TABLE 1

CAPSULE SUMMARIES OF GEOTECHNICAL DOCUMENTS

TITLE	SUMMARY
Evaluation of Future Tailings Disposal, 50 years of Additional Disposal, Utah Copper Division (UCD) Tailings Pond Near Magna, Utah, Kennecott Minerals Company (Dames and Moore, August 1983)	This study evaluated the tailings disposal options for continued operation of the Magna tailings impoundment for a 50 year mine life. The study was commissioned in association with the Copperton Concentrator modernization to assure continued tailings disposal capacity. The study evaluated both static and seismic stability and found acceptable static stability. Regarding seismic stability, it was found that the annual probability of liquefaction was similar to that subsequently reported by Klohn Leonoff. It suggested that the acceptance of this seismic risk would be a management decision given that the stability of the dikes would be maintained against excessive deformations during a major earthquake. Kennecott subsequently commissioned an independent study by Klohn Leonoff to evaluate the acceptability of the seismic hazard.
Geotechnical Evaluation of Tailings Impoundment (Klohn Leonoff, 1988)	This report summarizes a geotechnical evaluation of the tailings impoundment, focused primarily on two cross sections: one in the Southeast Corner and one in the Northeast corner. The investigations include the 1987 CPT soundings and drill holes. The study characterized the tailings as having an average SPT blowcount (N) of 8 to 10. The average $(N_1)_{60}$ reported was about 4 for the tailings. The work included 14 CPT soundings and 3 sampled drill holes. CPT soundings were advanced by Foundex-Alaska. Drill holes were advanced using rotary wash methods and bentonite drilling mud. SPT blowcounts were obtained using accepted procedures (after Seed, et. al., *1985).* Laboratory testing of the tailings included index properties, cyclic triaxial, and consolidated undrained (CU) shear strength tests. Klohn Leonoff summarized the results of CU and consolidated drained (CD) tests on Kennecott tailings, which indicated effective friction angles of 35° for tailing sands and 33° for tailing fines. They also reported undrained shear strength ratios ranging from 0.26 to 0.36. Stability analyses on a cross-section of the Southeast Corner yielded a factor of safety of 2.3 under static, drained loading conditions, using a friction angle of 35 degrees. The report concluded that the saturated tailings are subject to liquefaction and the post-earthquake strength of the tailings was estimated to be 300 psf. The post-earthquake stability was analyzed by estimating a zone of liquefied tailings necessary to produce a factor of safety less than one. An assessment was made of the risk of failure due to seismic loading over a 30 year time period, which indicated a probability of failure of 6% for the Magna (Southeast Corner) section and 7% for the Pond (Northeast corner) section.
Kennecott – Reduction Study (Klohn Leonoff, 1989)	As a follow on to the 1988 report, Kennecott commissioned a study to evaluate the seismic risk around the entire perimeter of the South tailings embankment. The study divided the perimeter of the tailings impoundment into various zones based on standard penetration test (SPT) blow counts based on previous data. The study addressing which options could be used to upgrade portions of the impoundment, including: dewatering, ground improvement and berm construction. The study recommended that field investigations be completed to further evaluate the tailings properties, further refine these concepts and develop methods to improve the tailings impoundment.
Summary of 1989 Field Investigation Report (Klohn Leonoff, 1990)	This report presents the results of field investigations completed in 1989 and presents data not summarized in previous KL reports. Three programs were described, referred to as (I) the decant pond relocation program, (2) the perimeter program, and (3) the dewatering program. The decant program investigations were related to the Northeast corner and are not summarized as they are not relevant to the Southeast Corner project. The Perimeter Program investigations included a total of 48 drill holes (22 with SPT sampling, 26 for piezometer installation only with no sampling), installation of 48 piezometers (24 open standpipes and 24 pneumatic), and 10 CPT soundings (including 5 seismic cone soundings) around the full perimeter of the impoundment, of these 22 drill holes and 14 CPT's were located on the Southeast Corner. Standard SPT sampling procedures were followed and the hammer energy was calibrated for the SPT sampling; however, these holes were advanced using hollow stem augers with the auger column filled with clear water to the ground surface prior to and during removal of the hollow stem plug. Although this procedure is not in accordance with the recommendations of Seed, et. al, *(1985),* it was anticipated that filling the column with water prior to sampling would likely reduce the tendency of the sands to "boil" at the bottom of the hole. Therefore, these SPT blowcounts were believed to be acceptable. No undisturbed samples were taken and only water content testing was completed (by Sergeant Hauskins and Beckwith). The Dewatering Program investigations on the Southeast Corner consisted primarily of the installation of piezometers. Klohn Leonoff supervised the installation of 117 standpipe piezometers before Kennecott personnel assumed supervision in May, 1989. In addition, 11 supplemental drill holes with SPT blowcounts were completed. No interpretation of any of the data collected was presented in this report.
KUCC Tailings: Influence of Soil Aging and Failure Mode (Klohn Leonoff, Feb 1991) Magna Tailings Impoundment, Risk Reduction - Southeast Corner, Assessment of Buffer Zone Option (Klohn Leonoff, May 1991) Magna Tailings Impoundment, Risk Reduction - Southeast Corner, Assessment of Embankment Ground Improvement Options (Klohn Leonoff, May 1991) Magna Tailings Impoundment, Risk Update, Internal Wedge Study (Klohn Leonoff, May 1991)	In the early 1990's Kennecott commissioned a series of literature studies combined with ongoing site characterization to assess various options for improving the tailings properties along the southeast corner of the Magna impoundment. These studies evaluated the influence of soil aging on shear strength, the influence of operating versus non-operating impoundments on failure mode, the potential for mechanically improving the properties of the tailings and the potential to drain or desaturate the tailings. The studies found that the following generally improved the conditions and reduced the risks of liquefaction and seismic flow failure: o Aging generally improves the soil properties over time, and this improvement is generally well documented, o Abandonment or cessation of operations tends to reduce the seismic flow failure potential (based on tailings performance case histories from the 1965 M7- 7 1/4 Chilean earthquake) o Dewatering improves the seismic performance o Ground improvement will improve seismic performance. However, these studies cautioned that assigning improved engineering design parameters based on these factors was problematic and a direct cause and effect could not always be established by review of case histories. Ground improvement methods were evaluated and it was determined that in most cases the tailings were too fine a grain size to determine whether the improvement would be effective from characterization of the grain size distribution properties alone. Large field trails would be necessary to determine the effectiveness of ground improvements and such field trials were problematic from the view point that the trials themselves may compromise stability. The studies found that if any single or combination of these methods were used, a buffer zone would need to be established around the facility in order to address the uncertainties in utilizing these improvement options.

TABLE 1 (cont.)
CAPSULE SUMMARIES OF GEOTECHNICAL DOCUMENTS

TITLE	SUMMARY
Task 2 Supplemental Geotechnical Investigation, Southeast Corner, Existing Tailings Impoundment (Woodward-Clyde Consultants, 1991)	This report summarizes the investigations completed at the Southeast Corner of the Magna tailings impoundment by WCC in 1991 in conjunction with the (North) Tailings Modernization project. This task was completed primarily to determine whether a liquefiable silt layer actually existed in the foundation sediments at the Southeast Corner. Specifically the scope was: • To estimate undrained shear strength profile for the foundation soils beneath the existing impoundment and in the free field; • To perform a CPT sounding in the vicinity of a previous Klohn Leonoff drillhole in which a "silt layer" was identified in order to obtain a CPT signature for this material; • To understand the thickness and lateral extent of a silt layer previously identified; • To compare the results of SPT blowcounts obtained using rotary wash and hollow stem auger drilling methods; and • To measure the profile of shear wave velocity with depth. The field investigation consisted of six cone soundings (including one seismic cone), two rotary wash drill holes, and self boring and Menard pressuremeter testing. Three CPT soundings were located in the free field (one of which was the seismic cone sounding), two were advanced through the south starter dike (CPWC- 132 and CPWC-300) and one was advanced through the crest of the Southeast Corner (CPWC-130). The two CPT soundings were advanced through the underlying foundation sediments after drilling through the starter dike. Laboratory testing consisted of index property tests, consolidation tests, and unconsolidated-undrained (UU) triaxial compression tests. In addition, a microstratigraphic study was completed on undisturbed samples of foundation sediments from a drillhole advanced in the free field. Correlation between CPT's and microstratigraphy on undisturbed samples indicated that the previously identified liquefiable silt layer in the foundation was actually a relatively dense sandy silt with interlayers of clay.
Geotechnical Site Characterization Report, Tailings Impoundment Modernization Project, North Expansion (Woodward-Clyde Consultants, 1991)	This report presents the characterization of the future site of the proposed North Expansion to the Magna tailings impoundment. The primary focus of this report was to provide engineering properties of the foundation soils that will underlie the North Expansion embankment; however, it was relevant to the Southeast Corner dewatering evaluation in that engineering properties of the foundation soils are derived in this report. This project included extensive field investigations and laboratory testing of the foundation sediments. Field investigations of the foundation included 18 drill holes, 3 self-boring pressuremeter holes, 70 CPT soundings, 4 seismic cone soundings, and 7 test pits. Laboratory testing included index property tests, unconsolidated undrained triaxial strength tests, static direct simple shear tests, cyclic direct simple shear tests, laboratory vane tests, consolidation tests, and permeability tests. In addition, three cone soundings, one seismic cone sounding, and 1 drillhole with pressuremeter testing were advanced on the Southeast Corner. Significant conclusions of this report were 1) that the foundation sediments arc not considered to be liquefiable and 2) the development of the undrained static and post-earthquake shear strength relationships of the foundation soils.
Kennecott Utah Copper, Southeast Corner Modernization, Stepback Dike Design Report (Klohn Leonoff, June 1992)	This report provides design recommendations for the step back dikes that were constructed along the southeast corner. The report evaluates various slope configurations ranging from 10 – 20 horizontal to 1 vertical slopes that would essentially be constructed at a post earthquake residual slope angle configuration. These slopes were postulated to remain stable under earthquake loading and not increase the height rating of the impoundment as operations continued.
Kennecott Utah Copper – Assessment of Vertical Pumping Wells (Klohn Leonoff , 1992)	Kennecott commissioned a study to evaluate the effectiveness of vertical pumping wells and evaluate the phreatic surface conditions that would be required to modify the slope failure mechanism from a flow failure to intact blocks of tailings materials displacing on a liquefied layer. The report provided guidance to the target phreatic surface conditions that would be required for dewatering to be effective in modifying the failure mode. The report also summarized the reduction in the size of the (preliminary design) berm that would be required should dewatering prove effective in significantly lowering the phreatic surface in the impoundment.
SEC Modernization, Geotechnical Characterization (Klohn Leonoff, 1992)	This three-volume report summarizes the geotechnical site characterization completed by Klohn Leonoff for the Southeast Corner modernization. This characterization included both the foundation and the tailings materials. Investigations include 33 CPT soundings (20 through foundation sediments, 13 through the tailings), 23 drill holes (10 through foundation sediments and 13 through tailings), 19 auger holes through tailings, and installation of 12 piezometers. Continuous sampling was completed in 5 borings through the tailings and in 2 borings into the foundation sediments. In addition, 6 shear wave velocity profiles were completed with a seismic cone, 2 in the tailings and 4 in the foundation. Drilling was conducted by Elgin Explorations and the CPT's were advanced by Conetec. Laboratory testing of the tailings included index property tests, consolidated undrained triaxial strength tests, and moisture characteristic (water content versus soil suction) tests. In addition, laboratory testing of the foundation soils included index property tests, direct shear strength tests (ASTM D3080), and cyclic triaxial tests. The report presents the interpretation of the foundation sediments, which is in general agreement with the characterization for the North Expansion in WCC (1991). Interpretation of the tailings include maps showing spatial distribution of (N1)60 and fines content and the division of the tailings into four zones (T1, T2, T3, and T4) reflecting the gradual deposition of finer tailings at increasing distance from the discharge point. The significant conclusions of this report relevant to the Southeast Corner dewatering evaluation include: • A downward hydraulic gradient was observed in the tailings, equal to an average of 40% of hydrostatic pressure. • A lowering of the phreatic surface in the two coarsest zones of tailings (T1 and T2) was observed during the two year period after installation of the horizontal drains and wick drains. In addition, the coarsest tailings in Zone T1, at the western limits of the Southeast Corner appeared to have reached steady state seepage conditions. An effective friction angle of 34 degrees was selected to represent the tailings strength under saturated, drained loading. • The values of (N1)60 observed in the tailings indicate that liquefaction is expected to occur in the saturated tailings during a seismic event. • The recommended values of post-earthquake (residual) strength ratio (Sr/σ'v) of the tailings ranged from 0.06 for the finer tailings to 0.08 for the coarser tailings

TABLE 1 (cont.)

CAPSULE SUMMARIES OF GEOTECHNICAL DOCUMENTS

TITLE	SUMMARY
Kennecott Utah Copper – Southeast Corner Berm Design (Klohn Leonoff, June 1993)	To address the uncertainties inherent with ground improvement, dewatering and buffer zone options, KUCC commissioned an evaluation of the size of the berm needed to contain a liquefaction failure of the southeast corner and south segment of the Magna tailings impoundment. The design was based on foundation and embankment characterization work and provided a feasibility level design for a berm. The berm would require relocation of SR201, the golf course and a number of infrastructure items. Construction would take approximately 8 years following permitting, infrastructure relocation and would utilize a significant portion of the sand fraction of the tailings that would be needed to construct the North tailings facility.
Instrumentation Installation Report (Klohn-Crippen Consultants, Ltd., 1993)	This report summarizes the site investigation, instrumentation installation, instrument baseline readings, and laboratory testing and analysis completed by Klohn-Crippen in 1993 at the Northeast and Southeast Corners. (The Northeast corner investigations are not summarized in this document.) Data relevant to the Southeast Corner Dewatering evaluation include Resistivity CPT (RCPT) tests, drill holes, laboratory work correlating resistivity and degree of saturation, and additional laboratory testing on tailings materials. The RCPT and drill holes were completed in proximity to pump well E3B-303 and E3B-103. Four drill holes with undisturbed sampling were advanced on the Southeast Corner using rotary wash methods with drilling mud. Soil moisture tubes were installed in three of these drill holes. In addition, three Sondex settlement systems were installed to monitor settlement of the dewatered tailings. Nine standpipe piezometers and 24 vibrating wire piezometers were also installed in the tailings embankment at this time. Eight RCPT soundings were advanced by Conetec. The locations of these instruments, soundings and drill holes were surveyed. Baseline readings were obtained of the Sondex settlement rings, soil moisture tubes, and piezometers during March and April, 1993. Samples taken during these investigations consisted of 114 undisturbed piston tube samples, 114 tube bottom samples, 2 auger grab samples and 1 water sample. Testing on these samples included index properties (water contents, densities, specific gravity, and particle size distribution); unconsolidated undrained (UU) strength tests, and consolidation tests. The results of this study indicated a good agreement between the measured in situ degree of saturation and the saturation determined from the resistivity cone. They also recommended that a laboratory testing program be implemented to assess the degree of desaturation of the tailings needed to prevent liquefaction induced strength loss.
Seismic Hazard Evaluation, Kennecott Tailings Impoundment Modernization Project, Magna, Utah (Woodward-Clyde, 1994)	Deterministic and probabilistic seismic hazard analyses were performed for the North Expansion and selected locations of the existing tailings impoundment (including Southeast Corner) using state-of-the-art methods. Results of the deterministic analyses using empirical data led to design MCE and OBE ground motion parameters. Results from the probabilistic analyses were used to evaluate the likelihood of occurrence associated with the design MCE parameters and to provide means to estimate the design OBE parameters. The design MCE was determined to be a Mw 7 earthquake occurring on the East Great Salt Lake fault, the design OBE a Mw 6.5 random earthquake. For the Southeast Corner, the following probabilistic peak horizontal acceleration values for a M 7.5 event were developed is this consistent?: Peak acceleration on soil for probability of 10% in 50 years : 0.25g Peak acceleration on soil for probability of 10% in 100 years: 0.33g
Inundation Technical Memorandum , Kennecott Tailings Impoundment, Salt Lake County, Utah (Woodward-Clyde Consultants, 1994)	This report provides a tailings impoundment failure inundation map that was included in the EAP for the existing tailings impoundment. Two separate modes of failure were analyzed for tailings impoundment failure: 1) overtopping of impoundment north embankment by storm water flooding, and 2) earthquake induced failure of impoundment embankment at any location. The inundation map shows results from both failure modes. In the area of the Southeast Corner, the earthquake induced failure was estimated to result in inundation measured from the toe of the embankment of about 1,100 to 4,300 feet for the East Slope, and about 900 to 2,600 feet for the South Slope. The analysis method for the earthquake induced failure used was developed by Lucia et al. (1981) and is a simplified two-dimensional limit equilibrium analysis. The flood failure methodology was a new dam break methodology using tailings flow characteristics.
Summary of Southeast Corner Dewatering (Memorandum by J. Pilz, Kennecott, 1995)	This technical memorandum summarizes the progress observed by Kennecott to date in dewatering the Southeast Corner. Kennecott observed that the RCPT testing provides a reliable method of measuring the degree of saturation (Memorandum by J. Pilz, (within about 10% to 20%). The following observations have been drawn from the monitoring program: • A zone of saturated tailings remains above the phreatic surface (i.e., capillary zone), ranging from about 5 to 20 feet. • Above the capillary zone, the degree of saturation in the tailings has been reduced to between 30 and 80 percent. • A drawdown in the phreatic surface of approximately 28-30 feet at the embankment crest has resulted in a reduction in the saturated zone of 12-15 feet. • The rate of desaturation at the crest is estimated to be about 5 to 10 feet per year within the radius of influence of the pumping wells. Lower on the slope, above the horizontal drains, the rate is about 2-3 feet per year. • Slight increases in the CPT tip resistance (Qc) and correspondingly $(N_1)_{60}$ have been observed. It appears from the CPT testing that the $(N_1)_{60}$ values may have increased on the order of 1 to 2 blowcounts since initiation of the dewatering program in 1991. Included in this memorandum are plots of RCPT soundings (CPT tip resistance and resistivity), change in piezometric levels with time, piezometer response to well operation, and soil moisture tube data. Attached is a memo from Ric Jones describing Tritium analyses completed by Kennecott on water from wells on the Southeast Corner. These analyses are discussed in the geohydrologic data review memorandum. Also attached to the memorandum are the results of preliminary embankment dewatering modeling completed by J. Pilz using SEEP/W. One model represents a line of wells parallel to the embankment crest. The second is a cross section of the Southeast Corner. The tailings permeability was varied from 10^{-4} cm/s to 10^{-6} cm/s. These preliminary analyses indicated that for coarser tailings, dewatering can effectively reduce the phreatic surface to a relatively low level. For materials with permeabilities less than about 10^{-6} cm/s, the effectiveness of dewatering is substantially reduced. Included in this section are plots of water level and pumping rates in the Southeast Corner

TABLE 1 (cont.)

CAPSULE SUMMARIES OF GEOTECHNICAL DOCUMENTS

TITLE	SUMMARY
Characterization of Decant Pond Clay: Attachment G 1 to Appendix G: Abutments and Northeast Corner; Geotechnical Detailed Design Report (Woodward-Clyde Consultants, 1995)	This document characterizes the decant pond clay (a special case of the plastic whole tailings described in Attachment G2) located in the Northeast corner of the existing tailings impoundment. The focus of the characterization was undrained shear strength and permeability. The undrained shear strength (both static and post-earthquake) was established based on laboratory tests performed on undisturbed samples. The significant conclusions of this document relating to the Southeast Corner are: • The post-earthquake shear strength ratio (S_r/σ'_v) of decant pond clay for use in design was established as $S_r/\sigma'_v = 0.20$ • The static undrained shear strength ratio (S_r/σ'_v) of decant pond clay for use in design was established as $S_r/\sigma'_v = 0.32$ for triaxial loading conditions and 0.23 for simple shear loading conditions. • The hydraulic conductivity (permeability) of decant pond clay estimated from laboratory tests was on the order of 1 x $l0^{-7}$- cm/s to 3 x $l0^{-7}$ cm/s. • Decant pond clay is found beneath the cyclone station pad and may be encountered to a lesser extent along the east side of the Southeast Corner. Therefore, these engineering properties are relevant to those portions of the project.
Characterization of Whole Tailings: Attachment G2 to Appendix G: Abutments and Northeast Corner; Geotechnical Detailed Design Report (Woodward-Clyde Consultants, 1995)	This document characterizes the whole tailings in the existing tailings impoundment. Focus of characterization was shear strength, especially post-earthquake undrained shear strength. The Kennecott whole tailings were characterized as two distinct materials: non-plastic whole tailings and plastic whole tailings. The post-earthquake strength was established based on back calculation from case histories and from quasi steady-state (QSS) laboratory tests on reconstituted samples. The reconstituted samples were prepared using a slurry-sedimentation technique that represents the depositional environment observed in the impoundment. Input from the Design Review Board comprised of Professor I. M. Idriss, Professor James K. Mitchell and Mr. George Beckwith was provided, along with special consultation from Professor Kenji Ishihara from Japan. The significant conclusions of this document relating to the Southeast Corner are: • The post-earthquake shear strength ratio (S_r/σ'_v) of nonplastic whole tailings for use in design was established as $S_r/\sigma'_v = 0.12$. The S_r/σ'_v indicated by laboratory testing of the whole tailings ranged from 0.15 to 0.39. The case history studies generally supported the selection of a post-earthquake shear strength ratio of 0.12 as a reasonable residual strength. • The static undrained shear strength ratio (S_r/σ'_v) of nonplastic whole tailings for use in design was established as $S_r/\sigma'_v = 0.35$ for triaxial loading conditions and 0.23 for simple shear loading conditions. • The post-earthquake shear strength ratio (S_r/σ'_v) of plastic whole tailings for use in design was established as $S_r/\sigma'_v = 0.20$. • The static undrained shear strength ratio (S_r/σ'_v) of plastic whole tailings for use in design was established as S_r/σ'_v, = 0.32 for triaxial loading conditions and 0.23 for simple shear loading conditions. • The drained (effective stress) friction angle for all whole tailings (plastic and non-plastic) was conservatively selected as $\Phi' = 25$ degrees. This value was also selected to represent post earthquake conditions for partially saturated whole tailings. These strength parameters are relevant to the tailings materials found at the Southeast Corner.
Summary of Geotechnical Data Review, Technical Memorandum, Geotechnical Design of Dewatering Measures, Tailings Impoundment Modernization Project, Southeast Corner (Woodward-Clyde Consultants, 1996)	This technical memorandum summarizes previous reports and site investigations relevant to the Southeast Corner, including laboratory testing results. The memorandum provides a summary of the engineering properties of the foundation soils and tailings in the Southeast Corner area based on existing data. Additional site investigation are proposed including CPTs and drill holes in the Southeast Corner area.
Summary of Geohydrologic Data Review, Technical Memorandum, Geotechnical Design of Dewatering Measures, Tailings Impoundment Modernization Project, Southeast Corner (Woodward-Clyde Consultants, 1996)	This technical memorandum provides capsule summaries of various documents prepared by Dames & Moore, Kennecott and Klohn Crippen between 1992 and 1996 relevant to dewatering. It provides a discussion on the spatial distribution of hydraulic parameters and associated implications to the proposed dewatering modeling, and a review of the potentiometric surface response to various dewatering methods that have been implemented in the Southeast Corner. The memorandum provides preliminary design parameters to be used in the dewatering modeling, and recommends additional site investigations such as Resistivity CPTs.

TABLE 1 (cont.)

CAPSULE SUMMARIES OF GEOTECHNICAL DOCUMENTS

TITLE	SUMMARY
Design Basis Memorandum, Geotechnical Design of Dewatering Measures, Tailings Impoundment Modernization Project, Southeast Corner (Woodward-Clyde Consultants, 1996)	This memorandum summarizes the work completed for the Design Basis Verification of the Southeast Corner Dewatering Project. It provides qualitative descriptions of the anticipated results to be accomplished by dewatering and design criteria to accomplish this goal. It concludes that dewatering the embankment will result in a reasonable improvement in seismic performance. Simplified analyses indicated that dewatering alone will likely reduce probability of failure to an acceptable level for smaller earthquakes such as the OBE. When combined with additional mitigation measures, post-earthquake factor of safety that meets State requirements may be attained in the long term under MCE conditions. Additional conclusions and recommendations include the following: Seismic Hazard: The OBE was determined to be a random earthquake with a return period of 200 years and an M 6.5 resulting in a PGA of 0.14g. The MCE was determined to be an event occurring on the East Great Salt Lake fault with an M 7 resulting in a PGA of 0.38g. Liquefaction Triggering: Small improvement in CPT tip resistance occurred since dewatering started 4 years ago. Under OBE loading, factor of safety against liquefaction is marginal, but dewatering is expected to result in OBE loading to not trigger liquefaction. Under MCE conditions, factor of safety against liquefaction is quite low, and dewatering is not expected to prevent liquefaction. Therefore, the saturated tailings are expected to liquefy under MCE loading and post-earthquake strengths should be used. Impact of Variable Site Conditions: South side of Southeast Corner is expected to be amenable to dewatering because of greater permeability of tailings. Dewatering alone is expected to upgrade this embankment portion. East side of Southeast Corner does not appear conducive to dewatering because of relatively low permeability in that area. Much of that area consists of clayey material which typically does not trigger liquefaction, but can exhibit significant strength loss and large deformations during earthquake shaking. Alternative stabilization method may be feasible on this impoundment portion. Post-Earthquake Stability: Post-OBE factor of safety should increase to 1.2 when continuing dewatering. Post-MCE factor of safety is expected to increase to 1.0 from dewatering, but is not expected to increase to 1.2 from dewatering alone.
Summary of Supplemental Field Investigations, Technical Memorandum, Geotechnical Design of Dewatering Measures, Tailings Impoundment Modernization Project, Southeast Corner (Woodward-Clyde Consultants, 1996)	Supplemental field investigations were completed in April 1996 at the Southeast Corner. This technical memorandum includes a map showing the locations of the six drill holes and the CPT soundings, as well as the locations of previous investigations, the boring logs, and a table summarizing the samples taken from the drill holes. (CPT data was submitted separately by ConeTec)
Tailings Impoundment Modernization Project, Southeast Corner, Southeast Corner Seismic Upgrade Design, Geotechnical Site Characterization (Woodward-Clyde Consultants, 1997)	This report presents the geotechnical characterization of the Southeast Corner for the final design of seismic upgrades to the Southeast Corner. The characterization effort included review of existing geotechnical and geohydrologic data, development of design cross-sections, completing supplemental field investigation, and conducting laboratory testing. The following conclusions were made: • The Southeast Corner can be characterized into three reaches based on predominant tailings gradation. Western reach of South Slope with coarsest tailings. Eastern reach of South Slope with tailings becoming progressively finer with increasing distance from single point discharge, Eastern Slope with finest gradation having been influenced by intermittent periods of decanting along this reach. • Dewatering efforts have made a positive impact on the phreatic surface. Water levels adjacent to horizontal drains have dropped 2 to 3 ft/yr, rate is slowing down. Jet pumps drew water surface down 5 to 10 ft/yr but are no longer operational. 1995 dewatering wells along eastern slope indicate to draw down so slow to be essentially impractical. Since 1991, phreatic surface has dropped about 40 ft in westen reach, about 30 feet in eastern reach. • Resistivity cones provided reasonable indication of the desaturation zone and confirmed the lowered phreatic surface. • Tailings are highly interbedded and can be divided into their elemental materials: Southeast Tailings Clay (STC), Southeast Tailings Silt (STM), and Southeast Tailings Sand (STS). • Dry unit weight ranges from 72 to 104 pcf, with a mean of 86 pcf, water content ranges from 10 to 50 percent with a mean of 28 percent. SPT N_{60} can be related to CPT point resistance q_c by a factor of 6. • Phreatic surface within Southeast Corner can be characterized to be 60 percent of hydrostatic pressure, indicating significant downward gradient. • Tailings are slightly overconsolidated with OCRs ranging from 1.2 to 2.5. • Shear wave velocities range from 400 ft/s at the surface to 800 ft/s at depth. • Vertical permeabilities are about $5x10^{-4}$ cm/s in STS material, and about $1x10^{-7}$ cm/s to $1x10^{-6}$ cm/s in the STM and STC materials. • Strength properties of tailings are: Saturated Tailings: Undrained shear strength: STM and STS materials under triaxial loading $c_u/\sigma'_{v,c} = 0.35$ for $\sigma'_v \leq 8$ ksf, $c_u = 0.18\ \sigma'_{v,c} + 1.35$ ksf for $\sigma'_v > 8$ ksf, under DSS loading $c_u/\sigma'_{v,c} = 0.23$; STC material under triaxial loading $c_u/\sigma'_{v,c} = 0.29\ (OCR)^{0.8}$, under DSS loading $c_u/\sigma'_{v,c} = 0.23\ (OCR)^{0.8}$. Effective friction angle: $\phi' = 34°$. Post-earthquake undrained shear strength: $c_{upe}/\sigma'_{v,c} = 0.12$. Partially Saturated Tailings: Undrained shear strength: $\phi' = 34°$ in the ESA for saturation < 85%, for saturation ≥ 85% $c_u/\sigma'_{v,c} = 0.35$ under triaxial loading and $c_u/\sigma'_{v,c} = 0.23$ under DSS loading. Post-earthquake shear strength: $\phi' = 34°$ in the ESA for saturation < 85%, for saturation ≥ 85% $c_{upe}/\sigma'_{v,c} = 0.12$. • Dewatering to partially saturated conditions significantly improves post-earthquake undrained shear strength of STM and STS materials. • Foundation properties are the same as characterized in previous reports by Klohn Leonoff and Woodward-Clyde.
Alternatives Evaluation Report, Tailings Impoundment Modernization Project, Southeast Corner, Southeast Corner Seismic Upgrade (Woodward-Clyde Consultants, 1998)	This report contains preliminary designs for three alternatives to upgrade the seismic stability the south slope of the Southeast Corner. These are 1) mechanically stabilized backfill (MSB) wall with shear key, 2) small berm with shear key, and 3) large berm with highway relocation. The three alternatives were evaluated for stability and deformation under MCE loading and it was concluded that they all would satisfy slope stability and deformation criteria except for the large berm without a shear key (and highway relocation), which would experience uncontrolled deformations due to progressive failure developing in the Upper Bonneville clay layer. A foundation shear key through the clay layer was therefore recommended for all stabilization alternatives considered. Conceptual-level designs were developed for the MSB wall with shear key and the small berm with shear key alternatives.

TABLE 1 (cont.)

CAPSULE SUMMARIES OF GEOTECHNICAL DOCUMENTS

TITLE	SUMMARY
Dewatering Design Report – Southeast Corner Seismic Upgrade Design (Woodward-Clyde Consultants, 1998)	This document includes an extensive review of monitoring data and supplemental field and laboratory testing programs to judge the impact of partial saturation of the dewatered tailing on post-earthquake strength. The Report evaluates whether dewatering measures alone will be sufficient to achieve adequate seismic stability by the end of the project life, or if additional upgrade measures will be required. Target phreatic surfaces required to achieve seismic stability for the South Slope are identified. The Report also contains a list of recommendations to supplement the existing dewatering measures and the monitoring program along the South Slope. The South Slope is evaluated at three study cross-sections: 1) Section KLC – representative of the western reach of the South Slope; 2) SE2 –representative of the eastern reach of the South Slope, and 3) KLD – representative of the transition zone between the eastern and the western reaches. Field hydraulic conductivity measurements indicate that the eastern reach of the South Slope is less permeable than the western reach. State of the art laboratory testing included cyclic shear strength testing of partially saturated tailings samples. Results indicate that tailings with a degree of saturation of 85 percent or greater underwent significant pore pressure generation and large strains. Tailings that are less than 85 percent saturated do not experience these large strains during cyclic testing. Seepage Analyses: Finite element seepage models (SEEP/W) are utilized to evaluate the effectiveness of the dewatering wells along the entire South Slope. These seepage models, after being calibrated to the 1998 pore pressure conditions, are used to predict the future phreatic levels at the end of the project design life. Different combinations of well locations, well spacing, and pumping rates were evaluated to achieve the required target phreatic surfaces. The western reach of the South Slope (KLC) was expected to dewater more rapidly to a phreatic level corresponding to a post-earthquake factor of safety greater than 1.0, well within the design life of the project. The eastern reach of the South Slope (SE2) was estimated to dewater at a much slower rate because of the lower permeability of the tailings in this area. Recommendations: Additional dewatering wells were recommended along the entire South Slope to supplement the existing wells such that the final well spacing would be about 200 to 250 feet. (Note that the 1998 well spacing along the eastern reach of the South Slope was approximately 110 feet. Slope Stability: Using the projected phreatic surfaces, post-earthquake factors of safety corresponding to MCE[1] loading conditions were calculated. - Section KLC: FS > 1.30 for large failure surfaces; 1.04 < FS < 1.14 for small surfaces at the toe of the slope. - Section SE2: FS ≈ 0.95 for a small surface at the toe; FS ≈ 1.10 for a large, global failure surface. The accompanying dynamic deformation analyses indicate that for cross sections KLC and SE2, the post-earthquake deformations would be tolerable. Therefore, it is concluded that the South Slope would satisfy the design criteria by the end of the project life, provided the dewatering of the South Slope progresses as anticipated. The East Slope was evaluated at study cross section SE3, which represents the least permeable tailings materials along the Southeast Corner, and was modeled as a layered system consisting of upper and lower non-plastic tailings zones with a layer of plastic (clayey) tailings in between. Seepage analyses: SEEP/W seepage model was developed for SE3 and calibrated to the 1998 pore pressure conditions. This seepage model was also used to predict future phreatic levels at the end of the project life, including two lines of dewatering wells located along the mid-slope and crest of the impoundment. Slope Stability: The projected post-MCE factor of safety for SE3 does not meet the stability design criteria, even including the projected effects of the dewatering wells. Recommendations: The existing wells along the east slope are to be decommissioned due to the difficulty and ineffectiveness of operating dewatering wells in the low permeability tailings materials along the East Slope, and an alternate seismic upgrade approach is to be considered for the East Slope.
Independent Analysis of Deformations, Southeast Corner Seismic Upgrade Design, Tailings Impoundment Modernization Project, Kennecott Utah Copper Corporation, Magna, Utah (AGRA, June 1998)	This report summarizes an independent assessment of the potential for seismically-induced deformations occurring near the Southeast Corner (Section KLC and KLD). The report indentifies the initial liquefaction zone that would develop due to earthquake shaking, the expansion of that zone after the earthquake in response to progressive deformations, and the extent of flow liquefaction and runout. A simplified limit equilibrium method was used to estimate the flow distance. Analysis parameters are based in part on back-calculated parameters for the Feb. 3, 1998 slide event at the Northeast Corner. Additional input for parameters was from relevant case histories of flow failures in similar materials. Analysis evaluates 1997, 2003 and 2018 groundwater conditions (assuming continued dewatering). Results indicate 770 feet of runout beyond toe for 1997 conditions, about 200 feet for 2003 conditions, and no flow for 2018 conditions. Recommendation includes construction of a dike of compacted fill to contain a potential runout from affecting residential area located southeast of Southeast Corner.

[1] The Maximum Credible Earthquake or MCE is the largest earthquake that a particular fault is capable of generating. In the MCE event there would likely be widespread damage throughout the Salt Lake valley.

TABLE 1 (cont.)

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TITLE	SUMMARY
South Slope Seismic Evaluation Report (URSGWC, 1999)	The report evaluates the pore pressures along Cross Sections KLC and SE2, and concludes that, due to the lower permeability tailings in the vicinity of Cross Section SE2 and the corresponding lower rate of dewatering, the stability of Cross Section SE2 is the most critical cross section. 1999 pore pressures along Cross Section SE2 gradually vary from about 60 percent of hydrostatic at the crest to 70 percent at mid-slope and 90 percent near the toe. Slope stability of Cross Section SE2 (using 1999 pore pressure conditions) is evaluated: - FS (existing static drained) ≥ 1.5(design criteria) - FS (post-MCE) ≈ 0.9 - FS (static drained target phreatic surface = additional lowering of the 1999 phreatic surface in the mid-slope area by 20 feet) ≈1.0 - FS (post-MCE target phreatic surface = additional lowering of the 1999 phreatic surface in the mid-slope area by 50 feet) ≈ 1.2
East Slope Stability Evaluation Report (URSGWC, 1999)	The report updates the pore pressure and slope stability conditions along the East Slope. This report also incorporates revised overconsolidation ratios for some of the tailings and foundation materials based on additional field and laboratory investigations. Estimated pore pressure contours are developed for four cross sections along the East Slope – SE3, SE4, SE5 and SE6. The existing static drained factors of safety for these cross sections are calculated to be in excess of the design criteria of 1.5; however, minimum post-MCE factors of safety are calculated to be between 0.5 and 0.7 for all four cross sections.
Geotechnical Evaluation Summary Report for December 17, 1999 State Engineer's Meeting (URSGWC, 1999)	The report the site characterization effort that evaluated the slope surface geometry, subsurface stratigraphy, engineering material properties, and pore water pressure conditions along the perimeter of the entire impoundment. Results from the site characterization were used to develop the slope stability models. The report discusses the technical approach to slope stability analyses, liquefaction potential evaluation, dynamic deformation analyses, and run-out analyses that were performed for the slopes of the entire impoundment. This includes updated preliminary values for seismic loading conditions based on an ongoing regional seismic hazard study of the Salt Lake City region. Only the values of PGA for the MCE were updated, the PGA values for the OBE were not estimated because that part of the ongoing study was not completed at the time. The updated MCE was a Mw 7 ¼ earthquake on the East Great Salt Lake Fault resulting in a PGA for the Southeast Corner of 0.31g. Results from the slope stability analyses, liquefaction potential evaluation, dynamic deformation analyses, and run-out analyses are presented. The results indicated that design criteria were met for the East and South Slopes under steady-state seepage and OBE loading conditions. For MCE loading conditions, neither slope satisfied the design criteria for existing conditions; however the South Slope was expected to meet the criteria in the future assuming continued dewatering would meet targeted levels. The East Slope was not expected to satisfy the design criteria under MCE loading in the future. The run-out distance from a potential seismically induced flow failure was estimated for 1998 conditions. Results indicated that the run-out distance along the South Slope could vary between 450 and 700 feet from the existing toe, and be less than 1,200 feet along the East Slope. The potential run-out from the East Slope would not impinge on any public roads or buildings. The new DRUM method that was used for the run-out analyses was peer reviewed by Professor I M Idriss and Professor Ray Seed.
Seismic Hazard Analyses for Kennecott, Letter Report (URSGWC, 2000)	The previously determined MCE from 1994 was re-evaluated considering new information on the local seismic sources and earthquake ground motion attenuation. The MCE event was increased to Mw of 7.25 resulting in a PGA of 0.32g for the Southeast Corner area.
Earthquake Scenario & Probabilistic Ground Shaking Maps for the Salt Lake City, Utah, Metropolitan Area (Wong et al. 2002, UGS Miscellaneous Publication 02-5)	This publication is the final result of the ongoing regional seismic hazard study referenced in URSGWWC 1999 Geotechnical Evaluation Summary Report.
South Tailings Embankment, Southeast Corner Dewatering Review Report (AMEC, 2002)	This report summarizes the results of supplemental field investigations performed at the Southeast Corner in late 2001 and early 2002, and evaluates the state of dewatering along the South Slope. Field investigations included: - Eight resistivity cone penetration test soundings with pore pressure dissipation testing - Installation of two vibrating wire piezometers. The liquefaction potential of the tailing materials was updated based on the 2002 CPT soundings. CPT tip resistance values are used to evaluate if there was an increase in tailings density and tip resistance that would equate to a greater resistance to liquefaction. Results indicate no change to liquefaction potential. Tailings material along the South Slope is still subject to liquefaction during the MCE event. Average dewatering rates are developed for the South Slope and are used to estimate when the phreatic conditions along the South Slope would meet the target levels to achieve a factor of safety equal to 1.0. Dewatering rates (i.e. the rate of decrease in elevation of the phreatic surface) are: - About 4.5 to 5 feet per year at Section SE2 - About 10 to 15 feet per year at Section KLC Based on these rates, AMEC estimates that the target phreatic surfaces could be achieved by the years 2006 to 2008, and that the dewatering progress should be re-evaluated at that time.

TABLE 1 (cont.)

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TITLE	SUMMARY
Dewatering and Seismic Stability Evaluation, Southeast Corner of Kennecott Utah Copper South Impoundment (URS, 2006)	This report documents the dewatering progress to date of the Southeast Corner and provides estimates for the seismic stability for 2005 and future conditions of the Southeast Corner. The project limits for this study extend from the west end of the south clarification canal east to the southeast corner of the impoundment, and then north to the East Cyclone Station. Comprehensive field investigation program consisting of 23 resistivity cone penetration tests, along with numerous pore pressure dissipation tests, was completed to 1) Identify zones of partially saturated tailings with a degree of saturation less than 85 percent – based on the 1998 geotechnical laboratory testing, Southeast Corner tailings with a degree of saturation less than 85 percent are not likely to liquefy during a seismic event, and to 2)Use the dissipation test results to develop trends for the distribution of pore pressures with depth at several key locations, especially where there are no existing piezometers. Seismicity: Recent changes in the seismic hazard of the project area were evaluated, including the regional seismic hazard study completed in 2002 for the Utah Geological Survey. After reviewing and discussing the new work both internally and with outside industry experts, it was concluded that the seismic hazard has not changed sufficiently to justify changing the seismic design level. Furthermore, the methodology used in 1998 still represents the state of practice. 2005 pore pressure data plots (from the vibrating wire piezometers and cone dissipation tests) are used to estimate the current location of the phreatic surface and the distribution of pore pressures along the study sections. Because of a strong downward gradient, the pore pressure distributions with depth are generally less than hydrostatic. 2005 pore pressure distribution trends indicate that the pore pressures along the South Slope are generally between 40 to 60 percent of hydrostatic. Pore pressures along the East Slope are generally in the range of 60 to 80 percent of hydrostatic. This difference in behavior reflects the fact that the tailings along the east slope are considerably finer than the tailings along the south slope. Without active dewatering measures, the east slope tailings drain at a much slower rate. A comparison of 2005 pore pressure trends to the 1999 data indicates: • The phreatic surface and the underlying pore pressures along majority of the South Slope have been considerably lowered by the dewatering wells. • Along the toe of the South Slope, the pore pressures have shown little improvement since 1999. The toe area is outside the zone of influence of the dewatering wells, the hydraulic gradient has decreased in this area, and the discharge from the current line of horizontal drains is not significant enough to actively lower the phreatic surface along the toe area. • Along the East Slope, the phreatic surface has decreased compared to the 1999 conditions; however, the rate of the decrease is significantly slower than that observed along the South Slope. • The most significant decrease in the phreatic surface along the East Slope has occurred in the vicinity of the East Cyclone Station**.** This reflects the fact that the area underneath and around the East Cyclone Station was heavily wicked prior to the construction of the cyclone station. • The rate of pore pressure decrease at the Southeast Corner has slowed since late 2002. Cone resistivity data is interpreted using the previously established relationship between soil resistance value and degree of saturation presented in URS' 1998 study. Data from these resistivity plots was used in conjunction with the pore pressure distribution plots to identify zones of partially saturated tailings with a degree of saturation of 85 percent or greater. Due to the significantly lower than hydrostatic conditions, the resistivity plots show complex variability in the Southeast Corner tailings, indicating that at several locations, coarse material which is below the phreatic surface may be partially saturated to a significant depth. This trend is more pronounced in the coarse-grained tailings. The site response analysis and the associated liquefaction triggering evaluations completed as part of URS' 1998 study are used for the 2005 conditions. Results from these 1998 evaluations, coupled with URS' latest understanding of soil liquefaction behavior, are used to develop minimum cone tip resistance values that would be required to preclude liquefaction in the Southeast Corner area. Rather than relying on a single criteria, information from numerous sources, including degree of saturation, pore pressure distribution, and cone tip resistance values, is used together to identify the extents of the potentially liquefiable tailings. This methodology has advanced from URS' previous approach that conservatively assumed that all Southeast Corner tailing sands with degree of saturation equal to or greater than 85 percent are potentially liquefiable. Slope stability analyses are performed using the latest pore pressure data and updated model geometries for post-MCE loading conditions. Results for South and East Slopes for large shear surfaces involving the 1991 crest dike have factors of safety greater than 1.0, which is a significant improvement compared to the 1999 conditions. Results for South Slope mid slope shear surfaces have also benefited from the crest dewatering, and the calculated factors of safety for these shear surfaces are also above 1.0. Results for toe shear surfaces along the South Slope, where the effect of dewatering has been minimal, still indicate potential post earthquake instability with factors of safety less than 1.0. Results for East Slope mid slope shear surfaces and the toe shear surfaces indicate post-earthquake instability with factors of safety less than 1.0. Overall, the existing dewatering measures have stabilized the South Slope to an extent that the minimum required factors of safety are met for static drained, undrained and post Operating Basis Earthquake (OBE)2 loading conditions. Conclusions: The possibility of a large flow slide has been greatly diminished. However there remains a risk of a limited toe slide along the South Slope during an MCE event. It is also possible that the limited slide could progress into the slope. Along the East Slope, where cessation of deposition has been the primary source of improvement, the risk of a significant flow slide triggered by an MCE event still remains. Fortunately, based on the 1998 run-out evaluations, the flow slide along the East Slope is expected to remain within the Kennecott property limits. Considering the huge volume of water in storage in the tailings and the rapid response of piezometers to cessation of dewatering well operation indicates that the well system operation must continue for the foreseeable future. Review of the operational history of the dewatering system indicates that it is being operated in a reasonable and effective manner. Recommendations: To address the risk of local post-earthquake instability at the toe of the South Slope, active intervention is required in addition to continued operation of existing dewatering wells. The additional measures would be limited in size and extent. Options may include additional active dewatering measures, in situ soil improvement and a limited toe stability berm along with decommissioning the clarification canal.

[2] The Operating Basis Earthquake or OBE is an earthquake loading that could be expected during the design life of the facility. According to Utah statutes it has a minimum return period of 200 years.