

*MS - SE Corner***Kennecott  
Utah Copper****Memorandum**

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LAW DEPARTMENT

B.D. Farmer

**Subject: SE Corner Task Force Recommendations***Summary*

A review of the potential exposure to third parties from a flow event at the South East Corner of the Magna Impoundment, as a result of a significant seismic event, was undertaken. This review was comprised of two separate and independent technical analyses of the potential run-out from such an event, from leading geotechnical experts. With regard to the south slope, these analyses have shown that the third party risks are limited in such an event to portions of Highway 201, adjacent Questar and telephone utilities, users of the Magna golf course, and in the very worst case run-out scenario, potentially some houses in the Meadow Green Estates subdivision and the north end of the Utah Copper Community Park Baseball Field. A number of mitigating alternatives were evaluated on the basis of past mitigating practices. As a result, a number of recommendations have been made, including:

- an accelerated de-watering program,
- a notification plan,
- a small berm near the subdivision,
- and a highway warning system.

The combination of these recommendations will substantially decrease the risk factors associated with a potential liquefaction failure, and substantially reduce the third party risks described herein. The east slope is being evaluated for potential third party exposure and mitigating measures will be recommended in 1998.

*Background*

Since about 1988, the stability of the South East Corner of the Magna Impoundment in the event of a significant seismic event has been subject to review with regard to minimizing third party risks. Immediate remediation response included the installation of 315 horizontal drains at the toe of the South East Corner embankment in 1989-90, supplemented with wick drains to assist vertical drainage. Extensive geotechnical investigations and analyses were undertaken.

Additionally, KUCC constructed a step back dike along the South East Corner in April 1991. Concurrently, a de-watering test program employing vertical pumping wells was initiated. The de-watering program has been expanded since 1991, as incremental success has been achieved. Additional efforts to improve the embankment stability have been ongoing and are the focus of this initiative.

Over the past several months, the SE Corner Task Force has convened for the purposes of reviewing and evaluating the dynamic stability status of the South East Corner of the Magna Impoundment. The South East Corner is the focus of review due to the combination of the potential for liquefaction under dynamic loading, and risks to third parties should a flow slide occur. The scope of this investigation included a detailed review of all studies and records relating to the seismic stability of the South East Corner from 1988 to the present. For the purpose of the review, third parties potentially affected in the areas of interest would include Highway 201, utilities along Highway 201, vacant third party land, the Magna Golf Course, the Utah Copper Community Park, and limited properties within the town of Magna (including homes within the Meadow Green Estates subdivision). Figure 1 shows the location of third parties with respect to the South East Corner.

There are two types of seismic events typically studied in the course of dynamic loading analyses (an operating basis earthquake, or OBE, which is defined as about a one in 200 year seismic event, and a Maximum Credible Earthquake, or MCE, which would be the most significant seismic event, occurring at a rate of about once every 1,350 years), however, the analysis focused on the MCE, since this would have a greater potential impact, however more remote, and is mandated by Utah statutes for new dams and structures. The MCE selected for these reviews would be about a MW7 earthquake on the East Great Salt Lake Fault but could also be a nearly equivalent MW7 originating on the Wasatch Fault. Two consulting firms, Woodward-Clyde and AGRA Earth and Environmental, were selected to carry out separate and independent flow failure run-out analyses for the southern alignment of the South East Corner in the event of an MCE. These firms were selected on the basis of their credentials and knowledge of the Magna impoundment; both are recognized as world leaders in this field. These analyses were conducted to evaluate current potential run-out, and the potential run-out at several points in time in the future on the basis of expected future decreased water level conditions within the South East Corner. As a result of continued de-watering measures, the forecast of the future conditions were developed based upon de-watering trends observed over the last few years.

In conjunction with this technical assessment, a number of improvements to the South East Corner were also evaluated for the purposes of further mitigating third party impacts. These additional measures were evaluated on the basis of their expected effectiveness. It should be noted that the upper bench step-backs, flattening of the slope and de-watering to lower the phreatic surface within the impoundment (the mitigation alternatives selected in 1991), have provided a significant reduction in third party exposure in the event of a dynamic failure due to a significant seismic event. The success of these approaches were considered in this evaluation, and form a key component of the basis for a recommendation for further mitigation in the future.

### *Results of Flow Failure Run-out Analyses*

For the purposes of these analyses, run-out is defined as a situation where “seismically induced liquefaction of enough tailings material could initiate a release of tailings material from the impoundment. The ensuing flowing mass would initially gain speed with time; however, the mass would eventually slow down, reach a stable configuration, and would come to rest in a post-liquefaction state.” These analyses were based on the forecasted lowering of phreatic levels consistent with the existing de-watering program; as noted later, an accelerated de-watering effort would significantly improve results of these analyses in a shorter time frame. In both cases described below, these run-out analyses’ models were calibrated with actual slides, including the KUC North East Corner incident in February 1998. The locations selected for the two analyses are effectively equivalent in terms of potential run-out, and are shown on the attached Figure 1.

#### Woodward-Clyde Analysis

The approach which has been used the most often to evaluate the amount of flow failure run-out is the method developed by Lucia, et al (1981). Generally, this is a simplified two-dimensional limit equilibrium analysis of the liquefied material downstream from the impoundment. The analysis takes into account several parameters (including resisting force along the base and lateral pressures at the back of the wedge of liquefied material), in addition to the weight of the liquefied mass, strength of material and volumes. These are used to calculate the residual height of the tailings at an embankment breach, slope, and ultimate run-out distance. There are limitations to this approach, primarily as it relies on only static forces to model what is effectively a dynamic process. As a result, Woodward-Clyde has developed a modified approach which models the dynamic nature of a run-out. Basically, this method looks at several configurations; 1) “initial”, where the factor of safety (FS) is less than one; 2) “statically stable”, where the mass has moved to a point where on a static basis, the FS would be one, but the slide would continue due to associated momentum; and 3) “dynamically stable”, where the velocity of the slide is zero, and the static FS would generally be greater than one.

Woodward-Clyde performed run-out analyses on three cross-sections along the South East Corner of the Magna Impoundment, including SE-2 in the vicinity of the E-4 tailings feed line (the cross-section considered to be most at risk), KL-C (a section about 3200 feet to the west, in more stable materials) and SE-C (at the South East corner). The locations of these sections are shown on the attached Figure 1. These sections were analyzed for potential run-out occurring today, in 2005, and 2018. The estimated run-outs for these cases were as follows:

Table 1

	Run-out Distance (feet)		
	<u>1998</u>	<u>2005</u>	<u>2018</u>
SE-2	540-690	340-510	240-315*
KL-C	450-630	0	0
SEC	540-690	340-510	240-315*

\*By 2018, the run-out could range from 240 to 315 feet in the event a flow slide is triggered, which Woodward-Clyde considers unlikely based on other more detailed analyses.

Note that Woodward-Clyde has qualified these estimates with respect to the uncertainty of residual shear strengths. The estimates are considered to represent best values employing state-of-the-art methodologies.

Woodward-Clyde determined that KL-C exhibited a post-earthquake factor of safety greater than one from 2005 onward. Prior to 2005 the run-out would be less than SE-2, but in 1998 would be nearly equivalent to SE-2, with the run-out distance declining rapidly past 1998. For the corner (SE-C), Woodward-Clyde determined that offsetting factors would lead to a run-out of the corner nearly equivalent to the SE-2 estimate. Therefore, Woodward-Clyde has concluded that the maximum run-out for either Sections SE-2 or SE-C is about 700 feet under 1998 conditions, declining to about zero to 300 feet by 2018.

#### AGRA Analysis

The AGRA analysis utilized the Lucia simplified equilibrium model as modified by Vick (1991). The rationale for undertaking this second approach was to perform an independent check of the Woodward-Clyde dynamic methodology on a more conventional basis to evaluate the sensitivity of the analysis and ensure that it was supportable.

In the AGRA analysis, a number of variables need to be assumed. Based on the progressive nature of a dynamic failure, the first requirement is to effectively evaluate the extent a failure encroaches into the impoundment, which determines the volume of material involved in the failure. Cases 1, 2, and 3 reflect the range of failure size based on progressive dynamic failure. While Case 2 is considered to be the most likely by AGRA, Case 3 represents a worst-case scenario where the slide would propagate to the crest of the impoundment. The second critical variable represents the undrained shear strength adjusted to consider various factors ranging from momentum to site conditions (Sus), which establishes the run-out distance for any given amount of flow volume. The lower the value, the longer the run-out distance. While an Sus factor of 80-100 psf typically would be used for the interbedded sands and silts representative of the South East Corner, a factor of 40 psf is consistent with the finer grain materials typical to the North East Corner incident of February 1998. Recent South African studies indicate that this variable may be additionally influenced by the run-out surface conditions; for example, a slide preceded by wet weather (resulting in a wet run-out surface) may cause a factor of 40 psf to be applicable to the site conditions, while a slide preceded by dry conditions may result in a factor between 80-100 psf.

AGRA reviewed two cross-sections, KL-D (near Woodward-Clyde's SE-2), and KL-C (see Figure 1 for locations). Like Woodward-Clyde, AGRA felt the conditions improved to the west and identified the KL-D area as the zone of potential maximum run-out. The analyses were performed for embankment phreatic conditions as presently exist (1997) and those expected in 2003 and 2018, and can be summarized as follows:

Table 2

			<u>Run-out Distance (feet)</u>		
			<u>1997</u>	<u>2003</u>	<u>2018</u>
KL-D	Case 1	40 psf	420	185	15
	Case 1	80 psf	240	40	0
	Case 1	100 psf	171	0	0
	Case 2	40 psf	770	485	270
	Case 2	80 psf	460	270	125
	Case 2	100 psf	355	200	50
	Case 3	40 psf	1410	1050	530
	Case 3	80 psf	760	570	220
	Case 3	100 psf	680	460	190

Based upon these results, AGRA has concluded that for the present phreatic conditions the extent of the liquefied zone would approximate Case 2 and the run-out would not exceed 770 feet, assuming wet surface conditions in the event of a significant seismically induced flow slide occurring today. The most extreme run-out for present conditions is a potential Case 3 total volume of slide under wet surface conditions (i.e. after a heavy rainfall), resulting in 1410 feet of run-out, diminishing to 1050 feet by 2003 and 530 by 2018. The Case 3 scenario is not believed to be likely by AGRA. The AGRA Case 3 flow volumes correspond with those of Woodward-Clyde, however, Woodward-Clyde believe that the run-out distances will be less, on the order of 700 feet. AGRA has further concluded the flow volume will probably be between Cases 1 and 2 by 2003 and under wet conditions the run-out would be on the order of 425 feet, and negligible by 2018 when the slide volume will probably be reduced to a Case 1, qualified by the uncertainty which exists around the dynamic behavior of the tailings above the phreatic surface and the undrained shear strength of the materials.

For KL-C, the section to the west, the run-out estimates are less, but do get as high in 1997 as 1050 feet for Case 3 at 40 psf, diminishing to 530 feet by 2003. Finally, AGRA noted that the tendency of tails to break into blocks (such as took place on the NE corner in February), and the possible absorption of energy from flow into the Clarification Canal, may serve to further restrain movement in run-out modeling (although Woodward-Clyde discounts the benefits of the Clarification Canal).

#### Summary of the Two Analyses

To summarize, the run-out analyses have shown that the only areas of potential third party risk (excluding vacant land) on the South East Corner in the event of a significant seismic event would be Highway 201, adjacent Questar and telephone utilities, possibly people on the Magna Golf Course, and in the worst case, potentially a number of the homes in the northwest portion of the Meadow Green Estates subdivision (about 1200-1400 feet from the actual Southeast Corner) and the north end of the Utah Copper Community Park Baseball Field. Remediation alternatives considered were based on this technical assessment of the potential magnitude of run-out.

### *Remediation Alternatives*

A number of alternatives have been and are in the process of being developed and evaluated in conjunction with the analyses of potential run-out distances, with the intent of providing seismic stability prior to the year 2018. These alternatives can be described as follows:

- Accelerated de-watering – as discussed previously, de-watering has been shown to be effective in lowering the phreatic level in the South East Corner embankment, and reducing the potential run-out in the event of a significant seismic event. The principle issues associated with de-watering relate to the rate and uniformity of phreatic level drawdown. This is related to the inability of vertical wells to develop anything but a narrow drawdown cone, and the relative ineffectiveness of horizontal drains in de-watering in the vertical dimension, given the interbedded horizons within the tailings impoundment. To address these issues, a plan has been developed to install additional vertical wells and horizontal drains where technically applicable, coupled with a wick program on the stepback and embankment slopes to improve vertical groundwater migration and accelerate the rate of phreatic drawdown. The application of wicks would be different from the existing application on the Magna Impoundment. Instead of wicks being used to reduce pore pressures, the wicks would be placed to improve the communication of interstitial water within the tails, thereby making the horizontal drains and vertical wells more effective in de-watering. Wicks in the vicinity of the vertical wells are also expected to improve the influence of the well drawdown cone. Trial testing on the South East Corner has shown that this application improves the effectiveness of horizontal drains. Preliminary estimates to install this enhanced de-watering are in the range of \$1.5 - 3.0 million for 1998 depending on the technical applicability of the varying de-watering measures.
- Protective berm on South East Corner – three conceptual alternatives for a stabilizing berm on the southern side of the South East Corner have been considered. These options include a mechanically stabilized backfill (MSB) wall along the lower portions of the existing embankment slope, a small berm constructed along the lower portions of the existing embankment, and a large berm in the same area. Each of these options were considered with and without a shear key. These options would substantially improve the seismic stability of the South East Corner, particularly with respect to Highway 201 and adjacent services. Of these alternatives, MSB is probably the most attractive as it provides less risk than the second case and would be more practical to design and construct than the third case, which would require a shear key and a relocation of the west-bound lanes of Highway 201. It is estimated that construction would take until 2003, to allow sufficient time for underflow to be available for construction material, which is otherwise required for the Northern Expansion Embankment. Relocation issues related to the clarification canal (including water management issues) have not yet been resolved and may be problematic, potentially to the extent that this alternative may not be practical. Other issues include the need to maintain de-watering after the berm is constructed, permitting, long construction times (including where to obtain construction materials) and cost. It is estimated that a stabilizing berm would cost in the range of \$50 million.
- Highway (and railroad) warning system – since the run-out analyses indicate that the most likely impacts would be limited to Highway 201 and potentially parts of the railroad line, a

conceptual warning system was designed to limit road and rail traffic in the event of a significant seismic event. The key to this approach is the uncertainty to the timing of a flow failure following a significant seismic event. The flow could occur instantaneously following the event (in which case a warning system would not be of assistance), or up to 24 hours after the event. Warning signs would be posted at approximately 13 locations along highways and entry roads, in addition to potentially along the railroad. These signs would be connected via telemetry to about seven (up from the current four) accelerographs designed to measure seismic events. Select signs would be "Variable Message Boards" and would be blank, illuminating warning messages after a significant seismic event. The cost for individual signs ranges from \$1000 to \$50,000, and would be similar to those employed by UDOT on existing highway projects for traffic control. This system would require close coordination with UDOT, Union Pacific Railroad (UPRR), City of Magna, and others. Including telemetry and process controls, the estimated total cost of the proposed system ranges from \$0.5 million to \$1.0 million, depending upon level of sophistication and coordination requirements.

- Subdivision berm – studies in South Africa and KUC's own experience in the North East Corner incident have indicated that relatively small berms and deflection structures, located some distances from a tailings embankment, have been effective in slowing and/or diverting the final stages of a run-out. Such a structure could effectively divert the worst case run-out event (AGRA Case 3 scenario) that could impact a limited portion of the Meadow Green Estates subdivision. The effective life for a small berm would be until 2003, or less when combined with an accelerated de-watering scheme. The cost of a tapered berm with a maximum height of about 15 feet, approximately 1400 feet long north west of the subdivision, would cost about \$400,000.

#### *Task Force Recommendations*

In developing these recommendations, the Task Force took into consideration the scope and success of remediation activities and related policies undertaken by prior KUC management since this issue arose about 10 years ago. In 1991, a large berm/embankment structure alternative, involving the complete relocation of Highway 201, was discarded in favor of the approach taken, which included upper crest stepbacks with active tailings storage moved 2000 feet from the toe of the embankment, in addition to an extensive de-watering program, including horizontal drains along the southern and eastern slopes, wick drains from the crest, and vertical pumping wells along the crest. A total of \$12-13 million was expended since 1988 on these efforts. The current run-out analyses, when compared to estimates from earlier studies, show that these steps have been significantly more effective than expected.

Based on the technical analyses of potential run-outs, and an assessment of mitigation alternatives in light of possible third party impacts, the Task Force has the following recommendations:

- The primary means of mitigation should continue to be de-watering, based upon the success to date in reducing the magnitude of run-out as a result of a significant seismic event. An aggressive approach is recommended to be taken, involving a combination of new vertical

wells, a new tier of horizontal drains where technically applicable, and two phases of wick installation.

- Develop a comprehensive notification plan involving the Utah State Engineer, other Utah agencies and relevant parties, such as potentially the Utah State Seismic Board, and others as appropriate, including third party land owners and tenants (including the golf course and users of the Utah Copper Community Park). It is recommended that L. Cononelos and B. Williams should be involved in this planning. This plan should be sequenced to first inform the Utah State Engineer, as early as June, and proceeding with the balance of the notification as we conclude the east side slope/run-out evaluation, to provide coordination of adjacent property owner notification.
- In conjunction with the development of this notification plan and discussions with appropriate third parties, develop a warning system tied to existing and new seismic measuring instrumentation around the Magna Tailings Impoundment, focused on roads and potentially the UPRR. The decision to implement such a system would be made based upon input from the Utah State Engineer, UDOT, and others as appropriate. The final decision to put a warning system should consider other non-KUC related seismic risks and damages which may be expected in the Salt Lake City basin. Of course, an agreement with UPRR would be required before a railroad implementation program, and may not be required if the UPRR does not see justification.
- An engineering plan should be developed for a small berm on the south side of Highway 201 to mitigate the worst-case run-out exposure to the Meadow Green Estates subdivision. A final decision to implement this plan should reflect that even in the worst case (i.e. AGRA Case 3 with 40 psf Sus), the run-out would not reach the subdivision insofar as exposure to the subdivision will be eliminated by 2003 or even sooner under the proposed accelerated de-watering recommendation.
- Once it has been demonstrated that risks have been minimized, under even the worst case run-out (by constructing the small berm to the south of Highway 201), proceed with disposition of the remaining nine lots and homes in the Meadow Green Estates subdivision.
- Incorporate potential risks to the Utah Copper Community Park (under the worst case run-out scenarios) into the overall notification plan, and signage similar to that considered for the golf course, recognizing that the field is fenced and locked, and used only under adult supervision. Be prepared to consider engineering a small concrete diversion berm (about one meter high) along the north side of the outfield in the event of significant community concern.
- Continue to acquire third party real estate parcels along the south and east sides of the Magna Tailings Impoundment which could potentially be impacted by a seismic-induced run-out.
- Over time, be prepared to reconsider the appropriateness of a larger berm to strengthen the South East Corner embankment in the event that de-watering is shown not to be sufficient to mitigate the impacts of a significant seismic event. This will be particularly the case as the mine gets closer to final closure in 2018 or later (pending an upgrade of underground

reserves) and final closure requirements for a MCE seismic event, recognizing that berm requirements will be considerably less than they are currently under most de-watering scenarios. The effectiveness of the currently proposed mitigation measures, in combination with the practical problems associated with large berms (including construction timing problems), result in a large berm option not to be recommended at the current time.

Note that many of these recommendations will require third party approval, including that of potentially the State Engineer, UDOT, other agencies, and possibly the public in the case of a subdivision berm. These recommendations are subject to obtaining these third party approvals. In addition, these recommendations should be evaluated in conjunction with the legal analysis provided by Cardey-Yates and Webster in a separate memorandum.

In conjunction with these recommendations, there will be a need to carry out additional work on the East side of the embankment, north of the SE corner. Woodward-Clyde has recently observed that de-watering has been less effective in lowering the phreatic level in this area. Run-out analyses will need to be carried out in this area, and third party impacts and mitigating options should be reviewed. Work to date has included the scoping of a stabilizing berm for this area which would cost about \$41 million, and other options should be considered including a more distant berm, similar to that proposed for the subdivision. While the task force was initially assigned to also review this issue, the priority of the current efforts have focused on the southern embankment of the South East Corner. In the near term, in coordination with the other South East Corner efforts, the work should be focused on the review on third party exposures, and oriented toward more distant berms and/or notification options, particularly for the Norcroft residence, recognizing the past history of discussions regarding tailings issues.

For the most part, these recommendations can be implemented within the existing Tailings Expansion project, and put into place during 1998, with some carryover into 1999.

### *Follow-up Recommendations*

With the technical work complete to date, and the previous recommendations, the South East Corner Task Force has met its goals. However, follow-up work, both in conjunction with this Task Force and in response to the investigation related to the February North East Corner incident, has indicated other areas which warrant further investigation. The focus of these investigations would be limited to mitigating third party liability and would concentrate in the following parts of the existing impoundment:

- NE Corner; remediation under static load is now complete and efforts would focus on the UPRR under conditions of dynamic loading and mitigating future effects of the Northern Expansion.
- East side of the NE Corner under conditions of static and dynamic loading; this portion of the existing impoundment still needs to achieve a 1.3 FS under static conditions. Initial remediation is planned during the balance of 1998 to achieve 1.3. In the future, additional remediation stages are planned to maintain the 1.3 FS as the embankment rises to its ultimate height over the next few years.

- North slope; while this area is exposed to run-out in the event of a large seismic event, there would be no third-party liability, but exposure to KUC assets (i.e. Northern Expansion) does exist. Over time, this exposure is also self-mitigating as the North Expansion begins to accept tailings. It is not proposed that North slope issues be included in this follow-up work.



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