Preliminary Conceptual Post-Closure Water Management Plan for Kennecott Utah Copper Corporation

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Preface

The Record of Decision (ROD) issued in December 2000 regarding the KUC South Facilities Groundwater Plume documented the preferred remedial alternative as containment and extraction of the acid plume, followed by treatment. Neutralization of acidic mine-related waters was generally accomplished by mixing with tailings from the Copperton Concentrator, which have historically contained excess neutralization capacity. After mining there would be no tailings, so a different approach to management of these waters would be needed. When the ore/tailings do not possess the required neutralization potential, the acidic mine waters must be neutralized by adding lime to the tailings system. Such lime addition causes severe scaling of the tailings pipeline that is costly to remove. Therefore, lime treatment of acidic mine waters in a separate facility was investigated in order to determine performance criteria and cost-effectiveness of this process. This report presents data collected during the evaluation of the treatment of KUCC acidic mine waters via precipitation with milk of lime. The test plan for these activities was laid out in the document *Test Plan for the Evaluation and Optimization of Metals Removal from Kennecott Utah Copper Acidic Mine Waters Via Alkali Precipitation and Physical Sequestration (March 2002).* The results of this work have also been used to develop a preliminary conceptual post closure water management plan for KUCC. This plan will be updated formally as part of the 5-Year Reviews during Remedial Action so that a final engineering design for all aspects is available prior to actual end of mining at Bingham Canyon, which is expected to be sometime between 2013 and 2030 depending on long-term mine planning.

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1.0 EXECUTIVE SUMMARY

KUC Engineering Services produced a work plan to guide testing related to the treatment of AMW generated on KUC property on the west side of the Salt Lake Valley. This work plan was entitled "*Test Plan for the Evaluation and Optimization of Metals Removal from Kennecott Utah Copper Acidic Mine Waters Via Alkali Precipitation and Physical Sequestration"* (hereafter referred to as the "*Test Plan*"). In order to implement the testing described in the plan, a pilot scale lime treatment plant was constructed inside of the existing membrane filtration building. Testing was carried out on two types of AMW:

1. Meteoric Leach Water (MLW) from the East Side Collection System (ESCS);
2. Acid Plume Water (APW) from well ECG1146.

In the *Test Plan*, it was stated that testing would also be carried out on the concentrate product from the nanofiltration of APW. Due to the shutdown of active leaching at KUCC, nanofiltration is no longer a component of the water treatment scheme. Therefore, the study of that particular source was terminated and no data concerning the treatment of that source are presented here.

Lime treatment was evaluated from pH 6 to pH 10. For each pH level, the solids load, solids composition, filtrate water quality, lime demand, and settling behavior were observed. Several tests were run with recycle of thickened sludge to determine if reagent demand could be decreased by sludge recirculation. A series of tests to determine the effect of different quality (i.e. sulfate concentration) waters for slaking was performed. Scaling in the reactors and associated piping was also monitored.

The following conclusions summarize the findings of the test work performed:

- Under the conditions of the tests, recirculation of sludge did not have a statistically significant effect on the lime demand of acid well water. Because high quality lime and slaking water were used (as a practical necessity) for these tests, they may not show increases in efficiency that could be observed using industrial quality lime and lower quality slaking water.

- Lime demand correlates fairly well to the dissolved aluminum concentration in the feed water.

- The sludge produced from lime treatment of APW to pH 7.9 passed TCLP, with the highest TCLP component being cadmium, at ~ 0.25 ppm in the leachate, lower than the 1.0 ppm regulatory limit for TCLP leachate.

- The sludge, if dewatered on a vacuum or pressure filter, will contain from 25% to 32% solids. This solids percentage is similar for sludges made from both waters, and all recycle fractions.

- The sulfate content of water used for lime slaking will have a significant effect on the lime demand of acid mine waters. Efficiency is reduced by as much as 6% per 1000 mg/L increase in sulfate concentration.

- The quality of water discharged from this process will meet current UPDES permitted discharge limits (outfall 012) to the Great Salt Lake.

This work was used as the basis to construct a preliminary conceptual post closure water management plan for KUCC. Sludge generation, management and disposal have been identified as the key post closure water management issues for the acidic waters. This plan will be updated formally as part of the 5-Year Reviews during Remedial Action so that a final engineering design for all aspects is available prior to actual end of mining at Bingham Canyon, which is expected to be sometime between 2013 and 2030 depending on long-term mine planning.

2.0 GLOSSARY OF TERMS

AMW - Acid Mine Water - Water that contains elevated levels of dissolved solids due to contact with artificially exposed ore bodies or waste rock dumps. This term is used interchangeably with Acid Mine Drainage (AMD).

APW - Acid Plume Water - Water extracted from the acidic groundwater plume in the Kennecott South Zone A.

Comparability - A qualitative term, which expresses confidence that two data sets can contribute to a common analysis and interpolation.

Dual-Stage Reactor - A pilot plant configuration where two reactors in series are used, with each reactor treating to a different pH, (i.e. pH 5 in the first reactor and pH 8 in the second).

East Side Collection System (ESCS) - The East Side Collection System was constructed to collect all waters, which passed through the East Side waste rock dumps, whether artificial or meteoric in origin. With the termination of active leaching, this system collects strictly meteoric waters and delivers them to the Precipitation Plant, where they are stripped of their copper content. ESCS waters make up one of the two major process influent sources.

Effluent - The treated liquid stream produced by a wastewater treatment technology.

Industrial Wastewater - Wastewater that contains primarily process wastewater.

Influent - Wastewater introduced to the wastewater treatment technology under evaluation for treatment.

Lime - CaO or burnt lime. Milk-of-lime (MOL) solutions are made by mixing powdered burnt lime with water to make a slurry of $Ca(OH)_2$ via $CaO + H_2O \rightarrow Ca(OH)_2$.

Major metals - For the purpose of this test plan, the major metals are aluminum and magnesium.

Minor metals - For the purpose of this test plan, minor metals are zinc, iron, manganese and copper. (See also - trace metals)

MLW - Meteoric Leach Water.

Membrane Filtration Plant (MFP) - The facility southwest of the Bingham reservoir which uses nanofiltration and reverse osmosis processes to segregate contaminated waters into two streams, one of lesser purity than the feed stream, and one of greater purity.

Normally Distributed Data - Data that form a bell-shaped curve when plotted as a graph; the mean is at the center of the distribution on the graph and the curve is symmetrical about the mean; the mean equals the median; the data are clustered around the middle of the curve with very few values more than three standard deviations away from the mean on either side.

Percent Recycle (% recycle) - The volumetric flow of return thickened sludge into the reactor, as a percentage of the feed rate of influent.

Percent Solids Recycle (% solids recycle) - The mass transfer rate of solids reporting to the reactor via sludge recycle divided by the mass transfer rate of solids to the thickener.

Performance Data - Removal efficiency and effluent concentration data for core and supplemental parameters.

Precision - A measure of the agreement between replicate measurements of the same property made under similar conditions.

Representativeness - Measure of the degree to which data accurately and precisely represent a characteristic of a population parameter at a sampling point or for a process condition or environmental condition.

Settling Rate - The rate at which sediment will move downward in a quiescent solution. The settling rate will be measured by the rate at which the surface of the slurry bed in a graduated cylinder moves downward during the unhindered settling phase of a settling test.

Sludge - The solids that are obtained from the lime treatment of AMW. In this document, sludge will refer to the partially dewatered AMW/Lime Treated precipitate slurry of such consistency observed in filter cake, which contains 25%-35% solids.

Slurry - The mixture of treated AMW and solids as they are discharged from the lime reactor, before any dewatering or thickening steps have been performed. Depending on the mix of feed waters, this mixture will contain anywhere from 3-6.5% solids.

Standard Operating Procedure - A written document containing specific instructions and protocols to ensure that quality assurance requirements are maintained.

Start-Up - The period from the time the wastewater treatment technology is put on-line until stable operating conditions are achieved.

Stable Operation - The period during which the wastewater treatment technology performs in a consistent manner following a start-up period, within the range of Experimental Design-specified operating conditions.

Target Constituents - Wastewater parameters the concentrations of which are specifically removed or reduced by the wastewater treatment technology.

Test Plan - A written document that describes the procedures for conducting a test or study according to the verification protocol requirements for the application of a wastewater treatment technology at a particular site. At a minimum, the Test Plan shall include instructions for sample and data collection, sample handling and preservation, precision, accuracy, goals, and quality assurance and quality control requirements relevant to the particular site.

Thickener Underflow - The underflow portion of a thickener into which AMW lime slurry has been fed. This material contains from 10-15% solids.

Trace Metals - For the purpose of this test plan, trace metals are nickel, cadmium, and arsenic. Although arsenic (if present) is most likely in complex anionic form as an oxide, it is included in the group of trace metals for editorial convenience.

Upset Condition - A condition that causes the wastewater treatment technology performance to exceed the range achieved during operation under the stable conditions defined by the Experimental Design. Such conditions may include, but are not limited to, equipment installation or operator error, unforeseen change in the influent wastewater characteristics, acts of God, or other unusual conditions. Sub-standard performance does not necessarily indicate the occurrence of an upset.

Verification - To establish evidence on the performance of a wastewater treatment technology under specific conditions, following a predetermined study protocol(s) and Test Plan(s).

Verification Report - A written document, prepared by Engineering Services, containing raw and analyzed data, QA/QC data sheets, descriptions of collected data, procedures and methods used in the verification testing.

3.0 DESCRIPTION OF THE TEST PLATFORM AND DATA COLLECTION ACTIVITIES

3.1 Test Platform

A pilot scale test facility was designed to give maximum flexibility for testing various configurations of AMW feed waters, recycle of sludge, reagent introduction, and settling behavior. A conceptual schematic of the general plant configuration is given in Figure 1 (Appendix B). A listing of system components is given below:

- (2) 22" diameter x 30" high, open, cylindrical HDPE reactors, each equipped with an 8 inch four bladed impeller capable of 0-300 rpm rotational frequency, and four equidistant 2" baffles;
- (3) 120 gallon stainless steel reagent mix tanks equipped with 1780 rpm mixers. These tanks were used to mix and store the 1.0 lb/gal MOL reagent slurry;
- (2) pH probe – hose pump control assemblies for reagent addition.
- 56" diameter 780 gallon thickener with center well and rake.
- 1.3 m^3 tilted plate settler;
- (1) 0-10 gpm hose pump;
- (1) 0-2.5 gpm hose pump;
- (1) 0-6 gpm diaphragm pump;
- (1) 0-1.6 gpm diaphragm pump;
- Allen-Bradley programmable logic controller (PLC) with RSView industrial control software interface.

The Test Plan identified the main variables of interest to be: retention time, sludge recycle, final pH, and point-of-entry for reagent. The control of each of these variables will be discussed below.

3.1.1 Retention time

Retention time in the reactor(s) was controlled by balancing two parameters of the plant design, namely, reactor volume and total reactor flux. Reactor volume control was approached in several different ways over the test period. The initial method of level control was to allow the solution from Reactor 1 (R1) to flow out an existing port in the reactor and flow by gravity to Reactor 2 (R2). While this method was stable enough, it didn't allow for any change of reactor working volume. The second configuration used a float switch to turn on a withdrawal pump to move liquid from one reactor to the other, or from a reactor to the thickener. This method was cumbersome because it required a pump and a valve, which could malfunction and cause a plant upset. The second fault with this system was that it caused the reactor liquid level to cycle. The period of this cycling would be approximately 6-10 minutes (depending on the total reactor flux), and the magnitude was approximately +/- 15% of the working volume. This behavior made it impossible to maintain a constant working volume, and by extension, a constant retention time.

A simpler approach was then implemented which required the elevation of R1 approximately 2 feet above R2. A drain hose running from the bottom of R1 up and over a gooseneck in the hose and down to R2 allowed for constant liquid transfer, without cycling. A vent was cut into the hose at the top of the gooseneck to avoid siphoning the contents of R1 into R2 at an uncontrolled rate. Transfer of treated water + solids to the thickener from R2 was achieved by mounting a withdrawal hose pointing straight down against the side of the reactor. This hose was connected to a positive displacement pump that was set to a withdrawal rate greater than the reactor flux. This allowed a constant, non-cycling draw of treated slurry from R2, maintaining a constant reactor volume. The effluent from this pump was sent to the top of the thickener, where it was discharged into the thickener center well.

Feed water addition to the reactor circuit was controlled by a hand valve and measured with a magnetic flow meter. Plant personnel closely monitored the feed water flow and recorded it frequently in the operator's logbook. The feed water flow rate was also transmitted to the control room PLC and thus a high and low alarm could be set to warn the operator of a significant drift from test conditions.

3.1.2 Sludge Recycle

Recycle of sludge from the underflow of the thickener was accomplished using a peristaltic pump set at a constant feed rate. The recycled sludge was then re-introduced into the circuit at the bottom of R1. In tests where sludge recycle rate was being varied, the % recycle was controlled by adjusting the recycle pump feed rate. Measurements of % solids in the thickener underflow were then used to back-calculate the % solids recycle (or the ratio of recycled solids to new solids produced in the reactor).

Since only a portion of the underflow sludge was taken for recycle to R1, a separate hose pump was used to withdraw additional thickener underflow. The flow through this pump was controlled by the plant operator, using the thickener sludge bed depth as a guide. A steadily dropping bed indicated to the operator the discharge flow rate needed to be reduced, while a steadily climbing sludge bed indicated a needed increase in flow rate.

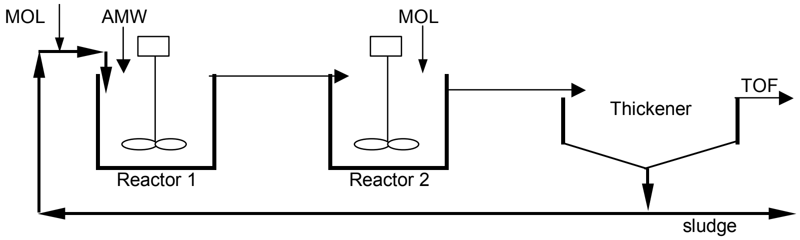
The overflow discharge from the thickener was routed into a single hose so that the flow rate could be measured, and samples of the thickener overflow could be taken for elemental analysis.

3.1.3 pH control

For early tests, pH control was maintained in the reactor(s) by manually adjusting the lime feed pumps to keep the pH in the appropriate range. Eventually, an automatic system utilizing a feedback loop control was implemented which gave tighter control (i.e. reduced variation). Regular checks of the process meters against freshly calibrated bench pH meters were performed to determine drift in the process probes. These checks indicated that drift did in fact occur, and it was particularly pronounced when treating to pH levels over 7 su. At these higher levels, gypsum formation on and in the junctions of the probes tended to cause the probes to drift high, causing a decrease in lime demand as the control circuit corrected to the artificially high readings. Another effect of scaling on the probes was an increase in response time to system changes. This behavior caused problems with the reagent addition feedback loop, manifested as pronounced cycling in the signal fed to the reagent pump whenever a minor change in pH occurred. Major upsets in the pH of the reactor often took hours to smooth out, compared to only minutes when the probes were new. The indication from the tests is that regular pH probe maintenance or replacement is essential to establishing a stable pH level, and to provide proper recovery capability in the event of a system upset.

3.1.4 Reactor Configuration and Reagent Addition Schemes

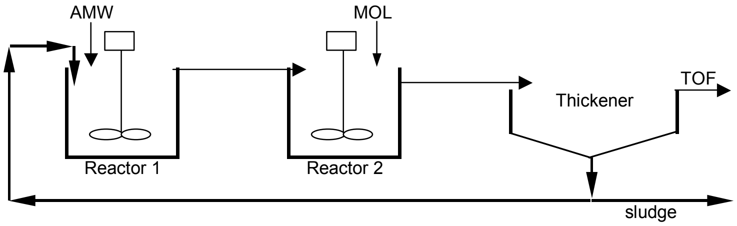
Lime treatment experience and several literature references suggest that certain schemes of adding MOL to the reactors would result in increased lime efficiency and reduced scaling. One scheme involved mixing the MOL with the incoming recirculated sludge before entry into the reactor:



This method was tested but soon abandoned due to severe scaling in the piping system where the lime and sludge mixed. The extremely high sulfate concentration in the recycled sludge of approximately 26,000 mg/l caused gypsum scaling to occur at a rapid rate. The severe scaling impacted the plumbing at the point of entry for MOL, clogging it and causing an upset condition.

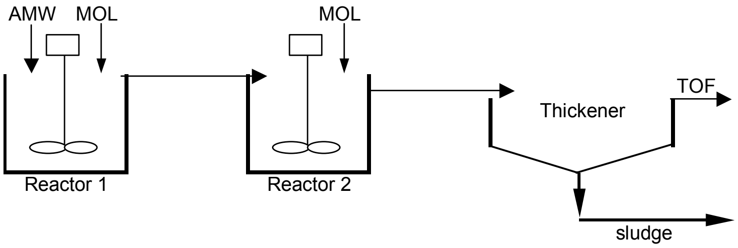
Several other mixing configurations were tried. A list of the other attempted configurations is given below:

A second method is to first mix the recycled sludge with incoming feed water, allow them to react until all the excess alkalinity (if any) in the sludge has been used up, and then raise the pH in a second reactor with MOL to the desired level.



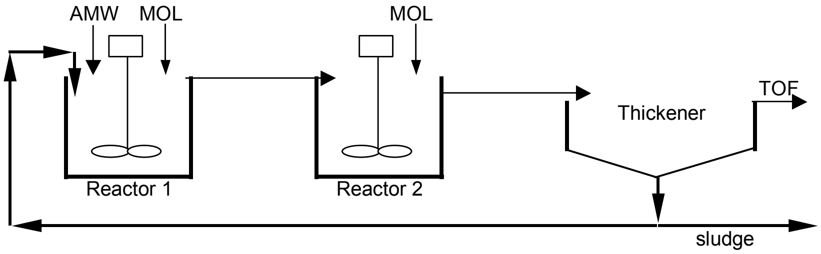
This method is referred to as a dual-stage with recycle, with MOL addition only to R2, and was used for test MOL 15 & 16.

A third method is to add MOL and feed water together in the first reactor, bring that mixture up to a moderate pH (~5) with milk-of-lime, and then in a second reactor, bring the pH up to the desired final treatment level, with no sludge recycle.



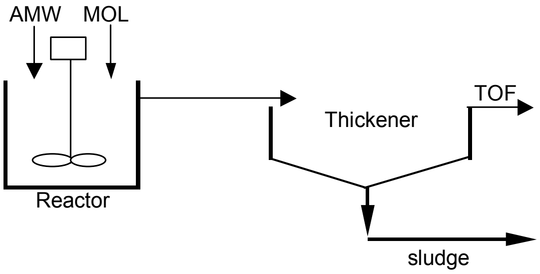
This is a dual-stage single-pass method (single-pass meaning no sludge recycle), with MOL added to both R1 and R2. This configuration was used for tests MOL 22,24 and 25.

A fourth method is to add the milk of lime, recycled sludge, and feed water together in the first reactor, bring that mixture up to a moderate pH (~5) with milk-of-lime, and then in a second reactor, bring the pH up to the desired final treatment level.



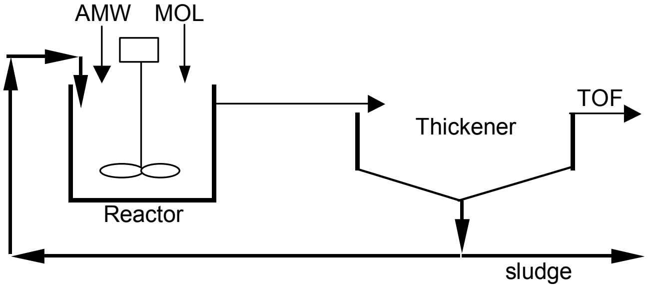
This is also a dual-stage with recycle method, with MOL added to both R1 and R2. This configuration was used for tests MOL 18 through MOL 21.

A fifth method is to treat AMW in a single reactor to the final pH with no recycle of sludge.



This single-stage, single-pass configuration was used for tests MOL 2 through MOL 14.

A sixth method is to treat AMW in a single reactor with simultaneous sludge recycle and milk-of-lime addition.



This single-stage with recycle configuration was not explored.

Some configurations were investigated more heavily than others. Table 1 (Appendix A) lists the test ID numbers for all tests for which data are included in this report. The number of stages (reactors in series) is indicated, as well as the pH target for each stage, the recycle fraction per stage, the "average" retention time per stage, feed water type, and reagent type.

3.2 Data Collection Activities

During each test, samples were collected at regular intervals to measure parameters of interest. These parameters included:

- Alkalinity of the MOL mixture
- Total metals in R1, R2 and thickener underflow dried filter cakes.
- Dissolved metals in reactor slurry filtrate
- Reactor slurry solids load
- Filter cake solids density
- Dissolved metals in thickener overflow
- Total metals in thickener overflow
- TSS in thickener overflow
- Settling velocities of various slurries

Process parameters were also recorded by the plant operator in the operator's logbook. These parameters included:

- Feed water flow rate
- MOL feed rate (flow rate of MOL solution into the reactors)
- Feed water conductivity
- Reactor pH(s)
- Recycled sludge flow rate
- R1 to R2 flow rate. (to back check sludge recirculation flow rate)

- Thickener discharge flow rate

The logging of process parameters was usually performed every two to three hours during a test. The collection of samples for analytical work was only performed once per day. It should be noted that samples were only taken after the system had been stable for several hours.

MOL analysis was performed whenever new MOL solution was added to the reagent feed tank. The preparation of MOL solution was performed in a mix tank separate from the reagent addition tank to avoid upsetting the system. All MOL solutions made with bagged lime had a nominal concentration of 1.0 lb CaO/gallon of solution, and were then analyzed for alkalinity via titration with acid.

Process data from the plant operators' logbook were ultimately consolidated into MS Excel spreadsheets, which were used to calculate average lime demand per reactor, as well as the mean and variation in pH readings (if applicable), feed flow rates, reagent flow rates, and lime demands. Analytical parameters were determined in the lab by the methods indicated in the Test Plan. The raw data were then transferred to the Excel workbook created for each discreet test.

4.0 RESULTS AND DISCUSSION

4.1 Solution Chemistry

Two different feed waters were used for treatment: Meteoric Leach Water (MLW) and Acid Plume Water (APW). Because of logistical reasons, only MOL 18 used MLW for feed to the pilot plant. All other tests used APW. Table 2, (Appendix A), shows the average chemistries of these waters as used in the current testing. The MLW stream has a greater variability in composition than the APW stream, because it is a composite of several individual flows that may vary in rate and composition themselves somewhat rapidly. The APW stream, being drawn from a relatively homogenous body of groundwater, tends to remain stable in composition. Both APW and MLW contain extremely high levels of aluminum, magnesium, and sulfate. Iron, copper, zinc, manganese and calcium are present in fairly high amounts, and cadmium, nickel, and arsenic are present in amounts, which are lower still, but high enough to require removal. The removal of these elements from solution to alleviate environmental discharge concerns is one of the fundamental reasons for evaluating lime treatment, and is the focus of this section of the report.

As indicated in Table 1, the test runs MOL 2 through MOL 14 were run using a single stage reactor, with no sludge recycle back to the reactor. The purpose of this test series was to evaluate sludge production numbers, sludge elemental makeup, and dissolved phase metal content of the treated slurry at pH levels above and below the expected pH 7. The dissolved phase metal content of the treated slurries is of particular interest because it represents the expected water quality in the tailings impoundment discharge in the post-closure lime treatment scenario. The dissolved phase metal concentrations were determined by filtering slurry discharged from the reactor through a 1 μm nominal filter and analyzing the filtrate by Atomic Adsorption (AA).

Table 3 in Appendix A illustrates the solution chemistry of slurry filtrates for APW treated to pH 6,7,8 and 10. These concentrations are what can be expected to be present in the discharge water of a lime treatment plant clarifier. Comparison of these levels to UPDES permitted discharge levels to the Great Salt Lake via outfall 012 (Table 4) indicates that all parameters would be below discharge limits. It should be noted that some of the parameters, such as cyanide and selenium, which are contained in the discharge permit, are not historically associated with AMW and so were not analyzed.

The control of suspended solids was not aggressively addressed during the phase of testing that is the subject of this report. The level of total suspended solids (TSS) present in the effluent of a thickener/clarifier is dependent to a great degree on the addition of an appropriate water-soluble polymer to agglomerate floating particles and cause them to form a rapidly settling floc. Settling of this type of material can be accomplished with off-the-shelf products, and indications from the testing are that with sufficient retention time no polymer may even be necessary.

Table 5 in Appendix A lists data obtained from total metals analysis of thickener overflow from MOL test 19. This test used a dual stage reactor with sludge recycle, treating APW to pH 7.9. During the test, four grab samples were taken and analyzed for TSS, total and dissolved metals, and total and dissolved sulfate. One sample was analyzed for arsenic, nickel and cadmium as well as the regular panel of aluminum, magnesium, calcium, copper, iron, manganese and zinc. (The dried sludge from this sample was also submitted for TCLP testing, the results of which are reported in section 4.2.1, following).

The Table 5 data show conclusively that the waters were treated to levels that meet the outfall 12 discharge requirements listed in Table 4.

4.2 Solids Chemistry

4.2.1 TCLP studies

The neutralization of metals in Kennecott AMW will produce a solid byproduct that must be disposed (a discussion of disposal options is discussed in section 5 of this document). TCLP analysis was performed on a representative sample of the MOL 19 sludge and on two samples of single-stage sludge to help in understanding the environmental engineering requirements that the disposal options would demand. Specifically, it is of concern whether or not the sludge would exhibit the toxicity characteristic as defined by the Resource Conservation and Recovery Act (RCRA). The TCLP (toxicity characteristic leaching procedure) was chosen over the SPLP (synthetic precipitation leaching procedure) because the leaching solution used in the former method is generally considered to be more aggressive than the solution used in the latter, and a successful test using a more aggressive leaching solution may be a better indicator of long-term stability.

The samples were prepared by vacuum filtering the slurry, with no rinse, and submitting the wet filter cake for analysis. The MOL 19 sample was made from pH 7.9-treated acid plume water in a dual-stage reactor, with sludge re-cycle. This sample passed TCLP leachate criteria for all components. In fact, no analytes were detected except cadmium, which was reported at 0.26 mg/L, well below the regulatory limit of 1 mg/L.

The second TCLP analysis was performed on sludge generated from the treatment of MLW to pH 7.9, in a single reactor setup with no re-cycle. This sample was run in duplicate, and both sets of data are recorded. This material also passes TCLP leachate limits, with cadmium reported at 0.08 and 0.06 mg/L for replicates 1 and 2, respectively.

These data clearly show that the sludge is non-hazardous in terms of the Toxicity Characteristic, regardless of the mode of production or feed water type.

4.2.2 Sludge Composition

Table 7a illustrates the bulk % composition of dried sludges according to the treatment pH. “Dried sludge” is sludge that was filtered out of the slurry, rinsed in DI water, and dried in an oven at 120ºC. These data were taken from tests MOL 2-13, which were performed in single-pass single-stage configuration, treating APW.

Table 7b shows the average pH 5 and pH 7.9 sludge compositions from test MOL 19, which was a dual stage test with 50% volumetric sludge recycle, treating APW.

Table 7c shows the average pH 5 and pH 7.9 sludge compositions from test MOL 18, a dual stage, 50% sludge recycle test treating MLW.

4.2.3 Sludge Production

Based on the assumption that the final sludge would be air-dried, it will retain significant amounts of water containing dissolved salts. To simulate this scenario, two unwashed filter cakes were dried at 60ºC side-by-side with rinsed filter cakes dried at 120ºC. The data for these unwashed, “air-dried” sludges are displayed in Figure 2. MOL 10 was the test during which this investigation was performed.

Examination of Figure 2 shows that an increase in mass of approximately 40% is seen between the two scenarios, “unwashed, air dried”, and “rinsed and oven dried”. This increase is due in roughly equal parts to extra water and dissolved salt retention. The washing of sludge on test samples was done to determine the true composition of the solid phase, without interference from adventitious salts that precipitated directly out of solution upon drying. This method of sludge preparation has a negative result, however, of underestimating the sludge production rate for unwashed, air-dried sludges, which will be the product in a full-scale treatment scenario. Therefore, it is instructive to make a distinction between the sludge production scenarios with and without cake washing and active drying.

Figure 3a shows the dry equivalent sludge load generated by APW at each pH level for the two sets of conditions (i.e. washed and unwashed), as well as the wet sludge production rate for unwashed filter cake. It should be noted that the shape of the curve through pH 9 is probably not smooth (i.e. linear) from 8-10. Prior bench testing indicates that the magnesium precipitation is complete somewhere around a measured pH of 8.5 and pH 9, and so the curve hits a plateau in that region and changes slope. That means the slope of the curve probably increases between pH 8.3 and levels out pretty much by pH 9 to the level seen at pH 10.

Because the mixed wastewater stream will contain varying amounts of APW and MLW, and correspondingly variable amounts of aluminum, Figure 3b was constructed to allow the calculation of sludge production based on treatment pH and aluminum concentration in the mixed feed water. This graph incorporated average dry sludge production rates, which were then used to calculate the wet sludge production rate at a normalized 30% solids content. The data from this graph are used for the discussion in Section 5 "Sludge Handling and Disposal".

Using Figure 3b and assuming an expected case flow of 1500 gpm APW, a MLW flow of 800 gpm, and aluminum concentrations of 2000 and 5000 ppm, respectively, sludge production for treatment to pH 7-8 will range from 1200-1700 lbs per 1000 gallons. For the expected case flow of 2300 gpm, that equates to 725,000 to 1,027,000 tons per year of 30% solids sludge.

The density of filter cake ranges from 1900 to 2300 lbs/yd^3, depending on the % solids content (Figure 3c). For the standard sludge at 30% solids, the density is very close to 1 ton per cu-yd. Using this density value, the calculated volume required to store sludge generated from a 24 hours per day, 365 day per year treatment plant treating 800 gpm MLW and 1500 gpm APW is 450 to 637 acre feet per year.

4.2.4 Solids Settling Behavior

Producing a sludge that settles well is important to help control the size of thickening equipment in the final design of the treatment plant. To aid in understanding the settling behavior, simple settling tests were performed to determine the changes in settling behavior observed at different treatment pH levels. The tests consisted of loading a 2 L graduated cylinder with thickener feed slurry, mixing the slurry to ensure homogeneity, and then allowing the sludge to settle undisturbed while periodically recording the elapsed time and the level of the phase interface between the top of the slurry and the beginning of clear supernatant. Data collection was complete after the settling rate became too slow to measure. A generic graph displaying these data is attached as Figure 8.

There were three regions of settling observed that warrant discussion. The first region of the fastest settling is labeled as the "free settling" region. Typically the free settling region is described as the region where solids diffuse downward through the solution without hindrance from neighboring particles. Because of the extreme amount of suspended solids in the treated waters, this region may be rather narrow, since by visual inspection it appears that neighboring precipitate particles are already making contact with one another before the onset of settling. There still seems to be a region where the settling is faster right at the beginning before it changes slope to the next region.

The next region is labeled as the "hindered settling" region. In this phase, the settling solids are hindered in their downward motion by more particles below them, or by friction from neighboring particles. The last region is the "compaction region", where the sludge undergoes slow dewatering and re-arrangement with only small decreases in total volume.

From these graphs we can get two important pieces of information. The slope of the curve in regions 1 and 2 allows to calculate thickener rise rates; that is, the maximum volume of water per unit area per time unit (in a thickener) that would allow for particles to maintain downward travel. This calculated number is reported in units of gal ft^{-2} min^{-1}.

The second piece of information we can get is the "ultimate" settling volume fraction. This number can be obtained by simply reading the lowest volume fraction data point from the curve. It can also be estimated by drawing an imaginary asymptote (parallel to the x-axis) along the bottom of the curve back to the y-axis, and record the volume fraction at the intersection. Since sludge continues to condense in the compaction region, the ultimate settling volume calculated in this fashion might not be the true, infinite time frame ultimate settling fraction. Rather, it represents the best sludge-settling fraction achievable in a realistically sized thickener.

Each of tests MOL 4-14 included the collection of at least one set of settling data. These data were plotted and the rise rates and ultimate settling fraction were recorded in Table 9. An immediately interesting observation is that the rise rate seems to decrease from pH 6 to 8, but increases again at pH 10.

The theoretical rise rates given in Table 9 reflect the behavior of untreated sludge only. Further testing will allow us to find an appropriate polymer to add as a flocking agent, which may result in improvements in settling velocity. Therefore, these reported rise rates are conservative in nature.

4.3 Lime Demand

The amount of lime required to achieve a certain pH is obviously a key element in treatment cost evaluations. Lime demand was determined by averaging numerous individual milk-of-lime (MOL) flow measurements for each test. The MOL for all tests was prepared at a fixed concentration of 1.0 lb/gal. Assays of each MOL batch were performed by titration with strong acid.

Figure 4 shows the average lime demand versus pH for treating APW in a single-pass, single-stage reactor. On this chart, the lime demand for pH 7-8 treatment of APW is indicated to be approximately 60-70 lb/1000 gallons. Figure 6 shows the lime demand for all other tests, including dual stage reactor configurations and tests using sludge recycle. As stated previously, the composition of APW is moderately stable. The water quality of MLW, however, especially in terms of aluminum concentration, tends to vary widely (from 4500 to 6700 ppm Al). Therefore, it seemed appropriate to try and peg lime demand on an analytical parameter, rather than on simple flow rate. The most likely candidates for this approach were sulfate and aluminum. Lime demand was plotted versus aluminum and sulfate concentrations to determine which candidate showed the most linear response. Figure 5 shows the plot of these data. Aluminum shows a more linear response to lime demand than sulfate. It seems logical from these data to use units of "pounds burnt lime per pound of dissolved aluminum ratio", (lb CaO / lb Al) then as a more convenient unit to report lime demand for APW and MLW sources. This approach to reporting lime demand was used to produce Figure 6, which shows the lime demand in terms of lb CaO / lb Al ratio for given pH treatment levels. The data presented in this chart are also displayed in tabular form in Table 8. There is a preponderance of data points around pH 8 region, because all of the sludge recirculation and slaking water variability tests used the dual-stage pH 5 – pH 7.9 treatment scenario as a constant. It is interesting that the average lime demand for test MOL 18, which used MLW as feed, is right among the APW data. This observation reinforces the idea that the CaO / Al weight ratio relationship is valid over a wide range of aluminum concentrations.

In Figure 6 several data points are in the pH 8 range and are higher than the majority of others. Standard lime preparation for the pilot plant used fine-bagged lime mixed with RO permeate slaking water. While this mixture provided a relatively trouble free (i.e. grit free) reagent source, the full-scale plant will use coarser lime feed and water that contains a significant amount of sulfate. In order to investigate the effect of sulfate in slaking water, three alternative MOL mixtures were prepared, to be run in the plant in the same manner as the "normal" milk-of-lime. These test mixtures, in order of increasing sulfate in the slaking water, were:

- Fine lime slaked with RO permeate, <10 mg/l sulfate.
- Fine lime slaked with K60/K109 deep well water, ~1300 mg/l sulfate.
- Fine lime slaked with Copperton Concentrator process water, ~2800 mg/l sulfate.
- Milk-of-lime obtained from the Copperton Concentrator (CC). This lime is received as –3/8", and slaked with CC process water in a vertical ball mill, which simultaneously mixes and grinds the lime into smaller particles

The data from these tests are displayed in Figure 7. It is apparent that sulfate concentrations in slaking water have a significant effect on lime demand, and that this effect increases with increasing sulfate concentration. The increase in lime demand between tests where bagged lime was slaked with CC process water, and the CC MOL test, indicates that the initial particle size of the lime also has an effect. CC MOL contained a large amount of grits, ~4% by weight, which also contributed to its lower efficiency. The lime demands determined in the pilot testing using fine bagged lime probably represent the best case scenario in terms of lime usage, while the CC MOL test probably represents the worst case scenario, as the milling of CC MOL is engineered with the foreknowledge that the material will undergo further dissolution in the milling process. Because of the significant savings possible in the use of clean versus high sulfate slaking water, investigations into the construction of an RO system strictly to provide slaking water is warranted.

For a base case scenario of 800 gpm MLW and 1500 gpm APW a conservative lime requirement for treatment to pH 8 is ~315 lb/min. At an MOL concentration of 1.5 lb/gal, this would require 210 gpm of RO permeate. A plant conservatively designed to produce 500 gpm of RO permeate would provide ample slaking water to the process.

5.0 SLUDGE DISPOSAL OPTIONS

5.1 General Logistical Considerations

The treatment of AMW and APW will produce a significant volume of sludge requiring disposal. The absolute volume of sludge produced will depend on:

The total combined flow rates of MLW and APW treated.
The combined acidity due to aluminum, iron, copper, zinc, manganese and sulfuric acid in the composite stream.
The configuration and pH target level of the reactor system

Current estimates are that the future flow rate of APW will range from 500 to 2500 gpm, and that the flow of MLW will range from 500 to 1000 gpm. The flow rate of APW will vary as a function of, observed effect on aquifer recharge behavior, plume containment, and/or other water management options that KUC chooses to pursue. MLW flows, which have been decreasing since the end of active leaching in 2000, may continue to decrease from their current levels (approximately 800-1000 gpm) to an unknown base flow rate.

For the purpose of providing a starting point for discussion of sludge treatment, it is useful to pick a set of flow values, which represent a reasonable estimate of the average expected future flow rate. We will therefore use a base case of 800 gpm MLW and 1500 gpm APW for the purpose of illustrating the slurry, sludge, and decant water volumes in the following disposal scenarios. These two sources will be responsible for over 90% of the south-end neutralization requirement, with the other 10% coming from pit dewatering and other miscellaneous flows. The contribution of these other waters to the total sludge volume will not be significant.

Henceforth, the term “slurry” or “reactor discharge” will be used to describe the raw effluent from the lime reactor, before thickening, filtering or drying. The solids content of this material, under the conditions of the base case, will vary from 6-8% by weight. Slurry that has been concentrated in a thickener and removed as underflow will be referred to as “thickened slurry” or “thickener underflow”. This material will contain 8-16% solids. Overflow water from the thickener is referred to as “thickener overflow”.

The 6-8% solids thickener underflow can be further de-watered by filtration, centrifugation, or evaporation. Filtration on a filter press or belt filter yields two products: filtrate and filter cake. As noted in Table 3 and the discussion in Section 4.1, filtrate is primarily a magnesium sulfate solution, which contains small amounts of suspended solids, and the dissolved solids are mainly magnesium, calcium, and sulfate. Filter cake contains from 25 to 35% solids and has the consistency of refrigerated margarine. It is suspected that material of this consistency can be made from thickener underflow without filtration by allowing the underflow to settle for extended periods of time (i.e. several years) in a wet repository under pressure from supernatant solution. This pressure may enable micro channeling in the solids, which over time would release increased amounts of pore water, thus increasing the solids content of the remaining sludge. This assumption, however, has not yet been proven for the material generated specifically from the treatment of KUC AMW with lime. The water liberated from the pore space is assumed to be of the same quality as the thickener overflow water.

Given the basis of 800 gpm MLW and 1500 gpm APW, KUC will generate approximately 0.75 to 1.02 million tons of calcium sulfate / metal hydroxide filter cake per year from its South End Area. This equates to a volume of 750,000 to 2,000,000 cubic yards per year, or 450 to 640 acre feet per year. In a maximum flow scenario, this number could go as high as 2 million tons of sludge per year. This sludge would contain approximately 30 % solids as filter cake by weight and have a pH of 7 to 8.2. As shown in Tables 7a-c, the solids would consist (on a dry solids basis) of approximately 55-60% calcium sulfate (anhydrite and various hydrates), 10-30% aluminum hydroxides/hydroxysulfates, 5-10% iron, copper, zinc, and manganese hydroxides. Less than one percent of the sludge would consist of cadmium, nickel, chromium and arsenic precipitates. These trace metals would be present predominantly as co-precipitated or sorbed fractions on the hydroxides.

Prior to mine closure, the treated slurry will be co-disposed with mill tailings in the Copperton tailings line and will be placed in the Magna Tailings Impoundment. At current mill output, the sludge solids from the neutralization process reporting to the impoundment will be less than 1% of the total solids. KUC also intends to investigate the practicality of suspending sludge discharge to the tailings line during key periods when final tailings lifts are being deposited on large surfaces to be revegetated. After open pit and/or underground operations have ceased, KUC may consider alternative locations for handling and disposal of the lime sludge. It is anticipated that the acidic water flows will continue and will need to be treated until at least 2050.

Alternatives to lime treatment, which could reduce the scope of a sludge storage solution, may be considered by KUC. However, the pursuit of such options will only occur if they prove to be economical while still maintaining a treatment level that allows for acceptable discharge water qualities.

While the Bingham Mine is in operation, the acidic flows will be added to the tailings stream originating at the Copperton Concentrator. The neutralization potential (NP) of the tailings will be used to treat the acidic flows, with supplemental lime addition as needed to maintain a pH of approximately 7 in the tailings as they are deposited into the tailings impoundment. It has been proven that water discharged from the impoundment to the Great Salt Lake (GSL) will meet current UPDES concentration limits by maintaining a pH greater than 6.7 at the North Splitter Box.

It is anticipated that a supplemental lime treatment plant will be built at the Copperton Concentrator prior to closure of Bingham open pit mining operations. Mine closure of the open pit is anticipated to be approximately in 2013. KUC is also considering continuing the Bingham Mine as an underground operation. Underground operations would start simultaneously with closure of the open pit and are projected to terminate around 2026. Tailings from the underground ore would also receive the acidic flows from the acid plume and meteoric leach water. However, the underground operation will generate less tails material, and therefore will not provide the current level of NP.

5.2 Sludge Disposal Locations

Prior to mine closure, lime-treatment sludge generated will be added to the tailings line and deposited along with the tailings in the Tailings Impoundment. Post closure treatment will require the use of an appropriate storage site. Five possible options for sludge disposal have been identified. Each option has been considered and compared for environmental health risk, groundwater protection and technical feasibility. The following options would be considered after mine closure (Appendix B; Figure 9):

1. Magna Tailings Impoundment
2. Construct New Repository
3. Bingham Mine Pit
4. Melco Pit at the Barney Canyon Mine
5. Bingham Canyon Mine waste rock

5.2.1 Tailings Impoundment

The Magna Tailings Impoundment would have many possibilities for sludge disposal. Assuming that there are no mining operations generating tailings, the north or south impoundment could be used to store sludge. It is not anticipated that the Tailings Impoundment would need to be lined to manage neutralized gypsum sludges. Acidic flows would be neutralized prior to contact with the tailings impoundment. If the acidic flow were treated at the south end (e.g. Copperton Concentrator) the following criteria would apply:

- The lime treatment plant would be located adjacent to the upgradient end of the tailings line at the Copperton Concentrator, and any waters that need lime addition would be treated with the resulting sludge disposed of in the tailings line;
- The lime treatment sludge would be routed to Tailings Impoundment, either to south or north impoundment

5.2.1.1 South Impoundment Considerations

Current plans call for reclaiming the south impoundment with vegetation. Portions of the northern half of the south impoundment (areas 3A, 3B, 3C, and 3D equaling ~700 acres) have relatively high soil conductivities due to high chloride waters that were added in the late 90s and early 2000 and to evaporation in the process water circuit. The salinity in area 3 will likely inhibit the establishment of a stable vegetative cover.

Long-term management of the risk for oxidation of sulfides at the surface of the tailings can be managed by three strategies: keeping the tailings wet, locally treating or even removing zones that might acidify, or possibly by burying the area with the alkaline lime-treatment sludges or with non-acid generating tailings.

As each of the respective areas of the north and south cells of the South Impoundment are covered with sludge and the sludge surface dries, a vegetated soil cap or net neutralizing tailings cap would need to be placed. As long as the sludge surface is wet, no vegetated soil cap will be necessary.

5.2.1.2 North Impoundment

Areas would need to be segregated (as for the South Impoundment) to limit the footprint of the sludge and the footprint for the decanted water. If the lime plant were located at the Copperton Concentrator, the discharged slurry would be fed by gravity to the area. If the slurry is thickened at the lime plant, the increase in viscosity may require it to be pumped to the impoundment. Another option would be to let unthickened slurry flow in a pipe from the Concentrator to the North End and thicken it there.

If the lime plant were to be located adjacent to the North Impoundment, thickener underflow could be placed in the impoundment and the decant water, after clarification, could be discharged to the GSL.

Given the predicted volume of sludge per year, a series of sub-cells would need to be constructed, where access could be gained between the cells. This access would serve as pipeline routes and road entry. During the summer months, much of the decant water would be left on the cells for evaporation. During winter, the decant water would be pumped to that portion of the impoundment containing the filter pack so that TSS could be removed from the water for discharge to the GSL. As the various cells are filled, the embankments between the cells would be raised to an appropriate height to withstand the added weight. It is anticipated that 5 to 6 sludge lifts could be placed in each cell. The lifts would be designed so that the embankments could withstand the hydrostatic pressure. Upon placement of the final lift of sludge and evaporation of the water, a soil cap or net neutralizing tailings cap would be put on and vegetated.

The design criteria will need to be further refined at 5 years prior to mine closure. A specific investigation related to this will include the effects of the sludges regarding the geotechnical stability of the impoundment.

5.2.2 Lined Repository

This option would include building a lined repository adjacent to the lime treatment facility on KUC property, either adjacent to the Copperton Concentrator or at a nearby location. Given the volume of sludge produced on an annual basis, 500,000 tons to 1,000,000 tons per year, the lined repository would need to be designed to hold upwards of 13 millions tons or about 13 million cubic yards. As the portions of the sludge dry in the repository, a temporary cap would need to be designed to control re-suspension of fine particles by wind. Upon closure of the repository, an appropriate final cap would need to be placed. Selection of the repository site will also be based on the permeability of the underlying geologic units and the quality of the underlying aquifer(s). For example, the aquifer(s) located on the northern end of the Oquirrh Mountains near the Great Salt Lake are very saline and are not considered drinking water aquifers. This area is also underlain by thick lacustrine sediments with low permeability.

5.2.2.1 Lined Repository Sludge Handling

The lined repository would be best located adjacent to the lime treatment plant. This assumption includes the process of re-circulating the sludge and making a thickened sludge to reduce the volume. If the sludge was not thickened, the sludge could be slurried from the treatment plant to the repository. The repository could be located over a contaminated aquifer (acid/sulfate) or non-drinking water aquifer such as those located near the Magna Tailings Impoundment. If thickened slurry were placed in the repository and it contained approximately 10 percent solids, it would need to be pumped into the repository. Decant water from the separated sludge would be pumped from the repository and routed to discharge to the GSL provided that it meets discharge standards.

5.2.2.2 Lined Repository Sludge Storage

After the sludge was air dried (evaporation of water), either a synthetic liner or clay liner would need to be placed on top. A vegetated, soil-cap would be placed on the liner, and runoff water would be routed to appropriate management (i.e., to control TSS before discharge).

5.2.3 Bingham Mine Pit

The Bingham Mine pit may be a viable alternative to receive sludge after mine closure, provided that no underground block caving operation has been conducted. If KUC proceeds with underground block caving, the surface pit bottom will subside differentially according to location(s) of the block caves. The Bingham pit bottom is approximately five and one-half miles southwest of the Copperton Concentrator.

If there were no underground operations, two scenarios would exist in the pit area in post-closure. KUC may be required to maintain a dry pit or may be allowed to let a pit lake form and not let the water level rise above the high concentration pyrite zones at approximate elevation 4900 ft AMSL. Given the concentrations of residual sulfate in the aqueous phase of the sludge, it is not anticipated that cake or slurry would be allowable discharge into an un-lined pit. The following discussions *assume a dry lined pit (assuming that it is even possible)*.

Since the lower portions of the pit at closure will be more than 1000 below the regional potentiometric surface, the pit would need to be pumped into perpetuity to remain dry. Below in-pit water elevation of 4900 feet, groundwater flows radially into Bingham Pit at a rate that is faster than the rate of evaporation. Depending on final closure of the pit, the sludge may need to be placed in a synthetically lined repository, and ground water would need to be pumped out adjacent to the lined area and the pit bottom to prevent inflowing groundwater from contacting the sludge. Even with aggressive peripheral dewatering, this pumping would likely exceed 500 gpm. Placing the sludge in the pit would require modification to the existing DOGM reclamation and DEQ groundwater discharge permits. The sludge could be placed as dewatered filter cake or as raw plant effluent slurry. The slurry water would contain 15,000 mg/L to 20,000 mg/L sulfate and would probably not be allowed to commingle with ground water. Groundwater in the pit would generally contain 1,000 to 2,000 mg/L sulfate. The supernatant water would need to be pumped from the pit and routed to the tailings line.

5.2.3.1 Bingham Pit Sludge Handling

The acidic water would be treated with lime at the Copperton Concentrator site or at a mine-pit site. The resulting slurry could either be pumped to the pit or thickened, filter pressed, and hauled in cake-form to the pit. If the slurry is pumped to the pit, after settling the decant water would need to be pumped from the pit and either treated or discharged to the tailings line. From the tailings line, this water would be placed in the North Tailings Impoundment and allowed to flow through the filter blanket (a layer of high hydraulic conductivity tails and alluvial material) and discharged by permit to the Great Salt Lake (GSL). If the lime plant is located in the pit, then the sludge would be thickened and the overflow water would be routed to the Tailings Impoundment.

Dependant upon whether the sludge was filter pressed or left as a slurry, certain infrastructure would need to be developed. If a filter press were required, it would be located near the lime treatment plant where the sludge is generated, and the thickener overflow and filtrate streams would be routed to the tailings line. If the unthickened slurry were pumped from the Copperton Concentrator, substantial piping would be required in the subgrade, capable of handling flows in the 5,000 to 6,000 gpm range with head ranging from 900 ft to 1200 ft. Instead of making sludge at the concentrator site, the lime plant and sludge thickener likely would be located within the Bingham Pit, and the acidic flow would be routed to the pit. Both scenarios would require detailed cost-benefit studies to determine which arrangement would be the most logistically and financially sound.

5.2.3.2 Bingham Pit Sludge Storage

The pit would need to be managed to protect groundwater quality. A liner above and below the sludge would prevent leakage of residual water in the sludge to groundwater and prevent infiltration of meteoric water and groundwater flowing into the pit. Given the spalling nature of the pit walls, and the influx of groundwater below and adjacent to a liner, the maintenance of a liner over the long term may not be possible.

Even though groundwater flows radially into the pit, the high sulfate water associated with the sludge could degrade the groundwater that would need to be pumped from the pit. The sludge storage area would also need to be fenced off so that wildlife could not access the sludge. There is also the possibility that low pH AMD would infiltrate the sludge and re-mobilize the precipitated heavy metals. To counteract this possibility is may be necessary to keep the clarified water level in the pit equal to the potentiometric surface of the water table, (if that is even possible), resulting in a static balance between pit water head and groundwater pressure. Careful assessment of the source, flow behavior, and water qualities of all inflows will need to be performed to evaluate the validity of this approach adequately. Another approach would be to isolate all known inflows, tunnel into their source, feed them into a pipe and pump them out of the pit before they can co-mingle with the sludge. Again, the long-term instability of the pit walls may make this option a logistical impossibility if a liner is required.

5.2.4 Melco Pit

Melco Pit is located approximately 2 miles west of the Copperton Concentrator. This pit is part of the completed Barneys Canyon Mine operation. The pit bottom is approximately 100 ft above the water table and there are no seeps or springs within the pit. Mining was completed in 2001. Groundwater in the pit area would be required to meet drinking water standards. The nearest culinary wells (3 wells) are approximately one and one-half miles east (Copperton Concentrator) and the Copperton Improvement District wells are approximately three miles east-north-east. The pit would need to be lined to prevent residual or slurry water from infiltrating to groundwater. Pit decant water would need to first be pumped from the lined pit to a treatment plant to reduce suspended solids and then routed to either the Tailings Impoundment, or to GSL. The filtered sludge could also be hauled to the lined pit and the filtrate would then be sent directly to the Tailings Impoundment. Either possibility would require modification to DOGM and DEQ permits.

5.2.4.1 Melco Pit Sludge Handling

Techniques for handling the sludge would be the same as Bingham Pit (ref. Section 5.2.3.1). If the sludge were delivered in cake-form, the residual water would be substantially less and any free or standing water would need to be pumped from the pit. The pit is located approximately 1,000 ft higher than the Copperton Concentrator.

5.2.4.2 Melco Pit Sludge Storage

The pit would need to be managed to protect groundwater quality. A liner above and below the sludge would prevent leakage of residual water in the sludge to groundwater and prevent infiltration of meteoric water. As portions of the pit become filled, in addition to the liner, a soil cap and surface water collection system would need to be designed to route meteoric water away from the repository. This meteoric water would then be routed to a treatment plant for use as either secondary or drinking water.

5.2.5 Bingham Mine Waste Rock

Bingham Mine waste rock dumps are located approximately two miles southwest of the Copperton Concentrator. The waste rock covers approximately 5,000 acres of land with approximately 1,200 acres of usable space. Sludge would be filtered and delivered in cake form. This sludge would be approximately 30 percent solids. The sludge layer would be capped, preferably with several feet of growth media, and vegetated. An alternative method of laying down the sludge would involve sandwiching layers of waste rock between layers of sludge, with a final growth media cap.

5.2.5.1 Waste Rock Sludge Handling

The sludge would be hauled and placed on the various available spaces. Berms would need to be installed to contain any lateral migration of the sludge. The sludge and final soil cap would also help reduce infiltration of meteoric water into the waste rock. 1,200 acres of usable area would take from 18-25 years to cover with a 10’ sludge layer at the expected case flows.

5.2.5.2 Waste Rock Sludge Storage

After completion of sludge delivery for each specific area, the sludge will need to be capped with several feet of topsoil and vegetated. The soil cap will need to be designed to allow more than 80 percent of the meteoric water to be stored and evaporated. The remaining meteoric water would be routed off of the sloped cap and piped to a water treatment facility. Water infiltrating the waste rock dumps would be captured by the existing cut off wall system and routed to the lime treatment plant with other AMW.

6.0 CONCLUSIONS

The treatment of Kennecott AMW via lime softening in the pH range 7-8 is a viable treatment alternative that will result in an effluent meeting all current permit criteria for discharge into the Great Salt Lake. The sludge produced will meet TCLP leachate contaminant limits for RCRA regulated metals.

Of the four types of reactor configurations used in the testing, none showed a clear advantage in terms of lime usage or reducing effluent contaminant levels. All four configurations produced treated waters that would meet the current UPDES permit limits for outfall 012, which discharges into the Great Salt Lake. The use of sludge recirculation, while not showing a clear advantage for lime demand under the conditions of these tests, may lead to increases in lime efficiency where industrial grade lime is used. Recirculation may free up unused alkalinity in lime grits that were not present in the lime used for these tests. Sludge recirculation also may lower the scale formation potential, however, this effect could not be substantiated in the pilot test work. A small increase in the leachability of cadmium was observed in sludge from tests utilizing sludge recycle, however, even with this observed increase the total concentration is only ~ 25% of the regulatory limit. Sludge recirculation is also expected to facilitate sludge dewatering and will therefore become important in a scenario with dewatered sludge disposal.

The sludges produced via lime treatment of KUC AMW will pass TCLP. Both APW and MLW sludges were tested. These two water sources comprise >90% of the alkalinity demand of all south end waters.

The Sludges can be dewatered on a vacuum or pressure filter to approximately 28-32% solids.

The *Test Plan* contained specific test objectives. These objectives and the response to them as presented in this report are listed below:

1. "Determine optimum sludge generation conditions for maximum settling velocity, filterability, and stability toward leaching."

   Of these items, the most important for long-term storage is stability toward leaching. Table 6 clearly shows that the sludges produced in this process are stable toward the TCLP.

   Settling velocities and filterability are desirable attributes to optimize the lime treatment process, but they are of no significance as long as the lime treatment slurry (sludge and water mixture) is being discharged into the tailings pipeline. The preliminary testing has determined some material specific settling rates for APW, which will be used for engineering purposes in the future. Filterability was not studied in the context of this testing phase.

2. "Determine optimum design for maximum efficiency of lime usage."

   Lime efficiency was studied in light of changing retention times, sludge recirculation, and slaking water quality. Of all these factors, slaking water quality had the greatest effect. The use of low sulfate slaking water will be key to economical lime treatment. The use of industrial grade lime and a full scale lime slaker as currently in use at the Copperton Concentrator will cause lime usage to increase up to 6% per 1000 mg/L increase in slaking water sulfate concentration. That is, slaking water that contains 1200 mg/L sulfate may see a 6% improvement of lime usage over slaking water that contains 2200 mg/L sulfate.

3. "Generate reagent cost per feed unit, and estimate power and equipment needs for upscale to a large plant."

   The reagent cost per feed unit has been calculated using lime demand data contained in this report as well as outside information. A large-scale plant has already been designed through the preliminary engineering stage, and the power and equipment needs have been calculated. The specific data generated in that endeavor are beyond the scope of this report.

4. "Determine the impact of sludge precipitation and removal on the water quality of the total system (tailings impoundment, process water recirculation, discharge of excess water to the Great Salt Lake).

Because of the determination of the expected effluent water qualities as shown in Tables 3 and 5 of this report, water managers can calculate theoretical water qualities for streams that contain fractions of these waters after discharge from the plant. The actual determination of the total water picture at KUC is beyond the scope of this report and will be reported elsewhere.

Overall, the test program answered the key questions surrounding lime treatment of KUC AMW streams, such as: How much lime is needed? What pH level is required to meet discharge standards? Is the sludge stable? How much sludge will be produced per volume and type of water? How will the remediation waters (acidic and RO concentrates) and resulting sludge be managed post-closure? These issues are core to addressing environmental concerns over the ultimate fate of these waters.

This plan will be updated formally as part of the 5-Year Reviews during Remedial Action so that a final engineering design for all aspects is available prior to actual end of mining at Bingham Canyon, which is expected to be sometime between 2013 and 2030 depending on long-term mine planning.

APPENDIX A TABLES

TABLE 1. Test Conditions

Test	Reagent type*	Feed Water	# of reactor stages	R1 pH Target	R1 pH actual	R1 retention time	R2 pH Target	R2 pH actual	R2 retention time, minutes	Volumetric Recirc Fraction
MOL 2	MOL	APW	1	-	-	-	6	5.98	37	0.00
MOL 3	MOL	APW	1	-	-	-	6	5.73	38	0.00
MOL 6	MOL	APW	1	-	-	-	6	5.95	38	0.00
MOL 7	MOL	APW	1	-	-	-	7	6.87	38	0.00
MOL 8	MOL	APW	1	-	-	-	7	7.00	38	0.00
MOL 9	MOL	APW	1	-	-	-	8	7.98	38	0.00
MOL 10	MOL	APW	1	-	-	-	8	8.01	38	0.00
MOL 11	MOL	APW	1	-	-	-	10	9.90	38	0.00
MOL 12	MOL	APW	1	-	-	-	8	8.03	38	0.00
MOL 13	MOL	APW	1	-	-	-	10	9.91	38	0.00
MOL 14	MOL	APW	1	-	-	-	10	9.95	38	0.00
MOL 15	MOL	APW	2	NA	4.63	15	8	7.96	15	1.60
MOL 16	MOL	APW	2	NA	4.47	10	8	7.89	15	1.00
MOL 18	MOL	MLW	2	5	4.94	42	7.9	7.83	45	0.25
MOL 19	CMOL	APW	2	5	5.00	45	7.9	7.90	45	0.50
MOL 20	MOL	APW	2	5	5.00	41	7.95	7.92	46	0.50
MOL 21	MOL	APW	2	5	4.99	55	7.95	7.96	55	0.25
MOL 22	MOL	APW	2	5	5.00	56	7.95	7.95	56	0.00
MOL 24	K60MOL	APW	2	5	5.00	53	7.95	7.90	52	0.00
MOL 25	CPWMOL	APW	2	5	5.00	54	7.95	7.90		0.00
MOL 30	MOL	MLW	1	-	-	-	6	6.0	30	0.00
MOL 30	MOL	MLW	1	-	-	-	6	6.0	120	0.00
MOL 30	MOL	MLW	1	-	-	-	7	7.0	30	0.00
MOL 30	MOL	MLW	1	-	-	-	7	7.0	120	0.00
MOL 30	MOL	MLW	1	-	-	-	8	8.0	30	0.00
MOL 30	MOL	MLW	1	-	-	-	8	8.0	120	0.00

* MOL = pulverized lime slaked with RO permeate, (<10mg/L sulfate) to 1.0 lb/gallon

K60MOL = pulverized lime slaked with Deep Well water, (~1300 mg/L sulfate) to 1.0 lb/gal

CPWMOL = pulverized lime slaked with Copperton process water, (~2800 mg/l sulfate) to 1.0 lb/gal

CMOL = Lime slurry obtained from Copperton Concentrator. -1/8" Lime slaked in a vertical ball mill with ~2800 mg/L sulfate process water.

TABLE 2. Average AMD Water Quality Ranges, mg/L

water type	Al	Ca	Mg	Fe	Cu	Zn
APW	1900-2100	430-500	4200-4600	420-520	100-140	120-140
MLW	4900-6700	480-600	9000-11000	600-800	300-500	160-250
water type	Mn	Ni	Cd	As	SO_4	
APW	380-420	24	0.98	0.053	29000 - 32000	
MLW	440-520				60000 - 75000	

TABLE 3. Dissolved Metals in APW Treated to the Indicated pH, mg/L.

Conditions	Al	Ca	Mg	Fe	Cu	Zn	Mn	SO4	Ni	Cd	As
average pH 6	29	516	4,252	232	17	79	378	18,365	*na*	*na*	*na*
average pH 7	1.1	486	3,726	0.46	0.06	0.22	184	16,789	*na*	*na*	*na*
average pH 8	1.5	503	2,776	0.31	0.07	0.11	45.8	12,363	0.053	0.044	0.014
average pH 10	2.4	726	17.8	0.13	0.06	0.04	0.12	1,743	*na*	*na*	*na*

Table 4 - Discharge Limits to GSL

Parameter	30 Day Average Discharge Limit, mg/L	Daily Maximum Discharge Limit, mg/L
Total Suspended Solids	20	30
Total Arsenic	0.25	0.5
Total Cadmium	0.05	0.1
Total Copper	0.15	0.3
Total Lead	0.3	0.6
Total Mercury	0.001	0.002
Total Selenium	NA	0.054
Total Zinc	0.224	0.5
Total Cyanide	0.1	NA
Total Dissolved Solids	NA	NA
Oil and Grease	NA	10
pH	> 6.5 and < 9.0	> 6.5 and < 9.0

Table 5 - Overflow Water Qualities for MOL19 (ph 7.9) with Total Metals and % Removal from Original Feed

Test run	type	TSS, mg/L	Al	Ca	Cu	Fe	Mg	Mn	Zn	As	Cd	Ni	SO4
MOL19B	Feed	-	2319	461	138.00	473.00	4895	428	139	*na*	*na*	*na*	32,303
	TOD[1]	-	1.13	479	0.03	0.18	4335	56	0.09	*na*	*na*	*na*	18,024
	TOT[2]	50	2.83	477	0.14	0.39	4428	56	0.12	*na*	*na*	*na*	18,188
	% Removal	-	99.95%	-3.90%	99.98%	99.96%	11.44%	86.9%	99.94%	*na*	*na*	*na*	44.20%
	% suspended	-	60%	0%	79%	54%	2%	0%	25%	*na*	*na*	*na*	nsd [3]
MOL19C	Feed	-	2340	460	134.00	451.00	4764	415.00	132	*na*	*na*	*na*	32,200
	TOD	-	0.15	490	0.02	0.01	3778	63.20	0.1	*na*	*na*	*na*	16,131
	TOT	<20	1.46	503	0.08	0.14	3741	66.37	0.10	*na*	*na*	*na*	16,337
	% Removal	-	99.99%	-6.52%	99.99%	99.998%	20.70%	84.8%	99.92%	*na*	*na*	*na*	49.90%
	% suspended	-	90%	3%	75%	93%	-1%	5%	-10%	*na*	*na*	*na*	nsd
MOL19D	Feed	-	2062	453	119.40	461.00	4447	410.00	131.0	*na*	*na*	*na*	29,731
	TOD	-	0.15	490	0.02	0.02	3520	113.00	0.11	*na*	*na*	*na*	15,760
	TOT	<20	2.77	513	0.14	0	3667	117.0	0.19	*na*	*na*	*na*	16,049
	% Removal	-	99.85%	-22.30%	99.87%	99.90%	10.94%	69.2%	99.84%	*na*	*na*	*na*	46.99%
	% suspended	-	95%	4%	86%	95%	4%	3%	42%	*na*	*na*	*na*	2%
MOL19E	Feed	-	2027	441	113.00	448	4223	397.0	129.00	0.053	0.977	24.30	29,834
	TOD	-	0.48	475	0.01	0.02	3427	109	0.09	0.014	0.044	0.05	15,226
	TOT	<20	2.11	506	0.06	0.20	3630	112	0.12	0.008	0.046	0.08	15,843
	% Removal	-	99.98%	-7.71%	99.99%	99.996%	18.85%	72.5%	99.93%	73.58%	95.50%	99.78%	48.96%
	% suspended	-	77%	6%	83%	90%	6%	3%	25%	-75%	4%	34%	4%
AVERAGE	Feed Average	-	2045	447	116	455	4335	404	130	0.053	0.977	24.3	29783
	TOD Average	-	0.32	483	0.015	0.0	3474	111	0.10	0.014	0.044	0.053	15493
	TOT Average	<20	2.44	510	0.100	0.3	3649	115	0.16	0.008	0.046	0.080	15946
	% removal	-	99.98%	-7.94%	99.99%	99.996%	19.87%	72.5%	99.9%	73.6%	95.5%	99.8%	47.98%
	% suspended	-	87%	5%	85%	93%	5%	3%	35%	-75%	4%	34%	3%

[1] Thckener Overflow, Dissolved

[2] Thickener Overflow, Total

[3] nsd = not statistically different

Table 6. TCLP Results on Sludge Filter Cake

Sample	Ag	As	Ba	Cd	Cr	Hg	Pb	Se
	Leachate Metal Values, mg/L							
Dual-stage with sludge recycle to pH 7.9	<0.1	<0.1	<0.1	0.26	<0.1	<0.0001	<0.1	<0.1
Single stage, no recycle, pH 7.9	<0.1	<0.1	<0.1	0.08	<0.1	<0.0001	<0.1	<0.1
Single stage, no recycle, pH 7.9 (dupilcate)	<0.1	<0.1	<0.1	0.05	<0.1	<0.0001	<0.1	<0.1
Single stage, no recycle, pH 6, rt = 30 min	<0.1	<0.1	<0.1	0.12	<0.1	<0.0001	<0.1	<0.1
Single stage, no recycle, pH 6, rt = 120 min	<0.1	<0.1	<0.1	0.15	<0.1	<0.0001	<0.1	<0.1
Single stage, no recycle, pH 7, rt = 30 min	<0.1	<0.1	<0.1	0.09	<0.1	<0.0001	<0.1	<0.1
Single stage, no recycle, pH 7, rt = 120 min	<0.1	<0.1	<0.1	<0.01	<0.1	<0.0001	<0.1	<0.1
Single stage, no recycle, pH 8, rt = 30 min	<0.1	<0.1	<0.1	<0.01	<0.1	<0.0001	<0.1	<0.1
Single stage, no recycle, pH 8, rt = 120 min	<0.1	<0.1	<0.1	<0.01	<0.1	<0.0001	<0.1	<0.1

Table 7a. Wt% Metals in Single-Pass, Single Stage APW Sludges. (dried at 120°C)

	Al	Ca	Mg	Fe	Cu	Zn	Mn	SO_4
pH 6 average	10.29%	15.88%	0.17%	1.75%	0.54%	0.31%	0.11%	45.9%
pH 7 average	9.69%	17.12%	0.68%	2.45%	0.66%	0.68%	0.73%	44.0%
pH 8 average	7.07%	17.42%	3.22%	1.70%	0.40%	0.45%	1.12%	44.7%
pH 10 average	3.64%	16.43%	7.94%	0.91%	0.21%	0.23%	0.72%	45.0%

Table 7b. Wt% Metals in Dual-Stage, Sludge Recycled APW Sludges

	Al	Ca	Mg	Fe	Cu	Zn	Mn	SO_4
pH 5 average	10.4%	14.5%	0.12%	1.03%	0.30%	0.068%	0.011%	50.3%
pH 7.9 average	7.72%	17.1%	1.32%	1.82%	0.48%	0.53%	0.91%	48.8%

Table 7c. Wt% Metals in Dual-Stage, Sludge Recycled MLW Sludges.

	Al	Ca	Mg	Fe	Cu	Zn	Mn	SO_4
pH 5 average	8.4%	16.9%	0.26%	1.07%	0.56%	0.16%	0.028%	52.0%
pH 7.9 average	7.5%	19.9%	2.4%	0.91%	0.51%	0.27%	0.477%	49.2%

Table 8. - Average Lime Demand for All Tests

Test	Reagent	Feed Water	# of reactor stages	R2 pH	Volumetric Recirc Fraction	Reagent Demand, lb/kgal	Reagent Demand, lb/lb Al
MOL 5	MOL	APW	1	5.94	0	53.8	3.1
MOL 6	MOL	APW	1	5.95	0	51.4	2.9
MOL 7	MOL	APW	1	6.87	0	58.4	3.4
MOL 8	MOL	APW	1	7.00	0	61.0	3.5
MOL 9	MOL	APW	1	7.98	0	75.4	4.4
MOL 10	MOL	APW	1	8.01	0	68.0	4.1
MOL 11	MOL	APW	1	9.90	0	125.0	7.5
MOL 12	MOL	APW	1	8.03	0	80.6	4.9
MOL 13	MOL	APW	1	9.91	0	140.0	8.5
MOL 14	MOL	APW	1	9.95	0	132.6	8.1
MOL15	MOL	APW	2	7.96	1.6	68.2	4.1
MOL16	MOL	APW	2	7.89	1	66.6	4.1
MOL 18	MOL	MLW	2	7.83	0.25	195.0	3.8
MOL 19	CMOL	APW	2	7.90	0.5	109.6	5.7
MOL 20	MOL	APW	2	7.92	0.5	67.1	4.0
MOL 21	MOL	APW	2	7.96	0.25	69.9	4.2
MOL 22	MOL	APW	2	7.95	0	70.7	4.2
MOL 24	K60MOL	APW	2	7.90	0	81.9	4.9
MOL 25	CPWMOL	APW	2	7.90	0	91.5	5.5

Table 9. - Settling Characteristics of APW Slurries

Test pH	Rise Rate, gal/hr ft2	Ultimate settling fraction, unitless
6	3.2 - 6.5	0.23 - 0.27
7	2.1 - 2.7	0.33 - 0.38
8	1.8 - 2.1	0.35 - 0.37
10	3.9 - 5.3	0.35 - 0.37

APPENDIX B - FIGURES

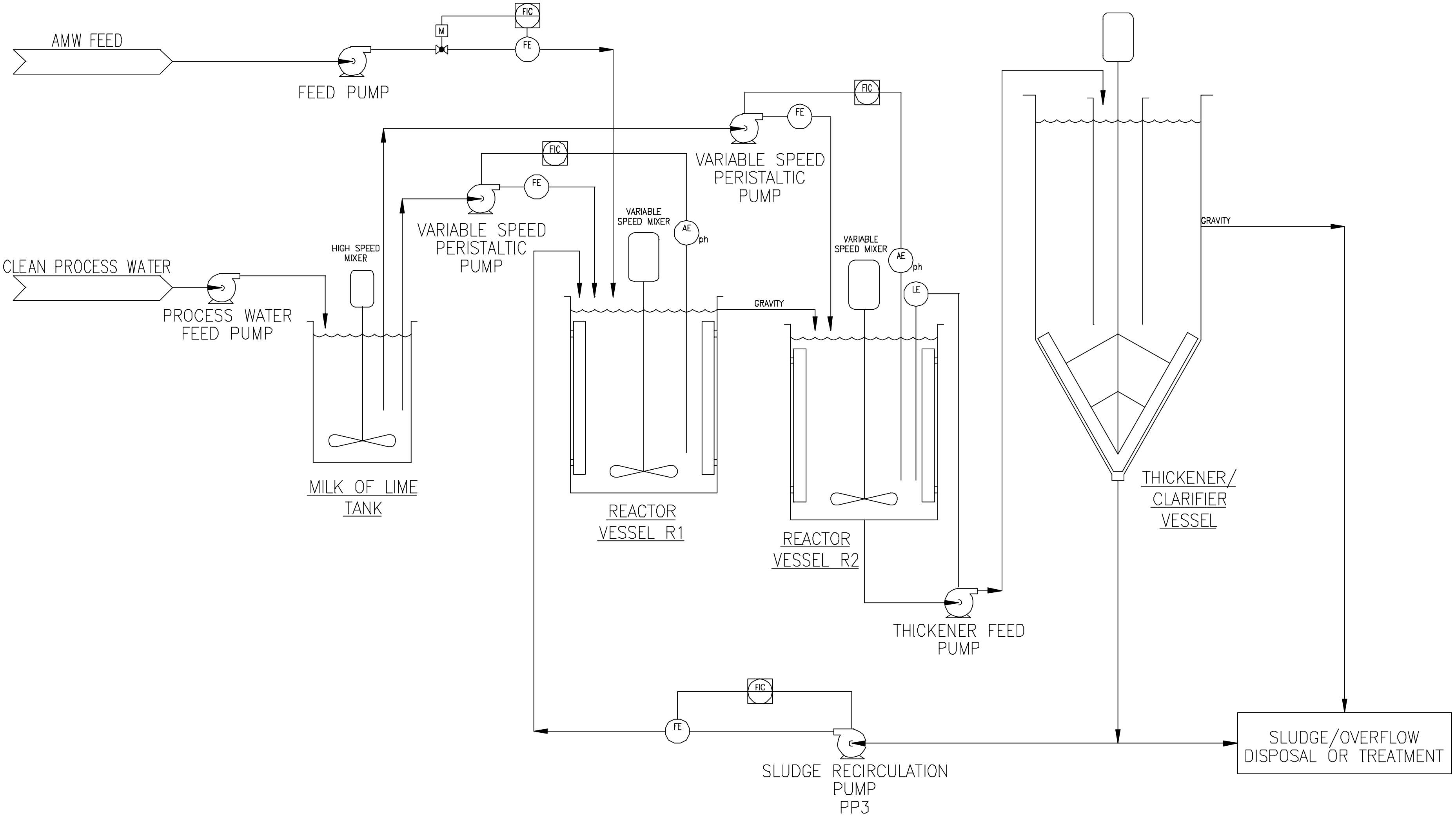
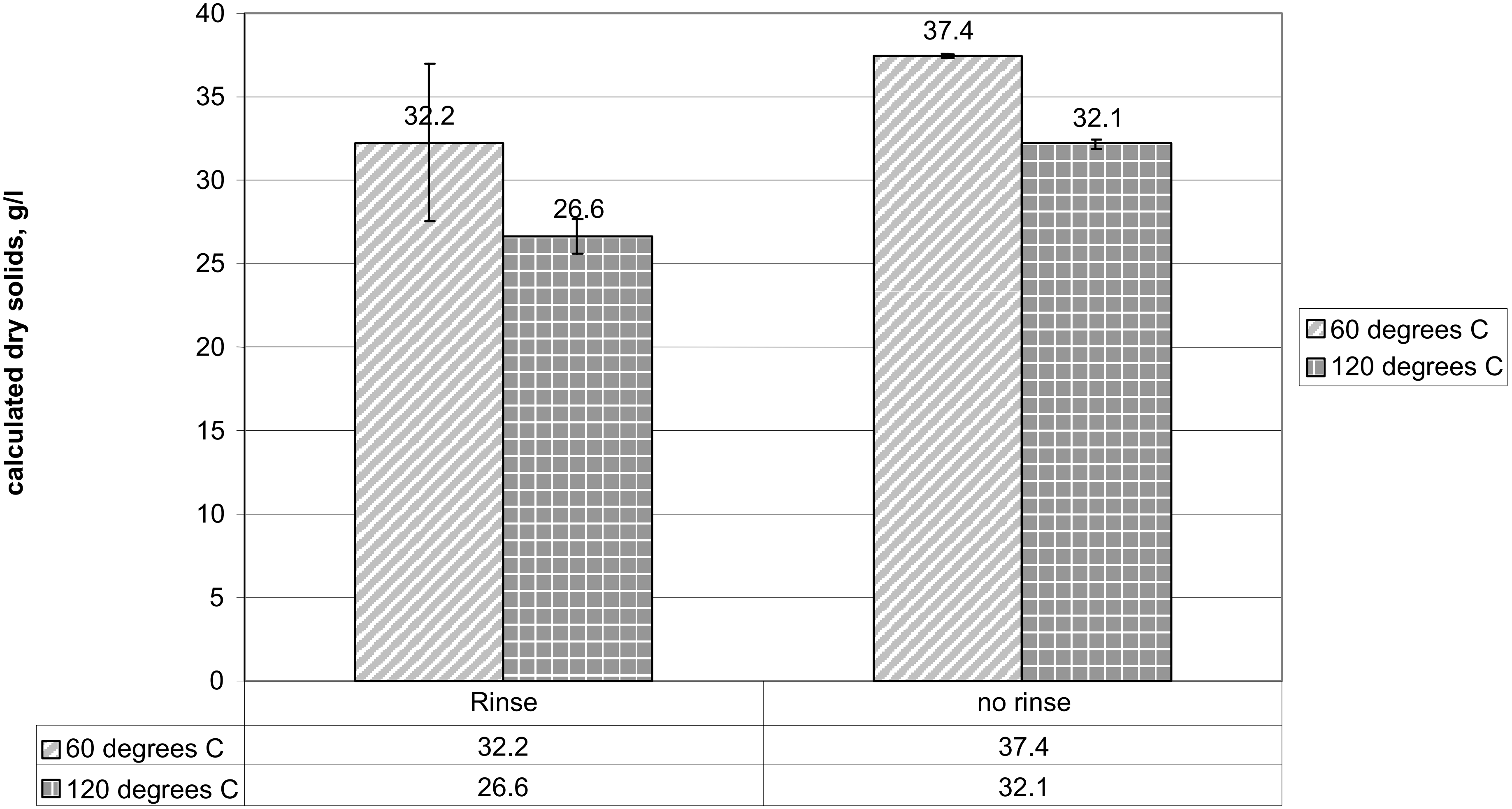


Figure 1 General Pilot Plant Configuration

Figure 2 Solids Load (grams/Liter) for Washed and Unwashed APW Lime Sludges at Two Drying Temperatures. MOL 10



	Rinse	no rinse
▨ 60 degrees C	32.2	37.4
▥ 120 degrees C	26.6	32.1

Figure 3a Average Sludge Production vs pH for APW Sludges

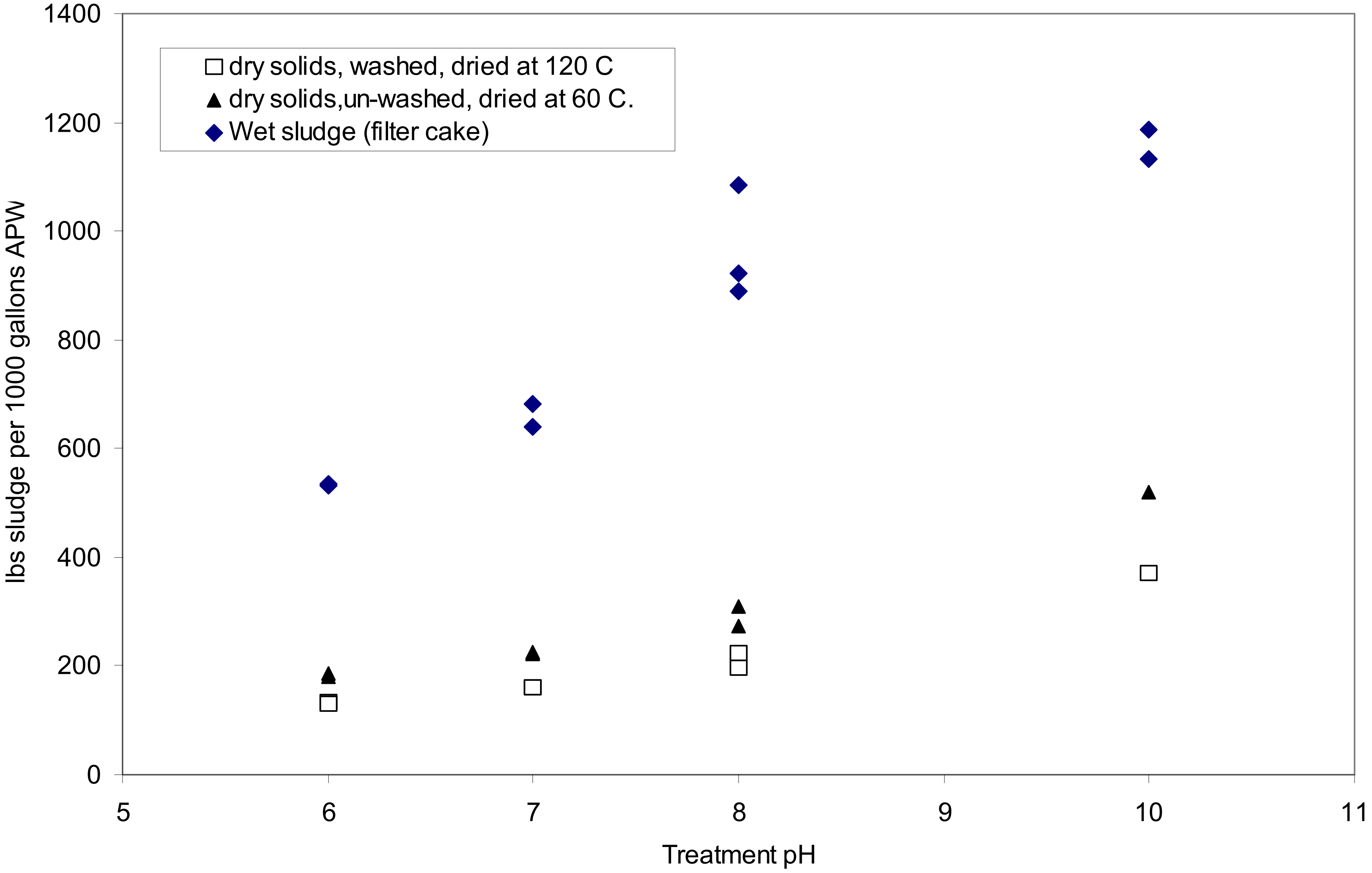
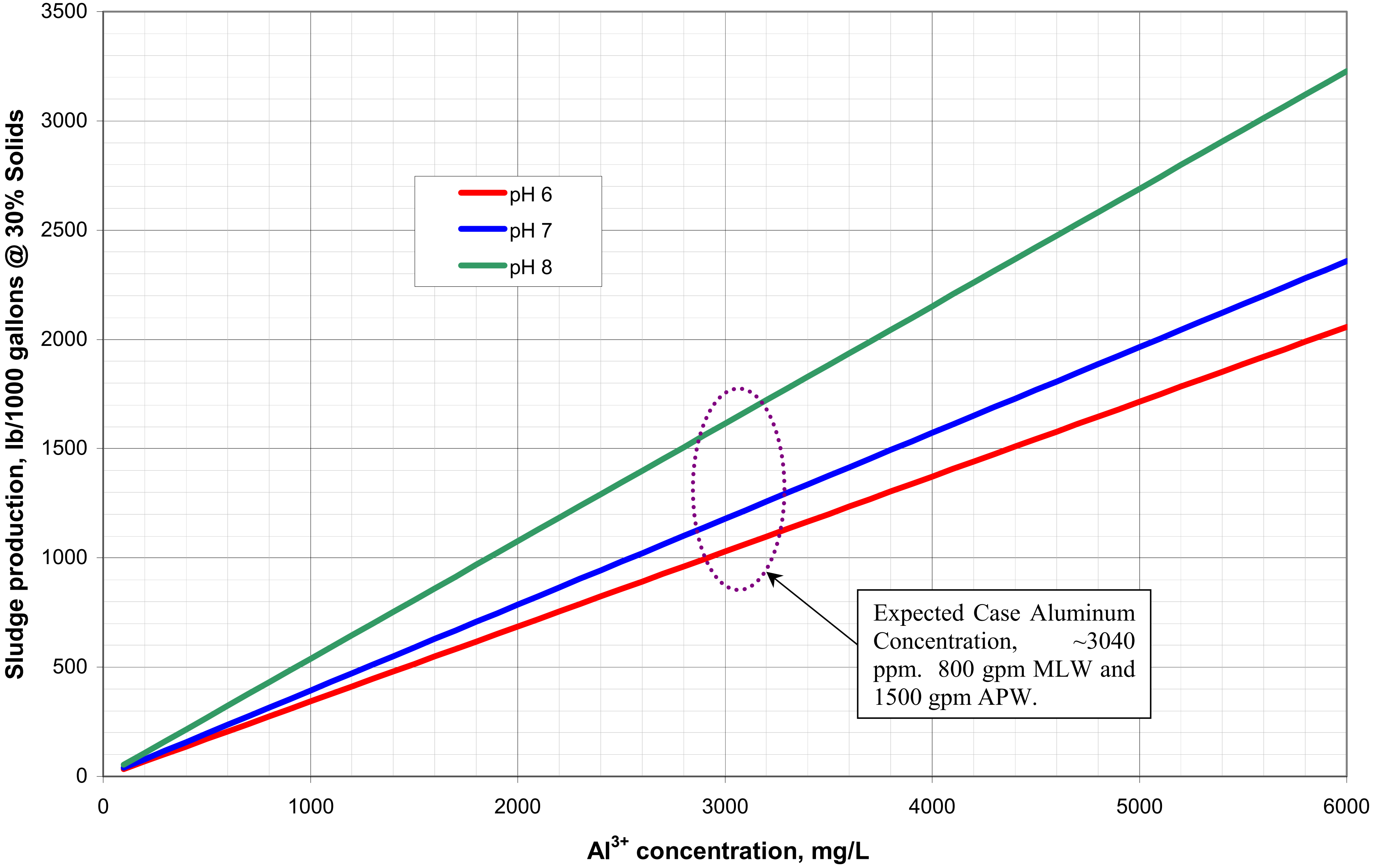


Figure 3b Filter Cake Production for KUC APW and MLW Mixed Wastewater



Expected Case Aluminum Concentration, ~3040 ppm. 800 gpm MLW and 1500 gpm APW.

Figure 3c Filter Cake % Solids vs Specific Gravity. MLW Treated with MOL.

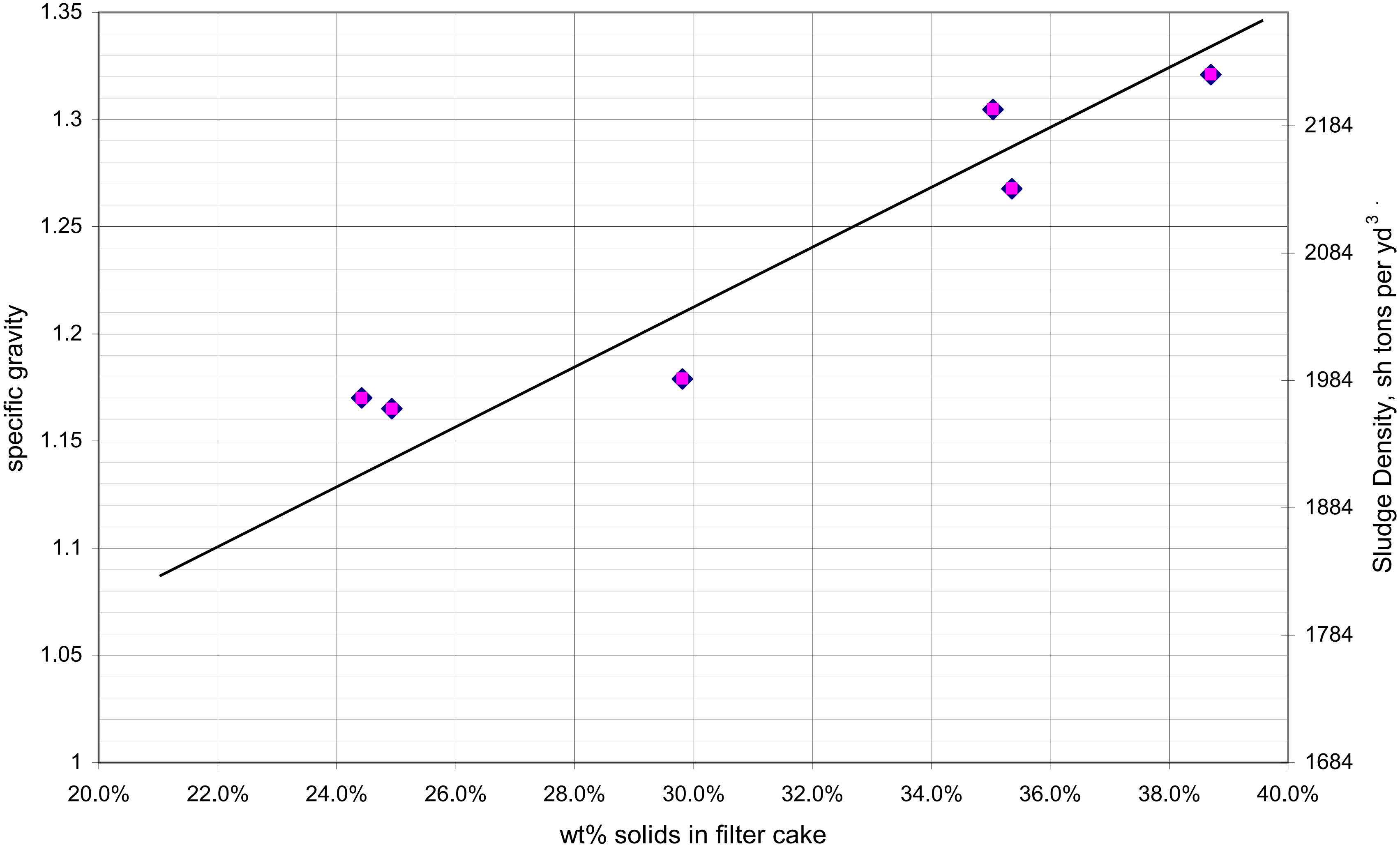


Figure 4 Single Pass APW Lime Demand vs Target pH

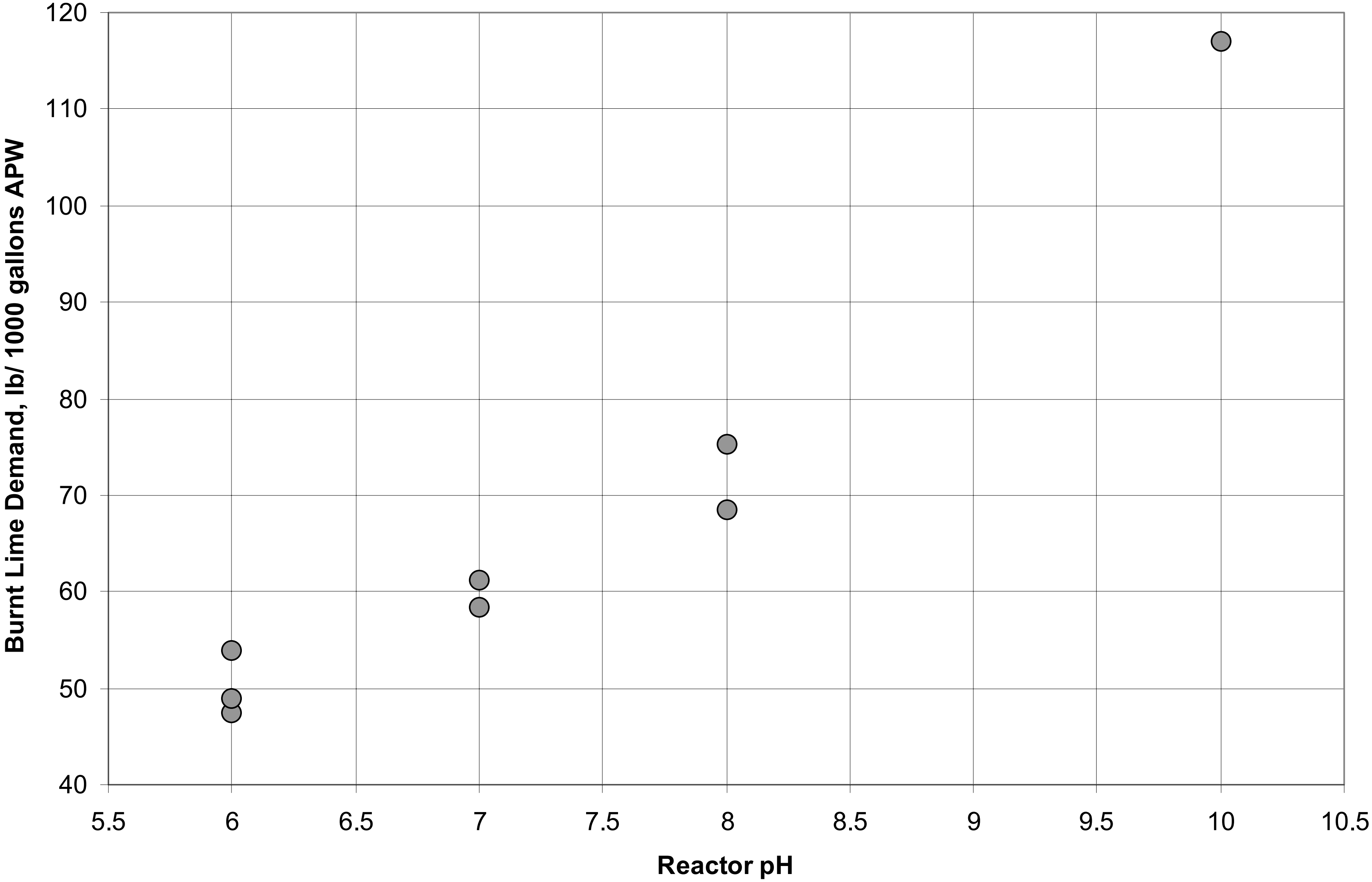


Figure 5 Linearity of Lime Demand Using Aluminum and Sulfate as Indicators

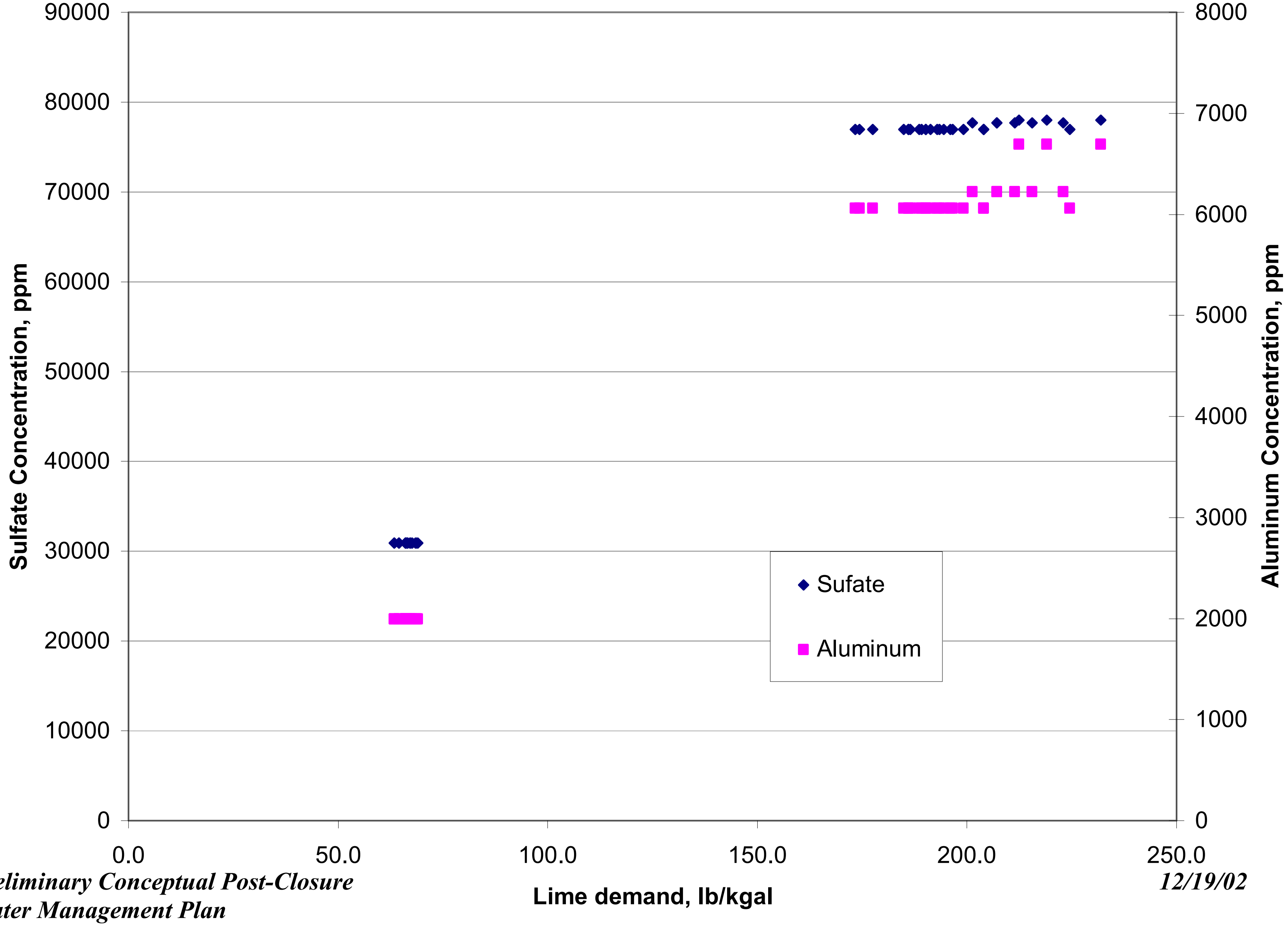


Figure 6 Lime demand, lb CaO/lb Al, for APW and MLW, vs Treatment pH

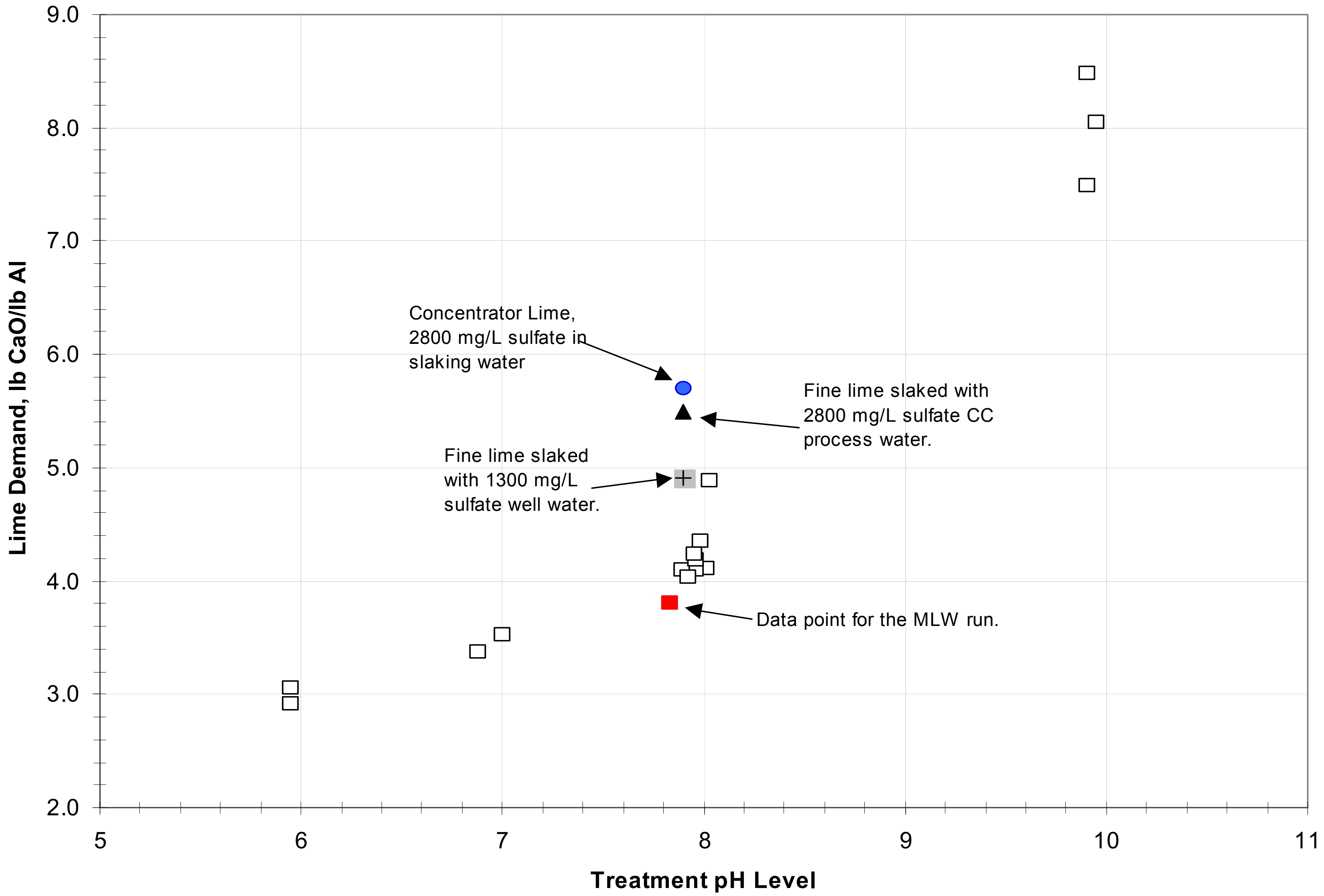
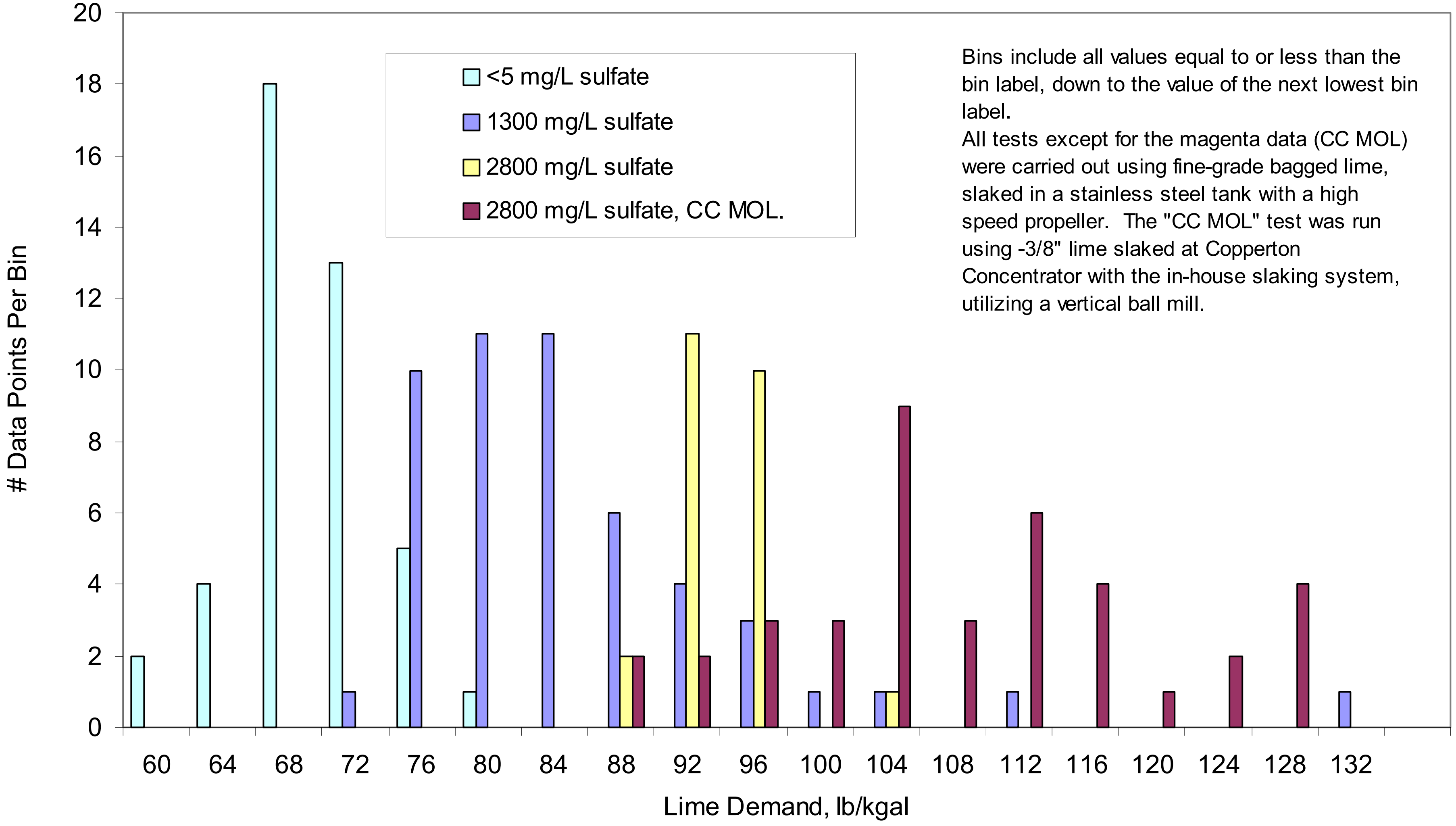


Figure 7 Distribution of Lime Demand Values for APW for Different Slaking Water Types



Bins include all values equal to or less than the bin label, down to the value of the next lowest bin label.

All tests except for the magenta data (CC MOL) were carried out using fine-grade bagged lime, slaked in a stainless steel tank with a high speed propeller. The "CC MOL" test was run using -3/8" lime slaked at Copperton Concentrator with the in-house slaking system, utilizing a vertical ball mill.

Figure 8 pH 6 Settling Tests – APW Treated With 1 LB/GAL MOL, Single Pass, Single-Stage Reactor. RT = 38 Minutes

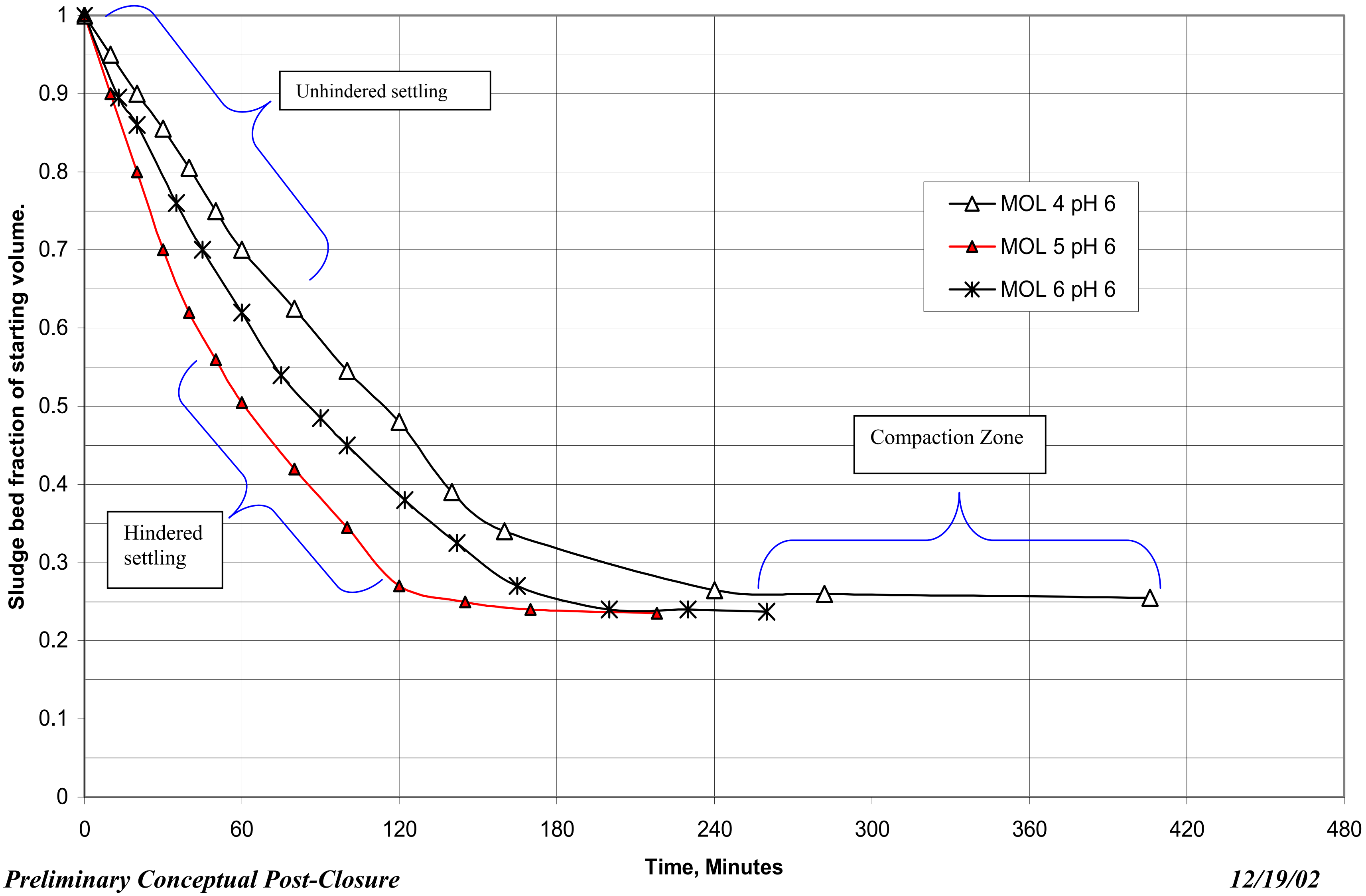


Figure 9 Location Map of Alternative Sites For Post-Closure Sludge Disposal