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Geotechnical
Environmental
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Iron King Mine/Humbolt Smelter Superfund Site

Cover Alternatives Evaluation for Iron King Mine Main Tailings Pile

Dewey-Humboldt, Yavapai County, Arizona

Prepared for:
EA Engineering, Science, and Technology, Inc.
405 S. Highway 121
Building C, Suite 100
Lewisville, Texas 75067

Submitted by:
GEI Consultants, Inc.
4601 DTC Boulevard, Suite 900
Denver, Colorado 80237

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Project 101950

Registered Professional Engineer (Civil)
CERTIFICATE NO. 50455
STEPHEN G. BROWN
Date Signed 10-20-2010
ARIZONA U.S.A.

Stephen G. Brown, P.E.
Senior Project Manager

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1.0 Introduction

This cover alternatives evaluation presents considerations, concepts, and an opinion of estimated budgetary costs for installing a cover on the Main Tailings Pile at the Iron King Mine, Dewey-Humboldt, Arizona. The mine was closed in 1968 and milling/processing operations at the Main Tailings Pile ceased in 1970. The facilities considered in this study include the Main Tailings Pile and the separate, smaller Iron King Mine Small Tailings Pond (termed Waste Area 2 in this study). The Iron King Mine is part of the Iron King Mine/Humboldt Smelter site, which is being managed by the U.S. Environmental Protection Agency (USEPA) under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA). Cover alternatives and selection of the preferred alternative will be further considered in the Feasibility Study and Remedial Design phases.

GEI Consultants, Inc., (GEI) performed this study under subcontract to EA Environmental, Science, and Technology, Inc. (EA). EA is under contract to the U.S. Environmental Protection Agency (USEPA) for performance of the Remedial Investigation and Feasibility Study at the Iron King Mine/Humboldt Smelter site.

2.0 Background Information

2.1 Site Description and History

A detailed site description is provided in the Remedial Investigation Report (EA, 2010). The Iron King Mine is located on the northeast slopes of the Bradshaw Mountains; about 12 miles east of Prescott, and about 1 mile southwest of the town of Dewey-Humboldt, Arizona, see Figure 1. The ore body was discovered circa 1880 and the mine started production in 1903. The Iron King Mine was an active mine during varied periods from 1903 to 1968 and ultimately closed December 1, 1968. Very limited and sporadic mining and milling operations occur in 1969 and 1970 and the mine goes idle by June of 1970.

The Iron King Mine area covers approximately 153 acres. A large portion of this area is covered by tailings. There are five retention ponds, five or more mine shafts, and a collapsed mine shaft (glory hole). The underground mine was expanded in 1936 to recover lead, gold, silver, zinc, and copper. The main ore body is associated with the Yavapai Schist strata. A 140-ton hammer mill was installed in 1936 to crush ore and was expanded to 225-ton capacity in 1938. A cyanide processing plant was added in 1940 to process mill produced tailings to enhance recovery of precious metals. The original drawings of the mine tailings storage areas, hoist structures, mine works, and underground workings were destroyed in a fire many years ago and no copies are available.

The tailings are in two discrete areas (Waste Areas 1 and 2, see Figure 5) that are located west of Arizona State Route 69. The Main Tailings Pile (Waste Area 1) is located between Iron King Road to the south and the mine operations buildings to the north. The Iron King Mine Small Tailings Pile (Waste Area 2) is located about 500 feet north of the Main Tailings Pile. The Main Tailings Pile is about 55 acres in area and has a maximum height of about 110 feet. The volume of tailings in the Main Tailings Pile has been estimated at about 6.4 million cubic yards (cy) (EA, 2010). The top of the tailings pile has a mild slope to the west and has a maximum estimated crest at about El. 4,750 feet.

Evident from the site visit are exposed native hillsides and abutments that confine the Main Tailings Pile on the north and south sides. The west extent of the Main Tailings Pile is limited by the rising slope of the valley bottom. The natural valley area located east (down slope) of the Main Tailings Pile has been filled to a depth of about 40 feet with tailings deposited primarily as a result of the 1964 failure and from subsequent erosion of the Main Tailings Pile. The east limit of the tailings is constrained by the site access road (constructed on the former railway grade embankment fill); although post-failure the tailings have been excavated adjacent to the access roadway embankment to form a small stormwater detention pond at the eastern limit of the site.

The USEPA Superfund process for the combined Iron King Mine/Humboldt Smelter sites has progressed through completion of the Remedial Investigation as of 2010.

2.2 Topographic Survey Information and Waste Area Delineation

No recent formal topographic or property line surveys have been performed to define the exact limits and geometry of the Main Tailings Pile. A survey (Famas, 2004) delineated the natural ground located to the west of the tailings pile and included the west edges of the tailings pile. There are available historic air photographs that show where tailings were deposited within the natural drainage features (USEPA, 2008). Recent topographic surveys prepared by Yavapai County were found to be not useful for design purposes.

2.3 Main Tailings Pile Construction

The Main Tailings Pile was constructed using a perimeter dike stacking method where hydraulically placed tailings were pumped from the mine milling facilities and discharged along the top of the perimeter pile containment dike, thereby raising the pile by accumulation of tailings deposits. A mixture of tailings and water was primarily discharged from low-height perimeter dikes located along the eastern perimeter of the main tailings pile, and to a limited extent wrapping around to the north and south perimeter. The sluiced tailings were controlled by a system of divider dikes and gentle slopes to flow in a generally east to west direction, with coarser grained fractions settling out close to the discharge point (east perimeter) and the finer grained material settling out progressively further to the west.

As the solids settled out, the process water continued to flow west and was collected in two detention basins located at the western extent of the Main Tailings Pile. Secondary settling and decanting of water occurred in the detention basin, and decant water was discharged through a drop inlet intake structure as return flow to the mine milling facilities. At the mine milling facilities, the return water was used to form a slurry with mill tailings, and was subsequently pumped to the top of the east perimeter of the Main Tailings Pile and deposited. Plant process water was likely a valuable resource in the arid environment and recirculation of the water to sluice the tailings was an important resource conservation measure. Information on the source of the water has not been provided, but was likely a combination of stored surface water runoff augmented by water pumped out of the mine or local wells.

2.4 Main Tailings Pile Condition Assessment

The Main Tailings Pile has the following key conditions based on observations made during a site visit performed by GEI Consultants, Inc., on July 1, 2010.

1. There is no cover or vegetation growing on the Main Tailings Pile.
2. There is interest on the part of the current owner in exploring opportunities to keep a portion of the tailings accessible and available for potential mineral resource recovery of ‘rare earth’ minerals for beneficial use after the majority of the tailings pile has

been formally covered and closed (personal communication with Steve Schuchardt of NAI, July 1, 2010). This would require a designated area on the top of the tailings pile to receive a “temporary cover” that could be removed and replaced at limited expense to mine the tailings.

3. There are a number of erosion channels and rills that occur on the steep perimeter side slopes. The east slope has a major flow slide failure that continues to promote further erosion of the exposed tailings pile. The reason for erosion is obvious, but the cause of the massive failure of the east slope on March 23, 1964 is not well understood. Only a cursory description of the failure event is available from letters written by the mine manager at the time that noted a series of lesser stability problems with the east slope area during a period of 8 to 10 years prior to the failure event.

4. The tailings pile at Iron King does not have gas generating properties based on the available documentation and investigation reports. The tailings pile has no known municipal waste within it and, as a result, the tailings pile should not produce gas as a result of decay of organic materials.

5. The Main Tailings Pile generally consists of weak, apparently saturated silt based on limited available exploration data. We infer from the available information that an extremely fine silt interior mass is marginally contained by an outer shell of very fine silt of limited thickness. There is no substantial, engineered, tailings dam structure that serves as a containment structure as would be associated with the more common hydraulically-placed mine tailings ponds that deposit a coarser range of mill tailings or with conventional water storage dams. No geotechnical borings have been installed to characterize the tailings material properties including water content, strength and compressibility. The current stability of the Main Tailings Pile, while having no significant failures since 1964, is considered to be less than the minimum recommended factor of safety of 1.5 that would be associated with static stability of a high hazard water storage dam, and could be marginal. This condition does not necessarily indicate impending instability under the current loading conditions, but could indicate impending instability if loads are significantly modified or increased as a result of cut slope geometry, rapid filling, regrading, or if the tailings pile is subjected to extreme hydraulic (precipitation) or seismic (earthquake) loading events similar to those that would be considered for a high hazard water storage dam.

6. The side slopes of the Main Tailings Pile are too steep (estimated at about 1.5H:1V) to receive and support a final cover. The slopes of the tailings piles need to be flattened to 3 horizontal to 1 vertical (3H:1V), or flatter, allow a stable cover to be constructed over the tailings and to provide sufficient mass and strength to meet static and seismic stability requirements.

7. The steep slopes (approximately 1H:1V) of the tailings deposits located next to Arizona State Route 69 highway and detention ditch were observed to be promoting

erosion of the tailings at this location because the slope lacks vegetation or other erosion control measures.

2.5 Geotechnical and Hydrologic Information

No geotechnical borings have been installed to characterize the tailings material properties including strength and compressibility.

The 24-hour, 25-year flood event is expected to be the design flood for the cover system. An estimate of the design flood runoff is discussed in Section 3.1 Surface Water Management. A formal hydrologic analysis and flood routing study has not been performed for the site or for potential cover alternatives.

3.0 Design Criteria

The purposes of a final cover are to control migration of contaminants from the Main Tailings Pile via groundwater, surface water, and air pathways. The goal of the cover design will be to encapsulate the tailings; minimize infiltration of precipitation and surface water; stabilize and contain the Main Tailings Pile against the design loading conditions; function with minimum maintenance; promote drainage and minimize erosion of the cover; and accommodate settling and subsidence so that the cover's integrity is maintained. The cover does not need facilities to collect or vent gas because gas is not expected to be generated by the tailings.

3.1 Surface Water Management

The tailings pile cover must be sloped and covered with a free draining material that is stable, aesthetic and requires little maintenance in this arid region. Guidance values for design of covers over the top (flatter) portion of the Main Tailings Pile indicate slopes ranging from 2 percent to 5 percent are generally acceptable (USEPA, 2004). We suggest the upper level of the tailings pile be regraded to drain at a 2.5 percent slope toward the west. Draining surface water to the west would take advantage of the historic drainage direction toward the detention ponds located at the west extent of the Main tailings Pile, consistent with tailings pile operations when the mine was operated. The side slopes of the cover are expected to range from about 3H:1V (33 percent) to 4H:1V (25 percent) to encapsulate the tailings and to address the long-term stability of the tailings pile.

These slopes will prevent ponding of water and provide positive drainage of runoff from the cover. The 2.5 percent slope on the top of the tailings pile was selected to provide positive drainage while limiting the amount of earthwork required to construct the cover. The maximum hydraulic conductivity of the cover is limited to be no higher than one order of magnitude less than the underlying natural ground, which precludes accumulation of excess water within the tailings and associated potential for leachate generation.

The cover, stormwater collection swales, and stormwater drainage slopes need to safely collect and convey runoff from a 24-hour, 25-year precipitation event away from the closed tailings pile without significant erosion and damage to the cover in accordance with RCRA Subtitle D minimum requirements, which will need to be evaluated for applicability to this CERCLA site. Use of vegetation as a primary erosion control method would be difficult to implement and maintain at this site because of the very arid environment. Guidance and practical experience suggests the use of gravel and crushed rock in this situation to serve as an armament against erosion. However, to meet aesthetic objectives, plants may be incorporated into specific areas of the cover system by constructing a vegetated cover over the armored components of the cover. The design would need to address the selection of plant types that would not result in damage to the underlying cover materials, and include plans for sustaining and maintaining the plant material.

The 24-hour, 25-year precipitation event for the site is 3.58 inches of precipitation (NOAA, 2006). Based on a tailings pile cover surface area of about 55 acres, the runoff volume from the 24-hour, 25-year storm event would be about 16.5 acre-feet. Stormwater detention facilities will need to be designed to safely store the calculated runoff from the design storm based on the final site configuration.

Discharge of stormwater to surface water is considered a point discharge and must comply with National Pollutant Discharge Elimination System (NPDES) permit requirements of the Clean Water Act as regulated by the State of Arizona and the USEPA. NPDES permit requirements will also need to address the requirements if a portion of the tailings pile is left open with only a temporary cover to enable future beneficial reuse of tailings as a mineral resource. Stormwater from the temporary cover area will need to be collected, routed, and stored separately from the main cover runoff to avoid co-mingling of potentially different water quality conditions.

The NAI Storm Water Pollution Prevention Plan (SWPPP) (Brown & Caldwell, 2008) provides an analysis of the surface water runoff from the Iron King Mine area. According to the plan, all runoff from a 100-year storm event would be contained by a system of nine retention ponds. A figure depicting the location and designations of each of the retention ponds and table with the storage capacity is presented in the SWPPP.

3.2 Slope Stability and Settlement

The geometry and condition of the existing Main Tailings Pile has not changed significantly since the cessation of active tailings placement in the early 1970s. We observed that that the hydraulically placed perimeter tailings, which form the containment of the interior weaker tailings, have become somewhat hardened and desiccated by exposure. A sample taken from a few feet below the surface of the tailings pile and within 50 feet horizontal distance of the perimeter of the pile indicates the coarser exterior materials are very fine silt particles that have 70 percent finer than the #200 (74 micron) sieve and 54 percent finer than the #400 (38 micron) sieve. A sample taken from a few feet below the surface of the tailings pile and several hundred feet horizontal distance from the perimeter of the pile indicates the interior materials are extremely fine silt particles that have 90 percent finer than the #400 (38 micron) sieve. The tailings materials are granular and do not appear to have cohesive properties. Due to the very fine size of the silt particles the tailings materials retain water by capillary tension in the pore spaces resulting in nearly saturated tailings as indicated by the data from direct-push sampling tool investigations and a monitoring well that is screened within the tailings (MW-05).

Consequently, the Main Tailings Pile could be characterized as consisting of a weak, approximately saturated, extremely fine silt interior mass that is marginally contained by an outer shell of very fine silt of limited thickness. There is no substantial tailings dam structure that can be defined as a containment structure as would be associated with the more common hydraulically-placed mine tailings ponds that deposit a coarser range of mill tailings or with a conventional water storage dam. The failure surface of the 1964 massive failure of the east wall penetrated the outer containment shell and exposed weaker deposits in the interior of the tailings pile.

No geotechnical borings have been installed to characterize the tailings material properties, including strength and compressibility, or to fully ascertain the thickness of tailings or the condition of the natural foundation soils. The natural foundation soils are expected to be alluvium consisting of primarily granular soil (gravel, gravelly sand, and gravelly silt) as indicated by the Remedial Investigation Report (EA, 2010).

The existing Main Tailings Pile has not had a major failure since the early 1960s, which demonstrates that it is marginally stable with a factor of safety slightly higher than, or possibly equal to, 1.0. A factor of safety of 1.0 represents the impending instability, with increasing likelihood of failure as the factor of safety decreases below 1.0, and increasing likelihood of stability as the factor of safety increases above 1.0. The minimum recommended factor of safety for static steady-seepage loading conditions is 1.5 (FEMA, 2004). The existing tailings pile was constructed with exterior slopes that are estimated, in lieu of surveying data, to be about 1.5 horizontal to 1 vertical (1.5H:1V) with intermediate benches of modest width. However, in the early 1960s when the tailings pile was raised to near its current height, a portion of the east face failed massively on March 23, 1964 (Shattuck Denn Mining Company, 1964) and the failed wet tailings flowed down valley with the majority of tailings stopped by the access roadway embankment that is adjacent to Arizona State Route 69. Use of the tailings pile continued following the failure by establishing a new perimeter dike approximately one hundred feet back from the head scarp of the failed area and there was no reported tailings pile slope instability issues for the remaining duration of tailings placement until 1968 when the mine closed. The observed conditions indicate there was no attempt to regrade or backfill the failed area after the failure, which was left open to erode as evident by the tailings located down slope of the breach area and the detention basins to collect and contain runoff and eroded tailings. Continued erosion of tailings from the very steep exterior slopes/scarp of the failed area is evident. The slopes/scarp of the failed area has the steepest slopes of the Main Tailings Piles and is expected to have the lowest stability factor of safety of the east slope. Tension cracks were observed at the top of the failed slope area indicating a current factor of safety that may approach unity (1.0) after periodic saturating rain events.

Features were observed on the east slope of the Main Tailings Pile during our site visit that indicate events that could have led to the 1964 failure were present at other locations along the east wall of the pile. These features include apparent locations where wet tailings from the interior of the pile bulged or squeezed out of the outer crust material and were subsequently contained and buttressed with gravel fill before conditions could worsen and result in a failure. The presence of poor stability conditions prior to the major failure is further supported by statements in an internal Shattuck Denn Mining Corporation letter from the Prescott mine manager to Mr. La Morte in the New York office, dated March 25, 1964, that indicate *"Part of the front wall of the lower tailings pond collapsed the evening… March 23, 1964. This particular part of the wall has been a trouble spot for the past 8 or 10 years."* Bulging and squeezing conditions are expected to have occurred more frequently as the height of the tailings pile increased.

To meet static stability objectives, the Main Tailings Pile will need to have additional support provided for the steep slopes, and in particular for the high and steep east slope. The additional support will need to be in the form of a buttress fill to flatten the overall slope and provide sufficient mass and strength to improve the stability of the tailings pile to meet the recommended minimum values for all loading conditions including end of construction, steady seepage, sliding and seismic.

3.3 Seismic Stability Requirements

To meet USEPA requirements, a landfill and cover system must be stable for accelerations that exceed a peak 0.1g based on a minimum of 90 percent probability of non-exceedance in 250 years based on 2008 USGS regional probabilistic seismic maps. In the general location of Dewey-Humboldt, Arizona the maximum horizontal peak ground acceleration for a 2 percent probability of exceedance in 50 years, which is the same as a 90 percent probability of non-exceedance in 250 years, is 0.12 of the acceleration of gravity (g, 32.174 feet per second per second).

The tailings pile was constructed using hydraulic methods with no mechanical compaction and there is currently no information regarding the strength of the tailings. The site is in a moderate area of seismicity. These conditions raise concerns about the long term static and seismic stability of the fill and cover systems. Additional support will need to be in the form of a buttress fill to flatten the overall slope and provide sufficient mass and strength to improve the stability of the tailings pile to meet the recommended minimum values for seismic loading conditions.

4.0 Cover Systems

4.1 Conceptual Cover Alternatives

Several conceptual cover alternatives have been developed for use in estimating the effort and budgets required for construction of a cover for the Main Tailings Pile. The cost of cover systems is directly proportional to the area that needs to be covered. A goal of this study is to evaluate alternatives that reduce area of the tailings pile and the associated cover to reduce the cost of the cover system while meeting goals for long term stability. A key approach is to use the east tailings materials and tailings materials excavated from the top of the tailings pile, and tailings materials from the north tailings area (Waste Area 2) as fill material to create a stabilizing berm around the tailings pile. Tailings from the Iron King Mine Small Tailings Pile (Waste Area 2) that is located about 500 feet north of the Main Tailings Pile can be excavated and hauled to the east toe of the Main Tailings Pile and placed as fill to flatten and buttress the steep existing slopes.

The cover will be constructed of materials that armor and stabilize the tailings materials, reduce the potential for infiltration of surface water into the tailings, and reduce the potential for erosion of the tailings by controlling surface water runoff. The area available after removal of the east tailings, which is located between the Main Tailings Pile and State Route 69, is expected to be suitable for construction of stormwater detention/retention ponds. Four conceptual alternatives have been developed, as follows:

Alternative 1. Alternative 1 would effectively remove the Main Tailings Pile and Waste Area 2 contaminant sources. The Main Tailings Pile and Waste Area 2 would be excavated, transported off-site, and disposed at a hazardous waste landfill. The area of tailings removal is illustrated on Figures 4 and 5. This alternative employs a fully-encapsulating cover that does not provide access for potential future mineral recovery from the tailings pile for beneficial use. Disposal of the tailings may require more than one licensed landfill because of the large volume of the tailings (about 6.4 million cy or about 11.7 million tons). Currently, there are four hazardous waste landfills within 9 hours of the site: Chemwaste Kettleman Hills in Kettleman City, California (620 miles), U.S. Pollution Control, Inc. Grassy Mountain near Murray, Utah (580 miles), U.S. Ecology in Beatty, Nevada (380 miles) and GSX Chemical Services in Westmoreland, California (320 miles). Excavation of the tailings would have to be managed and staged so that the tailings pile would remain stable and to limit dust emissions off-site. We have assumed that the tailings would not have to be dried before transporting to the landfill.

Alternative 2. Consolidate and reconfigure the tailing materials to construct a stabilizing buttress by regrading the steep slopes using excavated tailing from the east tailing area, from the top of the Main Tailings Pile, and from Waste Area 2. The buttress would have 3H:1V slopes, or flatter, and a cover would be installed over the entire regraded tailings pile, see Figures 6 and 7. This alternative employs a fully-encapsulating cover that does not provide access for potential future mineral recovery from the tailings pile for beneficial use. The east crest of the Main Tailings Pile will be raised by about 10 feet, such that the drainage slope to the west (currently shown as 2.5 percent) provides sufficient excavation quantities for construction of the buttress while promoting runoff of surface water. The stabilizing buttress will consist of compacted tailings materials only for this alternative.

Alternative 3. Consolidate and reconfigure the tailings materials to construct a stabilizing buttress with 4H:1V slopes, or flatter, and to include a compacted earth stabilizing toe berm on the east slope in addition to the compacted tailings buttress, see Figures 8 and 9. The buttress slopes on the north and south sides will be constrained within the property lines by constructing 4H:1V slopes supporting with a geosynthetic-reinforced, mechanically stabilized earth (MSE) buttress, see Figure 9. The MSE buttress has an average height of 9 feet and is 1,370 feet long on the north side of the tailings pile and 560 feet long on the south side of the tailings pile. This alternative employs a fully-encapsulating cover that does not provide access for potential future mineral recovery from the tailings pile for beneficial use. As in Alternative 2, the top of the Main Tailings Pile will be graded from east to west at a 2.5 percent slope to avoid generating excess excavated material while promoting runoff.

Alternative 4. Consolidate and reconfigure the tailings materials in accordance with Alternative 3 and limit the extent of the cover on the top of the tailings pile to allow future mineral recovery, see Figure 10. For purposes of this study, we have assumed the future mineral recovery area would be limited to a surface area of 8.5 acres, or less. The future mineral recovery area would need a temporary cover consisting of a 2 foot thick soil layer to control dust and a stormwater control system, which would be addressed in future design phases if needed.

The cover area, quantity of earthwork, and associated cost opinion for the cover alternatives is summarized in Table 1.

Table 1. Summary of Cover Area, Earthwork Quantities, and Cost Opinion for Each Alternative

Alternative	Cover Area (Acres)	Tailings Excavation (CY)	Tailings Fill (CY)	Import Soil Fill (CY)	Estimated Cost* ($)
1. Dispose Off-Site	N/A	6,400,000	N/A	N/A	$2,000,000,000 or more
2. Consolidate and Stabilize with Tailings Buttress	51.6	947,000	947,000	0 (1)	$ 17,319,000
3. Alt 2 with Combination Tailings & Earth Buttress	56.0	833,000	833,000	485,000(2)	$ 30,810,000
4. Alt 3 with Future Mineral Recovery Area	46.6	833,000	833,000	485,000(2)	$ 30,294,000(3)

*Cost basis, assumptions, line items, and contingencies are discussed in Section 6.
1. Zero import fill quantity assumes the design will be adjusted to balance the tailings cut and fill quantities.
2. Imported earth fill for construction of the earth stabilizing berm.
3. Includes cost for temporary cover for mineral recovery area.

These cover alternatives have not been evaluated for stability requirements, seepage requirements, and hydrologic flood and flood routing conditions because of the conceptual nature of the alternatives and the lack of engineering data currently available for the analyses.

In general, the flatter 4H:1V slopes used with Alternatives 3 and 4 provide increased stability under static and earthquake loading conditions as compared to Alternative 2, which used 3H:1V slopes. Alternative 4 increases the feasibility of constructing the flatter 4H:1V slopes by incorporating an MSE wall such that the cover will not encroach on adjacent private property, but may have reduced stability compared to Alternative 3 under earthquake loading conditions.

4.2 Cover Materials

Cover materials will need to address the requirements for control of surface water infiltration; stability of the tailings and cover mass; minimize erosion; minimize maintenance; promote drainage and minimize erosion of the cover; and accommodate settling and subsidence of the cover and underlying tailings.

A compacted clay layer is typical cover material used to reduce infiltration of surface water into the tailings pile. The compacted clay layer typically underlies a geomembrane to provide a double lining. The availability of clay having a hydraulic conductivity less than or equal to $1x10^{-7}$ cm/sec is rare in northwestern Arizona. A comprehensive evaluation of potential sources of such material has not been conducted for this study. However, based on inspection alone, low hydraulic conductivity clay is not available on site and this material would need to be imported to the site from an offsite source that is likely many miles away. An acceptable substitute for a compacted clay layer is a commercially available geocomposite lining (GCL) that consists of granulated bentonite clay between two layers of geotextile that is fused to a textured geomembrane. A GCL is applicable for cover slopes that do not exceed 5 degrees because the friction angle of partially hydrated or partially saturated bentonite is in the range of 6 to 9 degrees.

The cover on top of the tailings pile will have a slope of less than 8 degrees, and the proposed materials shown in the typical cross-section on Figure 12 are considered suitable to address the performance goals. The proposed materials include 1.5 feet thickness of coarse aggregate (gravel and cobbles) to provide armament and erosion control, underlain by a separation non-woven geotextile and geomembrane supported geosynthetic clay lining (GCL) to provide control of infiltration.

Performance goals for the steeper side slopes will require the cover have increased shear strength compared to the cover on top of the tailings. Proposed materials that are considered suitable to address the performance goals for covering the steeper side slopes includes a geogrid for additional shear strength on the steeper side slopes and eliminates the GCL because of its low shear strength. A typical cross-section of the cover for steeper side slopes is shown on Figure 13. The proposed materials include 1.5 feet thickness of coarse aggregate (gravel and cobbles) to provide armament and erosion control, underlain by a biaxial geogrid. The infiltration control layer beneath the geogrid includes a separation non-woven geotextile and a geomembrane that is textured both sides for additional interface shear resistance. Use of a single geomembrane without an underlying clay layer (GCL) is considered appropriate because the rate of runoff will be much higher on the steeper side slopes, which reduces (and likely eliminates) the potential for infiltration.

To control runoff on side slopes that exceed 20 feet in height, the slopes will be benched at intermediate heights. Runoff from the slope above each bench will be collected on the benches by perforated pipes that will safely convey the water to the bottom of the slope. The proposed materials and configuration of the cover and pipes on the benches is shown in cross-section on Figure 14.

5.0 Data Gaps

Numerous data gaps were identified in this study that limited the level of development of this study and that will be key to development and characterization of design alternatives, final design, and cover cost estimates. Key data gaps include the following:

1. Engineering material properties of the tailings materials including index properties, strength under various loading conditions, and compressibility. Index properties and strength parameters will be needed for analysis of slope stability, and for evaluation of the tailings for use as a construction fill material. The magnitude and time-rate of compressibility of the tailings will be needed for evaluation of settlement of the tailings pile when loaded with the cover materials and for the tailings where used as a construction material. Similarly, engineering material properties will need to be obtained for other materials used in construction of the cover and this may include onsite natural soil, onsite mine waste rock, imported soil, and geosynthetic materials.

   Geotechnical borings are needed to perform in-situ tests and to obtain samples for laboratory testing to characterize the tailings material properties. Several geotechnical borings are needed at the toe and crest of the breach area and within the interior area of the tailings pile to determine the depth of tailings and location of the perched phreatic surface. Geotechnical explorations may be performed using rotary mud drilling with standard penetration testing (SPT), cone penetrometer with piezometer (CPTu) soundings, and geophysical methods. Laboratory tests of the tailings are needed to measure the undrained and drained strength, hydraulic conductivity, and compressibility properties of the tailings and foundation materials.

   Undisturbed samples of the tailings materials are needed to determine if static liquefaction or bearing capacity failures could occur during mass regrading or construction of buttresses, or under extreme loading conditions that may occur over the long-term post-construction period. Construction of the cover may require raising the height of a portion of the tailings (additional cover material or fill material to grade the cover). Raising the height also raises the load on the existing tailings and it will be necessary to know if the foundation tailings are saturated and if they respond to the increased load and associated strain with contractive or dilative behavior. Contractive behavior of saturated sluiced tailings (ash) in response to increased load was the key factor in the massive failure of coal ash residual material that occurred at the TVA's Kingston Dredge Pond on December 22, 2008. At TVA Kingston, the saturated sluiced ash catastrophically failed by static liquefaction due to loss of shear strength in the very soft sluiced fly ash and river sediment at the foundation level of the 80-foot high tailings pile.

These parameters are fundamental to analysis of the stability during construction and the long-term stability of the regraded Main Tailings Pile and cover materials.

The geotechnical program will require planning to identify the number and type of samples and data objectives. The geotechnical laboratory testing program will include index property tests, strength tests, and consolidation/compressibility tests. The testing program would likely include a special series of triaxial compression tests on undisturbed samples to evaluate whether the tailings material dilates or contracts when sheared and to compare the in-place relative density to the critical density state. Other tests may be required to determine the response of the tailings to static and earthquake loading conditions. The geotechnical program may also include field tests to evaluate the in-place strength, permeability, shear modulus, and density of the tailings mass.

2. Multi-level pneumatic piezometers need to be installed at various locations and depths within the tailings pile to enable understanding of water pressures within the tailings pile and the underlying natural foundation soil and to enable monitoring of changes in water pressures during cover construction and the post-construction monitoring period. The information obtained will be used to evaluate the location of the phreatic water surface within the tailings pile for use in stability analysis of the tailings pile and the cover system. A minimum program should include installing piezometers at 7 locations, with 2 measurement sensors per location. The sensors would be installed to evaluate conditions in the upper and lower zones of the saturated tailings, and in saturated zones in the foundation soil.

3. Develop a site base map for use in design that includes topographic survey information for the entire Main Tailings Pile, Waste Area 2, and related structures, roadways, wells, and construction areas. The topographic information should include a Digital Elevation Model (DEM) with 1-foot contour line intervals set to elevation. Benchmarks to be used for the survey should be thoroughly reviewed to avoid the apparent issues with matching surveys at the limits of quad sheets that coincide at the tailings pile site. If possible, import and merge the base map information from the adjacent Famas, 2004 survey, to provide comprehensive information on the adjacent properties to the west and north of the tailings pile. This topographic survey, combined with information from geotechnical explorations is needed to define the exterior limits and thickness of the tailings to enable estimation of the volume of the tailings that need to be relocated or moved to consolidate and regrade the existing Main Tailings Pile.

4. Develop topographic survey to provide the geometry of the failed area on the east slope of the Main Tailings Pile for use in back-calculation of the failure conditions and estimation of material strength at the time of failure.

5. Obtain a property line survey and title/easement evaluation for all properties that will be potentially affected by the construction to enable negotiation of temporary construction easements, permanent easements, and property acquisition, as necessary.
6. Because of the potential cost impact, sources of construction materials need to be established and are critical to managing the selection of cover alternatives. Only a small quantity of mine waste rock was observed at the site during the site visit. A source of gravel, cobbles, and riprap for the cover armoring layer and erosion control structures will be needed.
7. Install geotechnical borings along transects to determine the depth of the tailings material, evaluate material properties of the tailings material, and to evaluate the underlying native foundation material. Perform geotechnical laboratory tests on selected samples obtained from the borings.
8. Install geotechnical borings to obtain samples of onsite soil for evaluation as potential fill or stabilization cover construction material. Perform geotechnical laboratory tests on selected samples obtained from the borings.
9. Obtain samples of onsite mine waste rock for evaluation as potential cover construction material, such as an erosion protection material. Perform geotechnical laboratory tests on selected samples.
10. Perform an evaluation of historic and current seismic activity using probabilistic and deterministic methods to identify the basis and magnitude of the design earthquake.

6.0 Supporting Information for Construction Cost Opinion

The opinions of cost presented in Tables 2 to 5 have been prepared for guidance in project evaluation and implementation for the information available at the time the opinion was prepared and based on a conceptual level of study.

The conceptual cover alternatives were developed without benefit of topographic mapping. The Main Tailings Pile limits were based on elevations of a few monitoring wells and direct push exploration locations located within the tailings pile and by scaling from aerial photos. The volume of the existing Main Tailings Pile was estimated by comparing the estimated DEM of the Main Tailings Pile with a digitized DEM of the 1958 USGS quadrangle topographic map for the area.

We have assumed that the tailings cut and fill quantities for Alternatives 2, 3, and 4, where relatively close in value, will be adjusted in the design process to result in an approximately balanced earthwork such that a significant quantity of imported material is not required for the buttress fill.

Construction cost estimates are based on our evaluation of the major construction items appropriate to complete the work. For unit price items, quantity estimates were developed from the conceptual alternative layouts. Lump sum prices are based on either quantitative or qualitative estimates of the work required and the corresponding cost. The calculated quantities were increased by 10 percent to account for variability in the available map information, approximations in the estimating process, and cost variability.

The cost estimates include an allowance for construction contingencies. This allowance is essentially a tool for managing the financial risk of a project. At the conceptual level of project development, construction contingencies are typically included to allow for project construction cost increases that could result from a variety of factors including:

Unforeseen conditions at the site or unexpected project development issues:

- Approximations in estimating
- Integration of new and/or more detailed project information or more detailed or rigorous analyses
- Other unforeseen or unexpected costs

The total allowance for construction contingencies used in these conceptual cost estimates is 30 percent, which includes contractor mobilization/demobilization, bonds, and insurance.

The costs for engineering field investigations, design engineering and permitting have not been included.

Project costs will depend on a variety of undetermined factors beyond our control, including (but not necessarily limited to) actual labor and materials costs, competitive market conditions, final project scope, implementation schedule, continuity and experience of construction personnel, level of personal protection required, and insurance costs. As a result, the project costs as developed in a future final design are expected to vary from the cost opinion presented herein.

The major cost line items for the four alternatives are presented in Tables 2 through 5.

Table 2. Alternative 1: Dispose Off-Site

Item	Quantity	Unit	Unit Price	Amount
Cover	0			0
Bench Drains	0			0
Tailings Excavation	6,400,000	CY	$10.94	$ 69,984,000
Tailings Haul and Disposal	6,400,000	CY	$364.50	$2,332,800,000
Construction Subtotal				$2,402,784,000
Contingency (not used)				0
Subtotal with Contingency				$2,402,784,000
Total				**$2,402,784,000**

Note: Costs for engineering and permitting have not been included.

Table 3. Alternative 2: Consolidate and Stabilize with Tailings Buttress

Item	Quantity	Unit	Unit Price	Amount
Cover	51.6	Acres	$104,360	$ 5,424,000
Bench Drains	8,481	Feet	$18.75	$ 159,000
Tailings Excavation and Fill	947,311	CY	$8.17	$ 7,740,000
Imported Earth Fill	0			0
Construction Subtotal				$13,322,000
Contingency (30%)				$ 3,997,000
Subtotal with Contingency				$17,319,000
Total				**$17,319,000**

Note: Costs for engineering and permitting have not been included.

Table 4. Alternative 3: Alternative 2 with Combination Tailings and Earth Buttress

Item	Quantity	Unit	Unit Price	Amount
Cover	56	Acres	$104,360	$ 5,962,000
Bench Drains	4,240	Feet	$18.75	$ 80,000
Tailings Excavation and Fill	833,200	CY	$8.17	$ 6,808,000
Imported Earth Fill	485,200	CY	$20	$ 9,704,000
MSE Wall	19,107	SF	$60	$ 1,146,000
Construction Subtotal				$23,700,000
Contingency (30%)				$ 7,110,000
Subtotal with Contingency				$30,810,000
Total				**$30,810,000**

Note: Costs for engineering and permitting have not been included.

Table 5. Alternative 4: Alternative 3 with Future Mineral Recovery Area

Item	Quantity	Unit	Unit Price	Amount
Cover	46.6	Acres	$104,360	$ 4,959,000
Temporary Cover (mineral recovery area)	8.5	Acres	$64,823	$ 606,000
Bench Drains	4,241	Feet	$18.75	$ 80,000
Tailings Excavation and Fill	833,200	CY	$8.17	$ 6,808,000
Imported Earth Fill	485,200	CY	$20	$ 9,704,000
MSE Wall	19,107	SF	$60	$ 1,146,000
Construction Subtotal				$23,303,000
Contingency (30%)				$ 6,991,000
Subtotal with Contingency				$30,294,000
Total				**$30,294,000**

Note: Costs for engineering and permitting have not been included.

7.0 References

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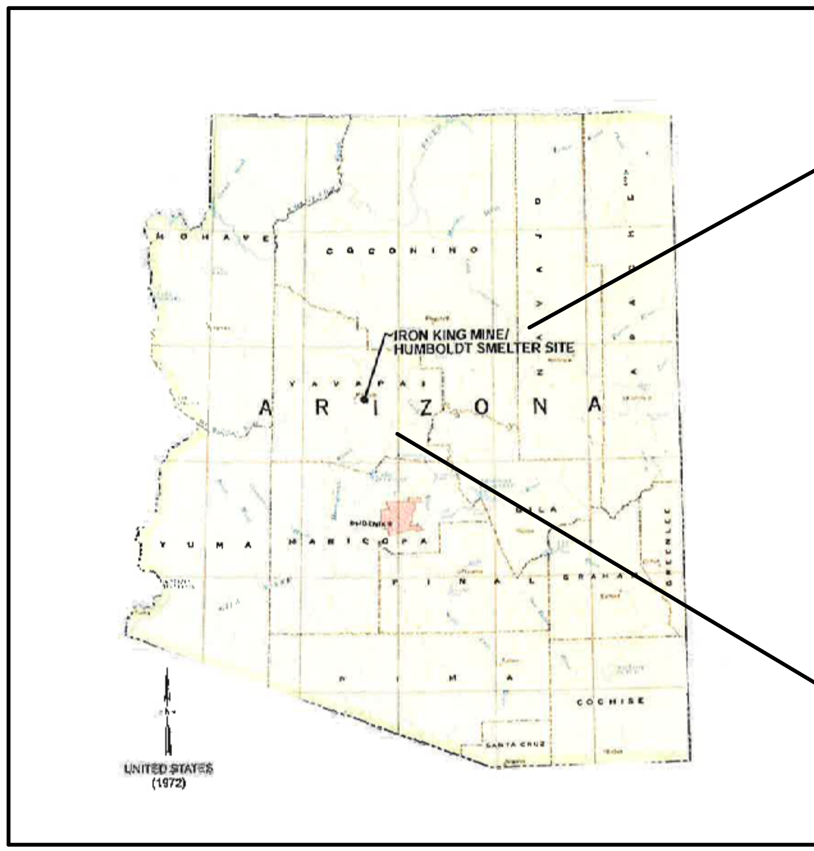
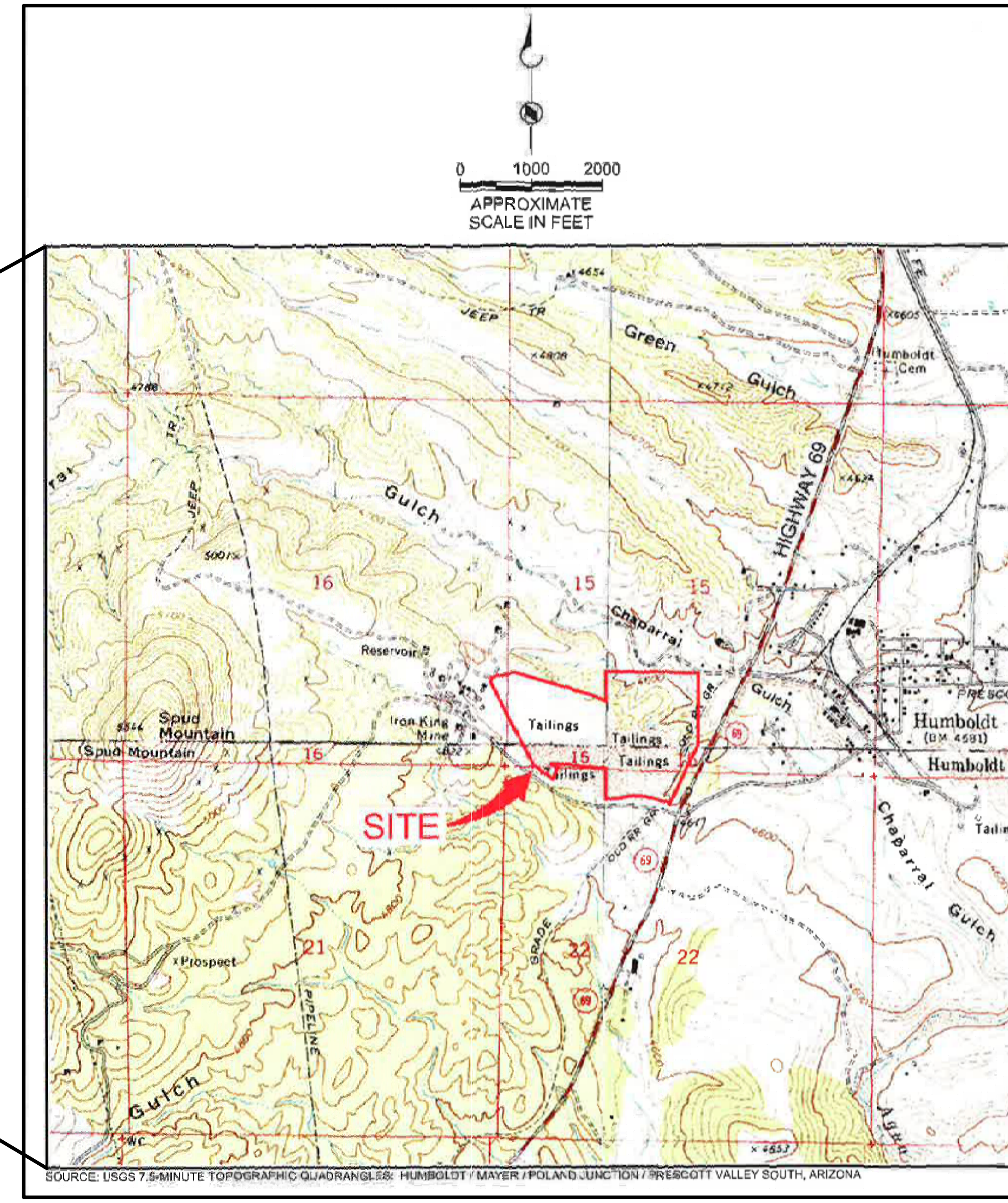
Figures





NOTES:

1. STATE OF ARIZONA IMAGE TAKEN FROM AERIAL PHOTGRAPHIC ANALYSIS OF IRON KING MINE/HUMBOLDT SMELTER SITE, FIGURE 1, PREPARED BY THE EPA.
2. QUADRANGEL IMAGE TAKEN FROM STORMWATER POLLUTION PREVENTION PLAN, HUMBOLDT PLAN, FIGURE 1, PREPARED BY BROWN AND CALDWELL.

IRON KING MINE DEWEY-HUMBOLDT SMELTER DEWEY-HUMBOLDT, YAVAPAI COUNTY, ARIZONA	GEI Consultants	SITE LOCATION DIAGRAM
EA ENGINEERING, SCIENCE, & TECHNOLOGY, INC. LEWISVILLE, TEXAS	Project 101950	October 2010 Fig. 1

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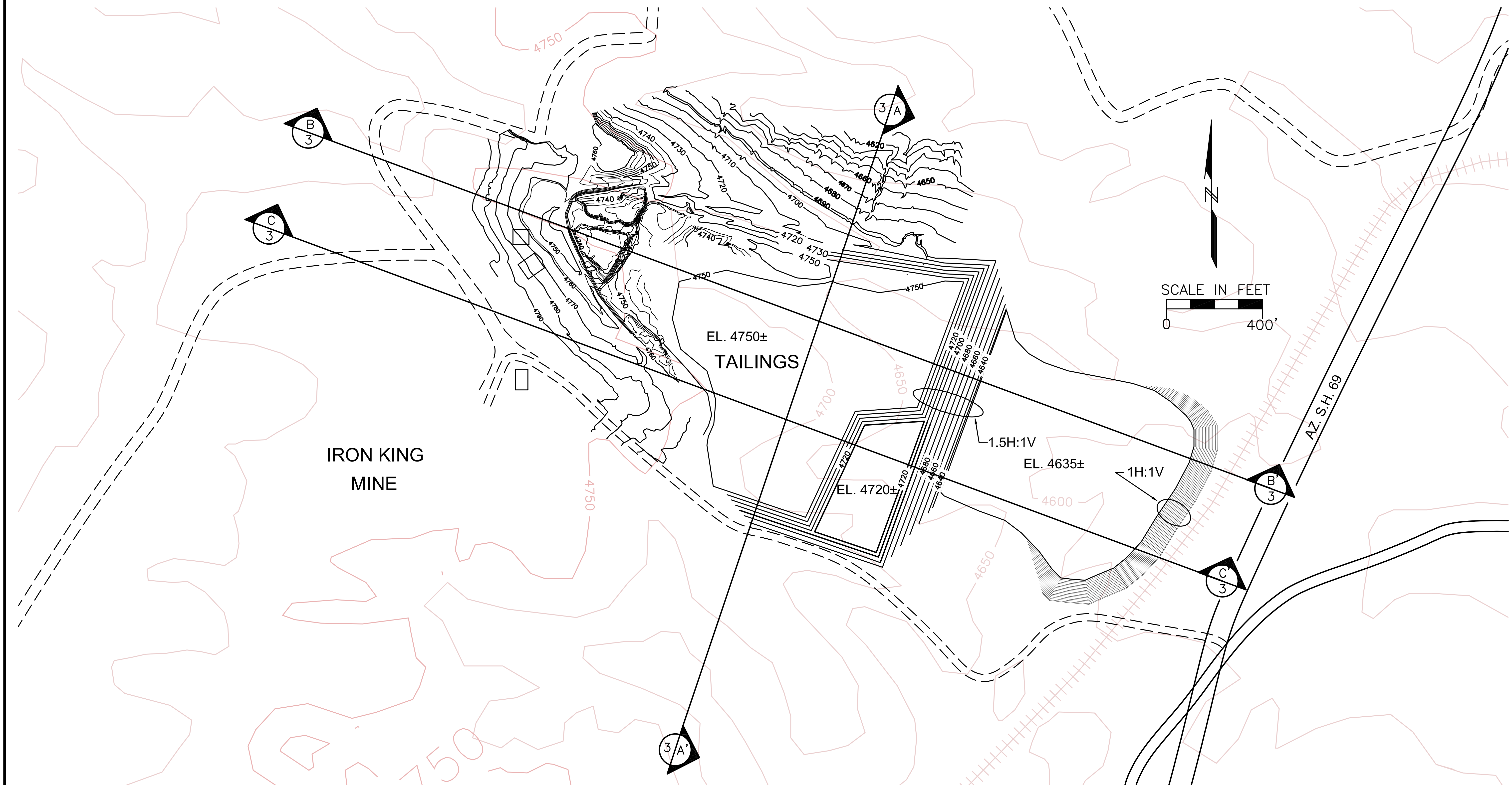

NOTES:

1. BASE GRADES WERE OBTAINED FROM DIGITIZING CONTOUR DATA FROM 1958 GEOLOGIC SURVEY MAP (50 FOOT CONTOURS).
2. THE EXISTING GRADE CONTOURS WERE OBTAINED FROM A PARTIAL 2004 SURVEY ON THE WEST SIDE OF THE TAILINGS BASIN AND FROM ELEVATIONS OF TWO EXISTING WELLS ON THE EASTERN SIDE.
3. THERE WAS NO CURRENT SURVEY AVAILABLE TO OBTAIN PROPERTY LINE INFORMATION.
4. THERE WAS NO GEOTECHNICAL DATA AVAILABLE FOR THE SITE

LEGEND:

A/3 — A'/3 CROSS SECTION LOCATION

IRON KING MINE
DEWEY-HUMBOLDT SMELTER
DEWEY-HUMBOLDT, YAVAPAI COUNTY, ARIZONA

EA ENGINEERING, SCIENCE, & TECHNOLOGY, INC.
LEWISVILLE, TEXAS

GEI Consultants

Project 101950

PLAN VIEW - EXISTING SITE CONDITIONS

October 2010

Fig. 2

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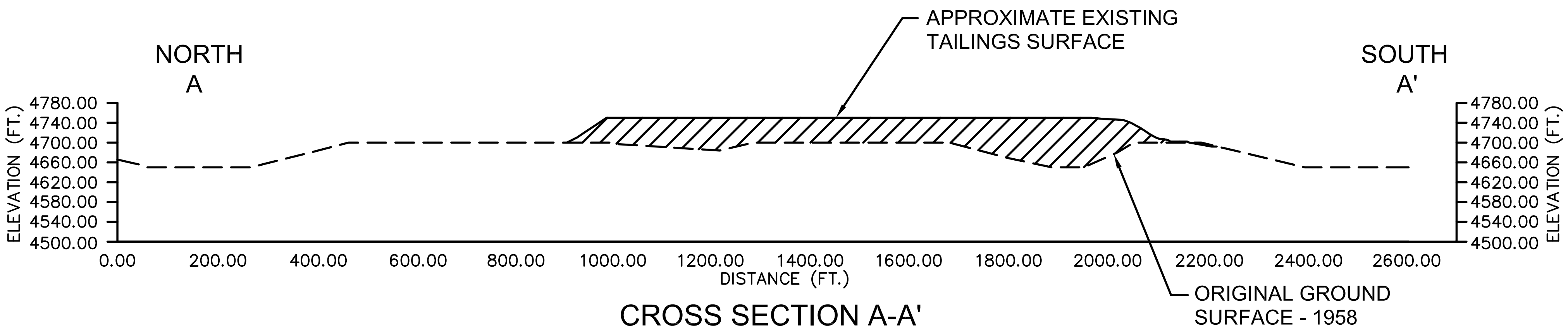
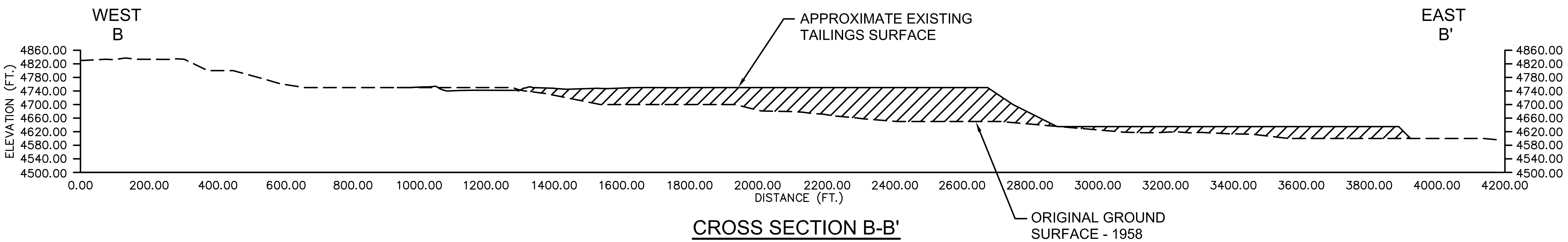


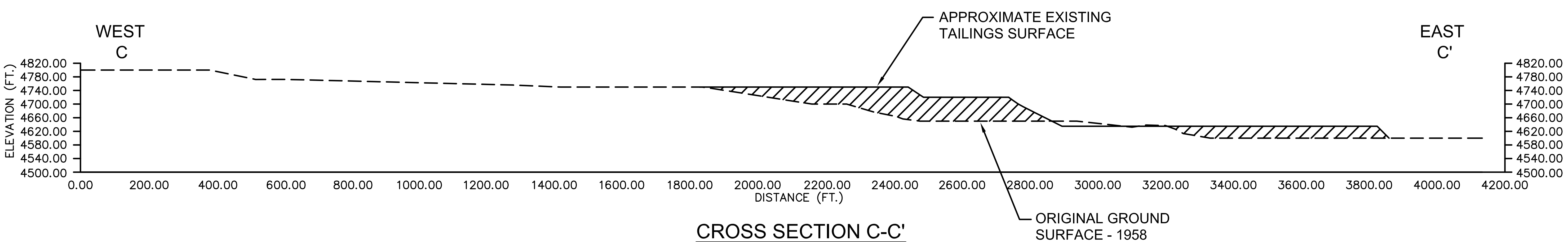
CROSS SECTION A-A'

SCALE: 1" = 300' HORIZONTAL
1" = 300' VERTICAL



CROSS SECTION B-B'

SCALE: 1" = 300' HORIZONTAL
1" = 300' VERTICAL



CROSS SECTION C-C'

SCALE: 1" = 300' HORIZONTAL
1" = 300' VERTICAL

IRON KING MINE
DEWEY-HUMBOLDT SMELTER
DEWEY-HUMBOLDT, YAVAPAI COUNTY, ARIZONA

EA ENGINEERING, SCIENCE, & TECHNOLOGY, INC.
LEWISVILLE, TEXAS

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CROSS SECTIONS - EXISTING CONDITIONS

October 2010

Fig. 3

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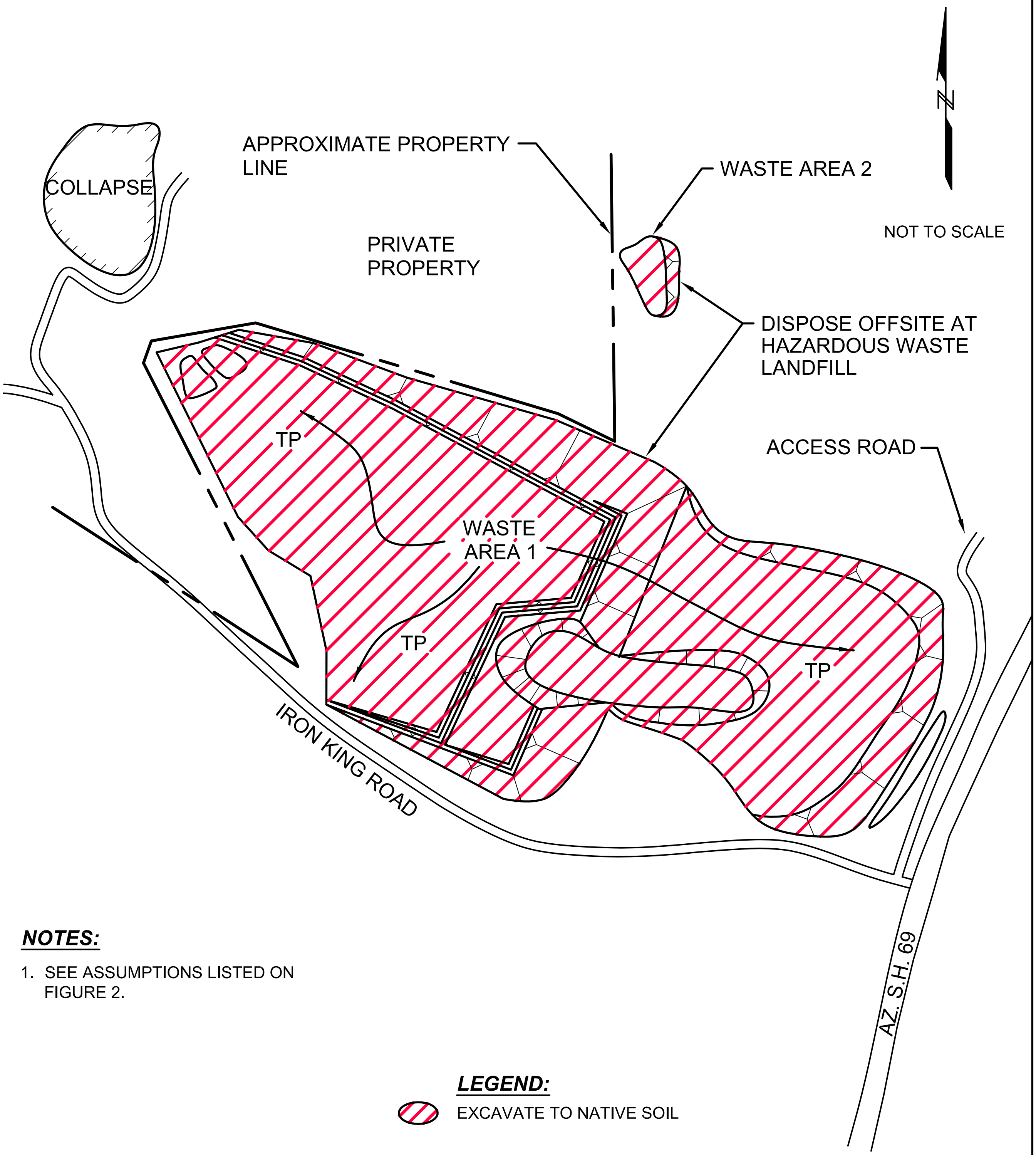
OPTION 1: REMOVAL OF ALL TAILINGS AND TRANSFER TO OFF-SITE HAZARDOUS WASTE LANDFILL



NOTES:

1. SEE ASSUMPTIONS LISTED ON FIGURE 2.

LEGEND:

EXCAVATE TO NATIVE SOIL

IRON KING MINE DEWEY-HUMBOLDT SMELTER DEWEY-HUMBOLT, YAVAPAI COUNTY,ARIZONA	GEI Consultants	PLAN VIEW OPTION 1
EA ENGINEERING, SCIENCE, & TECHNOLOGY, INC. LEWISVILLE, TEXAS	Project 101950	October 2010 Fig. 4

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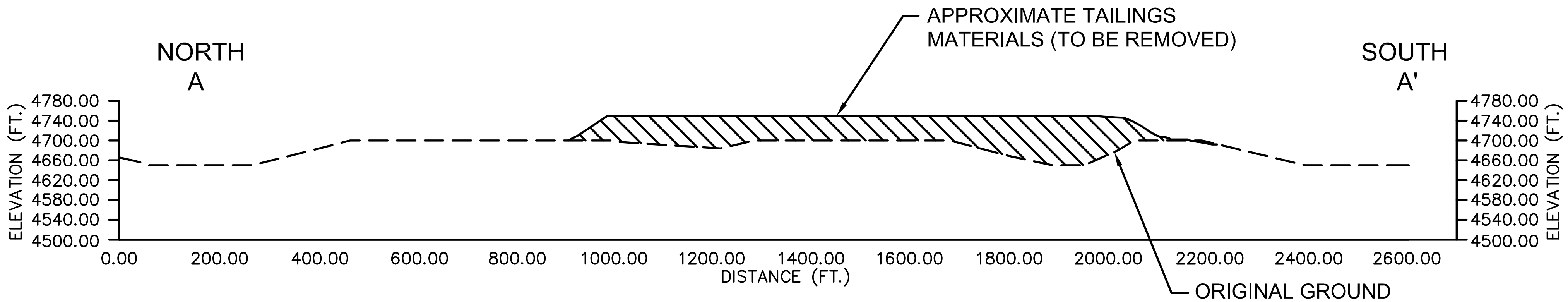
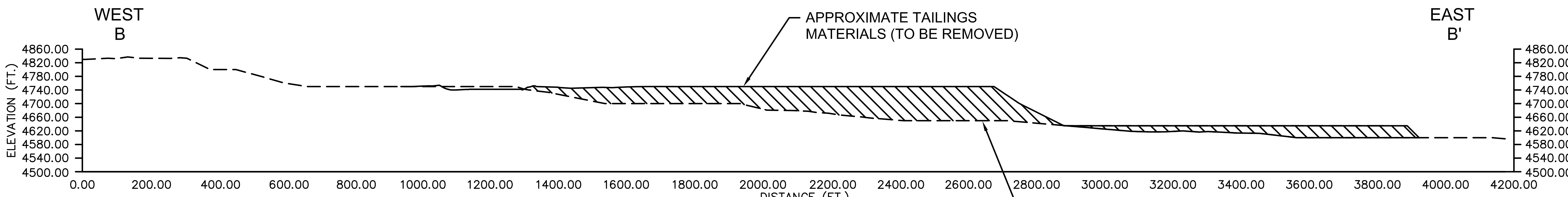
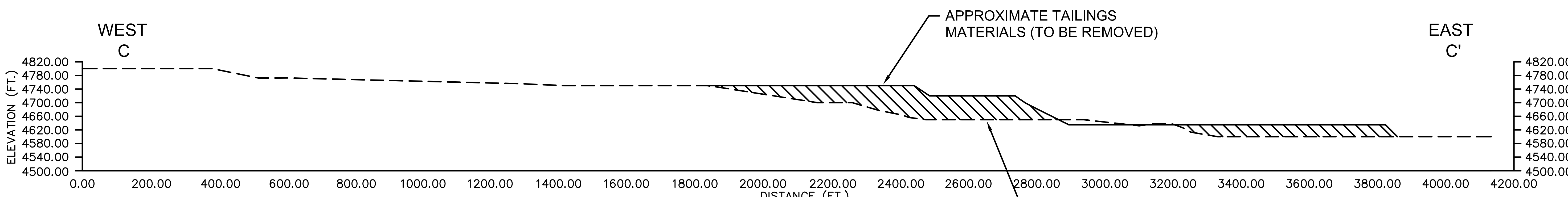
OPTION 1: REMOVAL OF ALL TAILINGS AND TRANSFER TO OFF-SITE HAZARDOUS WASTE LANDFILL



CROSS SECTION A-A'
SCALE: 1" = 300' HORIZONTAL
1" = 300' VERTICAL



CROSS SECTION B-B'
SCALE: 1" = 300' HORIZONTAL
1" = 300' VERTICAL



CROSS SECTION C-C'
SCALE: 1" = 300' HORIZONTAL
1" = 300' VERTICAL

LEGEND:
TAILINGS MATERIALS TO BE REMOVED

IRON KING MINE DEWEY-HUMBOLDT SMELTER DEWEY-HUMBOLDT, YAVAPAI COUNTY, ARIZONA	GEI Consultants	CROSS SECTIONS OPTION 1
EA ENGINEERING, SCIENCE, & TECHNOLOGY, INC. LEWISVILLE, TEXAS	Project 101950	October 2010 Fig. 5

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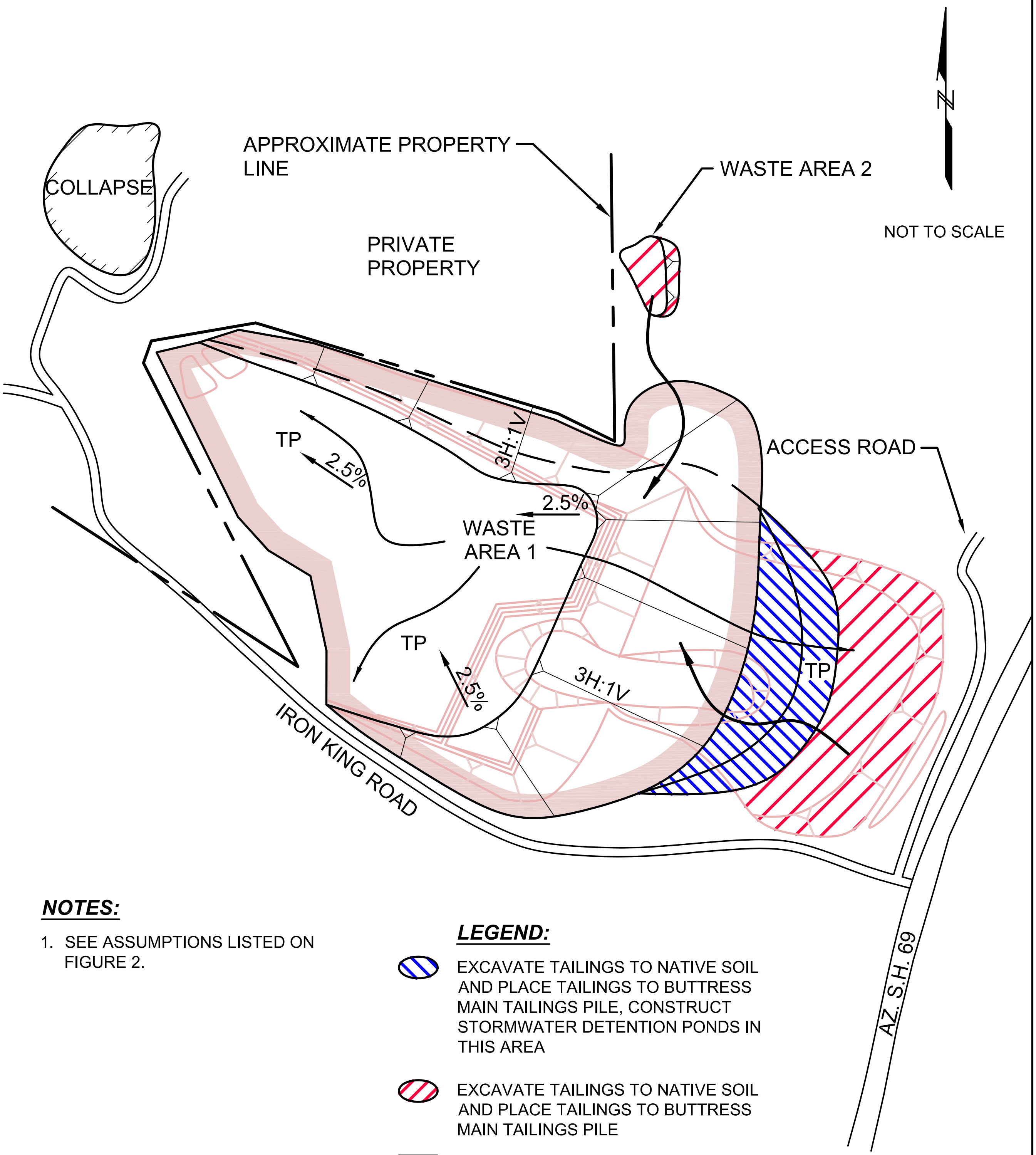
OPTION 2: FULL COVER SUPPORTED BY TAILINGS BUTTRESS FILL



NOTES:

1. SEE ASSUMPTIONS LISTED ON FIGURE 2.

LEGEND:

- EXCAVATE TAILINGS TO NATIVE SOIL AND PLACE TAILINGS TO BUTTRESS MAIN TAILINGS PILE, CONSTRUCT STORMWATER DETENTION PONDS IN THIS AREA
- EXCAVATE TAILINGS TO NATIVE SOIL AND PLACE TAILINGS TO BUTTRESS MAIN TAILINGS PILE
- CAP LIMITS

IRON KING MINE DEWEY-HUMBOLDT SMELTER DEWEY-HUMBOLT, YAVAPAI COUNTY,ARIZONA	GEI Consultants	PLAN VIEW OPTION 2
EA ENGINEERING, SCIENCE, & TECHNOLOGY, INC. LEWISVILLE, TEXAS	Project 101950	October 2010 Fig. 6

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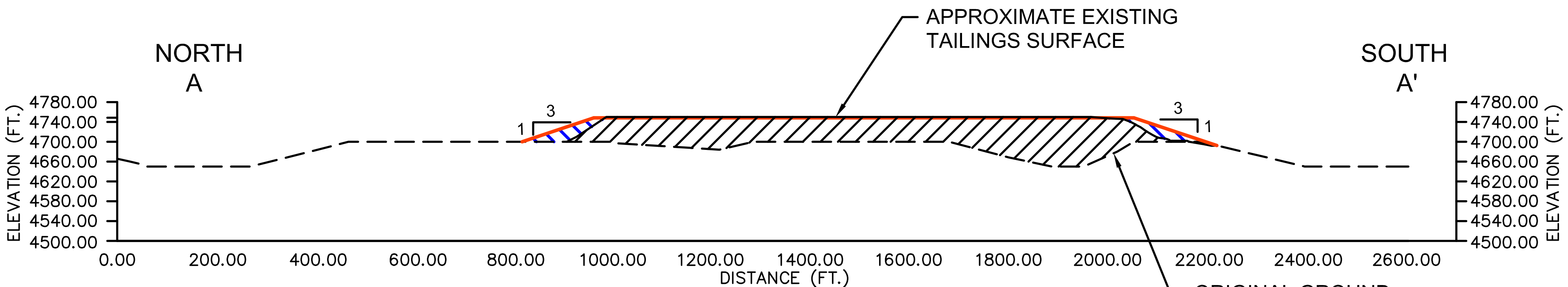
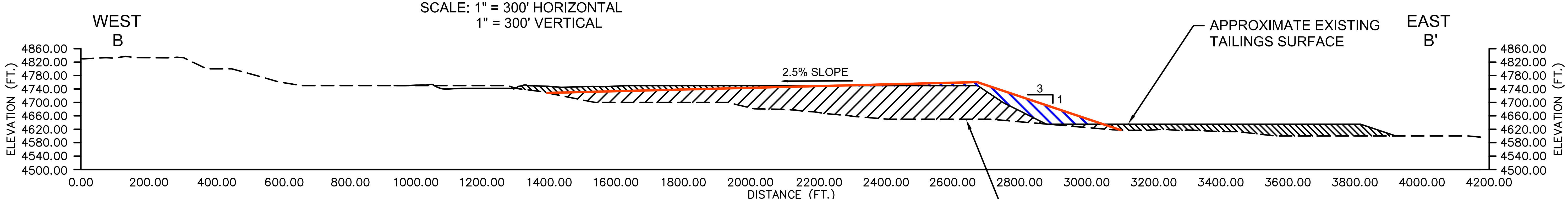
OPTION 2: FULL COVER SUPPORTED BY TAILINGS BUTTRESS FILL



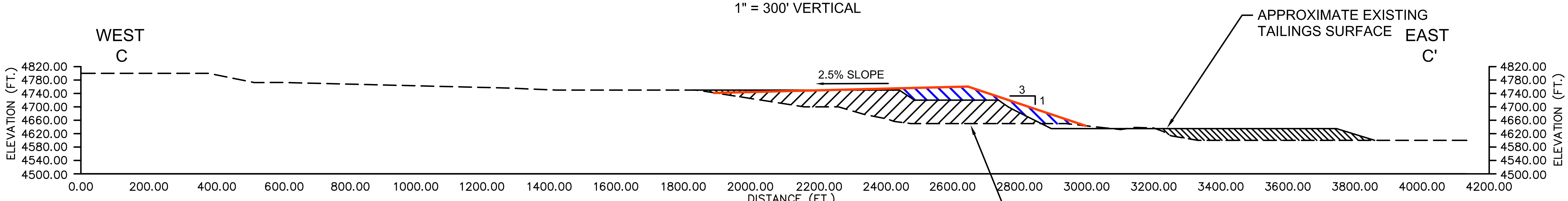
CROSS-SECTION A-A'

SCALE: 1" = 300' HORIZONTAL
1" = 300' VERTICAL



CROSS SECTION B-B'

SCALE: 1" = 300' HORIZONTAL
1" = 300' VERTICAL



CROSS SECTION C-C'

SCALE: 1" = 300' HORIZONTAL
1" = 300' VERTICAL

LEGEND:

- PROPOSED SURFACE
- TAILINGS TO BE REMOVED AND USED AS FILL IN OTHER AREAS
- UNDISTURBED TAILINGS AREA
- TAILINGS FILL AREA

IRON KING MINE DEWEY-HUMBOLDT SMELTER DEWEY-HUMBOLDT, YAVAPAI COUNTY, ARIZONA	GEI Consultants	CROSS SECTIONS OPTION 2
EA ENGINEERING, SCIENCE, & TECHNOLOGY, INC. LEWISVILLE, TEXAS	Project 101950	October 2010 Fig. 7

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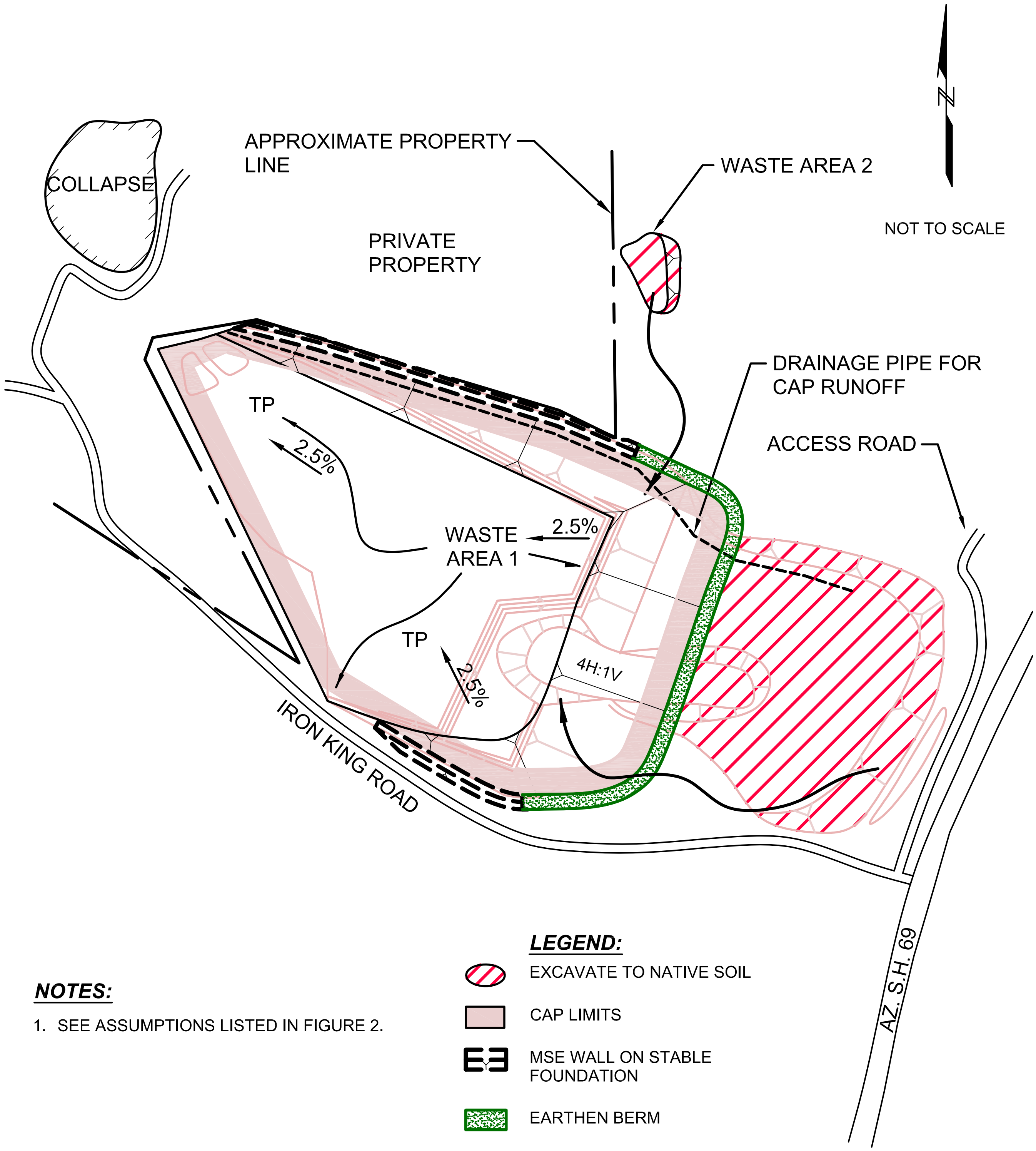
OPTION 3: FULL COVER SUPPORTED BY MSE WALL AND PERIMETER BERMS



NOTES:

1. SEE ASSUMPTIONS LISTED IN FIGURE 2.

LEGEND:

EXCAVATE TO NATIVE SOIL

CAP LIMITS

MSE WALL ON STABLE FOUNDATION

EARTHEN BERM

IRON KING MINE DEWEY-HUMBOLDT SMELTER DEWEY-HUMBOLT, YAVAPAI COUNTY,ARIZONA	GEI Consultants	PLAN VIEW OPTION 3:
EA ENGINEERING, SCIENCE, & TECHNOLOGY, INC. LEWISVILLE, TEXAS	Project 101950	October 2010 Fig. 8

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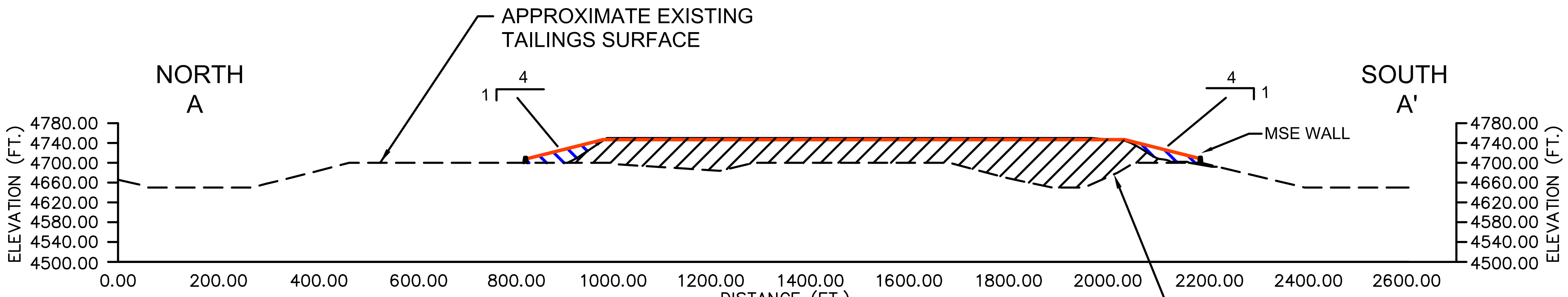
OPTION 3: FULL COVER SUPPORTED BY MSE WALL AND PERIMETER BERMS

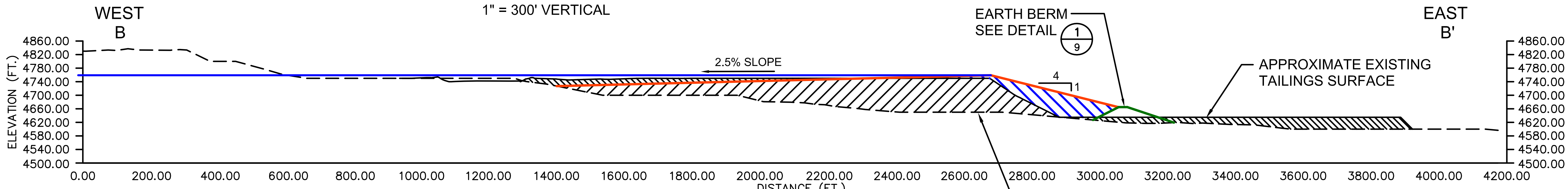


LEGEND:

- PROPOSED SURFACE
- TAILINGS TO BE REMOVED AND USED AS FILL IN OTHER AREAS
- UNDISTURBED TAILINGS AREA
- TAILINGS FILL AREA

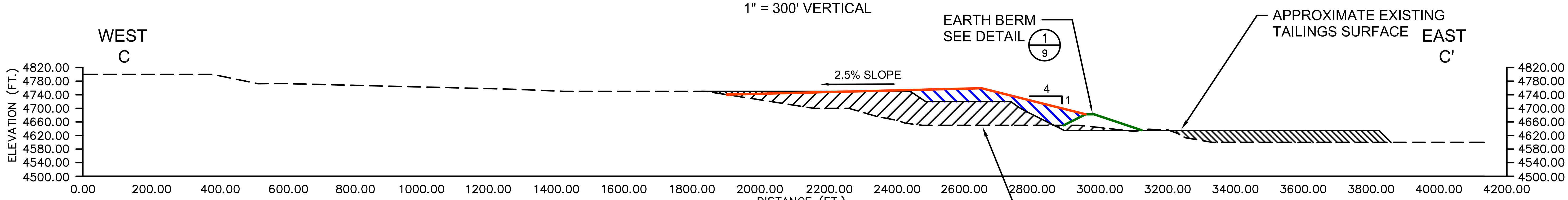
CROSS SECTION A-A'

SCALE: 1" = 300' HORIZONTAL
1" = 300' VERTICAL



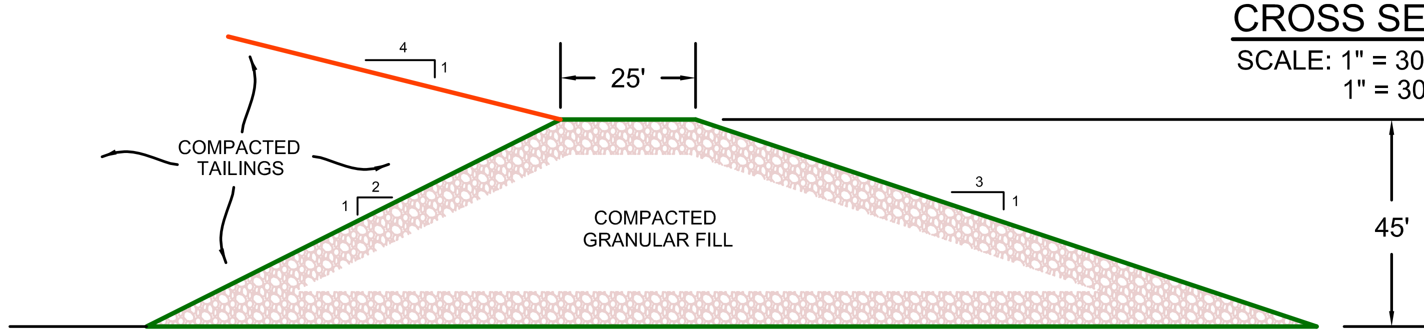
CROSS SECTION B-B'

SCALE: 1" = 300' HORIZONTAL
1" = 300' VERTICAL



CROSS SECTION C-C'

SCALE: 1" = 300' HORIZONTAL
1" = 300' VERTICAL



PERIMETER BERM DETAIL 1/9

NOT TO SCALE

IRON KING MINE
DEWEY-HUMBOLDT SMELTER
DEWEY-HUMBOLDT, YAVAPAI COUNTY, ARIZONA

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CROSS SECTIONS OPTION 3

October 2010 Fig. 9

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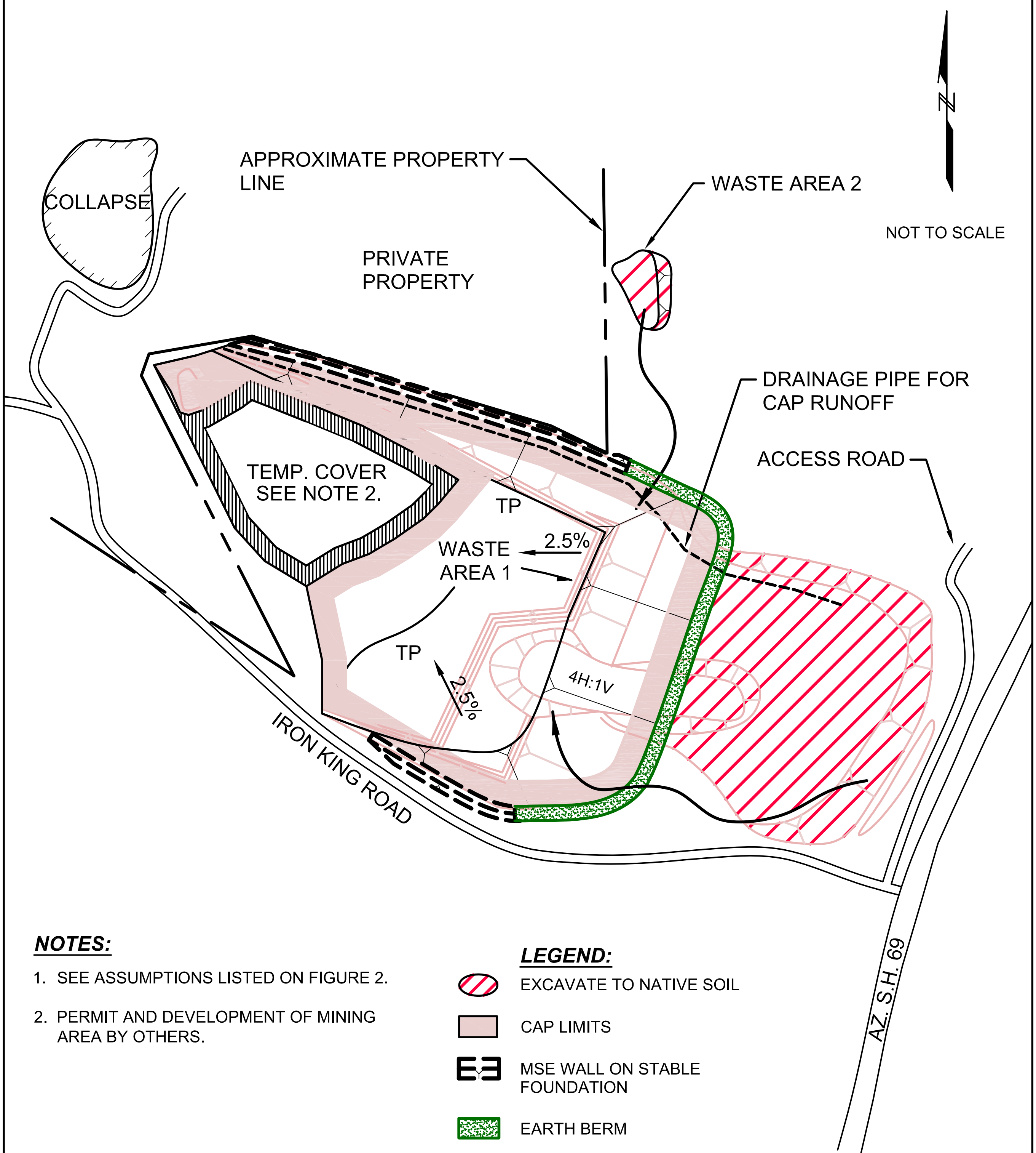
OPTION 4: COVER WITH LIMITED RESOURCE RECOVERY



NOTES:

1. SEE ASSUMPTIONS LISTED ON FIGURE 2.
2. PERMIT AND DEVELOPMENT OF MINING AREA BY OTHERS.

LEGEND:

- EXCAVATE TO NATIVE SOIL
- CAP LIMITS
- MSE WALL ON STABLE FOUNDATION
- EARTH BERM

IRON KING MINE DEWEY-HUMBOLDT SMELTER DEWEY-HUMBOLT, YAVAPAI COUNTY,ARIZONA	GEI Consultants	PLAN VIEW OPTION 4:
EA ENGINEERING, SCIENCE, & TECHNOLOGY, INC. LEWISVILLE, TEXAS	Project 101950	October 2010 Fig. 10

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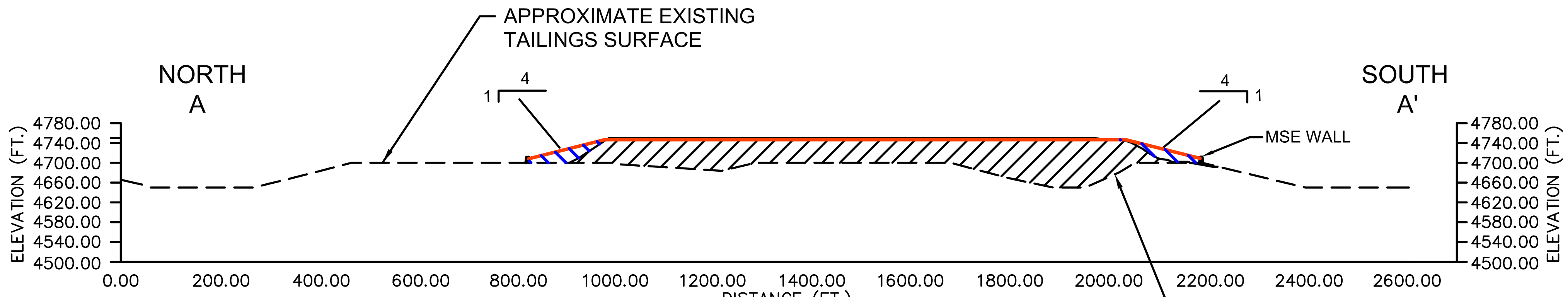
OPTION 4: COVER WITH LIMITED RESOURCE RECOVERY

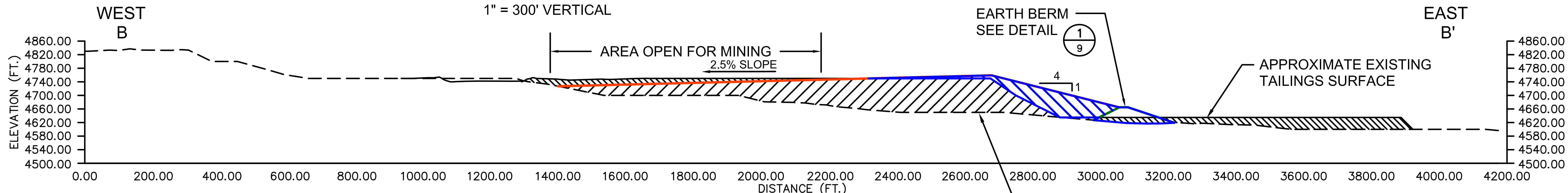


CROSS SECTION A-A'

SCALE: 1" = 300' HORIZONTAL
1" = 300' VERTICAL

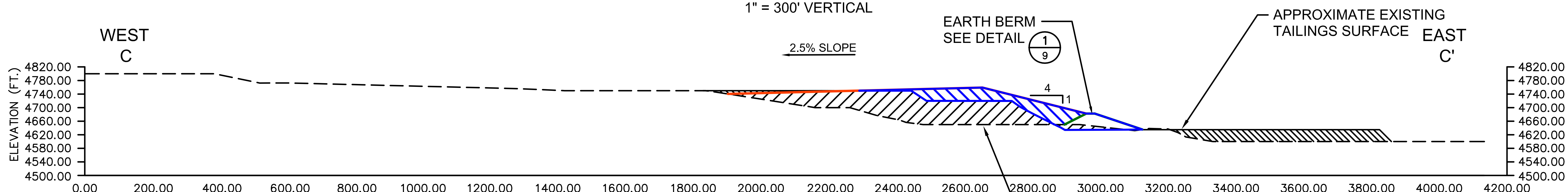
LEGEND:

- PROPOSED SURFACE
- TAILINGS TO BE REMOVED AND USED AS FILL IN OTHER AREAS
- UNDISTURBED TAILINGS AREA
- TAILINGS FILL AREA



CROSS SECTION B-B'

SCALE: 1" = 300' HORIZONTAL
1" = 300' VERTICAL



CROSS SECTION C-C'

SCALE: 1" = 300' HORIZONTAL
1" = 300' VERTICAL

IRON KING MINE DEWEY-HUMBOLDT SMELTER DEWEY-HUMBOLDT, YAVAPAI COUNTY, ARIZONA	GEI Consultants	CROSS SECTIONS OPTION 4
EA ENGINEERING, SCIENCE, & TECHNOLOGY, INC. LEWISVILLE, TEXAS	Project 101950	October 2010 Fig. 11

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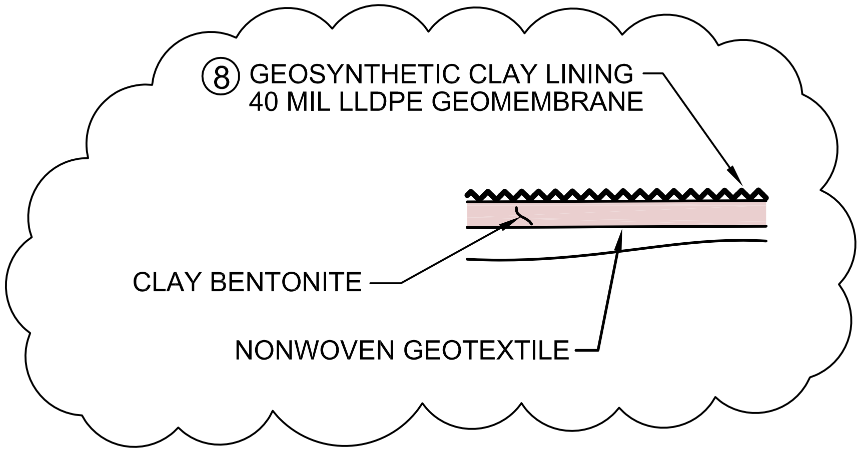

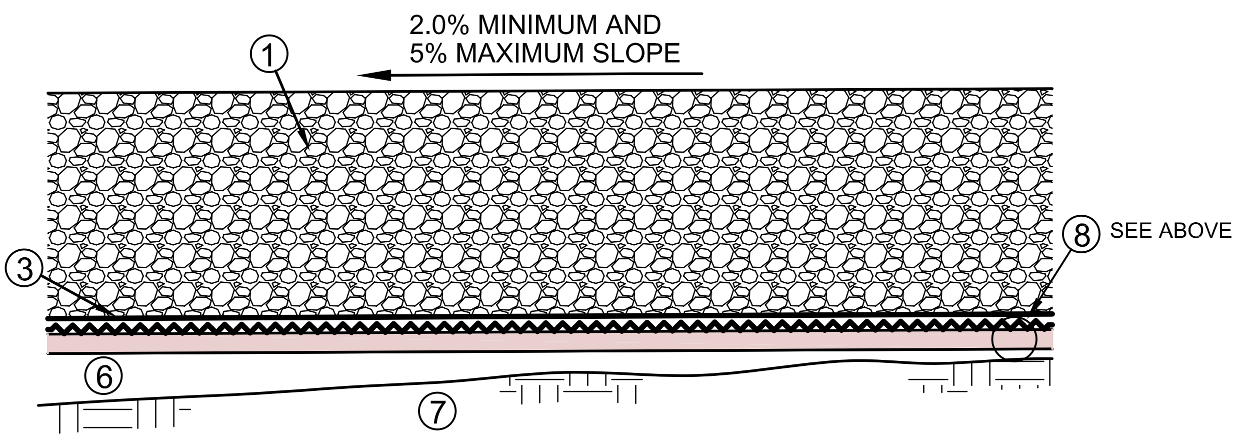

COVER FLATTER THAN 8%

LEGEND:

- (1) COARSE AGGREGATE (1.5 FEET THICK)
- (3) GEOTEXTILE, 16 oz./yd^2 NONWOVEN
- (6) REGRADED AND COMPACTED TAILINGS
- (7) EXISTING TAILINGS
- (8) GEOSYNTHETIC CLAY LINING

NOT TO SCALE

IRON KING MINE DEWEY-HUMBOLDT SMELTER DEWEY-HUMBOLT, YAVAPAI COUNTY,ARIZONA	GEI Consultants	COVER DETAIL FOR SLOPES FLATTER THAN 8%
EA ENGINEERING, SCIENCE, & TECHNOLOGY, INC. LEWISVILLE, TEXAS	Project 101950	October 2010 Fig. 12

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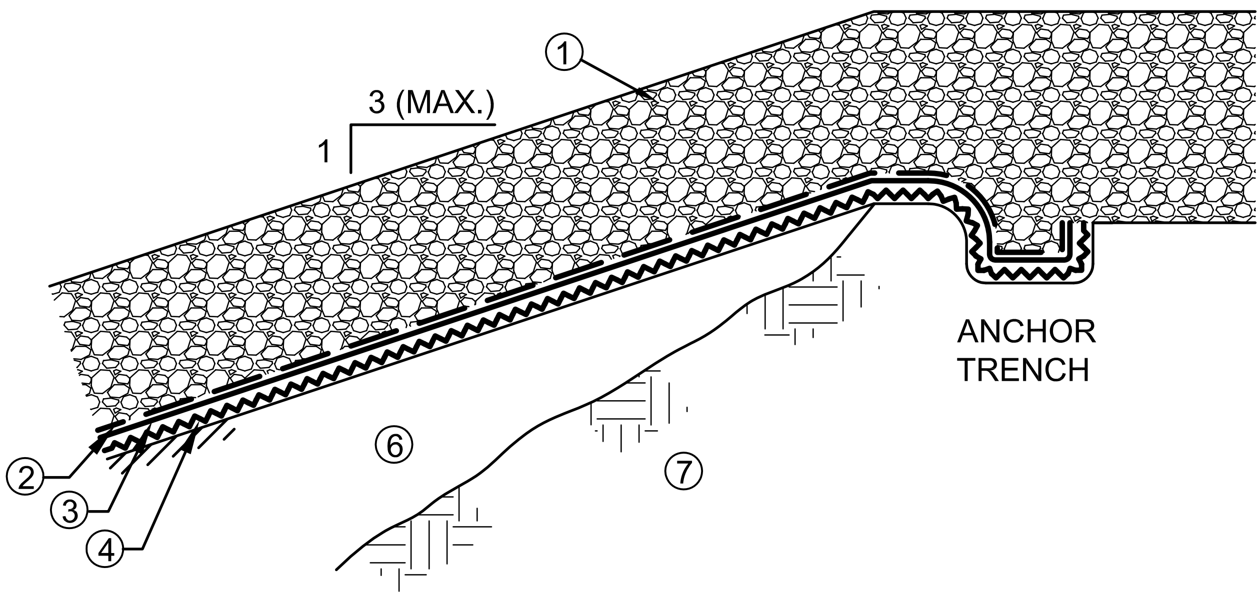

COVER STEEPER THAN 8%

LEGEND:

1	COARSE AGGREGATE (1.5 FEET THICK)
2	GEOGRID (BIAXIAL) HDPE
3	GEOTEXTILE, 16 oz./yd^2 NONWOVEN
4	40 MIL LLDPE TEXTURED GEOMEMBRANE - TEXTURED BOTH SIDES
6	REGRADED AND COMPACTED TAILINGS
7	EXISTING TAILINGS

NOT TO SCALE

IRON KING MINE DEWEY-HUMBOLDT SMELTER DEWEY-HUMBOLT, YAVAPAI COUNTY,ARIZONA	GEI Consultants	COVER DETAIL FOR SLOPES STEEPER THAN 8%
EA ENGINEERING, SCIENCE, & TECHNOLOGY, INC. LEWISVILLE, TEXAS	Project 101950	October 2010 Fig. 13

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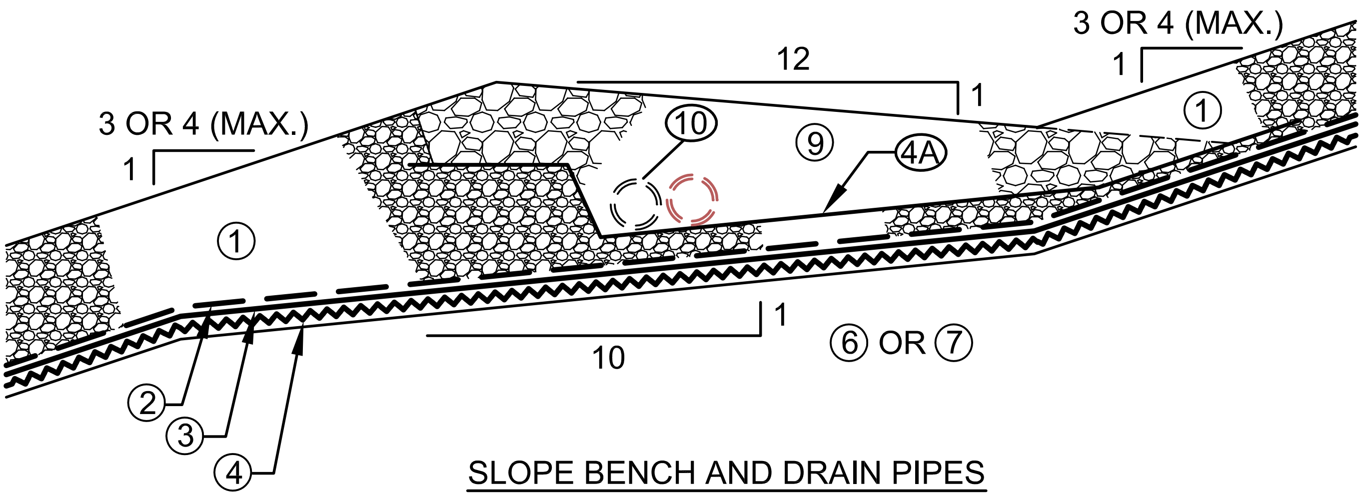

SLOPE BENCH AND DRAIN PIPES

LEGEND:

1	COARSE AGGREGATE
2	GEOGRID (BIAXIAL) HDPE
3	GEOTEXTILE, 16 oz./yd^2 NONWOVEN
4	40 MIL LLDPE TEXTURED GEOMEMBRANE - TEXTURED BOTH SIDES
4A	LLDPE RUB SHEET (60 MIL) TEXTURED BOTH SIDES
6	REGRADED AND COMPACTED TAILINGS
7	EXISTING TAILINGS
9	RIPRAP
10	HDPE SDR 32.5 PERFORATED PIPE (DIAMETER AND NUMBER TO BE DETERMINED)

NOT TO SCALE

IRON KING MINE DEWEY-HUMBOLDT SMELTER DEWEY-HUMBOLT, YAVAPAI COUNTY,ARIZONA	GEI Consultants	SLOPE BENCH AND DRAIN DETAIL
EA ENGINEERING, SCIENCE, & TECHNOLOGY, INC. LEWISVILLE, TEXAS	Project 101950	October 2010 Fig. 14

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