RECLAMATION

Managing Water in the West

Existing Condition of the Leadville Mine Drainage Tunnel

Leadville Mine and Drainage Tunnel Project, Colorado
Great Plains Region

U.S. Department of the Interior
Bureau of Reclamation

FINAL DRAFT June 2008

Mission Statements

The mission of the Department of the Interior is to protect and provide access to our Nation's natural and cultural heritage and honor our trust responsibilities to Indian Tribes and our commitments to island communities.

The mission of the Bureau of Reclamation is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public.

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prepared by

Technical Service Center

Geotechnical Engineering

Michael Gobla, Civil Engineer, P.E.

Engineering Geology

Mark Vandeberg, Geologist, P.G.

Peer Reviewer

Lloyd Crutchfield, P.G., Manager Engineering Geology Group

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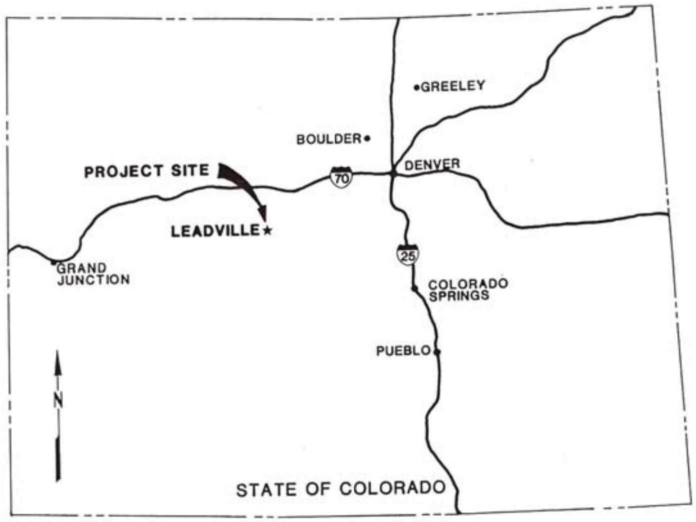
1.0 INTRODUCTION

The Leadville Mine Drainage Tunnel (LMDT) is an underground excavation constructed during World War II and the Korean War to drain groundwater from metal mines located at Leadville in Lake County, Colorado. The LMDT is not a tunnel in the strict sense of the word in that there is not a surface opening at each end of the underground excavation. It actually is a drainage adit of just over two miles in length. The LMDT portal is located about 1.5 miles north of Leadville adjacent to the south bank of the East Fork of the Arkansas River as shown in Figure 1.

Since its construction, the LMDT has experienced partial collapse and blockage of portions of the drainage flow pathway along the tunnel. A reservoir of water, called the "mine pool" has formed in the upper reaches of the LMDT as a result of water being impounded behind the suspected areas of collapse. The water table associated with the mine pool has been rising over the years while the quantity of water draining from the LMDT has declined. Local residents, both local and state officials, and the EPA have expressed safety concerns relating to the possibility of a sudden release of water behind the blockage. Bureau of Reclamation (Reclamation) employees at the LMDT Water Treatment Plant, and neighbors in a small residential community called the Village at East Fork, are located adjacent to the LMDT portal and are potentially at risk from a "failure" of the LMDT. The Bureau of Reclamation, Technical Service Center, with participation by the Great Plains Region and Eastern Colorado Area Office, has been tasked to perform an assessment of the potential for failure of the LMDT.

This report documents the current condition of the LMDT and serves as a factual summary description upon which subsequent investigations will be founded. The report describes the current condition of the LMDT including its history of construction and operation, geologic materials penetrated, dimensions of the excavation, materials of construction, and seepage rates and water table levels experienced. Facilities below the LMDT portal are also described along with a description of the borings drilled along the LMDT alignment for water extraction and water level monitoring.



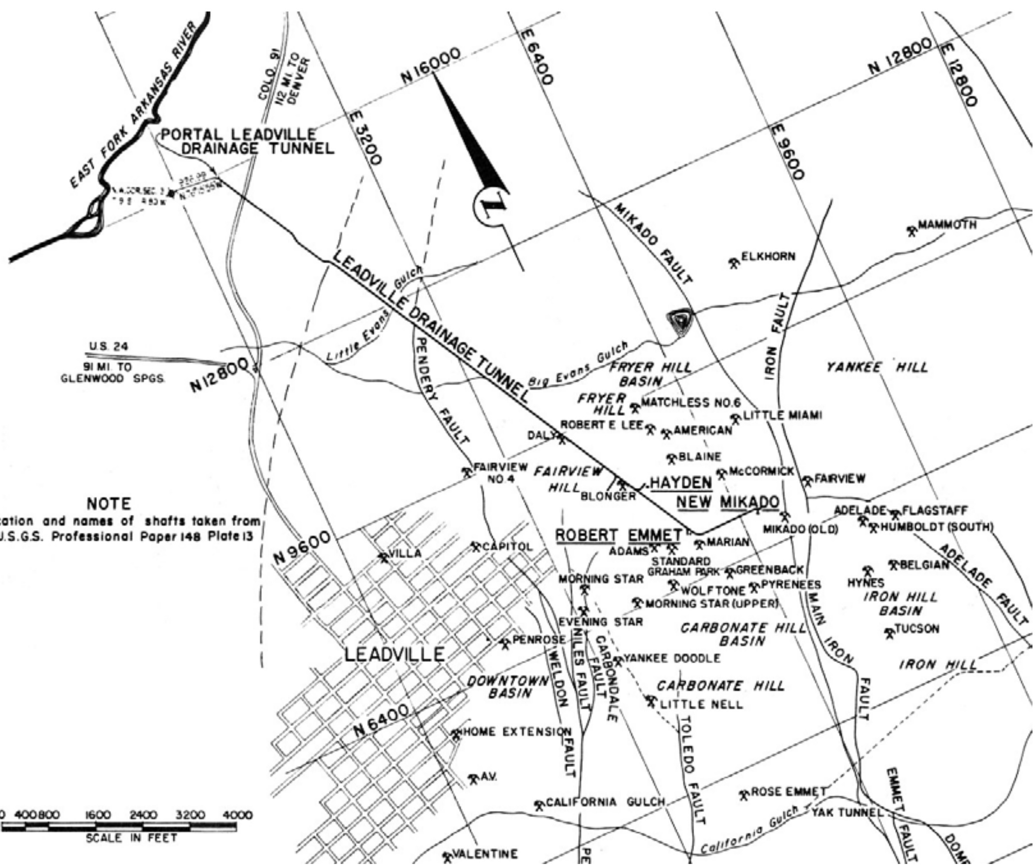


Figure 1. Location of the LMDT at Leadville, Colorado.

2.0 HISTORY OF THE LEADVILLE MINE DRAINAGE TUNNEL

The LMDT is an underground excavation constructed during World War II and the Korean War to drain groundwater from metal mines located at Leadville in Lake County, Colorado. The portal area is located about 1.5 miles north of downtown Leadville near the south bank of the East Fork of the Arkansas River. The LMDT is a little more than two miles long and ends in the vicinity of Stray Horse Gulch located about one mile east of downtown Leadville (see Figure 1).

2.1 LMDT Background

The Leadville Mine Drainage Tunnel was constructed by the U.S. Bureau of Mines to drain the Fryer Hill, Downtown, Graham Park, and Iron Hill basins of the Leadville Mining District. Construction took place in two stages between 1943 and 1952. The first stage was terminated in 1945 due to increased costs resulting in fund exhaustion directly attributable to unexpected geologic conditions. The second stage, constructed during the Korean conflict, was driven from 6,600 to 11,299 feet. Historic mine workings of significant aerial extent are drained by the LMDT.

The Bureau of Mines documented areas of collapse and deterioration during their ownership. Deterioration of tunnel support and collapse of the tunnel are believed to have continued as evidenced by the increasing head in the mine pool located upstream of the Pendery Fault. Tunnel supports, including wooden timbers and steel sets, have deteriorated throughout sections of the LMDT.

Reclamation acquired the LMDT in 1959 for water rights associated with the tunnel with the intent of including the drainage water as part of the supply for the Fryingpan-Arkansas Project. Due to more senior existing claims on the water, no water rights were ever obtained by Reclamation. The LMDT drainage discharges into the East Fork of the Arkansas River. The Clean Water Act of 1972 prohibited discharge of any pollutant from a point source without meeting criteria specified in a site specific National Pollutant Discharge Elimination System (NPDES) permit. The LMDT drainage contains metals which were eventually determined to exceed water quality standards. To bring the discharge water into compliance, Reclamation designed and constructed a chemical precipitation water treatment plant using sodium hydroxide. This facility commenced operation in March of 1992. Reclamation operates the facility to remove heavy metals (cadmium, zinc, and iron) from the LMDT drainage water. The design capacity of the water treatment plant is 3.2 million gallons per day (MGD).

In addition to constructing the water treatment plant, Reclamation modified the LMDT in the vicinity of the portal on several occasions. The most significant modifications were during the 1990-1992 construction when a new wood-lattice and gravel-filled bulkhead, a 428-foot-long concrete tunnel liner, an outlet portal structure, and a geomembrane-lined detention pond were installed. Work on access roads to the plant and the small group of homes near the plant was recently completed, providing additional means for entering and exiting the area.

2.2 History Timeline

1860 – Placer gold was discovered bringing fortune seekers to a tributary creek near the headwaters of the Arkansas River. On April 6, 1860, John O'Farrel and his party stopped at noon. He went to the creek to get some water for his coffee. Upon breaking through the snow and ice he found gold lying on the sand bar. The men began working the area. A few days later Abe Lee exclaimed "boys I got all of California here in my pan!" Horace Tabor and Samuel Kellogg came by on April 26th and in two months time took out $75,000 in gold from their claims. Oro City was the name of the new town at California Gulch where $1 million in placer gold was recovered that first summer. Ten thousand people moved to Oro City by July of 1860 (Emmons and others, 1927). The rich gold placers were mined out in a few years time and the population fell to about two hundred.

1868 – Hard rock mining for gold commences at the Printer Boy Mine.

1874 – The heavy blue-colored sand, which annoyed the miners for years because it clogged their sluice boxes, is identified as a silver-bearing variety of the lead-carbonate mineral cerussite. A. B. Wood and W. H. Stevens hire prospectors to locate outcrops of rock containing the lead-carbonate silver ore. Silver mining is initiated on a small scale in 1875 on the Lime, Rock, and Dome claims.

1877 – Prospectors discover rich ores of lead and silver on Fryer Hill and in other areas of the district. Mining expands and the population growth results in the establishment of the city of Leadville.

1878 – The first successful smelter, the Harrison Reduction Works, is completed and begins operation. The silver rush continues and the population grows to 15,000.

1880 - The Denver and Rio Grande Railroad reaches Leadville. This enables an acceleration of the silver and lead mining activity.

1895 - The Yak Tunnel is started in California Gulch at an elevation of 10,340 feet to drain the Iron Hill portion of the mining district. Years later, through a series of eastward extensions it eventually reaches a length of approximately 4 miles.

1896 – Labor unrest stops production, the Downtown mines are allowed to flood.

1898 – Pumping of up to 15,000,000 gallons per day is required to drain the mines.

1901-1925 – Notable efforts to drain portions of the mining district include 1901-1907, 1915-1916, and 1923-1925 pumping to lower the water levels in the Fryer Hill, Graham Park, Carbonate Hill, and Downtown areas. These areas are all in the vicinity of the upstream end of the yet to be constructed LMDT.

1912 – The Yak Tunnel is 3.75 miles long, it reaches the Diamond Shaft.

1915-1916 – Pumping the Penrose Shaft starts May 8, 1915. It requires pumping until July, 1916 to unwater the Downtown mine workings. Thereafter a pumping rate of 1,500 gallons per minute (gpm) is needed to keep the workings unwatered.

1917 – The Fryer Hill and Graham Park area mines are unwatered by pumping.

1919 - A labor strike followed by economic decline closes all the Leadville mines except the Penrose. The Graham Park mines flood.

1921 - The Canterbury Tunnel is started near the base of Canterbury Hill at an elevation of 10,063 feet as a community project to explore for undiscovered ore deposits and drain a portion of the Leadville Mining District. Significant inflow of water occurs before the tunnel crosses the Pendery Fault. Work ceased in 1925 at a length of 4,172 feet, as the exploration results were disappointing.

1923 – The Graham Park mines are unwatered by pumping. The Penrose Shaft pumps stop in November allowing the Downtown mines to flood.

1933 – Mining in the district shuts down, the mines are allowed to flood.

1943 – 1945 The Bureau of Mines constructs the first segment of the LMDT to Station 66+00 to drain portions of the existing mines in the Leadville Mining District.

1949 – An appropriation of $750,000 was approved on October 12, 1949 for completion of the LMDT.

1950 – 1952 A contract is awarded to the Utah Construction Company in September, 1950. The LMDT is completed to Station 112+99 by March 1952.

1953 – Reinforcement of deteriorated timbering was completed along the first 2,500 feet of the LMDT by April 17, 1953. A total of 215 steel sets were placed.

1955 – Inspection identifies a cave-in of two steel sets from Station 40+25 to 40+30. Other problem areas are identified on a profile drawing dated March, 1955. Some repairs were made in May and June between Stations 38+50 and 48+75, and between Stations 65+00 and 66+00.

1956 - First sinkhole on the ground surface above the LMDT is reported in June.

1959 - Reclamation acquires the LMDT in December, 1959 as a potential water source for the Fryingpan-Arkansas Project and accepted "full custody, accountability, and future responsibility" for the LMDT with the stipulation that, "…Reclamation has no present intention of spending any funds on the maintenance and repair of the tunnel."

1966 – A sinkhole is discovered on July 5, 1966 located 125 feet down slope toward the portal from State Highway 91, which crossed the LMDT about 535 feet from the portal. Subsequent investigations find an accompanying cave-in of the tunnel.

1968 – In September a sinkhole develops 15 feet down slope from the edge of State Highway 91. The sinkhole was backfilled and several holes are drilled through the highway and into the tunnel beneath the highway, and were filled and cement grouted. Reclamation installs six observation wells to monitor the groundwater in the vicinity from the portal to Station 6+35.

1972 – On May 25, an explosive device was placed in the air line which passed through collapsed portions of the LMDT to Station 10+00. The blast increased LMDT outflows for a short period of time and then the flows diminished.

1973 - Reclamation awards a contract to clean out first 200 feet of tunnel, install new supports in the second 100 feet, and completely backfill all remaining sinkholes, voids, and un-collapsed portions of the tunnel between approximate Stations 1+25 and 5+00. A bulkhead of treated timbers is also installed at Station 2+00. To accommodate the work, Reclamation purchases and fences approximately 8 acres of land overlying and adjacent to the tunnel portal.

1975 – The Environmental Protection Agency (EPA) issues a NPDES permit to Reclamation because the effluent from the LMDT was determined to be a pollutant containing heavy metals in quantities exceeding applicable water quality standards. Conditions of the permit require effluent monitoring only.

1975 - Reclamation installs a 450 gallon per minute capacity pump at Station 6+35 in an attempt to maintain the groundwater table at a safe level in ground adjacent to the lower portion of the tunnel. This is a temporary fix.

1976 - Water is flowing out of the LMDT at a historic average of 1,570 gallons per minute or about 2,500 acre-feet annually. Numerous sinkholes are observed at the ground surface above the LMDT from Station 2+00 to approximately 6+50 and it is assumed that this portion of the tunnel is almost completely filled with sloughed material. A total of 12 sinkholes have been recorded over the years since 1956. The holes are at different locations along the first 650 feet of tunnel, but none are found from Station 6+50 to 10+00; it is assumed that the tunnel is partially filled with some areas being collapsed, but no sinkholes have ever appeared within this section of the LMDT (Station 6+50 to 10+00).

1976 - Public Law 94-423 (September 28, 1976) authorizes the Department of the Interior to rehabilitate the first 1,000 feet of the LMDT, and to maintain the tunnel in a safe condition, to monitor the quality of the tunnel discharge, and to make investigations leading to recommendations for treatment measures, if necessary, to bring the quality of the tunnel discharge in compliance with applicable water quality standards.

1978 - 1980 - The collapse material from the first 500 feet of the tunnel was excavated and the tunnel opening shored up. A bulkhead, constructed of steel beams and wooden timbers, was installed at Station 4+66.

1978 - Commissioner of Reclamation recommends to Secretary of the Interior on July 7, 1978, that the LMDT be plugged.

1983 - The contaminated mining area at Leadville is placed on EPA's National Priority List (NPL) naming it as the California Gulch Superfund Site. The 18-square-mile area was divided into 12 areas designated Operable Units (OU). The LMDT is hydraulically connected to OU6 and OU12. OU6 addresses contamination in Strayhorse Gulch and OU12 addresses Site-Wide Surface and Groundwater Quality.

1988 - Reclamation's Missouri Basin Regional Engineer completes a study of the tunnel plug from Station 4+66 to Station 6+32 and finds that the resistance would be more than adequate to handle the estimated range in hydraulic pressure based upon the most likely tunnel, soil, and groundwater conditions.

1989 - January, the Sierra Club and Colorado Environmental Coalition sue Reclamation alleging Clean Water Act violations as a result of discharges from the LMDT.

1989 – In February, Reclamation and EPA enter into a Federal Facilities Compliance Agreement (FFCA) in which Reclamation agreed to initiate construction of a treatment plant to treat discharges from the LMDT.

1990 - Consent Decree executed for the lawsuit based on the FFCA.

1990 – Construction of the water treatment plant and lining of a portion of the LMDT is initiated.

1992 - P.L. 102-575 authorized Reclamation to construct a treatment plant in order that water flowing from the Leadville Mine Drainage Tunnel may meet water quality standards, but specified that the plant "shall be constructed to treat the quantity and quality of effluent historically discharged" from the tunnel.

1992 - Reclamation completes construction of the LMDT water treatment facility, and has been treating water continuously since this time. A flow through wood-lattice bulkhead was constructed at Station 4+61. Gravel and cobble backfill was placed immediately behind the bulkhead. The tunnel downstream of the bulkhead was lined with reinforced concrete. Weep holes were installed through the concrete lining to drain surrounding groundwater into the tunnel.

1994 - EPA contracts with Reclamation for data gathering, analysis, design, construction, and oversight technical assistance activities associated with the California Gulch NPL Site.

1998 – Reclamation's technical assistance to EPA ends.

2000 - EPA begins channeling and routing contaminated surface water from OU6 into the mine pool through a drain installed at the Marian Shaft.

2001 - Reclamation completes an Emergency Action Plan (EAP) for the LMDT and Water Treatment Plant. A safety brochure was developed and distributed to the residents of The Village at East Fork.

2001 - Reclamation installs a water level indicator and other warning systems in and near the LMDT and ties this into the water treatment plant's auto-dialer for employees.

2001 - Reclamation hosts an Open House at the LMDT Water Treatment Plant.

2001 - A structural analysis was completed on the bulkhead at Station 4+61 by the Great Plains Region who found it to be sound with the plates and bolts used for the bearing of the timber members in good condition.

2002 - Two wells were drilled and three existing holes were enlarged along the alignment of the tunnel in 2002 with the purposes of monitoring water levels along the tunnel, obtaining groundwater quality sampling points, and gathering rock quality data along the tunnel. Boreholes LMDT-B1 and –B2 are new monitoring wells constructed by Reclamation at Stations 46+66 and 96+66, respectively. Hayward Baker modified three existing (pre-tunnel construction) test holes along the tunnel alignment at Stations 25+15, 36+77, and 75+05.

2002 – In January, Reclamation's Eastern Colorado Area Office sends a memorandum presenting a status update of Leadville Mine Drainage Tunnel Activities to the Lake County Board of Commissioners. The memorandum discussed the road work to provide improved egress from the treatment plant and The Village at East Fork, implementation of an EAP, placement of the monitoring well at Station 10+25, and results of a bulkhead strength analysis.

2002 - An audible warning system is installed to alert The Village at East Fork residents in the event of an emergency. The system plays an alert message in Spanish and English.

2002 – In June, Reclamation submits comments to the EPA on the Draft OU6 Focused Feasibility Study, including concerns pertaining to the capacity of the LMDT Water Treatment Plant to adequately treat additional discharge from OU6 and Reclamation's lack of authority to treat contaminated water pumped from upstream of the proposed LMDT plug.

2003 - Road improvements are completed to the LMDT Water Treatment Plant and The Village at East Fork. These road improvements include the main access road from State Highway 91 and the secondary access road from U.S. Highway 24.

2003 - Reclamation participates with Lake County in a table-top exercise to test the response to a potential problem at the LMDT Water Treatment Plant.

2003 - September 3, EPA releases the final Record of Decision on the OU6 remedy. EPA selects the alternative to plug the LMDT and pump contaminated surface and groundwater to Reclamation's LMDT Water Treatment Plant for treatment.

2004 - Reclamation participates with Lake County in a functional exercise to practice for a potential problem at the LMDT Water Treatment Plant and test the EAP. An audible test of the emergency warning message was not conducted.

2004 – In February, EPA sends a letter to Reclamation Regional Director Bach, informing Reclamation of EPA's decision for OU6 and providing an initial draft of a Memorandum of Understanding (MOU) between Reclamation, EPA, and Colorado Department of Public Health and Environment (CDPHE) to implement the remedy.

2004 - Meetings and discussions are held between Reclamation and EPA, highlighting Reclamation's lack of authority to treat the contaminated water pumped from OU6.

2004 – Rocky Mountain Region Solicitor renders a Legal Opinion that under current law, Reclamation does not have authority to expand its treatment plant so there will be sufficient capacity to treat surface runoff from OU6 and the mine pool groundwater.

2005 - As part of other studies, the slope stability of the area between the portal and Station 10+25 was analyzed. The results indicated that the gross stability of the portal area to Station 10+25 is adequate for the ground conditions. The slope stability study examined several different groundwater and soil property scenarios.

2005 - Several versions of the draft MOU were sent back and forth between Reclamation, EPA, and CDPHE. In meetings with EPA and the State, Reclamation reiterates its position that if the sole purpose of the LMDT Treatment Plant is to implement OU6 remedy, the plant should be operated by EPA or Colorado.

2006 - EPA, Source-Water Consulting, and the University of Colorado present the results of an extensive study of ground water in the LMDT area titled "Hydrogeologic Characterization of Ground Waters, Mine Pools, and the Leadville Mine Drainage Tunnel, Leadville, Colorado". In the report, they conclude "The results of this investigation indicate that the LMDT drains only a small volume of mine pool water and a very large volume of regional bedrock and adjacent alluvial groundwater."

2006 - February, CDPHE submits a request to Senator Allard's office for legislation, "…that would provide Reclamation the necessary authority to cooperate with EPA and the State of Colorado in implementing the remedy proposed for OU6…" EPA's opinion was that Reclamation should pay for implementation of part of the remedy.

2006 - Reclamation receives a first draft of legislation from Interior's Congressional drafting service which included transfer of the treatment plant to EPA. On several occasions, draft legislation and the draft MOU were discussed and revised based on comments and discussions with EPA and Colorado.

2006 - Reclamation proposes a $30 million trust fund for future operation and maintenance of LMDT Treatment Plant. Colorado requests $50 million.

2007 - Continued discussions between Reclamation, EPA, and the State of Colorado on draft legislation and draft MOU. Mid-year, discussions stall over the trust fund level disagreement.

2007 - Reclamation meets with EPA, Lake County, State of Colorado, and others to discuss their concerns about the LMDT in October.

2007 - November 8, Reclamation receives a letter from EPA expressing its concerns pertaining to an uncontrolled, potentially catastrophic release of water from the LMDT which could endanger human life and the environment.

2008 - January 14, Reclamation asks EPA for their analysis supporting their concerns regarding an uncontrolled, potentially catastrophic release of water from the LMDT.

2008 - February 8, Reclamation receives a letter from EPA referencing studies completed by Reclamation in the 1970s to support their concerns pertaining to the sudden release of water from LMDT. No additional EPA-sponsored analysis is provided.

2008 - February 13, the Lake County Board of County Commissioners declares a state of emergency due to the LMDT mine pool's elevated level and the abundant snowpack.

2008 - Reclamation initiates a risk assessment to determine the true risk associated with the existing condition of the LMDT in February 2008. The risk assessment is scheduled to be completed by June 30, 2008.

2008 - February 19, Reclamation participates with other Federal, State, and Local agencies at public meeting conducted in Leadville.

2008 - On February 22, Reclamation tests the warning system at the LMDT Water Treatment Plant in conjunction with Lake County Office of Emergency Management.

2008 - February 28, Senate Bill S.2680 is introduced to amend the Reclamation Projects Authorization and Adjustment Act of 1992 to require the Secretary of the Interior to take certain actions to address environmental problems associated with the Leadville Mine Drainage Tunnel in the State of Colorado, and for other purposes. Also on February 28, House of Representatives Bill H.R. 5511 is introduced to direct the Secretary of the Interior, acting through the Bureau of Reclamation, to remedy problems caused by a collapsed drainage tunnel in Leadville, Colorado, and for other purposes.

2008 - On March 10, Reclamation tests the capacity of its water treatment plant. The plant successfully treats a flow rate of 2150 gallons per minute at the current water quality levels. On March 18, flow from the LMDT is 1120 gallons per minute.

2.3 Initial Bureau of Mines Construction

In the summer of 1943, surveys were made to select the portal site and survey the surface topography along the tunnel alignment. The portal site is located near the northwest corner of Section 13, T. 9 S., R. 80 W. of the 6th Principle Meridian, on the Hibschle Placer Claim, Patent Survey No. 399, owned by the Resurrection Mining Company. The Bureau of Mines purchased a portion of the Hibschle Claim in the portal area. In addition, the Ditch Placer Claim, Patent Survey No. 416, of 9.28 acres was acquired for the waste-rock dump. Access to the portal area was provided by construction of a 1,000-foot-long road by Lake County prior to construction startup.

An expenditure of $1.4 million was authorized in 1943 for construction of the LMDT and laterals. A cost plus fixed fee contract was awarded to Stiers Brothers Construction Company of St. Louis, Missouri. Construction activity began on December 6, 1943. This construction project is documented in Bureau of Mines Report of Investigations 4493 (Elgin and others, 1949) from which the following details and illustrations are taken.

Little was known about the geology of the first 7,000 feet of the tunnel alignment. A churn drill was used to drill ten holes through the glacial moraine. The 6-inch holes were drilled to tunnel level or to bedrock if it was encountered first. When bedrock was encountered, diamond core drilling was performed to determine the nature of the geologic formation encountered.

A surface plant consisting of nine buildings, a well and water tank, explosives storage, rail lines, and other utilities was soon established as shown on Figure 2. An excavation was cut into the hillside for the portal. A dragline was used to excavate a ditch to carry tunnel drainage to the East Fork of the Arkansas River. The track for dumping the tunnel excavation waste was carried to the southwest as shown on Figure 2.

Agreements were made with mine owners to provide royalty payments for ores to be extracted under the benefit of the drainage provided by the tunnel. Not all owners were willing to sign the agreements; in some cases, condemnation to obtain right of way was employed. A water level survey was conducted to determine the mean water levels in the various basins to be drained. A survey of shafts was initiated in early 1944. Of the 480 shafts examined, only 57 were open to permit water level measurements. Measurements were made on a quarterly basis to observe seasonal variations in water levels.

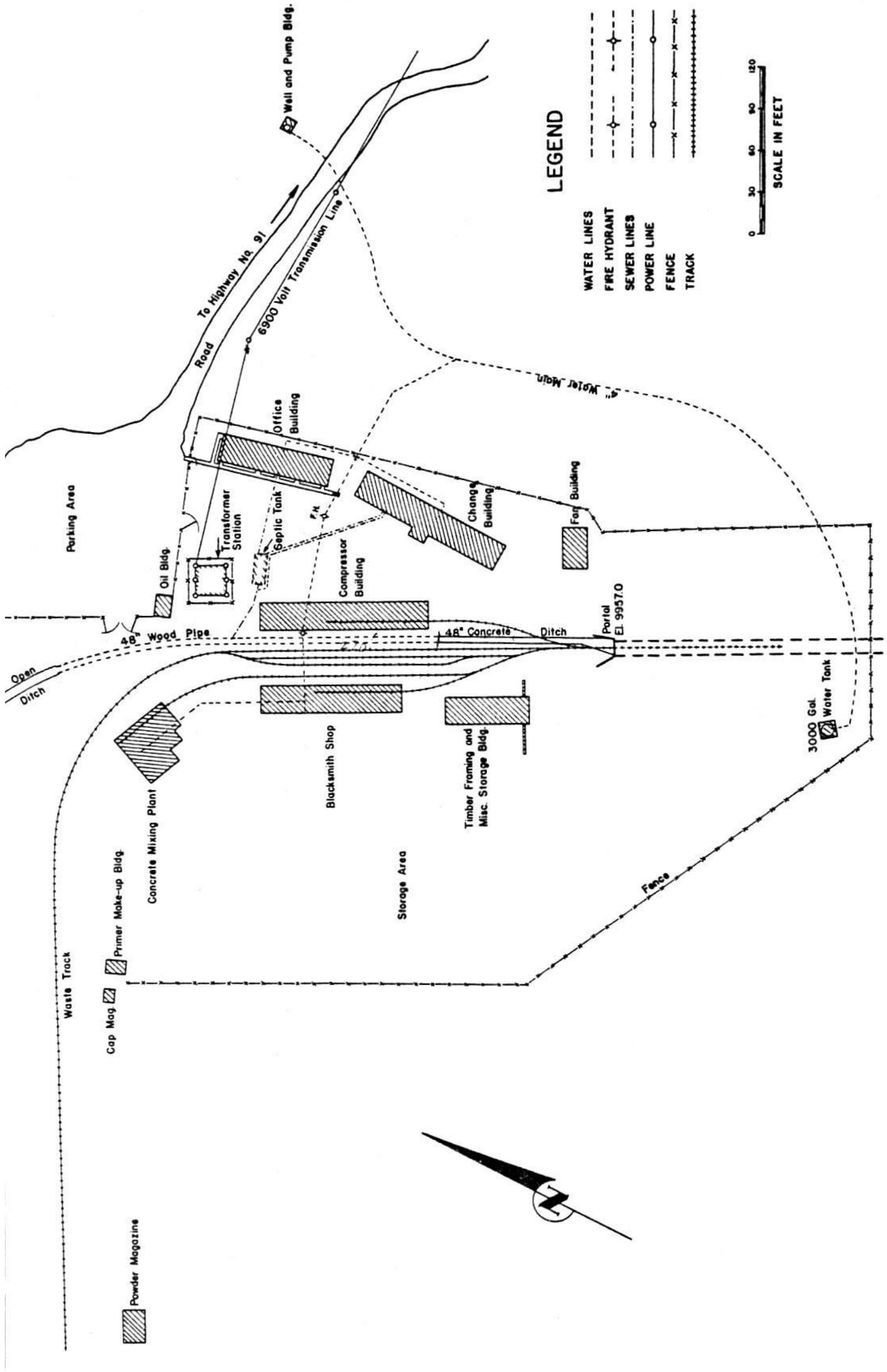


Figure 2. Surface plant facilities erected for construction of the LMDT. Note the track for disposal of excavated soil and rock turns to the southwest (Elgin and Others, 1949).

The amount of water draining from the LMDT was recorded on a daily basis using a Parshall flume weir installed at the portal. A similar weir was installed at the portal of the Canterbury Tunnel and measured every day to determine if driving the LMDT would capture some of the Canterbury flow. Weirs were also installed at California Gulch and the Valentine Shaft for recordation every 15 days.

The LMDT was excavated on a gradient of 0.3 percent, but this was increased to 0.5 percent in the rock section to provide faster water outflow and better flushing action. Caving of the tunnel occurred in August, 1944 from Station 20+50 to Station 21+26. This segment of the tunnel was in gray porphyry where the rock roof became very thin due to a zone of deeper glacial moraine than anticipated. As a result, it was decided to fill about 50 feet of the tunnel with sand and gravel, bulkhead it off, and start a new excavation adjacent to the original alignment. The deviation in alignment begins at Station 16+81 and returns to the original alignment at approximately Station 24+48. The first 335 feet of the LMDT was driven to create a clear opening inside the supports 10 feet wide by 11.5 feet high.

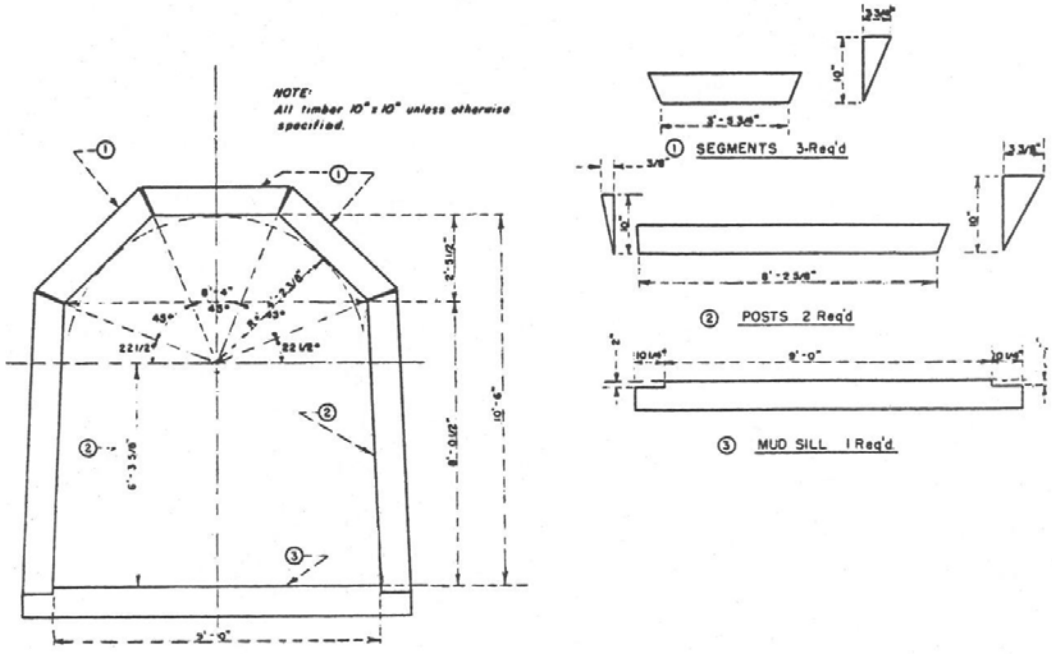
Because of the difficult excavation conditions, the excavated section was reduced to 9 feet wide by 10.5 feet high clear opening. The timber supports are shown in Figure 3. Bedrock in the invert was encountered at Station 3+50. The bedrock contact had a shallow dip such that it took until Station 6+35 for the bedrock to reach to 1.5 feet above the crown (top) of the LMDT excavation. This bedrock was weathered such that it was not until around Station 6+50 that a competent roof was obtained. Drilling and blasting were performed to break the bedrock prior to excavation. Where the rocks were naturally broken or where the roof was in glacial material, spiling was required to support the opening. Spiling is a method of excavation through heavy or caving ground. Spiling involves driving timber or steel roof supports at an angle up into the caved material. The supports are held in place in cantilever fashion by the preceding support set while the ground below the supports is excavated. Once excavated, a timber set is quickly placed to hold the far end of the cantilever in place. This new timber set forms the cantilever support for the next group of spiles to be driven. It is a slow and costly excavation method. Only the bottom was drilled and blasted, and the top was excavated using pneumatic spaders. Switch Stations were cut 4 feet into the right wall on a 250-foot spacing to facilitate switching cars with a “cherry picker.”

The difficulty of excavation resulted in exhaustion of funds with only 6,600 feet of the planned 17,000 feet of tunnel being completed. A total of 4,200 feet of the 6,600 feet of tunnel excavated required support. A total of 3,243 feet of tunnel was supported by timber sets spaced from 2 to 6 feet apart, (see Figure 3), and 957 feet of tunnel was supported by steel rail sets spaced from 3 to 5 feet apart, see Figure 4. The steel sets, consisting of 52-pound rail, were used in areas where the rock required only light support. The 10-inch by 10-inch timbers were used for support in heavy ground. A total of 465 feet of the timber-supported areas were concreted. The concrete was portioned by volume as 1:2.5:3.5 (cement:

water: aggregate) with 1.5-inch diameter coarse aggregate. As little water as possible was used because of the tunnel inflows. Calcium chloride was added to the concrete, at a rate of 1 pound per 100 pounds of cement, to accelerate set time. Gunite was applied to 2,065 feet of the unsupported tunnel to prevent sloughing, and to 335 feet of the supported portions. The gunite was one part cement to four parts clean, minus 10 mesh sand applied from ¼ to 3 inches thick. Quick setting cement with added calcium chloride (1 pound per 100 pounds of cement) was used to accelerate the set time of the gunite.

In driving the tunnel into fault zones, or other areas where the ground was extensively broken, holes 15 to 40 feet long were drilled into the face and grouted with neat cement. The cement grout was placed under pressures up to 1,000 pounds per square inch (psi).

The first 30 feet of the excavation encountered stream terrace clay, sand, and gravels. Next water-bearing glacial debris was encountered and the glacial soils produced about 50 gpm of water inflow. The bottom of the tunnel encountered the Weber Formation near Station 3+50. The slope of the bedrock was so gradual that the full face of the tunnel excavation was not entirely in rock until around Station 6+35. At this point, the 1.5 feet of rock above the tunnel was very weathered. Water inflows along this part-rock, part-soil segment increased to approximately 200 gpm. After the full face was in rock, spiling still had to be used because the rock was highly weathered and water inflows increased to 300 gpm. Competent rock did not appear in the crown until approximately Station 6+50. Deeper into the Weber Formation excavation, conditions improved and the face became relatively dry, with tunnel drainage decreasing to 200 gpm and nearly all of it coming from the moraine/bedrock contact area that had been passed. Only top lagging and timber sets spaced 6 feet apart were needed to support the unweathered portion of the Weber. Eventually steel rail sets were substituted because they were easier to install and the ground only required light support.



Framing details for standard wood tunnel set.

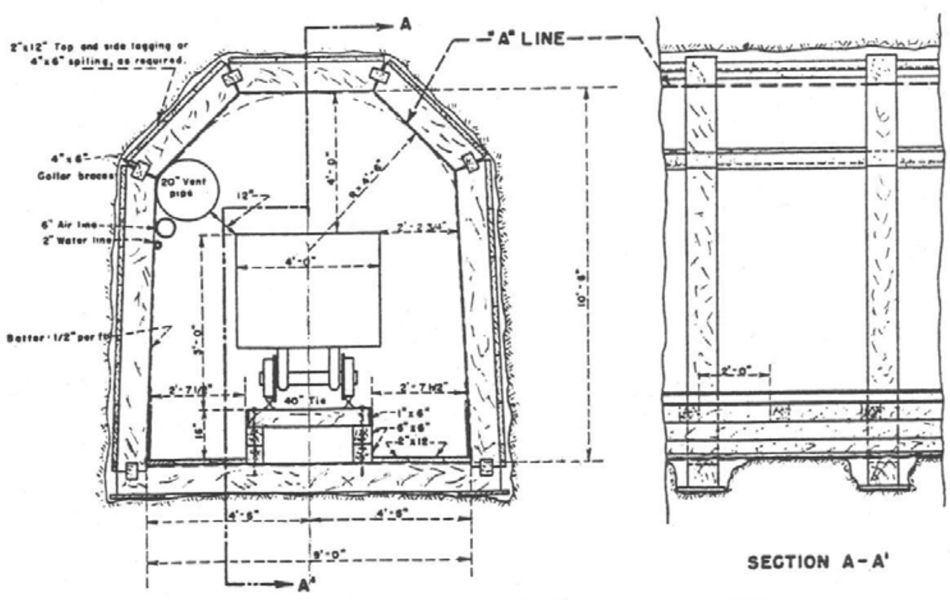
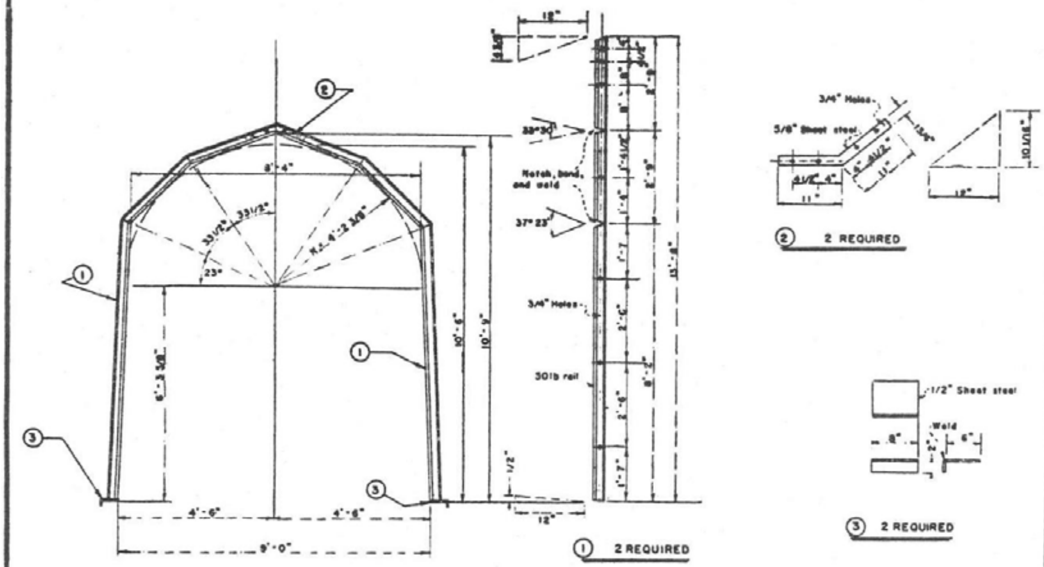
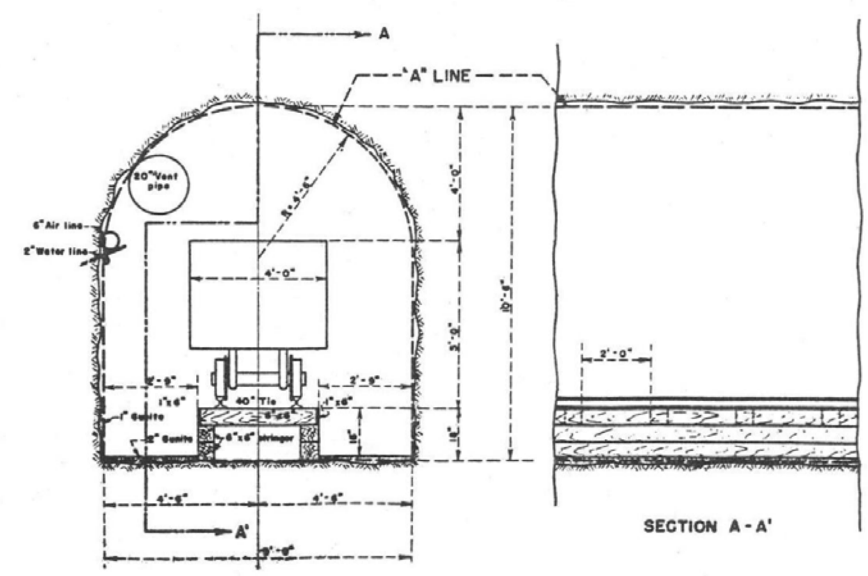


Figure 3. Timber support used in the first LMDT construction project. Illustration taken from (Elgin and Others, 1949).



Framing details for steel set made from 52-pound railroad rail.



Typical unsupported tunnel section.

Figure 4. Typical sections showing steel rail support and unsupported tunnel segments used in the first LMDT construction project. Illustration taken from (Elgin and Others, 1949).

At 2,100 feet, the tunnel entered a dike of gray porphyry. A large water flow was encountered at Station 21+26 feet which increased to 3,000 gpm and washed over 1,500 cubic yards of mud, sand, and broken rocks into the LMDT. After several hours, the flow eventually subsided to 200 gpm. The debris was cleaned out when caving caused the collapse of six steel sets and another inflow of 3,000 gpm was experienced. This flow subsided after a few hours. Cleaning the tunnel started another inflow so a wooden bulkhead was placed at Station 17+95 to stop the inflow. Test holes revealed that the bedrock over the tunnel was only 4- to 12-feet thick and that the inflows were from the overlying glacial material. A concrete bulkhead with drainage pipes was placed against the wooden bulkhead at Station 17+95 to prevent other inflows and a thick coating of gunite was applied to the tunnel walls and arch roof downstream of the bulkhead.

A parallel bypass tunnel was started at Station 16+81. The junction for the bypass developed heavy pressures. The timber supports were quickly reinforced. Planks were nailed to the timbers and concrete fill was placed behind the planks up to the top of the posts. Reinforcing steel was placed in the turnout arch and a concrete pillar was placed in the widest span of the arch. A 4-inch thick coating of gunite was applied to the turnout and along the tunnel to the bulkhead except for a 14- foot-long interval of tunnel where there was too much water inflow to permit gunite application. Three-segment arch sets to support the concrete walls were placed between the regular sets in the interval of water inflow. Holes were drilled through the concrete walls and grout was pumped in under pressures up to 750 psi to fill all voids. The bypass tunnel was offset to provide a 35-foot-wide pillar between the two excavations. Most of the excavation was performed using spaders to avoid shattering the roof rock by blasting. The porphyry was highly altered, crushed, faulted and had wet walls, but was penetrated and the tunnel drained about 300 gpm. The tunnel walls in the bypass were concreted flush with the timbers and a thick coating of gunite was applied to the arch. Weep pipes were placed for drainage wherever water was flowing to prevent development of water pressures behind the concrete. Other weep holes were drilled after the concrete had set. Holes were drilled into the tunnel face to probe ahead, and zones of loose rocks or heavy flows were grouted under high pressure ahead of excavation operations to consolidate the ground and reduce water inflows.

At Station 22+00 the tunnel entered the Leadville limestone. Water inflows increased to 500 gpm at the contact with the porphyry. A fault was crossed at Station 22+50 and the tunnel entered fractured quartzite. A large flow of water was experienced but the quartzite was hard, allowing excavation to continue. At Station 23+00 test holes encountered a brecciated water-bearing zone. The tunnel was advanced with spiling and breast boards but a large inflow of water, mud, and rocks broke in at Station 23+28. A temporary timber bulkhead reduced the inflow from 3,000 gpm to 1,100 gpm. The tunnel was concreted for a distance of 35 feet back from the face and grout was pumped in at high pressure through holes

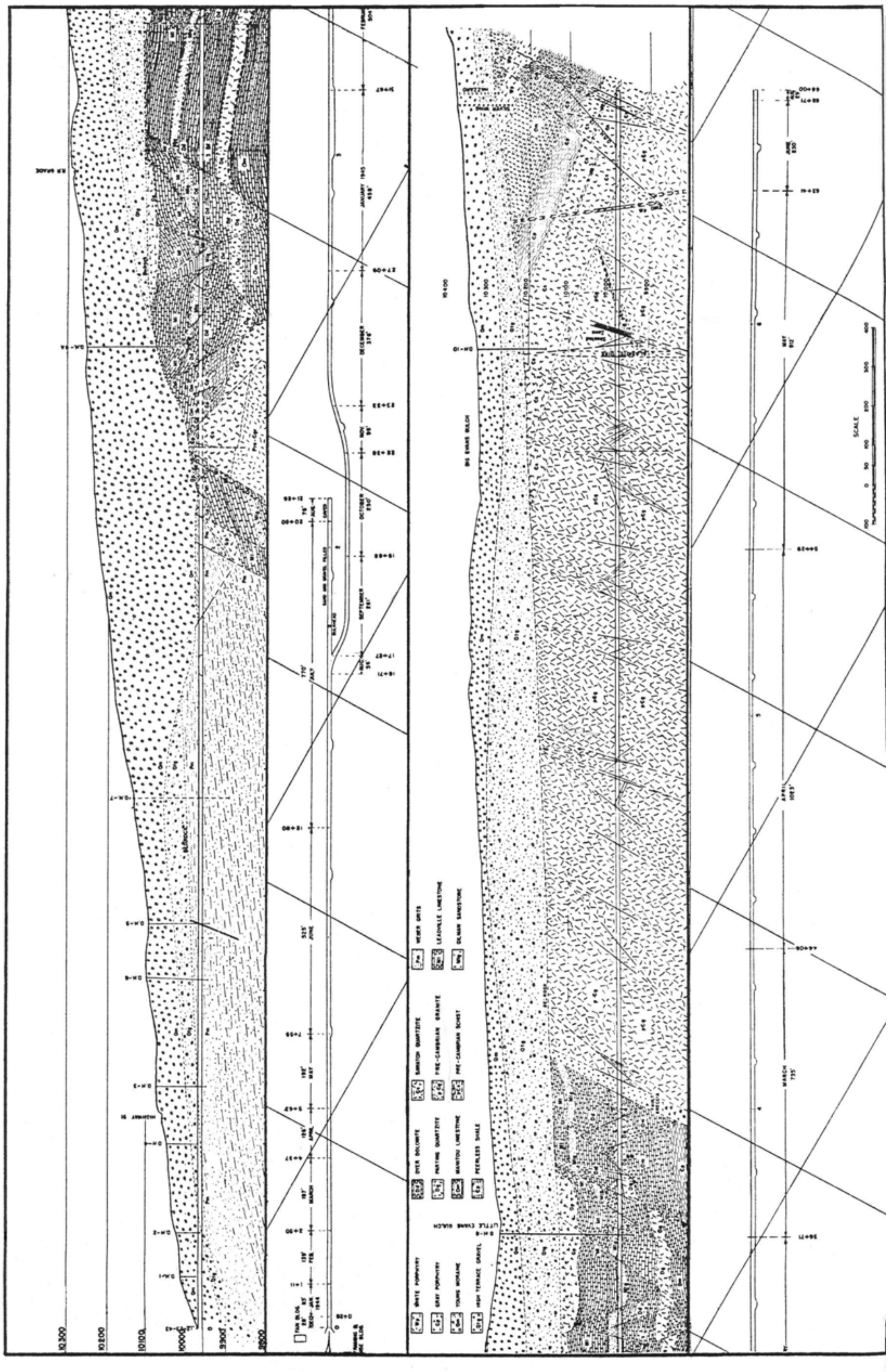


Figure 5. Plan and geologic section of LMDT from 0 to 6,600 feet from the portal. Illustration taken from (Elgin and Others, 1949).

drilled in a radial pattern. A thick concrete bulkhead with 4-inch pipes was placed at the face to prevent leakage of grout back into the tunnel. Next, 11 cubic yards of concrete were forced into the area behind the bulkhead. Holes 40 feet long were drilled through the bulkhead, and grouted at up to 300 psi placing 112 tons of cement. After setting, more 40-foot holes were drilled in to check consolidation and to provide weep holes. The tunnel was then advanced 30 feet through the fault zone where fractures from 1/8-inch up to 8-inches in width had been filled with grout. After the fault zone, the excavation entered limestone and shale which were fairly stable.

Another water-bearing, mud-filled breccia zone was detected by drill holes at Station 24+40. This zone was grouted with 1,448 sacks of cement and then it was excavated without difficulty. The bypass tunnel was driven a total of 791 feet and then it returned to the original alignment at Station 24+48. The tunnel continued in limestone and flows increased to 1,300 gpm. White-colored porphyry was encountered at Station 27+55 and test holes reaching the center of the dike produced a flow of over 1,600 gpm.

A large flow of water developed at Station 29+63. From 500 gpm, the flow increased to over 5,700 gpm in four hours time, raising the total tunnel outflow to 7,000 gpm. Over the next 48 hours, flow diminished and nearly stopped when additional flow broke in from the lower left wall. The rock in this area did not require support, but timber sets were installed as a precaution. The watercourse on the left side developed into a cavern with openings as large as 60 feet long, 15 feet wide and 20 feet high. The channel narrowed but persisted until Station 32+00 where it passed below the tunnel grade. Advantage was taken of the hard rock and natural opening to slab 156 feet of the tunnel wide enough for a siding track. Eventually, the watercourse drained and tunnel flow decreased to 1,500 gpm.

At Station 32+50 the tunnel entered a fractured and highly altered zone which required spiling and breast boards to keep mud and loose rocks from entering the tunnel. No flowing water was encountered in this 300-foot-long altered zone. Better rock was encountered next and required only light support of steel-rail sets and some gunite. At Station 37+80 the limestone was broken by numerous faults which required top spiling for excavation through the zone.

The Pendery Fault was encountered at Station 40+70 and the tunnel excavation entered pre-Cambrian granite. This 40-foot-wide zone was filled with fine breccia and carried some water. It was supported with timber sets on five-foot centers. The granite was fractured and blocky for a few hundred feet past the Pendery Fault and carried a small amount of water. Timber sets were placed to support the blocky ground. After passing Station 44+00 the tunnel was quickly advanced with timber supports only being required in short sections where dikes of altered alaskite and pegmatite rock were penetrated. All of the rock in this area was coated with gunite to prevent sloughing from the decomposing action of water and air. Beyond Station 60+00, the granite was broken by faulting and carried considerable flows of water. Timber supports were necessary.

Cambrian quartzite dipping at 21 degrees was encountered at Station 63+45 and the entire face was in quartzite by Station 64+50. Inflows at the contact of the granite and the quartzite increased the total tunnel flow to 4,000 gpm. All of the fractures in the quartzite were found to carry water. The quartzite did not require support and the fractures dried up. At Station 65+71 a heavy flow broke in from the upper left side of the face washing in fragments of quartzite and white porphyry, filling the tunnel for a distance of 40 feet. A series of four bulkheads were placed on the washed in material to stop the inflow. A 4- by 6-foot pilot tunnel was driven as a top heading starting at Station 65+60. First the tunnel was supported by timber sets on five-foot centers starting 30 feet back from the zone with poor rock. Spiling was required along with breast boards as the top heading was advanced, the lower portion of the tunnel was in hard quartzite, which had to be blasted, while the top was in broken porphyry and quartzite which required full support. At Station 65+90 the rock conditions improved so the top heading was no longer needed. At Station 66+00 orders were given to discontinue operations because of exhaustion of funds. The contract was terminated and all construction activity ceased on August 27, 1945.

2.4 Second Project Bureau of Mines Construction

Metal shortages during the Korean War generated renewed interest in mining at Leadville. On October 12, 1949, an appropriation of $750,000 was approved for completion of the LMDT. The Utah Construction Company was awarded a cost plus fixed fee contract on August 16, 1950. Details regarding the second project are summarized in Bureau of Mines Report of Investigations 5284 (Salsbury, 1956) from which the following details and illustrations are taken.

Construction commenced in September, 1950. A total of 4,698 feet of main tunnel, 548 feet of laterals, and 23 feet of shaft crosscuts were driven. The LMDT was driven on a heading of S 28 degrees, 53 minutes, 10 seconds E for the first 10,047 feet. Direct connections were made to the Hayden and Robert Emmet Shafts. The Hayden lateral was driven approximately 200 feet, the Downtown lateral was approximately 291 feet, and the Robert Emmet lateral was approximately 60 feet in length.

The mines of Graham Park on the western slope of Iron Hill were drained by the Robert Emmet connection; therefore, a planned direct connection to the Pyrenees Shaft was not completed. Instead, the LMDT alignment was turned due east at 10,047 feet from the portal, and an additional 1,252 feet was driven to cut through the Mikado Fault. This last 1,252-foot-long segment is referred to by the Bureau of Mines as the New Mikado lateral. A short segment of cross-cut was required to connect to the New Mikado Shaft, which was found to be caved at the tunnel level.

The LMDT ended in pre-Cambrian granite 11,299 feet in from the portal. The granite was not expected to be encountered and therefore the LMDT did not effectively drain the area east of the Mikado Fault. The LMDT was completed by March 1952. The geology along the LMDT alignment is shown in Figures 6, 7, and 8.

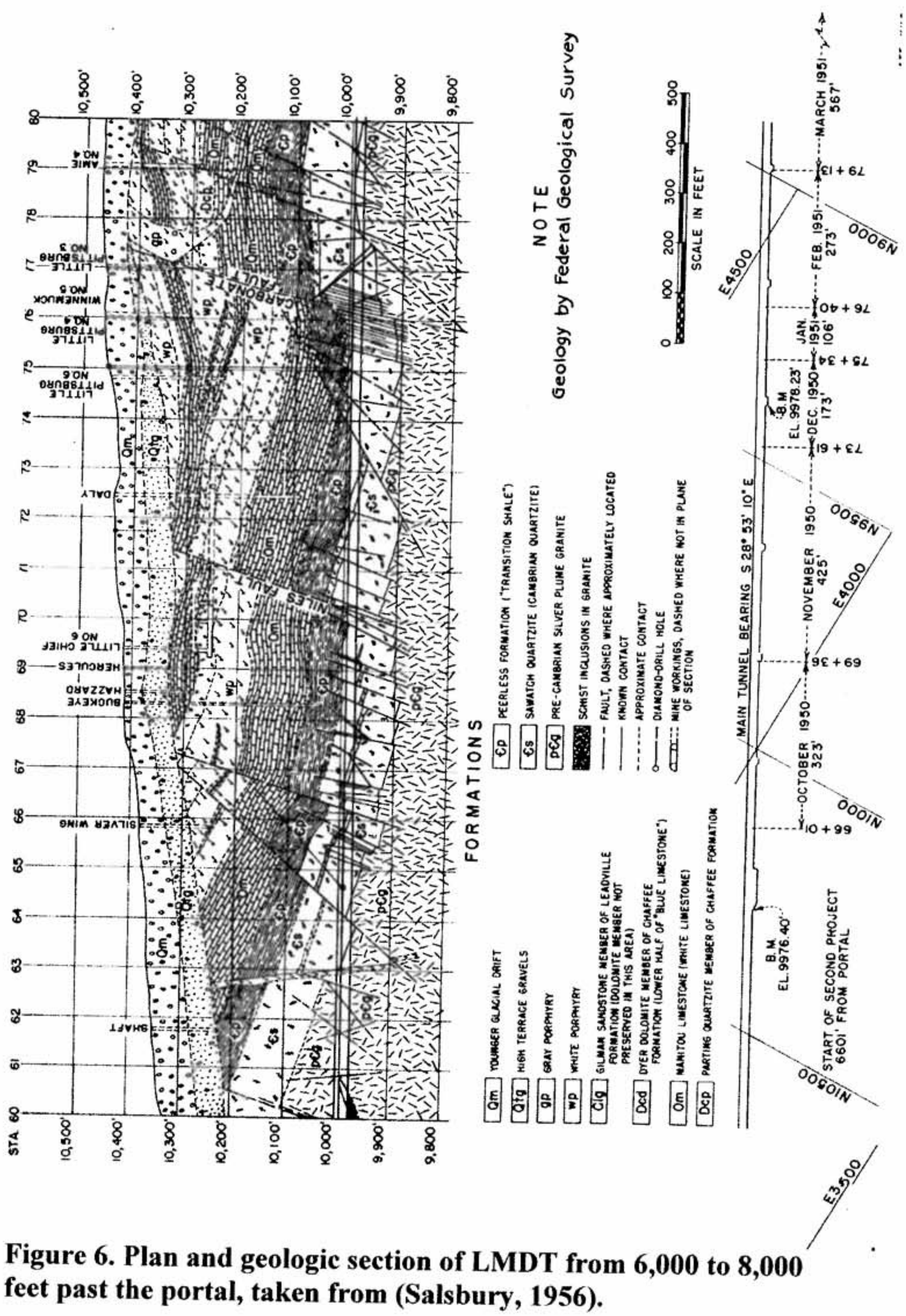


Figure 6. Plan and geologic section of LMDT from 6,000 to 8,000 feet past the portal, taken from (Salsbury, 1956).

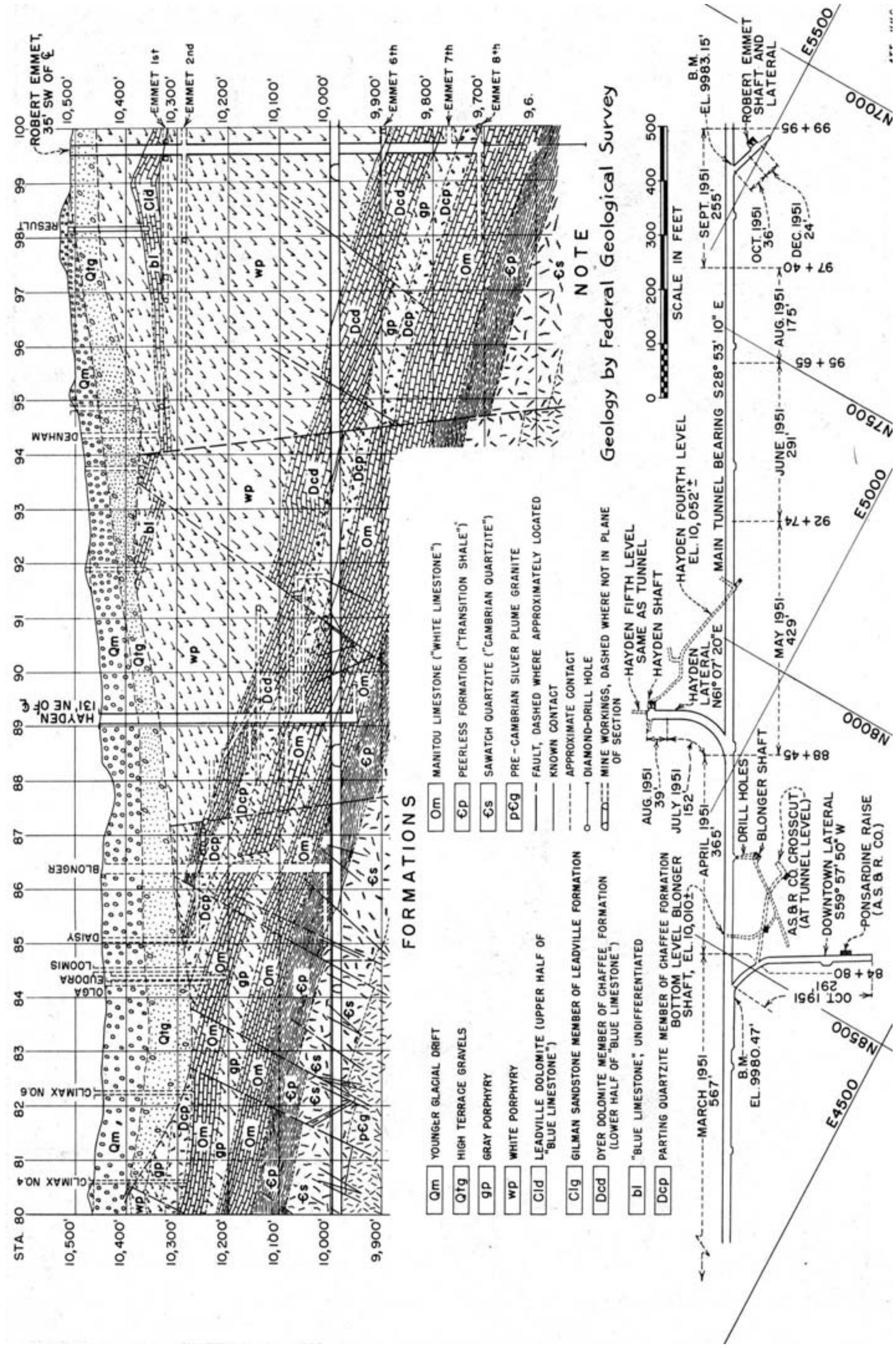


Figure 7. Plan and geologic section of LMDT from 8,000 to 10,000 feet past the portal, taken from (Salsbury, 1956).

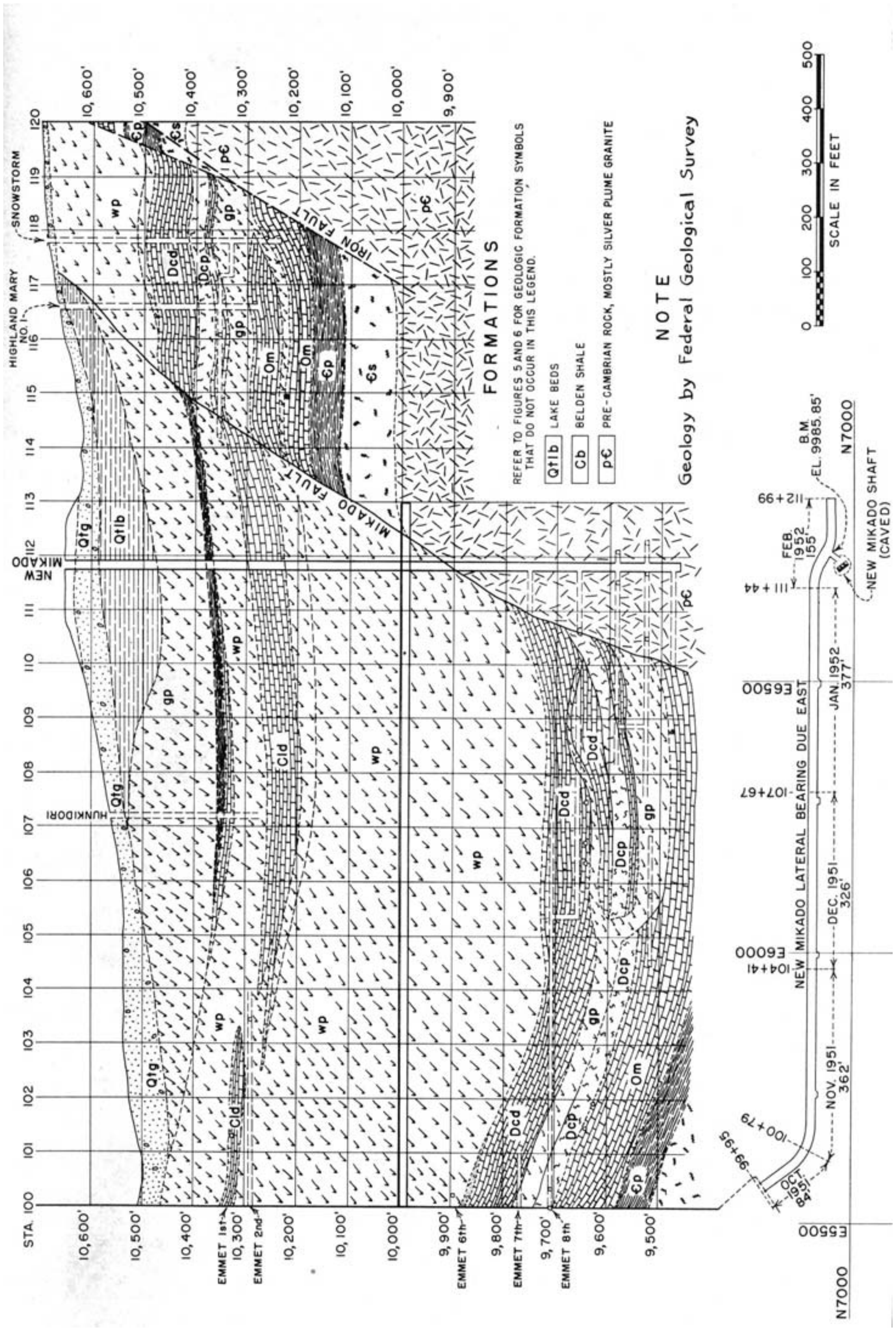


Figure 8. Plan and geologic section of LMDT from 10,000 to 11,299 feet past the portal, taken from (Salsbury, 1956).

The Bureau of Mines decided to reduce the size of the excavation to a 7.5 feet wide by 8.75 feet high clear opening inside the supports as shown in Figure 9. After some time, the smaller excavation size proved too tight for the drilling operation. In 1951, the excavation width was increased to 8 feet clear opening as shown in Figures 10 and 11. The initial tunnel work was carried on at a grade of 0.3 percent until rock was reached; then it increased to 0.5 percent. During the second project, the grade was reduced to 0.2 percent beyond Station 66+00. The total rise from the portal to the upstream face at Station 112+99 is 25.9 feet.

Experiences with wet flowing ground were repeated during the second project. Most of the problems were in the quartzite shear zones and in faults and softer formations where heavy water flows were experienced. Again, light to moderate support was provided by installing steel sets, heavy ground required support using 10-inch by 10-inch timber sets, and the caving and running ground required spiling. The timbers in the first project were not treated and were found to be prone to decay. The second project used timbers which were pressure treated with creosote at a rate of 10 pounds per cubic foot of wood. All supports were placed on 5-foot centers to match the rate of advance of each drill and blast round. Transverse track stringers were placed at each set to resist side pressure, but no side pressure was noted between Stations 66+00 and 100+00. Side pressure developed in the New Mikado lateral, and at the Mikado Fault (around 10,600 feet in). Side pressures also developed in areas where the porphyry formation was found to be swelling. No supports were placed in areas of solid ground. Overhead support was essential in some areas such as throughout the blocky porphyry from Station 96+00 to the Mikado Fault. The overhead support was provided as six to twelve 4- x 6-inch lagging placed around the arch portion. Of the 5,240 feet of tunnel and laterals driven during the second project, 3,688 feet were supported.

Ice curtains formed in the winter in the first 600 feet of the tunnel due to the constant drip of seepage. The ditch used beyond Station 66+00 was smaller than that of the first project and had an estimated capacity of 5,000 gpm. The maximum recorded flow through this smaller ditch was 3,765 gpm. The first constant water inflow was encountered near the Daly Shaft at Station 73+55.

Measurements of shaft water elevations in Fryer Hill, Graham Park, and the Downtown basin were resumed for those shafts that remained open during the years 1950, 1951, and 1952. A steady lowering of water levels in the Hayden Shaft was observed. By August, 1951 when actual connection via a 200 foot lateral was made with the LMDT, the Hayden Shaft had been drained virtually to tunnel level through connecting watercourses.

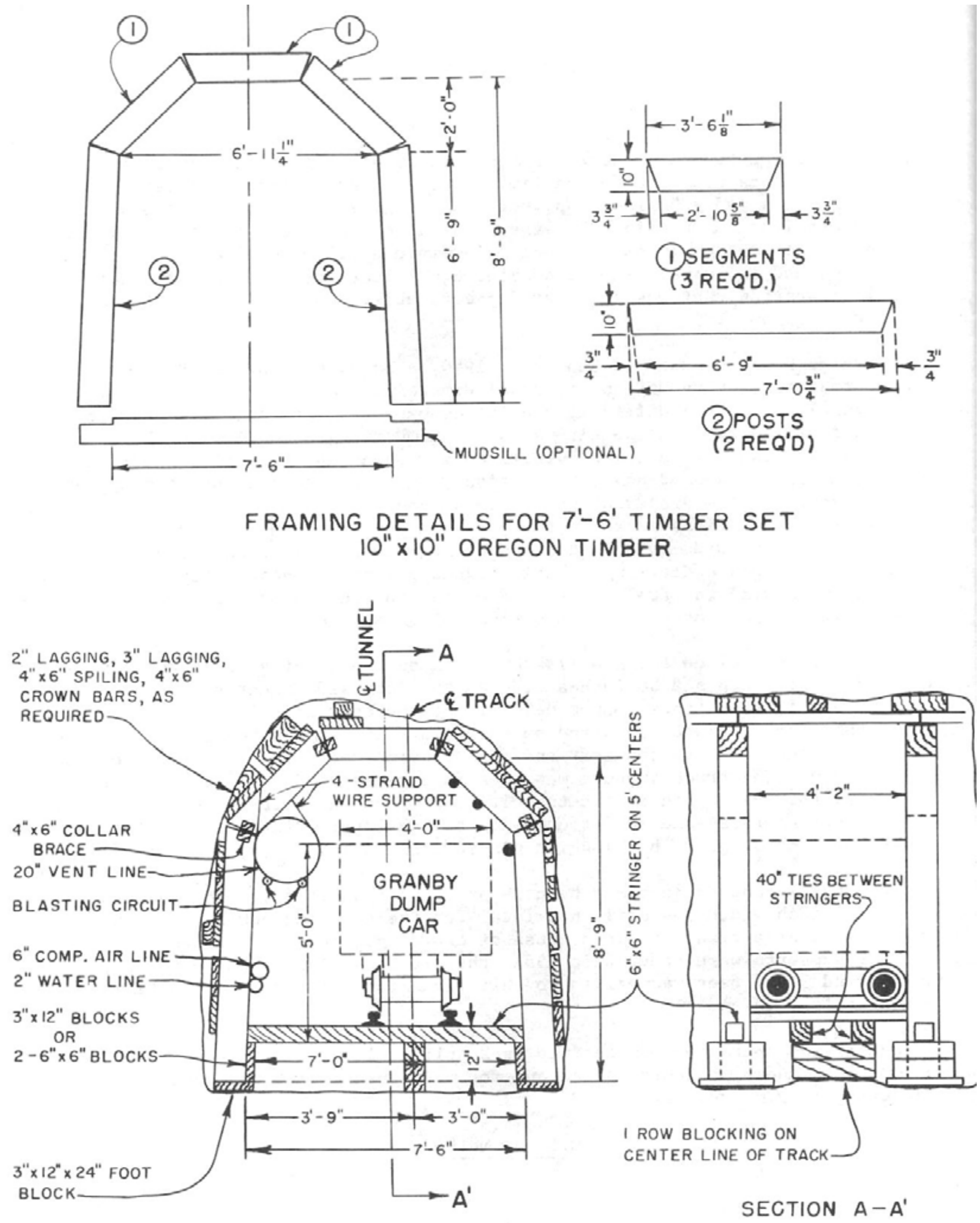


Figure 9. Timber supports used for a 7.5-foot-wide clear opening in the LMDT, taken from (Salsbury, 1956).

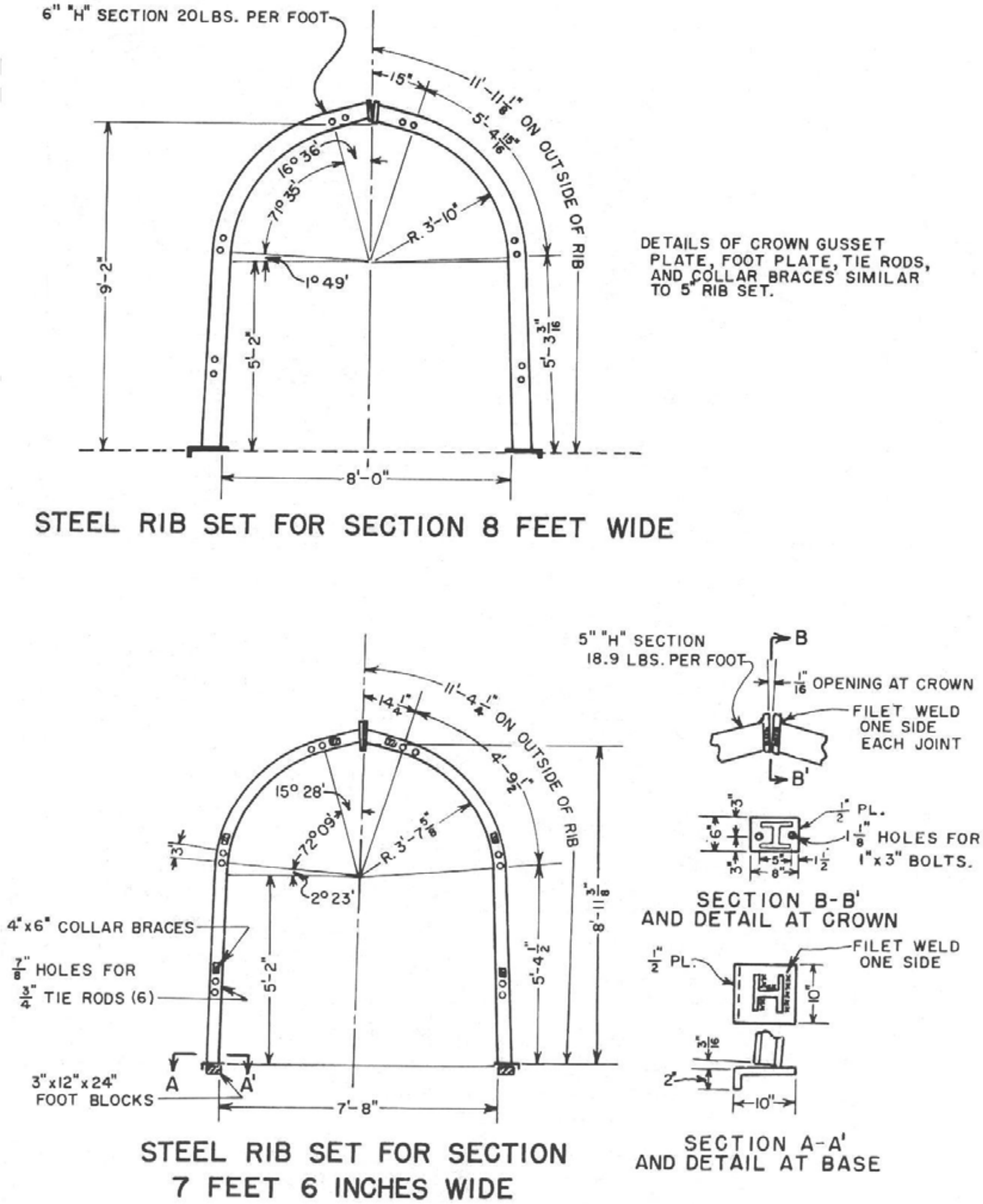
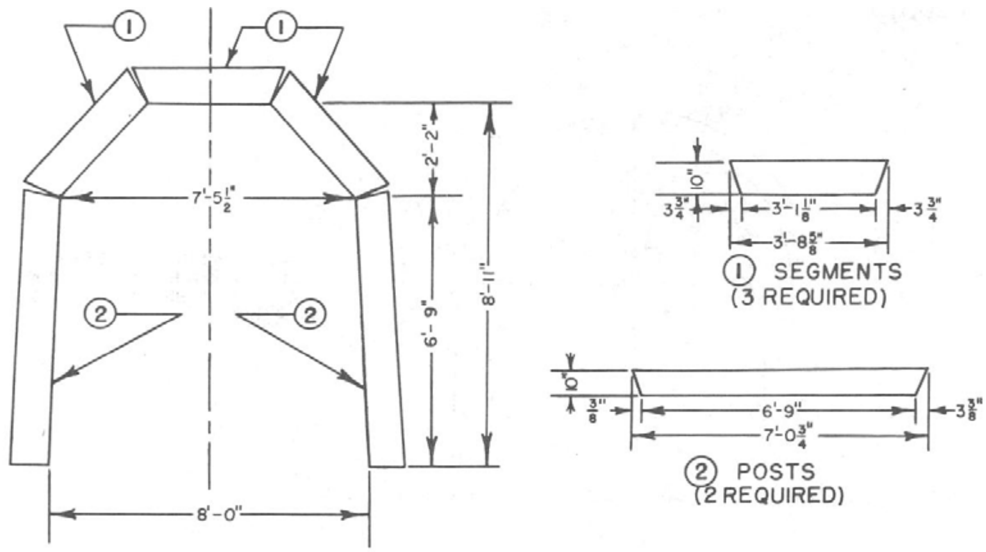
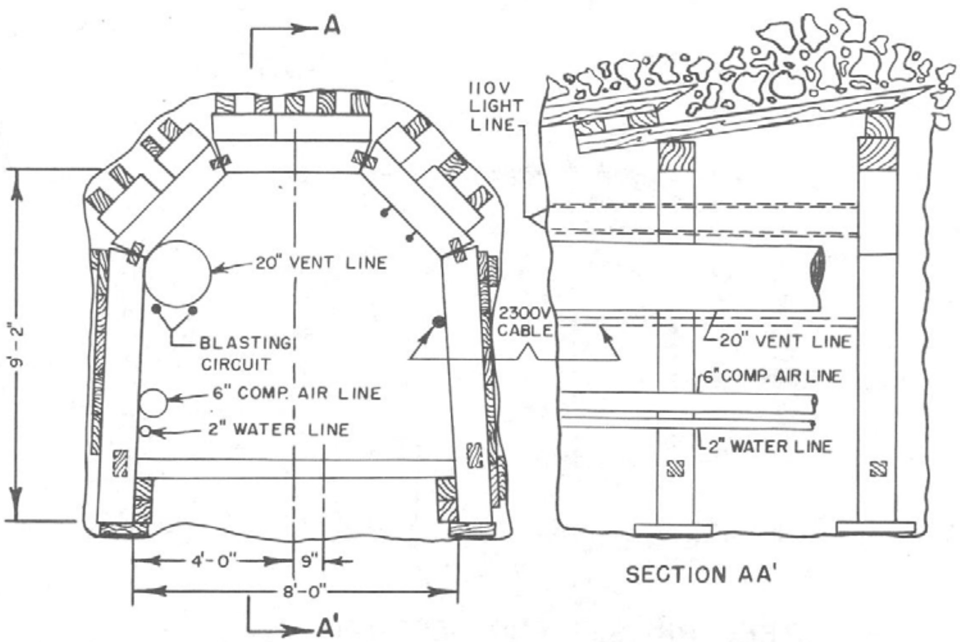


Figure 10. Steel supports used for a 7.5-foot and 8.0-foot-wide clear openings in the LMDT, taken from (Salsbury, 1956).



FRAMING DETAILS FOR 8—FOOT TIMBER SET 10"X10" OREGON TIMBER



SPILING OR CROWN BAR CONSTRUCTION ILLUSTRATED

Figure 11. Timber supports used for 8.0-foot-wide clear openings in the LMDT, taken from (Salsbury, 1956). The timber spiles are the wood supports driven into the roof at an upwards angle as shown in the upper portion of section AA.

A large inflow at Station 99+70 in July, 1951 was accompanied by a rapid drop in the water level in the Robert Emmet Shaft and other mine workings. The mines of Graham Park, including the Pyrenees, Greenback, Adams, and other shafts are interconnected with the Robert Emmet Shaft. There was an appreciable lag, indicating a minor obstruction of the drainage connections between mines.

A heavy waterflow cut in a limestone fissure in the Leadville limestone at Station 95+65 increased the rate of drainage from the Robert Emmet and other shafts rapidly, see Figure 12. By October 1951 the water level in the Robert Emmet Shaft was only a few feet above the tunnel floor, as determined by pilot holes drilled before actual connection. The flow entering the LMDT from the Robert Emmet Shaft since the connection remained nearly constant at about 400 gpm. The temperature of the flow was 52 degrees F. The water in the New Mikado lateral was 46 degrees F, and 41 degrees F for water flowing from the Daly Shaft at Station 73+57.

The LMDT passed near the Blonger Shaft and under a drift from that mine. Although the LMDT was in quartzite, it was known that weak Peerless shale was only a few feet above the excavation. From Station 84+50 to Station 86+50, numerous test holes were drilled ahead of the excavation to probe for water-filled mine workings. A car pass station was excavated in the LMDT adjacent to the Blonger Shaft and several 50 foot holes were drilled. It is thought that one of these holes penetrated the sump of the shaft but it made no water. In 1952, the American Smelting and Refining Company (ASARCO) drove a connection to the bottom of the Blonger Shaft verifying its location. It was found that the Blonger drift was five feet higher than shown on mine maps and it was completely filled with soft shale and timbers, thus explaining why no water had been encountered when the LMDT was excavated under the drift.

At Station 90+20, a test hole in the face encountered water under pressure. A total of 20 holes ranging from 20 to 40 feet long were drilled to drain the limestone formation. The flow soon diminished and further excavation encountered a fault zone. At the end of the LMDT (Station 112+99), two 40-foot-long holes were drilled ahead. A small flow of water developed indicating that the solid granite continued ahead. Additional information regarding water flows is contained in Table 1.

Figure 12. Photograph showing the inflow to the LMDT through a drillhole connected to the Robert Emmet shaft, taken from (Salsbury, 1956). This is prior to driving the Robert Emmet lateral.

Figure 13. Workers digging out a boulder embedded in running ground in sheared quartzite, taken from (Salsbury, 1956). The boulder prevented spiles from being driven.

Table 1. LMDT water flow measurements from (Salsbury, 1956).

Water Measurements During Second Project, Leadville Drainage Tunnel

Date of measurement	Discharge from tunnel, gallons per minute	Remarks	Water level1/ in Adams shaft	
			Feet above sea level	Date
Sept. 1946	2,065	End of first project. Face of tunnel at 6,600 feet.	10,163	June 1945
Sept. 1950	1,900	Start of second project.		
Nov. 27, 1950	1,176	Gradual decrease September to November.	10,111	Sept. 30, 1950
Nov. 28, 1950	2,630	"Daly fissure" at 7,357 feet cut.		
Dec. 1950	2,675-1,980	Fluctuating flow as tunnel advanced through small faults and fractures from 7,357 to 7,628 feet.	10,107	Dec. 18, 1950
Jan.-Apr. 1951	1,980-1,640	Decreasing flow as tunnel penetrated comparatively dry ground.		
Apr.-June 1951	1,640-2,480	Gradual increase as heading cut water-bearing fissures in limestone.	10,084	May 20, 1951
July 5, 1951	3,765	Maximum flow recorded during second project; open fissure in white limestone was cut.	10,087	June 20, 1951
July-Sept. 1951	3,765-2,875	Gradual decrease as water level in Graham Park mines was lowered.	10,063 10,020	July 20, 1951 Aug. 20, 1951
Oct. 1, 1951	2,925	Slight increase as drill hole tapped Robert Emmet shaft.	10,013	Sept. 20, 1951
Oct. 1-4, 1951	2,925-3,390	Additional holes drilled into Robert Emmet shaft.	9,993	Oct. 20, 1951
Oct. 4-Dec. 30, 1951	3,390-2,580	Flow decreased as water level in Robert Emmet shaft was lowered.	9,988	Nov. 20, 1951
Dec. 31, 1951	2,580	Connection made to Robert Emmet shaft.	9,987	Dec. 20, 1951
Jan. 1-Feb. 14, 1952	2,580	Nearly constant flow as New Mikado lateral was driven in white porphyry; no new water cut.	9,982	Jan. 1, 19522/
Feb. 14, 1952	2,580	Second project completed.		
Aug. 11, 1952	2,825	Maximum flow in 1952 with tunnel in standby condition; seasonal increase.		
May 11, 1953	1,770	Minimum flow in 1953; seasonal decrease.		
Aug. 21, 1953	2,200	Maximum flow in 1953; seasonal increase.		
May 7, 1954	1,460	Minimum flow in 1954; seasonal decrease.		
Aug. 5, 1954	1,850	Maximum flow in 1954; seasonal increase.		
Mar. 3, 1955	1,480	Late winter flow in 1955; seasonal decrease.		

1/ This represents the water level in Adams, Robert Emmet, and the mines of Graham Park. The Robert Emmet shaft could not be measured because of an obstruction.

2/ Floor of the Robert Emmet lateral at the shaft is 9,982 feet above sea level.

2.5 Bureau of Mines Maintenance

The cost of the first two LMDT construction projects was put at approximately $2.0 million (Bureau of Mines, 1952). At the time that the Bureau of Mines announced completion of the LMDT in March 1952, it was also announced that Bureau personnel would be used to replace timber in the older section of the tunnel, perform grouting of some heavy ground, and would lay concrete drainage pipe in ditches where the tunnel floor is fractured in crossing faults. The following maintenance data are taken from numerous Bureau of Mines memos and correspondence regarding the inspection and repair of the LMDT.

Contracts with George E. Davis and James P. Webb starting in December 1952 were awarded to place steel reinforcing between old timber sets (Salsbury, 1953). Cresote-treated lagging was also installed between the sets. The steel was blocked up to the old timber caps, lagging and spiling. The reinforcement of deteriorated timbering was completed along the first 2,500 feet of the LMDT by April 17, 1953, as detailed in Table 2. Two types of steel sets were used. One type consisted of 82 sets of 6-inch H beams. The other type consisted of 158 sets of 4-inch H section horseshoe sets which were excess from a tunnel project near Ft. Collins, Colorado.

A total of 215 steel sets, were placed, 75 heavy and 140 light, the remainder, 7 heavy and 10 light were held in reserve for future use. The 6-inch sets were used where there was the most decay of old timber, or where known soft formations were likely to require additional support. Lateral pressure at the portal due to frost heave required 8 heavy sets with spreaders.

Beyond Station 100+00, there was no ventilation and the timber spiling, lagging, and track ties were found to be decaying rapidly. The white porphyry did not continue to swell as originally observed during first excavation except at one point around Station 106+00.

Table 2. Steel supports installed in the LMDT in 1953 (Salsbury, 1953).

Distance from portal in feet	Number of heavy 6-inch steel sets	Number of light 4-inch steel sets	Comments
10 to 45	8		Spreaders were included to resist lateral pressure due to frost heave
105		1	
110 to 200	20		
220 to 270	11		
310 to 400		19	
560 to 590		7	
687 to 717		7	
750 to 770	5		At carpass (wide section of LMDT)
795 to 830		8	
855 to 880		6	
985 to 1005		4	
1065 to 1110		9	
1115 to 1210	25		At carpass
1240 to 1473		40	In alternate sets between sets reinforced with rail sets in 1952
1482 to 1509	6		At carpass
1520 to 1645		21	In alternate sets between old 52-pound rail sets
2256 to 2281		6	
2345 to 2355		3	
2365 to 2370		2	
2440 to 2457		4	
2465 to 2475		3	
Totals	75	140	

In August 1953, the tunnel flow was found to be 2,200 gpm. Mining was conducted on the Pittsburgh claim at the tunnel level.

In February, 1954 it was decided to make additional repairs to the LMDT. An inspection on March 4, 1954 found the lagging had failed at Station 109+75. Timber sets at Station 112+30 to 112+40 were showing signs of extreme pressure and the posts had been sinking into the floor. Spreaders were placed above track level to resist side pressure. The flow of water was 1,850 gpm. Additional inspections in March resulted in addition of more work to the project. It was decided to:

> 1) Clean main tunnel ditch at Downtown lateral, Hayden lateral, Robert Emmet lateral, New Mikado lateral, and elsewhere between Stations 66+00 and 109+70 to lower the water level in the ditch below the track. All muck to go to the waste dump outside the tunnel;
>
> 2) Straighten or replace 14 track stringer between Stations 106+35 and 107+00 and reblock the track and at the transition section at Station 110+00;
>
> 3) Place treated lagging between Stations 106+15 and 106+70, remove decayed lagging, and remove all debris and muck to the waste dump; and
>
> 4) Install three intermediate 10-inch by 10-inch treated timber sets between old sets from Stations 112+30 to 112+40 where the New Mikado lateral crosses the Mikado Fault.

In May, 1954 during the rehabilitation work, it was found that stringers underneath track ties in the Hayden and Robert Emmet laterals had broken and needed replacement. Also, the wooden walkway and the track ties beyond Station 99+24, where the air is stagnant, were found to be in poor condition. The stringers in the Hayden and Robert Emmet laterals were replaced and some walkway near the 3,000 foot siding and in the New Mikado lateral was replaced with creosoted 1-inch by 12-inch boards.

During the December 3, 1954, inspection, five sets, from Stations 106+45 to 106+65 showed side pressure near the base of the sets due to swelling of the altered porphyry rock. The 6-inch by 6-inch spreaders supporting the track were bowed upward and one was broken, the track rails were out of position. Three new spreaders were placed during the inspection at Stations 106+45, 106+55, and 106+65. The flow of water at the portal was 1,520 gpm.

A cave-in was reported in January 1955 at approximately Station 40+35 to 40+40 in the LMDT where 2 sets fell and water 2.5 feet deep formed behind a dam of rock and debris. An arch formed in the roof strata about 20 feet above the track. This section of the LMDT is in the Parting quartzite near the Pendery Fault. The fault is located from Station 40+70 to 40+95. The fault area was previously concreted and was still standing open. The area of the cave-in occurred in a section of 46 sets of continuous timbering from Station 38+50 to 40+75 in the Parting quartzite. The cause was dry rot of the timber, which deteriorated even though it had been coated with gunnite.

Further inspection showed that the LMDT was also likely to cave-in from Station 65+00 to 66+00 and that the squeeze at Station106+00 continued for at least 6 sets. Other problem areas were identified on a profile drawing dated March, 1955.

Repair was accomplished under contract 14-09-040-1132 with Robert L. Jones of Leadville from May 24 to June 6, 1955. By the time the repair work was under way, the tunnel had caved for 20 feet in length and to a height of 20 feet above the rail level. Six light steel sets were installed on five-foot centers. The open ground above the steel sets was cribbed and lagged. Four heavy steel sets were placed near Station 66+00. The recommended replacement of 46 sets from Station 38+50 to Station 40+75, which showed signs of dry rot was not undertaken except for the six light steel sets that were placed at the location of the cave-in. The recommended repairs to the deformed steel sets located from Station 106+45 to Station 106+65 were not undertaken.

In June, 1956 the Bureau of Mines reports "There is small cave in tunnel about 150 or 200 feet from the portal. There is small hole up on top of the Hill."

In September, 1956 a total of 53 10-inch by 10-inch creosoted-timber sets were installed in five locations. Details of the installation were not found but it was stated that most of the critical work identified in 1955 was performed. No work was performed in the Mikado lateral area.

Interest in disposal of the LMDT as surplus property intensified late in 1956. Inspections on December 5 and 6, 1956, found fallen timber blocking and rock at Stations 34+65 and 36+60. These locations were supported by steel rail sets and the timber blocking behind them had rotted out and fallen. The remainder of the LMDT was found to be open to the Hayden Shaft. The inspection did not enter the last 325 feet due to bad air. Four sections of the LMDT were found to be in a critical state of dry rot at Stations: 25+05 to 25+55 needing 10 sets, 28+00 to 28+40 needing 7 sets, 29+40 to 29+70 needing 9 sets, and 38+45 to 38+65 needing 4 sets. Also, timber in poor condition due to dry rot was noted from Station 20+50 to 22+50. At Station 89+35 a steel set was missing and the 10-foot lagging failed with two cars of rock fallen into the tunnel. Numerous areas of rotten lagging about to fail were noted at Stations 66+80, 85+70, 92+80, 93+25, 93+85, 102+50, and 104+50.

The requested repair work from the December 1956 inspection was still on the list of required repairs that were detailed in a June, 1957 inspection along with many more locations needing attention. It is not known if this work was completed.

It is estimated that the Bureau of Mines spent over $50,000 on post-construction maintenance from 1952 until 1959 (Reclamation, 1976).

2.6 Transfer to Reclamation

In December, 1959, Reclamation acquired the LMDT as a potential water source for the Fryingpan-Arkansas Project. Reclamation accepted "full custody, accountability, and future responsibility" for the LMDT with the stipulation that, "…Reclamation has no present intention of spending any funds on the maintenance and repair of the tunnel."

2.7 Occurrence and Filling of Sinkholes

A sinkhole was discovered on the slope above the LMDT on July 5, 1966 located 125 feet down-slope toward the portal from State Highway 91 (Reclamation, 1976). Subsequent investigations found an accompanying cave-in inside the LMDT about 260 feet in from the portal. This collapse prevented access further back into the LMDT but drainage flows continued through the 20-inch diameter steel ventilation pipeline at about 1660 gpm. On September 11, 1968, a cave-in occurred in the LMDT and a 20-foot deep sinkhole developed 15 feet down-slope from the edge of State Highway 91. The highway centerline crosses above LMDT Station 5+64.55. The LMDT was blocked by collapsed material but flow continued to discharge through the caved area via the ventilation pipeline. Reclamation issued specifications No. 700C-690 under a negotiated contract to quickly address the problem.

The sinkhole at the ground surface above LMDT Station 5+18 was backfilled with 175.5 cubic yards of earth backfill. An 8-inch-diameter test well was drilled 60 feet east of the highway and the 9 ft. by 11 ft. tunnel was found to be open. The casing was pulled to the top of the LMDT and water levels were measured to be 23 feet above the top of the tunnel. This water level indicated that the LMDT water discharge through the ventilation pipeline required some head to force the flow through the pipe. The flow was being partially retarded by the collapse.

Five 8-inch-diameter holes were drilled through the highway and adjacent areas along the tunnel alignment as shown in Figure 14. The drill holes encountered voids about half way down to the LMDT and were filled and grouted as detailed in Table 3. The gravel fill was sized from 0.75 to 1.5 inches in diameter. The procedure used was to drill to the level of the LMDT, fill the voids, if any, to the top of the tunnel, then lift the casing while filling with sand until the overlying void was encountered (Griffin and others, 1968). Once the casing was at the overlying void, more gravel fill was placed to fill the void. Next, the casing was left at the top of the gravel-filled upper void to enable grouting. A sand-cement slurry grout was injected to completely fill the upper void.

Table 3. Results of five injection drill holes into the LMDT in 1968.

Drill Hole Number	Voids Encountered	Gravel Placed yd^3	Grout Placed bags of cement	Condition of LMDT when drill hole reached the bottom
1	5-foot cavity between 61.9 and 66.9 feet above LMDT	7 at upper void	172	Tunnel filled to crown with caved material
2	4-foot cavity between 47.7 and 51.7 feet above LMDT	12 at LMDT, 0.5 at upper void	93	Tunnel filled to within 4 feet of crown with caved material
3	10-foot cavity between 49.7 to 59.7 feet above LMDT	48 at LMDT, 23 at upper void	185	Tunnel open
4	3-foot cavity between 58.4 and 61.4 feet above LMDT	4 at upper void	155	Tunnel filled to crown with caved material
5	1-foot cavity between 74.6 and 75.6 feet above LMDT	0.25 in upper void	5	Tunnel filled to crown with caved material
Totals		94.75	610	

Next, Reclamation installed six observation wells to monitor the groundwater in the vicinity from the portal to Station 6+35 as shown in Figure 14.

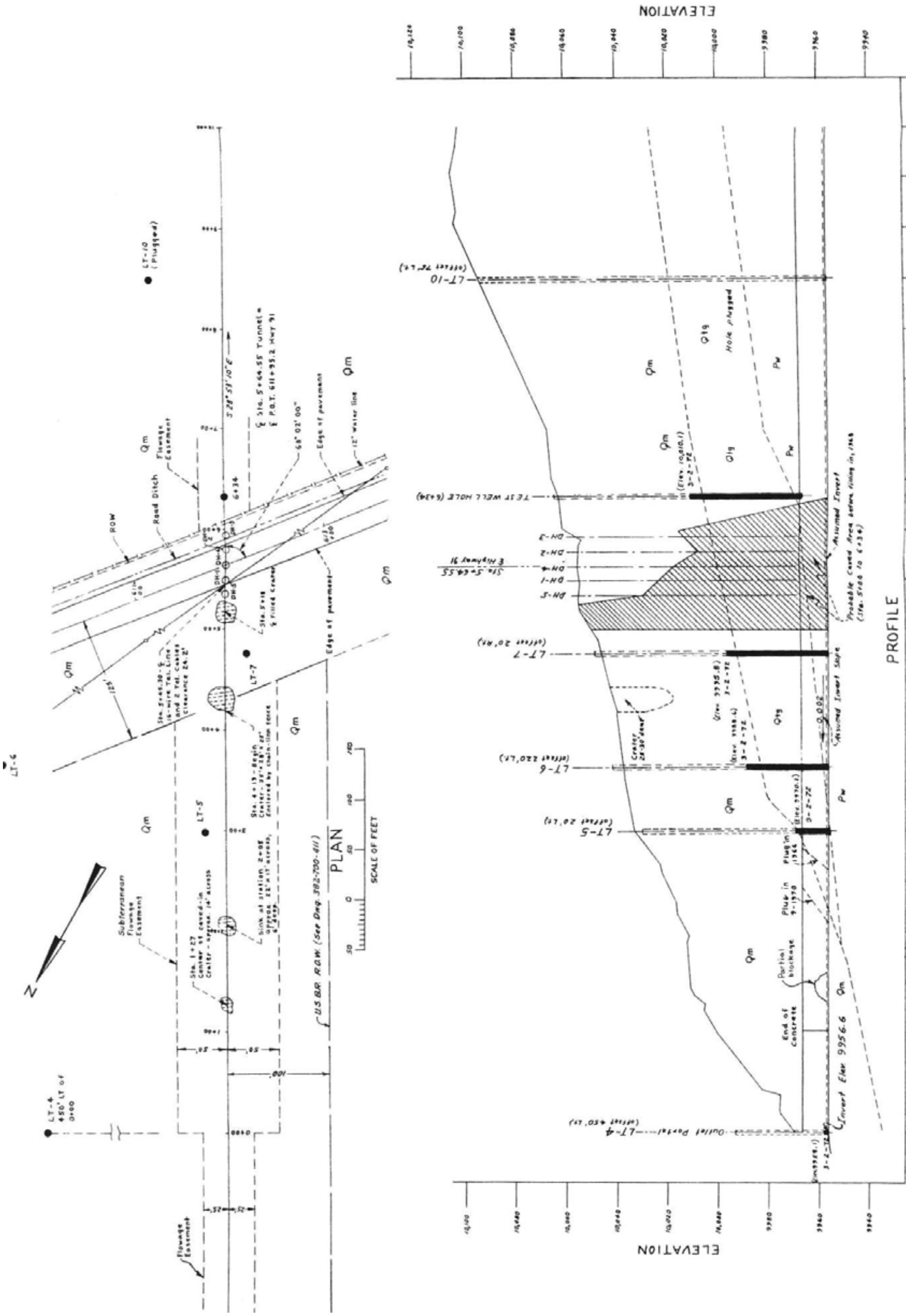


Figure 14. Plan and section showing condition of the LMDT in 1972 including the location of sinkholes, 1968 injection drill holes, and monitoring wells installed in 1968, taken from (Reclamation, 1976).

In 1972, flow that was coming through the ventilation pipe and the compressed air pipe diminished. The ventilation pipe and the compressed air pipe are from the original construction and they penetrate and carry flow through the collapsed zones and gravel injected portions of the LMDT. In order to reverse the diminishing flows, an explosive was detonated in the 8-inch compressed air pipe at approximate Station 10+00. This had the effect of increasing flows through the two pipes for a short period of time, but the flows eventually diminished again.

Development of other sinkholes and collapses in the tunnel continued to occur away from the highway from Station 2+00 to Station 5+00. In 1973, Reclamation awarded a contract to clean out first 200 feet of tunnel, install new steel 7-foot horseshoe shaped supports from Station 1+00 to Station 2+00, and completely backfill all remaining sinkholes, voids, and un-collapsed portions of the tunnel between approximate Stations 1+25 and 5+00 (Bennett, 1977). This work was performed under specification 700-797 (Reclamation, 1973). To facilitate the backfilling, percussion holes were drilled every 10 feet along the tunnel alignment. Voids in the tunnel and in the overlying soils were backfilled with a total of 450 cubic yards of gravel. A treated-timber bulkhead was installed at Station 2+00. A 24-inch-diameter corrugated metal pipe was installed and connected to the fallen 20-inch ventilation pipe and the 8-inch steel compressed air pipe. New track was installed in the first 200 feet of the LMDT to facilitate the work. Also, to accommodate the work, Reclamation purchased and fenced approximately 8 acres of land overlying and adjacent to the tunnel portal. An additional water observation well was placed at Station 3+40.

In 1975, Reclamation installed a 450 gallon per minute capacity pump in a well at Station 6+35 in an attempt to maintain a lower groundwater table adjacent to the lower portion of the tunnel.

In 1976, it was reported that the track installed in 1973 was in poor condition and that some additional sinkholes had formed since the 1973 work was performed to fill the tunnel (Reclamation, 1976). A total of 12 sinkholes had been observed over the years up until the summer of 1976. Since the more recent sinkholes were away from the highway, Reclamation began a program of erecting safety fencing around the holes rather than backfilling them as had been done in the past.

2.8 Modifications 1978-1980

Public Law 94-423, dated September 28, 1976, authorized Interior to rehabilitate the first 1,000 feet of the LMDT, and to maintain the tunnel in a safe condition, to monitor the quality of the tunnel discharge, and to make investigations leading to recommendations for treatment measures, if necessary, to bring the quality of the tunnel discharge in compliance with applicable water quality standards.

In 1976 seismic refraction surveys were made along the surface overlying the tunnel from Station 4+55 to 10+00 to locate subsurface voids and in 1977 a geologic design data report was prepared in anticipation of additional repair work (Bennett 1977).

Reclamation hired contractors to excavate the LMDT and perform consolidation grouting in the first 500 feet of the tunnel where sinkholes were developing to improve the stability of the tunnel and ground in the area. The collapse material in the first 500 feet of the tunnel was re-excavated and shored up. The excavation work was hampered by heavy water inflows. Several attempts were made in 1979 to drill and install a dewatering well to pump down water in the tunnel to facilitate the excavation work. A well at Station 6+65 was drilled to 98 feet into the tunnel where water 6 feet deep was seen to be flowing. While waiting for well screen, a sinkhole appeared adjacent to the drill rig and the hole was lost. Another hole was drilled at Station 7+22, but at a depth of 113 feet the cable broke and the bit was lost in the hole which was abandoned. There were large cost overruns associated with the construction project. Eventually, the excavation was completed, gravel backfill placed, and a bulkhead, constructed of steel beams and wooden timbers, was installed at Station 4+66, see Figure 15. Records regarding the extent of consolidation grouting performed, if any, have not been found.

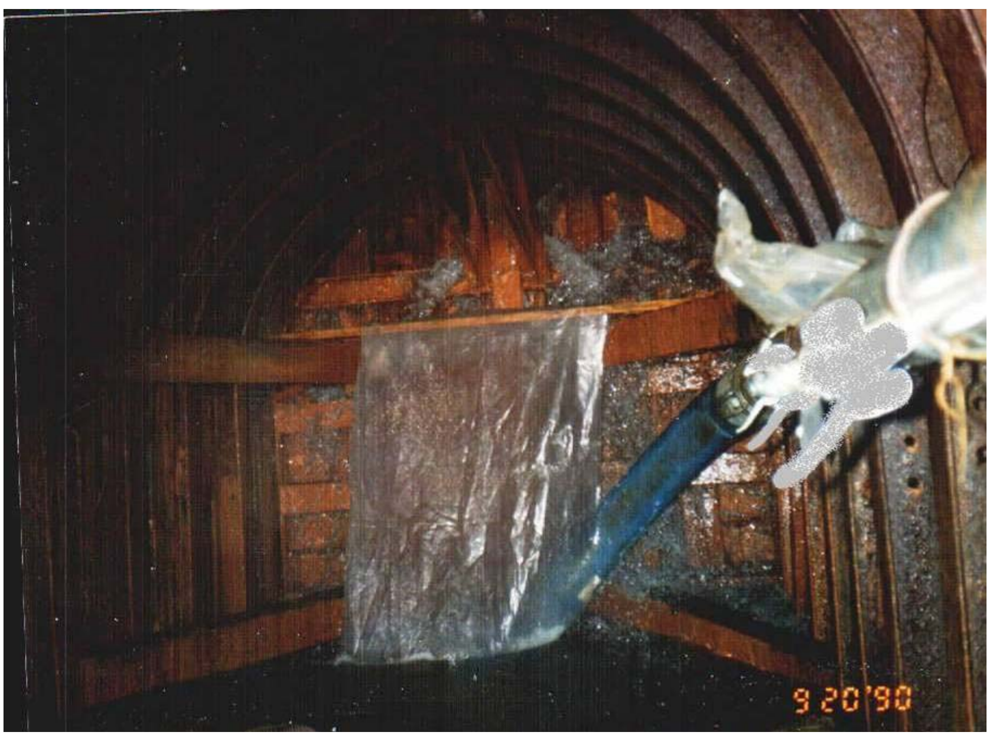


Figure 15. Photograph of the bulkhead located at Station 4+66.

On May 9, 1980, prior to completion of the bulkhead shown in Figure 15, Reclamation visually estimated flows from the vent pipe (250 gpm), cast iron air line (250 to 400 gpm), and there was seepage at the face, for a total of 600 to 800 gpm (Smirnoff and Allen, 1980). Figure 16 shows the locations of the vent pipe and air pipe.

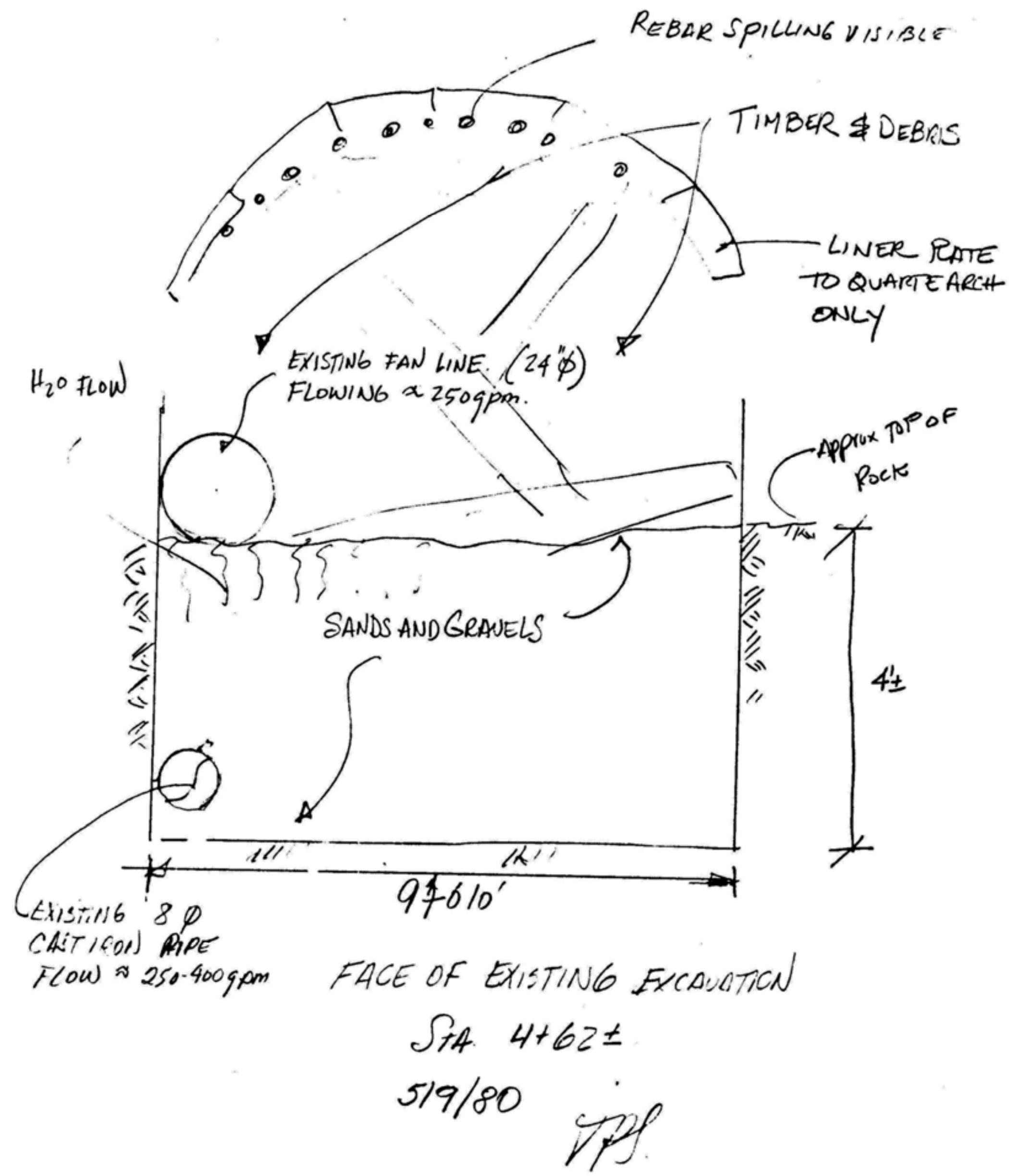


Figure 16. Sketch showing flows from vent pipe and compressed air pipe which extend through collapsed material in the LMDT, taken from (Smirnoff and Allen, 1980).

In 1988, Reclamation's Missouri Basin Regional Engineer completed a study of the tunnel plug and likely collapse zones from Station 4+62 to Station 6+32 and found that the resistance would be more than adequate to handle the estimated hydraulic pressure based upon the most likely tunnel, soil, and groundwater conditions.

2.9 Modifications 1990-1992

Design of a water treatment plant and lining of a portion of the LMDT was initiated in the late 1980s. Construction ran from 1990 to 1992. In 1992, P.L. 102-575 authorized Reclamation to construct a water treatment plant in order that water flowing from the Leadville Mine Drainage Tunnel may meet water quality standards, but specified that the plant "shall be constructed to treat the quantity and quality of effluent historically discharged" from the tunnel.

The work was covered by specification 0-SI-60-04100/DC-7804 (Reclamation, 1989). Reclamation completed construction of the LMDT Water Treatment Plant in 1992, and it has been treating water continuously since this time. Operation of an extraction well at Station 10+25 plus drainage outflow through the bulkhead now controls the water surface in the lower reaches of the tunnel.

A new portal structure was constructed further back into the hillside which was excavated back to facilitate the installation. The portal has sloping wing walls which extend from Station 0+10 to 0+32.5. The outside face of the portal is at Station 0+32.5 and the portal concrete structure extends back to Station 0+54. The portal is made from one-foot-thick reinforced 4,000 psi concrete. A six-foot-deep drainage sump is included in the structure with two outfall pipes, one to the detention pond and one to the treatment plant.

The concrete tunnel liner is approximately one-foot-thick 4,000 psi concrete with number 5 reinforcement bars. The existing steel sets were left in place embedded 5 inches into the concrete lining. Weep holes were placed through the lower walls of the liner and grout holes were placed into the roof. The existing fill behind the new concrete liner was grouted at 25 psi. The weep holes consist of a 2.5-inch-diameter PVC solid pipe into which a 1.5-inch perforated PVC pipe was inserted. The inserted pipe was wrapped with two layers of geotextile filter fabric prior to insertion into the larger pipe. The geotextile filter fabric also covers the interior end of the inserted pipe.

The existing timber bulkhead at Station 4+66 was left in place. Gravel backfill was placed between the existing bulkhead and a new wood-lattice bulkhead constructed at Station 4+61 to 4+60. Gravel backfill was 1.5 to 2.5 inches in diameter; however, this was problematic in that the flow moved the gravel into spaces between the lattice timbers and caused plugging off of the flow through the new timber lattice. A zone of 3-inch to 12-inch cobbles was instead placed immediately behind the new timber bulkhead at 4+61, which eliminated the plugging of the lattice. The new timber lattice, made of creosote-treated 2 x 12 Douglas Fir, is held together with stainless steel screws. A stainless steel support set was placed immediately in front of the timber lattice structure to lock it in place. The stainless steel support set is anchored to the concrete liner using ¾-inch-diameter stainless steel bolts.

2.10 Rock Mass Characterization Study

From September until November 2003 Reclamation conducted a drilling program for the EPA to evaluate the geotechnical and hydrologic nature of rock in areas where it might be possible to construct a hydraulic bulkhead in the LMDT as a component of Operable Unit 6 of the California Gulch Superfund Site. Two holes, designated LMDT-B1 and LMDT-B2 were drilled. Hole LMDT-B1 was drilled to evaluate the Precambrian Granite upstream of the Pendry Fault, and hole LMDT-B2 was drilled to evaluate the Pando Porphyry near the Robert Emmet Shaft. Prior to the evaluation, EPA engaged Hayward Baker to enlarge three existing (pre-tunnel construction) test borings and convert them into monitoring wells. The five holes involved in the study are detailed in Table 4.

Table 4. 2003 Rock Mass Characterization, Well Construction Details

Drill Hole	Station	Total Depth Feet	Hole Diameter Inches	Screened Influence Zone
LMDT-B1	46+66	360.0	7-7/8	325.0 to 360.0
LMDT-B2	96+44	534.5	7-7/8	350.0 to 534.5
LDT 25+15	25+15	281.0 tunnel crown	5-3/4	4” pvc pipe open to tunnel
LDT 36+77	36+77	298.0 tunnel crown	5-3/4	4” pvc pipe open to tunnel
LDT 75+05	75+05	470.0 tunnel crown	2-15/16	2” pvc pipe open to tunnel

The two holes drilled by Reclamation drifted off alignment as they went through the rock and failed to intersect the tunnel. Water tests indicated that the holes were near enough to the LMDT to be in hydraulic communication with it. The two new holes were cored and optically logged. Discontinuities were evaluated for strike, dip, openness, infilling, spacing frequency, etc. Plots were prepared in various graphical representations including pole, pole concentrations, contoured poles, rose diagram, contoured pole concentrations, contoured principal planes, and principal planes. The core was photographed and evaluated with regard to Rock Quality Designation, and the Rock Mass Rating and Q System ratings were determined. The report concluded that a hydraulic plug could be constructed in the granite upstream of the Pendery Fault in order to contain and control the mine pool.

2.11 Valve Controlled Bulkhead Study

Reclamation conducted a study for installation of a concrete bulkhead and a valve in the LMDT (Smith and others, 2005). It would have been installed just downstream of the existing lattice bulkhead at Station 4+62 for the purpose of shutting off the LMDT drainage flow for up to seven days to allow for water treatment plant shutdown and maintenance. Water would be allowed to build up in the ground behind the bulkhead provided that water did not back up to the point where it might cause a slope failure or a collapse of the tunnel liner.

Physical and strength properties were identified for use in the evaluation based upon available project data, interviews, and site visits, but no references were given, nor were any strength tests undertaken. The densities, strengths, and other data are assumed values; however, they appear to be reasonable for the type of materials involved. The assumed values are presented in Table 5.

Table 5. Material Properties Assumed for the 2005 Bulkhead Study.

Material	Property	Range of Values	Average Value
Glacial Moraine	Unit Weight, lb/ft^3	115 to 130	125
Glacial Moraine	Cohesion, lb/in^2	2 to 10	5
Glacial Moraine	Friction Angle, degrees	32 to 45	40
Glacial Moraine	Void Ratio, %	10 to 35	25
Glacial Moraine	Porosity, %	15 to 40	30
Glacial Moraine	Permeability, ft/sec	3.2×10^{-5} to 3.2×10^{-3}	3.2×10^{-4}
Terrace Gravels	Unit Weight, lb/ft^3	110 to 120	115
Terrace Gravels	Cohesion, lb/in^2	5 to 15	10
Terrace Gravels	Friction Angle, degrees	35 to 41	38
Terrace Gravels	Void Ratio, %	10 to 20	15
Terrace Gravels	Porosity, %	20 to 35	27
Terrace Gravels	Permeability, ft/sec	3.2×10^{-5} to 3.2×10^{-3}	7.0×10^{-4}
Weber Formation	Unit Weight, lb/ft^3	142 to 150	146
Weber Formation	Cohesion, lb/in^2	10 to 40	25
Weber Formation	Friction Angle, degrees	50 to 60	55
Weber Formation	Permeability, ft/sec	1.28×10^{-7} to 1.28×10^{-5}	1.28×10^{-6}

Using the data in Table 5, the slope stability of the hillside between the portal and LMDT Station 10+25 was evaluated using the computer program SLOPE/W. Factors of safety were computed for five cases with different piezometric water surface profiles ranging from the low seen in March 2004 to the historical high observed in the hillside after the 1976 collapse, which was multiplied by 1.6, which brought the piezometric surface to well above historic values. These high water cases were run for average and minimum strength values. The factor of safety determined was 3.74 and 2.59 respectively.

A determination of the likely loading on the concrete tunnel liner was undertaken using the computer program TUNANAL. This evaluation concluded that loading on the tunnel liner is sensitive to the elevation of the groundwater surface and that to maintain a reasonable factor of safety, the existing liner can not withstand any additional hydrostatic load. Continuous pumping from the well at Station 10+25 or another location must continue. A new tunnel lining, grout curtain at the bulkhead, shorter shut down period, and/or other measures may be required if a temporary shutdown of tunnel flows is to be achieved. The valve controlled bulkhead was not constructed.

2.12 Inspection March 25, 2008

On March 25, 2008, an inspection of the LMDT was made by Reclamation geotechnical engineers Michael Gobla and Jack Touseull, and civil engineer Kevin Atwater for the purposes of evaluating the structural integrity of the portal, tunnel liner, and timber lattice bulkhead. The inspection included the portal structure, drainage ditch, reinforced concrete liner, weep holes, and the timber lattice bulkhead. The concrete is sound and relatively fracture free. One lift line located about 3 feet above the door opening was damp as evidenced in the accompanying photograph in Figure 17. A few short hairline cracks were noted in the portal structure. The portal structure is in overall excellent condition.

Figure 17. Photograph of the LMDT portal structure taken on March 25, 2008.

Entrance to the portal is controlled by a steel door which is normally kept closed and locked. Just inside the LMDT portal is a floor grating with removable panels to allow access to the sump at the end of the two drainage ditches; a concrete walkway divides the ditches, see Figure 18. Beyond the grating, electrical equipment is located on the right side (looking downtunnel) for operation of the lights and ventilation system. The overhead lights, ventilation fan, and ventilation pipeline are shown in Figure 19. All of the equipment was in operating condition at the time of the inspection.

Figure 18. Photograph taken on March 25, 2008 looking at the downstream end of the LMDT showing the concrete center walkway with drainage ditches on either side and steel floor grating.

Figure 19. Photograph taken on March 25, 2008 looking upstream from the Portal area in the LMDT showing the ventilation fan, motor controls, and vent pipe at left, and the electric lights at the upper right.

The inside surface of the reinforced concrete tunnel liner in the downstream portion of the tunnel has been coated with a bright white reflective material. The presence of this coating obscures the condition of the concrete. The upstream portion of the reinforced concrete liner (where the liner is under higher soil and water loading) has not been coated. Approximately ten cracks were observed in the concrete lining. The cracks varied from hairline to about 1/16 of an inch wide. The two most significant cracks were found on the left side of the tunnel (looking downstream), one in the crown, (see Figure 20), and one along the wall about 4 feet above the floor. Both of these cracks were about 20 feet long and 1/16-inch wide. A small amount of calcium bearing mineral precipitates are forming from the seepage coming through the cracks. The seepage rates are very slow; at most locations the cracks are wet, but not dripping. The cracks are of little structural concern. Probing with an ice pick it was not possible to dig open the cracks. The concrete is sound and very hard, even right at the edge of the crack. Only one crack near the lattice bulkhead showed minor offsetting of the tunnel lining; at all other cracks, the lining is smooth and even across the crack.

Figure 20. Photograph taken on March 25, 2008 looking downstream from about midway inside the reinforced concrete lined segment of the LMDT. Note the calcium carbonate stalagtites forming from the slow seepage along a thin roof crack and at a joint in the concrete lining.

All of the tunnel weep holes show some level of clogging by mineral precipitates. Flow is minimal, and this has been so since their construction. The weep holes were constructed by placing a geotextile-filter-wrapped perforated pipe inside a solid PVC pipe inserted through the concrete liner. Cleaning of the weep holes must be done with care to not rupture the geotextile.

Figure 21. This crack located about 3 feet above the LMDT floor is the only one that showed offsetting of the concrete. The offset is about 1/8 inch.

Figure 22. Photograph of a weep hole in the reinforced concrete lining which is almost completely blocked by calcium carbonate precipitates.

Figure 23. Photograph taken on March 25, 2008 of the cobble and gravel-filled timber-lattice bulkhead at Station 4+61 of the LMDT. At left is the intake end of the ventilation pipeline.

The stainless steel tunnel support was visible just in front of the timber lattice bulkhead. The stainless steel support for the timber lattice has not been affected by its environment and is in like new condition. A regular steel post just downstream of the bulkhead is showing signs of deterioration, but this post is not an essential structural component of the tunnel. It does emphasize the point that the zinc and iron-rich water, even at near neutral pH, is capable of degrading regular steel over a period of time.

Behind the bulkhead are 3- to 12-inch cobbles behind which is a vertical zone of 1 ½ to 2 ½-inch gravel. During construction, finer sized gravel was used for the gravel fill, but when the timber lattice support was installed, it was found that the smaller gravel was carried into the lattice openings by the water flow and it resulted in constricting the drainage flow rate through the timber structure. A change was made to install a vertical zone of cobbles to lie in immediate contact with the timber lattice which is what was observed to be the case.

The timbers and cobbles above the water level have a thin coating of black manganese oxides. The timbers below the level of flowing water are coated with a layer of iron hydroxide precipitates about 1/8-inch thick. The precipitates have a firm but not hard crust, which when broken is soft underneath.

The timber comprising the lattice support structure remains in excellent condition. The 2-by-12-inch boards have maintained alignment and remain in sound condition. The timbers were probed with an ice pick; the tip of the ice pick would only penetrate into the wet timber 1/16 to no more than 1/8 of an inch. Most of the timbers above and all of those below the flow surface were probed with the ice pick.

At the time of the inspection, the tunnel outflow through the bulkhead was approximately 250 gpm. It is concluded that the LMDT structural elements are in excellent condition. Correct materials were specified and installed for this harsh environment. No significant degradation has been observed.

The only features requiring attention are the weep holes. Those showing more than half the pipe being filled with precipitates should be cleaned out. This can be accomplished by drilling/chiseling out the precipitates to remove the inner 1.5-inch diameter perforated pipe and its geotextile wrapping, and then insert new geotextile-wrapped pipe inserts into the 2.5 inch PCV pipes.

3.0 GEOLOGY

3.1 Regional Geology

The Leadville Mine Drainage Tunnel lies in the center of the Southern Rocky Mountain physiographic province. Generally, this province consists of greatly elevated, north-south strips of granite flanked by, and sometimes capped by sedimentary rocks. Intermountain basins, such as South Park, are common. The Sawatch Range, lying to the west of the tunnel, has the highest peaks of the Rocky Mountains.

The tunnel portal lies near the headwaters of the Arkansas River between the Sawatch and Mosquito Mountain Ranges. The tunnel itself is driven into the Mosquito Range. The portal and first 635 feet of tunnel lie in a terminal glacial moraine and terrace gravel.

3.2 Tunnel Stratigraphy

The LMDT penetrates the entire stratigraphic section of rocks present in the Fryer Hill and Carbonate Hill basins, including Precambrian granite and sedimentary Cambrian quartzite, Peerless shale, Manitou limestone, Parting quartzite, and Leadville "blue" limestone.

Surficial materials (glacial moraine and terrace deposits), consisting of gravel, cobbles, and boulders in a silt and sand matrix overlie the tunnel. The first several hundred feet (approximate Station 0+50 to 6+35) of the LMDT were constructed within these near-surface deposits.

Refer to Appendix A – *Geologic Cross-Section Along the Leadville Mine Drainage Tunnel* for detailed stratigraphy.

3.3 Structure

The rocks have undergone extensive deformation and tilting and have been intruded by sills and large masses of porphyry. In east-west or southeast-northeast section, the fault blocks of east-dipping sedimentary beds are dropped in steplike fashion to the west. In addition to the main faults, there are many intermediate faults within blocks. Many of the faults, such as the Pendery and Carbonate, are water bearing. The Mikado Fault was not water bearing at the tunnel level, at least where cut. When shear zones accompany faults, problems of support arose in driving through them.

Most the ore bodies are of the replacement type associated with the intrusives, and their placement have been controlled by structural factors such as pre-mineral faults or the damming effect of formations impervious to passage of mineralizing solutions. Post-mineral faulting sometimes displaced or broke up ore bodies, thus complicating exploration and mining.

The rock mass consists primarily of Precambrian granite and metamorphic rocks. Paleozoic sedimentary rocks overlay these basement rocks. The rock mass is heavily faulted, fractured and upturned as a result of the Laramide orogeny. Intrusions into the Precambrian and Paleozoic rocks along faults and between sedimentary rock layers have also occurred. The intrusions formed igneous porphyry bodies and ore deposits.

3.4 Hydrogeology

The LMDT is situated in a large, complex, groundwater system. The location and regional flow of ground water in the Leadville Mining District is directly controlled by the faulted boundaries of the various structural basins. Each basin retained its own ground water and circulation between the basins was not possible because of the presence of impermeable gouge along the faults. Mine workings including stopes, adits, and shafts have radically changed the original groundwater flow system in and around Leadville.

The regional hydrology for engineering purposes can be separated into two water bearing units. They are the unconsolidated surficial material and the bedrock aquifers. The groundwater levels in the surficial aquifer are shallow and generally controlled by the topography. Hydrologic studies, including dye tracer studies, have demonstrated that the fractured bedrock aquifer is hydraulically connected to the upper surficial aquifer. Further, there is an upwelling of bedrock groundwater into the alluvial aquifer that has been confirmed by monitoring in California Gulch. The unconsolidated aquifer is porous and tends to readily transmit ground water. The geometry of the bedrock is a controlling factor in groundwater flow in the surfical aquifer.

Water levels are monitored in several wells present along the LMDT alignment. Refer to Appendix A – *Geologic Cross-Section Along the Leadville Mine Drainage Tunnel* for locations of wells. Figure 24 shows water levels in wells along the lower portion of the LMDT alignment and Figure 25 shows water levels in wells and the Emmet Shaft along the upper portion.

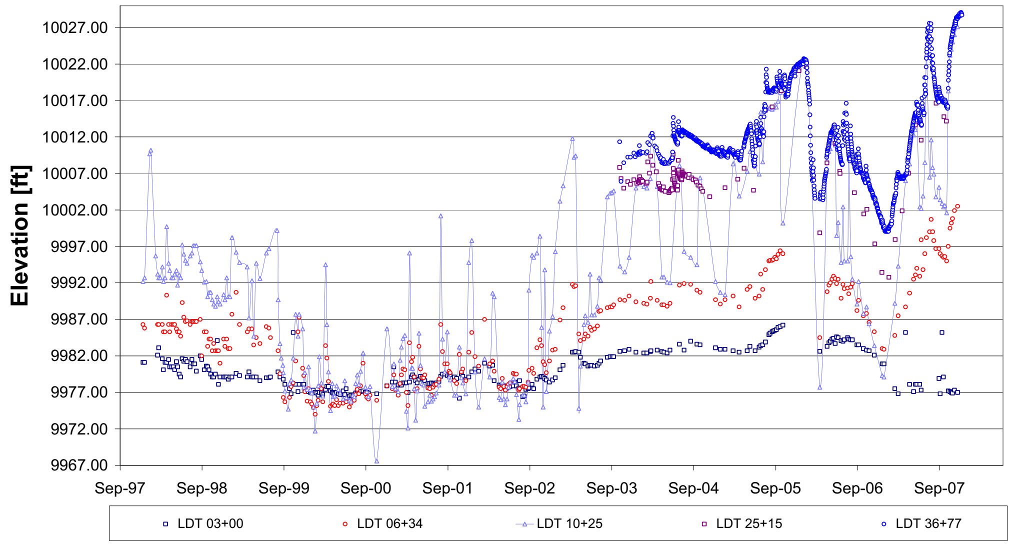


Figure 24. Plot of water levels in wells along the lower portion of the LMDT alignment.

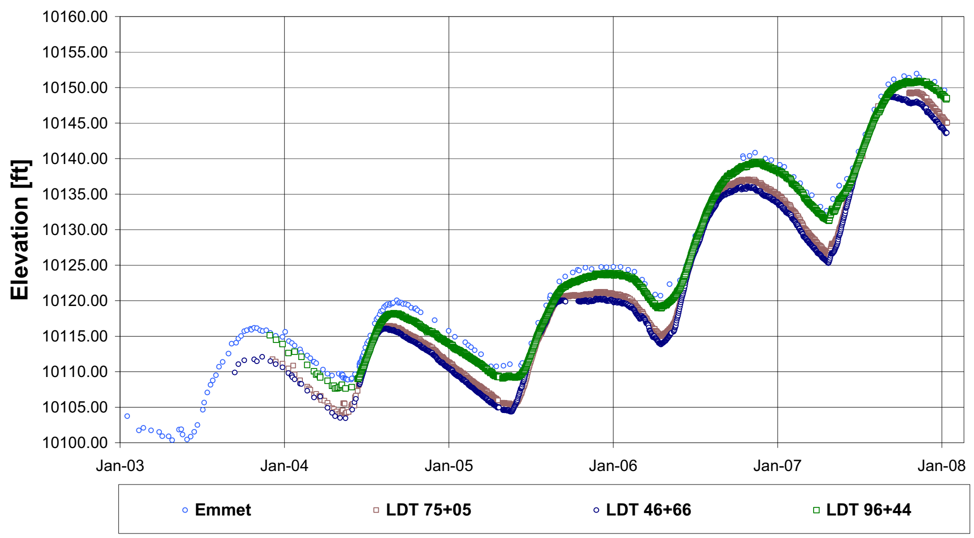


Figure 25. Plot of water levels in wells along the upper portions of the LMDT alignment

3.5 Seismicity

Estimated seismic loadings in the table below were derived from peak horizontal acceleration (PHA) hazard curves for Sugar Loaf Dam that were presented in the Technical Memorandum entitled "Screening/Scoping Level Probabilistic Ground Motion Evaluation for Mount Elbert Forebay, Sugar Loaf, and Twin Lakes Dams, Fryingpan-Arkansas Project, Colorado, 2002". PHA hazard curves for Sugar Loaf Dam provide reasonable estimates of seismic loading at the Leadville Mine Drainage Tunnel located less than 5 miles from dam.

Table 6. Seismic loading conditions for the LMDT.

Return Period (years)	PHA
500	0.05g
2,500	0.15g
10,000	0.35g

3.6 Previous Geologic Investigation

Ten holes were drilled by the U.S. Bureau of Mines in the 1940s to determine subsurface conditions to be encountered by the first 7,000 feet of tunnel. Of these, six were concentrated in the first 1,100 feet. The holes were churn drilled through the glacial moraine and terrace material to the top of bedrock. The bedrock portion was cored. Logs of these holes are not available; however, much of the information on the geologic cross section (Drawing No. 1335-D-2A) is based on data obtained from the drilling.

With no maintenance, the tunnel deteriorated rapidly, and sections of the tunnel arch supported exclusively by wood sets have collapsed. Some of the voids thus created worked their way to the surface and appeared as sinkholes. The first major sinkhole occurred at Station 4+00 in 1966. In 1968, a cave-in occurred next to State Highway 91. As a part of the emergency repairs, ten holes were drilled. Five of these were used to backfill subsurface voids (including the tunnel) and five were left open for water observation purposes. These holes were entirely in glacial moraine and terrace gravels. Logs are not available.

Again, in 1973, an attempt was made to fill all remaining subsurface voids from Station 2+00 to about Station 5+00. To locate the cavities, percussion holes were drilled at 10-foot intervals. Every place a void was encountered; it was backfilled with gravel (including the tunnel). During this same phase, an additional water observation well was placed at Station 3+40. Logs are not available for any of these holes. All holes were in glacial moraine and terrace gravels.

Four drill holes were completed in 1989 (DH 89-1 through -4) to gather geologic design data for the Treatment Plant. Depths of the four boreholes ranged from 13.0 to 19.8 feet. The holes encountered glacial moraine consisting primarily of sand and gravel with 20 to 25 percent fines with low to no plasticity. Locations of the boreholes are shown on drawing 1335-D-3.

Two wells were drilled and three existing holes were enlarged along the alignment of the tunnel in 2002 with the purposes of monitoring water levels along the tunnel, obtain groundwater quality sampling points, and to gather rock quality data along the tunnel. Boreholes LMDT-B1 and –B2 are new monitoring wells constructed by Reclamation for the EPA at Stations 46+66 and 96+66, respectively. Under contract with the EPA, Hayward Baker modified three existing (pre-tunnel construction) test holes along the tunnel alignment at Stations 25+15, 36+77, and 75+05. The original test holes were core drilled using small diameter diamond bits (AX and BX size). Hayward Baker enlarged the diameter of the existing holes and deepened them to intersect the crown of the tunnel. PVC pipe was installed in the enlarged boreholes to the crown of the tunnel and the annuluses were grouted.

The new boreholes, LMDT-B1 and –B2, failed to directly intercept the tunnel; however, camera inspection revealed connectivity with the tunnel through a series of open joints. Well screens and pea-gravel filter packs were installed adjacent to the tunnel. PVC riser pipes were grouted above the screened intervals.

Reclamation installed a piezometer at LMDT Sta. 10+25, 25 feet left in July 2002 to monitor drawdown adjacent to existing pumping wells installed in the LMDT. The piezometer has dual influence zones, one at the base of surficial materials and the other in the upper portion of bedrock.

4.0 PORTAL STRUCTURE STATION 0+32.5

The portal has been rebuilt on several occasions. The current portal structure was constructed during the 1990-1992 modifications. The work was covered by specification 0-SI-60-04100/DC-7804 (Reclamation, 1989).

The original portal was located at LMDT Station 0+00 and the first 30 feet of the LMDT was excavated through river deposits (clay, silt, sand, and gravel). The existing portal was constructed further back into the hillside (Station 0+32.5). The excavation would have removed all of the river deposited soils from around the LMDT.

The portal structure has sloping wing walls, which extend from about Station 0+10 to 0+32.5. The outside face of the portal is at Station 0+32.5 and the portal concrete structure extends back to Station 0+54. The portal structure is made from one-foot-thick reinforced 4,000 psi concrete. A six-foot deep drainage sump is included in the structure with two outfall pipes, one to the detention pond and one to the treatment plant. The portal structure was inspected on March 25, 2008 and found to be in excellent condition.

The elevation of the LMDT at the portal (door threshold) is 9,958.42 feet. Downstream of the entrance, the ground slopes up about two feet to the elevation of the service yard area. Details regarding the portal structure construction are shown on drawings 1335-D-18 Site Plan, 1335-D-124 Outlet Portal Structure Isometric View, Sections, and Detail, and 1335-D-125 Outlet Portal Structure Sections, and Details (See Appendix B).

5.0 TUNNEL SEGMENTS

5.1 Concrete Lined Segment Station 0+54 to 4+61

From the back of the portal structure at Station 0+54 to Station 4+61, the LMDT has been lined with reinforced concrete. This portion of the LMDT is surrounded by glacial soil deposits and the liner serves to prevent internal erosion and piping of the soil into the LMDT. From the portal structure to Station 3+50 the LMDT is completely surrounded by glacial soils. At Station 3+50, bedrock (sandstone and shale) was encountered in the floor of the LMDT. From Station 3+50, the bedrock contact rises along the walls of the tunnel with glacial soils remaining in the upper portion of the tunnel. It is not until Station 6+50 that the bedrock reaches the crown of the tunnel excavation. The original excavation was driven at a size of 10-feet wide by 11.5-feet tall clear opening inside the timber supports until Station 3+35, so roughly a 12-feet wide by 12.5 feet tall excavation. The section was reduced to 9-feet wide to 10.5-feet tall clear opening from Station 3+35 to Station 66+00, or a 11-feet wide by 12-feet tall excavation.

Since the liner has been completed, there have not been any more sinkholes occurring above the LMDT alignment. The concrete lining was constructed during the 1990-1992 modifications. The work was covered by specification 0-SI-60-04100/DC-7804 (Reclamation, 1989). Details of the reinforced concrete liner are found on drawing 1335-D-123 Typical Tunnel Section, Cutoff Wall, and Timber Bulkhead. The concrete lining was inspected on March 25, 2008 and found to be in excellent condition with the exception of the weep holes, which are becoming clogged with calcium carbonate precipitates.

The tunnel concrete liner is approximately one-foot thick and incorporates 4,000 psi concrete with number 5 steel reinforcement bars. Number 6 bars were placed at the lower corners. The existing steel sets were left in place embedded 5 inches into the concrete lining. One weakness in the design is that there is only 3 inches of concrete cover over the floor reinforcement in the ditches. The center walkway is an elevated section of concrete which forms the walls of the drainage conveyance ditches on either side. The walkway has a welded wire fabric for reinforcement. Weep holes were placed through the lower walls of the liner and grout holes were placed into the roof. The existing backfill behind the new concrete liner was grouted at 25 psi.

5.2 Timber Bulkhead and Gravel Fill Station 4+60 to 4+66

During the 1990-1992 modifications, gravel-fill was placed between the existing bulkhead at 4+66 and a new wood-lattice timber bulkhead constructed at Station 4+60 to 4+61. The gravel backfill was 1.5 to 2.5 inches in diameter; however, this was problematic in that the flow moved the gravel and caused plugging off of the flow through the new timber lattice. A vertical zone of 3-inch to 12-inch cobbles was instead placed immediately behind the new timber bulkhead at 4+61 which eliminated the plugging of the lattice. The new timber lattice, made of 2 x 12 inch creosote-treated Douglas Fir, is held together with stainless steel screws. A stainless steel L-shaped support was placed immediately in front of the timber lattice structure to lock it in place. The stainless steel support is anchored to the concrete liner using ¾-inch-diameter stainless steel bolts**.** Details of the bulkhead construction are shown on drawing 1335-D-123 Typical Tunnel Section, Cutoff Wall, and Timber Bulkhead. Inspection of this bulkhead on March 25, 2008 found it to be in excellent condition.

In a Memorandum (Armer, 2001), the stability of the bulkhead at Station 4+60 was evaluated. It was reported that with flow 2.5 feet above the floor (current condition), the bulkhead had a factor of safety of 3.3. If water flow were to rise to the full height of the LMDT, the factor of safety would be greater than 1.0 for the bulkhead assembly.

Figure 26. Construction photograph showing the cobbles behind the timber-lattice bulkhead at Station 4+60 of the LMDT.

5.3 Bulkhead and Backfill Station 4+66 to 5+00

In the Station 4+66 to 5+00 segment of the tunnel, the bedrock contact continues to rise, reaching half way up the sides of the excavation at Station 5+00. The steel (A-36) and timber bulkhead constructed in 1979 is located at Station 4+66. Behind this bulkhead, any remaining voids were filled with gravel. This segment of the tunnel (to Station 5+00) had previously been filled during the 1973 construction by drilling percussion holes every ten feet from the surface and placing gravel down into the tunnel voids. It is believed that this segment of the LMDT is still filled with a combination of collapsed glacial material and injected gravel.

5.4 Glacial Materials Station 5+00 to 6+50

The Station 5+00 to 6+50 segment of the tunnel has bedrock walls gradually rising from the mid-height to the crown of the tunnel. This segment of the LMDT is mostly filled with collapsed glacial soils. Although reports suggest this entire section of the LMDT was filled with gravel, no conclusive records have yet been found to verify the upper-most 20 feet having been filled. According to the drawing showing conditions in 1972 (Figure 14), the area filled was from Station 5+00 to Station 6+30. The drawing shows the tunnel open beyond Station 6+30 as of 1972. At Station 6+35, a cap of 1.5 feet of weathered bedrock was reported above the crown of the excavation and at this location the small top heading was terminated. An extraction well installed at Station 6+35 penetrates the tunnel and was used for draining the LMDT prior to installing the extraction wells at Station 10+25.

5.5 State Highway 91 Station 5+64.55

The centerline of State Highway 91 crosses over the LMDT at Station 5+64.55. Besides the paved highway, there are buried utilities in the ground adjacent to the highway.

5.6 Shallow Bedrock Crown Station 6+50 to 21+00

Bedrock (Weber Formation) was reported by the Bureau of Mines to have improved at Station 6+50 such that the spiling was discontinued and the spacing of timber supports was increased to 6 feet. The LMDT crosses interbedded sandstones and shales until Station 21+00 where it enters gray porphyry. Because of the problems excavating through the porphyry, a part of the LMDT was abandoned and a bypass tunnel was constructed beginning at Station 16+81. The bypass runs approximately 35 feet to the right (looking up tunnel) from the original alignment and extends to Station 24+48. The turnout, starting at Station 16+81 was concreted and a center pillar was placed as extra support across the wide opening. Holes were drilled through the concrete and grout was pumped in at 750 psi to fill all voids behind the supports.

Two extraction wells penetrate the LMDT near Station 10+25 and an observation well is offset 25 feet from the tunnel alignment.

5.7 Gray Porphyry Station 21+00 to 22+00

At Station 21+00 the tunnel entered a dike of gray porphyry. Advance of 26 feet into the area resulted in a peak water flow of 3,000 gpm, which washed over 1,500 cubic yards of mud, sand, and broken rocks into the LMDT. Attempts to clear the tunnel and continue on were met with similar inflows of water and muck. A wooden bulkhead was placed at Station17+95 to stop the inflow. Test holes revealed that the bedrock over the tunnel was 4- to 12-feet thick and that the inflows were from the overlying glacial material. A concrete bulkhead with drainage pipes was placed against the wooden bulkhead at Station 17+95 to prevent other inflows and a thick coating of gunite was applied to the tunnel walls and arch roof downstream of the bulkhead. The porphyry was altered and crushed but relatively dry. The walls were concreted flush with the support timbers. At Station 22+00 the Leadville Limestone was encountered.

5.8 Leadville Limestone Station 22+00 to 22+50

Continuing on the bypass alignment, the tunnel was excavated through the Leadville “blue” limestone without problems. Large flows of water were experienced at both contacts (downstream and upstream) of the adjacent rocks with the limestone.

5.9 Parting Quartzite Station 22+50 to 24+50

The Parting quartzite proved to be perhaps the most difficult of all the tunneling conditions. Initially the walls were hard but advance drillholes at Station 23+00 encountered a breccia zone. Spiling was used but a large flow of water and mud broke in at Station 23+28. A timber bulkhead reduced the flows from 3,000 gpm to 1,100 gpm. The tunnel was concreted 35 feet back from the face. A concrete bulkhead was placed against the face, and then grout was pumped in at high pressure through holes drilled in a radial pattern around the outside of the face. Next, 11 cubic feet of concrete was pumped in under pressure behind the concrete bulkhead. Holes were drilled 40 feet through the bulkhead and grouted at 300 psi, placing a total of 2,248 sacks of cement. More breccia zones were encountered. One at Station 24+40 took 1,448 sacks of cement to consolidate. The tunnel eventually turned back to the original alignment at Station 24+48.

5.10 Limestone Station 24+50 to 27+55

Limestone (Manitou) in this segment required only light support with steel rail sets and partial lagging. A 281-foot-deep monitoring well penetrates this segment of the LMDT at Station 25+15.

5.11 Porphyry Dike Station 27+55 to 29+63

Timber sets were required for a distance of 20 feet where an inflow of over 1,600 gpm was experienced.

5.12 Faults at Station 29+63

Two closely spaced faults at Station 29+63 experienced inflows of 5,700, gpm raising the total tunnel outflow to 7,000 gpm (the highest LMDT flow ever recorded). A cavern following the side of the tunnel with openings as large as 60 x 15 x 20 feet was observed. After the water drained out, the cavern sides were hard so 156 feet of the tunnel length was slabbed off to take advantage of the natural cavern openings to create a siding for the track.

5.13 Parting Quartzite Station 32+50 to 37+80

A fractured and altered zone of Parting quartzite rock was encountered from Station 32+50 to 37+80 which required spiling over the arch and some of the sides to prevent mud inflows. A 298-foot-deep monitoring well penetrates the LMDT at Station 36+77.

5.14 Limestone Station 37+80 to 40+60

Limestone (Manitou), highly broken was crossed by spiling. Later maintenance records mention that the parting quartzite is in or just above the roof of the tunnel along much of this segment of the workings.

5.15 Pendery Fault Station 40+70

The Pendery Fault zone was about 40 feet wide and contained fine breccia with some water. It was excavated with timber supports on 5-foot centers. The supports and intervening areas were concreted.

5.16 Precambrian Granite Station 40+60 to 63+45

The Precambrian granite was fractured and blocky and carried some water until Station 44+00 when ground conditions improved. Timber supports were only required in short sections where dikes of altered alaskite and pegmatites were penetrated. All of the rock in the unsupported section were gunited to prevent alteration by water and air. Beyond Station 60+00, the granite was more broken and carried considerable flows of water, so timber supports were required.

5.17 Lower Paleozoic Sedimentary Rocks 63+45 to 97+00

The rocks encountered along this segment include the Manitou Dolomite, Peerless Formation (Station 72+85 to Station 73+60), and Sawatch Quartzite. Generally poor rock requiring support was encountered, although some competent zones were reported. Particularly poor quality broken rock is present between 66+00 to 77+00 and 78+00 to 80+00. At Station 84+50 shale was nearby over the top of the LMDT resulting in heavy ground requiring timber supports.

Abundant faulting and folding is present over the entire reach. Major faults encountered include the Niles Fault at approximate 70+20 and the Carbonate Fault at approximate station 76+30. The Carbonate Fault contained significant water and two to three feet of soft gouge.

The LMDT gradient for drainage changes in this segment from 0.5 percent up to Station 66+00 to 0.2 percent beyond (upstream) of Station 66+00. Heavy water inflows were encountered at the Daly fissure located at Station 73+57. A 470-foot-deep monitoring well penetrates the LMDT at Station 75+05.

No mineralization was reported along the first 7,100 feet of the tunnel. The first signs of lead-zinc mineralization were encountered from Station 71+20 to Station 71+80 in the form of sulfide minerals occurring along the quartzite bedding planes. Slight amounts of mineralization along bedding planes in quartzite were encountered from Station 74+40 to Station 74+50. At Station 84+17 a 2-foot-wide zone of lead and zinc sulfides was encountered.

5.18 Downtown Lateral Station 84+70

The Downtown Lateral was all in quartzite. It was driven without the need for roof supports. A direct connection to a shaft was not made with this lateral, but later ASARCO made a connection with a raise from the Ponsardine Mine.

5.19 Hayden Lateral Station 89+22

The Hayden lateral was driven 191 feet to encounter the Hayden shaft at the 5th level of the Hayden mine workings. This portion of the LMDT is in white limestone.

5.20 Pando Porphyry Station 97+00 to 112+34

When last inspected the Pando Porphyry section of the tunnel (Station 99+83 to 112+34) was still open, but showing signs of lateral pressure. The supports and lagging have been replaced on several occasions in this part of the tunnel due to the swelling nature of the altered porphyry. With a lack of maintenance, it is possible that there is significant failure of supports in this section of the LMDT.

5.21 Robert Emmet Lateral Station 99+70 to 99+83

The LMDT encountered heavy inflows through a limestone fissure at Station 95+65 which began draining the Robert Emmet Shaft well before the Robert Emmet Lateral was initiated.

5.22 Mikado Fault to End Station 112+34 to 112+99

At the Mikado Fault, the LMDT passes from white porphyry into Precambrian granite. Little support was required in this segment of the LMDT. A short drift was excavated to connect with the base of the New Mikado Shaft which was found to be caved at the LMDT elevation. At the end of the LMDT at Station 112+99, two 40-foot long drill holes were drilled into the face beyond the end of the LMDT. Away from the Mikado Fault, it is likely that the portions of the LMDT in granite are still open.

6.0 LMDT YARD AREA DOWNSTREAM OF THE PORAL

6.1 Yard Area

Numerous treatment plant infrastructure components are located in and around the service yard area outside of the portal of the LMDT. The arrangement of the gravel-surfaced yard is shown on drawing 1335-D-18 Site Plan. Besides the water treatment plant and detention pond, there are the clearwell, electrical transformer, generator for emergency power, storage sheds, monitor wells, and chain link fencing. Access is through a 20-foot wide gate.

6.2 Detention Pond

A geomembrane-lined pond lies on the west side of the service yard and occupies approximately 0.5 acre. It can receive water from the LMDT sump or from the clearwell downstream of the water treatment plant. The detention pond is used to capture water flowing from the LMDT bulkhead during temporary plant shutdowns, and to retain water discharges from the plant which fail to meet NPDES water quality requirements for discharge to the river. It is 6-feet deep and is designed to hold 4 feet of water. Above 4 feet, pond overflow is directed to an overflow intake which has a pipe leading to the river. It has an impermeable 30-mil liner to prevent metals-laden water from percolating through the soil into the groundwater. The pond is surrounded on three sides by monitoring wells. The pond has a maximum volume of 601,100 gallons (Reclamation, 1991). If the pond were to fill, the water would overflow into the Arkansas River untreated. Since its construction, the pond has not spilled to the river.

6.3 Water Treatment Plant

The water treatment plant was constructed in 1990 to 1992. It is located downstream and to the right of the LMDT alignment (looking downstream). The plant is operated to remove CO_2, acidify the water with sulfuric acid to pH 5, neutralize the water using diluted sodium hydroxide, add polymer to settle the floc into sludge, filter and release the treated water. It has remained in continuous operation since 1992.

There are two parallel treatment trains of 1,100 gpm capacity each. The plant has difficulties in May of each year when zinc and other metals loading in the water spikes and must be run at a slower throughput rate. The main problems are the large amounts of sludge generated and the tendency to clog the sand filters. The plant monitors turbidity, pH, temperature, and conductivity of the water. The water inflow rate is measured at the well at Station 10+25, and at the intake sump at the plant. By subtracting the two numbers the inflow from the LMDT bulkhead drainage is computed. On March 25, 2008, the inflows were 750 gpm from the well and 250 gpm from the bulkhead.

6.4 Sludge Facility

After the initial operation of the plant, sludge storage became problematic during winter due to sludge freezing and sticking to containers. To remedy the problem, a sludge storage building was constructed immediately to the east of the water treatment plant.

6.5 Clearwell and Easement to East Fork - Arkansas River

Clean water discharged from the treatment plant is discharged to a below–grade sump located adjacent to the north side of the water treatment plant. The sump is called the “clearwell” and it has a building shell erected over it. Two 14-inch-diameter fiberglass-reinforced pipes convey water from the clear well. One pipe runs to the detention pond to allow capture and storage of water from the plant that does not meet discharge water quality standards. The other pipe runs through an easement to an outfall along the side of the East Fork of the Arkansas River. The location of the clearwell and buried pipes are shown of drawing 1335-D-60.

Figure 27. Aerial Photograph Showing the LMDT Portal Area Including the Water Treatment Plant, Adjacent Housing, and East Fork of the Arkansas River.

6.6 The Village at East Fork

The Village at East Fork is a 72 Space Community located off of Highway 91 in Leadville, Colorado. The community consists of modular homes approximately 10 years old.

Figure 28. The Village at East Fork. The East Fork of the Arkansas River is to the right of the photograph.

7.0 AUXILARY LMDT FACILITIES

7.1 Extraction Wells at Station 10+25

When sinkholes developed above the tunnel and adjacent to State Highway 91 in the 1970s, Reclamation responded by installing a dewatering well in 1977. The well was replaced by two new wells in 1991 (a primary and backup well), the wells are located at approximate tunnel Station 10+25. The wells and pumps at Station 10+25 provide the primary source of water input to the treatment plant. Stainless steel turbine pumps run by a motors sitting on top of the wells are used to extract water from the LMDT. The pumps have 1500 gpm capacity, but are limited by inflows to the LMDT at this time to around 750 gpm. A control house is located inside a fenced yard area which contains the well heads (see Figure 29. Only one of the wells and pumps is operated at a time. The other is a backup system. The control house contains the programmable motor controls for the pump motors and electronics for relaying data signals from the well and pump sensors to the water treatment plant.

Figure 29. View of Pumphouse and Extraction Wells in the vicinity of Station 10+25. May 28, 2008.

7.2 Observation Well at Station 10+25

An observation well with a piezometer having dual influence zones, one at the base of surficial materials and the other in the upper portion of bedrock, was installed in 2002 to monitor drawdown adjacent to extraction wells at Station 10+25, 25 feet left of LMDT centerline. The observation well at Station 10+25 is located just outside of the fenced area which contains the extraction wells and pumphouse.

7.3 Additional Observation Wells

Additional observation wells have been installed into and near the LMDT for monitoring groundwater levels. Following are additional observation wells at close proximity to the LMDT:

Table 7. Observation Wells in and near the LMDT.

Station	Offset	Surface Elevation	Penetrates Tunnel
3+00	20' Left	Approx. 10,034	No
4+70	20' Right	Approx. 10,046	No
6+35	None	Approx. 10,063	Yes
25+15	None	10,099.50	Yes
36+77	None	10,272.50	Yes
46+66	None	10,320.49	Yes
46+96	None	Approx. 10,321.	Yes
75+05	None	10,452.88	Yes
96+44	None	10,513.64	Yes

8.0 REFERENCES

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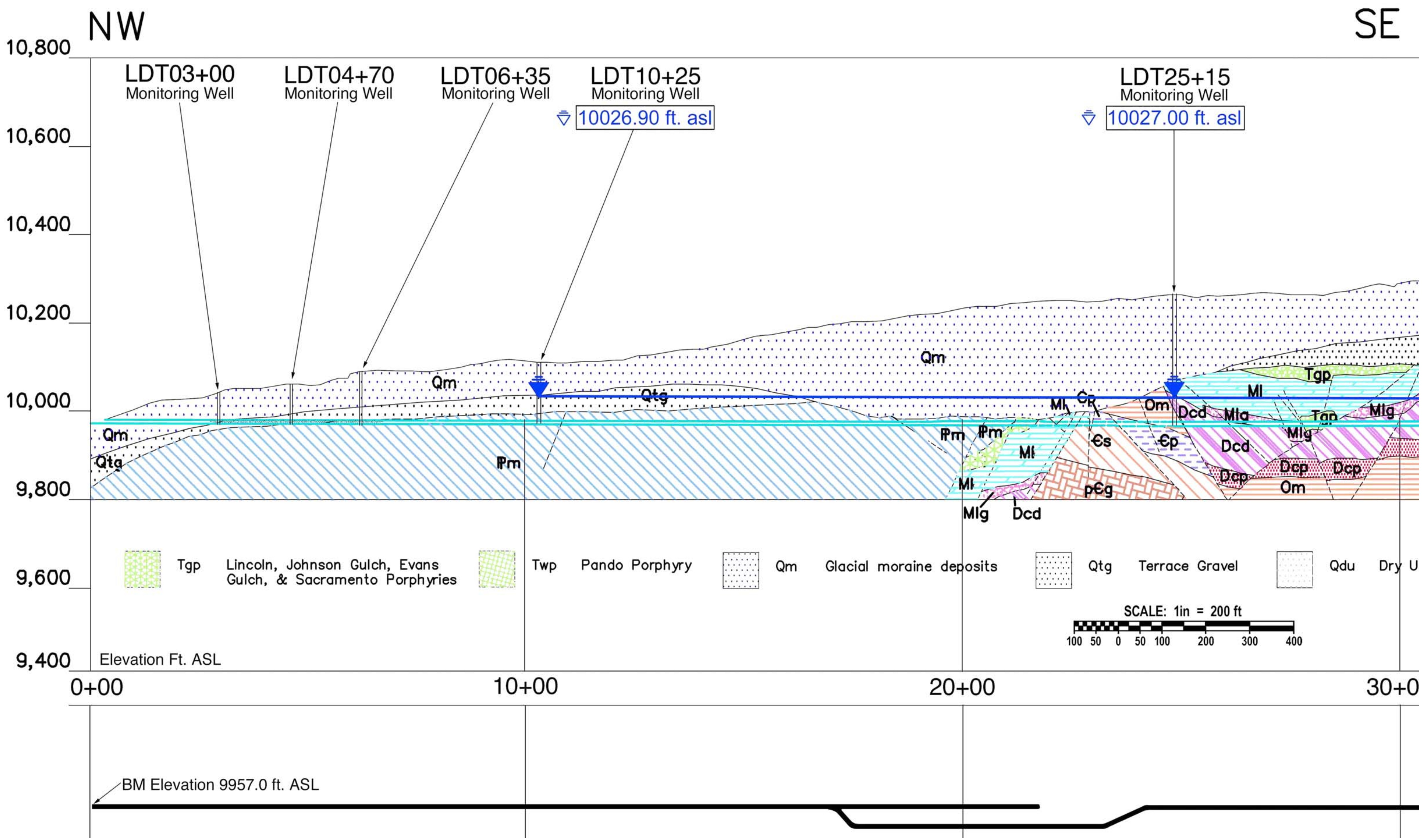
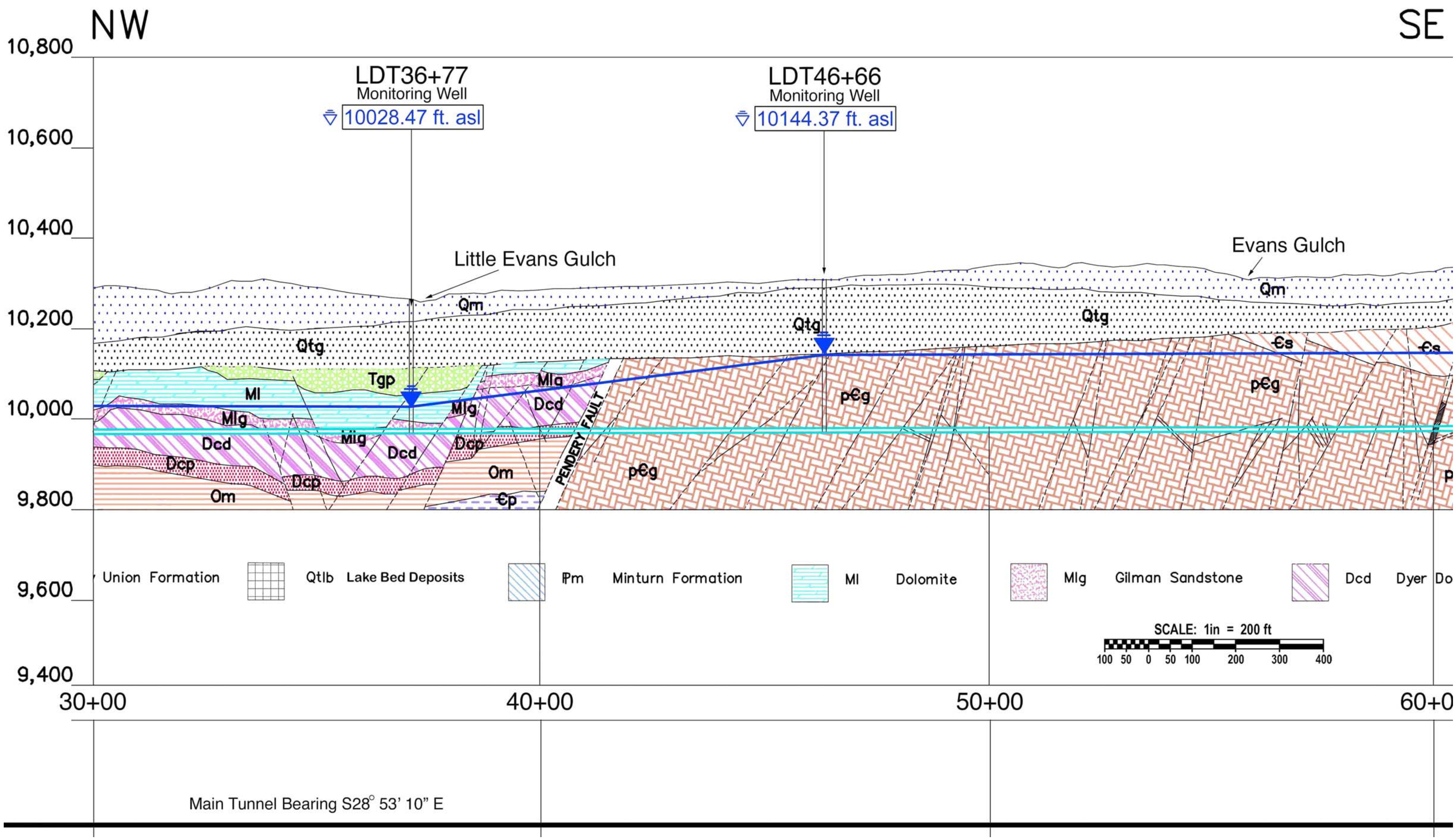
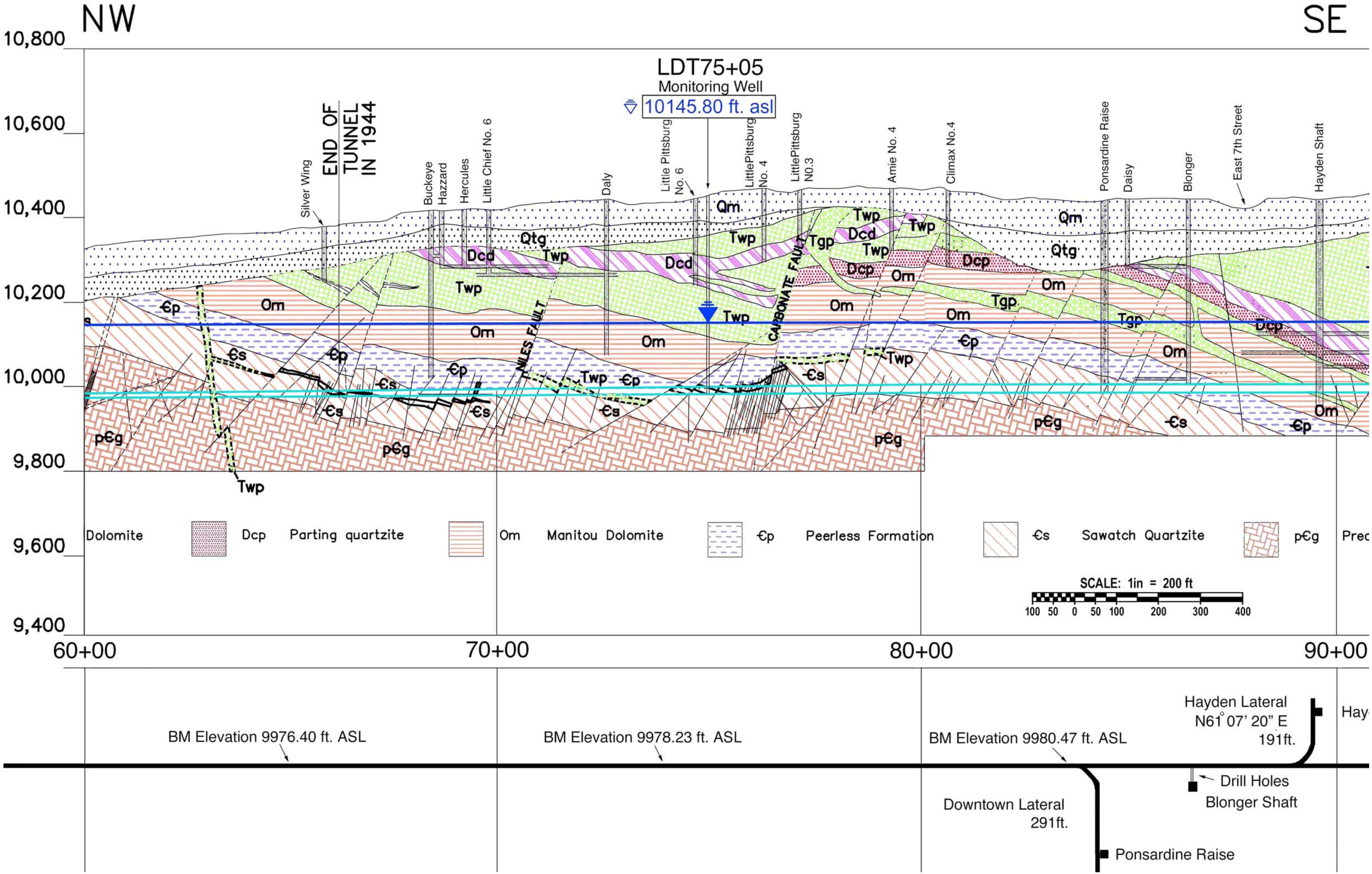
Appendix A

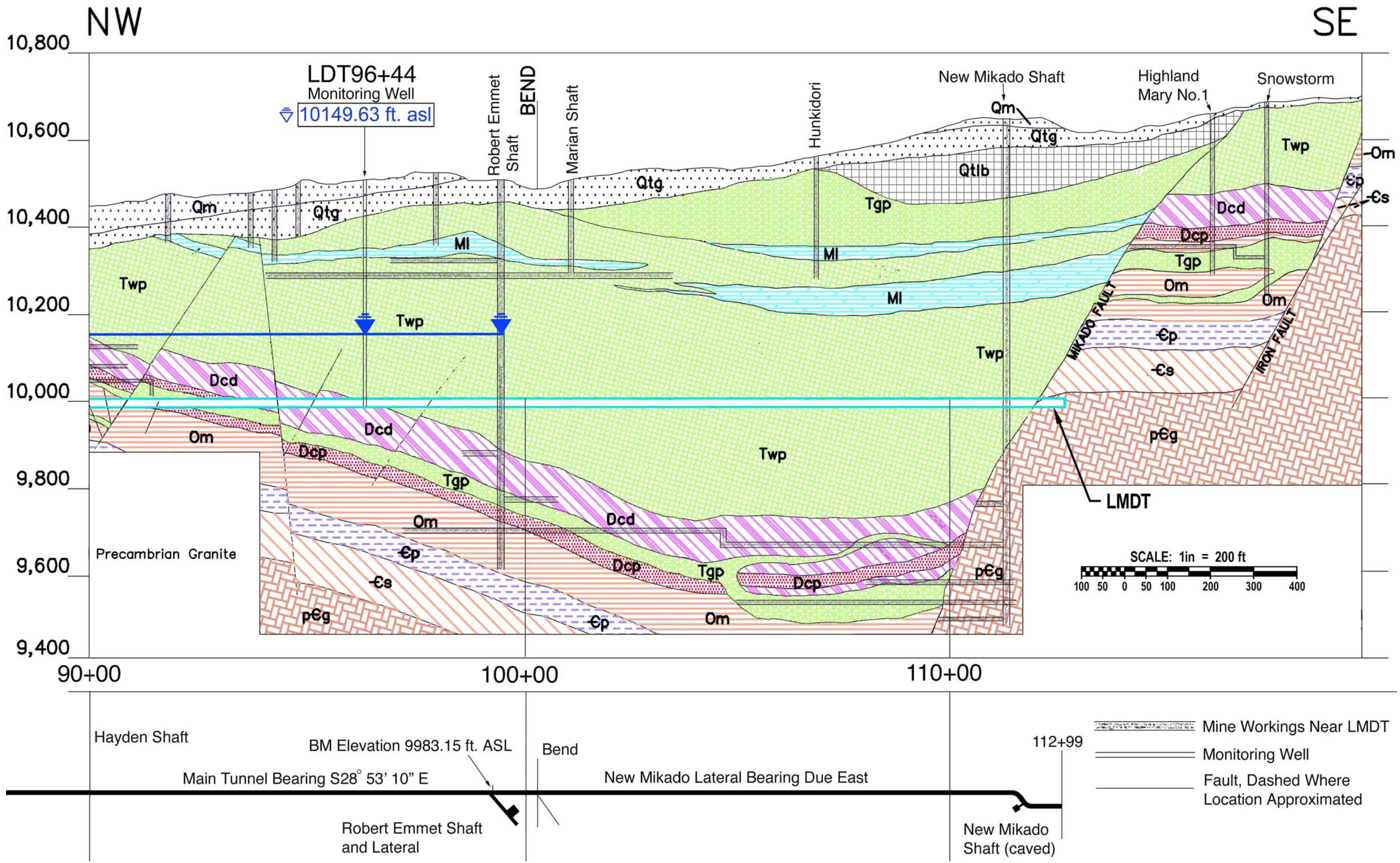
Geologic Cross-Section along the Leadville Mine Drainage Tunnel


NW
SE
10,800
10,600
10,400
10,200
10,000
9,800
9,600
9,400
LDT03+00
Monitoring Well
LDT04+70
Monitoring Well
LDT06+35
Monitoring Well
LDT10+25
Monitoring Well
10026.90 ft. asl
LDT25+15
Monitoring Well
10027.00 ft. asl
Qm
Qtg
IPm
Ml
Mlg
Mla
Dcd
Dcp
Om
Ꞓp
Ꞓs
pꞒg
Tgp
Tgp
Lincoln, Johnson Gulch, Evans Gulch, & Sacramento Porphyries
Twp
Pando Porphyry
Qm
Glacial moraine deposits
Qtg
Terrace Gravel
Qdu
Dry U
SCALE: 1in = 200 ft
100 50 0 50 100 200 300 400
Elevation Ft. ASL
0+00
10+00
20+00
30+0
BM Elevation 9957.0 ft. ASL


NW
SE
10,800
10,600
10,400
10,200
10,000
9,800
9,600
9,400
LDT36+77
Monitoring Well
10028.47 ft. asl
LDT46+66
Monitoring Well
10144.37 ft. asl
Little Evans Gulch
Evans Gulch
Qm
Qtg
Tgp
Ml
Mlg
Dcd
Dcp
Om
€p
€s
p€g
PENDERY FAULT
Union Formation
Qtlb Lake Bed Deposits
Pm Minturn Formation
Ml Dolomite
Mlg Gilman Sandstone
Dcd Dyer Do
SCALE: 1in = 200 ft
100 50 0 50 100 200 300 400
30+00
40+00
50+00
60+0
Main Tunnel Bearing S28° 53' 10" E

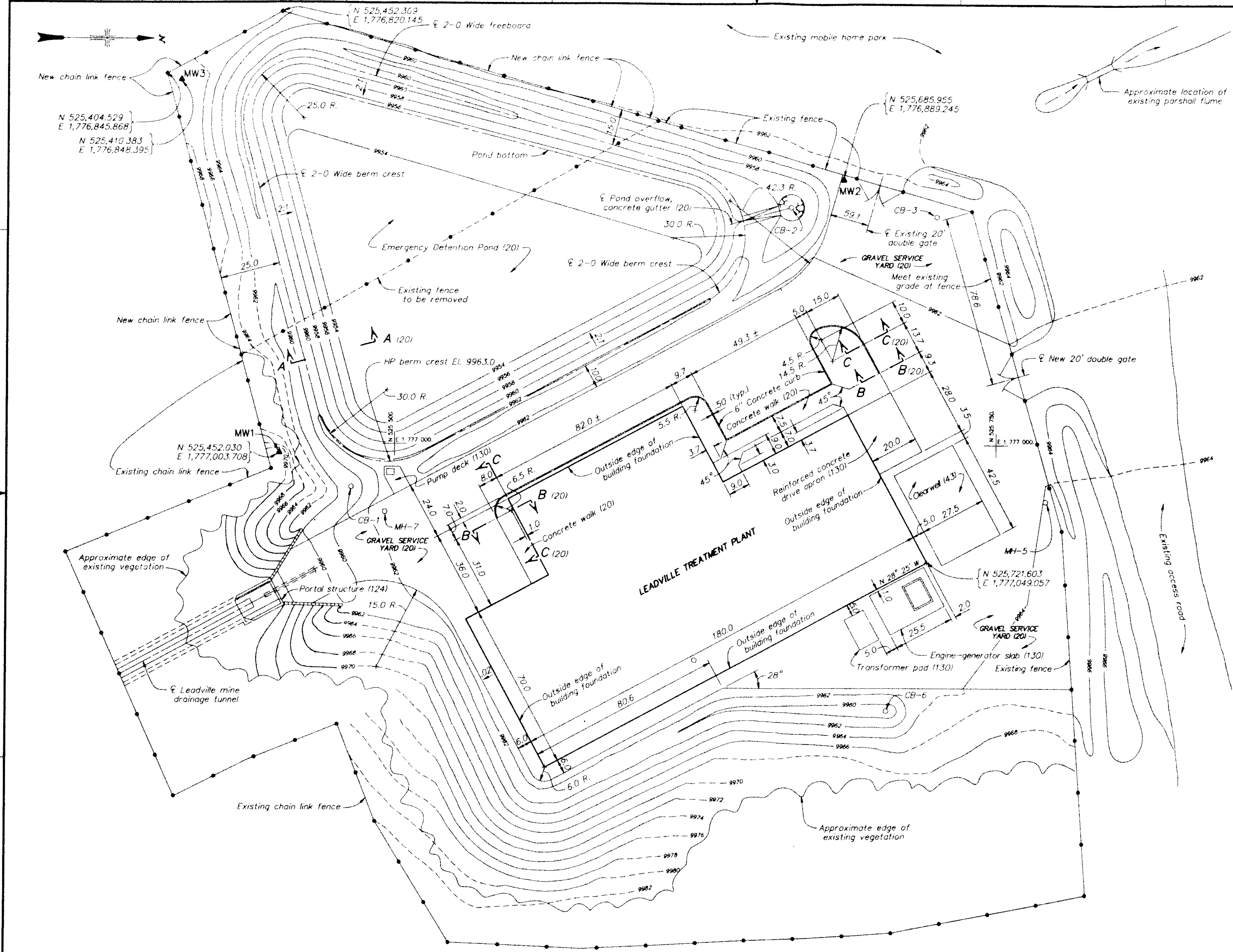


NW
SE
LDT75+05
Monitoring Well
10145.80 ft. asl
END OF TUNNEL IN 1944
Silver Wing
Buckeye
Hazzard
Hercules
Little Chief No. 6
Daly
Little Pittsburg No. 6
LittlePittsburg No. 4
LittlePittsburg NO.3
Amie No. 4
Climax No.4
Ponsardine Raise
Daisy
Blonger
East 7th Street
Hayden Shaft
NILES FAULT
CARBONATE FAULT
Qm
Qtg
Twp
Dcd
Dcp
Tgp
Om
€p
€s
p€g
10,800
10,600
10,400
10,200
10,000
9,800
9,600
9,400
Dolomite
Dcp Parting quartzite
Om Manitou Dolomite
€p Peerless Formation
€s Sawatch Quartzite
p€g Prec
SCALE: 1in = 200 ft
100 50 0 50 100 200 300 400
60+00
70+00
80+00
90+00
BM Elevation 9976.40 ft. ASL
BM Elevation 9978.23 ft. ASL
BM Elevation 9980.47 ft. ASL
Hayden Lateral
N61° 07' 20" E
191ft.
Hay
Drill Holes
Blonger Shaft
Downtown Lateral
291ft.
Ponsardine Raise


NW
SE
10,800
10,600
10,400
10,200
10,000
9,800
9,600
9,400
LDT96+44
Monitoring Well
10149.63 ft. asl
Robert Emmet Shaft
BEND
Marian Shaft
Hunkidori
New Mikado Shaft
Highland Mary No.1
Snowstorm
Qm
Qtg
Qtlb
Tgp
Ml
Twp
Dcd
Dcp
Om
Єp
Єs
pЄg
MIKADO FAULT
IRON FAULT
LMDT
Precambrian Granite
SCALE: 1in = 200 ft
100 50 0 50 100 200 300 400
90+00
100+00
110+00
Hayden Shaft
BM Elevation 9983.15 ft. ASL
Bend
112+99
Main Tunnel Bearing S28° 53' 10" E
New Mikado Lateral Bearing Due East
Robert Emmet Shaft and Lateral
New Mikado Shaft (caved)
Mine Workings Near LMDT
Monitoring Well
Fault, Dashed Where Location Approximated

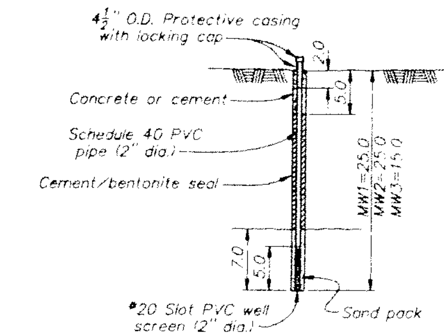
Appendix B

Selected Drawings from Specification 0-SI-60-04100/DC-7804 - Treatment Plant and Tunnel Lining, Leadville Mine Drainage Tunnel Project



PLAN

SCALE OF FEET



MONITORING WELL TYPICAL SECTION

(NO SCALE)

NOTES

CB–Catch basin, see (20).
MH–Manhole, see (20).
▲ –Monitoring well

REFERENCE DRAWINGS

GRADING AND DRAINAGE PLAN — 1335-D-19
GENERAL PIPING-PLAN AND ELEVATIONS — 1335-D-60
SITE WORK SECTIONS AND DETAILS — 1335-D-20
LANDSCAPING — 1335-D-21

ALWAYS THINK SAFETY

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

LEADVILLE MINE DRAINAGE TUNNEL PROJECT–COLORADO

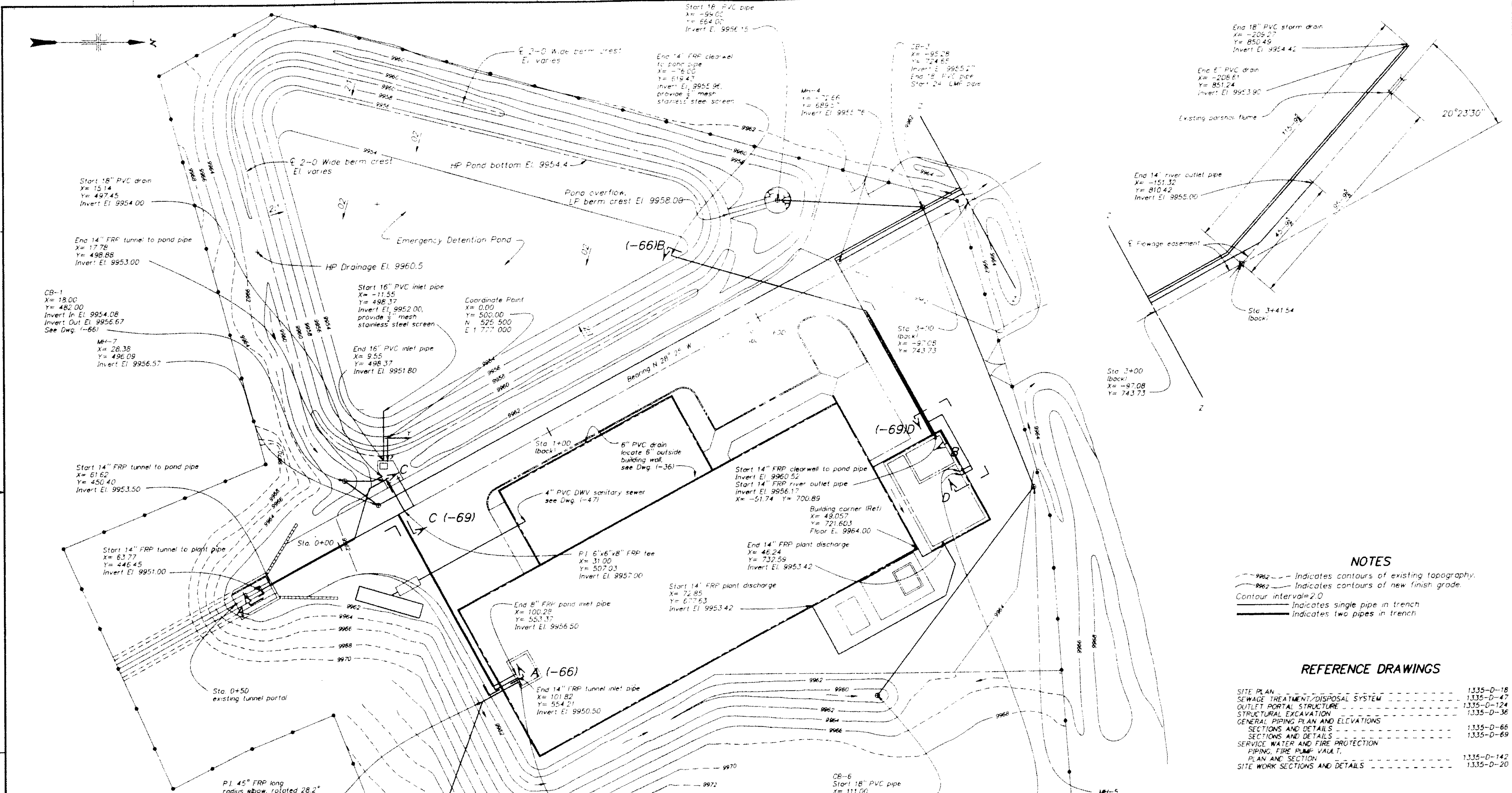
TREATMENT PLANT

SITE PLAN

DESIGNED JOHN F. PATTIE — TECHNICAL APPROVAL [signature]
DRAWN KEN E. SCHWAIRY — SUBMITTED [signature]
CHECKED C. LEW HOPKINS — APPROVED [signature]
CHIEF, CIVIL ENGINEERING DIVISION

DENVER, COLORADO — JUNE 30, 1989 — 1335-D-18

D (22 X 34)



NOTES

9962 Indicates contours of existing topography.
9962 Indicates contours of new finish grade.
Contour interval=2.0
Indicates single pipe in trench
Indicates two pipes in trench

REFERENCE DRAWINGS

SITE PLAN	1335-D-18
SEWAGE TREATMENT/DISPOSAL SYSTEM	1335-D-47
OUTLET PORTAL STRUCTURE	1335-D-124
STRUCTURAL EXCAVATION	1335-D-36
GENERAL PIPING PLAN AND ELEVATIONS	
SECTIONS AND DETAILS	1335-D-66
SECTIONS AND DETAILS	1335-D-69
SERVICE WATER AND FIRE PROTECTION PIPING, FIRE PUMP VAULT,	
PLAN AND SECTION	1335-D-142
SITE WORK SECTIONS AND DETAILS	1335-D-20

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UNITED STATES DEPARTMENT OF THE INTERIOR BUREAU OF RECLAMATION

LEADVILLE MINE DRAINAGE TUNNEL PROJECT-COLORADO

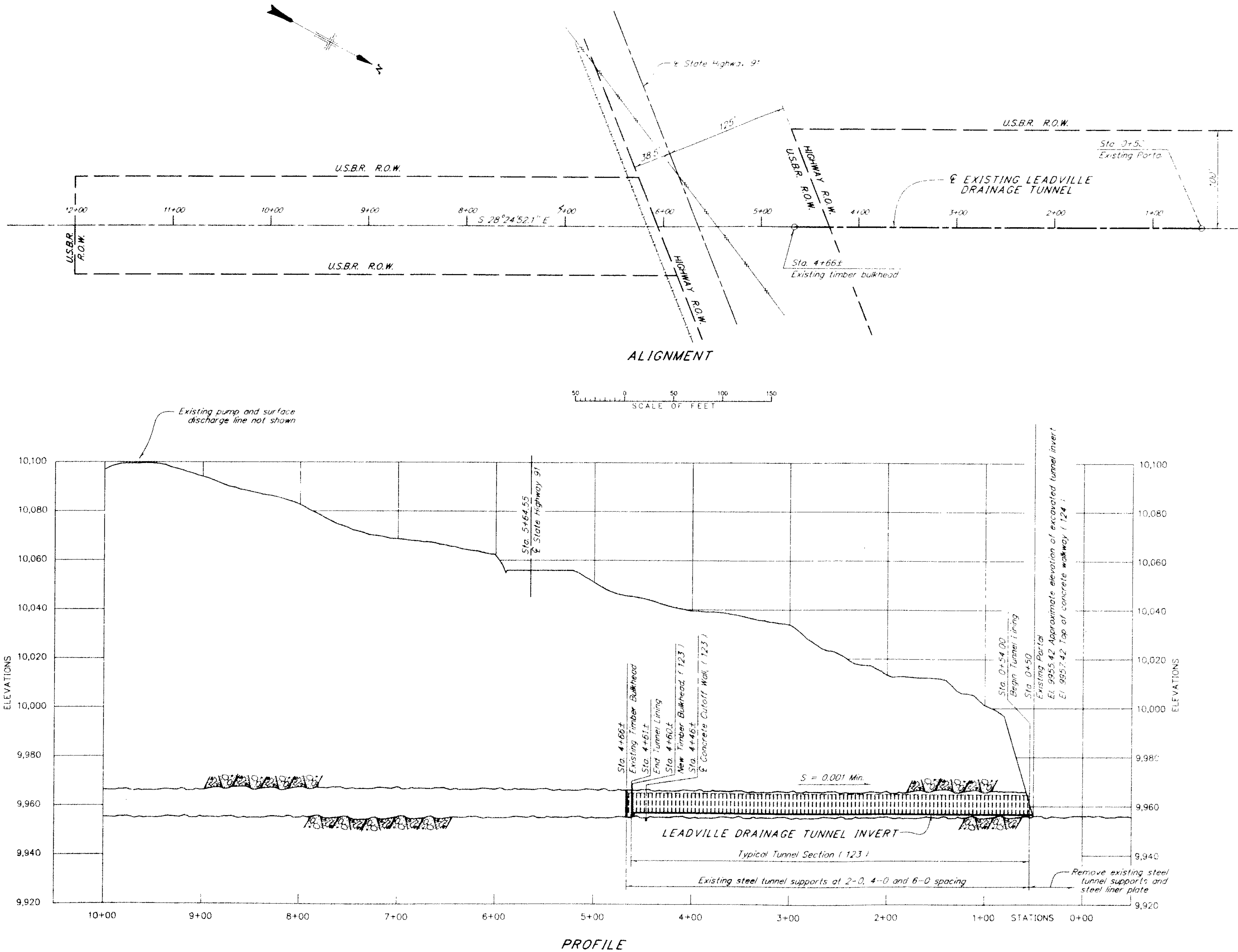
TREATMENT PLANT

GENERAL PIPING PLAN AND ELEVATIONS

DESIGNED [signature] TECHNICAL APPROVAL W. SATTLER
DRAWN MIKE KINNAN SUBMITTED [signature]
CHECKED [signature] APPROVED [signature] CHIEF, MECHANICAL BRANCH

DENVER, COLORADO JULY 17, 1989 1335-D-60

D (22 X 34)



NOTES

For Typical Tunnel Section, see (123).
This drawing compiled from project drawings 382-706-4028 and 382-700-290
Sta. 0+50 Leadville Drainage Tunnel (this specification) = Sta. 0+38.06 of original Leadville Tunnel (circa 1943).

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LEADVILLE MINE DRAINAGE TUNNEL PROJECT - COLORADO

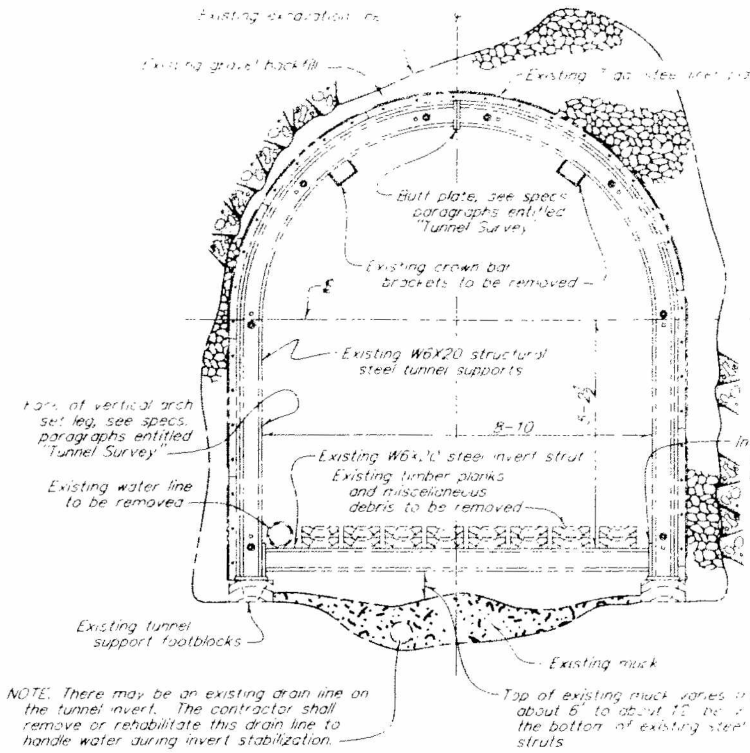
TUNNEL LINING

ALIGNMENT AND PROFILE

DESIGNED Bob Scully — TECHNICAL APPROVAL John Steighner
DRAWN Bob Scully — SUBMITTED K.D. Thomas
CHECKED [illegible] — APPROVED W. L. Sacg
CHIEF, WATER CONVEYANCE BRANCH

DENVER, COLORADO — FEBRUARY 8, 1989 — 1335-D-122

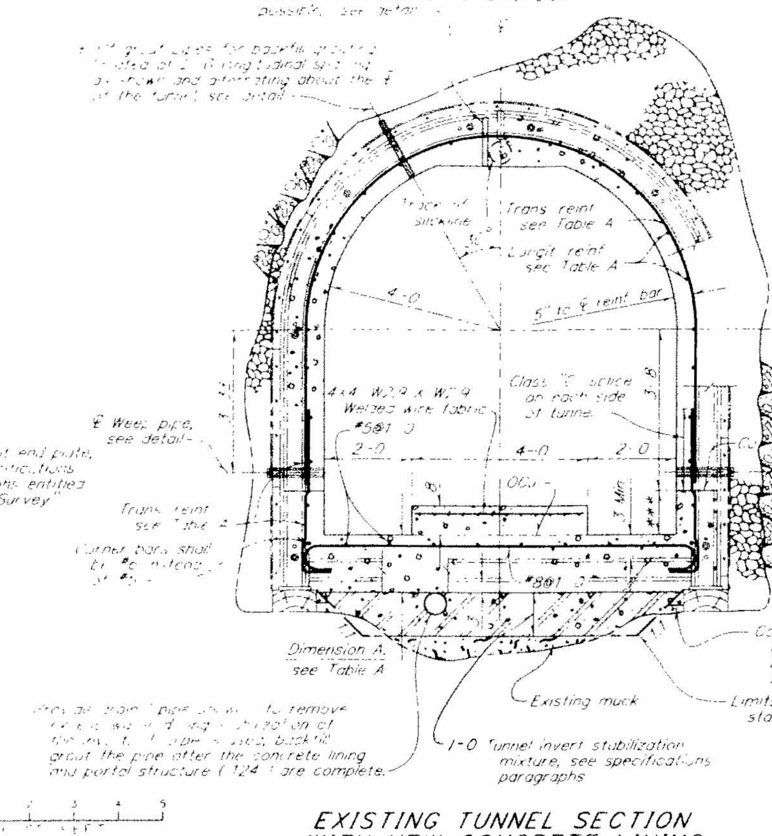
D (22 X 34)



NOTE: There may be an existing drain line on the tunnel invert. The contractor shall remove or rehabilitate this drain line to handle water during invert stabilization.

Top of existing muck varies from about 6" to about 12" below the bottom of existing steel struts

EXISTING TUNNEL SECTION

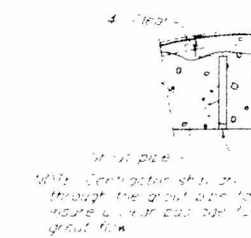


*** This dimension may vary depending on the final slope of finished invert (.001 min.). The contractor shall maintain a minimum of 3" cover over existing steel struts.

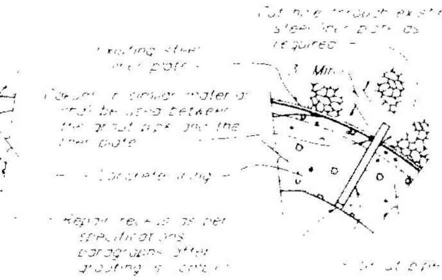
EXISTING TUNNEL SECTION WITH NEW CONCRETE LINING

TABLE A

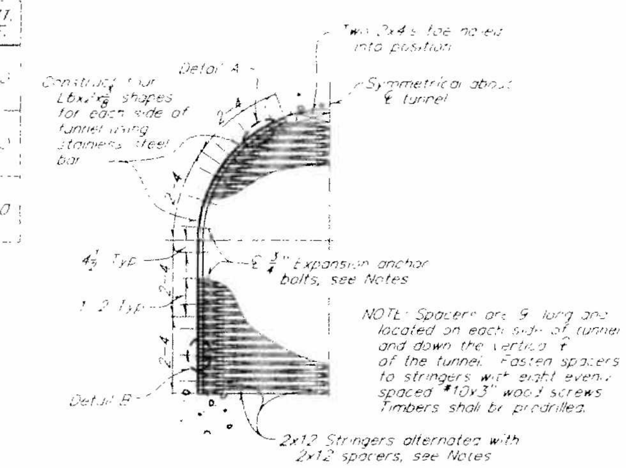
STATIONS	DIMENSION A	TRANS. REINF.	LONGIT. REINF.
STA. 0+54 to STA. 0+94	1-4 Min	#7@1-0	#7@1-0
STA. 0+94 to STA. 4+26	1-0 Min	#5@1-0	#5@1-0
STA. 4+25 to End of concrete lining (4+61±)	1-0 Min.	#5@1-0	#8@1-0



GROUT PIPE DETAIL FOR LINER GROUTING

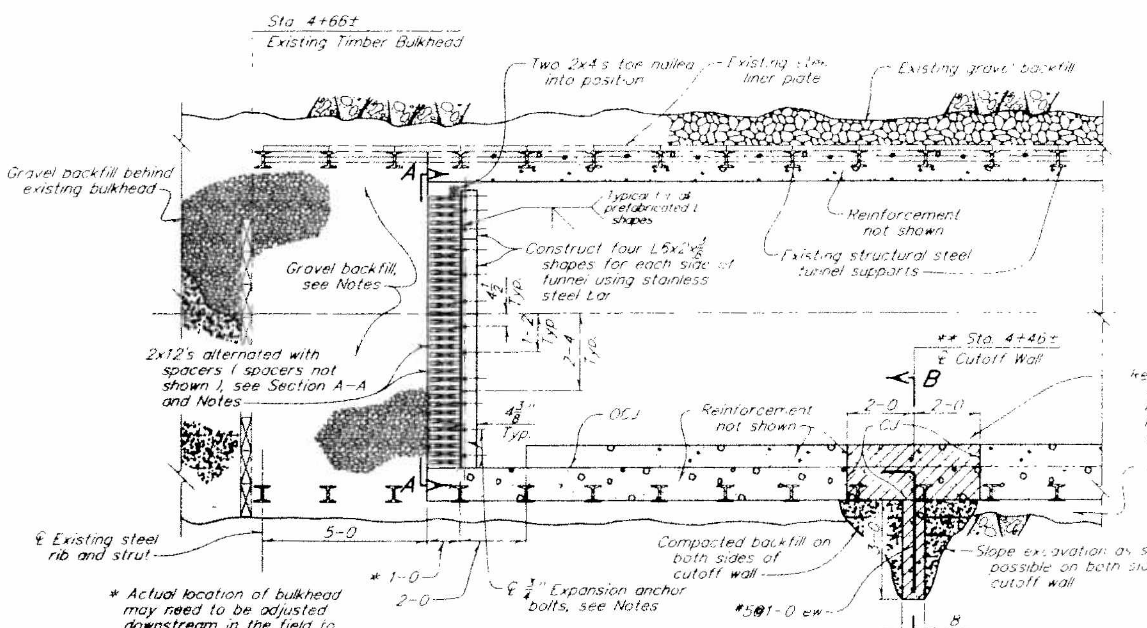


GROUT PIPE DETAIL FOR BACKFILL GROUTING



NOTE: Spacers are 9" long and located on each side of tunnel and down the vertical ℄ of the tunnel. Fasten spacers to stringers with eight evenly spaced #10x3" wood screws. Timbers shall be predrilled.

SECTION A-A



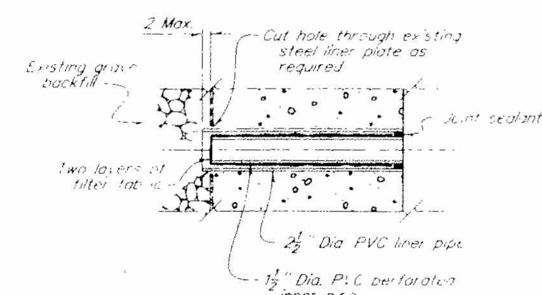
* Actual location of bulkhead may need to be adjusted downstream in the field to facilitate drilling holes for expansion anchor bolts where existing ribs and or concrete reinforcement may be in the way.

NOTE: Existing steel ribs and struts may be from 2-0 to 6-0 spacing, 2-0 spacing shown.

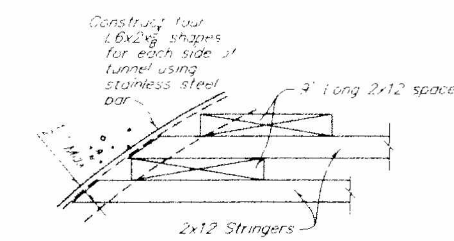
PROFILE OF EXISTING TUNNEL WITH NEW CONCRETE LINING NEAR EXISTING BULKHEAD

** Actual location of cutoff wall may need to be adjusted in the field if existing steel strut is in the way. The contractor may remove one existing steel strut if struts are on 2-0 spacing.

NOTE: The contractor shall not substitute backfill concrete for compacted backfill around cutoff wall.



WEEP PIPE DETAIL

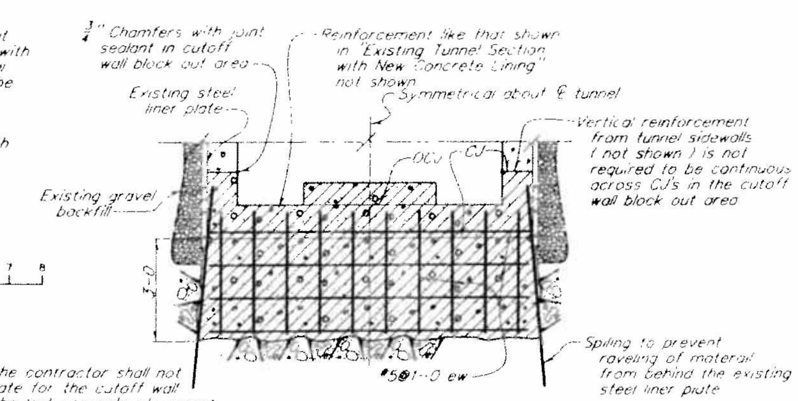


DETAIL A

DETAIL B SIMILAR

Reinforcement in cutoff wall blockout same as "Existing Tunnel Section with New Concrete Lining". Longitudinal reinforcement is not required to be continuous across CJ.

For details of invert stabilization, see "Existing Tunnel Section with New Concrete Lining" and specifications paragraphs



NOTE: The contractor shall not excavate for the cutoff wall until the last concrete placement of the tunnel lining within 25-0 of either side of cutoff wall has attained a compressive strength (f'c) of 4,000.

SECTION B-B

NOTES

For details of water handling during construction, see (160).
For alignment and profile, see (122).
For ventilation details, see (156).
For lighting details, see (158).
For general concrete outline notes, see 40-D-6517.
Chamfers are required on all exposed concrete edges, see 40-D-6517.
For general notes and minimum requirements for detailing reinforcement, Class 60, see 40-D-6263.
Tunnel lining design is based on a specified compressive concrete strength (f'c) of 4,000 lbs. per square inch at 28 days, and reinforcement with a specified minimum yield strength (fy) of 60,000 lbs. per square inch.
Splices for all longitudinal reinforcement bars shall be staggered.
Backfill grouting pressure shall be 25 pounds per square inch. Liner grouting pressure shall be 20 pounds per square inch. Grouting shall not begin until the floor blockout and the cutoff wall have been placed. Grouting shall be in accordance with the specifications paragraphs.
2x12 Timber stringers and spacers used in timber bulkhead shall be Douglas Fir-Larch, stud grade.
¾" Expansion anchor bolts shall be stainless steel and embedded 9" min. into concrete.
Holes drilled in L6x2x3/8's shall be 7/8" dia. Holes may be slotted in vertical direction to aid in installation.
Gravel backfill shall be 1½" to 2½" nominal size. Gradation shall meet ASTM C 33, size No. 2.

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LEADVILLE MINE DRAINAGE TUNNEL PROJECT - COLORADO

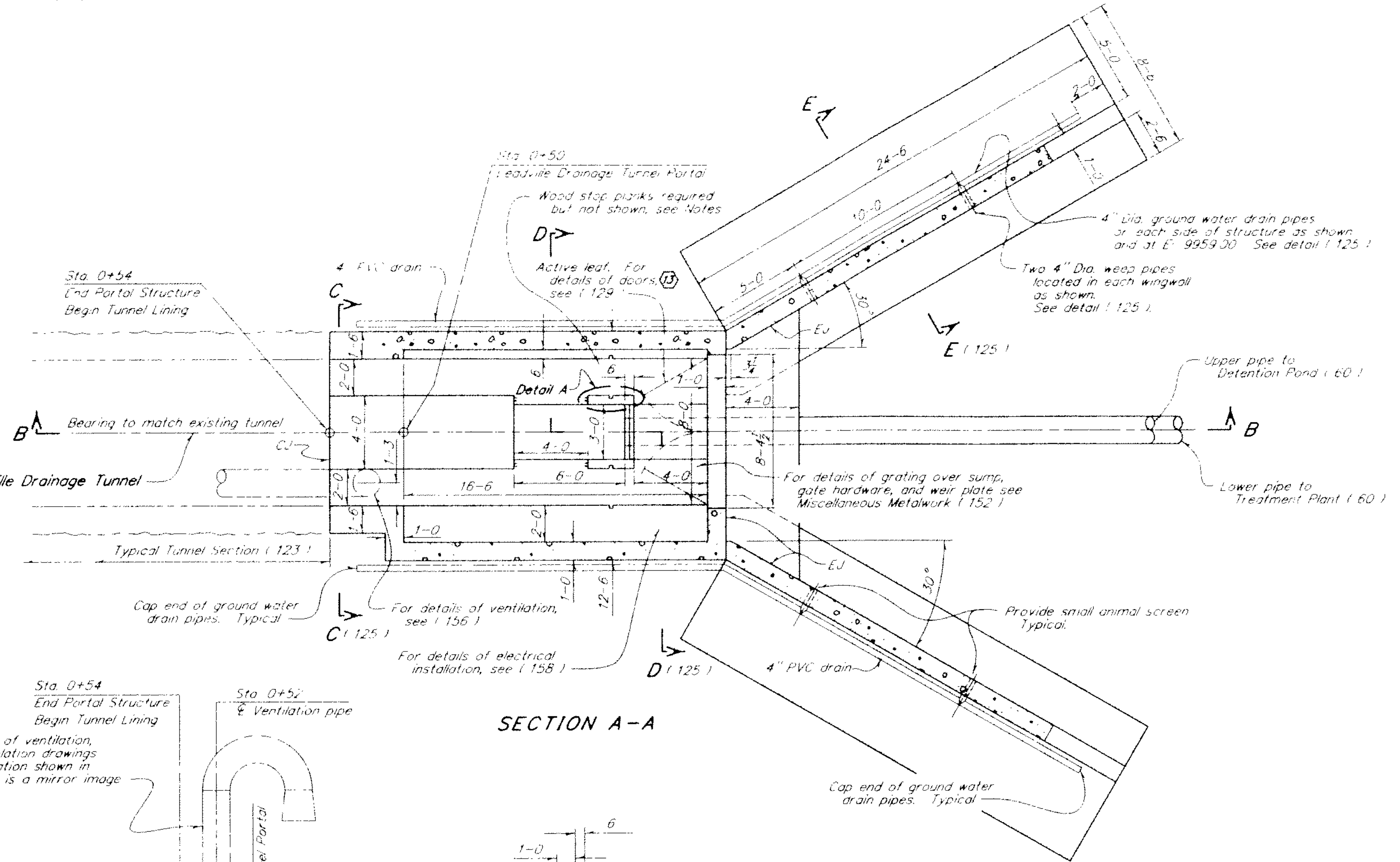
TUNNEL LINING

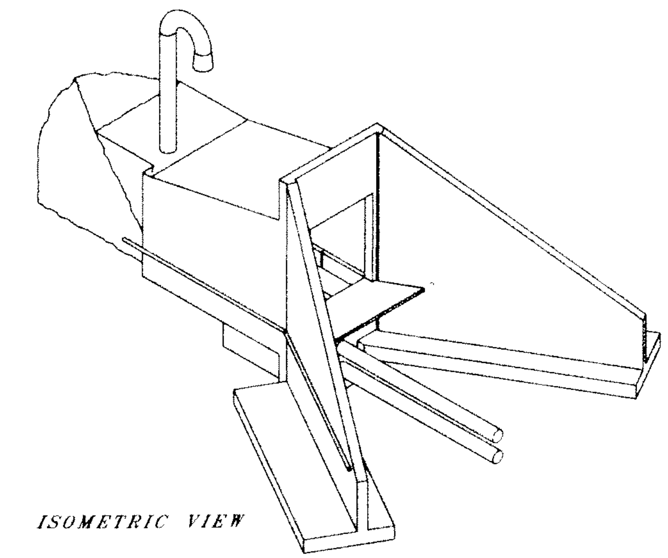
TYPICAL TUNNEL SECTION, CUTOFF WALL, AND TIMBER BULKHEAD

DESIGNED ... TECHNICAL APPROVAL ...
DRAWN ... SUBMITTED ...
CHECKED ... APPROVED ...

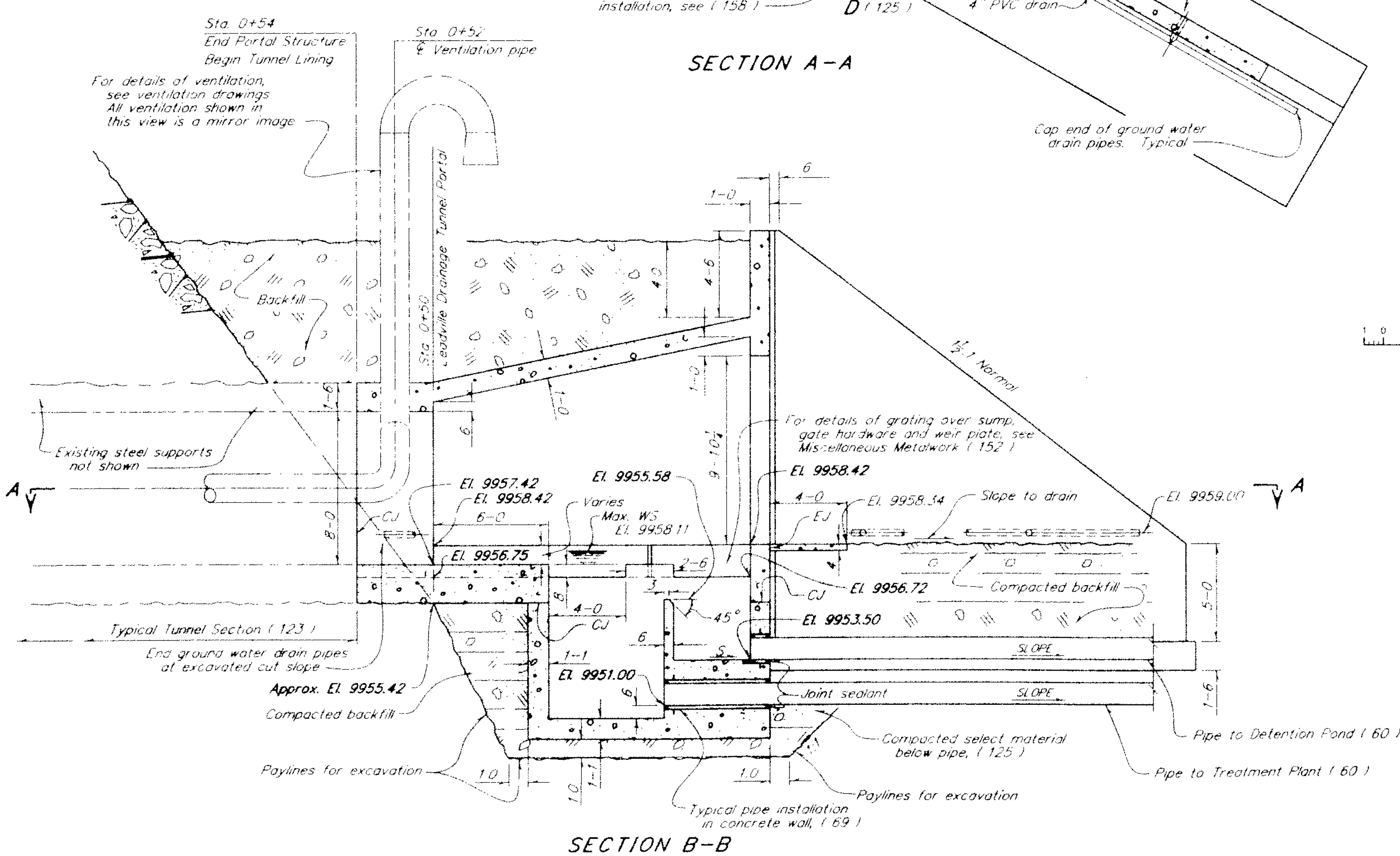
DENVER, COLORADO | FEBRUARY 16, 1989 | 1335-D-123

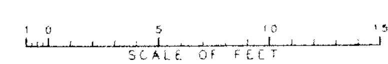
D (22 X 34)



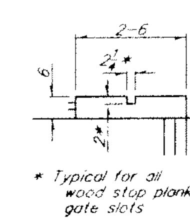


ISOMETRIC VIEW





NOTE: Vertical dimensions of sump are not to scale.



DETAIL A

LEGEND

Glacial Moraine or Terrace Gravel

(13) Designates door number. (129)

NOTES

For Outlet Portal Reinforcement, see (126)
The contractor shall field check as built conditions of wood stop plank openings and provide wood stop planks to suit.
Wood stop planks shall be in accordance with specifications paragraphs.
For general concrete outline notes, see 40-D-6517
Structural design is based on 4,000 pounds per square inch specified compressive concrete strength (f'c) at 28 days.
Foundation for concrete structures shall be prepared as described in the specifications paragraphs.
Structures shall be placed entirely on undisturbed earth, sound rock, or thoroughly compacted fill.
Backfill shall not be placed against the structure below El. 9955.42 until 7 days after last concrete placement below that elevation.
Backfill shall not be placed against the structure above El. 9955.42 until concrete has reached 28 day strength.
The contractor shall not use heavy equipment to place backfill on top of structure.

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LEADVILLE MINE DRAINAGE TUNNEL PROJECT – COLORADO

TUNNEL LINING

OUTLET PORTAL STRUCTURE

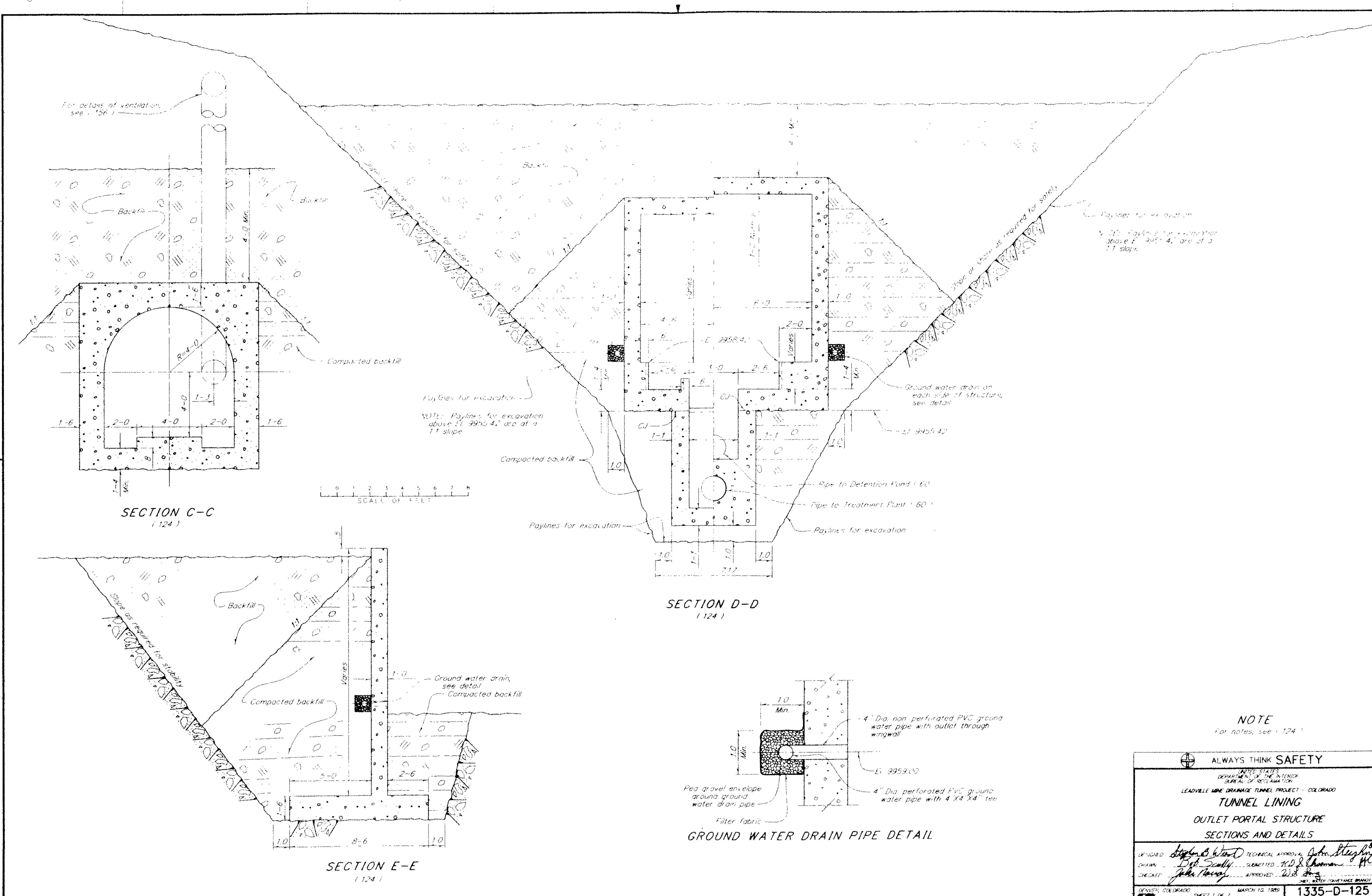
ISOMETRIC VIEW, SECTIONS, AND DETAIL

DESIGNED [signature] TECHNICAL APPROVAL [signature]
DRAWN Bob Scully SUBMITTED [signature]
CHECKED [signature] APPROVED [signature]
CHIEF, WATER CONVEYANCE BRANCH

DENVER, COLORADO MARCH 10, 1989
SHEET 1 OF 2

1335-D-124

D (22 X 34)



NOTE

For notes, see (124)

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LEADVILLE MINE DRAINAGE TUNNEL PROJECT - COLORADO

TUNNEL LINING

OUTLET PORTAL STRUCTURE

SECTIONS AND DETAILS

DESIGNED Stephen B. West TECHNICAL APPROVAL John Steghny
DRAWN Bob Scully SUBMITTED K.D. & Chroman
CHECKED John Novak APPROVED W.L. Long
CHIEF, WATER CONVEYANCE BRANCH

DENVER, COLORADO MARCH 10, 1989 SHEET 1 OF 2

1335-D-125

D (22 X 34)