

# RECLAMATION

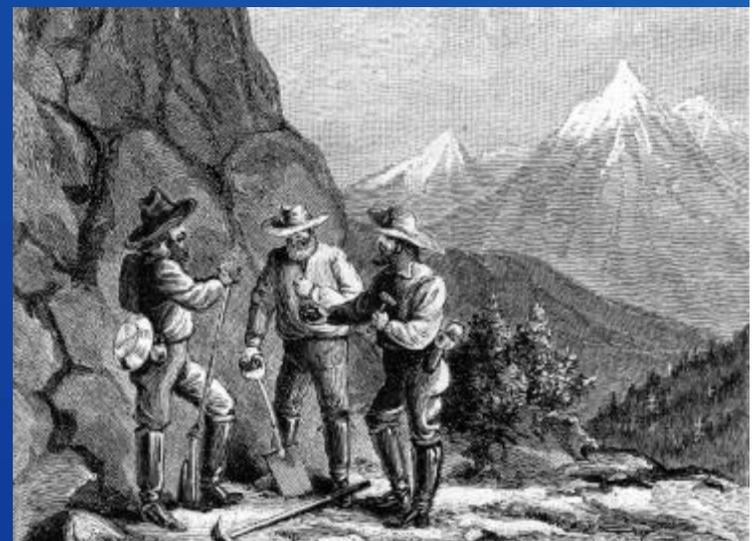
*Managing Water in the West*

## Design of a Hydraulic Plug for the Leadville Mine Drainage Tunnel

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U.S. Department of the Interior  
Bureau of Reclamation



# Presentation Overview

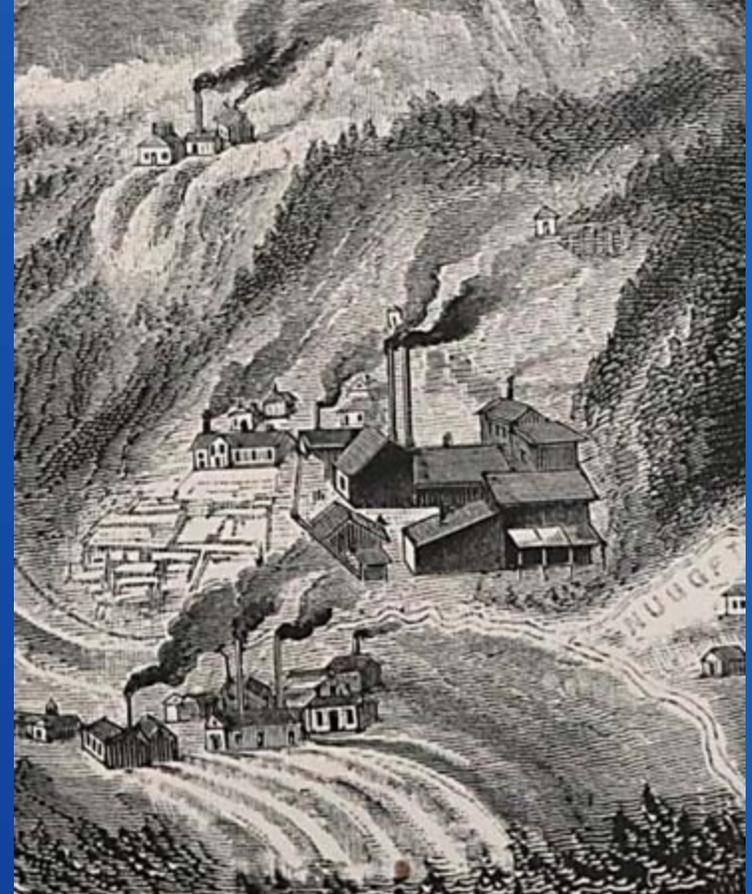
Discovery of Leadville

Smelters and Drainage Tunnels

Site Geology

Evolution of Hydraulic Plug Design

Technologies for Remote Installation



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# The Fiftyniners

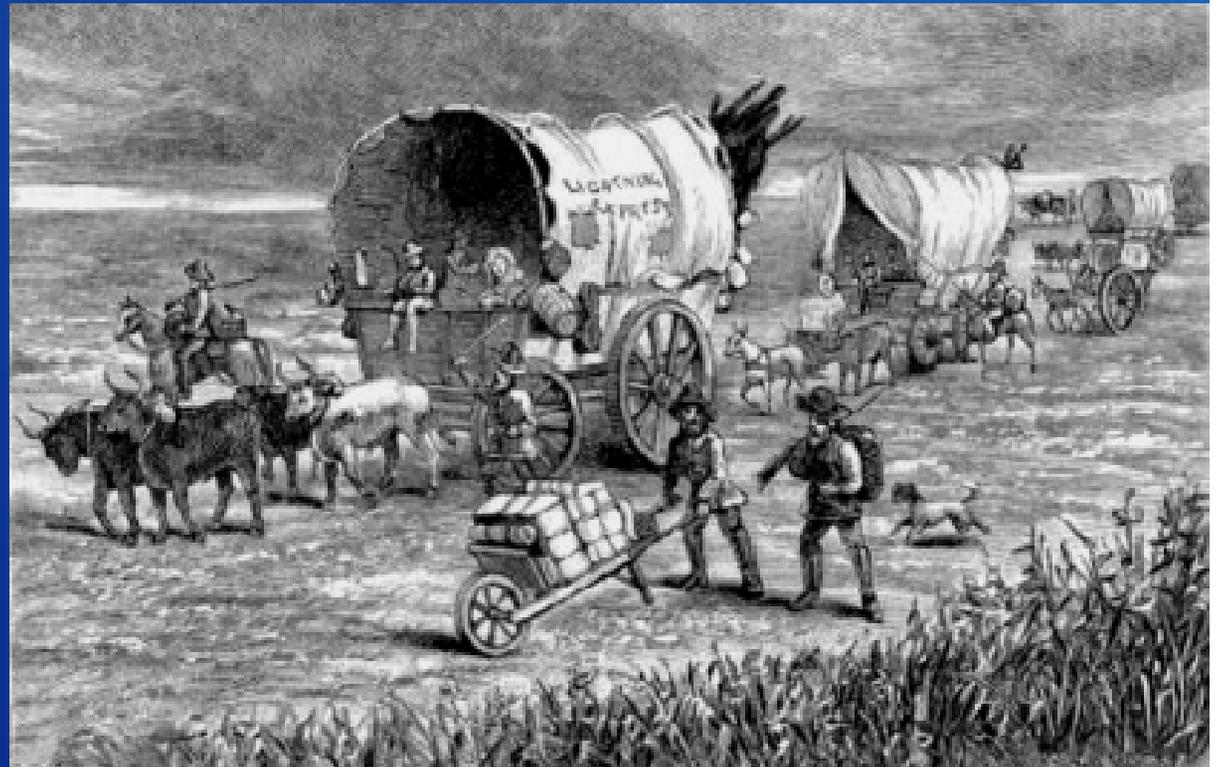
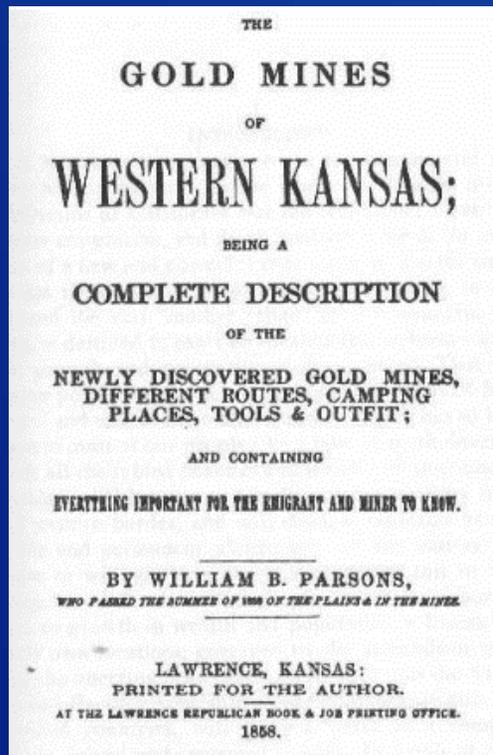
The second great gold rush.

Gold was discovered at Gregory Gulch in 1858.

In December William Parsons printed a guide book to the goldfields

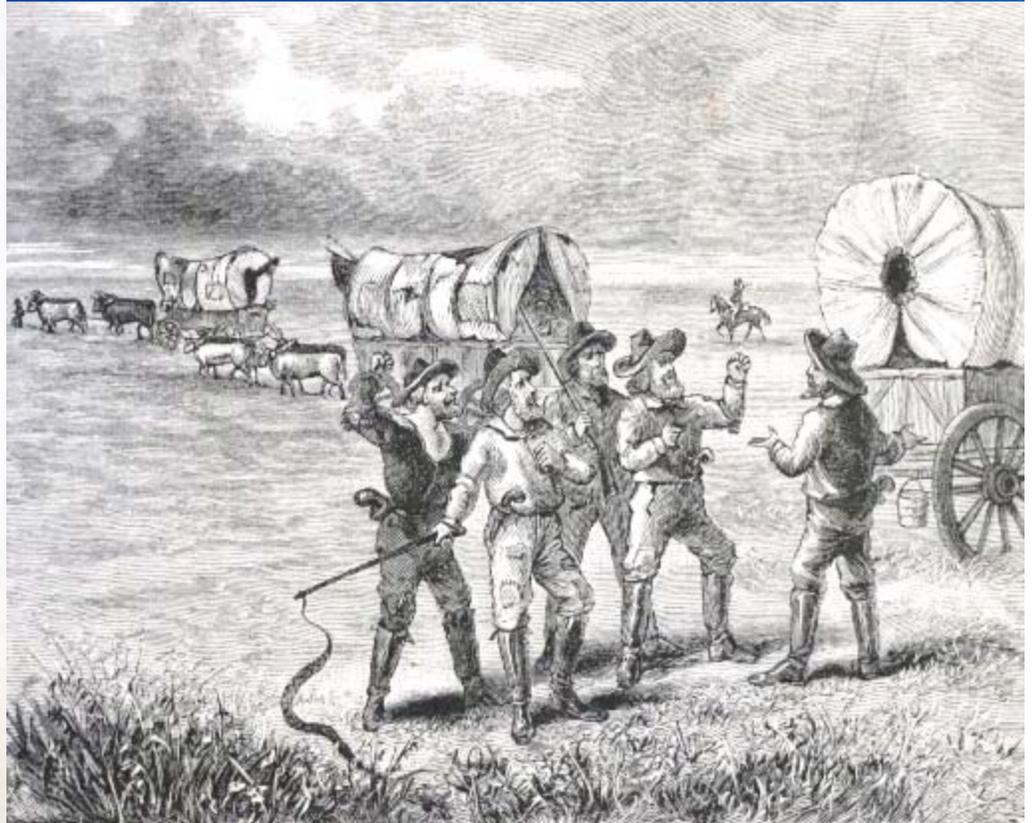
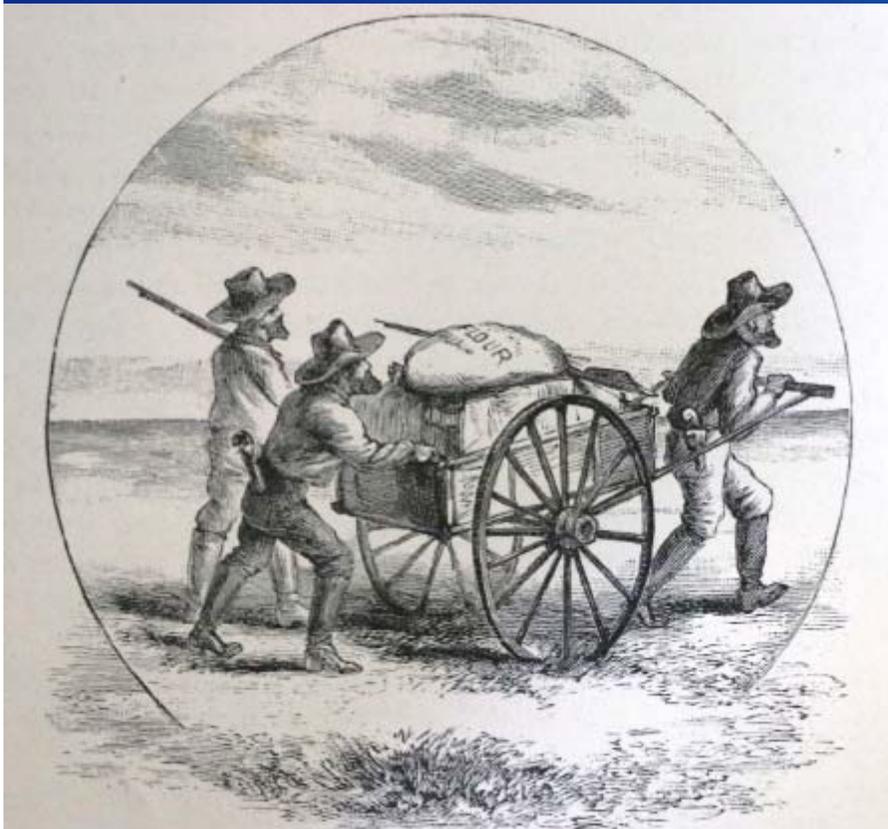
In February D. C. Oaks printed another guide book

Along with newspaper accounts they triggered the 1859 stampede.



# The Go Backs

Over 100,000 59ers rushed to the goldfields. Some gave up along the way, others stayed a few days and quit. Oakes narrowly escaped with his life when he was confronted on the trail by some gobackers while bringing in a sawmill.



# California Gulch

On April 6, 1860 John O'Farrel and his prospecting party stopped at noon along the upper Arkansas River.

Gathering water for making coffee, he broke through the snow and ice and accidentally discovered gold lying in the stream.



# Establishment of Oro City

Six days later Abe Lee exclaimed he had all of California in his pan! Oro City was established at California Gulch. The settlement grew rapidly, there were 10,000 people in the gulch by the end of the year.

California Gulch was the third bonanza discovery in Colorado. Three years later the placers declined, only 300 people were left in California Gulch



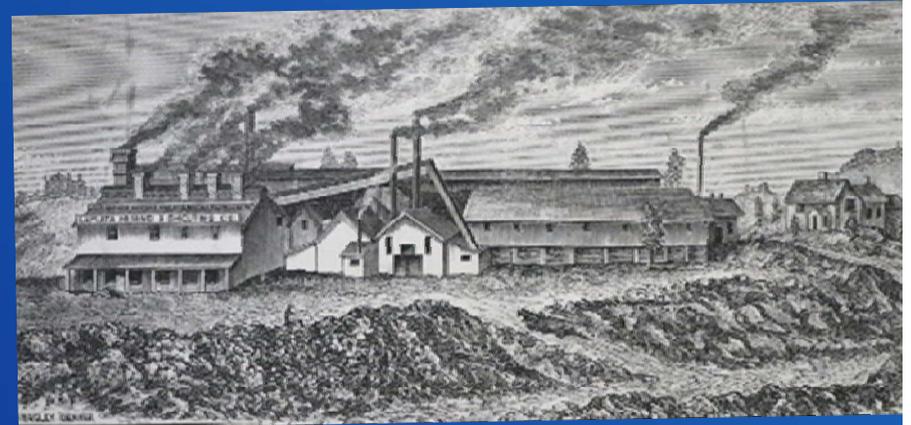
# Railroads and Smelters

After the placers declined, small hardrock mines became established. Development of the Little Pittsburg silver mine in 1878 led to the founding of Leadville

Several large smelters were built in Leadville

The Denver and Rio Grande railroad came in 1880, two more followed

Leadville became the largest mining district in Colorado



## Leadville Bonanza

Horace and Augusta Tabor came across the plains with baby Maxy in 1859 and went to Cherry Creek, they soon moved to Buckskin Joe (Alma). The first woman in the camp, she made money by cooking and doing laundry. In 1860 they moved to the rich discovery at Oro City. They eventually established a general store in Leadville.

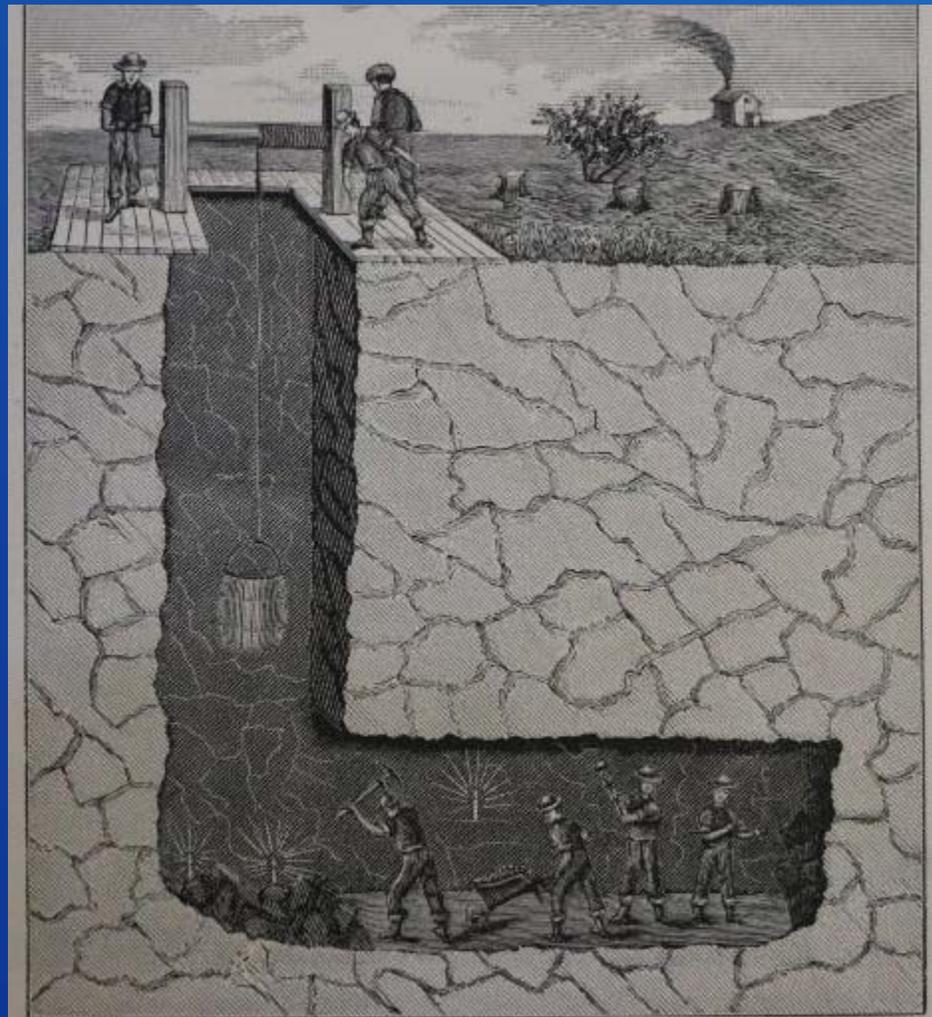


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# Discovery of the Little Pittsburg

Horace grubstaked August Rische and George Hook in 1877

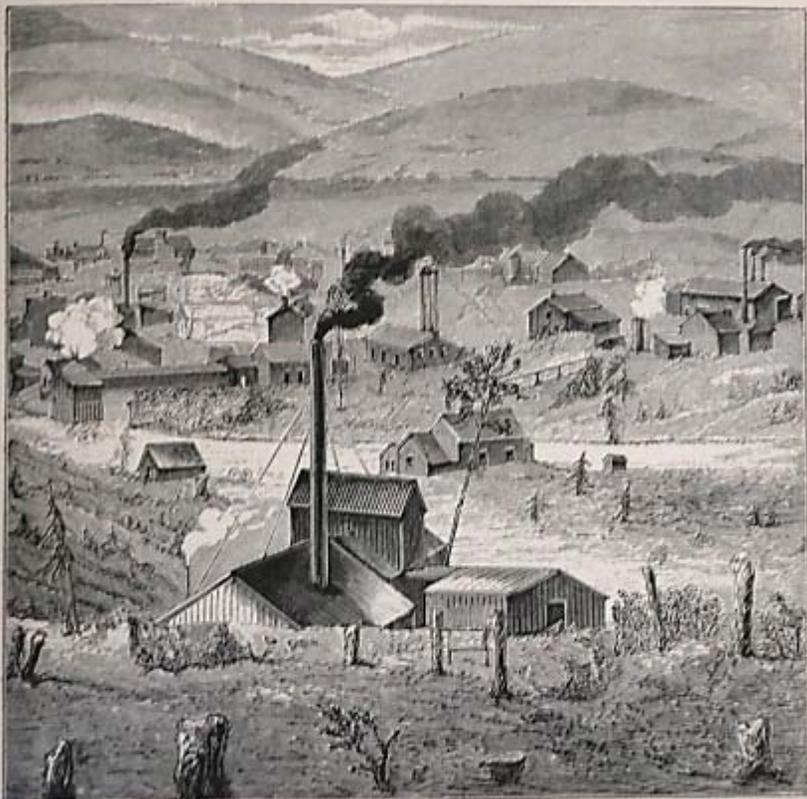
The grubstake included a jug of whisky. Rather than prospect the agreed area, they went a short distance out of town, finished the jug and started digging. At 26 feet they struck it rich.



LODE MINING

# Colorado's Silver King

Horace earned \$10,000 a day from his share in the Little Pittsburg mine. There were more discoveries, Horace had good luck investing in them. An attempt by "Chicken" Bill to cheat him by salting a claim backfired, the Chrysolite mine produced a fortune in silver for Tabor.



FRYER HILL.



FIFTY-FOUR THOUSAND POUNDS.

# Colorado's Silver King

Tabor spent the money as fast as it was earned. He built a mansion in Denver. He built opera houses in Leadville and in Denver, owned newspapers and a bank.

When he met 22 year old Elizabeth "Baby Doe" McCourt he left Agusta. Horace and Baby Doe had two daughters. He became Lieutenant Governor of Colorado, and served a short term as a U. S. Senator.

The 1893 silver crash wiped him out.



Matchless Mine

## Drainage Tunnels

Pumping water became a huge expense for the mines at Leadville. Drainage tunnels had been used elsewhere with good success.

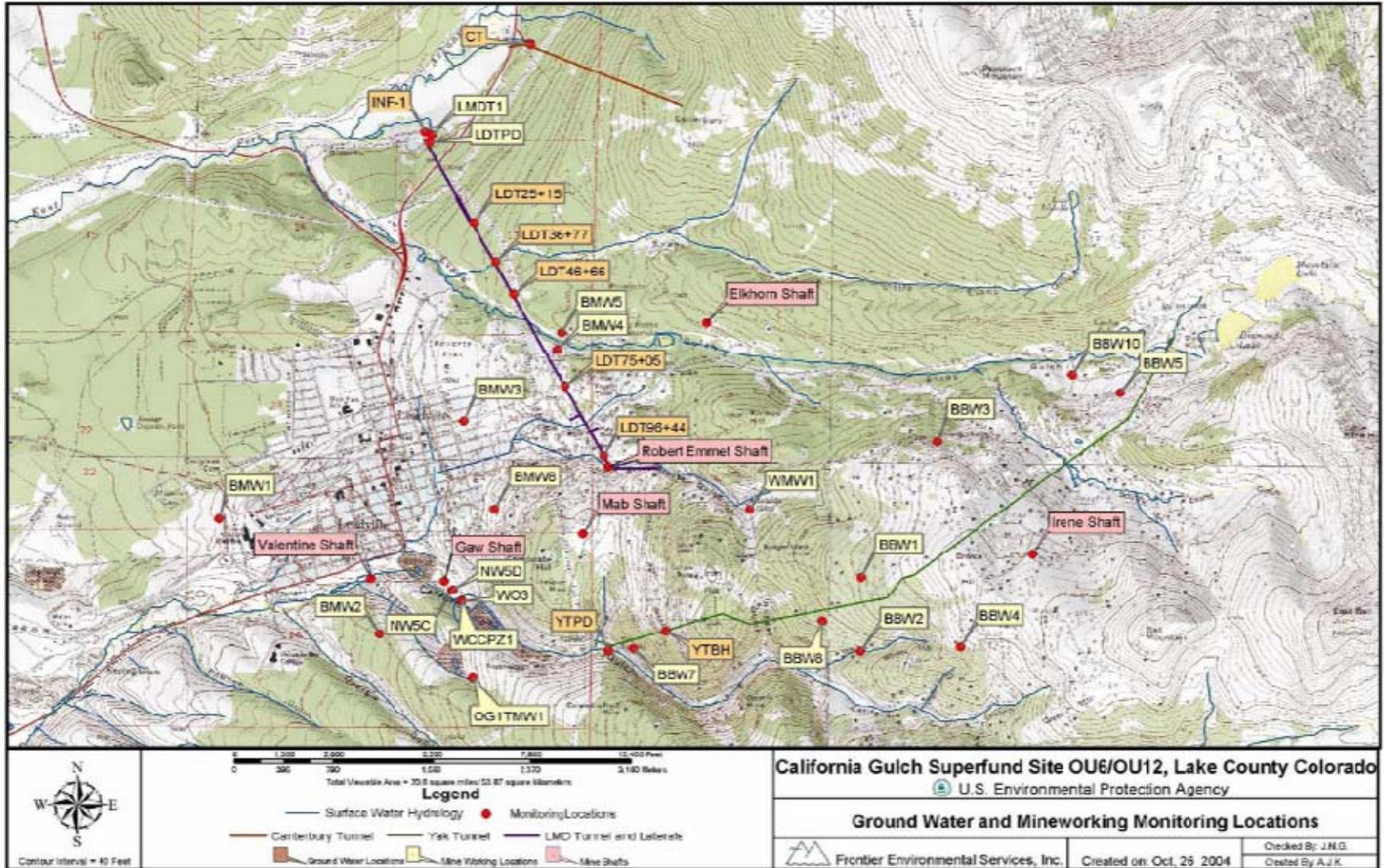
Work on the Yak Tunnel started in 1895, it drained mines in California Gulch and was extended 4 mi.

In 1921 the Canterbury Tunnel was started, it encountered difficult conditions. Today it supplies most of the drinking water for Leadville.

The Leadville Mine Drainage Tunnel (LMDT) was developed by the USDI Bureau of Mines in 1943-45 and completed in 1950-52

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# Map of the Drainage Tunnels



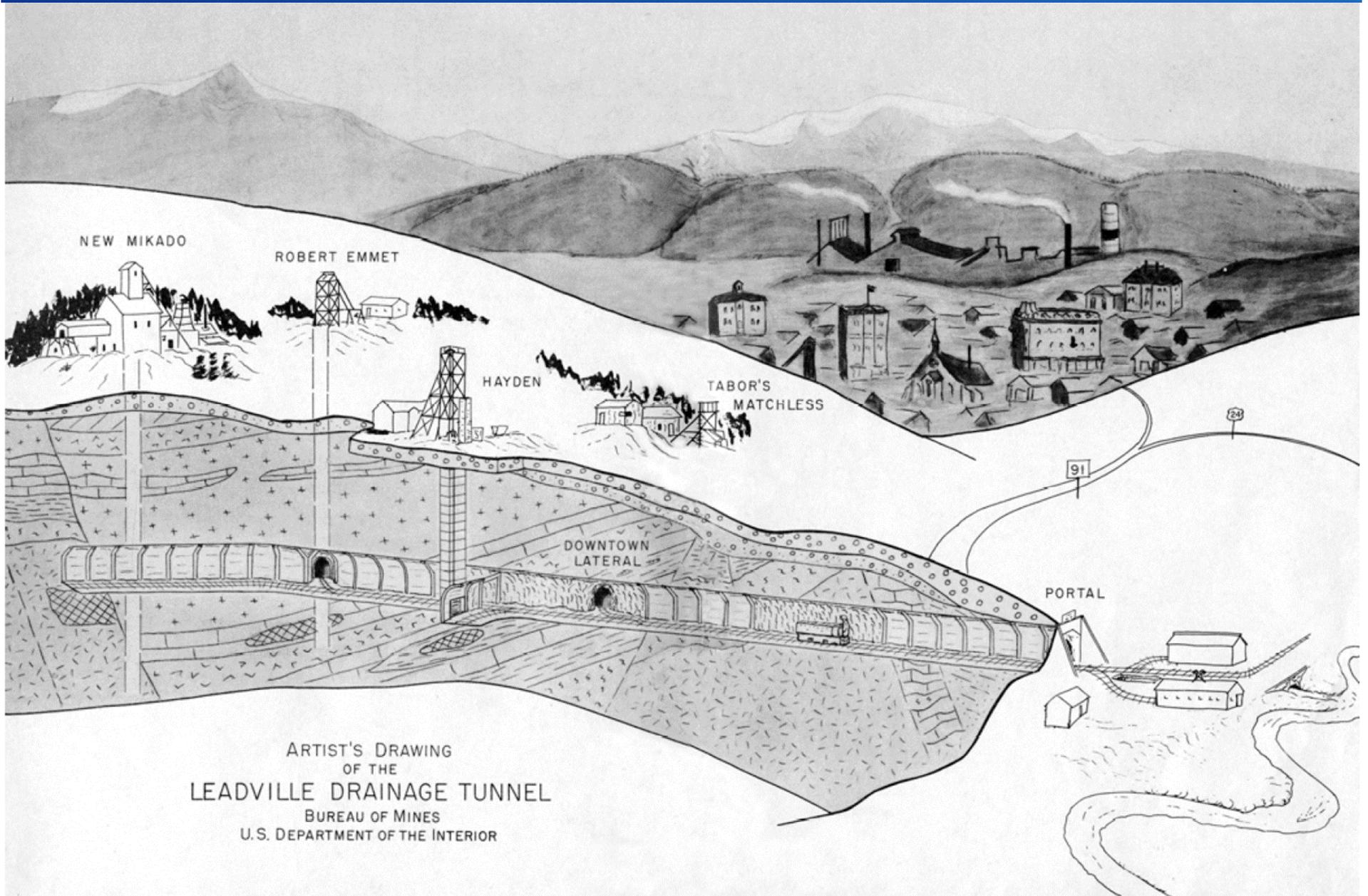
# Modern Day LMDT

**1959 - Reclamation acquires LMDT from the Bureau of Mines**

**1992 – A Water Treatment Plant is constructed and begins operations to remove heavy metals from the LMDT drainage**

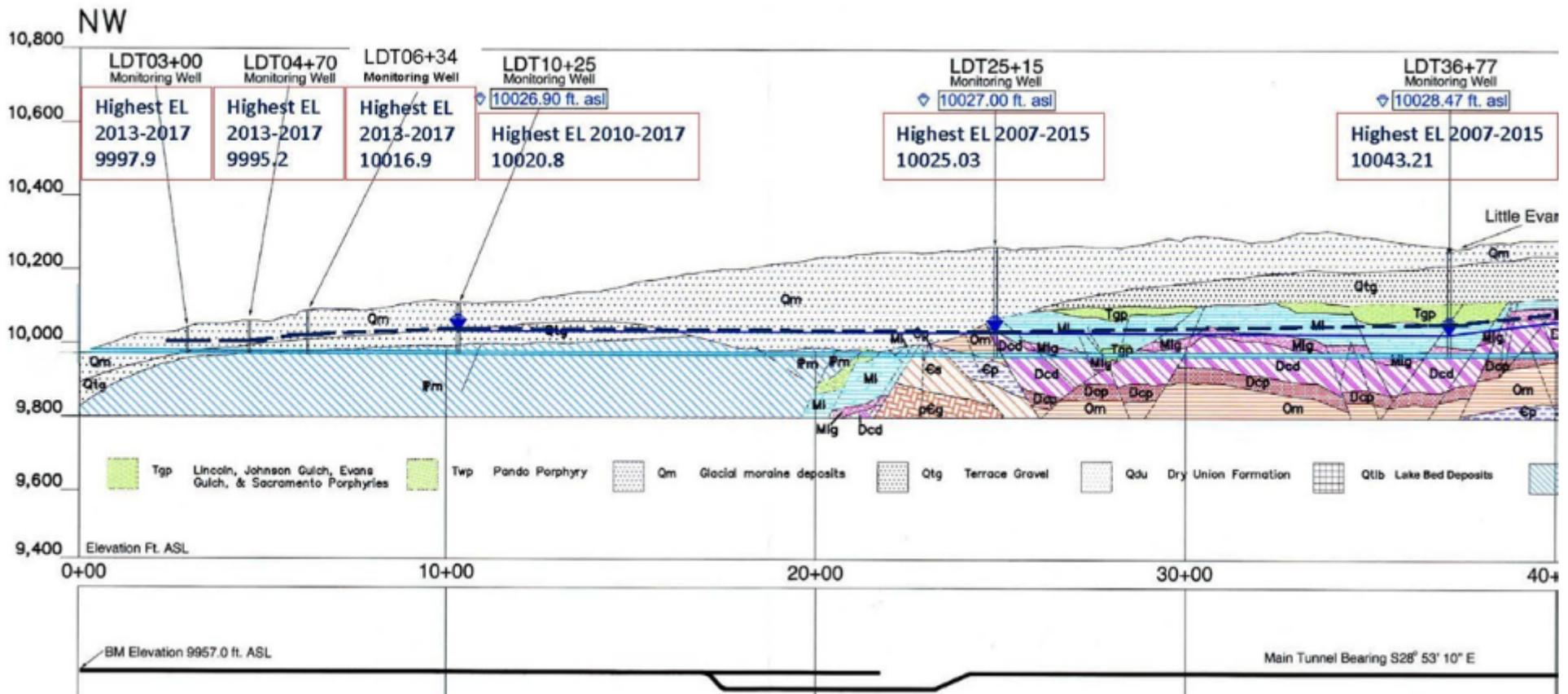


# Geology



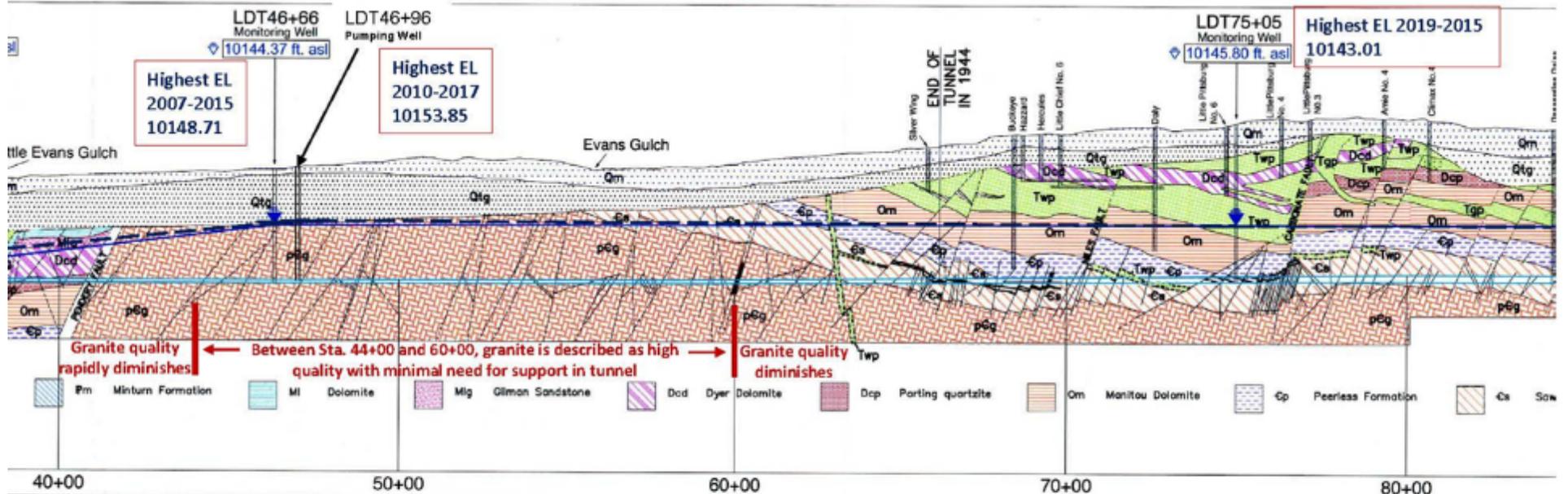
# Geology

The area contains glacial soils (mixture of silts, sands, gravels, and boulders) overlying Paleozoic sediments which rest on a Precambrian granite basement.



# Geology

About 2,000 feet of the tunnel penetrates Precambrian granite which is strong and not mineralized. This is the ideal plug location.

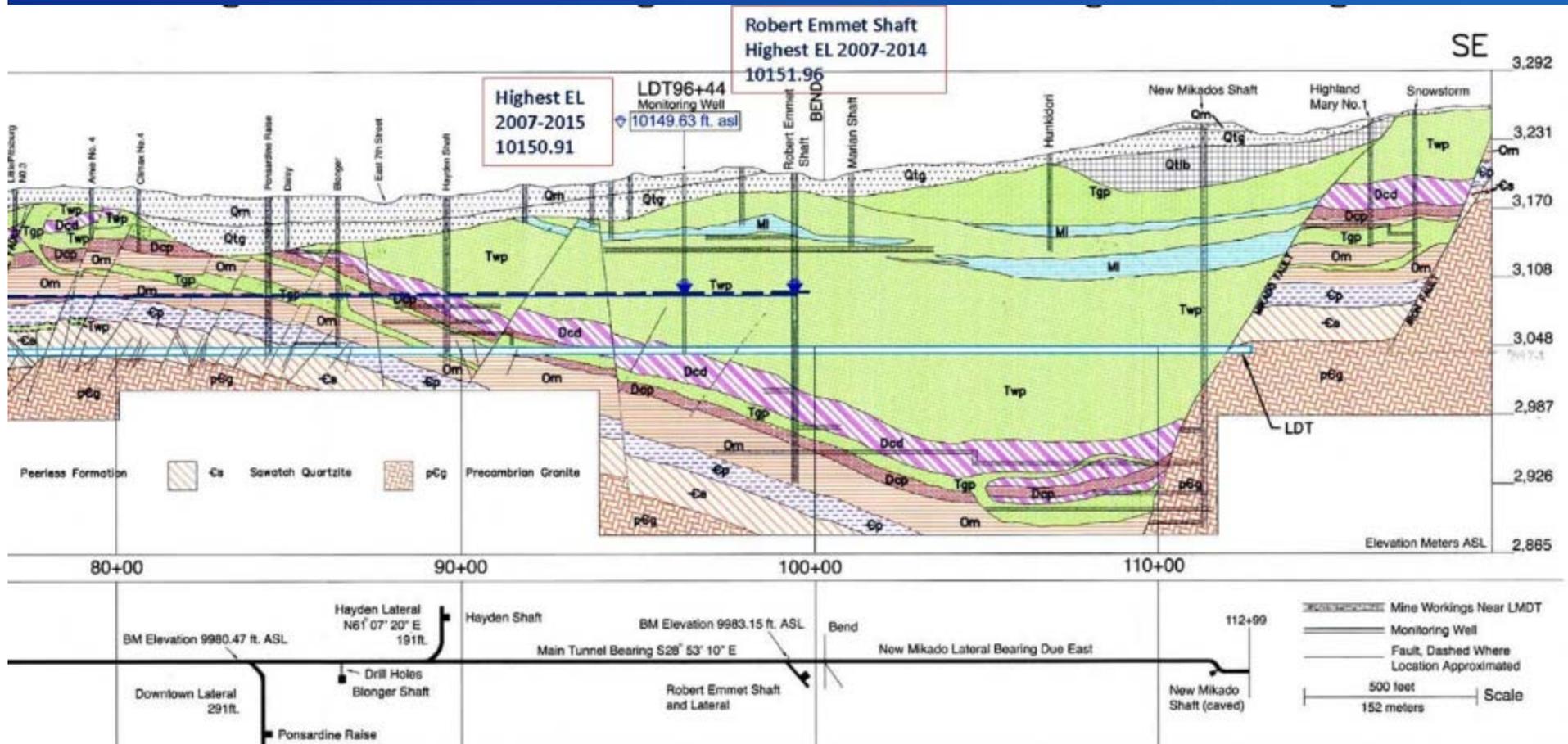


This figure provides water surface elevations for select monitoring wells for selected date ranges, based on available data. The solid blue water surface elevation line represents values used in the 2008 Risk Assessment, while the dashed dark blue line represents more recent data where available.

Downtown Lateral  
291ft.

# Geology

The mineralized sediments are highly fractured and with numerous interconnections between the larger mines and the tunnel the mine pool drains to the LMDT



# Hydrogeology

- Extensive groundwater studies by the EPA
- Acid water forms in the underground mines but extensive limestone occurrence raises pH to 6 for most of the year
- Spring snowmelt May-June results in pH of 2 to 3 acid water flushing through in the upper mine workings
- The LMDT drains a portion of the mine pool and a large area of fresh groundwater
- Plugging the Tunnel was selected by the EPA as the preferred option for Operable Unit 6 of the California Gulch Superfund Site

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# Benefits of Plugging the LMDT

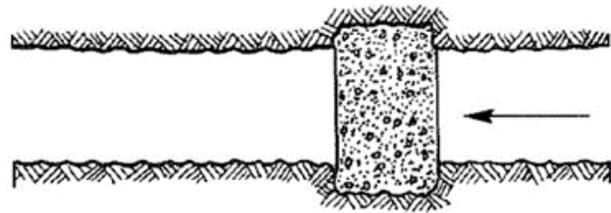
The tunnel flows are highly diluted by clean groundwater as the flow moves downstream to the portal.

Placing a hydraulic plug downstream of the mine pool will:

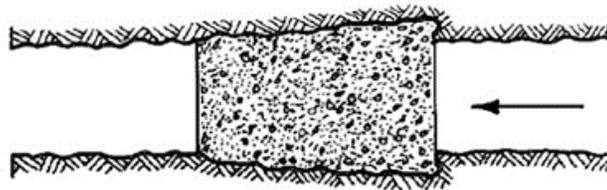
- Separate contaminated water from clean groundwater
- Provided an engineered containment of the mine pool
- Eliminate downstream dilution of the tunnel flow
- Greatly reduce the volume of water that must be treated

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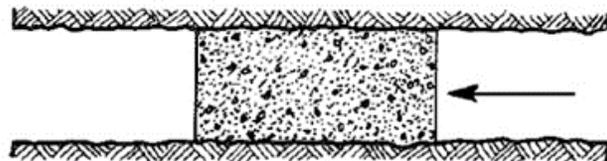
# Evolution of Plug Design



Slab keyed into walls



Taper plug



Parallel plug

KEY  
← Direction of hydrostatic pressure

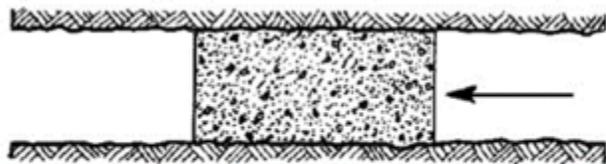
Heavily Reinforced, High Gradients, Extensive Grouting to Seal Plug

Less Reinforcement, Less Grouting, Water Pressure Helps Seal Plug

Little to no Reinforcement  
Low Gradients, Easier to Seal

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# Advantages of a Parallel Plug



Parallel plug

Need not have any reinforcement which might degrade in an acid environment

The extra length reduces the pressure gradient acting along the plug thus making it easier to seal the plug by grouting

Additional rock excavation is not needed

Greater longevity, the large mass of concrete will take a long time to degrade

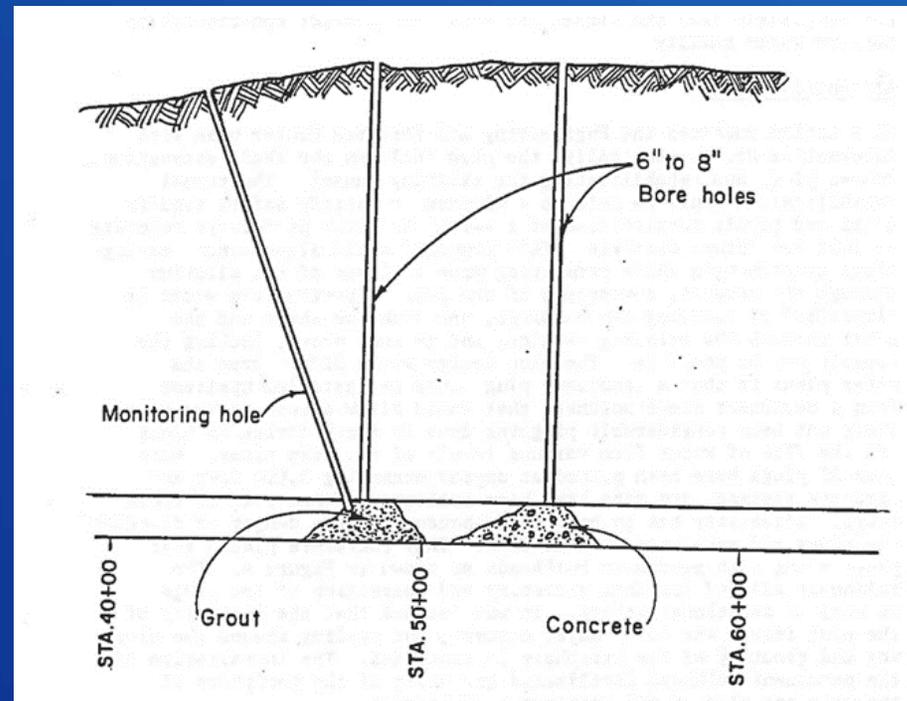
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# Remotely Injected Plugs

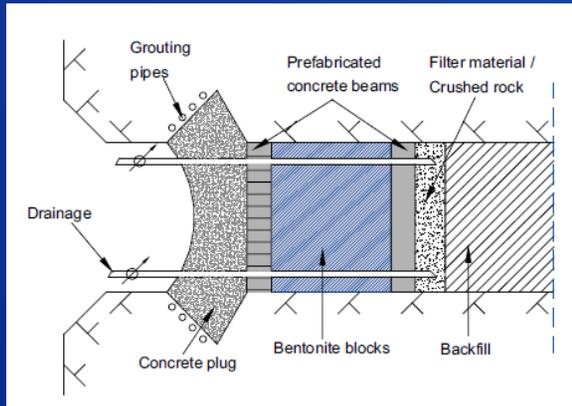
Developed for Eastern USA coal mines, many installations

Installed through boreholes where mine access is no longer possible

Used on hardrock mine sites on occasion

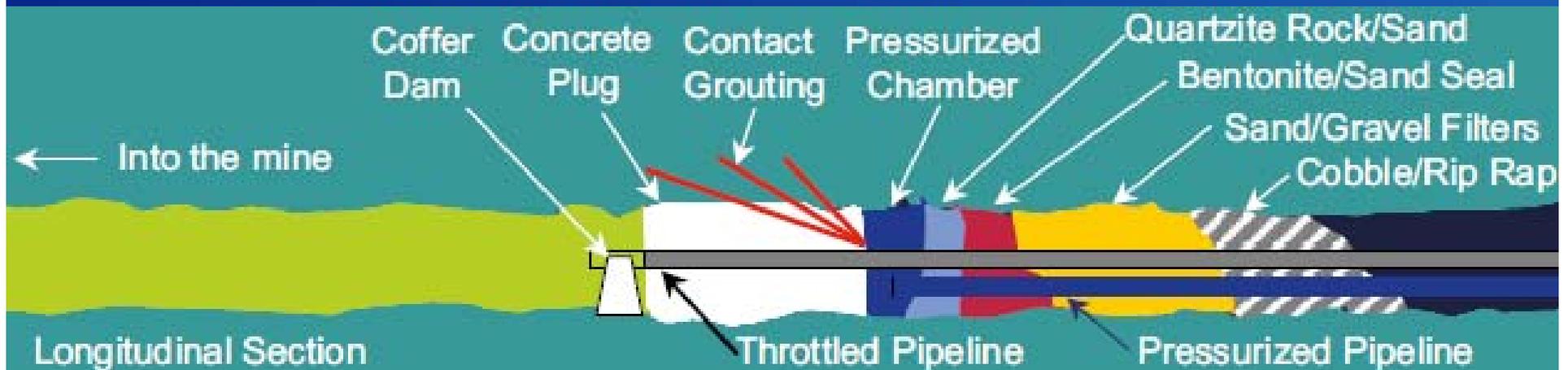


# Fancy Plugs



Combination concrete and soil plugs – clay with sand filters are being researched in Europe and Canada with hope to provide a long-term barrier after concrete fails

Millennium Plug – Developed in British Columbia for the Britannia mine closure  
Mimics an embankment dam with granular filters, supposed to last 1,000 years.



# Why Plugs Fail (It Rarely Happens)

Structural failure - hydraulic load applied prior to concrete gaining strength (Merrispruit Mine, South Africa)

Hydraulic fracturing of the surrounding rock - plug placed too close to the surface or rock too weak for the pressure applied (Tapien Pit, Marcopper mine, Philippines)

Shear failure of weak mineralized rock (Chandler Adit, Summitville, Colorado)

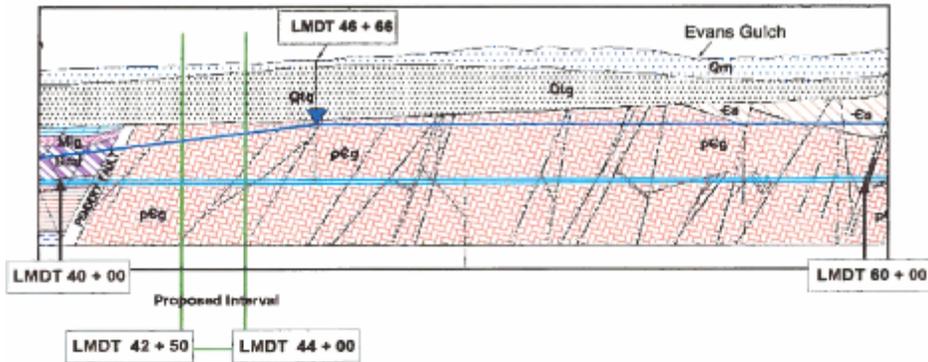
Weak mineralized or clay filled rock eroded by seepage flow resulting in excessive seepage (Reynolds Adit, Summitville, Colorado)

Excessive seepage at plug interface - Inadequate cleaning and sealing / grouting at the rock interface allows seepage between concrete plug and adjacent rock

Chemical degradation of plug materials over time – expected but has not occurred, concrete plugs are considered to have a minimum 100 year design life (probably longer)

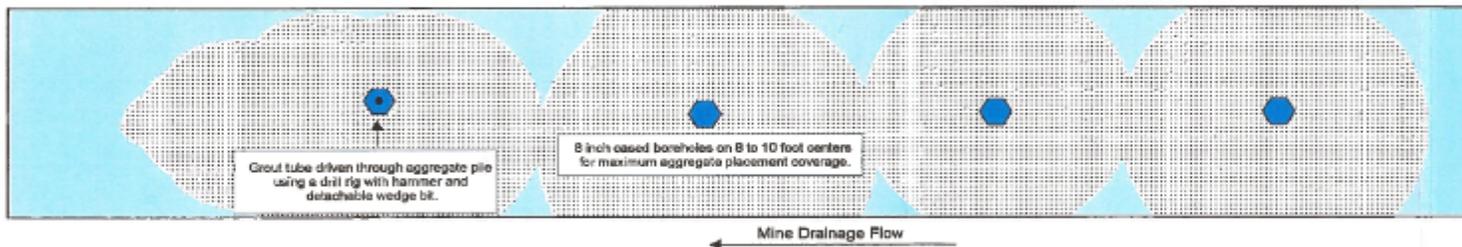
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# EPA Preferred Alternative for OU-6: Plug the LMDT remotely using boreholes

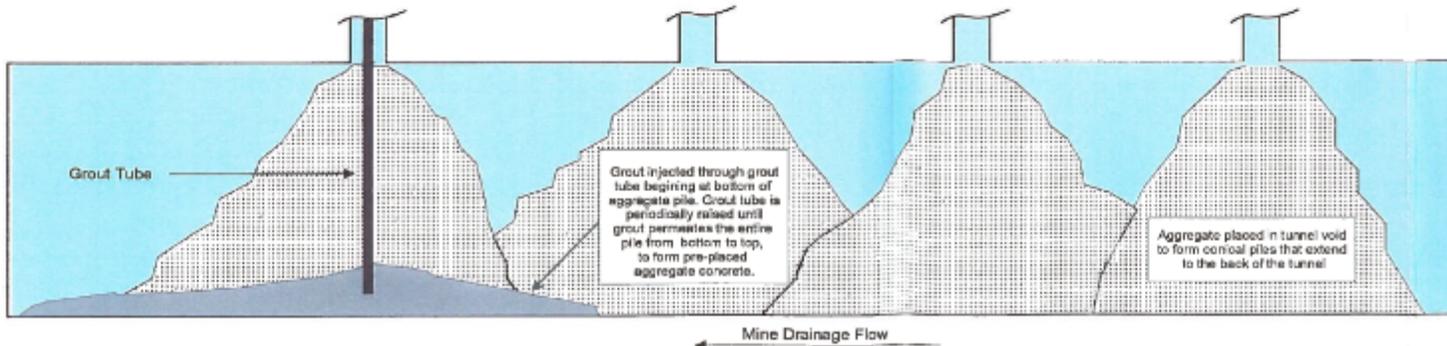


<b>Project:</b> LMDT Mine Pool Containment System		<b>Drawing No:</b> 3
<b>Title:</b> Diagram of Pre-Placed Aggregate Concrete Barrier Construction		<b>Production Date:</b> March 28, 2005
<b>Geographic Location:</b> Lake County, CO / California Gulch Super Fund Site OU6		
<b>Engineer:</b> Frontier Environmental Services, Inc.		<b>Drawn By:</b> A.J.K. <b>Checked By:</b> J.J.F.
<b>Legend</b> 		
(Not to Scale)		
U.S. Environmental Protection Agency		

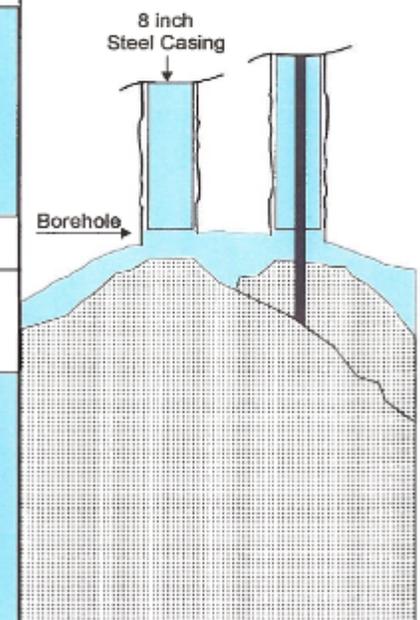
**Plan View - Borehole Pattern**



**Side View**



**Down Tunnel Cross Section**



# Plug Design for the LMDT

Remotely Injected Plug

Designed for 330 feet of Head (185 ft. actual head)

Design length of 27 ft required, will be increased to 60 ft for reliability

Greatest challenge is removing gravel, timber ties and steel rail from tunnel floor, and iron hydroxides from rock surfaces.

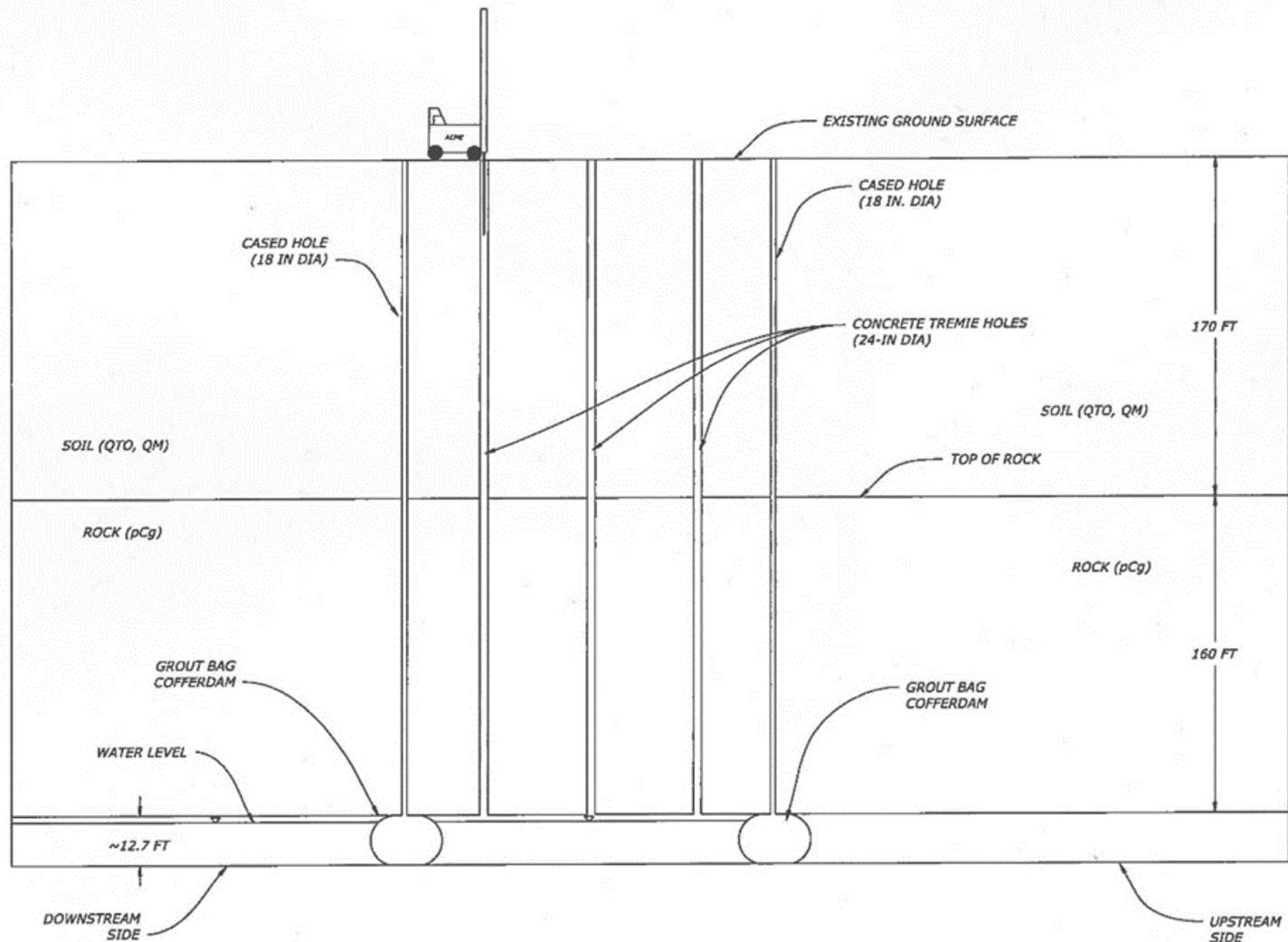


# Location drilled in 2008, confirmed old Bureau of Mines records of strong granite rock



# Step 1 – Remotely Install cofferdams by injecting geotextile tubes with concrete

## STEP 1 - GROUT BAG INSTALLATION, DEWATERING, TREMIE HOLE INSTALLATION



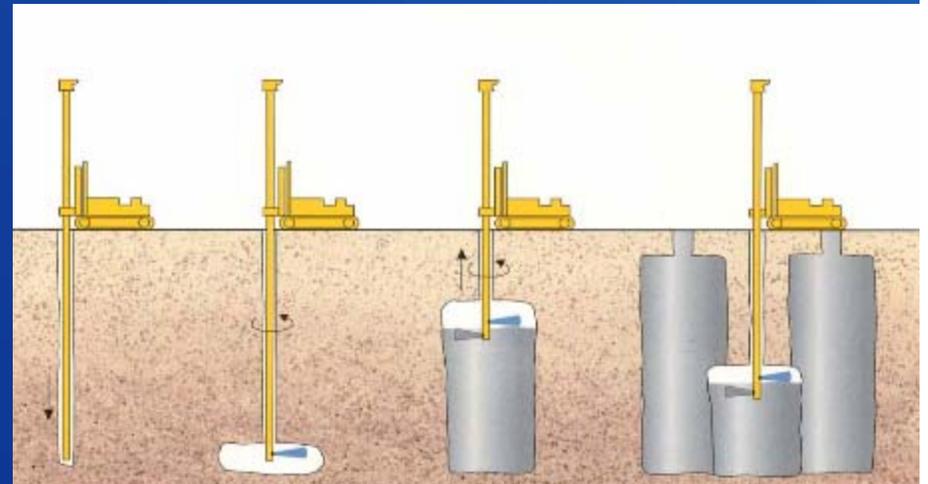
# Step 2 – Remotely remove debris and clean rock surfaces using water jet technology

Competing technologies

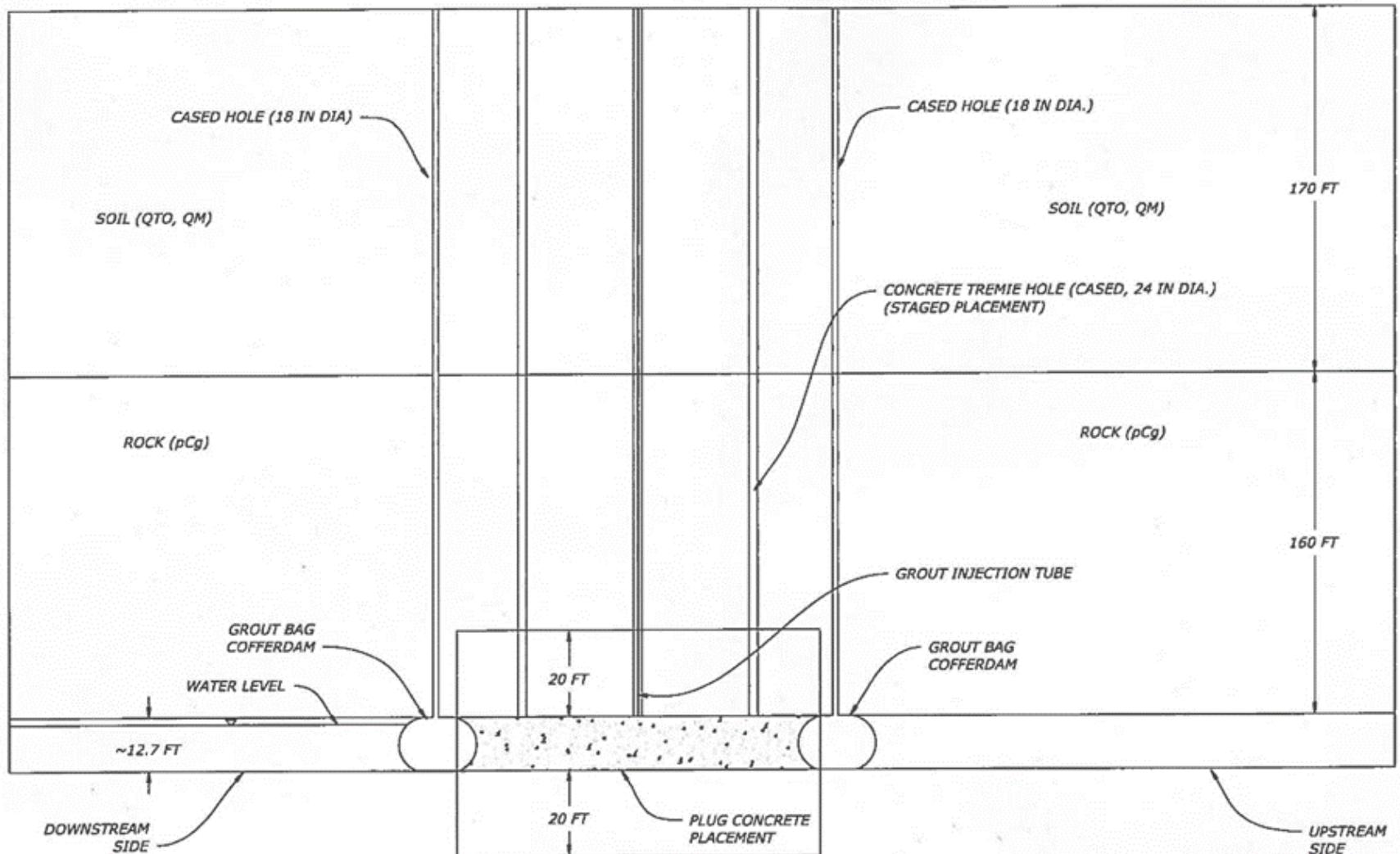
Jet cleaning – 10,000 to 20,000 psi water sprays to clean sewer pipelines

Jet grouting – 20,000 psi water spray for cutting and mixing soil with cement to form cement columns

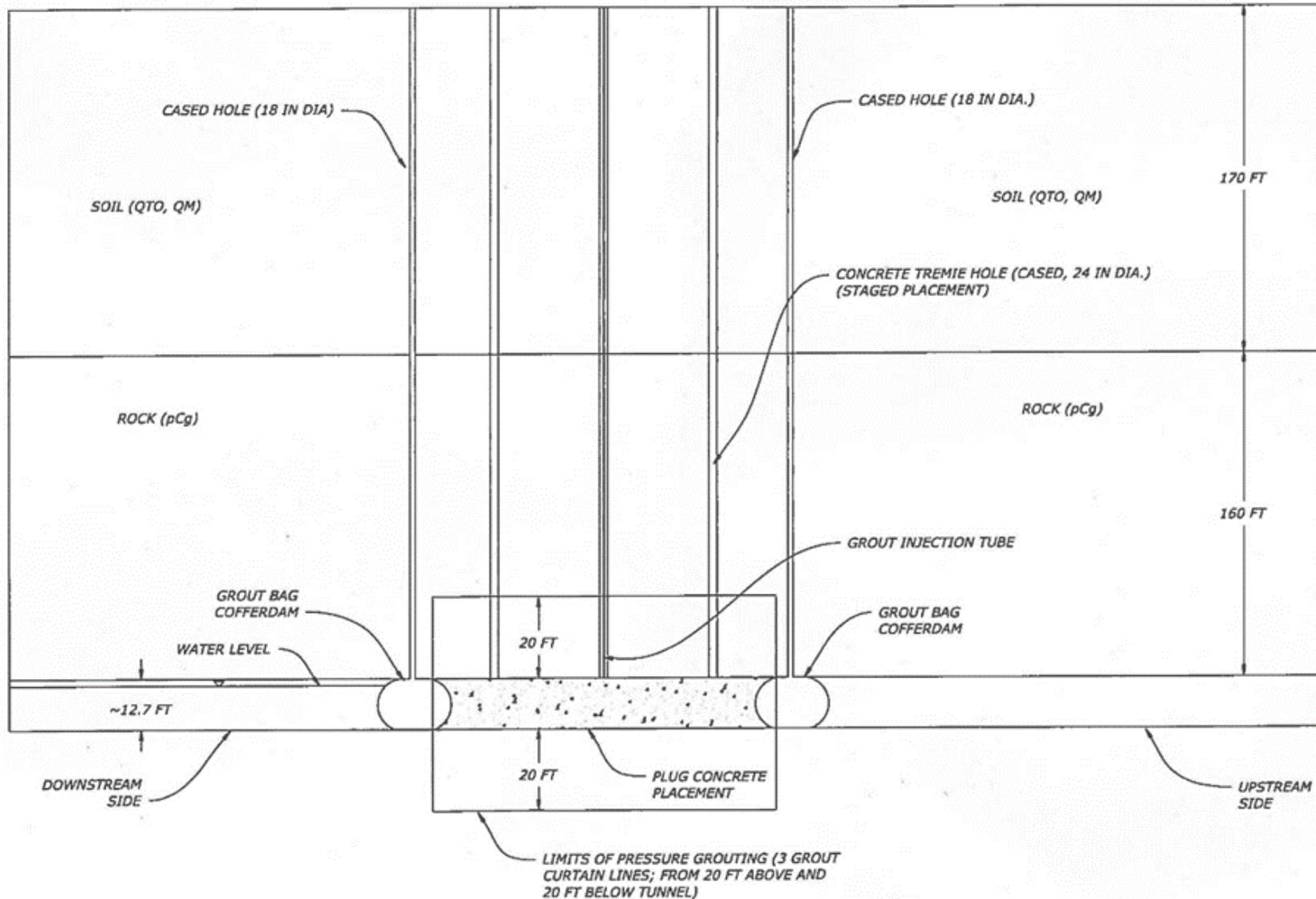
Superjet Technology – 32,000 to 40,000 psi water sprays recently developed and now in use by both of the above industries



# Step 3 – Inject Plug through boreholes



# Step 4 – Grouting to seal rock and plug



# Factors for High Quality Plugs

- Solid competent rock with minimal fractures, altered zones, jointed or bedding planes
- Determine expected head, add factor of safety
- Make plug long to lower gradient across structure
- Design concrete for acid water
- Remove debris and clean the rock surfaces for bonding
- Curtain grout around bulkhead to seal fractures
- Contact grouting of the joint formed when the bulkhead cures and shrinks away from the rock contact

# Conclusions

**Plugging the LMDT has the potential to greatly reduce water treatment volumes**

**Remote installation is the preferred method**

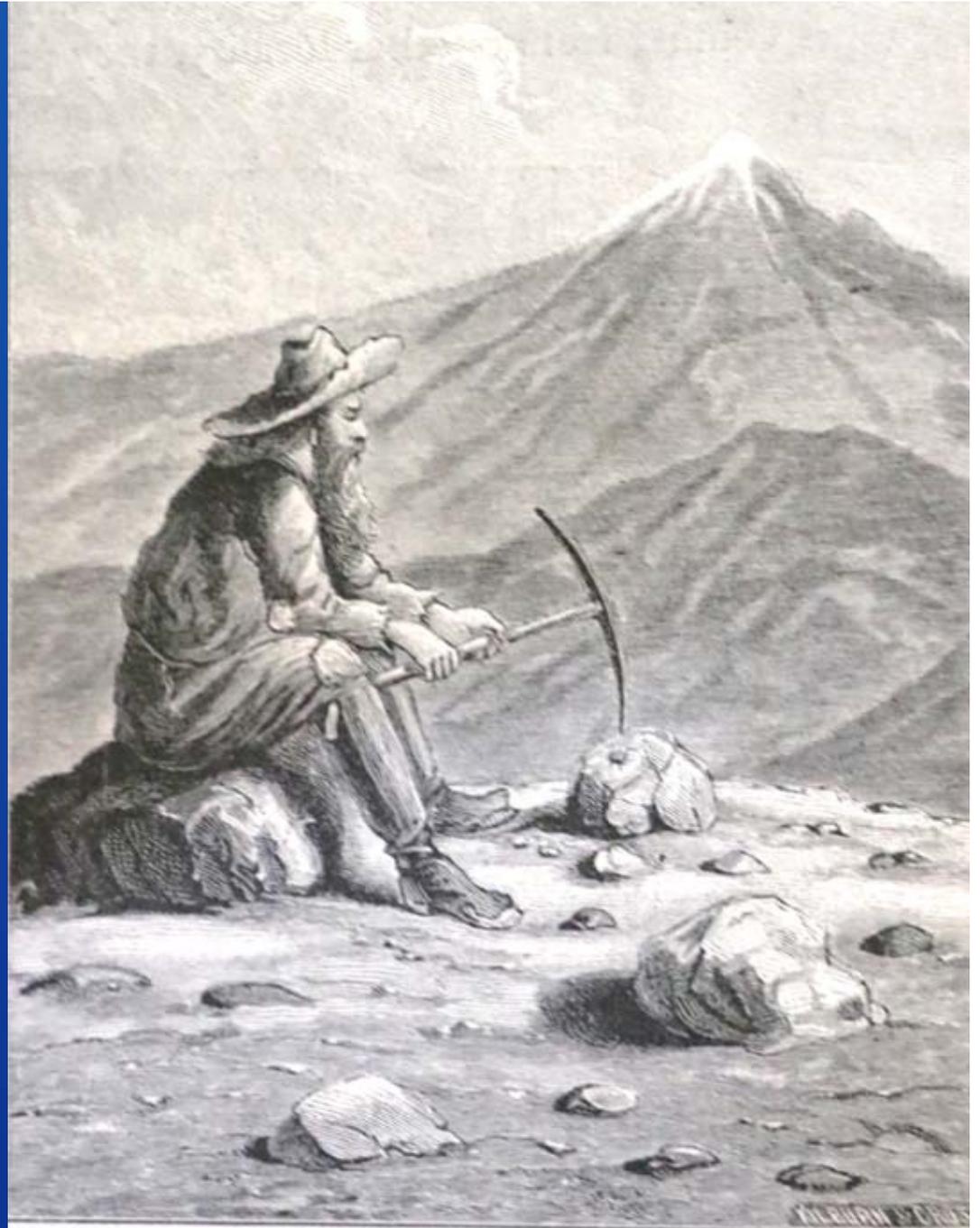
**New technologies such as geotextile tubes, and jet cleaning have improved the design**

**Cleaning the tunnel is essential for successful installation**

**The Feasibility Study will focus on cleaning technologies that can be applied to a tunnel at depth (over 300 feet).**

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# The End



FINDING GOLD BY ACCIDENT.