Yakima River Basin Study

Lake Kachess Inactive Storage Technical Memorandum

U.S. Bureau of Reclamation
Contract No. 08CA10677A ID/IQ, Task 4.9

Prepared by

HDR Engineering, Inc
Anchor QEA

U.S. Department of the Interior
Bureau of Reclamation
Pacific Northwest Region
Columbia-Cascades Area Office

State of Washington
Department of Ecology
Office of Columbia River

March 2011

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1.0 Introduction

This technical memorandum describes the design criteria, geology, facilities, property easement needs, challenges and next steps for a project that would withdraw additional water from Lake Kachess. The Lake Kachess Inactive Storage project site is located in west-central Washington just east of Interstate 90 (I-90) near the small town of Easton. Figure 1 below shows general project location and Figure 2 shows a more detailed aerial view of the pipeline alignment.

The purpose of the project is to better utilize the storage volume of water available in Lake Kachess by lowering the outlet of the lake, which would allow withdrawal of an additional 200,000 acre-feet of water for beneficial downstream use when needed.

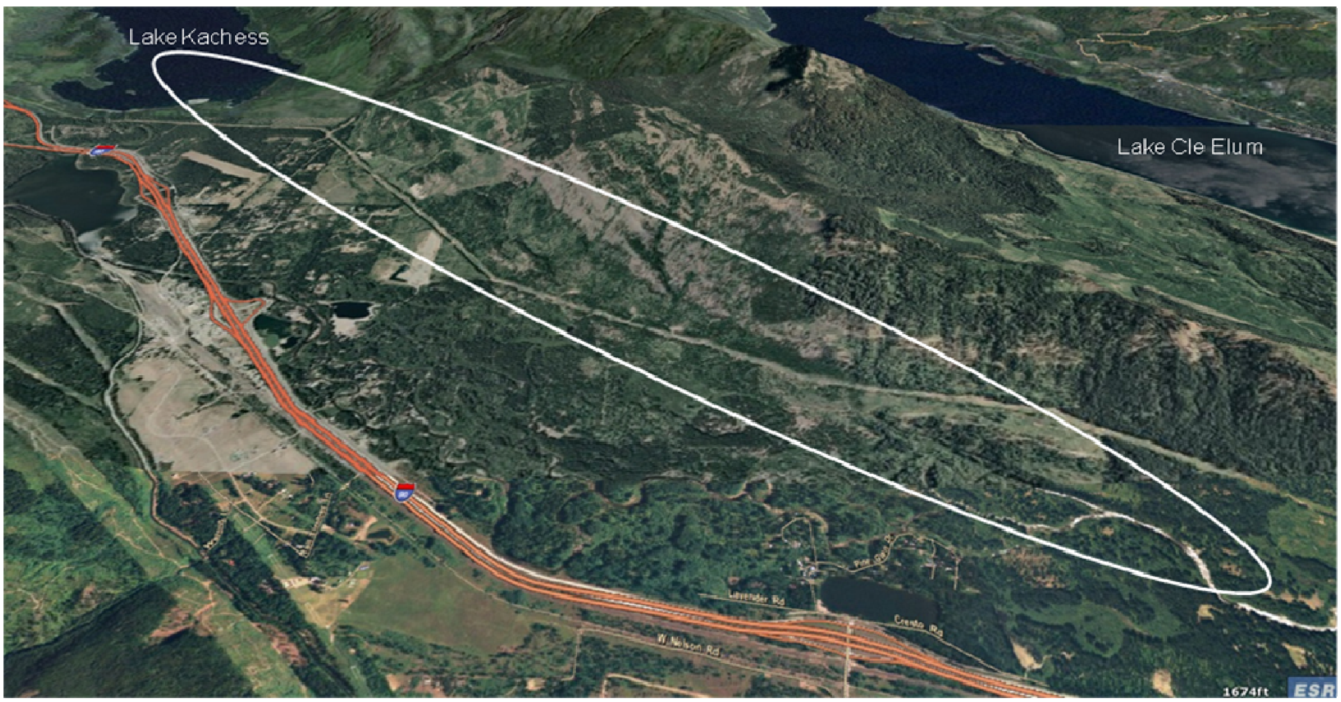

Figure 1. Lake Kachess Inactive Storage project Location (outlined in white)
(Note: Figure 2 shows a more detailed aerial view of potential alternative project facilities that are discussed in this report.)

Two alternatives have been identified to withdraw the additional water from Lake Kachess, both starting from a new lake tap outlet in the Lake Kachess Dam about 80 feet below the existing outlet at the southeast end of the lake: Alternative 1 would use a gravity-flow tunnel that would discharge approximately 4.6 miles southeast of the Lake Kachess Dam into the Yakima River; Alternative 2 would withdraw water through a pump station near the lake shoreline and discharge to the Kachess River just downstream of the dam.

The Lake Kachess Inactive Storage project is one of several potential structural and operation changes being studied to improve water resources management in the Yakima Basin. Other alternatives include: a flow transfer pipeline project between Lake Keechelus and Lake Kachess, the Wymer dam and reservoir project, conveyance improvements at the former Wapatox Power Plant, reducing or eliminating irrigation district diversions used for power production at the Roza and Chandler power plants during outmigration of juvenile anadromous fish, modifications of the Kittitas Reclamation District Main Canal and South Branch, and raising the pool level at Cle Elum Dam. These options are described in other technical memoranda as part of the Yakima River Basin Water Enhancement Project.

2.0 Design Criteria

2.1 Lake Kachess Storage Volume

The purpose of the Lake Kachess Inactive Storage project is to provide the capability to withdraw 200,000 acre-feet of water from Lake Kachess and transfer that flow into the Yakima River for beneficial downstream use when needed. This would be in addition to the volume that can currently be discharged through the existing Lake Kachess Dam outlet structure, which has a gate sill (bottom) at elevation 2192.75. Water stored in the lake below that elevation is currently designated as unusable “inactive” storage in the reservoir.

Based on a Lake Kachess bathymetric survey, removing an additional 200,000 acre-feet of water below the current outlet elevation 2192.75 would require drawing the lake down approximately 80 additional feet to approximately elevation 2110.

Figure 3 shows the Lake Kachess bathymetric survey contours, Figure 4 presents the existing lake area and capacity curves to elevation 2192.75, and Figure 5 shows an extended capacity curve for the lake down to elevation 2100. Table 1 below summarizes the existing and proposed Lake Kachess storage depths and volumes.

Table 1. Lake Kachess Existing and Proposed Storage Depths and Volumes

	SPILLWAY CREST ELEVATION (FEET)	TOP OF INACTIVE STORAGE POOL (FEET)	MAXIMUM STORAGE DEPTH[1] (FEET)	TOTAL STORAGE VOLUME (ACRE-FEET)
Existing Kachess	2,262	2,192.75	69.25	239,000
Proposed Kachess with New Outlet	2,262	2,110.00	152.00	439,000

[1]Existing and proposed storage depths are the differences between the spillway crest elevation and top of existing inactive storage pool and the proposed new inactive storage pool elevations.

2.2 Flow Transfer Rate

The capacity for transferring Lake Kachess water to the Yakima River either by gravity tunnel or pump station was established based on the need to convey the additional 200,000 acre-feet of water over an approximate four- to six-month irrigation season. An average flow rate of between 550 to 830 cfs would be required to convey the additional 200,000 acre-feet during the the four to six month season. There was also an expressed criterion for the project to have the ability to convey up to 1,000 cubic feet per second (cfs) at times during the season. With this higher maximum capacity, the flow could be distributed over a shorter period if needed for downstream demands and operations.

Based on these criteria, the tunnel capacity was established at 1,000 cfs to 1,200 cfs when Kachess Lake is at the top of the current inactive pool elevation 2192.75. As the lake is drawn down to elevation 2110, the tunnel capacity decreases (due to reduced differential heads between the lake and tunnel discharge to the river) to approximately 600 cfs. The assumption in the Integrated Plan model is for a flow of 1,200 cfs from the inactive pool until early October. More precise assessment of how the inactive storage will be used should be performed during preliminary design.

The actual capacities will vary within these ranges depending upon the head loss in the tunnel. In turn, the tunnel head loss will depend upon how much of the rock tunnel is left unlined, lined with shotcrete, and/or lined with precast or cast-in-place reinforced concrete.

To meet these same criteria for Alternative 2, the firm pump station capacity (one large pump out of service) was established at 1,000 cfs. The variability in flow as the inactive storage lake level drops will likely be less of an issue with the pumping option, but this will have to verified during preliminary and final design.

2.3 Fish Screens

The initial project concept did not include fish screening of the Lake Kachess lake tap outlet. There was some early discussion that that submerging the outlet in a minimum of 50 feet of water would negate the need for fish screens. However, after further discussion and agency comments at a project Yakima River Basin Water Enhancement Project Workgroup meeting, a criterion was included to add fish screening of the Lake Kachess outlet. With fish screening in place, the depth over the outlet could be reduced from 50 feet to about ten feet of water over the screens at minimum pool elevation, placing the top of the screens at elevation 2100.

2.4 Minimum Kachess River In-Stream Flow

Since the inactive storage project would draw the reservoir down below the existing outlet to the Kachess River, a minimum flow of 20 cfs would be pumped to the Kachess River to provide flow to that part of the river flowing into Lake Easton and on into the Yakima River. This in-stream flow capability would be provided for both the gravity tunnel and pumping alternatives.

2.5 Operational Rule

The Lake Kachess Inactive Storage gravity flow tunnel facilities are designed to only be operated after the Lake Kachess elevation has lowered to within a few feet of the existing outlet structure at elevation 2192.75. Opening gates (especially for the gravity tunnel alternative) with Lake Kachess much higher than elevation 2192.75 could result in flow rates that exceed the design flows – which could overwhelm downstream facilities and/or cause environmental damage. Using one smaller low flow gate and/or partially opening larger gates to limit flows under higher head conditions should be investigated during preliminary design.

3.0 Geology

The general project area is located on the eastern side of the Cascade Range, within the Cascade Volcanic Belt, close to the boundary between the northern and middle cascades. As noted in the geologic report for the Kachess Dam (Bennett 1993), the northern Cascades are marked by primarily intrusive and metamorphic rocks. The Straight Creek Fault is the major northerly trending fault of the northern Cascade Range and passes through the Kachess Lake and Yakima River valleys in the central cascades to the south. The central Cascades are dominated by

Mesozoic crystalline rocks and Eocene volcanic and sedimentary rocks (Cheney 1999). Cheney notes that, the Eocene stratigraphy consists of Teanway River and Manastash River blocks on the east side of the Straight Creek Fault and the Green River-Cabin Creek block on the west. The Yakima River Valley, which is traversed by Interstate 90, separates the Teanaway River block on the northeast from the Manastash River block on the southwest.

The geology of the area that includes the Alternative 1 tunnel alignment is shown on USGS geologic map of the Snoqualmie Pass Quadrangle (Tabor, *et al*. 2000). Figure 6 shows the surface geologic map along the proposed tunnel and the Alternative 2 transmission pipeline alignments and the location of the Straight Creek Fault. The tunnel alignment considered in this report passes through areas mapped with the following surface geologic units: Teanway Formation (Tt), Silver Pass volcanic member (Tssp), alpine glacial deposits (Qag), and alluvium (Qa). The pipeline alignment passes through areas mapped with surface geologic units of alpine glacial deposits (Qag) and alluvium (Qa). As noted in Bennett 1993, alpine glaciation was extensive in this area and has significantly modified the topography and mantled much of the area with glacial deposits.

Based on the geologic stratigraphy shown on Tabor, *et al*. (2000), it appears that the tunnel alignment predominantly passes through Teanaway River block rock consisting of Teanway Formation and Silver Pass volcanic member. Teanway River block, strongly deformed Eocene sandstone and siltstone of the Swauk Formation, and interbedded intermediate to felsic volcanic rocks of the Silver Pass volcanic member of the Swauk Formation are overlain by relatively undeformed basaltic flows of the Eocene Teanaway Formation; which are overlain by coal-bearing fluvial sandstones of the Roslyn Formation (Cheney 1999). The Teanaway Formation is mostly basalt with lesser felsic volcanic rocks and minor arkosic sandstone, while the Swauk Formation is predominantly arkosic sandstones with minor volcaniclastic rocks. The tunnel and tunnel access portals at each end are located such that they are anticipated to be primarily constructed within the bedrock. If this alternative is selected, detailed site-specific geotechnical and geological investigations will be required.

Based on the geologic information reviewed, it appears that the Alternative 2 transmission pipeline could be installed primarily within the alpine glacial deposits and the alluvium. Rock excavation may also be encountered during construction of the pipeline.

4.0 Facilities Description

4.1 Alternative Development

Drawing Kachess Lake down an additional 80 feet below an existing outlet (that has a dredged channel to remain open) presents a very significant engineering challenge. The following basic concepts were considered prior to selecting the two conceptual alternatives for further study:

- Floating pump station – This concept was briefly unsuccessfully attempted on Cle Elum Lake for a much smaller pump station in the late 1970s. Due to the issues associated with the required 1,000-cfs capacity pump station (e.g., large pumps and motors, power demands, pipeline sizes), this was deemed to be an impractical alternative for Lake Kachess.

- Deep-cavity pump station with vertical or horizontal centrifugal pumps and motors located within the cavity below the Lake Kachess water-surface elevation – The shaft would be excavated to the intake tunnel level and then the large pump station room cavity would be mined out of the rock at the end of the shaft. This concept would allow the vertical access shaft down to the pump station cavity to be much smaller in diameter than the shafts currently needed for the Alternative 2 vertical turbine pump station. The tunnel to the lake would be bulkheaded and tapped by pressure pipe manifolds leading to the suction side of the pumps. The pump discharge pipes would exit through the vertical shaft to the ground surface. Although this concept would allow for a smaller vertical access shaft, it would also introduce new complexities for pump station access, maintenance, and ventilation, as well as potential for accidental flooding of the cavity. Although not further refined or considered for this conceptual analysis, this configuration should be evaluated as part of a more detailed Alternative 2 pump station feasibility analysis.
- A siphon intake – Siphoning would only be practical for up to about 25 feet of drawdown. Since the nearly 60 feet of additional drawdown (80 feet total) would require a deeper intake, a partially siphoning intake was not further considered.
- Tunnels and a lake tap – Lake taps (often referred to as the Norwegian lake tap method) have been successfully accomplished at various locations around the world. This method requires that the lake tap location be underlain by a minimum depth of competent rock that can be tunneled through to reach a lake tap location. Detailed information about the underlying geology is not available, but since Lake Kachess is in a glaciated valley bounded by exposed rock it was assumed for this appraisal study that competent rock extends under the southeast edge of the lake and a lake tap could potentially be used for the outlet. If a lake tap cannot be used more conventional lake drawdown, coffer dams, surface dredging/drilling, and/or other underwater construction methods would have to be used.

4.2 Selected Alternatives

Two potential lake tap alternatives were identified to transfer an additional 200,000 acre-feet of water from Lake Kachess into the Yakima River. Both alternatives would require a lake tap and outlet from the southeast end of the lake to a tunnel, a control works structure, and either a tunnel or pump station.

Alternative 1 – Gravity Flow Tunnel. This tunnel would be aligned from the portal next to the lake, approximately 24,200 feet southeast and downstream to a discharge downstream into the Yakima River through a portal next to river. A relatively small 20-cfs pump station would supply water from the portal as a minimum instream flow to the Kachess River.

Alternative 2 – Lake Kachess Pump Station. This alternative would include a 1,000 cfs pump station located in the portal next to the lake. The station would pump water from the lake tap tunnel through an approximately 6,500-foot transmission pipeline aligned to the southwest to discharge into the Kachess River downstream of the existing Kachess Dam outlet channel.

Figure 7 is a plan view showing the project area elevation contours and the proposed project facilities for both alternatives.

This report uses available information to present two potential appraisal level alternatives. Definitive conclusions about the feasibility of these methods were beyond the scope of this appraisal level study and will require detailed predesign level evaluation. Significant challenges with these alternatives are:

- The need for more site specific and detailed geological information to confirm the feasibility of a lake tap in this location.
- The large-diameter and deep-tunneling shaft that will be required on the lakeshore.
- The long rock tunnel required to reach the Yakima River discharge location.
- The very deep pump stations that would be required for both alternatives (and much larger capacity for Alternative 2).
- Handling and removal of sediment from a deep pump station and tunnel system.
- An agency requirement for a submerged fish screen system over the lake tap outlet.

4.3 Lake Tap

There is a lack of specific geologic information for the proposed outlet area. However, based on general geologic maps of the area, it has been assumed in the development of alternatives for this report that an outlet tunnel could be founded in rock that could extend out under the south end of the lake. It was further assumed that the end of this rock tunnel could then be suitable for using a lake tap for opening the tunnel intake under a minimum of 80 feet of water.

The lake tap elevation in the lake bottom was set by allowing for a minimum of ten feet of water over the top of the fish screens at the minimum lake elevation 2110. The lake tap elevation was further lowered after accounting for the height of the fish screen assembly, and an assumed depth of silt over the rock in the bottom of the lake. The resulting top of the lake tap (at the lake bottom) was assumed to be at elevation 2072. Drawings of the proposed lake tap are shown on Figure 8 and Figure 9.

The approximately 2,900-foot-long, 13-foot-diameter tunnel would be mined from a deep portal near the lakeshore to the lake tap location in the lake (Figure 8). The lake tap riser shaft to the lake opening would either be an inclined or vertical, unlined 13-foot-diameter shaft. Although some assumed lake tap tunnel elevations are shown in the design concept, the depth of the tunnel under the rock surface and the thickness of rock to be left as the final plug would be determined by specialized designers. These design criteria could only be determined after completing a geotechnical exploration and testing program to obtain more specific information about lake-bottom rock characteristics.

At the end of the horizontal tunnel, the vertical or inclined riser shaft would be mined out of rock up to an elevation where explosive charges would be placed to remove the final plug section to the bottom of the lake. The holes for explosives would be drilled in circular patterns and detonated in a sequence to shatter and remove the rock to a finished cylindrical opening. Before remotely detonating the charges to remove the plug, the tunnel section would be filled with water except for a small pressurized air space at the end of the tunnel under the plug section. The pressurized air space would be designed to help keep the explosives dry and absorb the blast energy. The shattered rock from the plug would drop into a rock pit excavated at the end of the tunnel to receive the debris. This would leave an unobstructed section of tunnel to a gated control structure in the lakeshore portal. The gates in the control structure would prevent the rest of the tunnel (Alternative 1) or pump station (Alternative 2) from being flooded.

After the lake was drawn down to a minimum depth, a prefabricated fish screen assembly would be grouted in place over the lake outlet.

4.4 Lake Kachess Fish Screen

The Lake Kachess fish screen could consist of four cylindrical stainless steel T-screens manifolded every 90 degrees around a 12-foot-diameter steel can. Each of the four wedge-wire T-screens would be 7 feet in diameter and 26 feet long. Each T-screen would connect to the can using a 60-inch-diameter steel pipe. The entire screen system would be designed to be assembled on land (near the shoreline), then launched and floated out to be sunk in place over the recently exposed lake tap opening. Grout ports would be installed at the base of the assembly to help seal the annular space between the can and the rock-tap shaft.

It is expected that divers would perform seasonal cleaning and clearing of sediment around the screen before each use. Since Lake Kachess would already be down to its existing outlet elevation 2192.75, a maximum of 90 feet of water would be over the screens when cleaned. Figures 8 and Figure 9 show the proposed fish screen configuration. The lake tap opening may or may not lend itself to this kind of screen construction. Further evaluation of the need for a deep outlet fish screen may be warranted. If the deep outlet fish screen is required, additional analysis and comparison of other alternatives will be required to determine the most effective solution for screening the outlet.

4.5 Alternative 1 – Gravity Flow Tunnel

Alternative 1 includes a tunnel that starts at Lake Kachess portal and roughly parallels the Yakima River and I-90 east of the river under the Easton Ridge. The tunnel ends and discharges approximately 24,200 feet from the Lake Kachess portal at the Yakima River portal at approximately River Mile 196.5, about 0.6 miles east of Lavender Lake. From this downstream tunnel portal, the water would flow through an open channel to a discharge structure on the river bank. Figure 10 shows a proposed gravity-flow tunnel profile.

Tunnel Hydraulics

The top of the closed spillway gates for the Lake Kachess dam spillway is at elevation 2262. The outlet invert is at elevation 2192.75 for an active depth of 69.25 feet and active storage volume of 239,000 acre feet. The purpose of this project is to access an additional 200,000 acre feet of water below the existing outlet elevation. The tunnel would not be used until elevation of the lake surface is approaching elevation 2192.75 and can no longer be discharged through the existing outlet. Based on the Lake Kachess capacity curve, the additional 200,000 acre-feet requires the new outlet to be capable of drawing the lake down approximately an additional 80 feet below the existing outlet to elevation 2110.

To convey the 200,000 acre-feet over a four- to six-month irrigation season would require an average capacity of 550 to 830 cfs. Based upon 1994 routing, this effective time of use could be as short as 60 to 90 days – which would require an average flow of between 800 and 1,100 cfs. For this analysis, the range of tunnel capacity was selected to be from a maximum of 1,200 cfs at maximum (elevation 2192.75) Lake Kachess level to a minimum of 600 cfs at minimum (elevation 2110) Lake Kachess level. As mentioned earlier, the assumption in the Integrated Plan model is for a flow of 1,200 cfs from the inactive pool until early October. More precise assessment of how the inactive storage will be used should be performed during preliminary design.

For hydraulics purposes it was assumed that the tunnel would be partially lined and unlined rock with an average Manning roughness coefficient (n) of 0.025. The maximum desired flow velocity through the tunnel was set at 10 feet per second. To meet these hydraulic criteria, the tunnel was sized to be either a 13-by-13-foot horseshoe-shape or 14-foot-diameter circular tunnel.

The average water surface in the Yakima River at the discharge location at Yakima River Mile 196.5 is at approximately elevation 2075. To prevent fish from being attracted to the Yakima River outlet the discharge was set at elevation 2085 to provide a 10-foot, cascading-flow fish barrier along the river. That provides a maximum of approximately 107 feet of differential "driving" head between the tunnel inlet and outlet. As the reservoir is drawn down to elevation 2110 this driving head decreases to 25 feet and the corresponding flow through the tunnel would be down to approximately 600 cfs. Since the Lake Kachess elevation varies from 2192.75 to 2110, the overall average flow capacity through the tunnel would be about 1,000 cfs.

Tunnel Portals

A minimum of two tunneling portals would be sited; one at the south end of Lake Kachess and one near the Yakima River near River Mile 196.5, as described below. The Lake Kachess portal would serve as the launching portal for the lake tap tunnel mining and as either the launching or receiving portal for the tunnel to the Yakima River portal.

Lake Kachess Portal

The graded ground surface at the Lake Kachess portal would be at approximately elevation 2275. Because of the depth of the tunnel at the lake tap (approximately elevation 2020); the lake Kachess portal would be about 260 feet deep.

For the Alternative 1 gravity tunnel, the Lake Kachess portal would be approximately 65 feet in diameter. This diameter was selected to allow tunnel construction access and placement of the control gates and a 20-cfs instream flow pump station within the portal.

Figure 11 and Figure 12 show the Lake Kachess portal plans and section.

Yakima River Portal

The Yakima River portal near River Mile 196.5 would be approximately 55 feet in diameter. Depending on the depth to rock and which way the tunnel is driven and sloped, it could vary in depth from a minimum of 50 feet to a maximum of 80 feet from a surface grade at elevation 2092. This portal would be connected to an open channel and/or pipeline that would convey the flow to a discharge structure next to the Yakima River.

Figure 13 and Figure 14 show the Yakima River portal plan and sections.

Tunnel Isolation Gates and Instream Flow Pump Station

The Lake Kachess portal would contain tunnel-control and isolation gates as well as a relatively small pump station. Since the lake would be drawn down below the existing outlet to the Kachess River, the Lake Kachess portal would contain a 20-cfs pump station to pump water from the Lake Kachess portal via a pipeline to the Kachess River just below the existing outlet works from the dam when water surface elevations are below the existing outlet.

Because of the high heads on the gates, it is likely that they would be specially-manufactured roller gates. The first gate (or set of gates) would isolate the portal from the lake tap intake. A flooded chamber in front of the gate would provide underwater access to the gate, if needed. The second gate (or set of gates) would isolate the downstream Yakima River tunnel from the portal. The third gate would isolate the pump station wet well from the intake and tunnel. A stairwell would provide access through water-tight bulkhead doors to the lower sections of the pump station.

The 20-cfs pump station will contain two 20-cfs pumps (one on standby). An approximately 70-by-80-foot pump-station building at grade on top of the shaft would contain pump motors, piping, the electrical room and controls. An exterior valve vault would contain pump discharge valves.

The portal structure would also contain remote-system control and data systems as well as flow meters to monitor flow through the tunnel and flow being pumped to the Kachess River.

Instream Flow Pipeline and Kachess River Discharge Structure

The instream flow pump station would pump up to 20 cfs through a 24-inch-diameter, 6,500-foot-long steel pipe to a concrete discharge structure next to the Kachess River. The discharge structure would be sited just downstream of the existing dam outlet channel and upstream of Lake Easton. To prevent fish from entering the discharge structure, the bar-screened outlet will have 10-foot-high freefall discharge (weir elevation 2190) to the Kachess River at elevation 2180.

Figure 15 shows the instream flow pipeline profile.

Yakima River Tunnel

The tunnel would be approximately 24,200 feet long from the Lake Kachess portal to the Yakima River discharge portal. As discussed in the Section 3 (Geology), the Yakima River valley in this area is defined by rocky ridges to the west and east. The river in this area meanders through the valley that has been filled in with alpine glacial deposits and river alluvium. Figure 7 shows the tunnel alignment and Figure 10 shows the tunnel profiles.

A lake tap outlet requires that the tunnel be constructed in competent rock. Specific site geologic boring information is not available, but for this analysis the tunnel was aligned along the western slope of the Easton Ridge, which defines the eastern side of the Yakima River valley in this area. This alignment was selected because it would have the best likelihood of being in the Teanaway Formation rock that makes up a large part of the Easton Ridge. The rocky ridge is exposed for most of the tunnel length, but is buried in glacial and alluvial deposits at each end of the alignment. The depth to the rock in these locations is unknown. However, it was assumed that the portal shafts would be excavated through the valley glacial and alluvial deposits to the underlying rock and that the tunnel alignment would be deep enough to remain in the Teanaway Formation rock formation.

The tunnel would likely be excavated using a tunnel boring machine (TBM), but could also be excavated using conventional drill and blast methods. In either case, the finished inside dimensions would be approximately 13 by 13 feet for a horseshoe shape or up to 14 feet in diameter for a circular tunnel. The need for and methods for lining would be determined by the tunneling method and rock competency along the alignment.

The tunnel profile is shown with a gradual slope from the Lake Kachess portal to the Yakima River discharge portal. The actual depth and slope of the tunnel would depend on the geology along the alignment and the direction chosen for mining or TBM excavation. To allow self drainage during tunneling it is advantageous to excavate in a positive grade direction. It is also desirable to make the portals as shallow as possible. This current alignment assumes mining from the Yakima River portal.

All of these characteristics and design criteria would have to be determined after more information was obtained from a geotechnical boring program along the alignment. For this analysis, it was assumed that the tunnel would be partially unlined rock (60 percent) and partially lined with either gunite or formed-in-place concrete. Some rock bolting may be required in some tunnel sections.

Although it is not expected to be operated until the Lake Kachess reservoir elevation is at or very close to the existing inactive pool elevation 2192.75, the tunnel should be designed for pressures up to a maximum of 150 ft (65 psi) which corresponds to a full Lake Kachess elevation 2262.

Yakima River Discharge Structure

The tunnel would discharge to the Yakima River Portal at approximately elevation 2092. The upwelling flow from the portal would discharge through an open weir (with bar rack to prevent entry) into an open channel and/or pipe leading to a fish barrier discharge structure next to the river. To prevent fish from entering the discharge structure, the 125-foot-long discharge structure next to the river would include a free weir that is 10 feet higher (elevation 2085) than the river elevation 2075. The weir discharge structure would also be protected by a bar rack to prevent entry.

Sediment Handling

It is likely that fine sediments would be transported through the lake intake into the intake tunnel and Lake Kachess portal. The portal would include a provision for submersible deep sump pump to pump trapped sediment-laden water out of the portal. It is also anticipated that periodic dewatering to portal and discharge tunnel would be required to manually remove trapped sediments.

Construction Access and Power

The primary construction access would via local roads to and from the I-90 interchange at Milepost 70. Low-voltage power from local service lines is available. A high-voltage transmission line also parallels the tunnel alignment. Although not verified, it may be possible to step down power from this transmission line to power a TBM.

4.6 Alternative 2 – Lake Kachess Pump Station

Alternative 2 avoids the long gravity-flow tunnel by siting a 1,000-cfs pump station at the Lake Kachess portal. The pump station would pump flow to grade level to a discharge manifold connected to a pressure/gravity flow pipe that would convey the flow approximately 6,500 feet to a discharge structure next to the Kachess River just downstream of the existing Lake Kachess dam outlet channel.

Lake Tap and Fish Screen

The lake tap and fish screen would be the same as described in Sections 4.3 and 4.4.

Lake Kachess Portal

To contain a much larger pump station within the portal, the Alternative 2 Lake Kachess portal will be approximately 98 feet in diameter. The depth of the portal to intercept the lake tap tunnel would be the same as for Alternative 1.

Alternative 2 Lake Kachess portal and pump station plans and sections are shown on Figure 16 and Figure 17.

Alternatively to the configuration shown in this report and depending upon the rock depths and characteristics, a potentially less costly option would be to excavate a smaller diameter shaft from the surface to a larger cavity that would be mined out within the rock to contain pumps located within the cavity. Due to the limited scope of this report and lack of specific geological information at the site this optional refinement of this alternative was not investigated further.

Pump Station

The pump station would be designed for a maximum firm capacity (the capacity with one of the large pumps out of service) of 1,000 cfs. This would be provided by six 200-cfs pumps (currently shown as vertical turbine) arranged in a pattern to minimize the diameter of the portal shaft. Two additional 20-cfs pumps would provide minimum instream flow to the Kachess River if the lake was drawn down below the existing outlet and the larger pumps were not operating.

All of the pumps would be selected based on a static pumping head varying from a suction side elevation 2192.75 down to elevation 2110. The pump discharge elevation is set at approximately 20 feet below the pump station ground surface elevation 2270. Therefore the net static pumping head would vary from a low of approximately 60 feet to a maximum of 160 feet. The design setpoints for the pumps would be set for an approximate average total dynamic head (TDH) of the average static head of 110 feet plus the hydraulic losses in the pumping suction and discharge systems. The pump station capacity will vary with changes in the TDH caused by variations in the lake levels and head losses in the discharge piping.

The pump station will contain several control gates to isolate the pump station from the intake tunnel. The first gate would be a primary isolation gate, which would be backed up by isolation gates in front of each of two pump station wet wells. Finally, there would be two smaller gates in front of each of the small 20-cfs instream flow pumps.

The 110-by-136-foot pump-station building over the portal at the surface would contain the pump motors, piping, control valves, electrical room, and controls. The building also would have stairway access and hatches to access the gates and equipment within the portal and a bridge crane and/or hatches in the roof for equipment removal.

Discharge Manifolds and Pipeline

Each of the pump discharges would connect to a 96-inch-diameter steel pipe, one on each side of the pump station. These two pipes would then converge to a single 6,500-foot-long, 12-foot-diameter steel pipeline to convey the flow to the Kachess River. Currently this pipe is shown in the same alignment as the small 24-inch-diameter pipe to the Kachess River just downstream of the existing dam outlet. This large-diameter pipe could be shortened by approximately 1,200 feet by discharging to a point further downstream in the Kachess River just upstream of Lake Easton. But with this shorter alignment, a separate pipe and/or valves at a bifurcation from the large pipe would be required to divert a smaller 20 cfs to the dam outlet area. Therefore, for this appraisal level design the large pipeline was left in the same alignment.

The profile of the transmission main is shown on Figure 15.

The transmission main would be drained either back into the portal or through the discharge structure into the Kachess River. A combination air release/vacuum valve would be needed at the pump station to allow air into the pipe when it is draining and out of the pipe if it gets trapped.

For the Alternative 2 pump station, the Lake Kachess portal would be approximately 110 feet in diameter. This larger diameter is necessary to contain the control gates and the much larger 1,000-cfs pump station.

Surge Analysis and Provisions

Because of the large volumes of water being pumped with this alternative, it is likely that some provisions would need to be made to mitigate surge pressures in the pump column and/or discharge header. These provisions could include vacuum and air-release valves, pump-control valves, and/or surge tanks. A surge analysis was not conducted for this conceptual-level report, but provisions are made in the cost estimates for surge control.

Kachess River Discharge Structure

The transmission pipeline would discharge to the Kachess River at approximately discharge weir elevation 2190. The upwelling flow from the pipe would discharge into a 110-foot-long hydraulic transition structure next to the Kachess River. To prevent fish from entering the discharge structure, the structure would include a free weir that is 10 feet higher (elevation 2190) than the river elevation of approximately 2180. The weir discharge structure would also be protected by a bar rack to prevent entry into the structure. Figure 18 shows the Kachess River discharge structure.

Sediment Handling

It is likely that fine sediments would be transported through the lake intake into the intake tunnel and Lake Kachess portal. The portal would include a provision for submersible deep sump pump to pump trapped sediment-laden water out of the portal. It is also anticipated that periodic dewatering of the portal would be required to manually remove trapped sediments.

Construction Access and Power

The primary construction access would be via local roads to and from the I-90 interchange at Milepost 70. Low-voltage power from local service lines is available. A high-voltage transmission line also parallels the tunnel alignment. Although not verified, it may be possible to step down power from this transmission line to provide power to the large pump station.

Metering and Controls

The pump station would contain flow meters and automated data acquisition and control systems to operate the pumps. In addition to local operation, the pump station would be designed to be remotely monitored and controlled.

Security

The pump station would be a large and complex facility requiring significant perimeter security. It is expected that security measures would include fencing, intrusion sensors, remote camera monitoring and building alarm systems.

5.0 Property and Easements

The Kittitas County Assessor's web site was used to compile property ownership data and acquire the needed data to estimate the cost of the required easements for the pipeline and pump station from Lake Kachess to the Yakima River portal.

Data was compiled by using GIS tools on the website and re-drawing the proposed route on a parcel map. Data was then collected for each parcel along the route and combined with data from other surrounding parcels not on the route in order to determine realistic property values.

For this appraisal level study, the property analysis is based on the assumption that parcels where the pipeline or tunnel will cross open space will need a 50-foot permanent easement and a 100-foot temporary easement. The price for each permanent easement was based on 30 percent of the land value per square foot, while the temporary easement values are priced at 10 percent of the land value. These values are typical for utility easements. Land purchase is at 100 percent of the land value.

The conceptual pipeline alignment for the pipeline and pump station would require easements for a total of 26 parcels with three separate land owners. Fifteen of the parcels are owned by private landowners and 11 by the Wenatchee National Forest.

Estimated property and easements costs are included in a separate project cost memorandum.

6.0 Technical Issues for Future Consideration

6.1 Project Challenges

As the alternatives move forward to selection of the preferred alternative and final design, the following will require more detailed analyses and consideration;

- Construction of a lake tap outlet from Lake Kachess.
- Installation of a fish screen over a lake tap overlain with sediments.

- Construction of a deep Lake Kachess portal and pump stations.
- Construction of a long tunnel between Lake Kachess and the Yakima River discharge.
- Minimizing impacts to Kachess River and/or Yakima River.
- Powering either a TBM tunneling operation or a large pump station.

6.2 Next Steps

- Perform geotechnical exploration and testing to determine geological conditions for further alternative evaluation.
- Confirm the tunnel and/or pump station operational criteria and hydraulics and refine pump station options to perhaps reduce the size of the portal shaft.
- Confirm and refine the outlet structure(s) hydraulics.
- Further investigate and refine the feasibility of adding fish screens to the lake tap.
- Perform a more detailed power requirement analysis.

6.3 Cost Estimates

Cost estimates for the Kachess Inactive Storage project will be outlined in a separate memorandum.

7.0 References

1. Tabor, R.W., Frizzell, V.A. Jr., Booth, D.B., Waitt, R.B., “Geologic Map of the Snoqualmie Pass 30x60 minute Quadrangle, Washington”, USGS, 2000.
2. Cheney, E.S., “Geologic Map of the Easton Area, Kittitas County, Washington”, Washington Division of Geology and Earth Resources, Open File Report 99-4, December 1999.
3. Bennett, D.J., “Geologic Report: Modification Decision Analysis, Safety of Dams Program, Kachess Dam, Yakima Project, Washington”, Division of Design and Construction, Geology Branch, Idaho, Department of the Interior, Bureau of Reclamation, Pacific Northwest Region, March 1993.
4. Golder Associates, Inc., “Appraisal Assessment of the Yakima River Pump Exchange Alternative Delivery System for Roza and Sunnyside Valley Irrigation Districts”, Technical Series No. TS-YSS-11, U.S. Department of the Interior, Bureau of Reclamation, Pacific Northwest Region, October 2006.
5. “Yakima River Basin Storage Alternatives Appraisal Assessment”, Technical Series No. TS-YSS-8, U.S. Department of the Interior, Bureau of Reclamation, Pacific Northwest Region, May 2006.

8.0 List of Preparers

NAME	BACKGROUND	RESPONSIBILITY
HDR ENGINEERING, INC.		
Jim Peterson	Professional Engineer	Task Manager
Keith Goss	Professional Engineer	Task Engineer
Sri Rajah	Professional Engineer	Task Engineer
Joseph Looney	Real Estate Specialist	Property and Easements
Stan Schweissing	Professional Engineer	QC Reviewer

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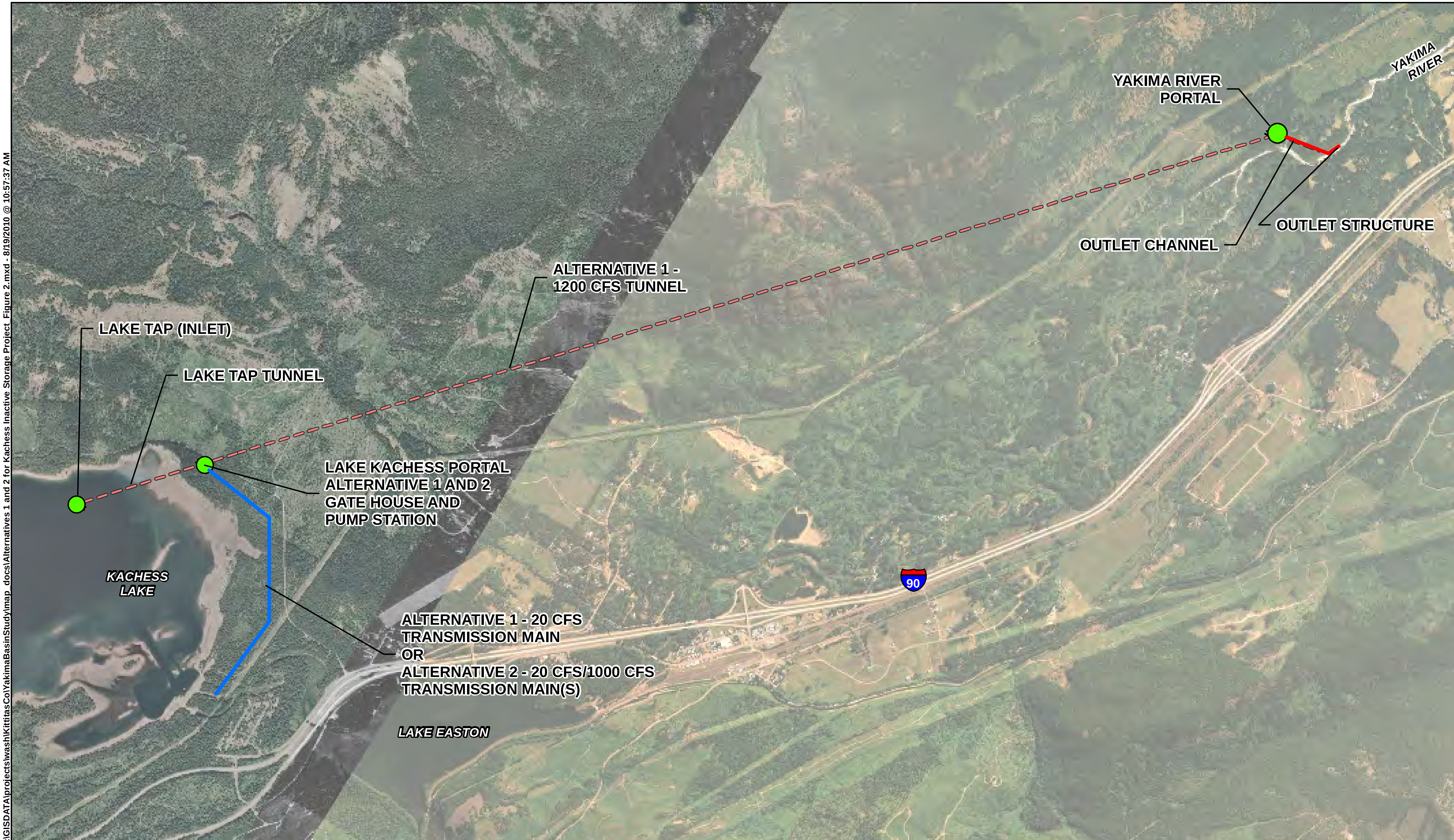


0 1,200 2,400
Feet

N E S W

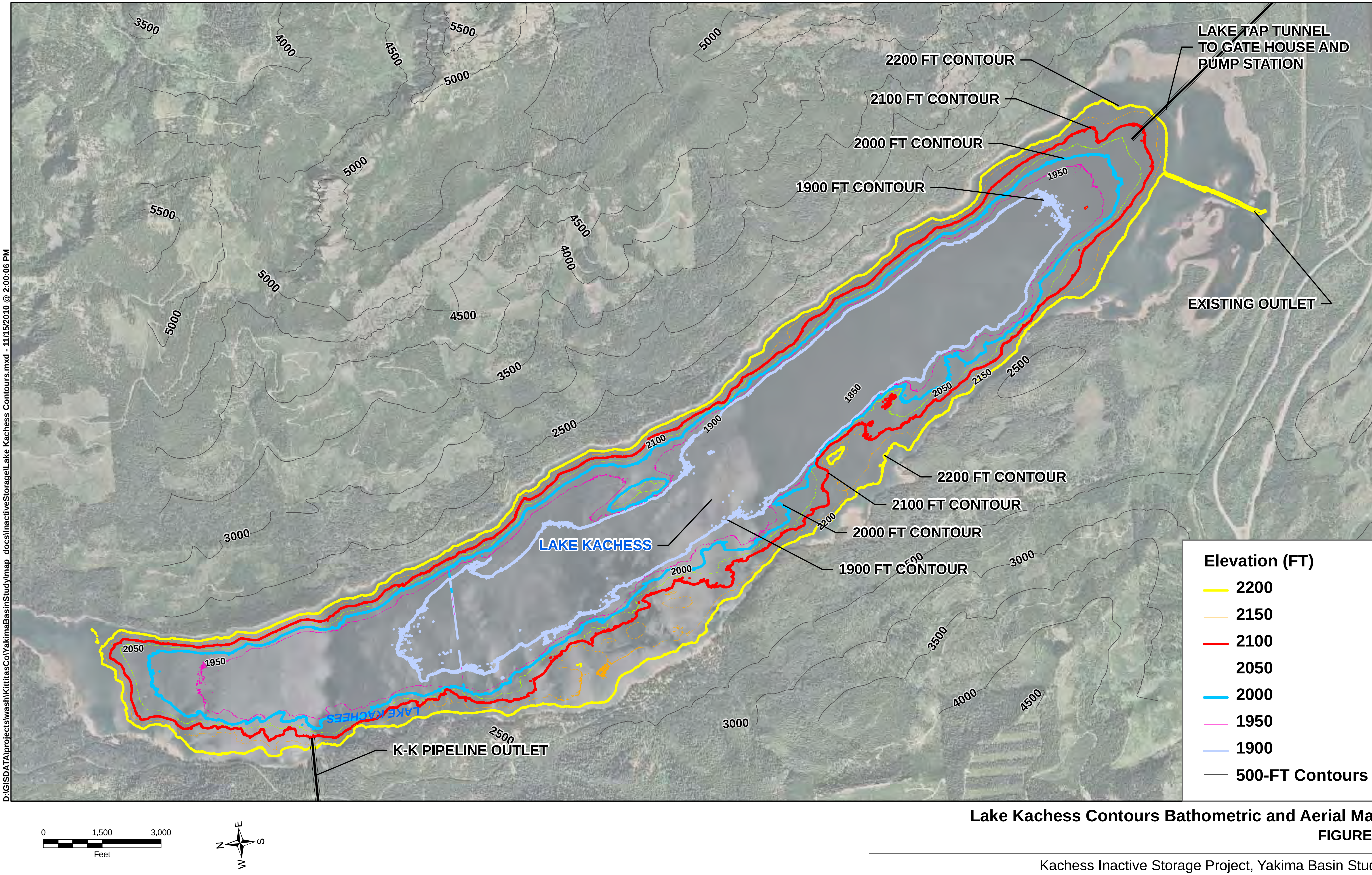
Source: USGS TOPOGRAPHIC MAP (Contour Interval 40')

Tunnel
River Instream Flow (20 cfs)
Outlet Channel

Alternatives 1 and 2 for Kachess Inactive Storage Project
FIGURE 2

Kachess Inactice Storage Project, Yakima Basin Study

D:\GISDATA\projects\wash\Kittitas Co\YakimaBasinStudy\map_docs\Alternatives 1 and 2 for Kachess Inactive Storage Project_Figure 2.mxd - 8/19/2010 @ 10:57:37 AM



Lake Kachess Contours Bathometric and Aerial Map

FIGURE 3

Kachess Inactive Storage Project, Yakima Basin Study

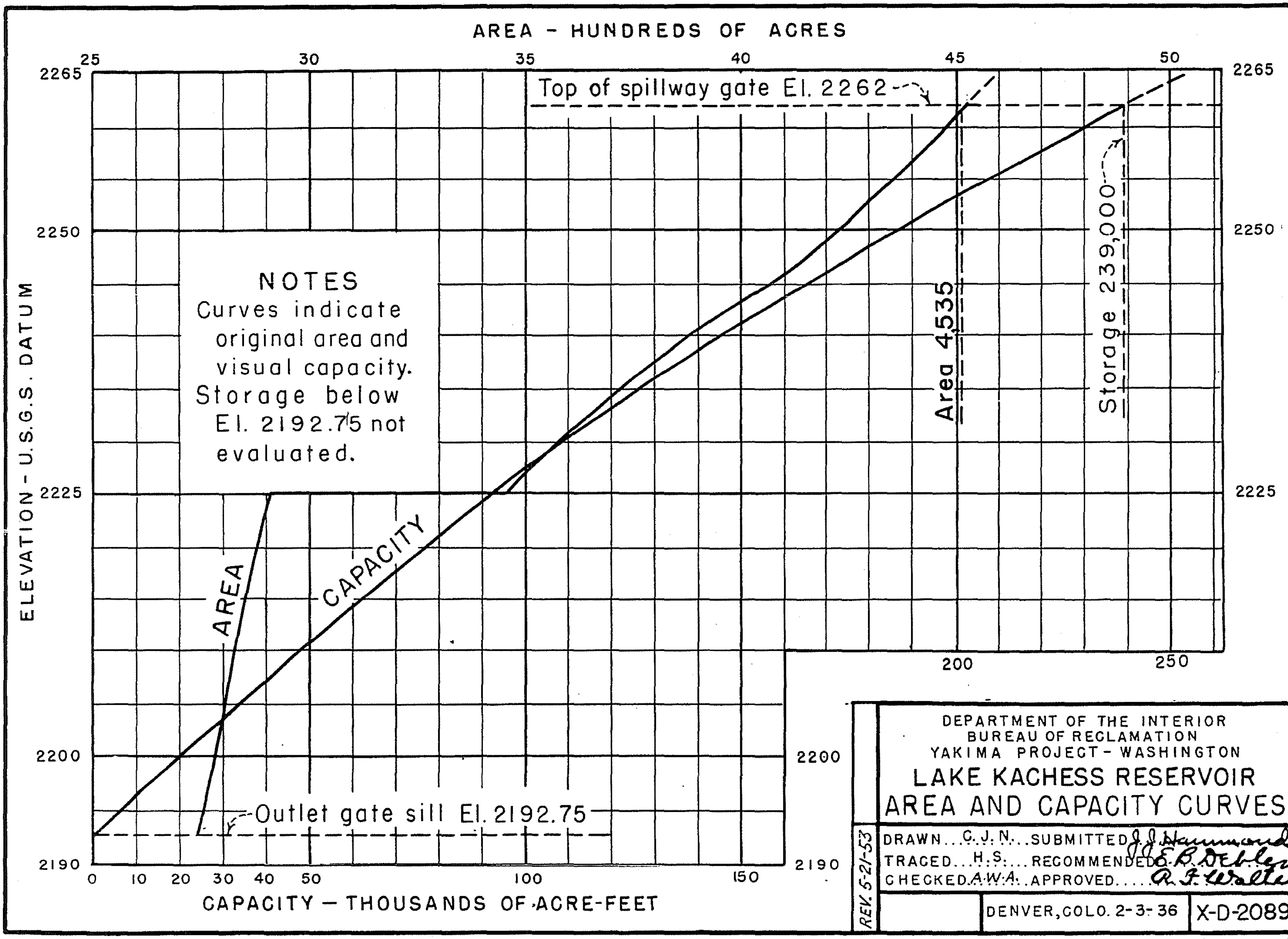
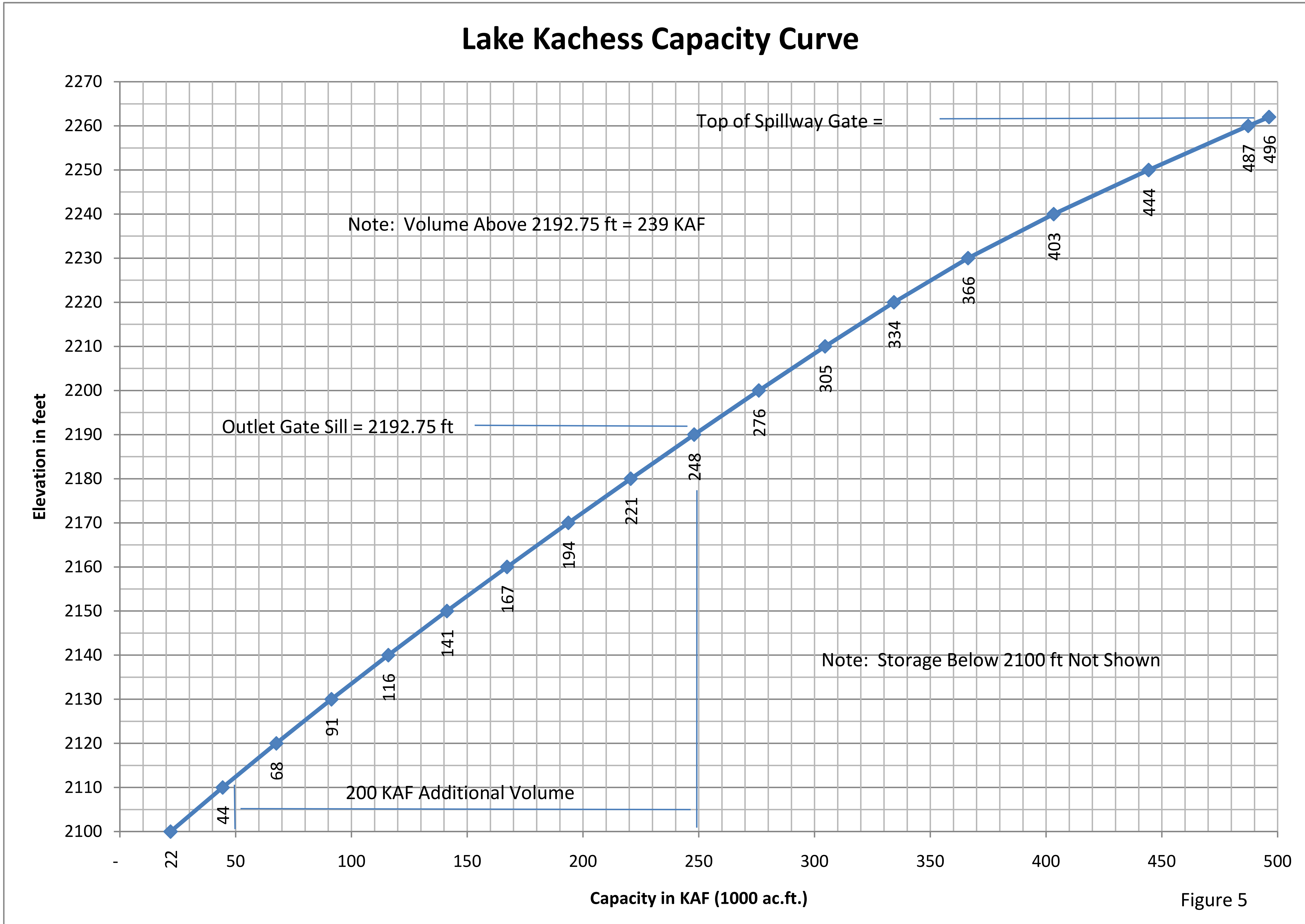
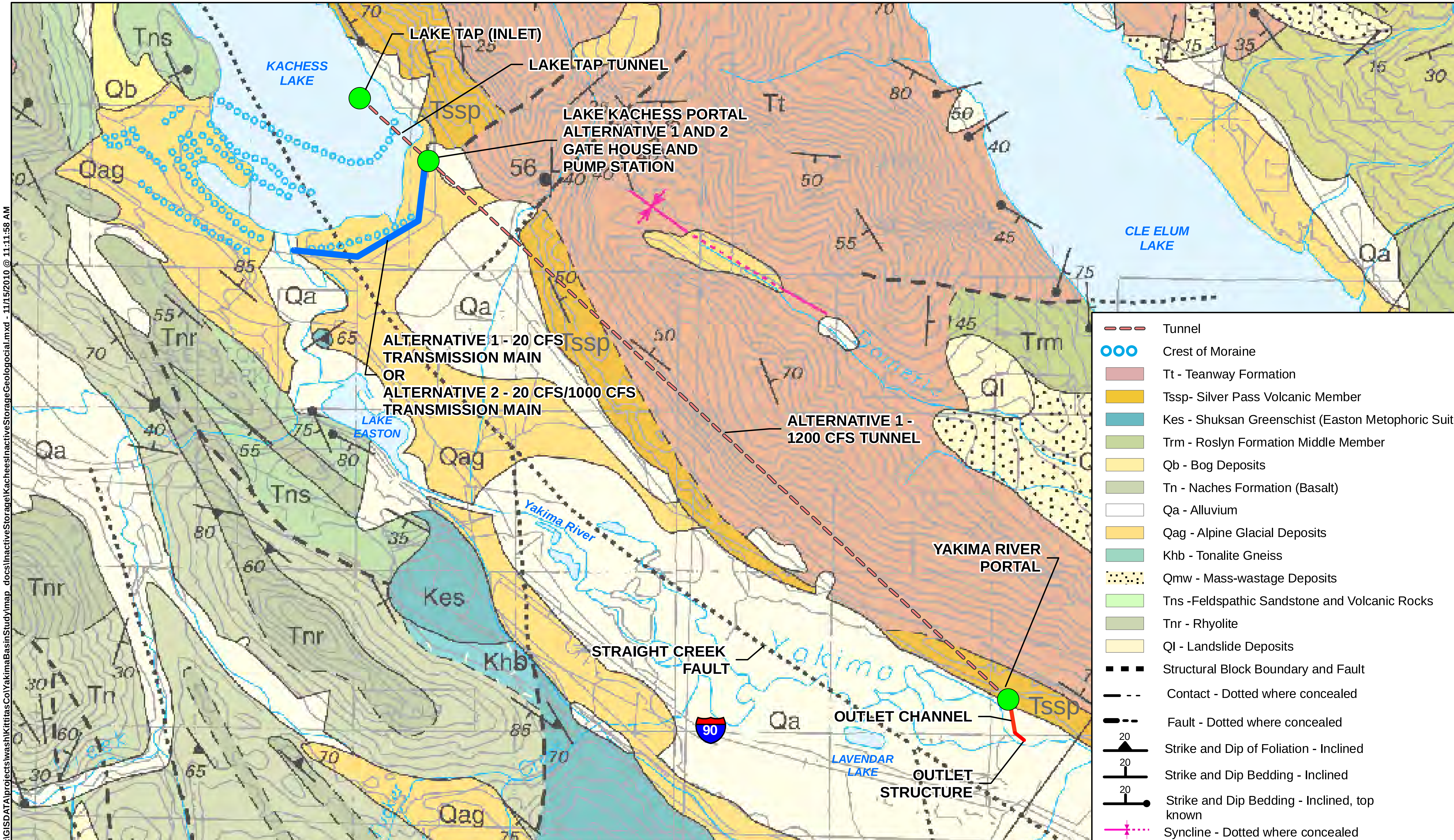

AREA - HUNDREDS OF ACRES
25
30
35
40
45
50
2265
2250
2225
2200
2190
ELEVATION - U.S.G.S. DATUM
Top of spillway gate El. 2262
NOTES
Curves indicate original area and visual capacity.
Storage below El. 2192.75 not evaluated.
Area 4535
Storage 239,000
AREA
CAPACITY
Outlet gate sill El. 2192.75
0
10
20
30
40
50
100
150
200
250
CAPACITY — THOUSANDS OF ACRE-FEET
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
YAKIMA PROJECT - WASHINGTON
LAKE KACHESS RESERVOIR
AREA AND CAPACITY CURVES
DRAWN C.J.N. SUBMITTED J.J. Hammond
TRACED H.S. RECOMMENDED E.B. Debler
CHECKED A.W.A. APPROVED R.F. Walter
REV. 5-21-53
DENVER, COLO. 2-3-36
X-D-2089

FIGURE 4


Lake Kachess Capacity Curve
Elevation in feet
Capacity in KAF (1000 ac.ft.)
Top of Spillway Gate =
Note: Volume Above 2192.75 ft = 239 KAF
Outlet Gate Sill = 2192.75 ft
Note: Storage Below 2100 ft Not Shown
200 KAF Additional Volume
2270
2260
2250
2240
2230
2220
2210
2200
2190
2180
2170
2160
2150
2140
2130
2120
2110
2100
-
22
50
100
150
200
250
300
350
400
450
500
44
68
91
116
141
167
194
221
248
276
305
334
366
403
444
487
496
Figure 5



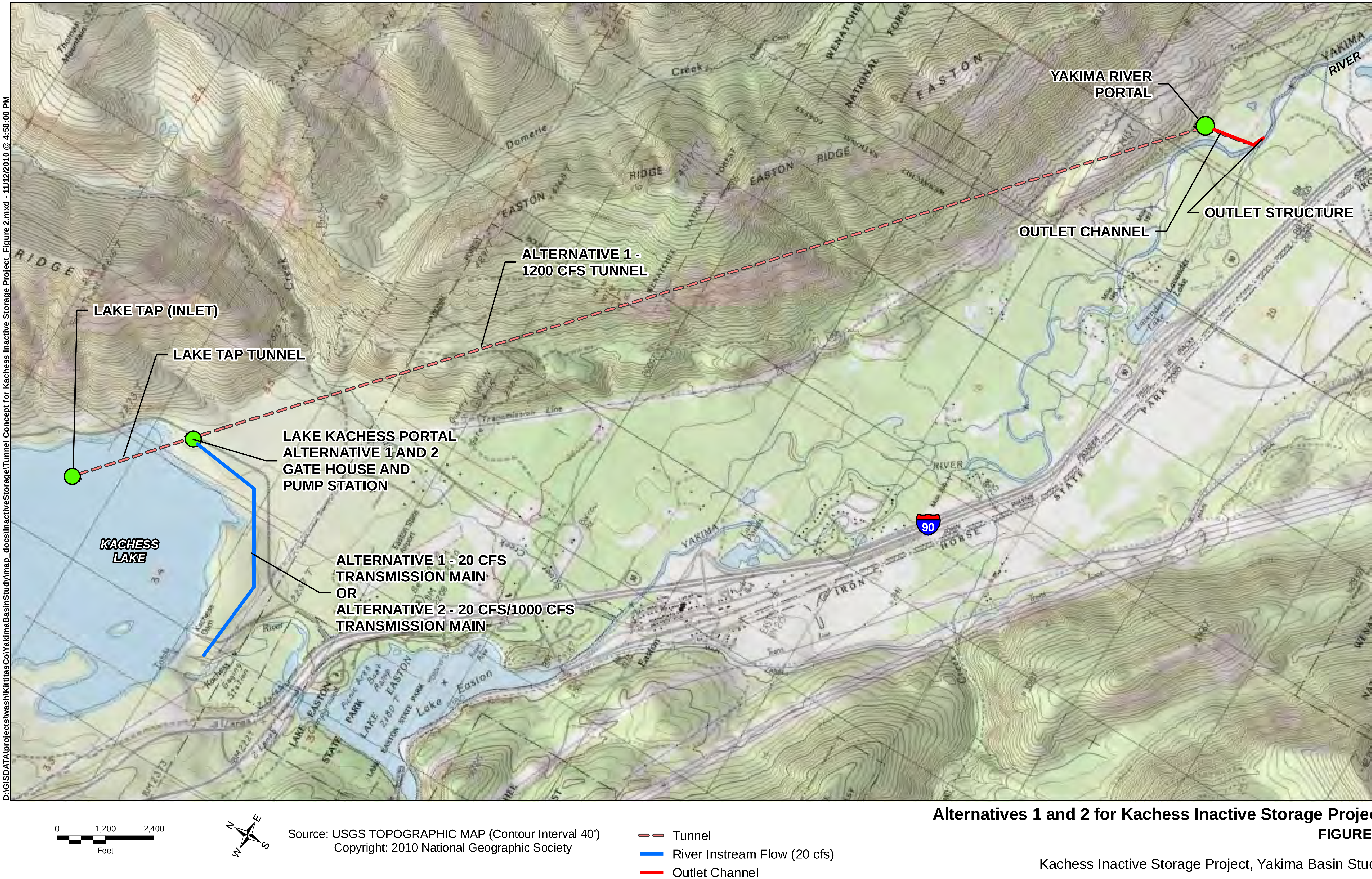
Source: Tabor, R.W., Frizzell, V.A. Jr., Booth D.B. , and Waitt, R.B. "Geologic Map of the Snoqualmie Pass 30 X 60 Minute Quadrangle, Washington", USGS, 2000.

0 1,500 3,000 Feet

N S W E

Published Surface Geology Map
FIGURE 6

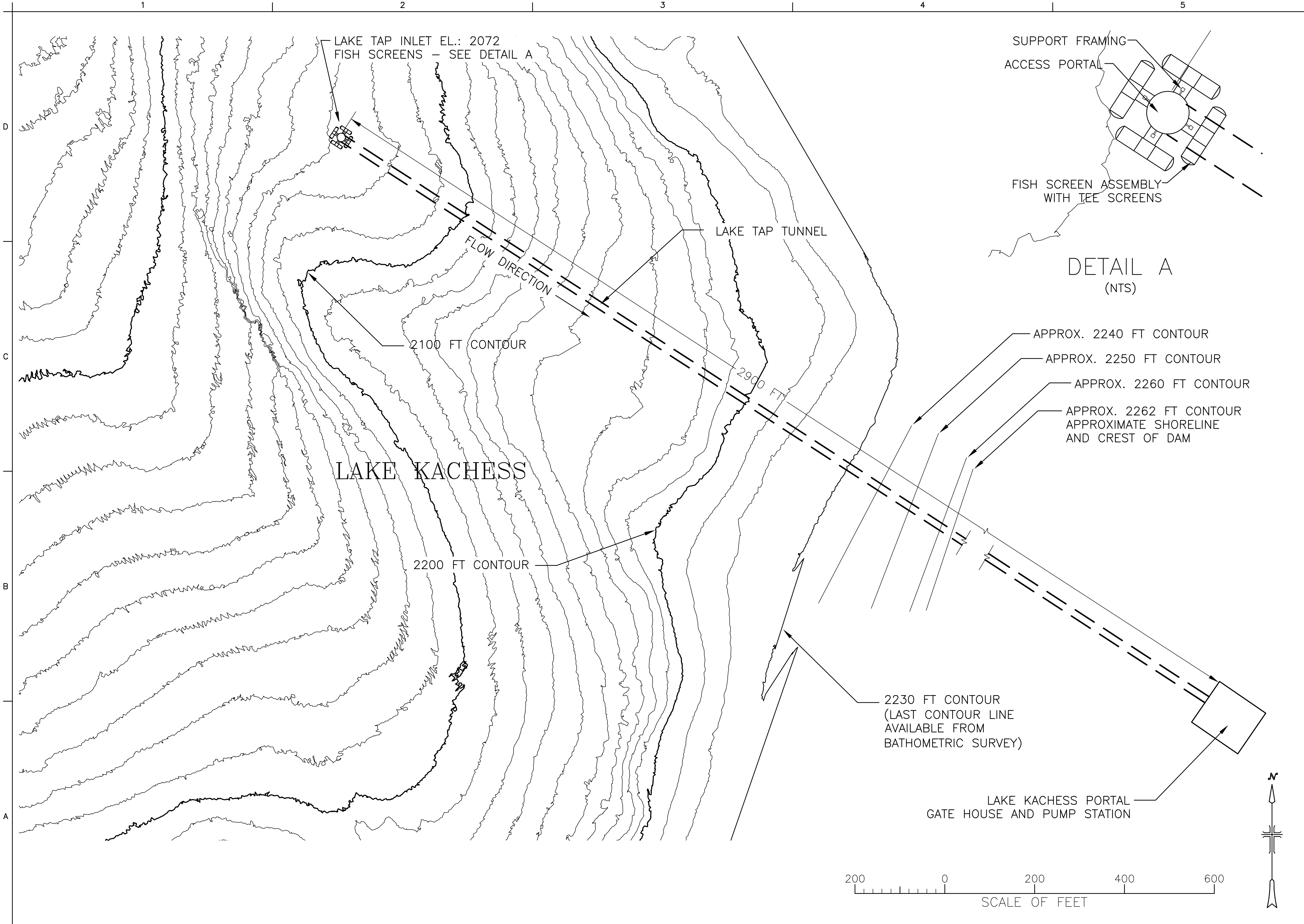
Kachess Inactive Storage Project, Yakima Basin Study



D:\GISDATA\projects\wash\KittitasCo\YakimaBasinStudy\map_docs\InactiveStorage\Tunnel Concept for Kachess Inactive Storage Project_Figure 2.mxd - 11/12/2010 @ 4:58:00 PM

Alternatives 1 and 2 for Kachess Inactive Storage Project
FIGURE 7

Kachess Inactive Storage Project, Yakima Basin Study



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YAKIMA RIVER BASIN STUDY

KACHESS INACTIVE STORAGE
LAKE TAP TUNNEL AND FISH SCREEN PLAN
FIGURE 8

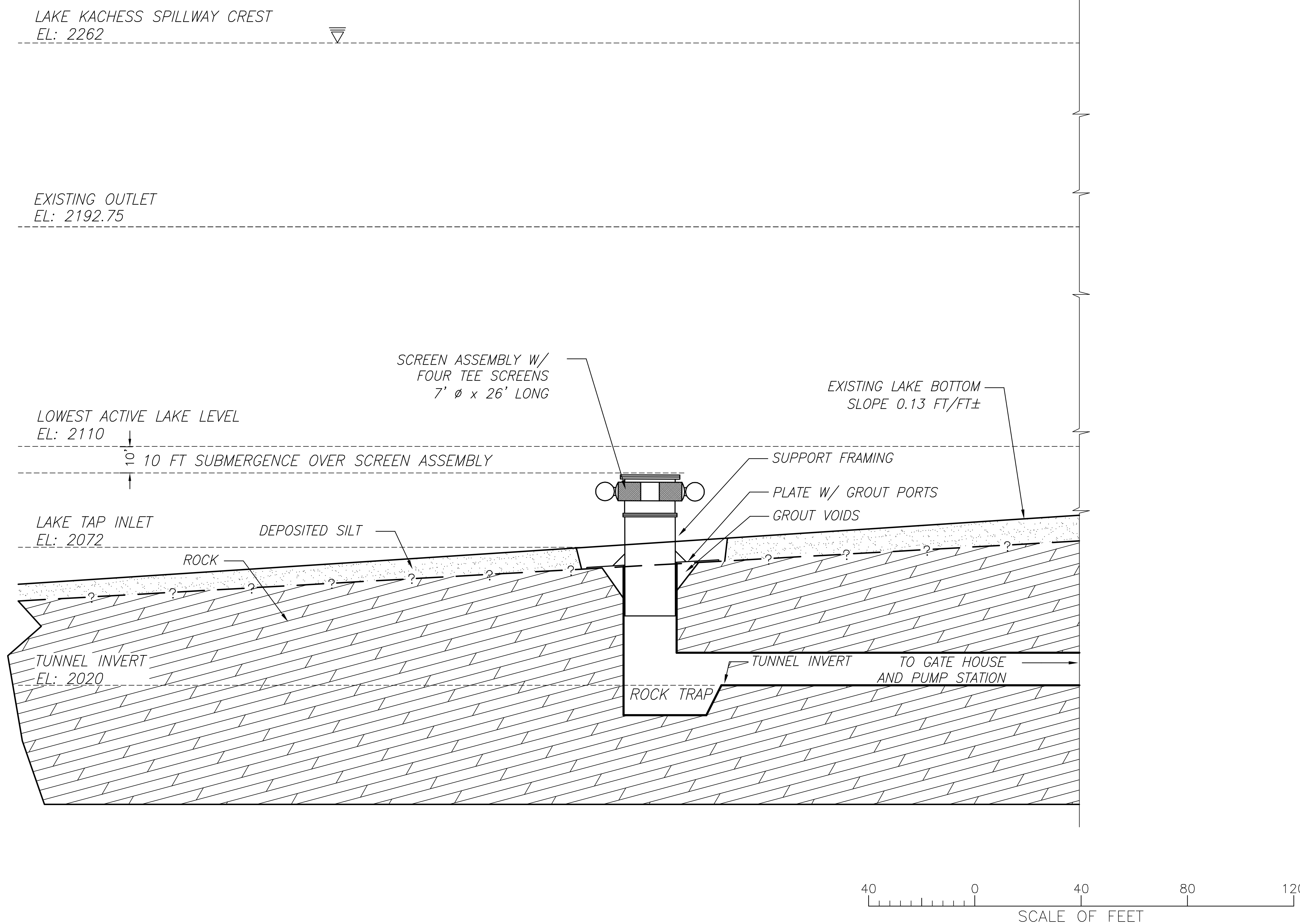
DESIGNED
DRAWN
CHECKED
TECH. APPR. NAME – TITLE
APPROVED ADMINISTRATIVE APPROVAL – NAME – TITLE
BOISE, ID 06.25.2009

FIGURE 8

SHEET OF

C:\pwworking\sea\d0445601\Tap at Lake Kachess.dwg, Layout1, 8/19/2010 11:45:24 AM, kgoss, Tabloid, 1:2

NOTES:
1. LAKE TAP AND FISH SCREEN OUTLET SHOWN AS A POTENTIAL DESIGN CONCEPT ONLY.
2. THE ACTUAL DEPTH OF SEDIMENTS AND DEPTH TO COMPETENT ROCK IS UNKNOWN.



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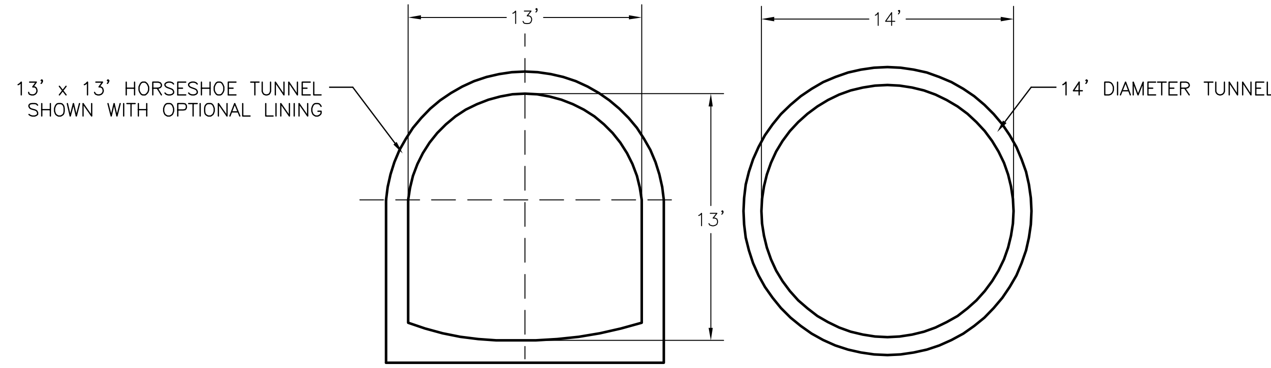
KACHESS INACTIVE STORAGE
SCHEMATIC LAKE TAP TUNNEL SECTION
FIGURE 9

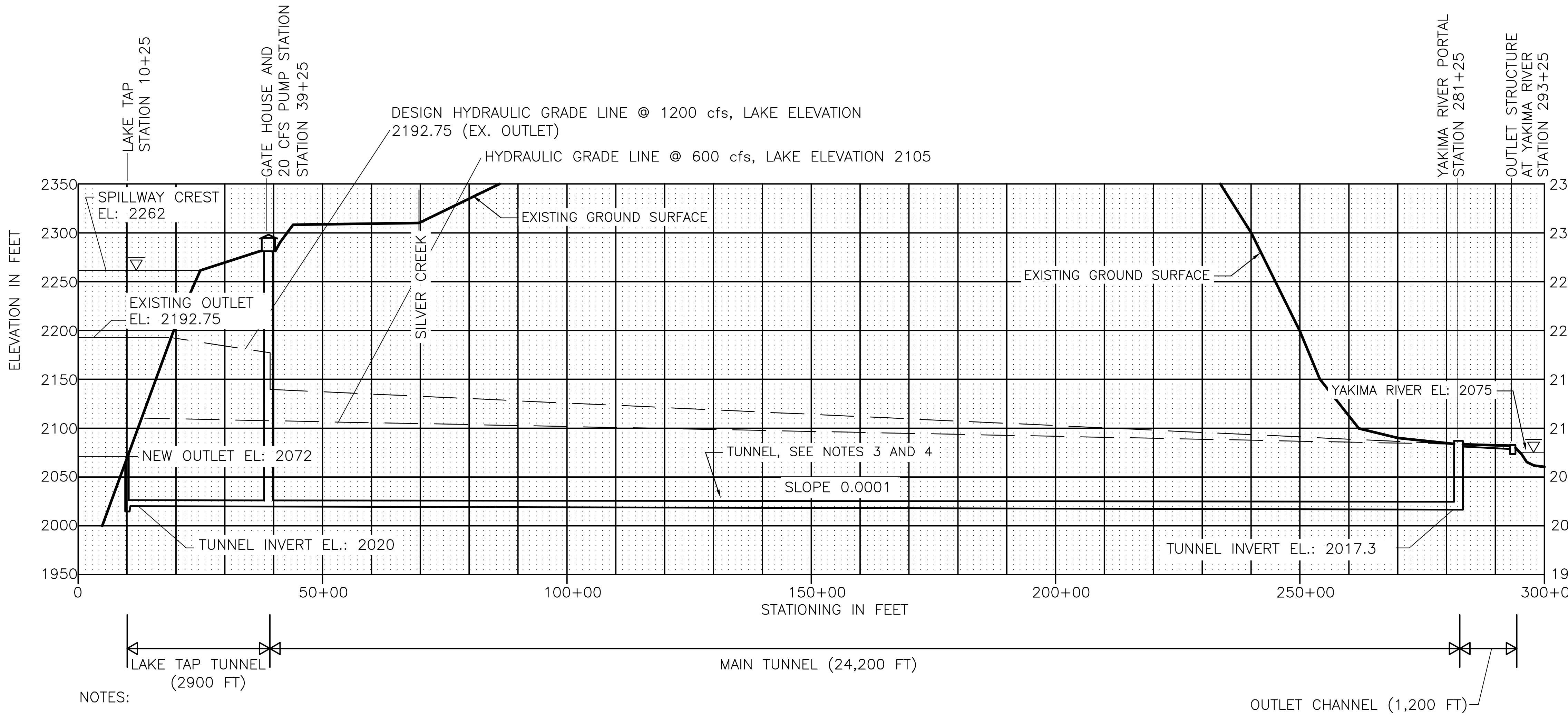
DESIGNED ________
DRAWN ________
CHECKED ________
TECH. APPR. ________
NAME – TITLE
APPROVED ________
ADMINISTRATIVE APPROVAL – NAME – TITLE
BOISE, ID 06.25.2009

FIGURE 9

———
SHEET X OF X



TUNNEL CROSS SECTION OPTIONS



NOTES:

1) STORAGE VOLUME OF LAKE KEECHELUS:
BETWEEN SPILLWAY CREST AND EXISTING OUTLET = 239,000 ac.ft.
BETWEEN EXISTING OUTLET AND PROPOSED OUTLET = 200,000 ac.ft.
2) AVERAGE ELEVATION OF YAKIMA RIVER AT PROPOSED TUNNEL DISCHARGE = 2075 ft.
3) TUNNEL LOCATION AND PROFILE SHOWN FOR CONCEPTUAL PURPOSES ONLY.
4) TUNNEL EQUIVALENT DIAMETER 14 FEET BASED ON DESIGN CRITERIA USED:
   - DESIGN FLOWS OF 1200 CFS AT LAKE ELEVATION 2192.75 ft WITH DECLINING FLOW RATE AS LAKE LEVEL DROPS.
   - DESIGN FLOW VELOCITY OF 10 FPS.

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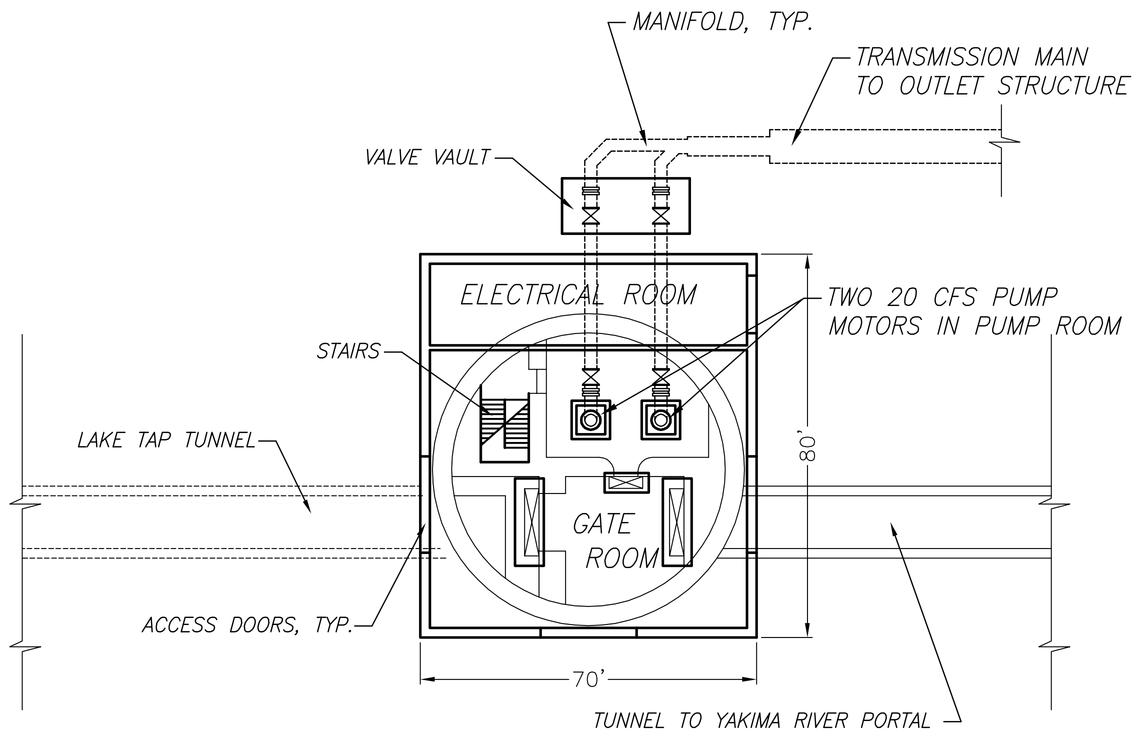
KACHESS INACTIVE STORAGE
ALTERNATIVE 1
TUNNEL PROFILE
FIGURE 10

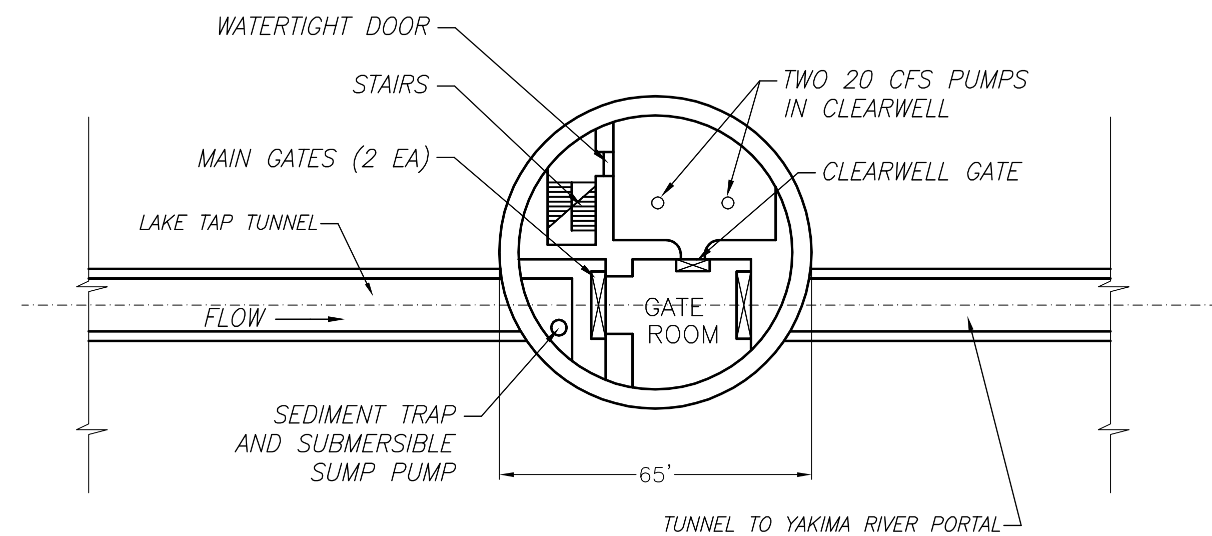
DESIGNED
DRAWN
CHECKED
TECH. APPR. NAME - TITLE
APPROVED ADMINISTRATIVE APPROVAL - NAME - TITLE
BOISE, ID 06.25.2009

FIGURE 10

SHEET X OF X

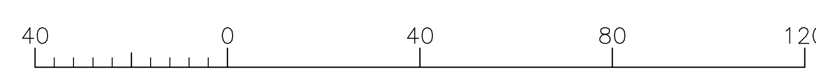


GROUND SURFACE FLOOR PLAN
AND BELOW GRADE MANIFOLD



CLEARWELL FLOOR PLAN

NOTES:
1) 20 CFS PUMP STATION FIRM CAPACITY IS 1 PUMP x 20 CFS PLUS ONE SPARE PUMP.
2) SEE FIGURE 12 FOR SECTION DRAWING.



SCALE OF FEET

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KACHESS INACTIVE STORAGE
ALTERNATIVE 1
TUNNEL & 20 CFS PUMP STATION PLANS
FIGURE 11

DESIGNED
DRAWN
CHECKED
TECH. APPR. NAME – TITLE
APPROVED ADMINISTRATIVE APPROVAL – NAME – TITLE
BOISE, ID 06.25.2009

FIGURE 11

SHEET X OF X

C:\pwworking\sea\d0445601\Kachess lake tap section.dwg, Small PS plans, 11/12/2010 10:35:25 AM, kgoss, Tabloid, 1:2

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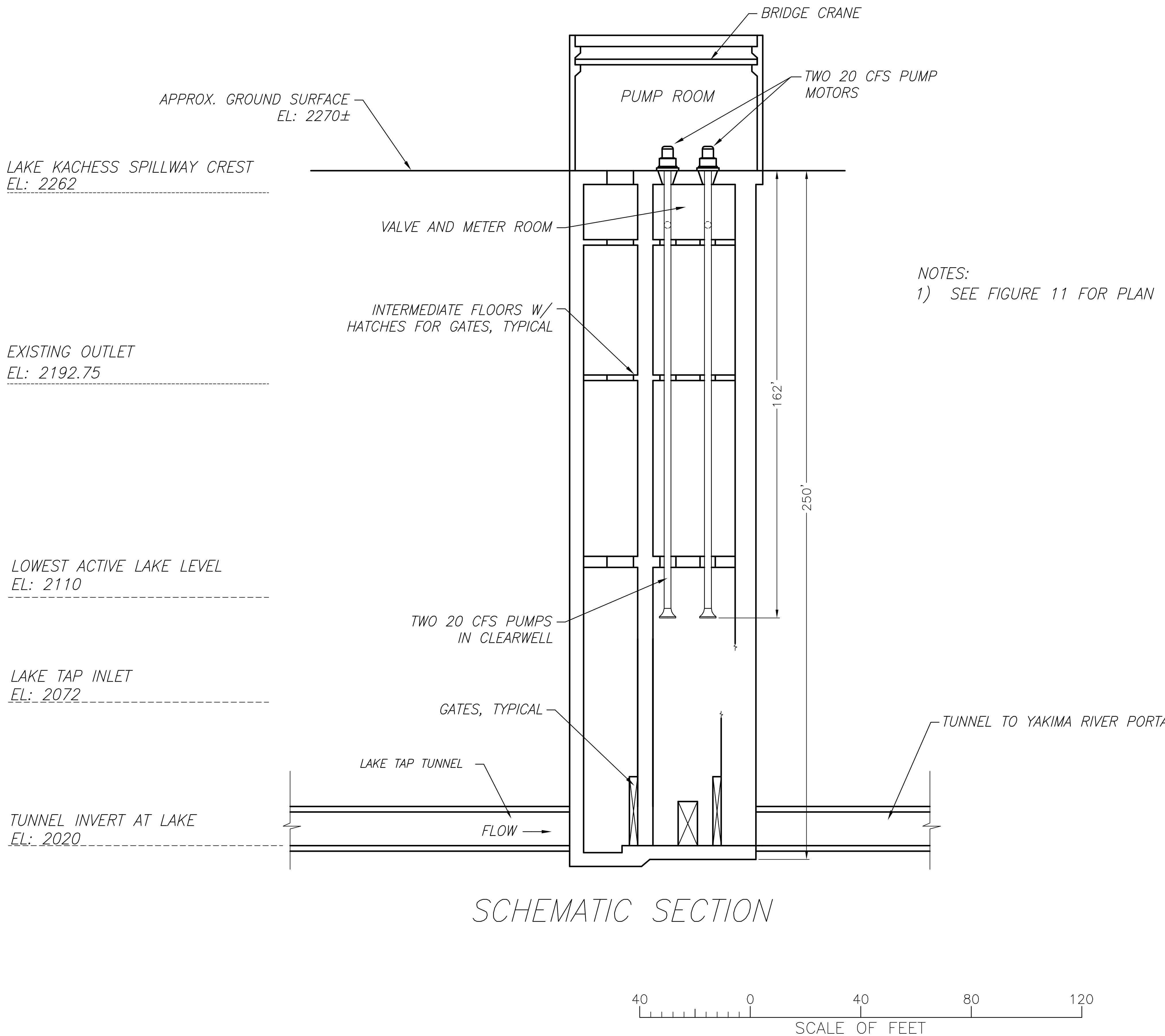

SCHEMATIC SECTION

NOTES:
1) SEE FIGURE 11 FOR PLAN VIEW DRAWING.

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KACHESS INACTIVE STORAGE
ALTERNATIVE 1
TUNNEL & 20 CFS PUMP STATION SECTION
FIGURE 12

DESIGNED
DRAWN
CHECKED
TECH. APPR. NAME – TITLE
APPROVED ADMINISTRATIVE APPROVAL – NAME – TITLE
BOISE, ID 06.25.2009

FIGURE 12

SHEET X OF X

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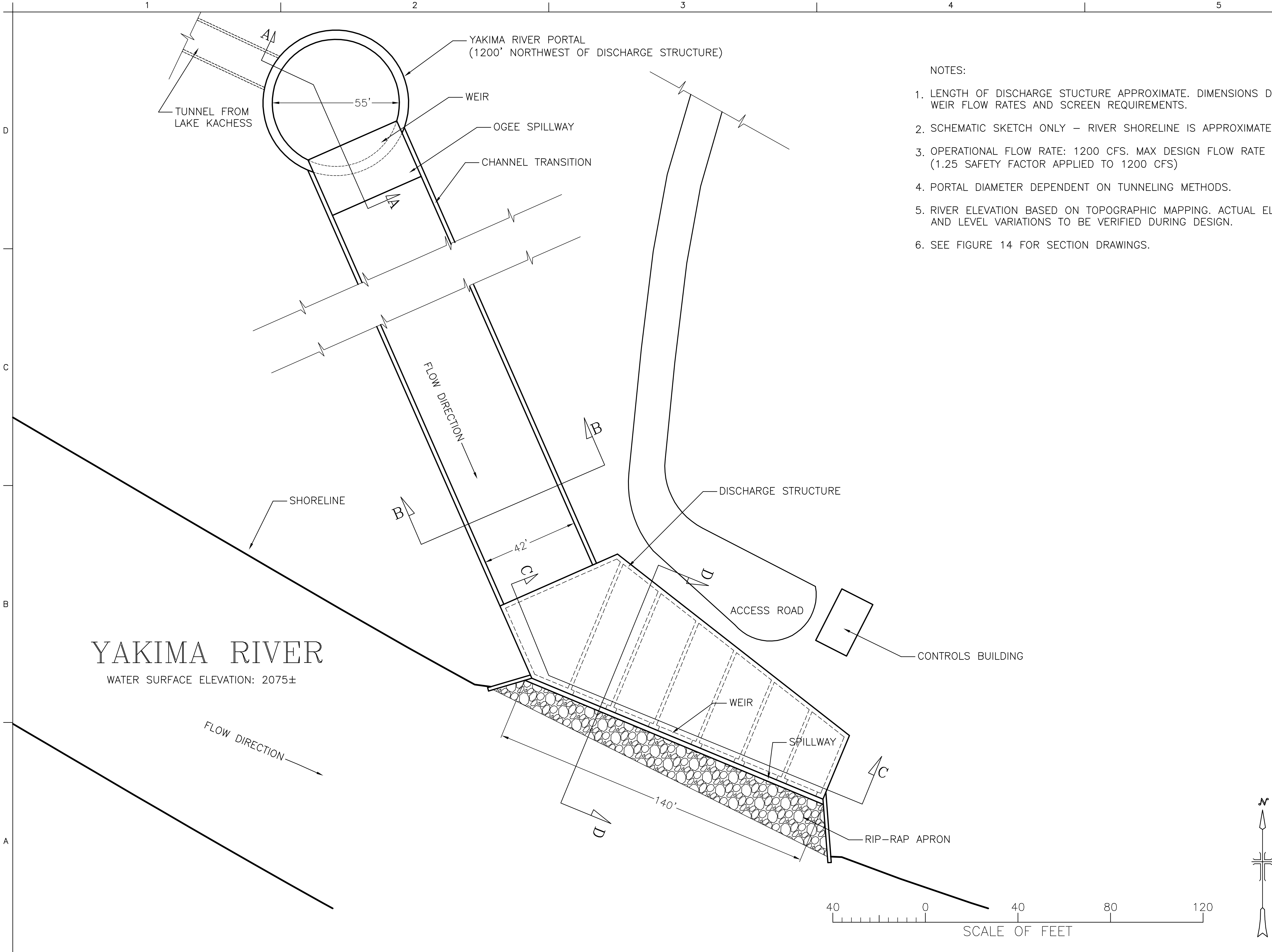

NOTES:

1. LENGTH OF DISCHARGE STUCTURE APPROXIMATE. DIMENSIONS DEPEND ON WEIR FLOW RATES AND SCREEN REQUIREMENTS.
2. SCHEMATIC SKETCH ONLY – RIVER SHORELINE IS APPROXIMATE.
3. OPERATIONAL FLOW RATE: 1200 CFS. MAX DESIGN FLOW RATE 1500 CFS (1.25 SAFETY FACTOR APPLIED TO 1200 CFS)
4. PORTAL DIAMETER DEPENDENT ON TUNNELING METHODS.
5. RIVER ELEVATION BASED ON TOPOGRAPHIC MAPPING. ACTUAL ELEVATION AND LEVEL VARIATIONS TO BE VERIFIED DURING DESIGN.
6. SEE FIGURE 14 FOR SECTION DRAWINGS.

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KACHESS INACTIVE STORAGE
ALTERNATIVE 1
YAKIMA RIVER PORTAL &
DISCHARGE STRUCTURE PLANS
FIGURE 13

DESIGNED
DRAWN
CHECKED
TECH. APPR. NAME – TITLE
APPROVED ADMINISTRATIVE APPROVAL – NAME – TITLE
BOISE, ID 06.25.2009

FIGURE 13

SHEET X OF X

C:\pwworking\sea\d0445601\Discharge structures.dwg, Yakima River plan, 11/17/2010 1:56:48 PM, kgoss, Tabloid, 1:2

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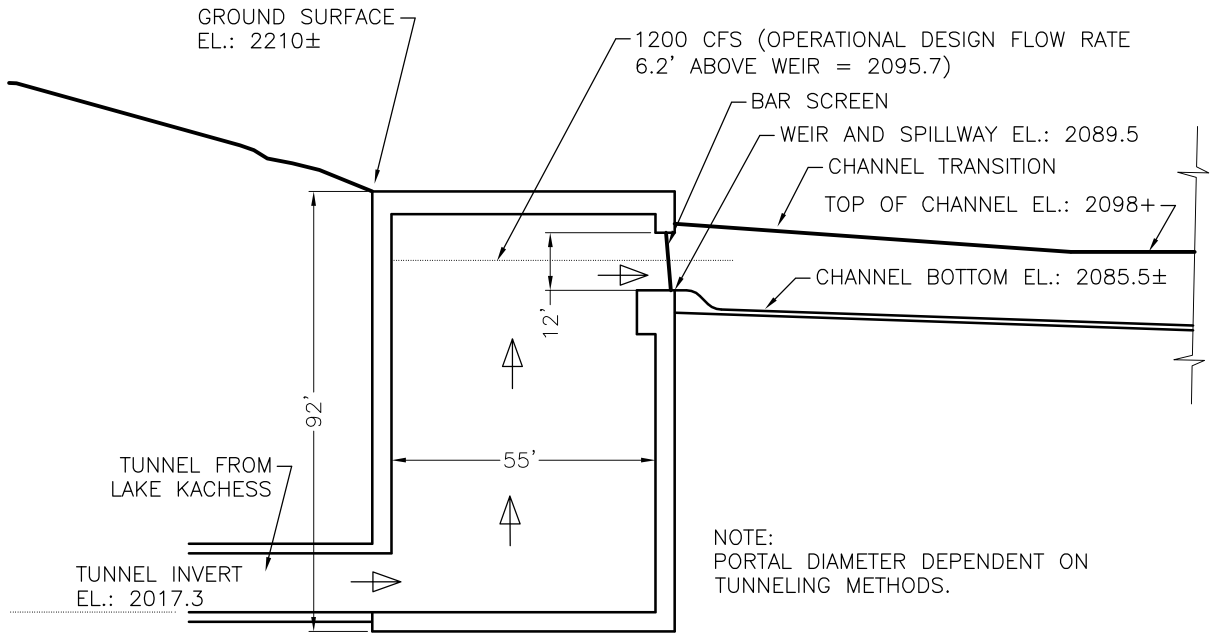
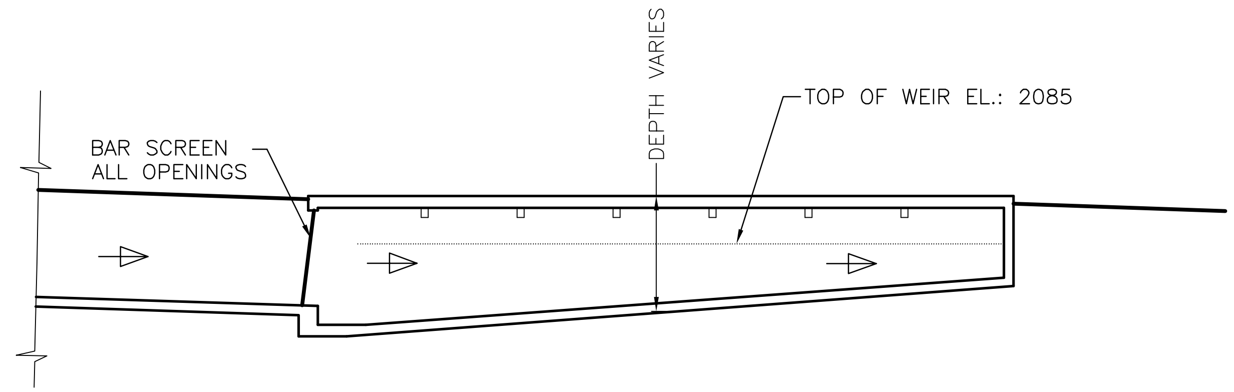
NOTES:

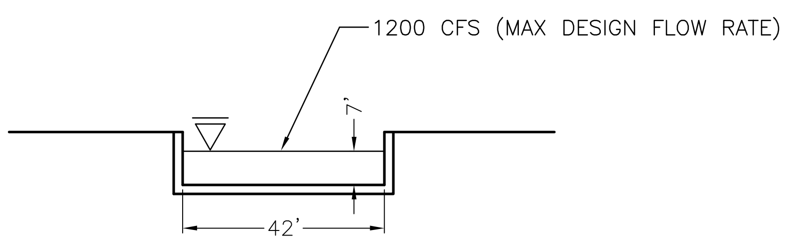
1. SEE FIGURE 13 FOR PLAN VIEW WITH SECTIONS.



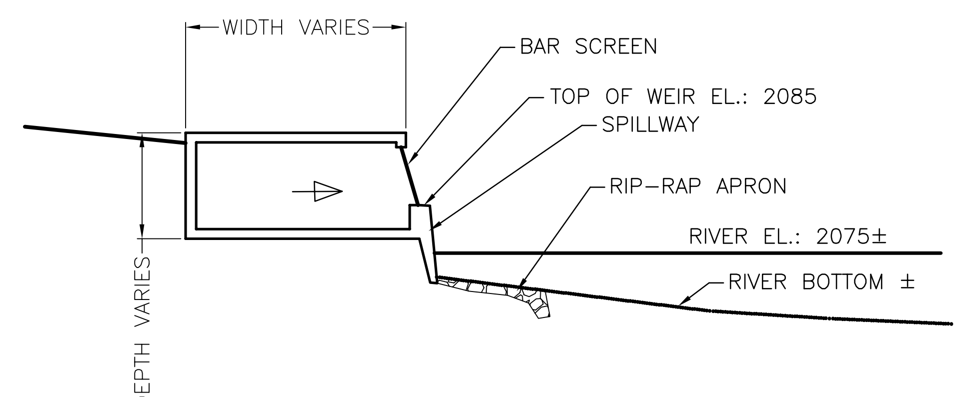
YAKIMA RIVER PORTAL
SECTION A–A



DISCHARGE STRUCTURE
SECTION C–C



CHANNEL FROM RIVER PORTAL
TO DISCHARGE STRUCTURE
SECTION B–B



DISCHARGE STRUCTURE
SECTION D–D

40 0 40 80 120
SCALE OF FEET

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KACHESS INACTIVE STORAGE
ALTERNATIVE 1
YAKIMA RIVER PORTAL SECTIONS
FIGURE 14

DESIGNED
DRAWN
CHECKED
TECH. APPR. NAME – TITLE
APPROVED ADMINISTRATIVE APPROVAL – NAME – TITLE
BOISE, ID 06.25.2009

FIGURE 14

SHEET X OF X

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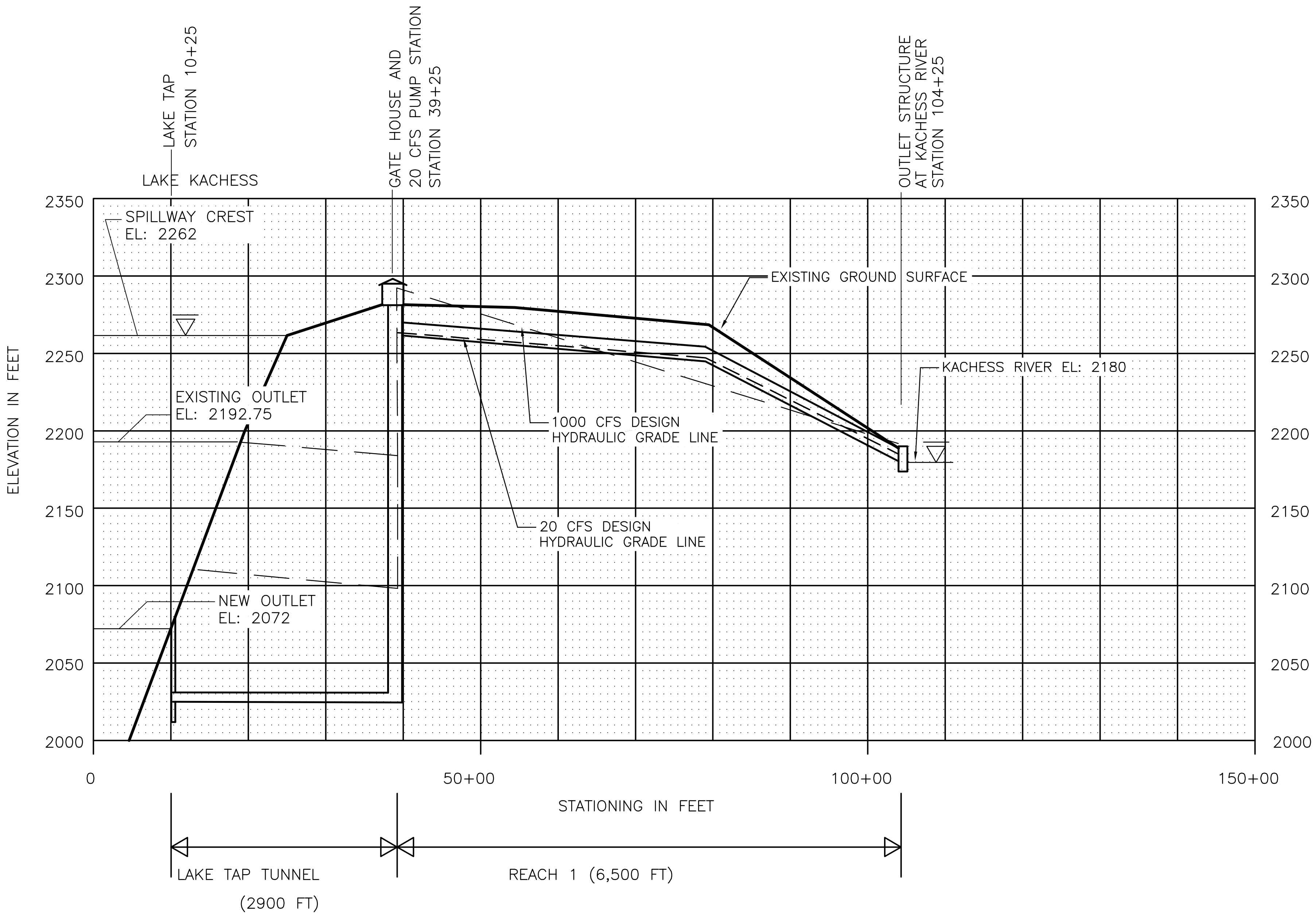

NOTES:

1) STORAGE VOLUME OF LAKE KEECHELUS:
   - BETWEEN SPILLWAY CREST AND EXISTING OUTLET = 239,000 ac.ft.
   - BETWEEN EXISTING OUTLET AND PROPOSED OUTLET = 200,000 ac.ft.
2) AVERAGE ELEVATION OF KACHESS RIVER AT PROPOSED OUTLET = 2208 FT.
3) PIPELINE LOCATION AND PROFILE SHOWN FOR CONCEPTUAL PURPOSES ONLY.
4) TRANSMISSION MAIN DIAMETERS BASED ON DESIGN CRITERIA USED:
   - ALTERNATIVE 1 – TUNNEL MAX DESIGN FLOW OF 1200 CFS AT LAKE ELEVATION 2192.75 FT WITH DECLINING FLOW RATE AS LAKE LEVEL DROPS (TUNNEL PROFILE SHOWN IN FIGURE 10) AND SMALL PUMP STATION DESIGN FLOWS OF 20 CFS AT LAKE KACHESS ELEVATION 2192.75 FT TO MAINTAIN INSTREAM FLOWS IN KACHESS RIVER. TRANSMISSION MAIN FOR 20 CFS IS 24 INCH DIAMETER PIPE.
   - ALTERNATIVE 2 – LARGE PUMP STATION DESIGN FLOWS OF 1000 CFS AT LAKE ELEVATION 2192.75 FT DECLINING FLOW RATE AS LAKE LEVEL DROPS AND SMALL PUMP STATION DESIGN FLOWS OF 20 CFS AT LAKE KACHESS ELEVATION 2192.75 FT TO MAINTAIN INSTREAM FLOWS IN KACHESS RIVER. TRANSMISSION MAIN FOR 1000 CFS IS 144 INCH DIAMETER PIPE. TRANSMISSION MAIN WOULD ALSO BE USED FOR 20 CFS FLOW WHEN SMALL PUMP STATION IS IN USE.

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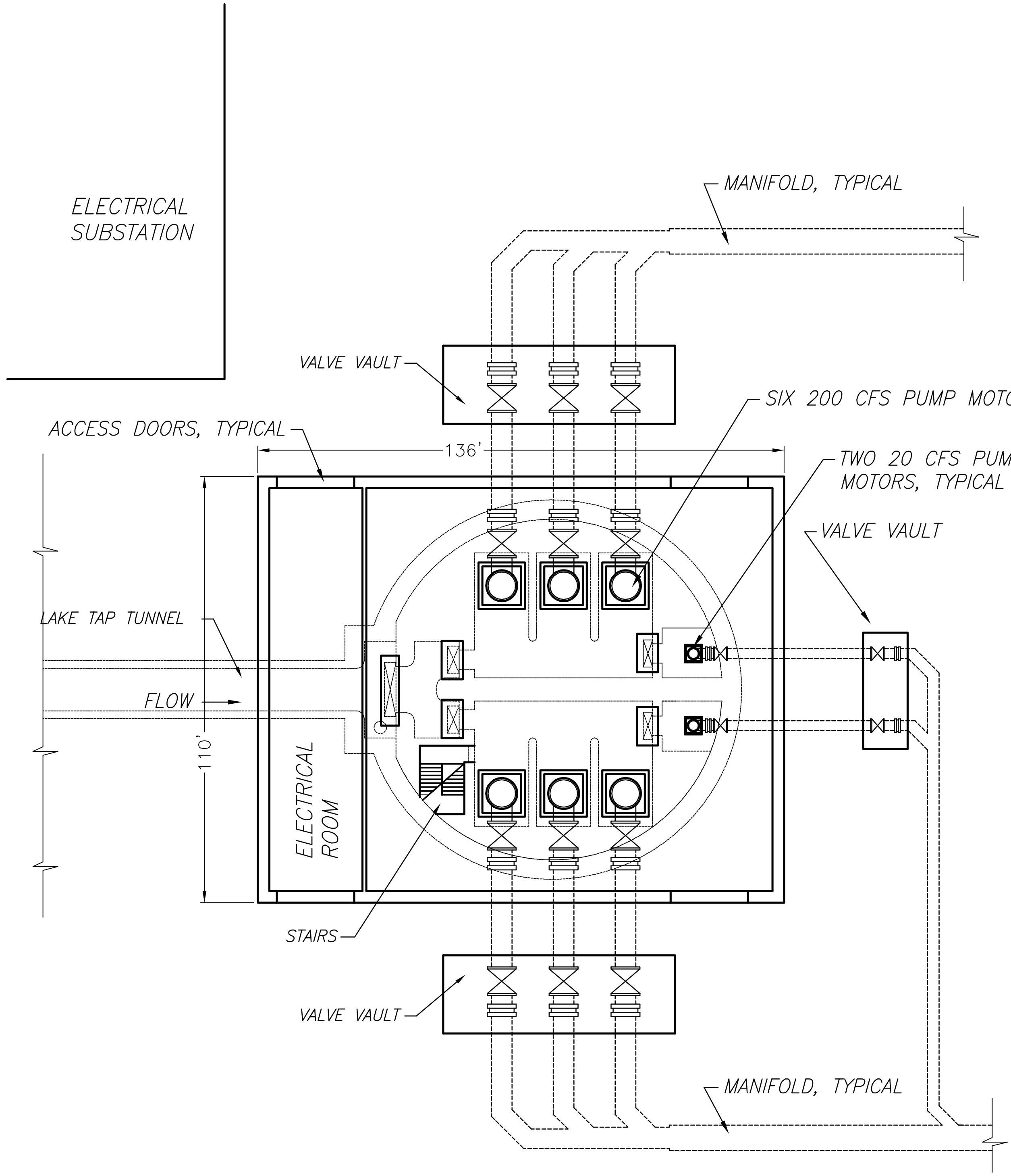
KACHESS INACTIVE STORAGE
ALTERNATIVES 1 AND 2
TRANSMISSION MAIN PROFILE
FIGURE 15

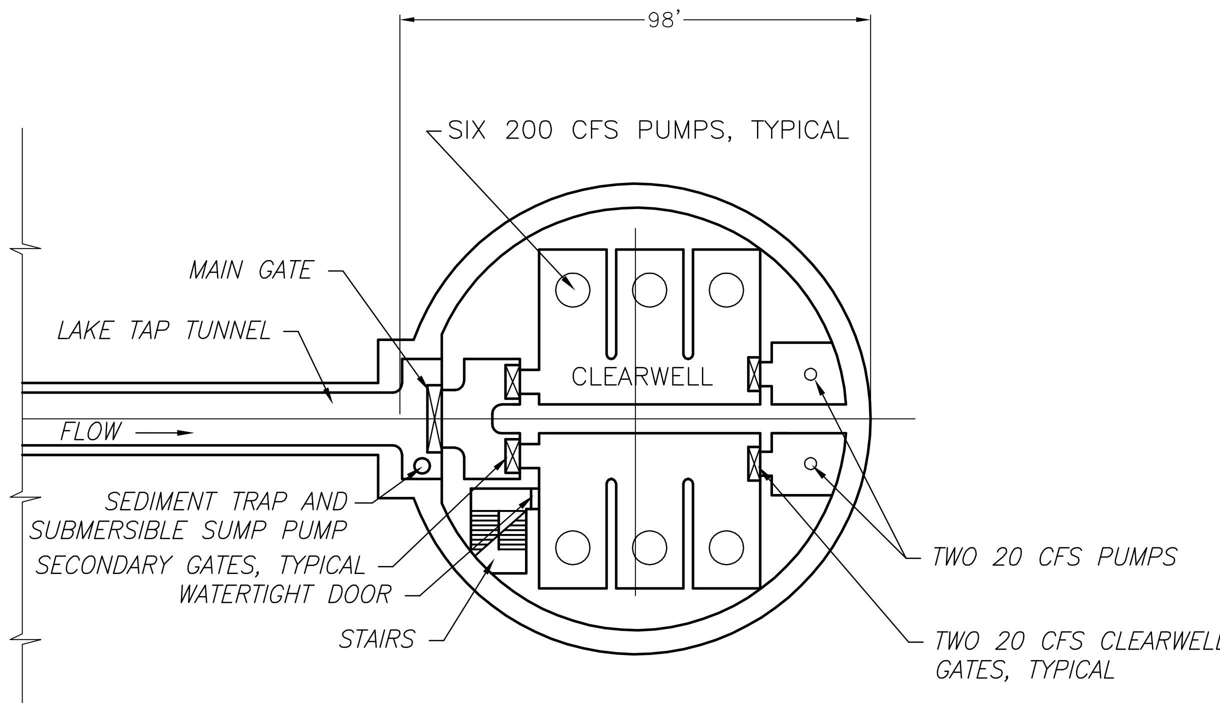
DESIGNED BG
DRAWN LM
CHECKED SS
TECH. APPR. NAME – TITLE
APPROVED ADMINISTRATIVE APPROVAL – NAME – TITLE
BOISE, ID 06.25.2009

FIGURE 15

SHEET X OF X



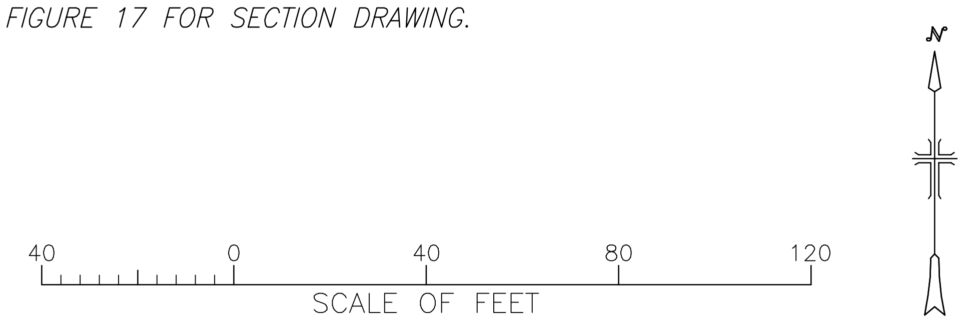
GROUND SURFACE FLOOR PLAN AND BELOW GRADE MANIFOLD



CLEARWELL FLOOR PLAN

NOTES:

1) 1000 CFS PUMP STATION FIRM CAPACITY IS 5 PUMPS x 200 CFS PER PUMP PLUS ONE SPARE PUMP.
2) 20 CFS PUMP STATION FIRM CAPACITY IS 1 PUMP x 20 CFS PLUS ONE SPARE PUMP.
3) 20 CFS PUMP STATION WOULD BE OFF WHEN 1000 CFS PUMP STATION IS PUMPING.
4) SEE FIGURE 17 FOR SECTION DRAWING.



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KACHESS INACTIVE STORAGE
ALTERNATIVE 2
1000 CFS & 20 CFS PUMP STATION PLANS
FIGURE 16

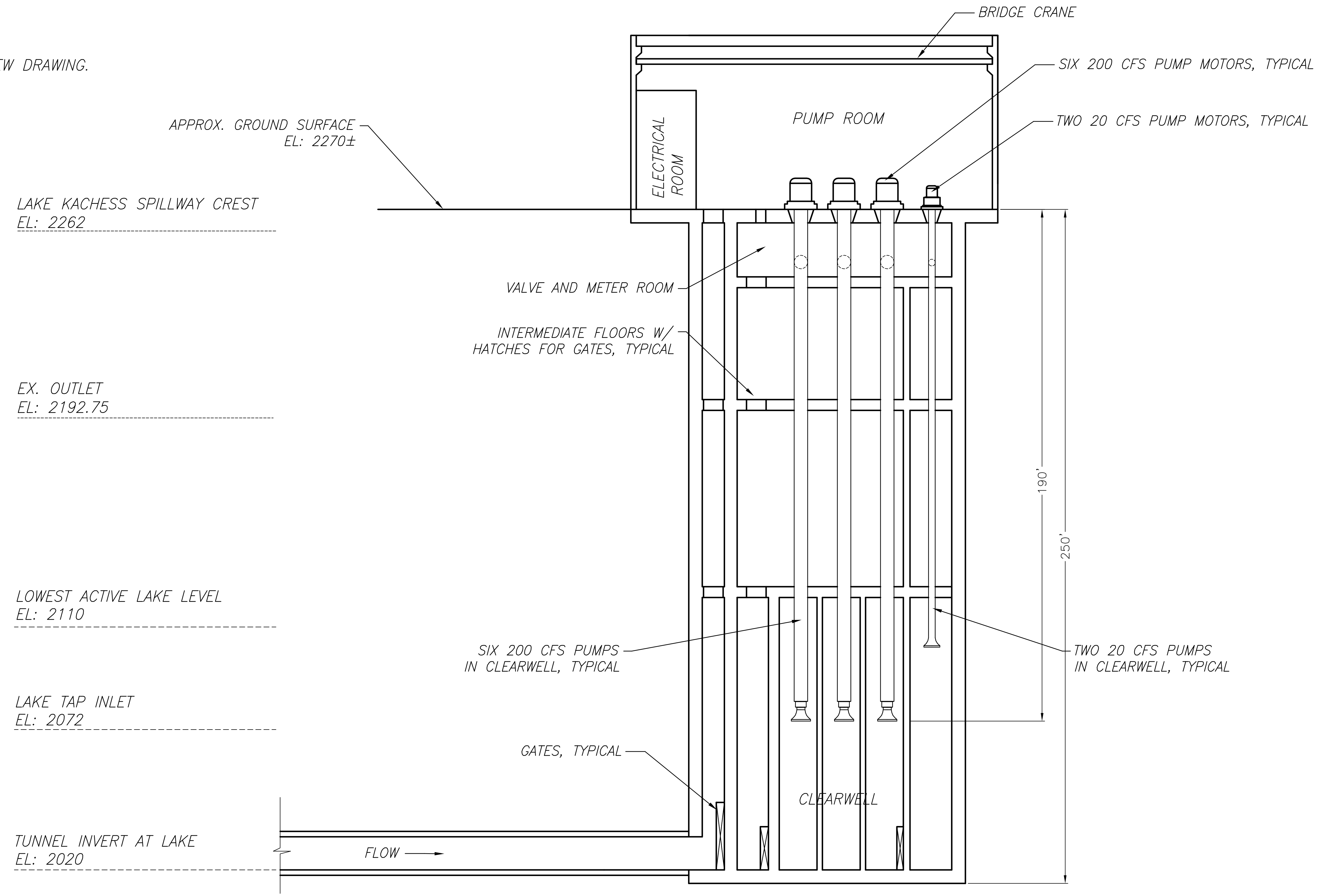
DESIGNED
DRAWN
CHECKED
TECH. APPR. NAME – TITLE
APPROVED ADMINISTRATIVE APPROVAL – NAME – TITLE
BOISE, ID 06.25.2009

FIGURE 16

SHEET X OF X

C:\pwworking\sea\d0445601\Kachess lake tap section.dwg, Large PS plans, 11/12/2010 10:34:36 AM, kgoss, Tabloid, 1:2

S:
SEE FIGURE 16 FOR PLAN VIEW DRAWING.



SCHEMATIC SECTION

40 0 40 80 120
SCALE OF FEET

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KACHESS INACTIVE STORAGE
ALTERNATIVE 2
1000 CFS & 20 CFS PUMP STATION SECTION
FIGURE 17

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APPROVED ADMINISTRATIVE APPROVAL – NAME – TITLE
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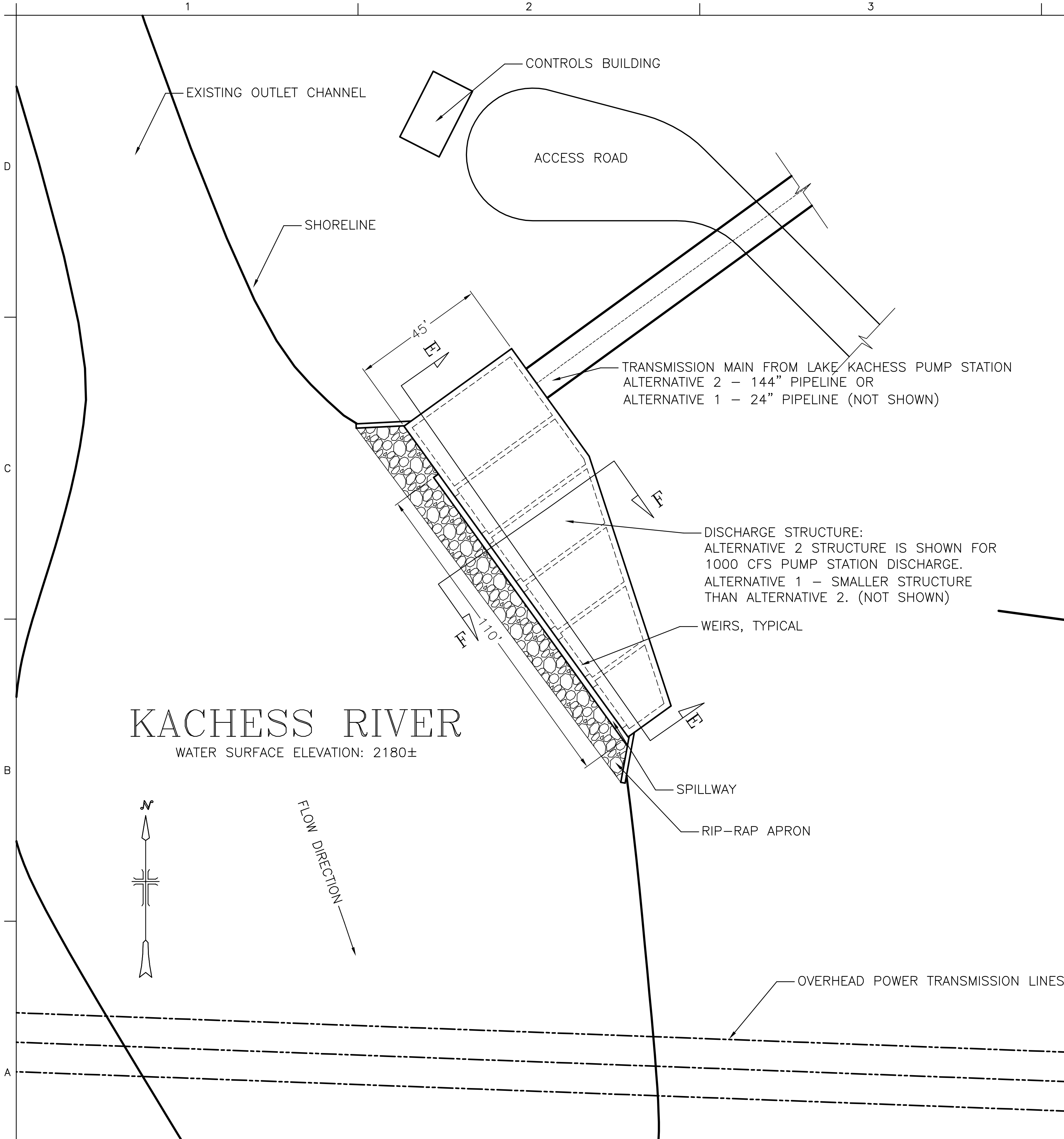
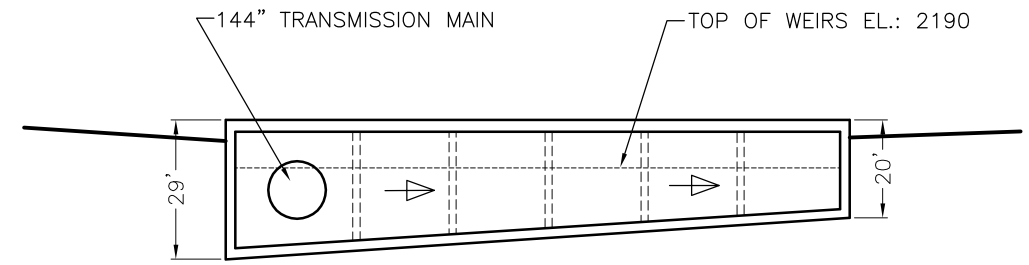
FIGURE 17

SHEET X OF X

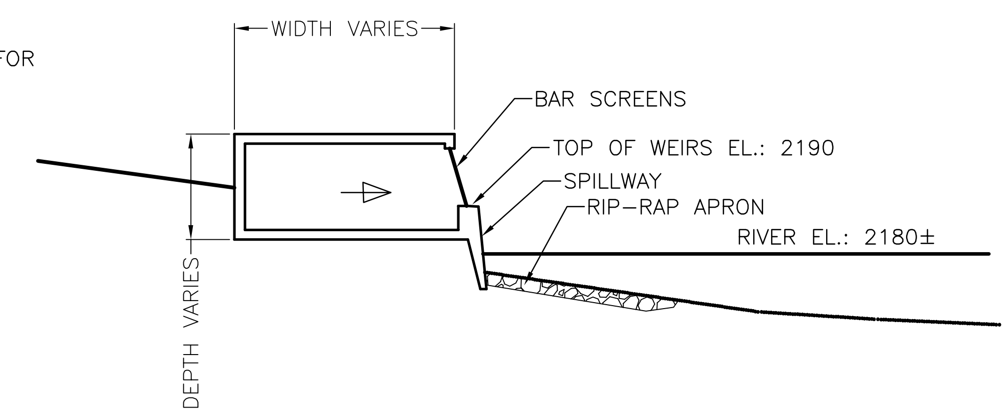
ALTERNATIVE 2

NOTES:
STRUCTURE SHOWN IS FOR ALTERNATIVE 2 (20 CFS PUMP STATION AND 1000 CFS PUMP STATION.)





DISCHARGE STRUCTURE
SECTION E–E



DISCHARGE STRUCTURE
SECTION F–F

NOTES:

1. LENGTH OF DISCHARGE STUCTURE APPROXIMATE. DIMENSIONS DEPEND ON WEIR FLOW RATES AND SCREEN REQUIREMENTS.
2. SCHEMATIC SKETCH ONLY – RIVER SHORELINE IS APPROXIMATE.
3. FLOW RATE: 1000 CFS FROM LARGE PUMP STATION, OR 20 CFS FROM SMALL PUMP STATION.

40 0 40 80 120
SCALE OF FEET

RECLAMATION
Managing Water in the West

ALWAYS THINK SAFETY

U.S. DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
YAKIMA RIVER BASIN STUDY

KACHESS INACTIVE STORAGE
ALTERNATIVES 1 & 2
KACHESS RIVER OUTLET STRUCTURE PLAN AND SECTIONS
FIGURE 18

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FIGURE 18

SHEET OF