DESIGN AND CONSTRUCTION OF THE
SPIRIT LAKE OUTLET TUNNEL, MOUNT ST. HELENS, WASHINGTON

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INTRODUCTION

Mount St. Helens in the Cascade Range of the State of Washington is one of a series of active volcanoes comprising a part of the "Ring of Fire," a circle of volcanoes and earthquake activity rimming the Pacific Ocean. The mountain is located about 45 miles northeast of the Portland-Vancouver metropolitan area (Figure 1). The eruption of Mount St. Helens began in the spring of 1980. Since then, the movement of

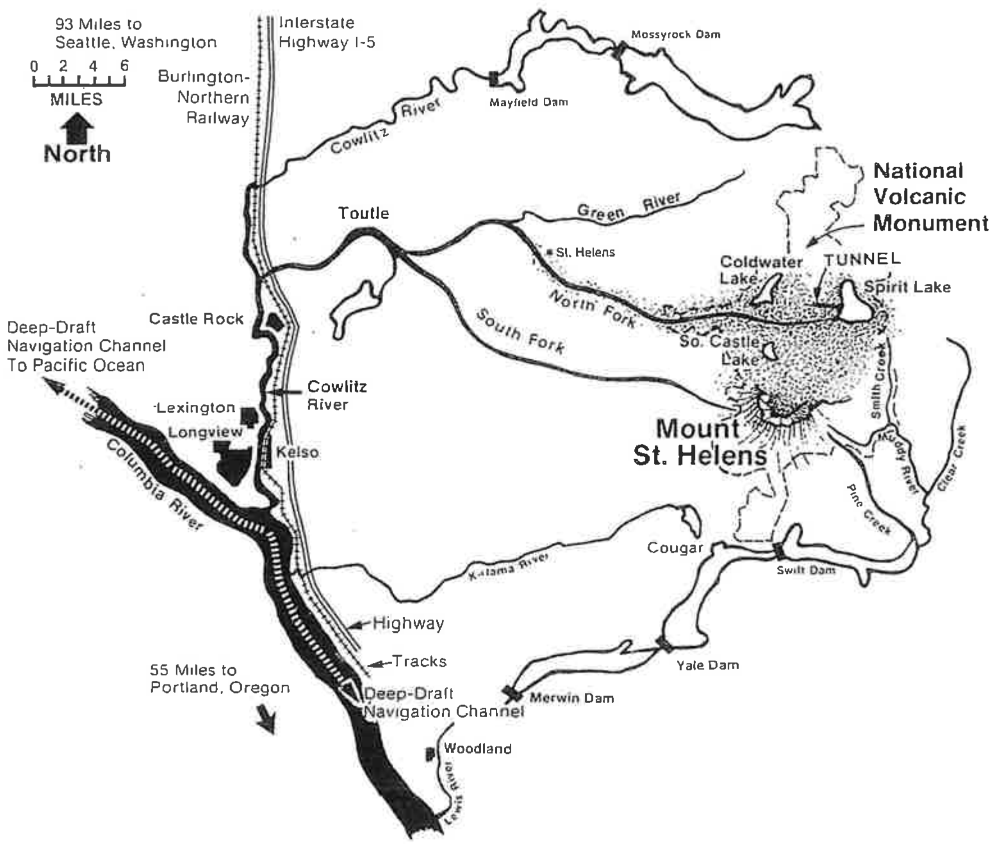

Figure 1. Vicinity and Location Map

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millions of tons of sediment has created a serious threat of area flooding and navigation disruption in the Columbia River. Before the eruption the mountain stood 9,677 feet high surrounded by state and private forest land and the Gifford Pinchot National Forest. A major feature of the landscape was 1,300-acre Spirit Lake approximately 4 miles northeast of the mountain.

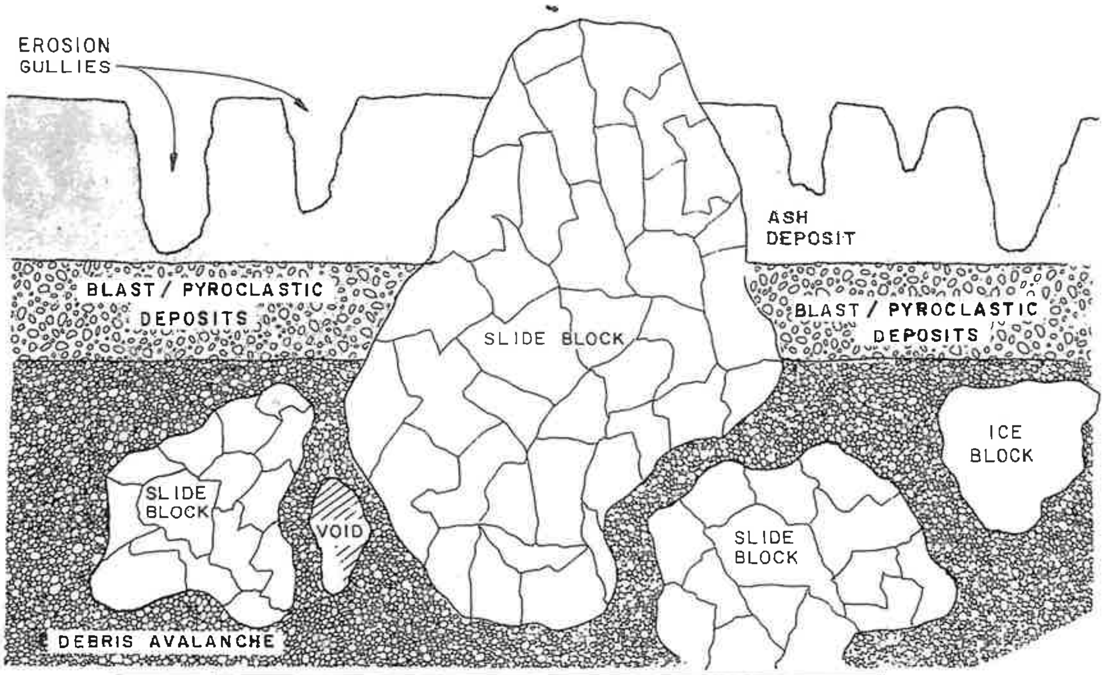
On the morning of May 18, 1980, the north slope of Mount St. Helens collapsed following a magnitude 5.0 earthquake that precipitated (almost simultaneously) the most catastrophic volcanic eruption in the continental United States in recorded history. A gravitational landslide ensued, transporting an estimated .6 mi^3 (2.8 km^3) of debris into the upper North Toutle River drainage basin (Figure 1). A massive debris avalanche completely filled the lake, blocking the natural outlet to the North Fork Toutle River with a deposit several hundred feet thick. This filling caused the lake to rise 200 feet to elevation (El.) 3400. At that elevation the lake volume was 126,000 acre-feet, 34,000 acre-feet less than the pre-eruption volume (160,000 acre-feet). By the summer of 1982, the lake would have risen almost 60 feet higher, increasing the volume of water held back by the debris "dam" to nearly 275,000 acre-feet.

In August 1982, the Portland District of the U.S. Army Corps of Engineers began a program of intensive field investigations to determine the composition of the nearly one square mile of avalanche deposit that forms the debris dam. Thirty-six exploratory holes were drilled between August and November 1982. Site investigations ceased in November with the onset of winter weather conditions. An additional 23 holes were drilled within the debris dam area beginning in March 1983. In-place density and permeability testing were performed in most of these borings. Thirteen exploratory holes were also drilled along some of the more promising permanent outlet alignments.

The debris dam consists mainly of "debris avalanche deposit" material ranging from silt to boulder size that had been deposited by the gravitational landslide (Figure 2). Overlying this material is a relatively thin deposit (generally 10- to 15-feet thick) of rock fragments called the "blast deposit." This designation represents fragments of the mountain which were ejected as the confinement of the outer shell was released by the landslide. The uppermost part of the deposit is a layer of ash and pumice (or "ash-cloud") from pyroclastic flows and airfall deposition occurring during the May 18 and subsequent eruptions. This layer ranges in thickness from a few inches to many tens of feet where the pyroclastic flows were channeled into depressions in the avalanche deposit surface. Minor mudflows from the mountain since the main eruption have added to the material forming the Spirit Lake blockage. The deposits forming the debris blockage are, by nature, extremely erodible and constitute a virtually limitless sediment source.

In 1982, a governmental task force was formed to evaluate the hazard posed by the blockage of Spirit Lake. The group determined that because of the composition of the debris avalanche deposit, subsidence potential, and active erosion, the debris dam could not safely pond water above El. 3475. If no preventive measures were taken and the area received average precipitation, it was estimated that Spirit Lake would reach El. 3475 by March 1983. The task force concluded that if Spirit Lake was allowed to reach that level, the debris dam could be breached, probably by piping through the uppermost ash material. This failure could cause catastrophic flooding and widespread damage in the Cowlitz Valley and interrupt Columbia River navigation.

As a result of these findings, the President directed the Federal Emergency Management Administration to design and construct an immediate, interim solution to mitigate the flood threat, and to study alternatives for a permanent solution. The Federal Emergency Management Administration, in turn, charged the Corps of Engineers with these tasks, which led eventually to the design and construction of the Spirit Lake Outlet Tunnel.



MATERIAL	γ_{MOIST} (pcf)	γ_{SAT} (pcf)	ϕ	% FINE	% SAND	% COARSE
ASH	84	88	30°	50-70	30-50	0-5
BLAST	120	125	35°	5-20	30-50	30-55
PYROCLASTIC FLOW	92	96	37°	10-20	60-80	10-20
DEBRIS AVALANCHE	125	130	37°	5-25	20-60	30-75

Figure 2. Debris Avalanche Material Distribution and Properties

INTERIM PUMPING

To prevent the lake rise and possible catastrophic failure of the debris blockage, emergency pumping was initiated in November 1982 (Figure 3). The pumping facility, constructed by Harder Mechanical, Inc. on a barge in Spirit Lake, consisted of 20 pumps (180 cfs average total capacity). Water was pumped from the lake through 3,450 feet of 5-foot-diameter steel pipe across the debris "plug" to a stilling basin, and from there to the North Fork of the Toutle River. The cost of the pumping plant, pipeline, operation, and maintenance was approximately $11 million. By the time pumping was terminated on April 1, 1985, approximately 263,000 acre-feet of water had been pumped from the lake since November 5, 1982. Without pumping, the lake level would have been more than 80 feet higher than the elevation of 3,452 feet that existed in April 1985.

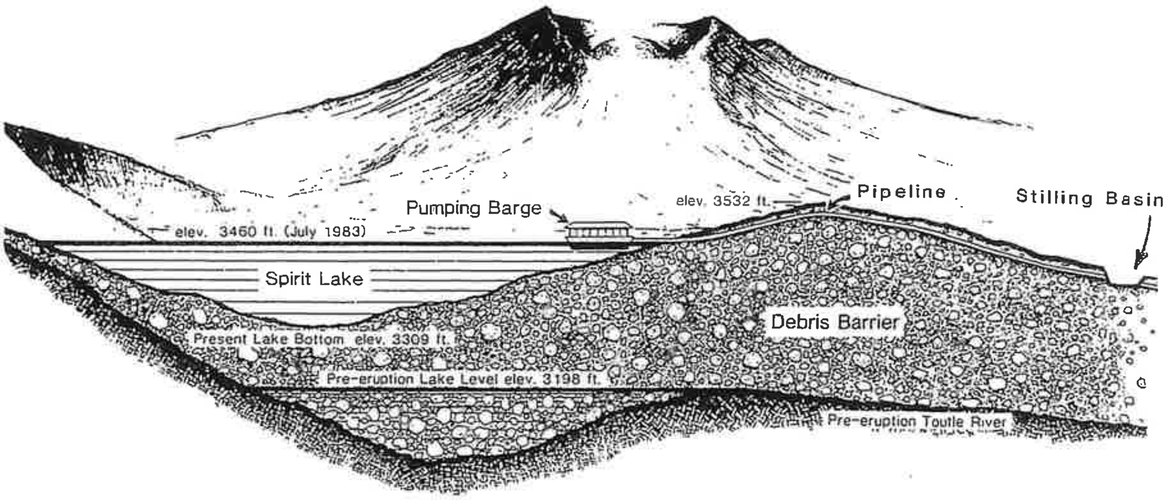


Figure 3. Interim Pumping

SPIRIT LAKE SAFE LEVEL DETERMINATION

An analysis was performed to determine a "safe" elevation at which the lake surface could be permanently maintained without danger of the lake breaching the debris blockage. Erosion of surface materials from the debris blockage, stability of critical slopes, piping of avalanche material, rise of Spirit Lake, possible flood, seismic and volcanic events, and necessary freeboard were key factors considered in determining the safe operating level. It was concluded that for the long term, a water level at or above El. 3460 could cause failure by piping of ash-cloud materials. The analysis further concluded that water levels at or below El. 3440 could permanently pond, saturate, and flow through the debris avalanche materials, with only a very remote chance of causing failure (Figure 4).

ALTERNATIVES CONSIDERED AND SELECTION CRITERIA

Four possible alternatives were considered for a permanent solution: (1) a buried conduit; (2) an open channel; (3) a tunnel; and (4) a permanent pumping facility. A number of potential alignments were considered for each alternative. Three alternative tunnel alignments were seriously evaluated during this process. The shortest tunnel extended approximately 5,000 feet from the lake's east side, the longest about 8,500 feet from the west side.

Because the project lies within the Mount St. Helens National Volcanic Monument, one of the key criterion was the degree to which the site would be disturbed. Constructibility considerations and cost were others. Because some of the alignments crossed the potentially unstable debris avalanche deposit, long-term stability was another important consideration. Downstream impacts, including those from erosion and sediment transport, water quality impacts, and effect on stability of the Spirit Lake and Coldwater Lake debris dams, were also

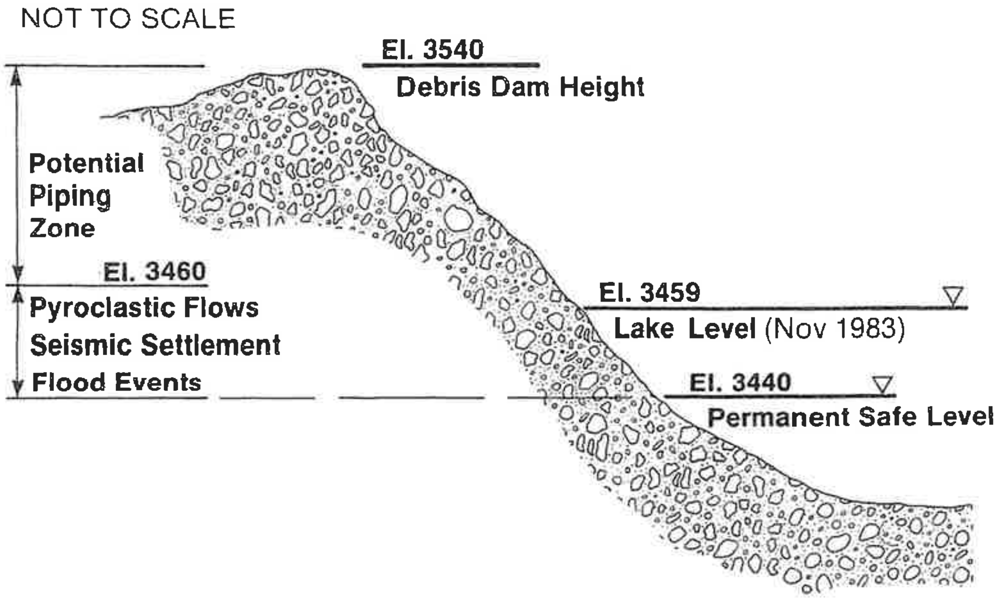


Figure 4. Spirit Lake Safe Height

considered. Finally, the mountain's proximity dictated that each alternative be evaluated for ability to withstand impacts from future volcanic or seismic events.

Based on these considerations, a straight tunnel extending approximately 8,500 feet from the west side of Spirit Lake, through a rock ridge, to South Coldwater Creek was ultimately selected as the preferred alternative (Figure 5).

SITE INVESTIGATIONS

Site investigations were limited by the remote location and the short time period between selection of the permanent outlet alignment and advertisement of the construction contract. The short design period was necessary to allow maximum time for construction during the summer months to complete the tunnel and remove the pumping facility before the 1985-86 winter season.

Between March and May 1984, a total of 10 core borings was drilled to help define site conditions along the tunnel alignment, primarily near the upstream and downstream portal areas. The U.S. Geological Survey provided an unpublished geologic map of the Spirit Lake area prepared during 1981-82. Additional surface geologic mapping was performed by Portland District geologists, again with particular emphasis on the portal areas. Rock samples obtained from the core borings were tested to determine strength properties and mining characteristics. Some testing of representative core samples was performed by Atlas Copco Jarva and the Robbins Company to evaluate "drillability" by a tunnel boring machine (TBM).

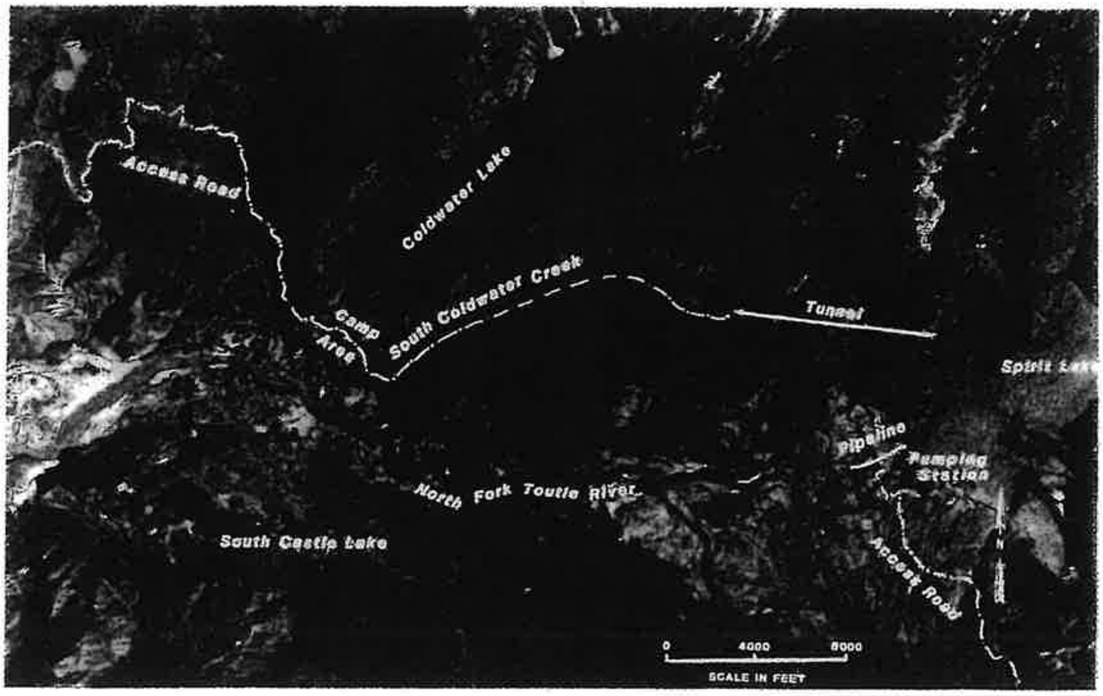


Figure 5. Spirit Lake Tunnel Alignment

Geologic conditions projected along the alignment prior to construction are shown in Figure 6. Bedrock consists of Tertiary tuffaceous and volcanic flow rocks. Quality and hardness vary with rock type and location. Core drilling produced Rock Quality Designation (RQD) values that generally averaged 70 to 75 percent, fracturing ranges from moderate to high (Terzaghi Class 3 to Class 5). Fractures are primarily tight, with clay fillings in those that occur within approximately 100 feet of the surface. Compressive strengths range from about 5,000 to 15,000 psi for the tuffaceous rock, and from about 15,000 psi to 35,000 psi for the flow rock. Hardness ranges from moderately hard (can be scratched with a knife blade but not with a fingernail) for some of the tuffaceous rock, to hard (cannot be scratched with a knife blade) for most of the flow rock.

Several fault and shear zones mapped at the surface were encountered during mining. These zones contained clay and fragmented rock that caused squeezing ground conditions in a few areas. Relatively minimal ground-water inflow was anticipated during mining, however, the shear zones were expected to contain trapped water.

DESIGN CONCEPT

The objective of the Spirit Lake permanent outlet project was to lower the lake surface by approximately 20 feet to El. 3440, and maintain that level with minimal fluctuation. In theory, lowering the lake surface to El. 3440 required draining approximately 2.8 billion ft^3 (21 billion gallons) of water, or about 65,000 acre-feet plus the inflow coming into the 275,000 acre-foot lake (the approximate size of the lake prior to drawdown).

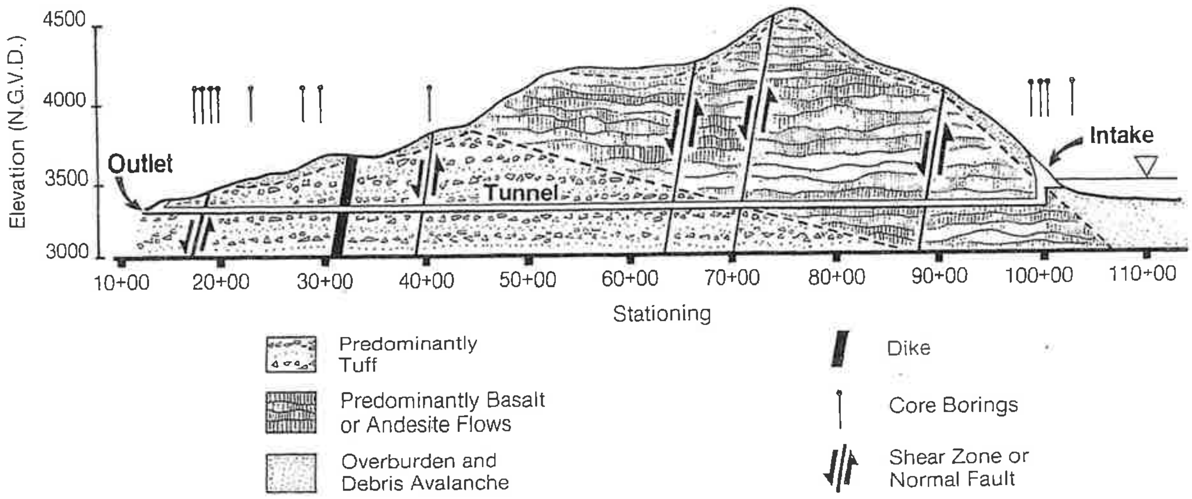


Figure 6. Geologic Profile of Tunnel Alignment Before Mining

During preliminary design, various intake and outlet concepts, tunnel cross sections, excavation methods, and lining alternatives were considered.

1. Intake Procedure. Several intake concepts were considered: a conventional lake tap; an open cut and staged intake plug excavation; a shaft and staged excavation (the method used at the Thistle Lake project in Utah); and an open cut behind a constructed cofferdam. The procedure finally selected was a variation of the shaft and staged excavation concept (Figures 7 and 8). The intake structure, a concrete bulkhead containing a single 4-foot by 4-foot gated opening with a maximum capacity of 500 cfs, was constructed behind a natural rock "cofferdam" left in place in the intake channel. The cofferdam was removed in one continuous operation prior to the start of lake drawdown.

Some flexibility in the lake control elevation was considered desirable due to uncertainties involved in determining the effects of future geologic events on the assumed "safe" lake level. Consequently, the design allows the lake surface to be lowered to El. 3400 (the tunnel invert grade), if necessary at some future date, without any modifications to the tunnel itself. Deepening the intake channel excavation and reconstructing the intake structure at a lower elevation would allow the lake surface to be lowered an additional 40 feet.

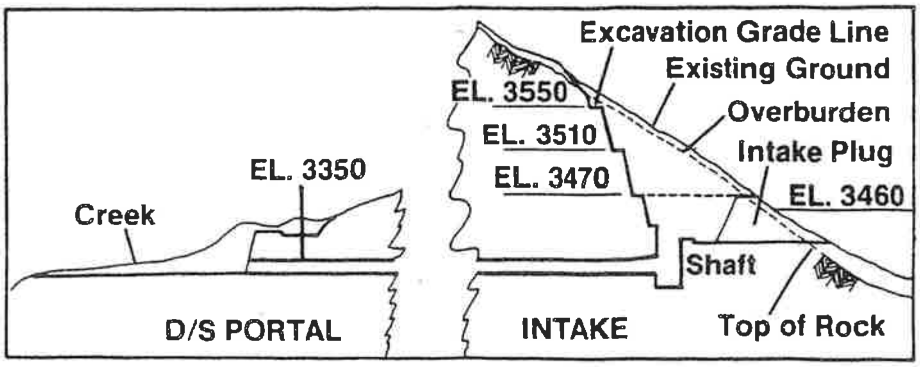


Figure 7. Excavation Profile

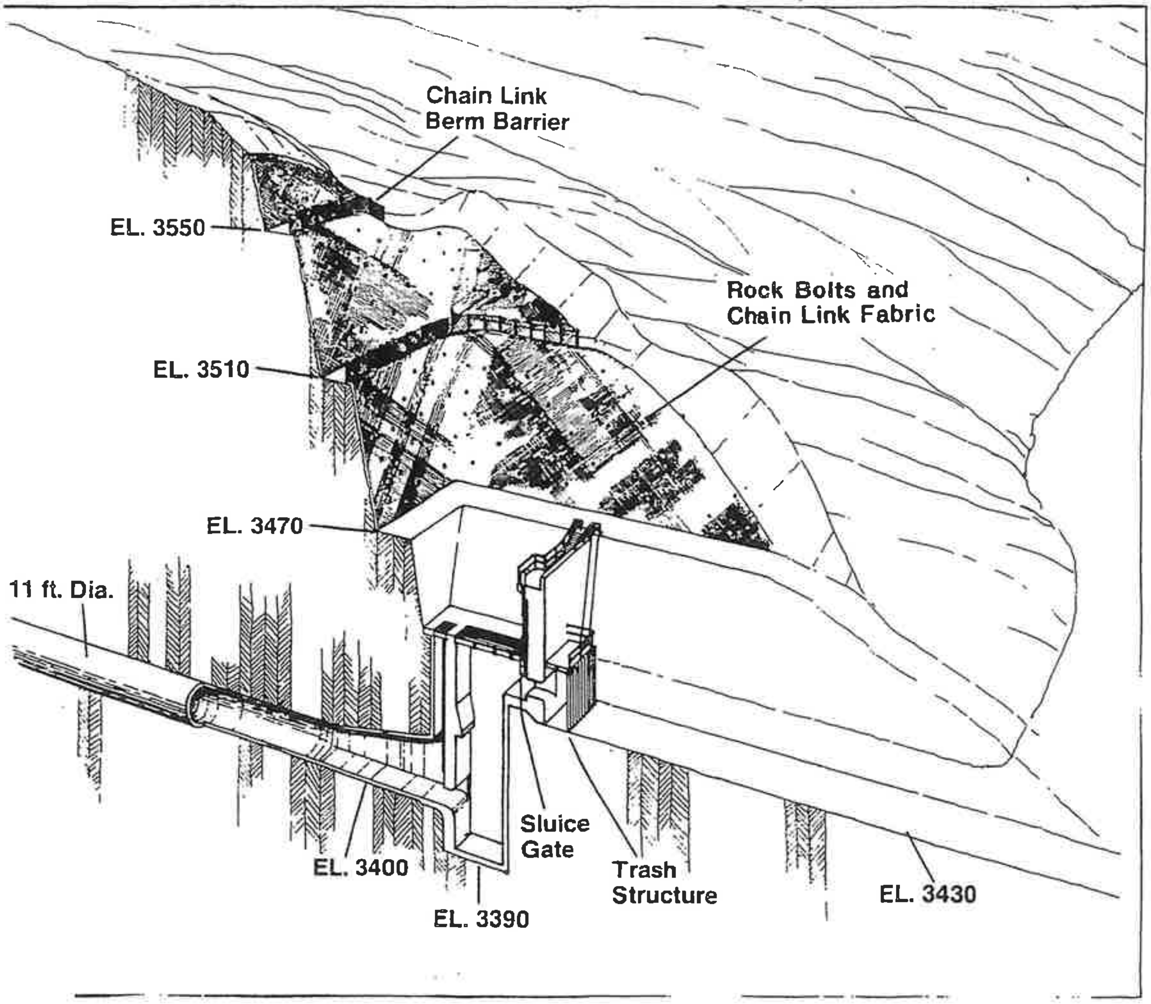


Figure 8. Intake Structure

2. <u>Tunnel Excavation and Support</u>. The design allowed the use of either drill-and-blast or TBM methods, because construction costs and time requirements were estimated to be roughly the same for each method. For the drill-and-blast method, a straight-leg horseshoe shape and smooth-wall blasting procedures would have been required. The

selection of a 12-foot-diameter size for the horseshoe tunnel was based mainly on constructibility considerations. For the TBM method, the short lead time precluded building a new machine for the project. The design allowed a range of sizes for a bored tunnel, so that a reasonable number of available used tunnel boring machines would be able to meet the specification. The minimum diameter allowed for the TBM tunnel was 10 feet 10 inches and the maximum allowed was 14 feet. The minimum diameter was dictated by hydraulic requirements. The maximum allowable diameter was based on cost and constructibility considerations.

Tunnel support was designed to be accomplished by the rock reinforcement method. For the drill-and-blast tunnel, support was to be provided by a combination of pattern rock bolts and a 4-inch layer of steel fiber-reinforced shotcrete; for the tunnel boring machine tunnel, support was to be spot rock bolts and a layer of steel fiber-reinforced shotcrete only. In poor rock conditions and anticipated fault zones, additional support was to be provided as needed with W6 x 25 steel ribs, spot rock bolts, and/or spiling bars. The shotcrete applied for support during tunnel construction was to serve as the final lining.

HYDROLOGY AND HYDRAULIC DESIGN

Spirit Lake was not only relocated by the eruption of Mount St. Helens, the hydrologic characteristics of its watershed were altered. The pre-eruption 14.9 square-mile forested watershed was transformed into an 18-square-mile basin denuded of vegetation. Mean annual precipitation over the Spirit Lake Basin ranges from 90 to over 120 inches. The mean annual snowfall amount is 283 inches, with 439 inches the maximum observed. The probable maximum flood was routed through Spirit Lake beginning at an elevation of 3,441 feet. Because of the possible catastrophic consequences of failure of the Spirit Lake debris barrier, the probable maximum flood was assumed to be preceded by a 100-year antecedent flood. The total volume of these two floods, over a period of 9 days, would be 56,000 acre feet (AF). Peak regulated outflow would be 500 cfs. The maximum lake elevation during the flood would be 3,459 feet, or the equivalent of an 18-foot rise. Because this is below the maximum safe lake level of 3,460 feet, it satisfied design criteria.

In considering the outlet works hydraulic features, certain long-term operating criteria were adopted for design. Those criteria were: (1) flow depth no greater than three-quarters the minimum clear tunnel opening; (2) lake pool normally at El. 3440; (3) gate remains fully opened after initial drawdown; and (4) maximum lake or pool level will not exceed El. 3460. (Flood routing revealed that a single 4-foot by 4-foot port, with an invert at El. 3436, through the inlet provided a normal lake elevation of 3,440 feet, and a lake fluctuation up to 5 feet above normal for most flows in the last 54 years of record.) The tunnel design discharge was based on 550 cfs (probable maximum flood condition.) The tunnel size depended on the hydraulic roughness, or tunnel wall smoothness, because of its influence on depth of flow. The approach channel will produce estimated velocities of less than 1 fps based on the maximum flow possible through the single intake port, regardless of lake level. Flow through the intake is controlled by a

4-foot by 4-foot slide gate over the exit. A 14-foot by 14-foot shaft, or downwell, located downstream of the intake structure permits flow to fall approximately 36 feet to a pool formed by a 10-foot deep rock trap. Flow enters directly into the tunnel through a 4-foot by 12-foot orifice in the back concrete wall of the downwell. Jet trajectories were determined for the full range of lake elevations and the effect of flow down the back wall on orifice flow was minimized by the installation of a deflector wall. Although the bottom of the shaft does not have direct jet impact, the need for a plunge-pool type energy dissipator required a shaft extending below the tunnel invert. A depth of 10 feet below the tunnel invert (El. 3400) was selected as sufficient to dissipate the energy. The orifice through the wall provides passage for flows directly into the tunnel at the same width (12 feet), and tends to reduce the wave propagation into the tunnel downstream. Air for the orifice and tunnel is supplied via the 4-foot by 14-foot access shaft behind the deflector wall. The 12-foot-wide by 18-foot-high tunnel entrance immediately downstream of the shaft concrete wall provides a transition into the circular tunnel configuration within 30 feet. The additional head room (top El. 3418) ensures adequate air passage for the design discharge at the tunnel entrance.

STRUCTURAL AND GEOTECHNICAL DESIGN

1. Intake Structure. The concrete intake wall functions as a dam and supports the sluice gate (see Figure 8). The wall spans the width of the intake channel. It is keyed 3 feet and dowelled into the rock. Designed as a simple span slab, it is inherently stable. The following loads were considered: (1) wall dead load; (2) external water force; (3) uplift; (4) earthquake forces; (5) ice and snow pressure; (6) wind pressure of 30 psf; and (7) wave pressure.

A zone 4 seismic coefficient of 0.20 (based on Corps of Engineers' Engineering Regulation 1110-2-1806) for the lateral earthquake force was used due to the unstable nature of the Mount St. Helens area. The seismic water force on the structure was based on the Westergaard parabola. An ice force of 5,000 psf for an ice thickness of 2 feet is assumed to load the structure at normal pool elevation. Snow pressure is based on an equivalent fluid pressure of 700 psf at El. 3446.5 on the downstream face of the structure. Based on previously measured snow depths, a basic ground snow depth of 13 feet was used. A stable snow slope of 40 degrees was combined with drifting snow. Due to the steep, high rock side slope, it was assumed that the snow would fill the void downstream of the concrete intake structure and pile to an assumed elevation of 3,505 feet. Lateral load was determined by the equivalent fluid pressure method using a snow density of 12 pounds per cubic foot. The following load conditions cause the maximum stresses in the structure: (1) earthquake during initial pool drawdown (lake El. 3465), and (2) water level at normal pool with snow pressure acting toward the lake.

The shaft deflector wall is simply supported at the rock wall to support horizontal loads. It is keyed 1 foot into the rock. Concrete/rock anchors are designed to resist all shear from horizontal loads. Columns support the vertical load of the wall adjacent to the orifice at El. 3400. The entire structure bears on rock at El. 3390. Force from the water jet is 2,000 psf horizontally and 1,600 psf vertically over 4 square feet at the centerline of the structure. It was considered possible that the orifice could plug and the water on the upstream face of the wall could rise to the pool level. Thus the wall was designed with the capacity to withstand water loads based on a pool elevation of 3,465 feet.

A trash structure was built on the lake side of the intake. It is a 13-foot-wide by a 16-foot-high galvanized steel structure located 6 feet upstream from the face of the concrete intake structure. It will allow debris up to 8 inches in diameter to pass. A sliding flush-out gate is built into the structure to aid in removing debris that may build up. The structure was designed using three L-shaped frames. It is embedded in rock at the base and bolted to plates on the face of the concrete intake structure on the top. Additionally, the trash structure has the capacity to withstand the impact of a 40-foot-long by a 3-foot-diameter log moving at a velocity of 1 fps. A 5-foot head differential was assumed to result from possible blockage of flow through the structure. A 10-foot head differential was checked as an overstress condition.

Excavation for the intake was accomplished using 4V on 1H presplit rock cut slopes. Resin-grouted rock bolts were used to support the rock slopes, with chain-link fabric used to prevent loose rock from raveling. The 1-1/4-inch diameter rock bolts varied in length from 14 to 24 feet. Although the rock reinforcement was installed as the excavation progressed, one of the major fracture systems dipped out of the slope and some rock fallouts did occur in the excavation backslope. These relatively minor areas were replaced with backfill concrete during construction.

2. Tunnel.

a. Original Design. Rock loads for the varying ground conditions were calculated using the modified Terzaghi system. The rock conditions assumed "average" for the tunnel were "moderately to very blocky and seamy," class 4-5, with an RQD of 70 to 75 percent. Based on the design investigations prior to construction, squeezing ground was anticipated within the major shear and fault zones predicted. Rock condition assumed in these zones was "squeezing rock, moderate to great depth," class 7-8. Stand-up time studies indicated that for average rock conditions, several days would be available to install supports with only a few hours available for squeezing rock situations. Although disturbance to the rock surrounding the excavation was considerably less with the TBM, compared to conventional drill and shoot methods, the possibility of loosening loads developing in the fractured rock, plus the possibility of encountering squeezing ground, dictated the selection of the specified support system.

Steel-fiber-reinforced shotcrete was specified as the primary reinforcement/support element due to its rapid ease of application and extra load-carrying capacity compared to plain shotcrete, or even shotcrete reinforced with conventional wire mesh. The rib set-shotcrete support system was to consist of steel rib sets with shotcrete placed as continuous blocking and lagging while erecting each rib set. This support system was intended to be used only in areas where rock conditions dictated the need. In squeezing ground, rib set spacing was to be reduced and invert struts required. The design of the rib set-shotcrete support system was based on both the steel rib sets and the shotcrete carrying the load. The magnitude of load carried by the rib set depended on the relative stiffness of the rib set and the shotcrete, the strength of the shotcrete as a function of time, and the rock load as a function of time. The rib set was designed to carry 75 percent and the shotcrete 25 percent of the rock load, except in squeezing rock. In squeezing rock, the rib set was designed to take all of the rock load. The rock load was assumed to mobilize at 50 percent initially and the remaining 50 percent over 4 days. The design procedure for the rib set considered the elastic effects of the rock, in addition to the procedures given in Corps of Engineers design manual EM 1110-2-2901.

b. Tunnel Construction. A total of 14 firms submitted bids for construction of the Spirit Lake Tunnel with five firms bidding drill-and-blast and nine bidding the TBM option. On June 7, 1984, a contract in the amount of $13,469,247 was awarded to a joint venture of Peter Kiewit and S.J. Groves. The contractor selected the TBM option, choosing to use an 11-foot-diameter Robbins Model 119-222 boring machine that previously had been used at the Terror Lake Project in Alaska. Weighing approximately 112 tons, the 55-foot-long TBM has a partially shielded cutterhead with: twenty-seven 17-inch-diameter, disc cutters; a two-gripper advance system; 4 electric motors, each with a 200 hp capacity; and about 400 feet of trailing gear and platform cars (Figure 9). A contractor proposal was accepted by the Corps to substitute smaller W4 x 13 rib sets and use precast concrete sections in lieu of shotcrete for the tunnel invert (Figure 9).

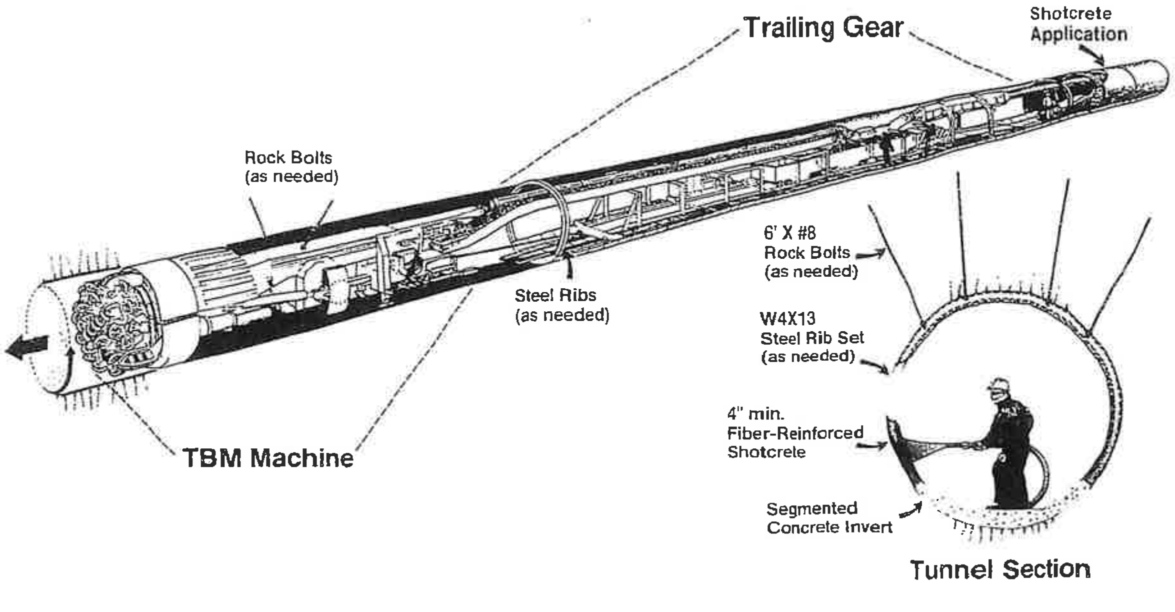


Figure 9. Tunnel Boring Machine

The tunnel was driven from the downstream end toward Spirit Lake, concurrently with excavation for the intake at the upstream end. At its maximum depth, the tunnel was mined 1,200 feet below ground. The first 230 feet of tunnel was excavated by drill-and-blast to proceed past a known shear zone before starting machine boring. The TBM started operations on September 28, 1984. On March 5, 1985, the TBM holed through into the completed intake transition and the first gate opening occurred in late April 1985.

Figure 10 indicates the rock encountered and support actually installed during mining. In the portion of the tunnel mined by the TBM, rib sets were used in areas determined by the Corps of Engineers field geologist or the contractor. Behind the TBM, the steel fiber-reinforced shotcrete was applied by the wet mix process, in areas determined necessary by the Corps' field geologist, to prevent possible future erosion, plucking, or sloughing. Mining and support were accomplished on a 6-day-week, 3-shift-per-day schedule. The average advance rate during TBM operation was 75 feet per day. Ground-water inflow into the tunnel varied from a sustained total average of 500-700 gpm, to maximum short-period inflows as high as 1,200 gpm in the case of one fault zone that contained a relatively large amount of trapped water. A total of 241 rib sets encased in shotcrete was used in nine shear/faulted rock zones. The foot plates of the rib sets were shaped to fit the edges of the precast invert slabs. The rib sets were blocked with timber wedges until shotcrete placement. Where squeezing ground was encountered (as predicted), rib set spacing was decreased to 2 feet. The contractor was not able to grout under the invert slabs due to excessive water flow. As a result, many of the invert slabs were broken or cracked during construction. In areas of rib sets, the broken or cracked slabs were removed and an invert W4 x 13 strut was welded in place and concrete placed to match the invert finish surface. A total of 2,760 cubic yards of shotcrete was placed in the TBM portion of the tunnel, and no rock bolts were required. Shotcrete thickness averaged about 2 inches in the areas where no steel sets were installed and about 6 to 8 inches where it was necessary to cover the sets.

AESTHETIC AND ENVIRONMENTAL CONSIDERATIONS

Design and construction were heavily influenced by the designation of the entire area as a National Volcanic Monument. Throughout both the design and construction periods, extensive coordination efforts were required to ensure the vested interests of the three Federal agencies involved with Mount St. Helens (U.S. Forest Service, U.S. Geological Survey, and the Corps of Engineers) were protected and served. Top priority was placed on minimizing any detrimental impact on the area. Both the downstream portal and the intake locations were selected and designed for minimum visual impact to the natural surroundings. Vehicle access into the area was allowed only on existing roads. No new roads were permitted for the intake construction, and only a temporary road for access to downstream construction. Impact on the area was further reduced by requiring construction camp facilities near the site to enable work to continue through the winter. Excavated materials from the intake were placed in the deeper portion of Spirit Lake, while rock from the tunnel was placed in a ravine just downstream from the tunnel portal and contoured to match the existing topography.

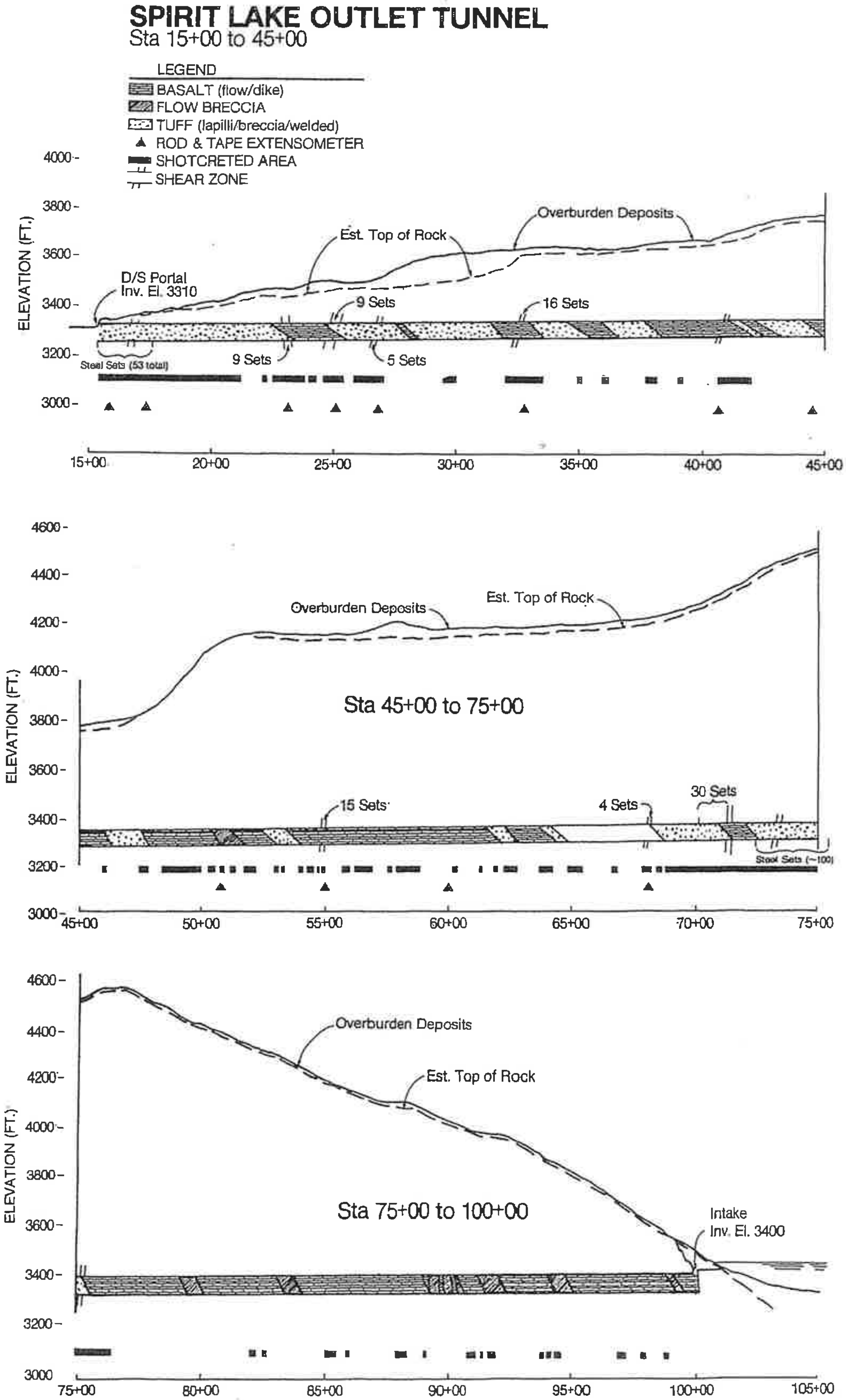


Figure 10. "As built" Conditions

LAKE DRAWDOWN

Drawdown of Spirit Lake through the completed tunnel began in late April 1985. The elevation of the lake surface at that time was approximately 3,452 feet, about 8 feet lower than had been expected during design. To minimize the erosion and sediment transport, a detailed downstream monitoring program was carried out during this period by personnel from the Corps, the U.S. Geological Survey, and U.S. Forest Service. Tunnel discharges, which were controlled by varying the intake gate opening, ranged between 200 and 450 cfs. Figure 11 is a photograph of the outlet and completed tunnel during lake drawdown.

By September 1985 the lake had been lowered to the desired El. 3440 control level. A floating log boom had been installed to prevent trash from entering the entrance channel. Figure 12 is a photograph of the completed intake structure taken after drawdown.

Figure 11. Completed Downstream Portal During Lake Drawdown Period

SUMMARY AND CONCLUSION

The total cost of the Spirit Lake Outlet Project was approximately $29,000,000. This figure includes about $12,350,000 for the cost of the interim pumping necessary to maintain the lake level at a safe elevation until the tunnel became operational. it also includes approximately $1,100,000 for Engineering and Design (including $793,000 for explorations) and $1,600,000 for Supervision and Administration during project construction. The tunnel bid price of $13,469,247 was increased to a final cost of about $13,660,000 as a result of change order work added during the contract. Considering that the Government Estimate at bid opening was $12,090,723 and the highest bid was $25,123,900, the final cost of the tunnel appears very reasonable.

As he spoke at the 27 April 1985 Spirit Lake Tunnel Dedication, Booth Gardner, Governor of Washington, summed up the feelings of those people who had lived below Mount St. Helens for 5 years, always wondering whether Spirit Lake was going to remain leashed. "The completion of the tunnel, an extremely impressive engineering feat, relieves the threat on the populated areas," he stated, "and allows the people of Cowlitz County to move one step closer to business-as-usual." Today the Spirit Lake tunnel is serving, and will continue to serve, the people who live near Mount St. Helens.

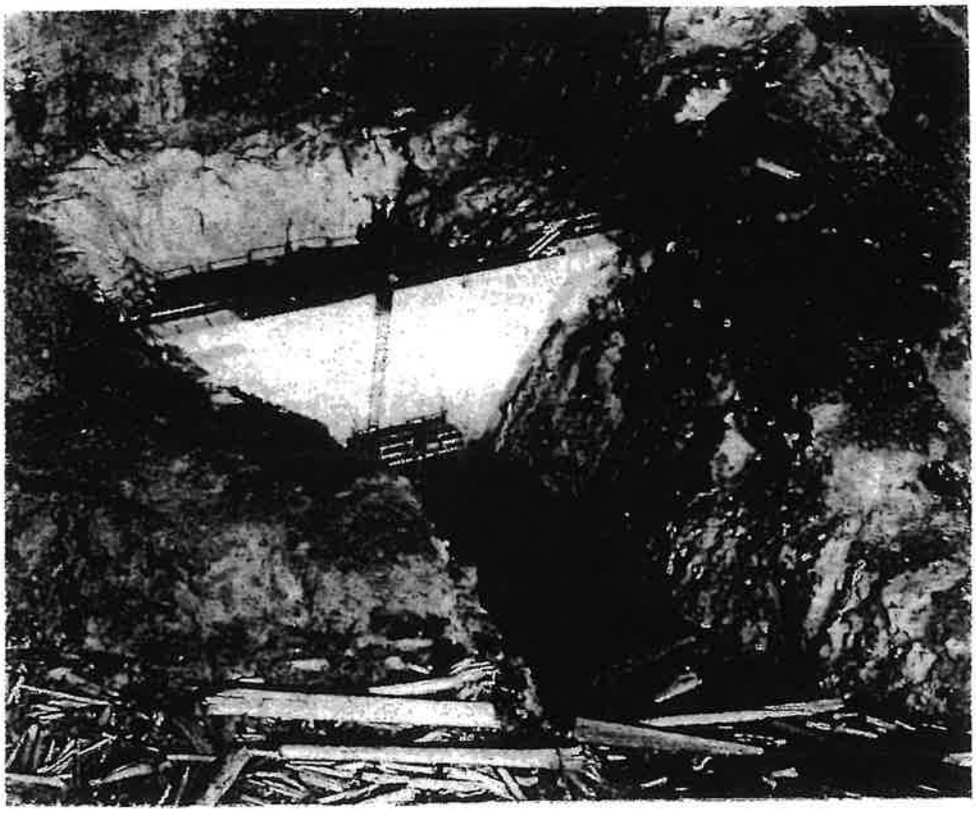


Figure 12. Completed Intake Structure After Lake Drawdown Period

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