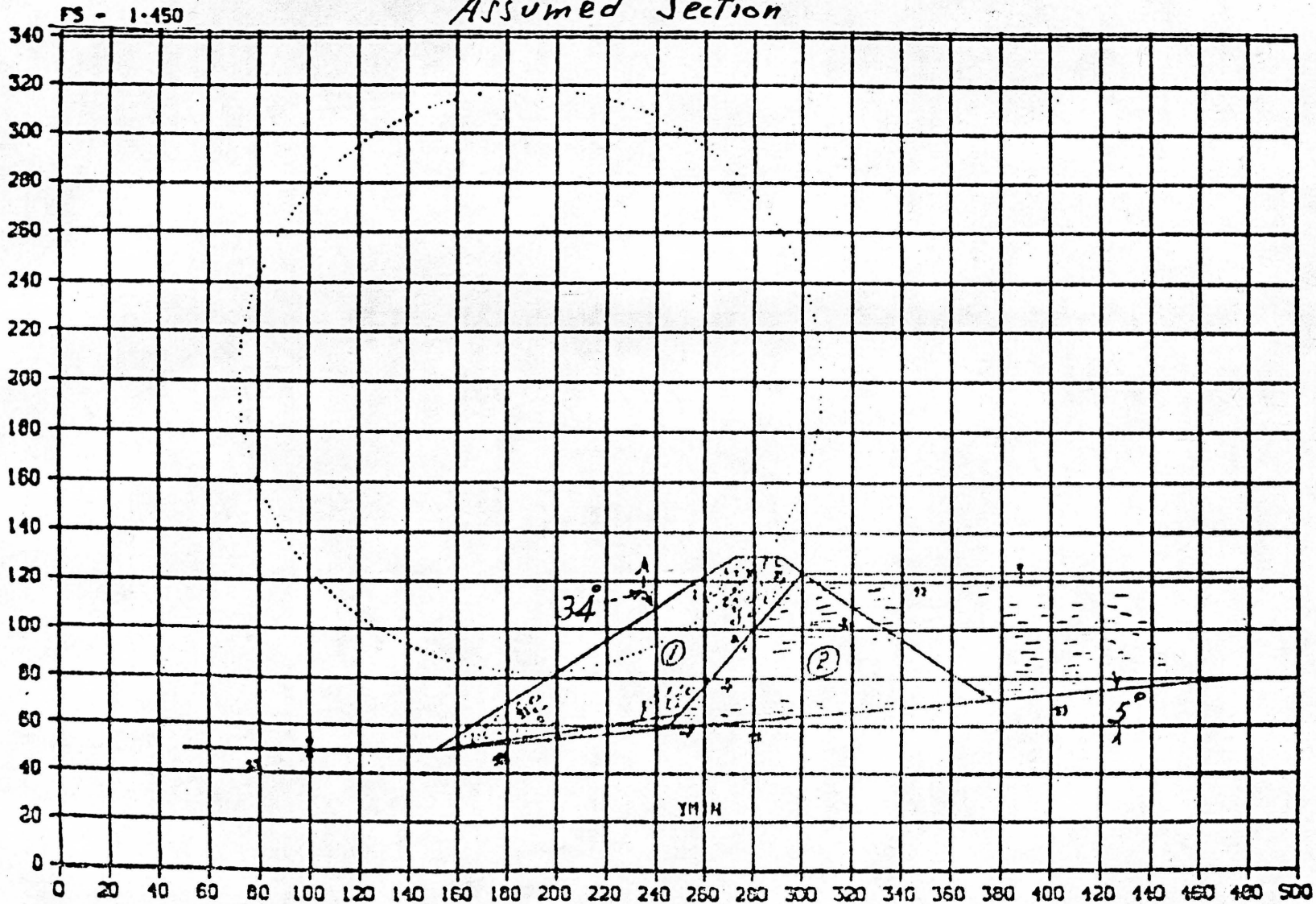
XXHORNSEYXX

Values based on tests of materials at Dresser #4.

- ① Wt=90°  $\phi=38^\circ$  C=0
- ② Wt=68°  $\phi=21^\circ$  C=1 psi

Static condition

Assumed Section



ENGINEERING, GEOLOGIC REPORT ON THE HORNSEY BROTHERS TAILINGS DAM 20715

Washington County, Mo.

LOCATION: SE $\frac{1}{4}$ , Sec. 23, NE $\frac{1}{4}$ , Sec. 26, T. 38 N., R. 3 E., Mineral Point Quadrangle

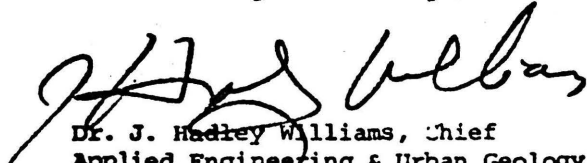
GEOLOGIC SETTING:

The dam is constructed on the Potosi dolomite. It is located on a northward draining tributary separated by a narrow ridge from Mill Creek. The dam has had previous problems of waterloss with pollution of springs in the Mill Creek area as the result of siltation.

The dam ranges from a maximum of approximately 90 feet high on the northward portion of the structure to an average height of 35 or 40 feet. Slopes generally are  $1\frac{1}{2}$  to 1. Crest width is 15 feet and freeboard is 6 feet. Several leakage is occurring on the eastern embankment near a waterline used to transfer water from a storage pond on Mill Creek into the tailings pond. Water may be leaking from the line. Water temperature at the outfall of the line is 70° F. Water in the area of leakage is 70° F. Leakage approximates 0.5 cfs. Leakage is spread out across some 100 feet along the toe of the levee. The levee affects of piping or becoming quick.

RECOMMENDATIONS:

Although the structure is extremely high and leakage as noted is significant, there are no visual signs of failure or reasons to suspect failure. Thus, from a geologic aspect, the site is not cited as being one needing remedial treatment.

  
Dr. J. Hadley Williams, Chief  
Applied Engineering & Urban Geology  
Missouri Geological Survey  
September 12, 1975

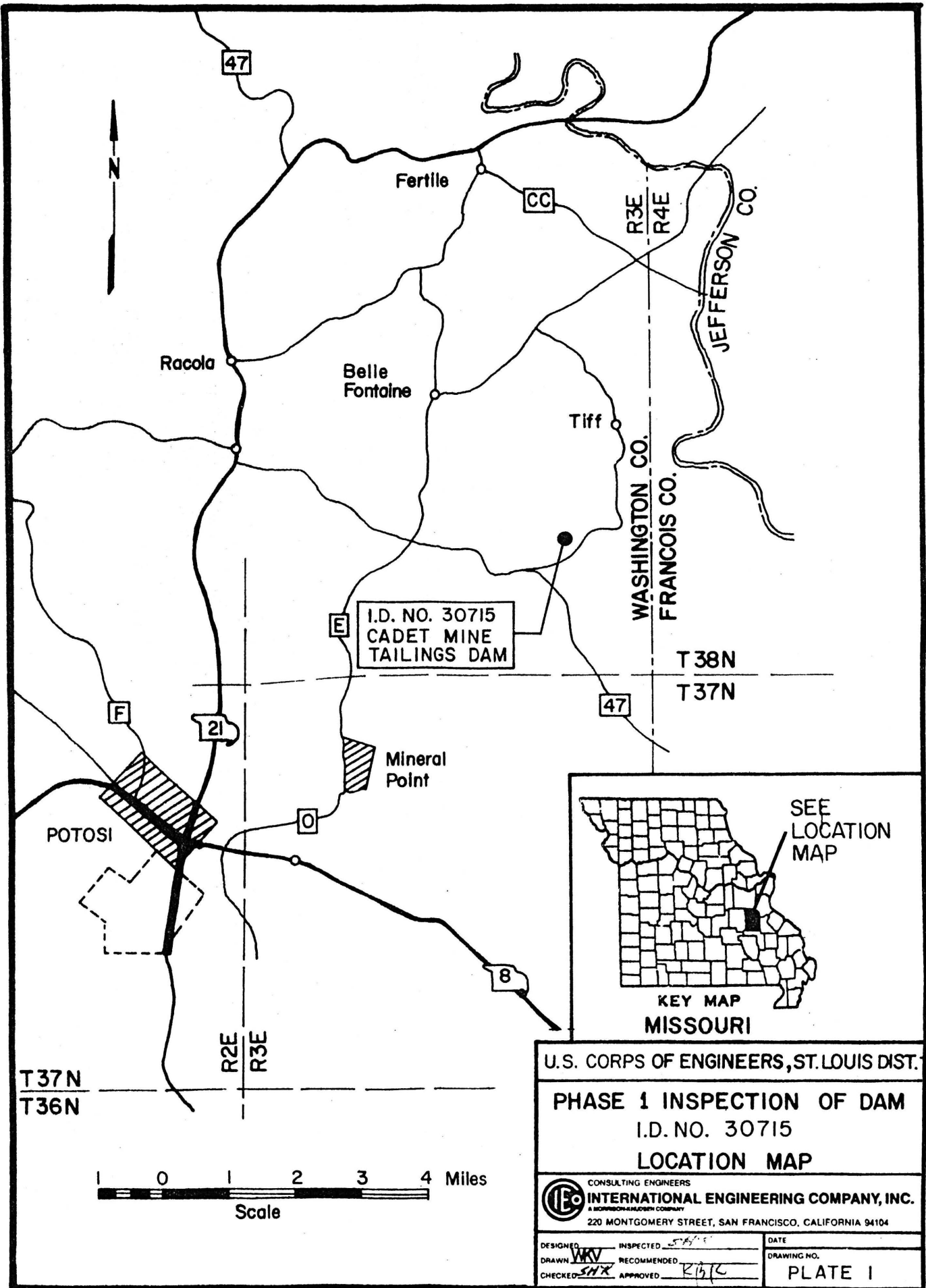
ADDENDUM TO HORNSEY BROTHERS BARITE POND

WASHINGTON COUNTY, MISSOURI

Visit on 31 August 1977 showed that high seepage rates exist along the eastern dike. Water flow was higher than observed on previous visits along the dike near the blacktop highway. Flow was equally as strong along other areas at the base of the levee as has been observed on previous visits. Gravel slumping along portions of the levee was also noted.



Dr. J. Hadley Williams, Chief  
Applied Engineering & Urban Geology  
Geology & Land Survey  
September 1, 1977

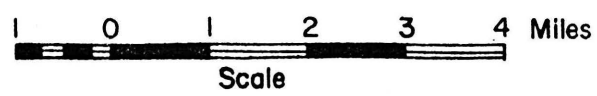


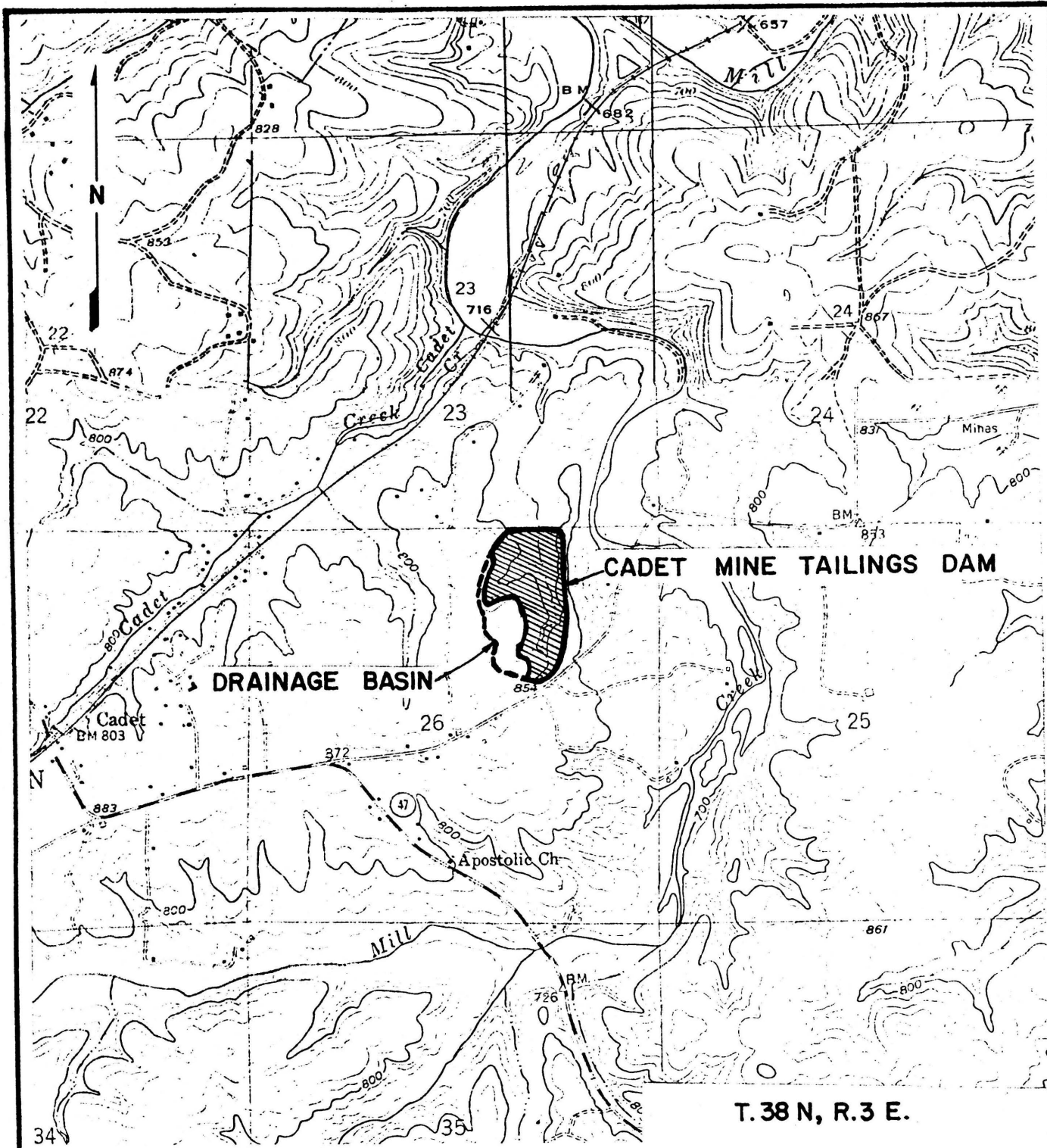
U.S. CORPS OF ENGINEERS, ST. LOUIS DIST.

**PHASE 1 INSPECTION OF DAM**  
**I.D. NO. 30715**  
**LOCATION MAP**

CONSULTING ENGINEERS  
**INTERNATIONAL ENGINEERING COMPANY, INC.**  
A MONTGOMERY WARD COMPANY  
 220 MONTGOMERY STREET, SAN FRANCISCO, CALIFORNIA 94104

|                    |                       |                |
|--------------------|-----------------------|----------------|
| DESIGNED           | INSPECTED             | DATE           |
| DRAWN <i>WKV</i>   | RECOMMENDED           | DRAWING NO.    |
| CHECKED <i>SHX</i> | APPROVED <i>R15/C</i> | <b>PLATE 1</b> |





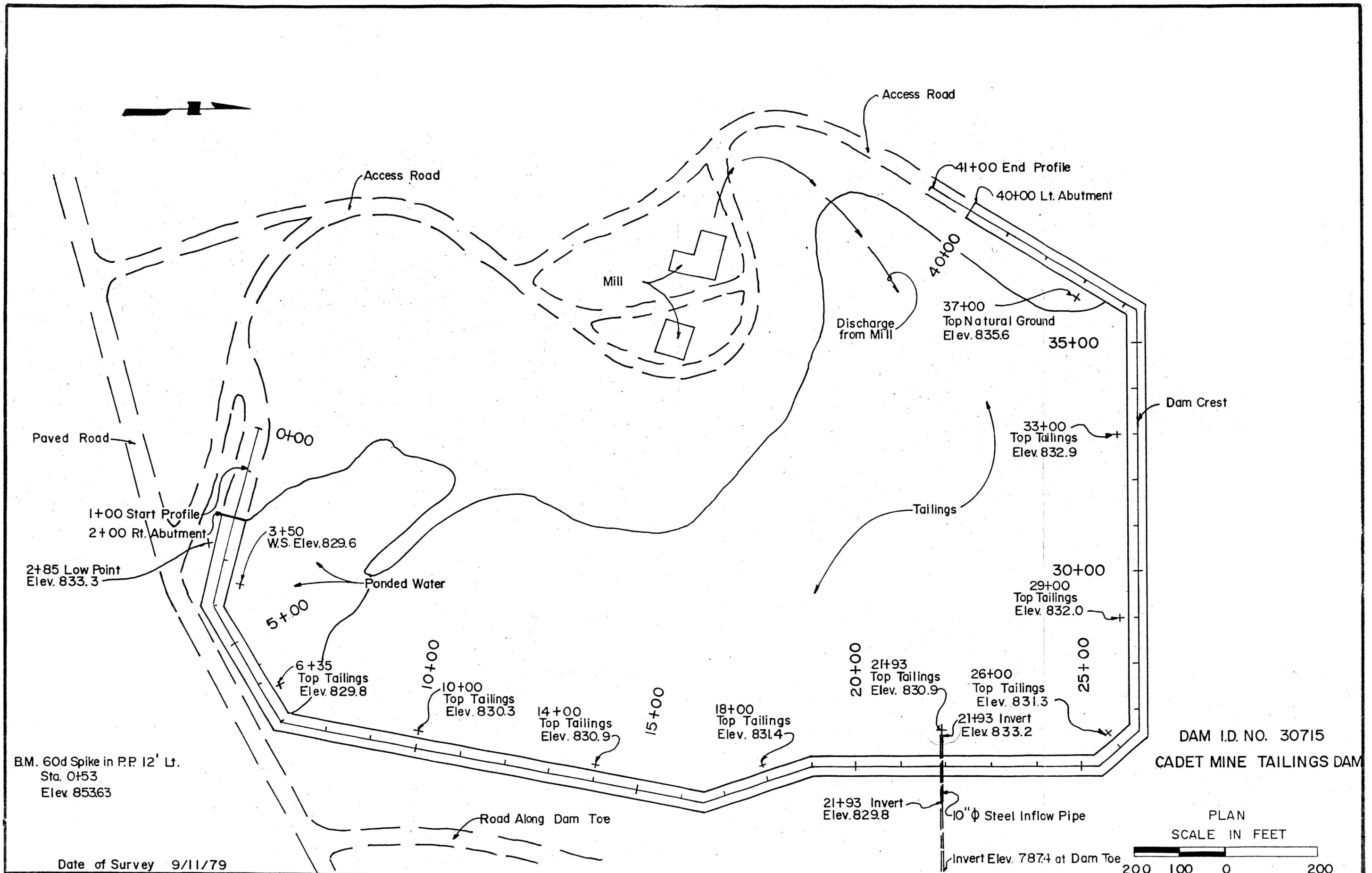
T. 38 N, R. 3 E.

Scale 1000 0 1000 2000 3000 4000 Feet

U.S. CORPS OF ENGINEERS, ST. LOUIS DIST.  
 PHASE I INSPECTION OF DAMS  
 I.D. NO. 30715  
 VICINITY TOPOGRAPHY

INTERNATIONAL ENGINEERING COMPANY, INC.  
 A MORRISON-KHULSHEN COMPANY  
 220 MONTGOMERY STREET, SAN FRANCISCO, CALIFORNIA 94104

|                    |                      |                   |
|--------------------|----------------------|-------------------|
| DESIGNED _____     | INSPECTED <u>SWK</u> | DATE _____        |
| DRAWN <u>BK</u>    | RECOMMENDED _____    | DRAWING NO. _____ |
| CHECKED <u>SWK</u> | APPROVED <u>PAH</u>  | <b>PLATE 2</b>    |

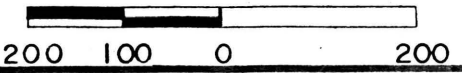


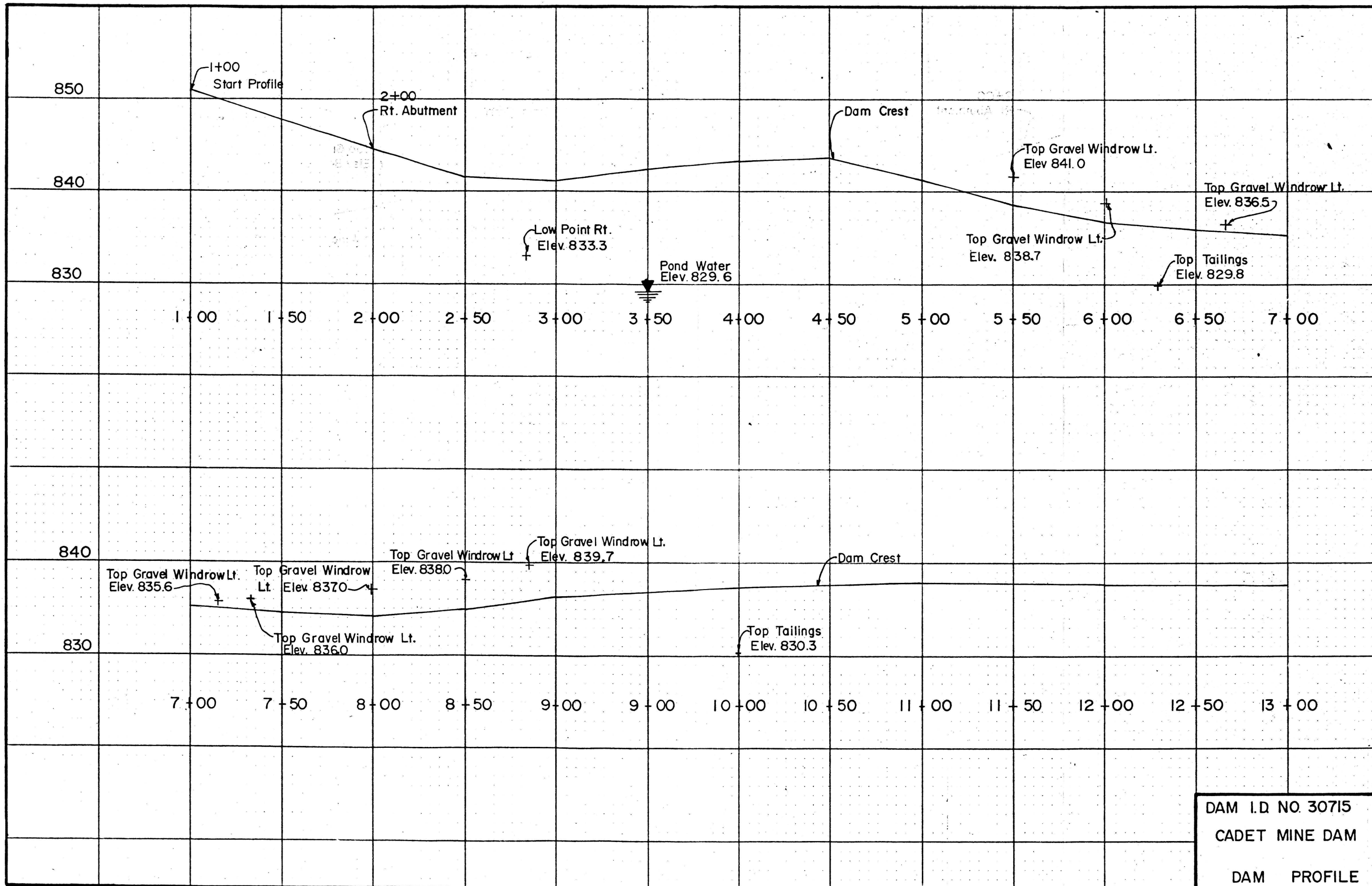
B.M. 60d Spike in P.P. 12' Lt.  
Sta. 0+53  
Elev. 85363

Date of Survey 9/11/79

DAM I.D. NO. 30715  
CADET MINE TAILINGS DAM

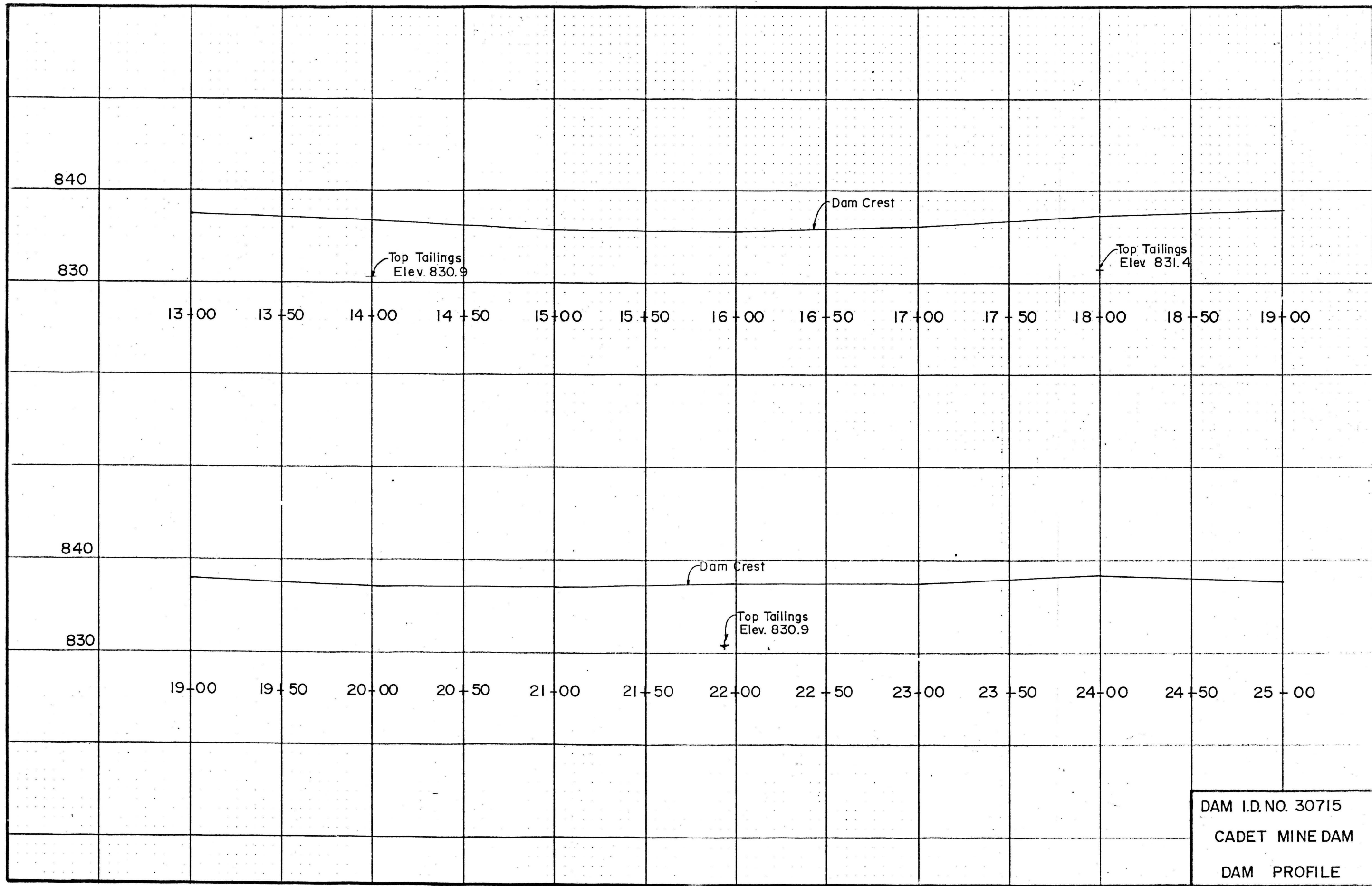
PLAN  
SCALE IN FEET



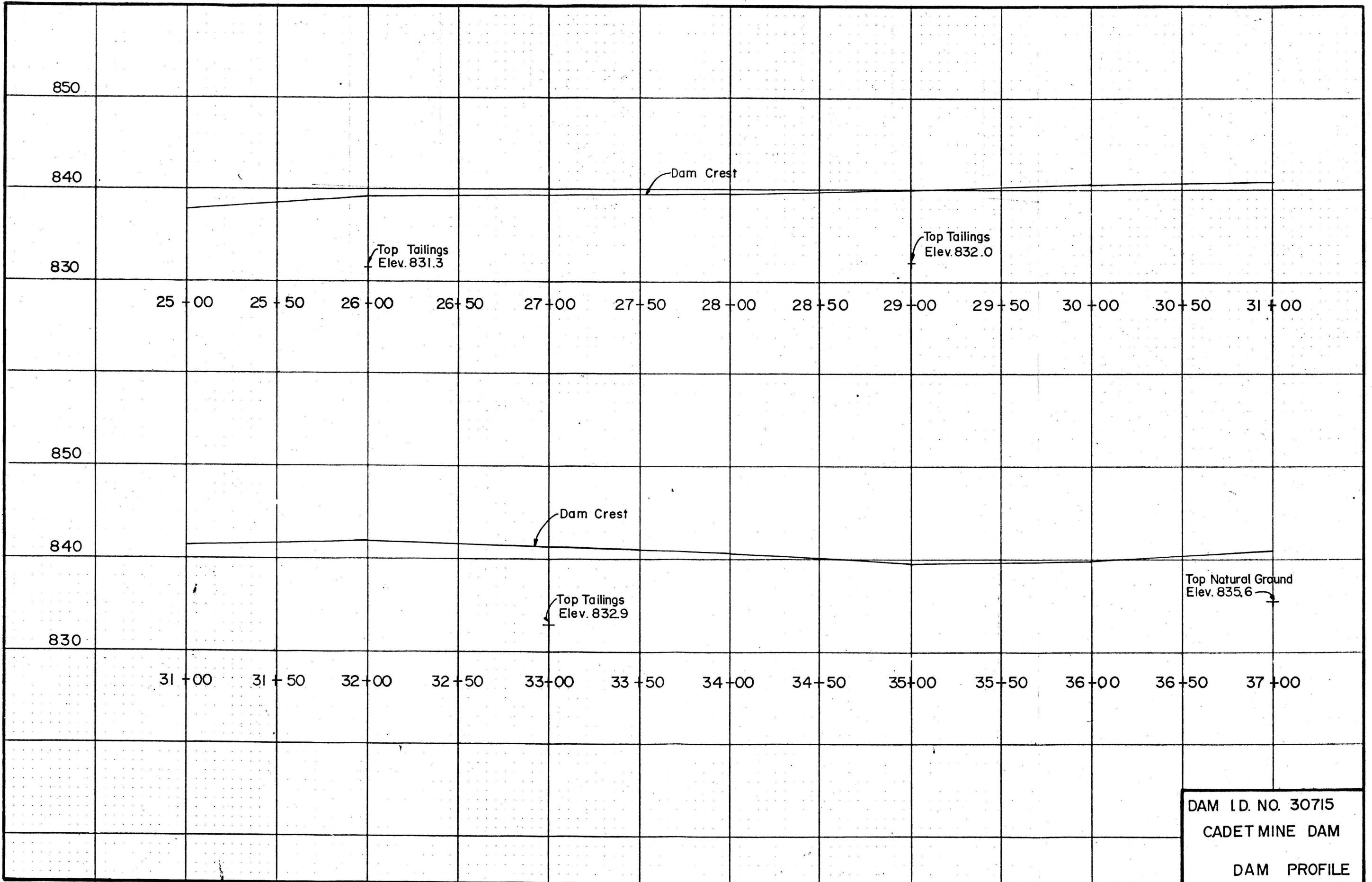


DAM I.D NO. 30715  
 CADET MINE DAM  
 DAM PROFILE  
 PLATE 4A

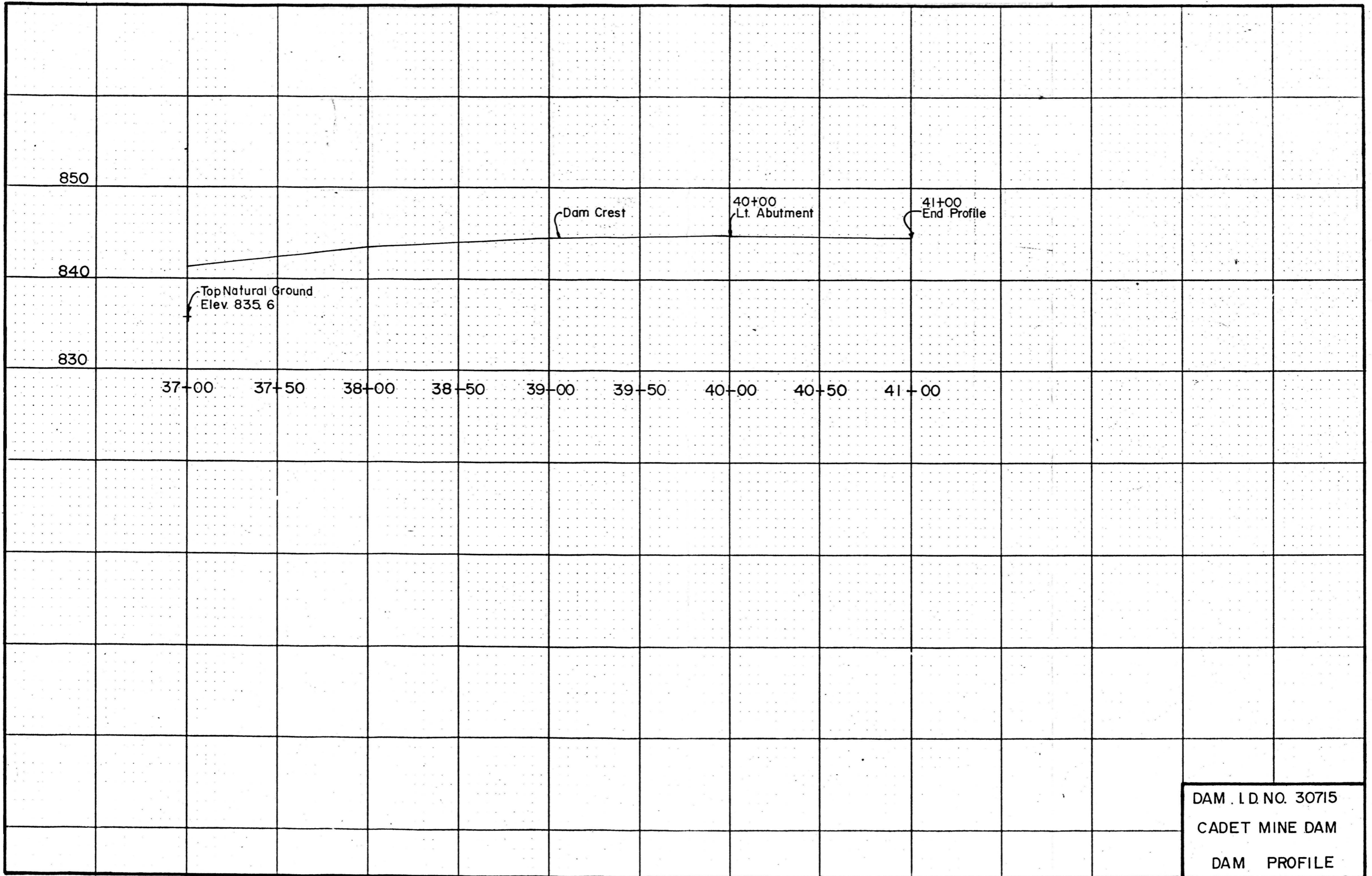




DAM I.D.NO. 30715  
 CADET MINE DAM  
 DAM PROFILE



DAM I.D. NO. 30715  
 CADET MINE DAM  
 DAM PROFILE



850

840

830

Top Natural Ground  
Elev. 835.6

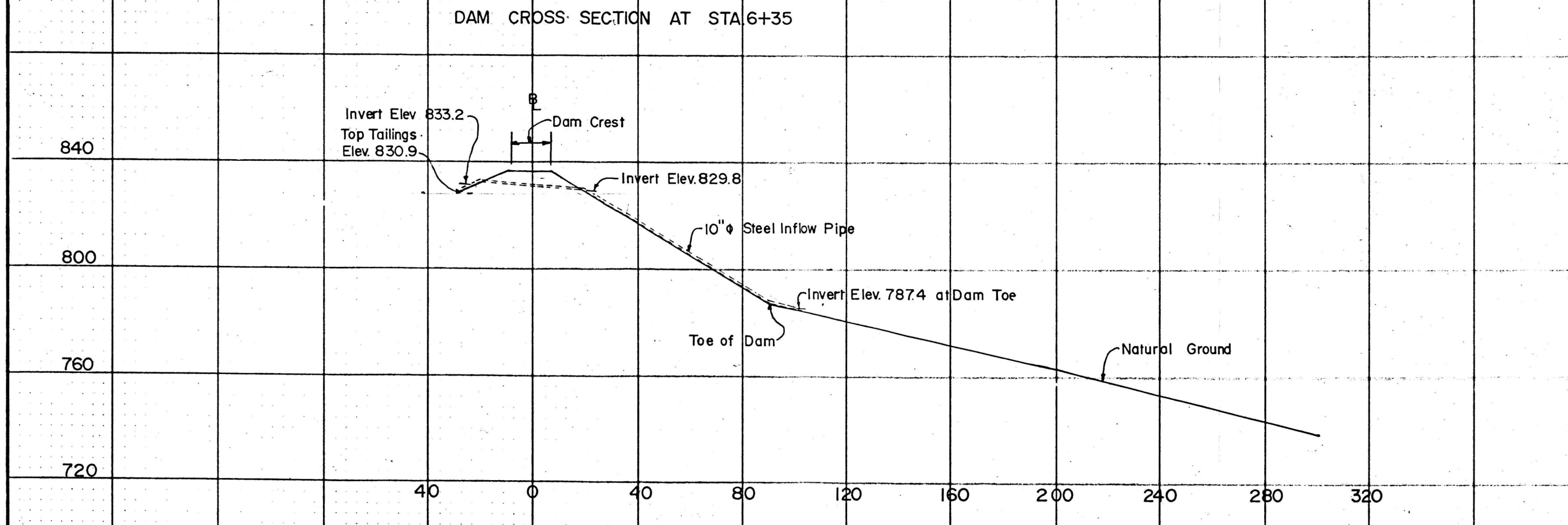
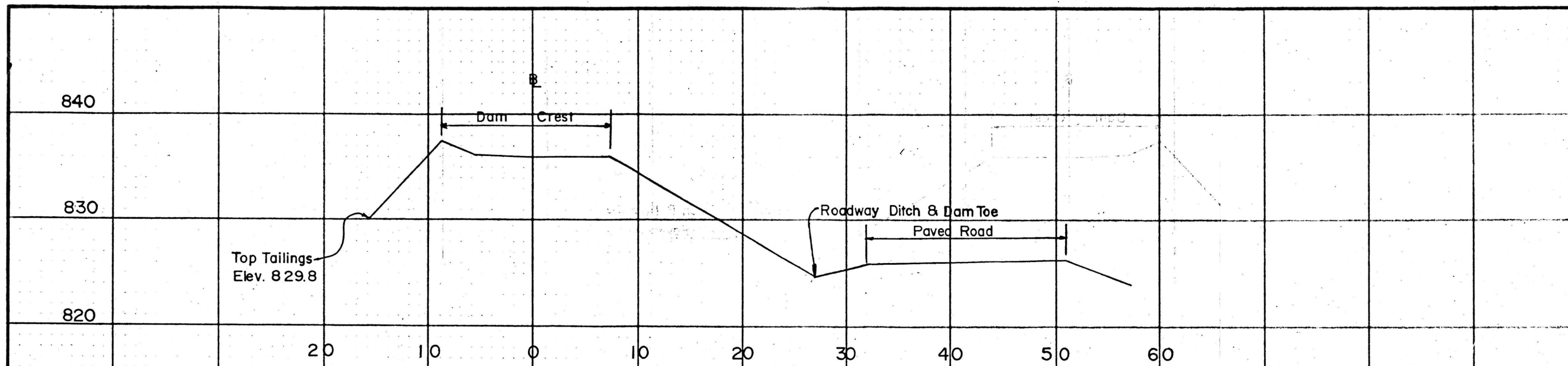
Dam Crest

40+00  
Lt. Abutment

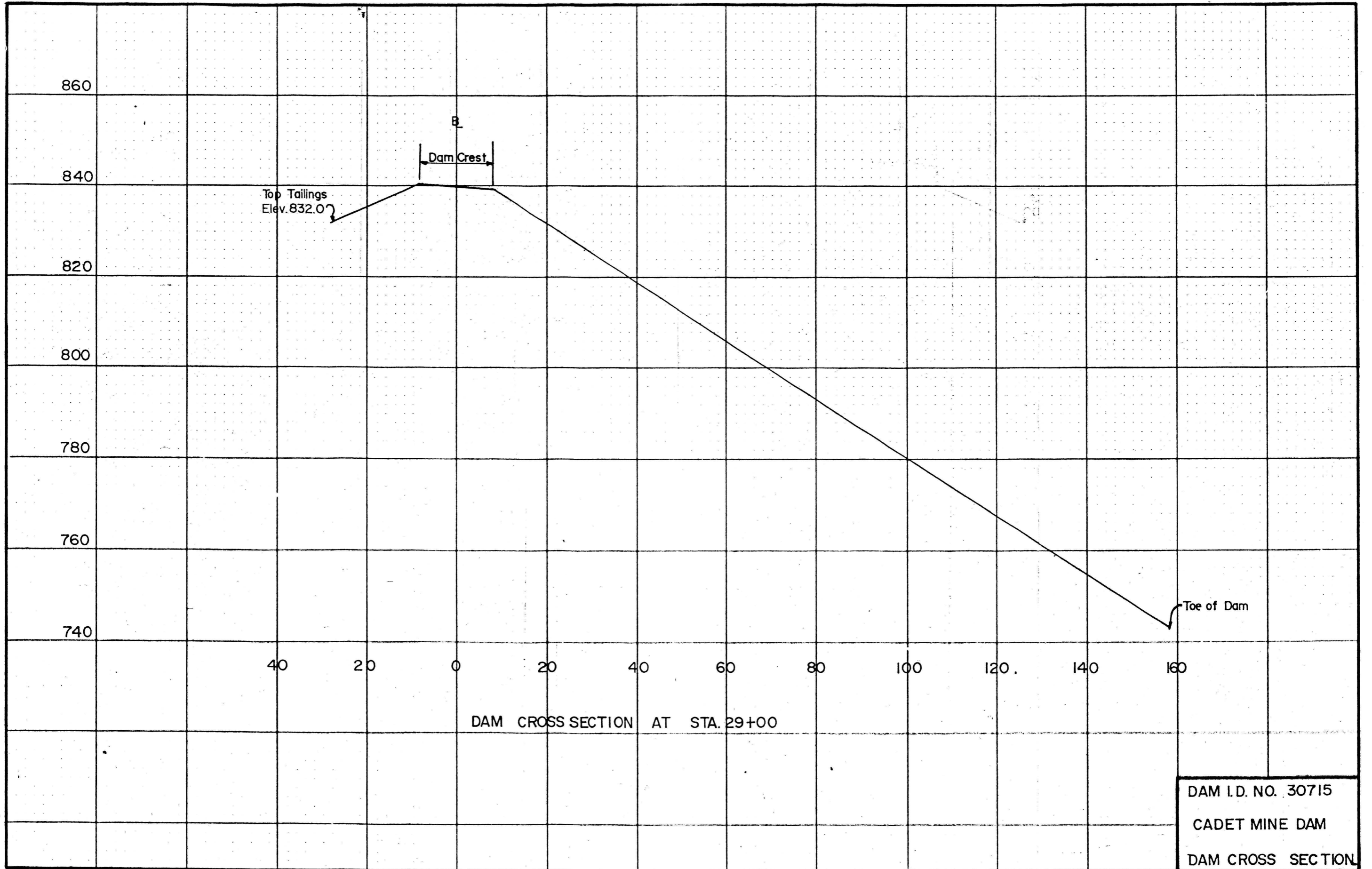
41+00  
End Profile

37+00    37+50    38+00    38+50    39+00    39+50    40+00    40+50    41+00

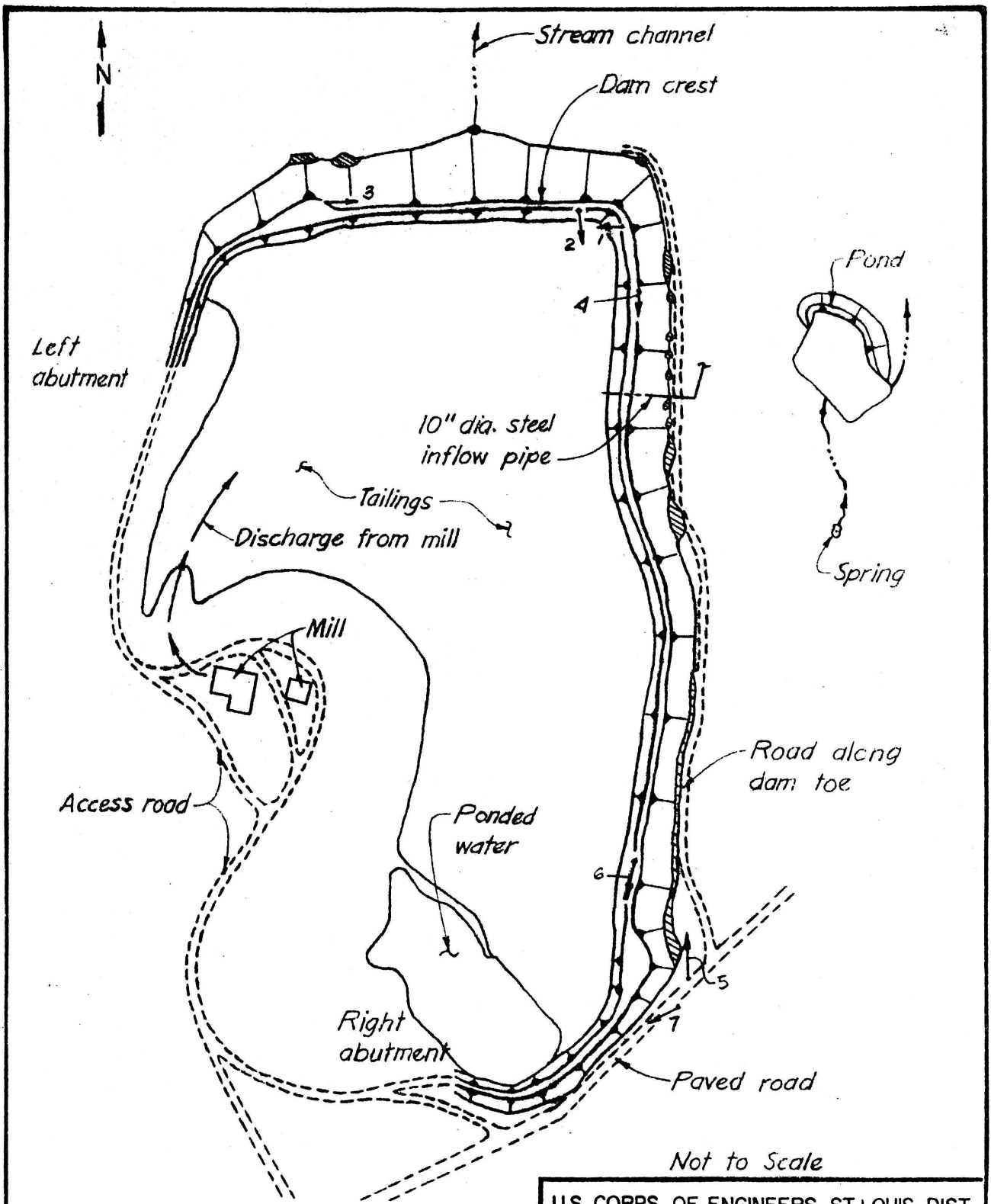
DAM . I.D. NO. 30715  
CADET MINE DAM  
DAM PROFILE



DAM I.D. NO. 30715  
 CADET MINE DAM  
 DAM CROSS SECTIONS






DAM I.D. NO. 30715  
CADET MINE DAM  
DAM CROSS SECTION



Not to Scale

LEGEND:

-  Seepage
-  Spring
-  Photograph number and view direction

U.S. CORPS OF ENGINEERS, ST. LOUIS DIST.

PHASE I INSPECTION OF DAMS  
I.D. NO. 30715  
PHOTOGRAPH LOCATION MAP

CONSULTING ENGINEERS  
**INTERNATIONAL ENGINEERING COMPANY, INC.**  
A MORRISON-KHULSHEN COMPANY  
180 HOWARD STREET, SAN FRANCISCO, CALIFORNIA 94105

|          |             |            |
|----------|-------------|------------|
| DESIGNED | INSPECTED   | <i>SHK</i> |
| DRAWN    | RECOMMENDED | <i>AAC</i> |
| CHECKED  | APPROVED    | <i>SHK</i> |

|                |
|----------------|
| DATE           |
| DRAWING NO.    |
| <b>PLATE 6</b> |

PHOTOGRAPH RECORD

CADET MINE TAILINGS DAM - I.D. NO. 30715

| <u>Photo No.</u> | <u>Description</u>   |
|------------------|--|
| 1                | View toward left abutment showing upstream face and crest of dam along north leg.  |
| 2                | View toward back of impoundment showing upstream face of dam along east leg.   |
| 3                | Downstream face and crest of dam along north leg.  |
| 4                | View toward back of impoundment showing downstream face and crest of dam along east leg. The 10-inch diameter inflow pipe at Station 21+93 is visible on the downstream slope.   |
| 5                | View north along downstream face of east leg of dam showing seepage and wet zones along the toe. The larger rock seen in the left foreground of the photograph is the screen and bull rock which was dumped at the low point along the dam at Station 8+00 to widen the crest. |
| 6                | View south along crest of east leg of dam at south end of impoundment. The low point in the dam crest and the widened crest at Station 8+00 are visible at the left side of the photograph just before the curve in the crest.   |
| 7                | Encroachment of the embankment fill onto the paved road adjacent to the south end of the impoundment near Station 6+00.  |





3



4





5



6



7