Final Pilot Testing Report

Plant Site Wastewater Treatment Plant Pilot Testing Program

Prepared for
Poly Met Mining Inc.

January 2013

BARR

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Table of Contents

List of Tables

List of Figures

List of Appendices

Executive Summary

Treatment technology evaluations conducted by Poly Met Mining, Inc. (PolyMet) and Barr Engineering (Barr) identified reverse osmosis (RO) as an established, commercially available treatment technology for removing sulfate from the Flotation Tailings Basin (FTB) seepage to a concentration of 10 mg/L, if needed to meet discharge requirements for the NorthMet Project (Project). This technology has been selected as the primary unit process for water treatment for the Plant Site Waste Water Treatment Plant (WWTP), along with ancillary unit processes for RO pretreatment (greensand filtration) and concentrate management (a specialty, secondary RO membrane process called vibratory shear enhanced processing, VSEP). The reject concentrate generated from the VSEP unit, which includes concentrate and membrane cleaning wastes, will be conveyed to the Mine Site Wastewater Treatment Facility (WWTF) for treatment in the chemical precipitation system.

PolyMet has completed a pilot and bench testing program for the WWTP that evaluated:

- greensand filtration – for iron, manganese, and total suspended solids removal
- reverse osmosis – for sulfate and dissolved solids removal
- VSEP – for RO concentrate volume reduction
- chemical addition – for permeate stabilization
- chemical precipitation of the reject concentrate – for removal of metals and sulfate

Pilot testing commenced in May 2012 and was completed in December 2012. The primary objectives of the WWTP pilot testing program were to collect sufficient information to:

- Confirm that the selected technologies can reliably meet the project water quality objectives
- Support the design of the WWTP
- Refine the capital and operating costs for the proposed system
- Support performance guarantees and system warranties

The pilot testing program yielded several very important results, including the following for the RO system:

- throughout the testing program, the RO system has consistently produced permeate with sulfate concentrations less than 10 mg/L

- the pretreatment selected for the RO system—greensand filtration and antiscalant addition—were effective in maintaining stable RO performance
- the RO system did not experienced significant fouling or scaling during the testing program
- the RO is being operated at a recovery of 80%, which is within the range initially targeted for the WWTP

A critical component of the WWTP will be the ability to manage the RO concentrate using the VSEP technology. The VSEP pilot test yielded the following results:

- The VSEP sulfate removal efficiency averaged 99.3%. Under the pilot test conditions, when the VSEP and RO permeates are blended, the sulfate concentration is less than 10 mg/L.
- The VSEP system has demonstrated recoveries ranging from 80 to 90%, within the Project's objectives.
- No irreversible fouling was observed during the course of testing. Once cleaning optimization was complete, the membrane flux was restored to its original flux after each cleaning.
- No decline in sulfate removal has been observed over time.

The discharge from the future WWTP will be a blend of RO and VSEP permeates. Testing was conducted on methods to adjust the pH and reduce the corrosiveness of the blended permeates. The permeate stabilization bench testing results produced the following conclusions:

- lime addition
    - lime addition was able to adjust the pH and meet most water quality targets, including measures of corrosiveness
    - two important factors were identified in the test that would need to be considered on a full-scale design:
        - Quality of lime used (to reduce turbidity from inert materials and minimize unwanted aluminum in the discharge)
        - Method of lime addition and reaction to minimize residual turbidity
- limestone contactor
    - the limestone contactor was able to adjust the pH and meet all water quality targets, including measures of corrosiveness.

- additional treatment after limestone contactor was needed to remove remaining carbon dioxide (e.g., air sparging).

Of the main tasks initially planned for the pilot testing program, only one is currently on-going: an autopsy of the RO membranes used in the test. The membrane autopsy will be used to identify potential problematic foulants remaining on the membrane, and to determine if adjustments to pretreatment or cleaning strategies are necessary for the full-scale system.

Supplemental testing was conducted at the end of the pilot test to (1) better quantify the removal of certain metals across the pilot treatment train and (2) to simulate the treatment processes that will be employed at the WWTF using the VSEP concentrate.

The metals removal test yield the following results for the RO and VSEP systems:

- Arsenic is expected to be removed primarily across the greensand filter, rather than the RO unit. Removal of arsenic by the greensand filter of up to 99.68% was observed on the pilot-scale.
- Cobalt, copper, lead, nickel, selenium, and zinc were observed to be well-removed by both the RO and VSEP systems, producing a blended permeate with concentrations below the Class 2B water quality standard.

Chemical precipitation bench testing was performed using VSEP concentrate to test performance of the treatment processes contemplated for the Mine Site WWTF. This is worst-case conditions due to the presence of anti-scalants and high ionic strength. The results of this testing indicated that oxidative pre-treatment of the VSEP concentrate is not likely required, and that performance and behavior of the contemplated treatment processes are similar to what is expected based on preliminary process calculations. The bench testing identified aluminum content of the lime reagent as a design consideration. The bench testing results will be incorporated into future design calculations as appropriate.

The initial design for the WWTP will be based partly on the results of the pilot testing. Because the WWTP is considered an adaptive engineering control, provisions for expansion of the plant and changes to the operating configuration of process units will be incorporated into the full-scale design to match the results of ongoing water quality monitoring and modeling efforts.

1.0 Introduction

Preliminary water quality modeling of the NorthMet FTB operation suggested that seepage from the facility could potentially impact surface water quality down-stream of the Project. To resolve this issue, an FTB containment system has been incorporated into the Project. While some or all of the water collected by the containment system can be returned to the beneficiation process, at times a portion of the water will need to be treated and discharged.

Water quality discharge limits will be determined in permitting and may include a limit as low as 10 mg/L for sulfate. Required treatment will be provided by the new Plant Site Waste Water Treatment Plant (WWTP).

Treatment technology evaluations conducted by PolyMet and Barr identified reverse osmosis (RO) as an established, commercially available treatment technology for removing sulfate to a concentration of 10 mg/L. This technology has been selected as the primary unit process for water treatment at the WWTP, along with ancillary unit processes for RO pretreatment (greensand filtration) and concentrate management (vibratory shear enhanced processing, VSEP). The preliminary process schematic for the WWTP is shown on Figure 1, along with its relationship to the Mine Site Waste Water Treatment Facility (WWTF).

In December 2011, PolyMet initiated a pilot and bench testing program for the WWTP to test each primary unit process for the proposed plant:

- Greensand filtration – iron, manganese, and total suspended solids removal
- Reverse osmosis – sulfate and dissolved solids removal
- VSEP – RO concentrate volume reduction
- Chemical addition – permeate stabilization

Additional testing of chemical precipitation of the reject concentrate for removal of metals and sulfate was also completed in support of the design of the WWTF.

The treatment train, as implemented on the pilot scale, is illustrated on Figure 2. Figure 2 also provides the locations for sample collection during the pilot testing program and the associated nomenclature used for the pilot program. The testing protocol developed for the program describes the objectives, schedules, and methods to be followed for the testing (Reference (1) and Reference (2)).

Pilot testing commenced in May 2012 and was completed in December 2012. The purpose of this report is to provide the results obtained during the testing program and to provide an evaluation of technologies and their performance with respect to the Project goals and future estimated water quality.

2.0 Testing Program Structure

2.1 Pilot Test Program Overview

The primary objectives of the WWTP pilot testing program were to collect sufficient information to:

- Confirm that the selected technologies can reliably meet the Project water quality objectives;
- Support the design of the WWTP;
- Refine the capital and operating costs for the proposed system; and
- Support performance guarantees and system warranties.

In order to meet the pilot testing objectives, the pilot testing program was conducted in phases, to provide periods of time for investigation and optimization and time for collection of data to assess the longer term performance of the processes under investigation. Each of the testing phases and its objectives are described in the following sections. The schedule followed for the testing program is illustrated on Figure 3.

2.1.1 Phase 1 – Well Testing

In December 2011 a new well was installed at the northwest corner of the existing LTVSMC tailings basin to provide source water for the pilot test. Initial testing was conducted on this well to determine its capacity to support pilot testing operations. Monitoring of the water levels in the pilot test well and nearby monitoring wells was conducted during the pilot testing program and ongoing water level data collection continues. The monitoring data was used to assess the aquifer characteristics and what, if any, effects the pilot test well operation has on nearby wetlands. A summary of the pumping tests conducted to assess the well capacity and the longer-term monitoring data can be found in Appendix A.

2.1.2 Phase 2 – Startup and Commissioning

Phase 2 consisted of the startup and commissioning of the reverse osmosis and greensand filter pilot units. This period provided an opportunity for pilot unit installation and assembly, tuning of control systems, implementation of the data collection procedures, and initiation of operation and the initiation of the process of determining operating conditions. Operator training by the vendor was provided during this phase.

2.1.3 Phase 3 – Membrane Selection, Pretreatment Investigations, and System Optimization

The purpose of Phase 3 was to identify pretreatment requirements and RO operating conditions that optimize the treatment train (balancing capital costs, operating costs, and reliability). During this phase, greensand filter operation as well as the recovery and flux of the RO system were adjusted and monitored to determine an operating approach for use in Phase 4.

2.1.4 Phase 4 – Steady-State Operation

During Phase 4, the treatment train and operating conditions based on the Phase 3 investigations were used. The treatment system was operated, largely unaltered, for the duration of Phase 4 under steady-state conditions. The purposes of this test were to gain longer-term operating data on the proposed system to evaluate system reliability, system performance with respect to water quality targets, life cycle cost, ability to effectively clean the membranes, and to generate permeate and concentrate for use in Phase 5 and 6 testing.

2.1.5 Phase 5 – Concentrate Volume Reduction Investigation

Once steady-state operation of the RO pilot was established, a study of further reduction of the concentrate volume was initiated via routing the RO concentrate through the VSEP system, by New Logic Research. The objective of this investigation was to evaluate the recovery, fluxes, and operational requirements for the VSEP equipment, and to characterize the resulting concentrate and permeate quality.

2.1.6 Phase 6 – Effluent Stabilization Investigation

The future WWTP effluent will be a blend of RO and VSEP permeates. The effluent blend will be void of alkalinity and hardness, making the water corrosive to piping and materials near the outfall. The objectives of the effluent stabilization investigation were to identify a stabilization method (e.g., addition of minerals) that will reduce the corrosiveness of the blended effluent, while maintaining compliance with the effluent water quality targets (Section 3.2).

2.1.7 Phase 7 – Membrane Fouling

After completion of pilot testing, select membranes will be removed from each membrane stage for a membrane autopsy. These membranes will be disassembled and samples of the flat sheet membrane will be removed for analysis. The membranes will be analyzed to identify potential problematic foulants remaining on the membrane. Depending on the results of the autopsy, adjustments to the pretreatment systems or cleaning systems may be made for the full-scale system. The membrane autopsy is on-going and will be completed in the first quarter of 2013.

2.1.8 Supplemental Testing

Towards the end of the pilot testing program, additional, related testing was conducted to support the Project. This supplemental testing included

- pilot-scale tests to better quantify the removal of select metals across the greensand filter, RO, and VSEP pilot units
- bench testing of the chemical precipitation processes to be used at the Mine Site

The results of the supplemental tests are also presented in this report.

2.1.9 Testing Facilities

The location of the pilot test well, SD004 (a seep from the existing LTVSMC tailings basin), and water holding tanks are shown on Figure 4. The well that is supplying water for the pilot test is a 4-inch-diameter, 71-foot-deep well. Water from this well and from SD004 was pumped into holding tanks at the tailings basin. From these tanks, water was pumped into tanker trucks, which transported the water to the Wayne Transports, Inc. facility in Virginia, MN. The pilot test facility at Wayne Transports is equipped with city water, hot water, power, internet connectivity, and sanitary sewer service. Drawings of the pilot test facility layout are provided in Appendix B.

2.1.10 Roles

2.1.10.1 PolyMet

PolyMet was the lead organization in the pilot testing effort. PolyMet activities included:

- contract development for the pilot testing equipment, laboratories, and consultants
- management of the pilot testing, equipment suppliers, laboratories, and consultants
- operation of the pilot units, including regular monitoring, assistance with process troubleshooting, and conducting clean-in-place (CIP) procedures for the pilots when required
- management and disposal of wastes generated during the pilot testing program

2.1.10.2 Barr Engineering

Barr staff provided the following services:

- development of pilot unit plans, specifications, and testing protocols
- dissemination of water quality data to PolyMet and to the equipment suppliers on a regular basis, as results became available from the laboratories

- coordination of and participation in meetings and conference calls with PolyMet and the equipment suppliers
- execution of bench testing for the effluent stabilization investigations
- technical support for process troubleshooting, data evaluations and interpretation, and performance evaluation
- assistance with the development of the refined construction and O&M costs, based on pilot testing results

2.1.10.3 Equipment Suppliers

The equipment suppliers for this pilot included:

- GE Water & Process Technologies (GE) – Greensand filter and RO pilot systems
- New Logic Research (NLR) – VSEP pilot unit

Equipment supplier activities included:

- provision of pilot test equipment in accordance with their contracts
- provision of on-site supervision of installation and startup
- completion of membrane selection and pretreatment investigations
- provision of training such that PolyMet staff has sufficient knowledge to support the pilot testing program
- participation in conference calls and meetings
- provision of a final report summarizing the pilot testing results
- provision of equipment capital costs and updated annual O&M costs for supplied equipment to support the development of a refined project cost estimate

2.1.10.4 Laboratories

Analysis of samples collected during the pilot testing program was provided by the following laboratories:

- Legend Technical Services, Inc. (Legend) provided all analytical services for routine sampling of the RO and VSEP systems.
- Pace provided as-needed analytical services for manganese testing where a very fast turn-around time was required.

- Environmental Toxicity Control (ETC) provided WET testing services for the effluent stabilization test.

3.0 Water Quality

3.1 Influent Water Quality

In December 2011 a new pumping well was installed and screened in the aquifer that extends beneath the existing tailings basin. This well was used as the feed water source for the pilot test. To avoid over-pumping the well, additional water from an existing seep from the tailings basin (at outfall SD004) was blended with the well water to produce feed water for the pilot unit. The water quality from these two sources is presented in Table 1 and Table 2. The approximate locations of the pilot test well and SD004 are shown on Figure 4.

Figure 5 shows the concentrations of total dissolved solids, total hardness, and sulfate for SD004 and the pilot test well since the initiation of pilot testing. Over the duration of the pilot test, the influent water quality from SD004 was relatively constant. The well water quality was of similar composition as SD004; however, it was more variable in concentration throughout the testing program. Figure 6 illustrates the influent iron and manganese concentrations for both water sources, and confirms the presence of relatively high concentrations of these constituents in the existing tailings basin drainage.

3.2 Treated Water Quality Targets

The final discharge from the WWTP must meet the applicable water quality discharge limits. The target treated water quality targets are shown in Table 3. The targets in Table 3 are the water quality targets for the blended RO and VSEP permeates, and represent the possible discharge limits as known during the development of the pilot testing program in late 2011.

4.0 Reverse Osmosis Pilot Test Results

4.1 Pretreatment

The greensand filter pilot unit provided by GE for the pilot test was a pressure filter (Figure 7). This filter is a 30-inch diameter unit filled with coarse gravel (5 inches), greensand filter media (30 inches), and anthracite (12 inches). The greensand media is silica sand coated with manganese oxide. Technical information on the greensand used during the pilot test and information on the GE pilot unit systems can be found in Appendix C.

For the pilot test, the influent was dosed continuously with potassium permanganate in order to (1) oxidize iron and manganese for removal by filtration and (2) regenerate the greensand media.

4.1.1 Filter Loading

Over the duration of the testing program, the influent flow rate ranged from 19 to 22 gpm. The resultant range of hydraulic loading to the filter was 3.5 to 4.9 gpm per square foot (gpm/ft^2) of filter bed area.

4.1.2 Filter Removal Rates

The greensand filter removal rates for total suspended solids, iron, and manganese are presented in Table 4. Overall (including startup and optimization phases of testing), the removal of total suspended solids across the filter averaged >87% (to less than the method reporting limit in the filtrate). During Phase 4, the removal of total suspended solids (TSS) was >90% on average. Iron removal by the filter consistently averaged >99.7%. Table 5 displays the greensand filtrate water quality.

During Phases 3 and early in Phase 4, it was noted that, at times, manganese was breaking through the filter (Table 5). Because of this, during Phase 4 at the end of August 2012, a trial to improve manganese removal was initiated. For this optimization, the permanganate dose was increased every other day, with daily monitoring of filter influent and effluent manganese. In order to protect the membranes from potential damage from excess permanganate (a strong oxidant), sodium bisulfite was dosed immediately ahead of the RO unit. Figure 8 provides an overview of the manganese removal results obtained during this optimization. A final potassium permanganate dose of about 4.5 mg/L was selected as the optimal dose for manganese removal based on the filtrate dissolved manganese concentration. As can be seen in Figure 8, manganese removal was significantly improved from an average of 81% prior to optimization to an average of 97% after optimization. The results suggest that the breakthrough of manganese observed during Phase 3 and 4 was likely due to the incomplete oxidation of dissolved manganese and/or insufficient regeneration of the greensand media at the permanganate doses initially applied during testing.

4.1.3 Residuals

Periodically, accumulated solids must be removed from the filter bed to maintain hydraulic capacity and performance. A filter backwash can be triggered based on filter run time, or more commonly, an increase in pressure drop across the filter. For the pilot unit, pressure drop was used to trigger backwash events. When the pressure drop across the unit reached approximately 10 psi, feed water was pumped up through the filter bed at a rate of 60 to 70 gpm (12 gpm/ft^2) to remove solids from the bed. During Phase 4 operations, the filter backwash frequency was approximately once every two days. Samples of the spent backwash water were collected and analyzed. Greensand filter backwash water quality results are summarized in Table 6. In addition to containing elevated concentrations of TSS, iron, and manganese—the targeted constituents—the spent backwash water also contained elevated concentrations of organic material (as chemical oxygen demand), silica, and a number of other metals such as aluminum, arsenic, barium, cobalt, copper, thallium, and vanadium. The removal of arsenic by the greensand filter was further quantified during supplemental testing (Section 7.0). The adsorption of certain metals to iron oxyhydroxide solids, which accumulated in the greensand filter media during the iron removal process, was further evaluated in chemical precipitation bench testing (Section 8.0).

4.1.4 Discussion

The primary purpose of the greensand filter was to protect the RO membranes by removing particulate matter, iron, and manganese. The filter removed TSS and iron to concentrations below the method reporting limits. Manganese was also significantly reduced, especially after optimization of the potassium permanganate dose during Phase 4. The RO membranes, as is discussed in more detail in Section 4.2, did not exhibit signs of fouling during the 7 month pilot test. The greensand filter was a simple-to-operate, effective means of pretreatment for the feed water from SD004 and the pilot test well.

In full-scale application, one of the primary design criteria for greensand filters is the hydraulic loading rate. The loading rate for greensand filters has the potential to affect the manganese removal efficiency, the backwash frequency, and the number of filters required for filtration. For this pilot test, the hydraulic loading rate was fixed by the pilot unit supplied by GE, and was higher than typical hydraulic loadings for this type of filter (approximately 4.5 compared to 3 gpm/ft^2), particularly given the concentrations of iron and manganese in the influent. However, higher-than-typical loading rates can be acceptable if demonstration testing shows acceptable treatment performance and backwash frequency, which was case during this pilot testing program. As previously mentioned, an autopsy of the RO membranes is on-going. Information from the autopsy will be used determine if iron, manganese, or other scalants or foulants accumulated at a rate that would be potentially detrimental to the membranes, given the duration of the pilot test program.

4.2 Reverse Osmosis

The RO pilot unit was provided by GE. A picture of the pilot test unit employed for the project is shown on Figure 9. Manufacturer's information on the pilot unit can be found in Appendix C. The RO pilot unit provided by GE used 18 4-inch-diameter RO modules housed in six vessels, in a 2-2-1-1 array. The membranes employed were low-pressure RO membranes (GE model AK90-LE).

The greensand filter effluent was treated with 1 ppm sodium bisulfite (to quench any excess permanganate from the filter and prevent membrane oxidation) and 2.2 ppm of Hypersperse MDC150, a scale inhibitor.

The pilot unit was operated continuously for approximately 8 hours per day, typically 5 days per week. At the end of each 8-hour shift, the RO system was flushed with permeate and shut down.

4.2.1 Flux and Recovery

During Phase 3 of the pilot test, a number of operating conditions were tested to optimize the RO system operation. The primary operating variables adjusted were recovery (the percentage of feed water volume that becomes permeate) and flux (the flow rate through the system per unit of membrane in service). In general, the higher the membrane flux, the lower the membrane area required for a given treatment capacity. However, operation at higher flux rates has the potential to increases the fouling rate of the membranes.

Phase 3 lasted approximately 8 weeks and the conditions tested were as follows:

- Condition 1 – 75% recovery, flux of 14 gfd – 3 weeks
- Condition 2 – 80% recovery, flux of 16 gfd – 3 weeks
- Condition 3 – 80% recovery, flux of 18 gfd – 2 weeks

The RO pilot unit performed well at all conditions tested. Condition 3 was considered a "stress condition" because the flux was at the upper end of what is generally used in the design of RO groundwater treatment systems (Reference (3)). Nevertheless, for the short duration test of this operating condition, no operational problems were encountered. The feed-to-concentrate pressure drop across the RO system was stable at all three conditions and was well below the threshold to initiate membrane cleaning (> 50 psi per stage). Changes in recovery and flux can also impact the salt rejection of the membranes. Over the conditions tested in Phase 3, no unacceptable or significant changes in permeate water quality were observed. For Phase 4, a flux of 16 gfd and recovery of 80% were selected. This combination of operating conditions was determined to provide an acceptable performance and reliability. The small increase in pressure drop at the 18-gfd flux condition further demonstrated the selected flux (16 gfd) is not an operational maximum.

During Phase 4, the RO membrane system operated continuously at a recovery of 80% and a flux of 16 gfd. The feed-to-concentrate pressure drop throughout Phase 4 was approximately 25 to 30 psi with little upward movement. The feed-to-concentrate pressure drop and the feed pressures experienced over the course of pilot testing are shown on Figure 10 and Figure 11. The absence of any substantial change in feed pressure or feed-to-concentrate pressure drop suggests that very little scaling or fouling of the membranes occurred during the pilot testing program. A membrane autopsy is currently underway to confirm this observation.

4.2.2 Permeate Water Quality

The RO feed (greensand filter effluent), permeate, and concentrate water quality data collected during Phases 3 and 4 are summarized in Table 5, Table 7, and Table 8, respectively.

4.2.2.1 Removal Rates

Average removal rates were estimated for those parameters with detectable concentrations in the greensand filter effluent (RO feed) and are displayed in Table 9. The average sulfate removal was 99.8% during the pilot test (see Figure 12 of sulfate removal). The average sulfate concentration in the RO permeate was 0.57 mg/L, and the highest sulfate concentration observed was 0.98 mg/L, well below the 10 mg/L water quality target. During Phase 4, the average salt passage through the membranes was <0.6% with no reported total dissolved solids (TDS, reporting limit of 10 mg/l) in the permeate as reported in the analytical results (see Figure 13).

Many other parameters, particularly the major anions and cations, were reduced by greater than 95%. However, in many instances the upper limit of removals were not determined in the routine testing because (1) the concentrations measured in the permeate were less than the method reporting limit and/or (2) the concentrations in the influent were low and close to the method reporting limit. For several metals, both of these conditions applied. Thus, supplemental testing was conducted to better quantify the removals by the greensand filter and RO systems (see Section 7.0 for methods and results).

For some constituents, removal by RO membranes is highly pH-dependent. Examples of this are ammonia, borate, and arsenite. For these compounds, over a range of pH values, they are present as unionized species. The unionized species are not well-removed by membranes. For this pilot test, the following observations were noted:

- Ammonia: At pH values below 7, most of the ammonia is present as the ammonium ion and can be removed by the RO process. However, the pH of the feed water to the pilot RO system is approximately 7.5, reducing the amount of ammonia that can be removed. In addition, the concentration of ammonia in the influent was relatively low. The low concentration in the influent limited the estimate of quantifiable removal by the RO system.
- Boron: It is well known that boron removal at pH values below the pKa (pH = 9.2) of boric acid is limited due to the lack of charge on the species. The boron removal during the pilot-testing program, while limited, was sufficient to maintain permeate concentrations below 0.5 mg/L, the Class 4A water quality standard. Specialty membranes or pH adjustment are typically required for greater boron removal.

Arsenic removal is further discussed in Section 6.0.

4.2.2.2 Comparison to Equipment Supplier Model

The suppliers of RO membranes commonly use models in their system design and to estimate the permeate water quality. Each supplier typically has developed their own models for their membranes, and each supplier has significant operating data collected over the years for validation of the model output. The model water quality input and output is generally limited to the major anions and cations, pH, boron, and certain constituents of concern with respect to membrane fouling or scaling (e.g., aluminum, barium, silica, strontium). Because equipment supplier models will likely be used during the full-scale system design, a comparison of their output and measured water quality data was made. Table 10 compares the model results with measured permeate water quality for 3 days throughout Phase 4, and Figure 14 graphically displays the comparison for sulfate. For each of these days, the system was operated at 80% recovery and 16 gfd. The water temperatures ranged from 12 to 16°C and the membrane age used in the model was 1 year. As can be seen from the figure and table, the equipment supplier model reasonably predicts the order of magnitude of the measured result. For sulfate, the model results are within 20% of the measured results.

4.2.3 Cleaning Requirements

Inorganic and organic scale and foulants build up on RO membranes over time and reduce performance. Membranes are chemically cleaned-in-place (CIP) to remove the foulants and restore performance. CIPs are triggered either when the system pressure drop reaches a predetermined value or increases by a certain percentage, if salt passage increases beyond a certain percentage, or on a regular time interval, if other parameters have not triggered a CIP. GE generally recommends that membranes be cleaned every 3-4 months (of continuous operation) if a CIP has not been initiated for other reasons.

Significant increases in pressure drop from the RO feed to the concentrate were not seen in any phase of the pilot testing. A CIP was conducted on July 30, 2012 to test the cleaning procedures recommended by GE. A low pH cleaner (citric acid) and a proprietary high pH cleaner from GE were used to clean the membranes during the CIP. The cleaning solutions were recirculated through the membranes in a two-step cleaning process and samples of the spent cleaning wastes were collected for analysis (Table 11).

The analytical results from the chemical cleaning wastes can provide insight into the fouling or scaling constituents on the membranes and which cleaner removes them. The following were elevated following treatment of each cleaner:

- low pH cleaner – chemical oxygen demand (COD, from the cleaner), TDS, aluminum, barium, calcium, iron, magnesium, manganese, sodium, vanadium, and zinc
- high pH cleaner – Sodium and COD (both from cleaner) and magnesium

In the low pH cleaning solution waste, iron and manganese were the metals present in the highest concentrations. This finding was one of the reasons for conducting the greensand filter optimization study described in Section 4.1.2.

4.2.4 Discussion

The selection of RO for treatment of water at the tailings basin was driven primarily by its potential to produce treated water containing less than 10 mg/L of sulfate. Throughout Phases 3 and 4, the RO membranes produced a permeate water quality that consistently met that that and other treated water quality targets (Table 3). As discussed in Section 4.2.2.1, the average sulfate concentration observed in the RO permeate was 0.57 mg/L (0.98 mg/L being the highest concentration observed), which is an average sulfate removal efficiency of 99.8% across the membranes. It is expected that sulfate removal may change over time as the membranes age, but it is also expected that, even with some degradation of performance, water quality targets are likely to be met.

Throughout the duration of the pilot testing program, no significant operational or maintenance problems were encountered. Based on influent water chemistry and RO treatment modeling conducted by GE, the recovery selected for the RO pilot unit was primarily a function of the solubility limits of calcium carbonate and silica, which become saturated or supersaturated at the membrane surface during treatment. During the pilot test, a scale inhibitor (a phosphonic acid salt solution) was used to manage the formation of scale and silica on the membranes. The membrane system did not experience a significant increase in pressure drop from the RO feed to the concentrate. This stability indicates that scaling and fouling were not significant during the pilot test and that the pretreatment systems in place were effective. This will be confirmed during the on-going membrane autopsy. Selection of the antiscalant for the full-scale plant will be made in consultation with the membrane supplier, based on the future water chemistry and operational performance of the system.

The feed pressures observed during the pilot were stable and were lower than many brackish water RO applications, averaging 123 psi. The low feed pressures translate to lower operational (energy) costs for pumping into the system.

5.0 VSEP Pilot Test Results

The VSEP pilot unit was provided by New Logic Research. A picture of the pilot test unit that was used in the pilot testing program is shown on Figure 15. Manufacturer's information on the pilot unit can be found in Appendix D. The unit can be operated in batch mode or single-pass (continuous) mode, and both operating modes were tested during the Phase 5 pilot testing activities. For the pilot test, RO membranes (ESPA series by Hydranautics) were used.

As discussed in Section 2.0, one of the main objectives for the VSEP system was to reduce the volume of the RO concentrate. By minimizing the concentrate volume, the sulfate concentration is increased, ideally to such a degree that sulfate mass can be removed by chemical precipitation at the WWTF (as depicted in Figure 1).

5.1 Pretreatment and Optimization

During the initial phase of testing for the VSEP unit, a number of methods for optimizing performance of the system were investigated:

- operational mode selection—batch versus single-pass operation—to maximize system recovery
- antiscalant dose selection to maximize system recovery
- acidification of the VSEP feed water to maximize system recovery
- cleaning chemical selection and cleaning procedure refinements to maximize the restoration of membrane flux

The preliminary investigations related to each of these are described in the sections that follow.

5.1.1 Operational Mode

The initial startup and optimization of the VSEP unit was led by the New Logic Research field engineer with assistance provided by PolyMet staff. New Logic Research operated the unit in both batch and single-pass mode and determined that greater flux stability could be achieved by operating the unit in batch mode. In batch mode, the VSEP system uses a constant cross flow along with vibration to reduce fouling and polarization at the membrane surface. For the batch process, a fixed volume of concentrate from the GE RO system is fed to the VSEP system. The concentrate from the VSEP unit is returned to the VSEP feed tank and the VSEP permeate is discharged (as illustrated on Figure 2). As a result, the concentration of total dissolved solids in the feed tank increases over the duration of batch processing. This process continues until the target recovery has been achieved or until the flow through the membrane falls below a predetermined threshold. The flow through the system decreases as the osmotic pressure increases and scalants and foulants accumulate on the membrane. When the terminal flow is reached, the membranes must be cleaned. It is possible to process more than one batch of concentrate before a cleaning is required.

5.1.2 Chemical Pretreatment

During New Logic Research's initial startup and optimization of the VSEP pilot unit, RO concentrate was initially processed without the use of any chemical additives. Without chemical addition, the recovery achieved by the VSEP pilot unit was only 10%. A single antiscalant (NRL 759) was added to the batch feed tank and the performance of the unit was re-evaluated. When NRL 759 was dosed at 10 ppm, the VSEP recovery improved to 65%. Higher doses of the antiscalant did not result in noticeable improvement.

Additional improvement in recovery was achieved by lowering the pH of the VSEP feed to approximately 6 to 6.5. At this pH range, the scaling potential of calcium carbonate is reduced. Using acid addition, the recovery across the VSEP unit was improved to 80 to 90%. Figure 16 illustrates the results of the initial pretreatment investigations. The membrane flux was sustained over the batch most effectively using a combination of antiscalant and pH adjustment.

After the initial optimization was completed, a second phase of optimization was conducted in which the following aspects of VSEP operation were investigated:

- Use of hydrochloric or sulfuric acid
- Timing of acid addition for pretreatment
    - A single acid addition event at the beginning of a batch
    - Adjustment of pH at the beginning of the batch, and again once a recovery of 50-65% was reached
    - Adjustment of pH during the batch only when the recovery reached 50-65%.
- Degree of pH adjustment necessary (pH 6.0 versus 6.5)

5.1.2.1 Acid Type

Over the duration of the VSEP pilot test, two types of acid were used for pH adjustment (pretreatment): 31.7% hydrochloric (muriatic) acid and 40% sulfuric acid. Hydrochloric acid is an effective means of pH adjustment, but within the wastewater management plans for the Project, chloride has the potential to accumulate within the system until reclamation. Sulfuric acid contributes sulfate to the system; however, this mass can be removed by the gypsum precipitation process at the WWTF. Figure 17 provides examples of two batches in which the VSEP feed water was pretreated with sulfuric and hydrochloric acids. The feed water was adjusted to pH 6 at the beginning of the batch and again midway through processing. As can be seen in the figure, the acids are similarly effective in maintaining the membrane flux throughout the batch. With respect to VSEP permeate water quality, when hydrochloric acid was used, the average sulfate concentration in the VSEP permeate was 12 mg/L and, under similar operating conditions (80-85% recovery and pH 6), when sulfuric acid was used, the average VSEP permeate sulfate concentration was 19 mg/L.

5.1.2.2 pH Adjustment Method

The initial optimization of the VSEP pilot unit demonstrated that pH adjustment of the feed water improved recovery. The method for pH adjustment was further refined in subsequent investigations. Figure 18 shows some of the results of the pH adjustment trials in which acid was added to the feed tank:

- Only once a recovery of 50 to 65% had been reached
- At the beginning of the batch, and again when a recovery of 50 to 65% was reached to maintain a pH of approximately 6 in the feed tank
- At the beginning of the batch only

As Figure 18 illustrates, all three approaches were able to achieve 80% recovery, however, the flux was more stable throughout the batch and higher at the end of the batch for Batches 16 and 20, which used pH adjustment initially. During Batch 20 pH was also adjusted again at a recovery of 60%. Throughout the numerous batches processed, the approach of adjusting pH initially consistently resulted in a more stable flux throughout the batch and a higher terminal flux at the end of the batch. Adjusting the pH again later in the batch did not provide significantly different or better results than a single, initial pH adjustment. Maintaining a higher flux rate over more of the batch, as is achieved by adjusting the pH at the beginning of the batch, results in less membrane area required (i.e., less capital cost) to treat the same volume.

5.1.2.3 Degree of pH Adjustment

The amount of acid used per 1,000-L batch typically ranged from 1,500-2,500 mL (of 40% sulfuric acid). For a full-scale system, the cost of chemicals for the system operation must be balanced with the capital costs of the VSEP membranes (membrane area required based on flux). For this reason, several runs were completed to compare the performance of the system at pH 6 versus pH 6.5. Some of these runs are presented in Figure 19. For these runs, the pH was only adjusted at the beginning of the batch. While the trends in flux over the batch were similar at pH 6 and 6.5, the flux for pH 6.5 was generally lower than that achieved for pH 6. The pretreatment acid dose was approximately 30% lower to achieve a pH of 6.5 compared to that needed to achieve pH 6. In addition to lower chemical consumption, operation at pH 6.5 requires less acid, which results in less sulfate in the feed water and less sulfate in the VSEP permeate. The capital and operational trade-offs resulting from the degree of acid adjustment will need to be considered during detailed engineering.

5.1.3 Recovery

In general, higher recovery results in less final VSEP concentrate volume, which has the advantages of (1) minimizing the volume of VSEP concentrate that must be conveyed or otherwise managed on full-scale and (2) maximizing the sulfate concentration in the VSEP concentrate that will be treated at the WWTF by chemical precipitation under the wastewater management approach outlined in Figure 1. A range of recoveries were tested during the pilot test, based on the results of the pretreatment investigations. Figure 20 shows the results from batches ranging from 80 to 90% recovery. The batches in the figure were pretreated with 10 ppm NLR 759 and sulfuric acid. The pH was adjusted to pH 6 at the beginning of each batch and again at approximately 60% recovery. The system flux was stable at all recoveries tested, however at 90% recovery, a noticeable decline in flux was observed and the membranes required more chemical cleaning after every batch to restore the system flux.

5.1.4 Cleaning

The VSEP membranes must be cleaned on a regular basis. As part of the optimization investigations, several different cleaning strategies were evaluated. Typically for membranes, including standard RO membranes, a two-step cleaning procedure is employed: an acid clean and a basic clean. The acid clean removes scale and foulants such as carbonate minerals and some metals. The basic cleaning step removes organic materials, silica, and biofilms. For the VSEP, three types of cleanings were tested:

- Hot water flush – no chemicals
- Acid clean – using a proprietary cleaning solution from New Logic Research, NLR 404
- Basic clean – using a proprietary cleaning solution from New Logic Research, NLR 505

When only antiscalant was used for chemical pretreatment, the membrane flux was shown to be restored most effectively by NLR 404, suggesting that acid-soluble minerals were limiting the recovery of the membrane. When both antiscalant and acid were used for pretreatment of the batch feed solution, NLR 505 was most effective in restoring membrane flux, suggesting that different components, possibly organic compounds or silica, were limiting recovery under those operating conditions.

Samples of spent cleaning solutions were collected and analyzed during pilot testing. Table 12 summarizes the resulting analytical data for two cleanings with NRL 505 and one hot water flush using RO permeate. For all cleanings, the spent cleaning solution contained elevated concentrations of chemical oxygen demand (COD). NRL 505 is an organic surfactant and expected to exhibit some COD, however elevated COD was also observed in the hot water flush waste. This indicates some possible accumulation of some organic material on the membranes. Additionally, barium was also elevated in the hot water flush waste, indicating potential accumulation of barium sulfate on the membranes.

Three critical observations can be made about the VSEP membrane cleaning process:

- The cleanings were able to consistently restore the membrane permeability to the original (new membrane) flux (70 gfd). This suggests that irreversible fouling, which reduces membrane life, did not occur.
- Cleaning temperature is an important variable for effective cleanings. New Logic Research recommended that the chemical cleaning solutions be 50°C for the cleaning process. During piloting, cleanings at that temperature and at colder temperatures were tested. Cleanings at 50°C were much more effective at restoring membrane flux.
- Pretreatment with acid and antiscalant may reduce the cleaning frequency required. When this pretreatment is applied, hot water flushes without cleaning chemicals between batches were sometimes sufficient to restore the flux.

5.2 Removal Rates

A summary of the VSEP permeate water quality is presented in Table 13. A preliminary estimate of average removal rates is shown in Table 14 and Table 15 (concentration and mass-based, respectively). Removal rates were estimated for those parameters with detectable concentrations in the RO concentrate (VSEP feed). Many parameters are reduced on average by greater than 90%. Similar to the primary RO unit, in many instances the upper limit of removals were not determined in the routine testing because (1) the concentrations measured in the permeate were less than the method reporting limit and/or (2) the concentrations in the influent were low and close to the method reporting limit. For several metals, both of these conditions applied and supplemental testing was conducted to better quantify the removals by the VSEP system (see Section 6.0 for methods and results).

For some constituents, their removal by RO membranes is highly pH-dependent. Examples of this are ammonia, borate, and arsenite. For these compounds, over a range of pH values, they are present as unionized species. The unionized species are not well-removed by membranes. For this pilot test, the following observations were noted:

- Ammonia: At pH values below 7, most of the ammonia is present as the ammonium ion and can be removed by the RO process. However, the pH of the feed water to the pilot RO system is approximately 7.5, reducing the amount of ammonia that can be removed. In addition, the concentration of ammonia in the influent was relatively low. The low concentration in the influent limited the estimate of quantifiable removal by the RO system.
- Boron: It is well known that boron removal at pH values below the pKa of boric acid is limited due to the lack of charge on the species. The boron removal during the pilot-testing program, while limited, was sufficient to maintain permeate concentrations below 0.5 mg/L, the Class 4A water quality standard. Specialty membranes or pH adjustment are typically required for greater boron removal.

With the exception of sulfate and boron, the VSEP permeate met the treatment targets listed in Table 3. However, as shown on Figure 1, at the full-scale WWTP, the VSEP permeate will be blended with the RO permeate prior to discharge. With blending, the pilot permeates would have a combined sulfate concentration of approximately 4 mg/L, based on 80% recovery across the primary RO system, 85% recovery across the VSEP, a primary RO permeate sulfate concentration of 1 mg/L and an overall average VSEP permeate sulfate concentration of 16 mg/L. Similarly with boron, when the VSEP permeate is blended with the RO permeate, the combined boron concentration of approximately 0.2 to 0.3 mg/L, which is less than the target water quality goal of 0.5 mg/L.

The VSEP concentrate quality was analyzed during the pilot test and those results are presented in Table 16.

5.3 Discussion

The VSEP system performed reliably throughout the test, both with respect to water quality produced and operation and maintenance. As illustrated on Figure 1, the Project will have two wastewater treatment plants. The VSEP concentrate from the WWTP will be transported to the WWTF for treatment in the chemical precipitation process. For the WWTP, the two technical objectives for the VSEP units are:

- produce permeate that, when blended with the primary RO system's permeate, meets the water quality targets, including the anticipated 10 mg/L sulfate limit; and
- reduce the volume of the RO concentrate sufficiently such that the concentration of sulfate in the VSEP concentrate is high enough to allow removal by gypsum precipitation at the WWTF

Achievement of the second objective is supported by operating at higher VSEP recovery rates However, with the batch VSEP process, as recovery is increased, the sulfate concentration in the VSEP permeate increases because of the increasing sulfate concentration in the feed tank. Thus, the two objectives must be balanced. If operation at higher recoveries is necessary and the VSEP permeate quality degrades, it is possible to treat all or part of the VSEP permeate through the primary RO system to remove additional sulfate before discharge.

6.0 Effluent Stabilization Bench Test Results

6.1 Overview

Because RO removes dissolved constituents from water, the permeate is virtually void of minerals including low amounts of calcium and alkalinity. Additionally, RO permeate often contains elevated concentrations of dissolved carbon dioxide. The carbon dioxide is formed from the reaction of antiscalant chemicals, which are added to RO feed water to prevent calcium carbonate scaling on the membranes, with bicarbonate alkalinity already present in the feed water. The resulting permeate, with low buffering capacity and low pH, is corrosive. Prior to discharge, RO permeate must be stabilized to meet the discharge water quality targets (Table 3).

An effluent stabilization bench testing experiment was designed and executed with two main objectives: (1) identify a stabilization method (e.g., addition of minerals) that will reduce the corrosiveness of the blended RO and VSEP permeates and maintain compliance with the effluent water quality targets in Table 3, and (2) produce a non-toxic effluent. For the purposes of the bench test, “non-toxic” was defined as water that was neither acutely or chronically toxic to *C. dubia*. The measure of chronic toxicity used for this evaluation was the estimated IC25 value. Two known treatment technologies were tested to meet the above objectives:

- Hydrated lime ($Ca(OH)_2$) and carbon dioxide (CO_2) addition
- Limestone bed contactors (LBC)

The permeate used for testing was a blend of RO and VSEP permeate generated by the RO and VSEP pilot unit, blended at a 5:1 ratio (representing recoveries of 80% for the RO unit and 80% for the VSEP unit). The stabilization bench testing was conducted at Barr’s wastewater laboratory.

In addition to the final water quality targets for the stabilized water shown in Table 3, the following additional targets to measure the corrosiveness and toxicity of the blended effluent were used in this evaluation:

- Langelier Saturation Index (LSI) ≥ 0
- Calcium carbonate saturation index (SI) > 0
- 7-day chronic WET test young reproduction $\geq$ 75% young reproduction of the laboratory control water sample
- $6.5 < pH < 8.5$

LSI and SI are both indices used to measure the scaling potential of calcium carbonate. Positive values for both indices indicate scale forming water versus corrosive negative values. The treatment targets for the stabilization tests were to obtain slightly positive values for each measure.

6.2 Lime Addition Bench Test

The lime and carbon dioxide stabilization process was first modeled using PHREEQC, an aquatic equilibrium model by the United States Geological Survey (USGS). The simulation was used to estimate the lime and carbon dioxide dosages that would be required to achieve the target SI, and the resulting final pH. Table 17 displays the modeling results of the estimated optimal lime dose.

An experimental protocol was then developed using the PHREEQC model dose as a guide. The protocol included the addition of lime to the blended effluent to increase the total hardness concentration of the blended permeates, followed by addition of carbon dioxide to achieve the target SI value. The lime dose would raise the SI value of the blended effluent above the target (0.1) and the carbon dioxide would reduce it to the target value. This approach results in water with minimal carbon dioxide fugacity, which lends stability to the effluent pH and provides stable water for WET testing.

Based on the modeling results shown in Table 17, a range of hydrated lime doses were added to the blended permeates and then the water was titrated down to a pH of approximately 7.3 using carbon dioxide during the bench tests.

6.2.1 Experimental Setup

The lime addition tests were conducted in a 4-L Erlenmeyer flask. A range of hydrated lime doses (Table 18) were added to 3-L aliquots of the blended effluent and were mixed vigorously on a stir plate. The samples were then titrated to a pH of 7.3 using a 5%:95% carbon dioxide and nitrogen gas mix. Final titrated blend samples were submitted to external laboratories for analytical and WET testing.

The hydrated lime used in the bench testing experiments was 94.3% $Ca(OH)_2$.

6.2.2 Results

6.2.2.1 Stabilized Water Chemistry

Table 18 presents a summary of the stabilization bench test results. Doses 4, 5, and 6 all met the calcium carbonate scaling potential water quality targets described in Section 6.1. Dosages 1, 2, and 3 did not have enough hardness and alkalinity to result in a positive LSI or SI value, indicating the final samples were still corrosive. When the results shown in Table 18 are compared to the targeted treated water quality targets presented in Table 3, the following observations can be made:

- turbidity - dosages 4, 5, and 6 exceed the turbidity goal
- TSS – doses 4 and 6 exceed the total suspended solids goal
- aluminum – doses 3, 4, 5, and 6 exceed the aluminum goal
- total hardness – dose 6 exceeds the total hardness goal

The water quality targets not achieved were likely affected by the grade of hydrated lime, lime contact time, and dosing methods. Excess turbidity and TSS likely, in part, resulted from the experimental setup and can be mitigated. Section 6.2.3 contains additional discussion of these issues.

6.2.2.2 Whole Effluent Toxicity

Based on the results from the bench testing, Dose 4 would likely produce the most stable blended effluent for the system. The LSI and SI values indicate the water would not be corrosive and the WET testing suggests the stabilized blended effluent would pass meet the WET (IC25) requirements.

Figure 21 displays the mean number of young produced per female for each dose compared to 75% of the control. Note that the raw, unstabilized water achieved a mean young production that was 53% of the control (i.e., an observable toxic effect). Doses 2-6 produced effluent that achieved a mean number of young produced per female of at least 75% of the control, suggesting that the stabilization approach reduced toxicity as intended despite the introduction of aluminum as described in the previous section. Dose 4 resulted in a mean young production higher than the control.

6.2.3 Implementation Considerations

Dose 4 was identified as the best dose for the blend of permeate tested. However, chemical dosing methods would have to be designed to avoid exceeding the treated water quality targets in Table 3.

Residual turbidity is a known operational challenge of using a lime addition to stabilize RO effluent (Reference (4)). As listed above in Section 6.2.2.1, lime doses 4 through 6 all exceeded the effluent turbidity limit. If lime addition is the chosen method of RO and VSEP effluent stabilization, effluent turbidity could be managed using the following techniques:

- High quality lime – Using high quality lime reduces the amount of inert material present to contribute to TSS and turbidity. For project implementation, the lime product used should be greater than 94% hydrated lime (purity used for bench testing) if available. High quality lime also has a high specific surface area which helps to maximize reactivity and minimize grit (Reference (5)).

- Liquid lime dosing – Dosing the lime as a liquid slurry rather than a solid provides minimal turbidity increases as less inert materials are present in liquid lime, and it avoids maintenance issues associated with dry lime (Reference (6)).
- Lime contact chamber – Contact chambers provide the necessary turbulent mixing time for the lime to fully dissolve into the blended effluent. The mixing or contact time is a key design parameter and is typically between 5-10 minutes (Reference (4)).

When the lime is initially dosed to the blended effluent, some of the dissolved carbon dioxide reacts with the lime and calcium carbonate precipitates and turns the mixture cloudy. As additional mixing time is allowed in the lime contact chamber, the remaining carbon dioxide reacts dissolving the newly formed calcium carbonate and reducing the turbidity again.

Along with turbidity, all treated water quality targets listed in Table 3 will need to be achieved in the final stabilized blended effluent. The aluminum measured in the stabilized water from the bench tests originated from the hydrated lime product. Using the measured aluminum and calcium concentrations it is estimated that the lime product used contained approximately 0.23% aluminum by weight. In order to achieve the 125 ug/L effluent aluminum concentration (Table 18), using Dose 4 the lime product would have to contain less than 961 mg aluminum/kg hydrated lime product (0.0961% aluminum). Below is a list of the closest lime suppliers to the future WWTP site and the standard aluminum concentration in their lime product:

- Graymont – hydrated lime product contains 0.2-0.4% aluminum oxide or 1,059-2,118 mg aluminum/kg hydrated lime product
- Carmeuse Lime & Stone – hydrated lime products contained on average 0.182% aluminum oxide in 2,012 or 963 mg aluminum/kg hydrated lime product
- Linwood Mining & Minerals – does not test for aluminum separately

The above concentrations indicate that identifying a supplier that can provide a lime product consistently with less than 961 mg aluminum/kg hydrated lime within a reasonable shipping distance will be an important consideration for this stabilization option.

6.3 Limestone Bed Contactor Bench Test

The limestone bed contactor (LBC) system is a semi-passive stabilization option that passes the blended effluent through a crushed limestone bed. As the blended effluent contacts the limestone media, it dissolves the limestone ($CaCO_3$) increasing both the hardness and alkalinity of the blended effluent. The rate of limestone dissolution is an important design parameter for an LBC system. Three different hydraulic loading rates were tested on three identical LBCs to identify the rate that would result in adequate introducton of hardness and alkalinity to the blended permeate.

As the effluent from the LBC columns was anticipated to still have a low LSI, due primarily to remaining dissolved carbon dioxide, air stripping and caustic addition were tested for final pH adjustment.

The objectives of this bench test were as follows:

- identify the maximum hydraulic loading rate that would achieve the treated water quality targets outlined in Section 6.1
- identify the best post-LBC treatment to achieve the treated water quality targets outlined in Section 6.1

6.3.1 Experimental Setup

The LBCs were constructed as 6-feet long, 2-inch diameter upflow columns (Figure 22). The tests were conducted using two types of limestone media:

- ¾-inch crushed landscaping limestone
- Columbia River Carbonates' Puri-Cal RO product with a particle size range of 2-3.4 mm (a product information sheet is provided in Appendix E)

Before both tests were conducted, the media was washed to remove fines. Also for both tests, the blended effluent was pumped at three different hydraulic loading rates through three identical upflow LBCs using a peristaltic pump.

The test program is illustrated in Figure 23. The first 2-L of effluent from each LBC was discarded and the next 6-L of sample from each LBC was collected for analysis. 2-L of the collected sample was sparged with compressed air, 2-L was dosed with caustic soda, and the final 2-L was left unamended. All samples were submitted for analytical and WET testing. Turbidity values were measured upon collection using a field turbidimeter.

6.3.2 Results

6.3.2.1 Stabilized Water Chemistry

The ¾-inch media resulted in an insufficient amount of alkalinity and hardness in the LBC effluent. The Puri-Cal RO product has a higher specific surface area and allowed for more $CaCO_3$ dissolution. Table 19 presents a summary of the results from the testing using the Puri-Cal RO product.

When Table 19 is compared with the targeted treated discharge water quality targets in Table 3 the following observations can be made:

- turbidity – Only the caustic dosed Rate 3 sample exceeded the goal
- total suspended solids – Only the caustic dosed, Rate 3 sample exceeded the goal
- metals – None of the samples exceeded any listed targets
- total hardness – None of the samples exceeded the target

Samples collected from the ¾-inch limestone testing were subjected to low-level mercury analysis. None of the samples had a detectable amount of mercury present, and therefore mercury was not tested for in the second round of LBC testing.

6.3.2.2 Whole Effluent Toxicity

Figure 24 displays the mean number of young produced per female for the LBC treatments, compared to 75% of the control sample's reproduction. As shown in the figure, the unstabilized permeate would not likely pass the IC25 criterion. The Rate 1 no treatment and sparged samples and the Rate 2 sparged samples produced effluent that achieved a mean number of young produced per female of at least 75% of the control.

6.3.3 Implementation Considerations

The LBC bench test results suggest that a limestone bed hydraulic loading rate (HLR) of 2.4 gpm/sf using the Puri-Cal RO product, followed by air sparging is able to produce a stabilized effluent that meets the treatment targets. However, in addition to HLR, there are other factors that will need to be considered for full-scale stabilization, such as residence time and bed depth.

For upflow contactors, HLRs ranging from 1.0-17.2 gpm/sf are typical (Reference (7)). The HLR is related to the flow rate of the LBC system required for a given reactor diameter. The highest HLR that achieves the treated water quality targets minimizes the number of LBCs required to stabilize the blended effluent flow. However, HLRs that are too high can cause media blowouts causing turbidity and TSS.

The residence time of the system is related to the dissolution rate of the limestone. Typical empty bed contact times (EBCT) range from 3.6 to 30 minutes for LBC systems (Reference (7)). Required residence times are related to the limestone media size. Larger diameter media has lower specific surface area which requires longer residence times to allow for adequate dissolution of the media.

After the residence time and the HLR are defined, the volume and therefore the bed depth of the LBC can be calculated. The calculated bed depth represents the minimum depth of media required to meet the treatment targets that must always be maintained.

As mentioned above, LBC systems are semi-passive. The limestone will need to be replaced periodically as it dissolves. If the blended permeate is applied at 2.4 gpm/sf to the LBCs and the system is operated 24 hours/day, then 3.38 pounds of limestone per day per square feet of LBC will need to be replaced. How often media is replenished to the LBCs or the available equipment sizes will determine the additional bed height above the minimum that will be added.

Sparge systems are added as a post treatment following the LBCs to strip any excess dissolved carbon dioxide remaining in the effluent. The dissolved carbon dioxide will likely off gas at the discharge point if not removed at the treatment site. Off gassing will cause a pH increase which is known to contribute to failed WET tests. Stripping the carbon dioxide before it reaches the final discharge point will produce a more pH stable water.

Upflow contactors were constructed for this bench test and are the most common LBC, but downflow contactors are also used. Upflow reactors typically result in a lower effluent turbidity and do not require backwashing, but an internal top screen does need to be used to prevent calcite from blowing out of the reactor. Downflow reactors provide calcite dissolution and sediment filtration. Disadvantages of downflow configurations include required backwashing, high turbidity waste streams, increased risk of TSS in the treated effluent from fines breakthrough, and higher capital and operational and maintenance costs (Reference (7)).

The upflow configuration was selected for this application because of the typically lower turbidity effluent and no backwashing requirement.

6.4 Discussion

The results of effluent stabilization bench testing indicated that WWTP effluent can be effectively stabilized via either lime/carbon dioxide treatment or LCB/air sparging. The results also showed that both methods are capable of reducing whole effluent toxicity of the WWTP effluent. Both methods have implementation considerations that must be evaluated further during design.

7.0 Metals Seeding and Arsenic Removal Tests

7.1 Overview

During the development of the SDEIS, the Minnesota Pollution Control Agency (MPCA) and Minnesota Department of Natural Resources (MDNR) inquired about the removal of certain metals across the RO system. These metals included: aluminum (Al), antimony (Sb), arsenic (As), boron (B), cadmium (Cd), chromium (Cr), cobalt (Co), copper (Cu), lead (Pb), mercury (Hg), nickel (Ni), selenium (Se), thallium (Tl), and zinc (Zn). Although these metals were not the primary focus of the pilot-test program, for some of these metals, sufficient data were collected during the routine pilot-testing program (see Table 9, Table 14, and Table 15) to evaluate removal efficiencies. As can be seen in the tables, for several metals, the removal rates are indicated as "greater than" a numerical value. This was primarily due to the very low influent concentrations of the metals. The calculation of the removal rates was limited by this and the method reporting limits in the RO permeate.

A further evaluation of metal removal efficiencies was completed by obtaining additional information via three methods:

- For those metals for which soluble salts could be readily obtained and safely handled, metals were added to the pilot-plant influent to experimentally determine the removal efficiencies across the RO and VSEP systems, and in the case of arsenic, also across the greensand filter.
- For those metals that could not be safely handled at the pilot-plant site or for which soluble salts were not available, a review of the scientific literature was conducted to summarize removal rates that have been observed by researchers in other applications.
- The RO membrane supplier, GE, was asked for additional data to support the observed removal rates for these metals across the membrane being used for this pilot-testing project.

The section summarizes the metals removal data and information that has been collected during the pilot-test, from the literature, and from the RO membrane supplier. The RO and VSEP processes will also be used for treatment of the West Pit lake overflow during long term closure at the WWTF. The future water quality of the West Pit Lake overflow is generally similar in composition to the water that has been tested during piloting with the inclusion of the metals testing described in this section. For this reason, the performance of the treatment processes for treatment of the West Pit lake overflow during long term closure is expected to be similar.

7.2 Methodology

7.2.1 Metals Seeding Test

For several metals that were not present in the influent in sufficient concentrations to determine the removal efficiencies, a test was conducted in which solutions of metals salts were added to the pilot-plant influent. The objective of this experiment was to better quantify the removal rates of As, Co, Cu, Ni, Pb, Se, and Zn across the RO and VSEP pilot-systems. These metals were added downstream of the greensand filter. The dosing and sampling locations are shown in Figure 25. Samples from the treatment train were collected during this test and analyzed for the metals under investigation. Because of the limited solubilities of some of the metals salts, three separate stock solutions were prepared and tested separately. These solutions were prepared as shown in Table 20, Table 21, and Table 22. The target doses correspond to the highest projected 90th percentile annual average concentration in the influent to the WWTP for any year, from the GoldSim water quality model for the Project for the first 20 years of operation. The metal salts selected for this experiment for As, Co, Pb, and Se were their reduced forms (i.e., As(III), Co(II), Pb(II), Se(IV)). Typically, the more oxidized species (arsenate versus arsenite or selenate versus selenite, for example) are larger and/or more ionized than the reduced forms and therefore are expected to have greater removal efficiency across the membranes. Thus, using the reduced forms of these constituents was expected to provide a conservative (i.e., worst case) estimate of removal.

Twenty gallons of each stock solution was made using RO permeate and reagent salts purchased from Fisher Scientific. The 20-gallon volume of metal stock solution provided approximately 15 hours of runtime of the RO unit for each of the three solutions.

The rejection of constituents by RO membranes can be influenced by a number of factors, including water temperature, water composition (other bulk ions), membrane age, membrane system recovery, the membrane system flux, and the membrane material. For this test, the operating conditions used were the same as used during the longer-term testing (Phases 4 and 5):

- RO system
    - recovery: 80%
    - flux: 16 gfd
    - membrane: GE AK-90 LE
    - antiscalant: GE Hypersperse MDC150 at 2.2 ppm

- VSEP system
  - recovery: 85%
  - flux: varies as the batch is processed
  - membrane: Hydranautics ESPA
  - antiscalant: NLR759 at 10 ppm
  - pH adjustment: feed adjusted to approximately 6.5 at the beginning of the batch using sulfuric acid

7.2.2 Arsenic Removal Test

A common method to remove arsenic from drinking water is greensand filtration. In the WWTP, if greensand filtration is employed as pretreatment to the RO system, it would be expected to remove the majority of the arsenic from the influent, rather than the RO system. For this reason, a separate 1-day experiment was conducted to determine the arsenic removal across the greensand filter. The experimental setup is illustrated in Figure 26. For this experiment, sodium arsenite was added to the pilot-plant feed tanks to a target concentration of 100 µg/L. The potassium permanganate dose at the greensand filter was 4 mg/L, the same dose that has been used since the oxidant dose optimization study conducted in August 2012. The arsenic concentrations in the feed tank effluent, greensand filter effluent, RO permeate, and RO concentrate were monitored during the test. The greensand filter was backwashed prior to the test to remove iron and other accumulated total suspended solids.

7.3 Results

7.3.1 Metals Seeding Test

Table 23 presents a summary of the analytical data collected during the metals seeding test for the RO and VSEP pilot-units. Calculated removal rates are presented in Table 24 (RO) and Table 25 (VSEP).

7.3.1.1 GE RO Pilot-Unit

As can be seen in Table 24, the metals seeding test allowed the determination of more precise removal efficiencies for As, Co, Cu, and Ni for the GE RO pilot-unit as compared to the previous pilot-testing run. Co, Cu, and Ni were well-removed by the RO pilot-unit, with removal rates in excess of 99.75%.

The average arsenic removal across the RO membrane system was 82.13% and was 66.67% across the VSEP pilot-unit. Arsenic was added to the influent as sodium arsenite, which is mostly present as the unionized species H_3AsO_3 at the neutral pH of the influent and is therefore less well-rejected by the RO membrane. Higher removal rates would be expected at higher pH values (i.e., greater than the pKa values for H_3AsO_3) and for arsenate, which is charged at the circum-neutral pH of the influent. Removal of arsenate by the RO membrane is reported to be greater than 98% (Reference (8)). Removal of arsenic was further evaluated in the arsenic removal test.

For Pb, Se, and Zn, the added metals were removed by the RO pilot-unit to below their respective method reporting limits in the RO permeate. The resulting removal rates in Table 24 are therefore minimum removal rates under the conditions tested.

7.3.1.2 VSEP Pilot-Unit

In general, the VSEP removal rates were similar to the RO pilot-unit rates and quantifiable removal rates were able to be determined for all seeded species. Concentrations of each metal were higher in the VSEP permeate than in the RO permeate due to higher influent concentrations in the VSEP feed.

For the WWTP, blending of the RO and VSEP permeates prior to discharge is being considered in the design process. Using the measured permeate concentrations for the metals added, and the systems' recovery rates, the blended permeate metals concentrations were estimated. This information is shown in Table 26. As can be seen, all of the parameters in the blended permeate would have concentrations below the Class 2B water quality standard.

7.3.2 Arsenic Removal Test

Table 27 summarizes the analytical data collected during the arsenic removal test. During this test, the oxidation of arsenite to arsenate by potassium permanganate and its subsequent removal across the greensand filter and the RO pilot-unit were evaluated. Three sets of grab samples were collected at the locations shown in Figure 26 during the 1-day test run. The feed tank As concentrations were observed to increase throughout the run. This likely reflects physical limitations to feed tank mixing at the pilot-test site. The concentrations, however, spanned the target influent concentration of 100 µg/L. The calculated removal rates are presented in Table 28. Arsenic was very well-removed by the greensand filter – producing filter effluent with arsenic concentrations that were well below the Class 2B water quality standard for all three sampling events.

7.3.3 Literature Review and Vendor Information

As indicated in the preceding sections, it was not possible to determine the removal efficiencies for some metals due to either low solubility of their available salts, or safety considerations at the pilot-plant site. For those metals that could not be tested, a review of the scientific literature was conducted. The sections below summarize the information obtained from GE and from the literature. A summary is also provided in Table 29.

7.3.3.1 Aluminum

RO is not typically employed for the removal of aluminum in water due to its potential to foul the membranes, and the resulting negative impacts on recovery and flux. Aluminum in feed water to a RO membrane can form colloidal aluminum oxides. Colloidal aluminum-silicates will also form if silicon is present above 10 mg/L and the pH is near 6.5 (Reference (9)). Gabelich et al. (Reference (10)) found that reducing the influent total aluminum to less than 50 μg/L significantly reduced membrane fouling and improved membrane performance. Operating at influent pH values less than five can reduce membrane fouling by reducing aluminum hydroxide formation (Reference (8)).

Removal of aluminum in tap water by RO to below the method detection limit has been documented (Reference (11)); however, the study makes no mention of fouling, long term treatability or feasibility especially on the industrial scale. Published rejection rates for aluminum in RO membranes in peer-reviewed literature were otherwise limited. An RO vendor website (Pure Water Products) suggested that aluminum rejection rates of 99% are possible at the commercial scale. It is likely that due to aluminum's relatively low solubility, it would primarily be removed upstream of the RO membrane through colloidal precipitation and filtration. Consequently, the RO system would likely receive very little dissolved aluminum.

7.3.3.2 Antimony

Antimony has been reported to be removed by RO membranes at efficiencies ranging from 99 to 99.2% at the bench scale (Reference (12); Reference (13)). The rejection of antimony was reportedly not affected by solution pH or the valence state of the antimony (+3 or +5), (Reference (14)). A personal communication with Paul DiLallo of GE suggested (Reference (8)) that antimony will be removed similarly to calcium (99.3% rejection during pilot-testing).

7.3.3.3 Cadmium

Cadmium rejection has been reported to be 99 to 99.4% at the bench scale and full scale, respectively (Reference (15), Reference (16)). A personal communication with Paul DiLallo of GE suggested (Reference (8)) that cadmium will be removed similarly to calcium (99.3% rejection during pilot-testing).

7.3.3.4 Chromium

Chromium rejection by RO membranes is reportedly high, at 98 to 99.5%, across a wide range of membranes at the pilot- and bench-scale (Reference (16), Reference (17)). A full scale tannery wastewater plant treating high concentrations of influent hexavalent chromium (500-3,000 mg/L) and NaCl (30,000 to 50,000 mg/L) was able to achieve maximum chromium rejection of approximately 80% (Reference (18)). Only one paper specifically tested rejection of chromium in both its +3 and +6 state (Reference (16)). The author did not report a significant difference in rejection between chromium in the +3 and +6 state. A personal communication with Paul DiLallo of GE suggested (Reference (8)) that chromium will be removed similarly to calcium (99.3% rejection during pilot-testing).

7.3.3.5 Mercury

Mercury removal by RO membranes is highly dependent on the type of membrane used. Mercury rejections ranging from 22 to 99.9% have been reported. The chemical state of the mercury is also an important factor in mercury removal. Urgun-Demirtas et al. (Reference (19)), found that mercury in the colloidal or particulate form was easily removed but that free mercury was removed at a lesser rate. Rejection values for organic mercury by RO membranes could not be found in the peer-reviewed literature, but one RO membrane vendor (DuPont) and the University of Nevada – Cooperative Extension claim that methyl mercury cannot be removed across a RO membrane.

Paul Dilallo of GE indicated in a personal communication (Reference (8)) that the rejection for mercury is estimated to be approximately 70%.

7.3.3.6 Thallium

A rejection value for thallium across a reverse osmosis membrane was only found in one published source: a 1983 review paper in the journal Desalination (Reference (20)) that categorized a list of metals including thallium as having rejection rates between 90 and 100%.

Paul Dilallo of GE who supplied the membranes used for pilot-testing indicated (Reference (8)) that thallium should have a similar rejection to calcium (average of 99.3% during pilot-testing).

It is also possible that some thallium will be removed prior to the RO unit (in pretreatment) due to its relatively low solubility.

7.4 Discussion

For the metals of interest to the MPCA and MDNR for the Project, removal from the WWTP influent by the proposed treatment train has been evaluated using pilot-testing, a review of the scientific literature, and by inquiry to the membrane supplier. The following conclusions can be made:

- Arsenic is expected to be removed primarily across the greensand filter, rather than the RO unit. Removal of As by the greensand filter of up to 99.68% was observed on the pilot-scale.
- Boron removal by RO membranes is highly dependent on the influent pH. It is well known that boron removal at pH values below the pKa of boric acid is limited due to the lack of charge on the species. The boron removal during the pilot-testing program, while limited, has been sufficient to maintain permeate concentrations below 0.5 mg/L, the Class 4A water quality standard. Boron concentrations are estimated by the GoldSim model to decrease over time from their current value, so future concentrations experienced by the full-scale WWTP will be less than that experienced by the pilot-units.
- Cobalt, copper, lead, nickel, selenium, and zinc were observed to be well-removed by the membrane systems, producing a blended permeate with concentrations below the Class 2B water quality standard.
- Cadmium and chromium are likely to be well-removed by the membranes, similar to the other heavy metals tested (copper, cobalt, lead, and zinc).
- Aluminum is a known foulant for RO membranes, especially at concentrations greater than 50 µg/L. If necessary, aluminum removal is likely to be via pretreatment in order to preserve membrane performance, rather than be removed by the RO membranes themselves.
- Limited information is available on the removal of thallium by RO membranes, but the reported rejection is in the range of 90 to 100%. Like lead, thallium is sparingly soluble under most conditions. Additional removal of both lead and thallium by RO pretreatment is possible, depending on the water chemistry conditions. Thallium concentrations in the influent to the WWTP are estimated by the GoldSim model to be below the Class 2B water quality standard.
- The scientific literature suggests that antimony will be removed by the RO membranes at rates of greater than 99%. Antimony is also sparingly soluble and additional removal may occur in pretreatment, prior to the RO system.

Mercury removal by RO is highly variable and dependent upon its speciation and the membrane selection. For these reasons, its removal is difficult to quantify. However, mercury concentrations in the WWTP influent during operations were not estimated by the GoldSim model.

8.0 Chemical Precipitation Bench Test Results

This section summarizes the objectives, methodology, and results for the bench testing performed using samples of VSEP concentrate.

8.1 Objectives

The objectives of the VSEP concentrate chemical precipitation bench test were to:

- determine if oxidative pre-treatment is necessary to free metals from anti-scalants prior to treatment via chemical precipitation
- for the high density sludge (HDS) metals process:
    - evaluate the degree of metals adsorption by iron oxyhydroxide sludge at various pH setpoints, sludge concentrations
    - evaluate the effect of two reaction times on the degree of metals adsorption by iron oxyhydroxide sludge
    - evaluate the required overflow rate/settling time for HDS solids
- for the sulfate (gypsum) precipitation process:
    - evaluate the degree of sulfate precipitation achieved by lime treatment/gypsum solids contact
    - evaluate the effect of two reaction times on the degree of sulfate removal
    - evaluate the effect of gypsum solids concentration on the degree of sulfate precipitation
    - evaluate the required overflow rate (settling time) for gypsum solids

8.2 Oxidative Pre-Treatment

8.2.1 Protocol

An initial screening test was conducted to evaluate whether or not oxidative pre-treatment is necessary to destroy antiscalants prior to chemical precipitation. An aliquot of VSEP concentrate was oxidized using potassium permanganate, added drop-wise while mixing, watching for the pink color to dissipate between drops. At the point where the pink color persisted, permanganate addition was ceased and the pre-treated water (along with an un-oxidized control) was subjected to the tests summarized in Table 30, at a 60 minute reaction time.

The water resulting from the screening tests was analyzed for the following parameters to determine if pre-treatment may be necessary for effective removal of metals and sulfate via chemical precipitation:

- metals HDS screening – Dissolved As, Sb, Be, B, Cr, Co, Cu, Fe, Pb, Mn, Ni, Se, Zn
- sulfate precipitation screening – Dissolved calcium, aluminum, dissolved sulfate

8.2.2 Results

The results of the oxidative pre-treatment screening test are in Table 31. The following conclusions can be drawn from the results:

- oxidative pre-treatment generally did not improve the removal of sulfate of metals relative to the un-oxidized control
- concentrations of dissolved metals in the untreated VSEP concentrate were generally low

Based on these results, it was decided to proceed with the other precipitation tests without the use of oxidative pre-treatment, and to increase the concentrations of metals in the VSEP concentrate by spiking with metals salt solutions.

8.3 Chemical Precipitation Testing

8.3.1 Protocol

8.3.1.1 Metals Spiking

As described in the previous section, the results of the oxidative pretreatment screening indicated that concentrations of several target metals were lower than anticipated future levels in the VSEP concentrate. It was therefore decided to spike the VSEP concentrate with higher concentrations of metals.

The elements cobalt, copper, nickel, arsenic, selenium, zinc and lead were chosen to be spiked into the untreated VSEP concentrate that represent the 90th percentile annual average concentrations anticipated in the VSEP concentrate for the design year at the Mine Site (Table 32).

Because of safety and disposal concerns associated with the creation of the stock solutions necessary to add these chemicals at the appropriate dose, the stock solutions that had already been prepared for the metals seeding test were used to add these metals to the water. The metals stock solution #1 has five metals at the concentrations indicated in Table 33. As a result of using this stock solution, it was not possible to exactly achieve the 90th percentile design year concentration for each individual metal. As such, it was decided to add a volume of stock solution to ensure that all 90^{th} percentile concentrations were met or exceeded for: cobalt, copper, nickel, arsenic and zinc. The 90^{th} percentile concentrations for selenium and lead were met exactly because those metals had been prepared as separate individual stock concentrations.

It should also be noted that, in the case of arsenic and selenium, the reduced species of these constituents were added. In the case of arsenic, the reduced species adsorbs less strongly to iron oxyhydroxides. In the case of selenium, the reduced species adsorbs more strongly.

8.3.1.2 HDS Metals Jar Tests

The HDS sludge was prepared by adding lime to 35 percent ferrous chloride solution until a pH of 7.5 was achieved. Air was then bubbled through the solution to oxidize the iron until all of the solution was a dark rusty red color. The solution was then centrifuged to separate the iron solids from the water, and washed three times with deionized (DI) water to remove excess chloride. The final solids content of the resulting ferric hydroxide sludge was measured at 26% (± 1%) by oven drying at 105°C.

The HDS Metals test was conducted in a series of jars. Each batch consisted of four jars filled with 1 liter of metal-spiked VSEP reject and dosed with the appropriate amount of iron oxyhydroxide sludge to achieve the desired solids content. The pH was adjusted using sulfuric acid or sodium hydroxide (as appropriate) to meet the target pH values specified in Table 33.

The jars were mixed using a Phipps and Bird jar tester. For each batch, samples were collected from each of the four jars after 30 and 60 minutes of mixing. The samples were then filtered through a 0.45 µm filter, and submitted to Legend for dissolved metals analysis. This sampling approach was intended to provide data regarding the degree to which dissolved metals adsorbed to the sludge at two different reaction times. The target analytes for dissolved and total metals analysis are provided in Table 34.

The residual water volume from the three iron solids contents at each pH was combined for use in subsequent settling tests. The residual water was diluted to 2L of volume with DI water and the anionic polymer flocculant Nalclear 7768 was added at 100 mg/g-iron solids to aid in settling. A settling test was performed using 2-L B-KER[2] jars, collecting settled water via the side sample port at 2, 4, and 6 minutes and analyzing for the total metals listed in Table 34. The intent of this approach was to evaluate the sensitivity of metals removal to settling time of the sludge. To that end, iron, along with cobalt and arsenic (the two most sensitive metals from a water quality target standpoint) were selected for total metals analysis in the settled water.

8.3.1.3 Sulfate Precipitation Jar Test

Gypsum sludge was prepared by reacting sodium sulfate and calcium chloride together to form gypsum precipitate. The precipitated gypsum was separated from the water via filtration and washed with a solution of calcium hydroxide (pH 12) to remove excess sodium, chloride, and sulfate. The solids content was determined by drying in an oven at 105°C.

This test was conducted in batches consisting of two 2-L jars filled with VSEP concentrate. The appropriate amount of gypsum solids were added to the jars, and the pH was adjusted to the desired set-point using lime slurry. The gypsum doses and target pHs used are shown in Table 35.

Samples were collected from each jar after 30 and 60 minutes of mixing, filtered via a 0.45-micron filter, and submitted to Legend for dissolved sulfate, calcium, and aluminum analysis. The intent of this approach was to evaluate the effect of time and solids content on the amount of sulfate precipitation as gypsum, as well as the contribution of added lime to the aluminum concentration of the water.

The remaining sample aliquots were allowed to settle, sampled via the side port at 2, 4, and 6 minutes and submitted to Legend for total sulfate, calcium, aluminum, and alkalinity. The intent of this approach was to evaluate the effect of settling time on the removal of precipitated gypsum and aluminum.

8.3.2 Results

8.3.2.1 High Density Sludge (HDS) Metals

Results for the HDS Metals test are in Table 36. It can be seen that removal of metals was generally good. Figure 27 through Figure 35 show the effect of time, pH, and solids content on the removal of each individual metal.

The reported analytical results suggest that the optimal concentration of iron oxyhydroxide sludge was between 0.5% and 1.5% at pH ranges greater than 8 for most metals. Selenium and chromium adsorption were less complete at higher pH values.

There was generally little difference in metals adsorption between the 30 and 60 minute reaction times. Selenium adsorption was marginally more complete at 60 minutes than at 30 minutes.

Results from the HDS sludge settling test are in Table 37, and are illustrated in Figure 36 to Figure 39. It can be seen that settling was more rapid at higher pH values. This likely was a function of not having optimized the anionic flocculant dose at each pH set-point. Had the flocculant dose been better optimized, performance likely would have been better at lower pH values. Notably, both the 4 and 6-minute settling times at the pH 10 set-point yielded cobalt and arsenic concentrations at or below the water quality targets for the WWTF. These settling times correspond with overflow rates of approximately 750 and 500 gpd/sf, respectively.

8.3.2.2 Gypsum Precipitation

Results for the gypsum precipitation test are in Table 38. It can be seen from the table that addition of 1 percent gypsum solids to the reaction improved sulfate removal over the 0.1 percent solids concentration. However, the treatment receiving 10 percent gypsum solids exhibited a higher concentration of sulfate than either of the lower solids concentrations. Likewise, an increase in the amount of dissolved aluminum was also observed with increasing solids concentrations. Lime is known to contain aluminum impurities, and was applied to increase the solution pH, as well as in the preparation of the gypsum solids. The gypsum solids were prepared from sodium sulfate, a soluble salt. Although the gypsum solids were washed, it is possible that they retained a high enough concentration of sulfate in the pore water to bias the results in the 10% solids sample.

Settling data for the 0.1% and 1% gypsum solids treatments is in Table 39. It can be seen from the table that the 1% solids treatment settled more rapidly than the 0.1% treatment, and approached the dissolved sulfate concentration at the 4-minute settling time. The 6 minute settling time exhibited a higher concentration of sulfate relative to 4 minutes. This is believed to be an artifact, possibly due to disturbance of the beaker during sampling.

8.4 Discussion

While future work will incorporate the results of the bench testing into the process design calculations for the Mine Site in more detail, the overall findings of the bench test comport well with the anticipated operating conditions and performance for the WWTF.

- Preliminary process modeling conducted to-date suggests optimal pH between 9 and 10 for metals removal via the HDS process. This range is supported by the bench testing data.
- Preliminary process modeling suggests an iron oxyhydroxide sludge concentration of approximately one percent in the HDS reactors for adequate removal of target metals. This is value is supported by the bench testing results.

- The observed bench testing results for sulfate precipitation are within the range suggested by preliminary process modeling.
- Preliminary process calculations assumed a reaction time of 60 minutes for both metals and sulfate removal processes. This time scale appears to be sufficient based on the bench testing results, and some reactions may achieve completion more rapidly than currently assumed.
- Preliminary process calculations assumed an overflow rate of 500 gpd/sf, which is supported by the bench test results.

Overall, the effects of antiscalants and high ionic strength of the VSEP concentrate were insufficient to inhibit removal of metals or sulfate beyond what is already anticipated in the preliminary process calculations. This is a significant finding, as the VSEP concentrate represents a worst-case scenario for these effects.

Some additional consideration of the contribution of lime to effluent aluminum concentrations in the chemical precipitation effluent is anticipated based on the results of this testing. It may be possible to optimize operation of the recarbonation process, which follows the gypsum precipitation process, to enhance removal of residual aluminum from the effluent.

9.0 Applicability to Future Conditions

A central goal of pilot testing program was to verify that the core treatment technology selected for the WWTP – reverse osmosis – could reliably meet the water quality objectives for the Project, particularly for sulfate. Of equal importance to the feasibility of implementing RO for the Project was demonstration that the RO concentrate could be successfully managed. Both objectives were met during the pilot testing program. It is understood that the quality of the influent to the WWTP may change over time, and that this may result in modifications to the WWTP around the core treatment technology, and hence the WWTP is considered an adaptive mitigation tool for the Project.

Table 40 provides a comparison of the pilot plant influent water quality with the Year 20 Plant Site and Year 75 Mine Site influent water quality estimates from the GoldSim project models. Particularly when the metals seeding tests are considered, the pilot testing program included similar water qualities to what is estimated the full-scale treatment plants may experience in the future. In the event that influent concentrations exceed those estimated by GoldSim or if removal rates for metals or other constituents are less than observed on the pilot-scale or in the literature, several treatment systems modifications are possible to improve performance. Potential modifications could include:

- **Pretreatment modifications:** Pretreatment modifications may include changes to the methods used to protect the RO membranes from scaling and fouling or to otherwise optimize the performance of the RO system. The greensand filter used for the pilot test performed well, but in the future, other options that could be considered include:
  - Additional iron removal prior to the greensand filter to reduce iron loading to the filter
  - Modifications to the antiscalant selection and/or dose
  - Softening or acid addition to reduce the scaling potential of the influent
  - Addition of chemical scavengers to improve metals removal
- **Post-treatment modifications:** The RO or VSEP permeates, if necessary, could undergo further treatment to improve water quality prior to discharge. Post-treatment modifications that could be considered include:
  - Additional treatment of the VSEP permeate through the primary RO system
  - Addition of polishing treatment units for removal of trace metals (e.g., ion exchange).

- **Treatment modifications:** Modifications to the core treatment technologies to improve treated water quality could include modifications to the membrane selection.

10.0 Summary and Conclusions

PolyMet has completed an extensive 7-month pilot testing program in support of the proposed design for the WWTP. The pilot testing program tested all of the major treatment components proposed for the WWTP: media (greensand) filtration, reverse osmosis, concentrate management, and effluent stabilization. Of central importance, it was demonstrated that reverse osmosis is a reliable and technically feasible treatment technology to meet the Project water quality objectives. Additionally, the RO concentrate can be successfully managed using volume reduction (VSEP) and chemical precipitation technologies.

The pilot testing program yielded several very important results, including the following for the RO system:

- throughout the testing program, the RO system has consistently produced permeate with sulfate concentrations less than 10 mg/L
- the pretreatment selected for the RO system—greensand filtration and antiscalant addition—were effective in maintaining stable RO performance
- the RO system did not experienced significant fouling or scaling during the testing program
- the RO was operated at a recovery of 80%, which is within the range initially targeted for the WWTP

The VSEP pilot test yielded the following results:

- The VSEP sulfate removal efficiency averaged 99.3%. Under the pilot test conditions, when the VSEP and RO permeates are blended, the sulfate concentration is less than 10 mg/L.
- The VSEP system demonstrated recoveries ranging from 80 to 90%, within the Project objectives.
- No irreversible fouling was observed during the course of testing. Once cleaning optimization was complete, the membrane flux was restored to its original flux after each cleaning.
- No decline in sulfate removal has been observed over time.

The discharge from the future WWTP will be a blend of RO and VSEP permeates. Testing was conducted on methods to adjust the pH and reduce the corrosiveness of the blended permeates. The permeate stabilization bench testing results produced the following conclusions:

- lime addition
    - lime addition was able to adjust the pH and meet most water quality targets, including measures of corrosiveness
    - two important factors were identified in the test that would need to be considered on a full-scale design
    - quality of lime used (to reduce turbidity from inert materials and minimize unwanted aluminum in the discharge)
        - method of lime addition and reaction to minimize residual turbidity
- limestone contactor
    - the limestone contactor was able to adjust the pH and meet all water quality targets, including measures of corrosiveness.
    - additional treatment after limestone contactor was needed to remove remaining carbon dioxide (e.g., air sparging).

Supplemental testing was conducted at the end of the pilot test to (1) better quantify the removal of certain metals across the pilot treatment train and (2) to simulate the treatment processes that will be employed at the WWTF using the VSEP concentrate.

The metals removal test yielded the following results for the RO and VSEP systems:

- Arsenic is expected to be removed primarily across the greensand filter, rather than the RO unit. Removal of arsenic by the greensand filter of up to 99.68% was observed on the pilot-scale.
- Cobalt, copper, lead, nickel, selenium, and zinc were observed to be well-removed by both the RO and VSEP systems, producing a blended permeate with concentrations below the Class 2B water quality standard.

Chemical precipitation bench testing was performed using VSEP concentrate to test performance of the treatment processes contemplated for the WWTF under worst-case conditions (i.e., presence of anti-scalants and high ionic strength). The results of this testing indicated that oxidative pre-treatment of the VSEP concentrate is not likely required, and that performance and behavior of the contemplated treatment processes are similar to what is expected based on preliminary process calculations. The bench testing identified aluminum content of the lime reagent as a design consideration. The bench testing results will be incorporated into future design calculations as appropriate.

The initial design for the WWTP will be based on the results of the pilot testing. Because the WWTP is considered an adaptive engineering control, provisions for expansion of the plant and changes to the operating configuration of process units will be incorporated into the full-scale design to match the results of ongoing water quality monitoring and modeling efforts.

11.0 References

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Tables

Table 1 SD004 Water Quality

Location		SD004	SD004	SD004	SD004	SD004	SD004	SD004	SD004	SD004	SD004
Date		5/14/2012	5/21/2012	5/29/2012	6/4/2012	6/11/2012	6/19/2012	6/26/2012	7/5/2012	7/10/2012	7/17/2012
Sample Type		N	N	N	N	N	N	N	N	N	N
	Fraction										
General Parameters											
Alkalinity, bicarbonate, as CaCO3	NA	**510 mg/l**	**520 mg/l**	**530 mg/l**	**510 mg/l**	**510 mg/l**	**500 mg/l**	**520 mg/l**	**510 mg/l**	**520 mg/l**	**520 mg/l**
Alkalinity, carbonate, as CaCO3	NA	< 20 mg/l	< 20 mg/l	< 20 mg/l	< 20 mg/l	< 20 mg/l	--	--	--	--	--
Alkalinity, total	NA	**510 mg/l**	**520 mg/l**	**530 mg/l**	**510 mg/l**	**510 mg/l**	**500 mg/l**	**520 mg/l**	**510 mg/l**	**520 mg/l**	**520 mg/l**
Carbon, dissolved organic	NA	**2.1 mg/l**	**2.5 mg/l**	**7.9 mg/l**	**3.8 mg/l**	**3.1 mg/l**	**2.1 mg/l**	**2.2 mg/l**	**2.9 mg/l**	**2.1 mg/l**	**2.3 mg/l**
Carbon, total organic	NA	**2.4 mg/l**	**2.3 mg/l**	**14 mg/l**	**2.0 mg/l**	**2.6 mg/l**	**2.3 mg/l**	**2.3 mg/l**	**3.0 mg/l**	**2.3 mg/l**	**2.5 mg/l**
Chloride	NA	**23 mg/l**	**22 mg/l**	**21 mg/l**	**21 mg/l**	**22 mg/l**	**22 mg/l**	**21 mg/l**	**22 mg/l**	**21 mg/l**	**21 mg/l**
Fluoride	NA	**1.7 mg/l**	**1.7 mg/l**	**1.7 mg/l**	**1.7 mg/l**	**1.7 mg/l**	**1.8 mg/l**	**1.8 mg/l**	**1.7 mg/l**	**1.8 mg/l**	**1.8 mg/l**
Nitrogen, ammonia (NH3), as N	NA	< 0.500 mg/l	< 0.500 mg/l	< 0.200 mg/l	< 0.200 mg/l	< 0.200 mg/l	< 0.200 mg/l	< 0.200 mg/l	**0.219 mg/l**	< 0.200 mg/l	< 0.200 mg/l
Nitrogen, Nitrate as N	NA	< 1.0 h mg/l	< 0.23 mg/l	< 0.22 mg/l	< 0.22 mg/l	< 0.23 mg/l	< 0.23 mg/l	< 1.0 mg/l	< 0.23 mg/l	< 0.23 mg/l	< 0.23 mg/l
Nitrogen, Nitrite as N	NA	< 0.20 mg/l	< 0.30 mg/l	< 0.30 mg/l	< 0.30 mg/l	< 0.30 mg/l	--	--	--	--	--
Orthophosphate, as PO4	NA	< 0.20 mg/l	< 0.20 mg/l	< 0.20 mg/l	< 0.20 mg/l	< 0.20 mg/l	--	--	--	--	--
pH	NA	**7.9 pH units**	**7.8 pH units**	**7.7 pH units**	**7.8 pH units**	**7.7 pH units**	**7.9 pH units**	**7.9 pH units**	**7.8 pH units**	**7.7 pH units**	**7.6 pH units**
Phosphorus, total	NA	**0.015 mg/l**	**0.013 mg/l**	< 0.100 mg/l	< 0.100 mg/l	< 0.100 mg/l	< 0.100 mg/l	< 0.100 mg/l	< 0.100 mg/l	< 0.100 mg/l	< 0.100 mg/l
Silicon dioxide	NA	**22.5 mg/l**	**26.8 mg/l**	**32.1 mg/l**	**38.7 mg/l**	**37.8 mg/l**	**38.7 mg/l**	**37.3 mg/l**	**35.7 mg/l**	**40.4 mg/l**	**36.4 mg/l**
Solids, total dissolved	NA	**1300 mg/l**	**1200 mg/l**	**1400 mg/l**	**1200 mg/l**	**1200 mg/l**	**1100 mg/l**	**1300 mg/l**	**1100 mg/l**	**1100 mg/l**	**1200 mg/l**
Solids, total suspended	NA	**10 mg/l**	**14 mg/l**	**15 mg/l**	**15 mg/l**	**42 mg/l**	**8.0 mg/l**	**22 mg/l**	**110 mg/l**	**9.2 mg/l**	**13 mg/l**
Specific Conductance @ 25oC	NA	**1500 umhos/cm**	**1600 umhos/cm**	**1600 umhos/cm**	**1600 umhos/cm**	**1600 umhos/cm**	**1700 umhos/cm**	**1700 umhos/cm**	**1600 umhos/cm**	**1700 umhos/cm**	**1600 umhos/cm**
Sulfate	NA	**460 mg/l**	**490 mg/l**	**500 mg/l**	**500 mg/l**	**370 mg/l**	**500 mg/l**	**490 mg/l**	**420 mg/l**	**490 mg/l**	**490 mg/l**
Sulfide	NA	< 0.12 mg/l	< 0.12 mg/l	< 0.12 mg/l	< 0.12 mg/l	< 0.12 mg/l	--	--	--	--	--
Metals											
Aluminum	Total	< 10 ug/l	< 10 ug/l	< 10 ug/l	< 10 ug/l	< 10 ug/l	< 10 ug/l	< 10 ug/l	< 10 ug/l	< 10 ug/l	< 10 ug/l
Arsenic	Total	**2.7 ug/l**	**3.0 ug/l**	**2.5 ug/l**	**2.1 ug/l**	**4.9 ug/l**	**2.4 ug/l**	**3.0 ug/l**	**20 ug/l**	**3.3 ug/l**	**3.1 ug/l**
Barium	Total	**32 ug/l**	**35 ug/l**	**35 ug/l**	**33 ug/l**	**45 ug/l**	**32 ug/l**	**32 ug/l**	**140 ug/l**	**32 ug/l**	**35 ug/l**
Boron	Total	**0.48 mg/l**	**0.47 mg/l**	**0.49 mg/l**	**0.45 mg/l**	**0.48 mg/l**	**0.47 mg/l**	**0.46 mg/l**	**0.46 mg/l**	**0.49 mg/l**	**0.50 mg/l**
Cadmium	Total	< 0.20 ug/l	< 0.20 ug/l	< 0.20 ug/l	< 0.20 ug/l	< 0.20 ug/l	--	--	--	--	--
Calcium	Total	**88 mg/l**	**92 mg/l**	**96 mg/l**	**90 mg/l**	**94 mg/l**	**88 mg/l**	**90 mg/l**	**90 mg/l**	**92 mg/l**	**91 mg/l**
Cobalt	Total	**1.0 ug/l**	**1.0 ug/l**	**1.0 ug/l**	**0.81 ug/l**	**1.1 ug/l**	**1.0 ug/l**	**0.84 ug/l**	**1.6 ug/l**	**1.0 ug/l**	**0.97 ug/l**
Copper	Total	**1.8 ug/l**	**3.7 ug/l**	**2.7 ug/l**	< 0.50 ug/l	**2.9 ug/l**	**2.4 ug/l**	**2.3 ug/l**	**2.9 ug/l**	**2.3 ug/l**	**2.9 ug/l**
Iron	Dissolved	**0.070 mg/l**	**8.2 mg/l**	**0.89 mg/l**	**0.66 mg/l**	**0.44 mg/l**	**0.76 mg/l**	**0.64 mg/l**	**0.66 mg/l**	**1.2 mg/l**	**1.3 mg/l**
Iron	Total	**4.4 mg/l**	**7.0 mg/l**	**5.0 mg/l**	**5.3 mg/l**	**12 mg/l**	**3.9 mg/l**	**8.6 mg/l**	**75 mg/l**	**4.8 mg/l**	**6.9 mg/l**
Lead	Total	< 0.20 ug/l	**1.4 ug/l**	**0.42 ug/l**	**0.93 ug/l**	**0.77 ug/l**	**0.32 ug/l**	**0.45 ug/l**	**0.71 ug/l**	**0.41 ug/l**	**0.61 ug/l**
Magnesium	Total	**170 mg/l**	**190 mg/l**	**180 mg/l**	**170 mg/l**	**170 mg/l**	**170 mg/l**	**180 mg/l**	**150 mg/l**	**170 mg/l**	**180 mg/l**
Manganese	Dissolved	**530 ug/l**	**430 ug/l**	**530 ug/l**	**570 ug/l**	**600 ug/l**	**560 ug/l**	**580 ug/l**	**670 ug/l**	**570 ug/l**	**540 ug/l**
Manganese	Total	**570 ug/l**	**590 ug/l**	**570 ug/l**	**570 ug/l**	**640 ug/l**	**640 ug/l**	**560 ug/l**	**900 ug/l**	**570 ug/l**	**540 ug/l**
Mercury	Total	< 0.500 ng/l	< 0.500 ng/l	< 0.500 ng/l	--	--	--	--	--	--	--
Nickel	Total	**3.0 ug/l**	**2.1 ug/l**	**3.2 ug/l**	< 0.50 ug/l	**1.8 ug/l**	**3.0 ug/l**	**2.6 ug/l**	< 0.50 ug/l	**3.5 ug/l**	< 0.50 ug/l
Potassium	Total	**13 mg/l**	**16 mg/l**	**13 mg/l**	**13 mg/l**	**12 mg/l**	**13 mg/l**	**13 mg/l**	**10 mg/l**	**12 mg/l**	**12 mg/l**
Selenium	Total	**1.4 ug/l**	**1.1 ug/l**	**1.6 ug/l**	< 1.0 ug/l	**2.0 ug/l**	**1.5 ug/l**	< 1.0 ug/l	< 1.0 ug/l	**1.1 ug/l**	< 1.0 ug/l
Silicon	Total	**18 mg/l**	**19 mg/l**	**17 mg/l**	**17 mg/l**	**20 mg/l**	**18 mg/l**	**19 mg/l**	**30 mg/l**	**19 mg/l**	**20 mg/l**
Sodium	Total	**89 mg/l**	**99 mg/l**	**89 mg/l**	**88 mg/l**	**84 mg/l**	**85 mg/l**	**84 mg/l**	**71 mg/l**	**85 mg/l**	**83 mg/l**
Strontium	Total	**540 ug/l**	**570 ug/l**	**570 ug/l**	**550 ug/l**	**550 ug/l**	**630 ug/l**	**590 ug/l**	**620 ug/l**	**570 ug/l**	**580 ug/l**
Thallium	Total	< 0.20 ug/l	< 0.20 ug/l	< 0.20 ug/l	< 0.20 ug/l	< 0.20 ug/l	--	--	--	--	--
Vanadium	Total	< 0.50 ug/l	< 0.50 ug/l	< 0.50 ug/l	< 0.50 ug/l	< 0.50 ug/l	< 0.50 ug/l	< 0.50 ug/l	**0.50 ug/l**	< 0.50 ug/l	< 0.50 ug/l
Zinc	Total	< 5.0 ug/l	< 5.0 ug/l	**6.4 ug/l**	< 5.0 ug/l	**5.7 ug/l**	< 5.0 ug/l	**5.4 ug/l**	**8.9 ug/l**	**5.5 ug/l**	**5.2 ug/l**

	Location	SD004	SD004	SD004	SD004	SD004	SD004	SD004	SD004	SD004	SD004
	Date	7/24/2012	8/7/2012	8/14/2012	8/21/2012	8/28/2012	9/4/2012	9/11/2012	9/18/2012	9/25/2012	10/2/2012
	Sample Type	N	N	N	N	N	N	N	N	N	N
	Fraction										
General Parameters											
Alkalinity, bicarbonate, as CaCO3	NA	540 mg/l	480 mg/l	570 mg/l	550 mg/l	600 mg/l	590 mg/l	600 mg/l	600 mg/l	600 mg/l	590 mg/l
Alkalinity, carbonate, as CaCO3	NA	--	--	--	--	--	--	--	--	--	--
Alkalinity, total	NA	540 mg/l	480 mg/l	570 mg/l	550 mg/l	600 mg/l	590 mg/l	600 mg/l	600 mg/l	600 mg/l	590 mg/l
Carbon, dissolved organic	NA	1.7 mg/l	2.6 mg/l	1.7 mg/l	2.1 mg/l	1.7 mg/l	2.3 mg/l	2.3 mg/l	2.0 mg/l	2.0 mg/l	2.6 mg/l
Carbon, total organic	NA	1.8 mg/l	3.1 mg/l	1.8 mg/l	2.0 mg/l	1.8 mg/l	1.9 mg/l	2.2 mg/l	2.2 mg/l	2.2 mg/l	2.1 mg/l
Chloride	NA	22 mg/l	24 mg/l	21 mg/l	21 mg/l	20 mg/l	20 mg/l	21 mg/l	21 mg/l	20 mg/l	20 mg/l
Fluoride	NA	1.8 mg/l	1.5 mg/l	1.7 mg/l	1.8 mg/l	1.7 mg/l	1.7 mg/l	1.6 mg/l	1.7 mg/l	1.6 mg/l	1.7 mg/l
Nitrogen, ammonia (NH3), as N	NA	< 0.200 mg/l	0.201 mg/l	< 0.200 mg/l	< 0.200 mg/l	< 0.200 mg/l	< 0.200 mg/l	< 0.200 mg/l	< 0.200 mg/l	< 0.200 mg/l	< 0.200 mg/l
Nitrogen, Nitrate as N	NA	< 0.23 mg/l	< 1.0 mg/l	< 1.0 mg/l	< 1.0 mg/l	< 1.0 mg/l	< 1.0 mg/l	< 1.0 mg/l	< 1.0 mg/l	< 1.0 mg/l	< 1.0 mg/l
Nitrogen, Nitrite as N	NA	--	--	--	--	--	--	--	--	--	--
Orthophosphate, as PO4	NA	--	--	--	--	--	--	--	--	--	--
pH	NA	8.1 pH units	7.9 pH units	7.9 pH units	8.0 pH units	8.0 pH units	7.9 pH units	7.8 pH units	7.9 pH units	7.7 pH units	8.0 pH units
Phosphorus, total	NA	< 0.100 mg/l	< 0.100 mg/l	< 0.100 mg/l	< 0.100 mg/l	< 0.100 mg/l	< 0.100 mg/l	< 0.100 mg/l	< 0.100 mg/l	< 0.100 mg/l	< 0.100 mg/l
Silicon dioxide	NA	37.7 mg/l	34.7 mg/l	52.1 mg/l	37.8 mg/l	38.4 mg/l	38.4 mg/l	42.6 mg/l	41.5 mg/l	40.1 mg/l	40.2 mg/l
Solids, total dissolved	NA	1300 mg/l	1200 mg/l	1300 mg/l	1400 mg/l	1300 mg/l	1400 mg/l	1400 mg/l	1300 mg/l	1400 mg/l	1400 mg/l
Solids, total suspended	NA	12 mg/l	24 mg/l	17 mg/l	14 mg/l	14 mg/l	17 mg/l	14 mg/l	12 mg/l	14 mg/l	20 mg/l
Specific Conductance @ 25oC	NA	1700 umhos/cm	1600 umhos/cm	1900 umhos/cm	1900 umhos/cm	1800 umhos/cm	1900 umhos/cm	1800 umhos/cm	1700 umhos/cm	1900 umhos/cm	1900 umhos/cm
Sulfate	NA	490 mg/l	400 mg/l	530 mg/l	550 mg/l	520 mg/l	520 mg/l	530 mg/l	530 mg/l	520 mg/l	620 mg/l
Sulfide	NA	--	--	--	--	--	--	--	--	--	--
Metals											
Aluminum	Total	< 10 ug/l	< 10 ug/l	< 10 ug/l	< 10 ug/l	< 10 ug/l	< 10 ug/l	< 10 ug/l	< 10 ug/l	< 10 ug/l	< 10 ug/l
Arsenic	Total	2.6 ug/l	2.9 ug/l	2.7 ug/l	2.5 ug/l	2.5 ug/l	2.7 ug/l	2.4 ug/l	2.6 ug/l	2.4 ug/l	2.7 ug/l
Barium	Total	32 ug/l	59 ug/l	36 ug/l	34 ug/l	32 ug/l	33 ug/l	30 ug/l	33 ug/l	31 ug/l	35 ug/l
Boron	Total	0.50 mg/l	0.45 mg/l	0.46 mg/l	0.51 mg/l	0.54 mg/l	0.48 mg/l	0.51 mg/l	0.50 mg/l	0.52 mg/l	0.53 mg/l
Cadmium	Total	--	--	--	--	--	--	--	--	--	--
Calcium	Total	92 mg/l	91 mg/l	100 mg/l	99 mg/l	98 mg/l	95 mg/l	97 mg/l	96 mg/l	96 mg/l	91 mg/l
Cobalt	Total	0.94 ug/l	0.79 ug/l	0.87 ug/l	0.95 ug/l	0.92 ug/l	0.88 ug/l	0.97 ug/l	0.91 ug/l	0.95 ug/l	0.97 ug/l
Copper	Total	3.8 ug/l	2.6 ug/l	7.2 ug/l	2.6 ug/l	2.6 ug/l	3.5 ug/l	2.8 ug/l	2.2 ug/l	2.5 ug/l	2.1 ug/l
Iron	Dissolved	1.0 mg/l	0.98 mg/l	0.45 mg/l	0.57 mg/l	0.44 mg/l	0.42 mg/l	0.49 mg/l	0.61 mg/l	1.2 mg/l	0.60 mg/l
Iron	Total	4.1 mg/l	7.9 mg/l	5.3 mg/l	4.8 mg/l	5.9 mg/l	5.9 mg/l	5.7 mg/l	5.0 mg/l	4.5 mg/l	6.5 mg/l
Lead	Total	1.8 ug/l	0.59 ug/l	6.3 ug/l	0.35 ug/l	0.34 ug/l	0.49 ug/l	0.63 ug/l	< 0.20 ug/l	< 0.20 ug/l	0.20 ug/l
Magnesium	Total	180 mg/l	160 mg/l	200 mg/l	200 mg/l	200 mg/l	190 mg/l	200 mg/l	200 mg/l	200 mg/l	190 mg/l
Manganese	Dissolved	550 ug/l	900 ug/l	590 ug/l	610 ug/l	610 ug/l	650 ug/l	620 ug/l	620 ug/l	640 ug/l	640 ug/l
Manganese	Total	570 ug/l	920 ug/l	610 ug/l	630 ug/l	610 ug/l	610 ug/l	630 ug/l	650 ug/l	630 ug/l	640 ug/l
Mercury	Total	--	--	--	--	--	--	--	--	--	--
Nickel	Total	< 0.50 ug/l	< 0.50 ug/l	< 0.50 ug/l	< 0.50 ug/l	< 0.50 ug/l	0.67 ug/l	1.1 ug/l	< 0.50 ug/l	< 0.50 ug/l	< 0.50 ug/l
Potassium	Total	14 mg/l	11 mg/l	15 mg/l	15 mg/l	13 mg/l	14 mg/l	14 mg/l	13 mg/l	13 mg/l	12 mg/l
Selenium	Total	< 1.0 ug/l	< 1.0 ug/l	< 1.0 ug/l	< 1.0 ug/l	< 1.0 ug/l	< 1.0 ug/l	< 1.0 ug/l	< 1.0 ug/l	< 1.0 ug/l	< 1.0 ug/l
Silicon	Total	19 mg/l	20 mg/l	20 mg/l	19 mg/l	20 mg/l	19 mg/l	20 mg/l	19 mg/l	20 mg/l	19 mg/l
Sodium	Total	88 mg/l	74 mg/l	96 mg/l	95 mg/l	85 mg/l	89 mg/l	88 mg/l	84 mg/l	84 mg/l	77 mg/l
Strontium	Total	600 ug/l	520 ug/l	660 ug/l	610 ug/l	600 ug/l	640 ug/l	630 ug/l	660 ug/l	660 ug/l	640 ug/l
Thallium	Total	--	--	--	--	--	--	--	--	--	--
Vanadium	Total	< 0.50 ug/l	< 0.50 ug/l	< 0.50 ug/l	< 0.50 ug/l	< 0.50 ug/l	< 0.50 ug/l	< 0.50 ug/l	< 0.50 ug/l	< 0.50 ug/l	< 0.50 ug/l
Zinc	Total	5.2 ug/l	< 5.0 ug/l	11 ug/l	5.9 ug/l	5.6 ug/l	5.9 ug/l	6.3 ug/l	< 5.0 ug/l	< 5.0 ug/l	< 5.0 ug/l

	Location	SD004	SD004
	Date	10/16/2012	10/30/2012
	Sample Type	N	N
	Fraction		
General Parameters			
Alkalinity, bicarbonate, as CaCO3	NA	**580 mg/l**	**590 mg/l**
Alkalinity, carbonate, as CaCO3	NA	--	--
Alkalinity, total	NA	--	--
Carbon, dissolved organic	NA	--	--
Carbon, total organic	NA	**1.8 mg/l**	**1.42 mg/l**
Chloride	NA	**20 mg/l**	**21 mg/l**
Fluoride	NA	**1.7 mg/l**	**1.6 mg/l**
Nitrogen, ammonia (NH3), as N	NA	< 0.500 mg/l	< 0.500 mg/l
Nitrogen, Nitrate as N	NA	--	--
Nitrogen, Nitrite as N	NA	--	--
Orthophosphate, as PO4	NA	--	--
pH	NA	**8.0 pH units**	**7.8 pH units**
Phosphorus, total	NA	**0.233 mg/l**	< 0.100 mg/l
Silicon dioxide	NA	**39.4 mg/l**	**37.3 mg/l**
Solids, total dissolved	NA	**1500 mg/l**	**1500 mg/l**
Solids, total suspended	NA	**12 mg/l**	**25 mg/l**
Specific Conductance @ 25oC	NA	**1800 umhos/cm**	**1800 umhos/cm**
Sulfate	NA	**520 mg/l**	**530 mg/l**
Sulfide	NA	--	--
Metals			
Aluminum	Total	--	--
Arsenic	Total	**2.6 ug/l**	**2.6 ug/l**
Barium	Total	**35 ug/l**	**34 ug/l**
Boron	Total	**0.51 mg/l**	**0.51 mg/l**
Cadmium	Total	--	--
Calcium	Total	**98 mg/l**	**97 mg/l**
Cobalt	Total	**0.90 ug/l**	**0.91 ug/l**
Copper	Total	**2.7 ug/l**	**1.8 ug/l**
Iron	Dissolved	**0.81 mg/l**	**1.1 mg/l**
Iron	Total	**5.4 mg/l**	**4.7 mg/l**
Lead	Total	**21 ug/l**	< 0.20 ug/l
Magnesium	Total	**200 mg/l**	**190 mg/l**
Manganese	Dissolved	**590 ug/l**	**590 ug/l**
Manganese	Total	**620 ug/l**	**610 ug/l**
Mercury	Total	--	--
Nickel	Total	< 0.50 ug/l	**0.68 ug/l**
Potassium	Total	**13 mg/l**	**11 mg/l**
Selenium	Total	< 1.0 ug/l	< 1.0 ug/l
Silicon	Total	**18 mg/l**	**19 mg/l**
Sodium	Total	**83 mg/l**	**82 mg/l**
Strontium	Total	**650 ug/l**	**630 ug/l**
Thallium	Total	--	--
Vanadium	Total	< 0.50 ug/l	< 0.50 ug/l
Zinc	Total	**25 ug/l**	< 5.0 ug/l

Table 2 Pilot Test Well Water Quality

Location		Well Discharge	Well Discharge	Well Discharge	Well Discharge	Well Discharge	Well Discharge	Well Discharge	Well Discharge	Well Discharge	Well Discharge
Date		5/14/2012	5/21/2012	5/29/2012	6/4/2012	6/11/2012	6/19/2012	6/26/2012	7/5/2012	7/10/2012	7/17/2012
Sample Type		N	N	N	N	N	N	N	N	N	N
	Fraction										
General Parameters											
Alkalinity, bicarbonate, as CaCO3	NA	530 mg/l	540 mg/l	550 mg/l	530 mg/l	540 mg/l	530 mg/l	580 mg/l	510 mg/l	360 mg/l	390 mg/l
Alkalinity, carbonate, as CaCO3	NA	< 20 mg/l	< 20 mg/l	< 20 mg/l	< 20 mg/l	< 20 mg/l	--	--	--	--	--
Alkalinity, total	NA	530 mg/l	540 mg/l	550 mg/l	530 mg/l	540 mg/l	530 mg/l	580 mg/l	510 mg/l	360 mg/l	390 mg/l
Carbon, dissolved organic	NA	2.6 mg/l	2.1 mg/l	8.1 mg/l	2.4 mg/l	3.0 mg/l	2.9 mg/l	3.1 mg/l	3.1 mg/l	7.3 mg/l	7.3 mg/l
Carbon, total organic	NA	2.3 mg/l	2.4 mg/l	13 mg/l	3.8 mg/l	6.5 mg/l	3.3 mg/l	6.2 mg/l	3.6 mg/l	8.1 mg/l	7.3 mg/l
Chloride	NA	22 mg/l	22 mg/l	22 mg/l	22 mg/l	21 mg/l	22 mg/l	21 mg/l	21 mg/l	31 mg/l	27 mg/l
Fluoride	NA	1.6 mg/l	1.6 mg/l	1.6 mg/l	1.7 mg/l	1.6 mg/l	1.5 mg/l	1.8 mg/l	1.6 mg/l	0.92 mg/l	1.1 mg/l
Nitrogen, ammonia (NH3), as N	NA	< 0.500 mg/l	0.889 mg/l	< 0.200 mg/l	< 0.200 mg/l	0.243 mg/l	< 0.200 mg/l	< 0.200 mg/l	0.649 mg/l	0.462 mg/l	0.508 mg/l
Nitrogen, Nitrate as N	NA	< 1.0 h mg/l	< 0.23 mg/l	< 0.22 mg/l	< 0.22 mg/l	< 0.23 mg/l	< 0.23 mg/l	< 1.0 mg/l	< 0.23 mg/l	< 0.23 mg/l	< 0.23 mg/l
Nitrogen, Nitrite as N	NA	< 1.0 h mg/l	< 0.30 mg/l	< 0.30 mg/l	< 0.30 mg/l	< 0.30 mg/l	--	--	--	--	--
Orthophosphate, as PO4	NA	< 0.20 mg/l	< 0.20 mg/l	< 0.20 mg/l	< 0.20 mg/l	< 0.20 mg/l	--	--	--	--	--
pH	NA	7.5 pH units	7.8 pH units	7.3 pH units	7.4 pH units	7.4 pH units	7.5 pH units	7.6 pH units	7.4 pH units	7.2 pH units	7.6 pH units
Phosphorus, total	NA	0.043 mg/l	0.053 mg/l	0.312 mg/l	0.156 mg/l	0.671 mg/l	< 0.100 mg/l	0.288 mg/l	0.202 mg/l	< 0.100 mg/l	< 0.100 mg/l
Silicon dioxide	NA	25.0 mg/l	31.3 mg/l	33.6 mg/l	32.1 mg/l	33.0 mg/l	38.8 mg/l	34.0 mg/l	36.4 mg/l	37.3 mg/l	34.1 mg/l
Solids, total dissolved	NA	1200 mg/l	1200 mg/l	1200 mg/l	1200 mg/l	1200 mg/l	1000 mg/l	1300 mg/l	1100 mg/l	460 mg/l	640 mg/l
Solids, total suspended	NA	20 mg/l	17 mg/l	96 mg/l	45 mg/l	150 mg/l	38 mg/l	210 mg/l	48 mg/l	42 mg/l	39 mg/l
Specific Conductance @ 25oC	NA	1600 umhos/cm	1600 umhos/cm	1500 umhos/cm	1600 umhos/cm	1600 umhos/cm	1600 umhos/cm	1700 umhos/cm	1600 umhos/cm	890 umhos/cm	1000 umhos/cm
Sulfate	NA	430 mg/l	450 mg/l	440 mg/l	460 mg/l	350 mg/l	430 mg/l	470 mg/l	450 mg/l	100 mg/l	160 mg/l
Sulfide	NA	< 0.12 mg/l	< 0.12 mg/l	< 0.12 mg/l	< 0.12 mg/l	< 0.12 mg/l	--	--	--	--	--
Metals											
Aluminum	Total	< 10 ug/l	< 10 ug/l	15 ug/l	11 ug/l	21 ug/l	22 ug/l	16 ug/l	< 10 ug/l	< 10 ug/l	< 10 ug/l
Arsenic	Total	5.4 ug/l	4.6 ug/l	11 ug/l	6.6 ug/l	14 ug/l	4.9 ug/l	8.6 ug/l	4.7 ug/l	5.8 ug/l	4.8 ug/l
Barium	Total	74 ug/l	75 ug/l	150 ug/l	120 ug/l	200 ug/l	94 ug/l	170 ug/l	150 ug/l	110 ug/l	120 ug/l
Boron	Total	0.47 mg/l	0.48 mg/l	0.49 mg/l	0.46 mg/l	0.50 mg/l	0.47 mg/l	0.47 mg/l	0.47 mg/l	0.28 mg/l	0.32 mg/l
Cadmium	Total	< 0.20 ug/l	< 0.20 ug/l	< 0.20 ug/l	< 0.20 ug/l	< 0.20 ug/l	--	--	--	--	--
Calcium	Total	77 mg/l	86 mg/l	86 mg/l	83 mg/l	91 mg/l	85 mg/l	88 mg/l	93 mg/l	68 mg/l	73 mg/l
Cobalt	Total	0.62 ug/l	0.59 ug/l	0.72 ug/l	0.52 ug/l	0.86 ug/l	0.70 ug/l	0.71 ug/l	0.60 ug/l	0.54 ug/l	0.52 ug/l
Copper	Total	3.1 ug/l	2.6 ug/l	4.3 ug/l	0.85 ug/l	40 ug/l	3.0 ug/l	10 ug/l	28 ug/l	3.5 ug/l	2.4 ug/l
Iron	Dissolved	5.3 mg/l	0.68 mg/l	9.5 mg/l	8.5 mg/l	7.3 mg/l	11 mg/l	9.6 mg/l	14 mg/l	15 mg/l	16 mg/l
Iron	Total	8.8 mg/l	11 mg/l	34 mg/l	27 mg/l	56 mg/l	14 mg/l	39 mg/l	19 mg/l	17 mg/l	17 mg/l
Lead	Total	0.54 ug/l	0.23 ug/l	0.32 ug/l	0.32 ug/l	6.8 ug/l	0.25 ug/l	3.0 ug/l	4.4 ug/l	1.1 ug/l	0.65 ug/l
Magnesium	Total	170 mg/l	190 mg/l	170 mg/l	170 mg/l	170 mg/l	180 mg/l	180 mg/l	160 mg/l	75 mg/l	86 mg/l
Manganese	Dissolved	570 ug/l	540 ug/l	480 ug/l	700 ug/l	930 ug/l	680 ug/l	920 ug/l	1100 ug/l	1400 ug/l	1400 ug/l
Manganese	Total	370 ug/l	490 ug/l	590 ug/l	600 ug/l	760 ug/l	770 ug/l	770 ug/l	1100 ug/l	1300 ug/l	1400 ug/l
Mercury	Total	< 0.500 ng/l	< 0.500 ng/l	< 0.500 ng/l	--	--	--	--	--	--	--
Nickel	Total	2.4 ug/l	2.2 ug/l	2.8 ug/l	< 0.50 ug/l	2.9 ug/l	2.7 ug/l	2.6 ug/l	< 0.50 ug/l	2.0 ug/l	< 0.50 ug/l
Potassium	Total	8.0 mg/l	10 mg/l	8.0 mg/l	8.9 mg/l	8.4 mg/l	8.6 mg/l	9.0 mg/l	7.2 mg/l	3.8 mg/l	4.3 mg/l
Selenium	Total	1.3 ug/l	< 1.0 ug/l	1.8 ug/l	< 1.0 ug/l	2.2 ug/l	1.5 ug/l	< 1.0 ug/l	< 1.0 ug/l	1.7 ug/l	< 1.0 ug/l
Silicon	Total	17 mg/l	19 mg/l	18 mg/l	18 mg/l	22 mg/l	19 mg/l	21 mg/l	18 mg/l	19 mg/l	19 mg/l
Sodium	Total	81 mg/l	99 mg/l	87 mg/l	88 mg/l	86 mg/l	80 mg/l	81 mg/l	74 mg/l	35 mg/l	39 mg/l
Strontium	Total	530 ug/l	530 ug/l	540 ug/l	550 ug/l	550 ug/l	590 ug/l	560 ug/l	540 ug/l	280 ug/l	360 ug/l
Thallium	Total	< 0.20 ug/l	< 0.20 ug/l	< 0.20 ug/l	< 0.20 ug/l	< 0.20 ug/l	--	--	--	--	--
Vanadium	Total	< 0.50 ug/l	< 0.50 ug/l	2.0 ug/l	1.2 ug/l	3.2 ug/l	0.52 ug/l	1.7 ug/l	0.89 ug/l	1.7 ug/l	1.5 ug/l
Zinc	Total	12 ug/l	6.7 ug/l	9.7 ug/l	9.7 ug/l	48 ug/l	7.2 ug/l	21 ug/l	26 ug/l	9.6 ug/l	6.3 ug/l

Location		Well Discharge	Well Discharge	Well Discharge	Well Discharge	Well Discharge	Well Discharge	Well Discharge	Well Discharge	Well Discharge	Well Discharge
Date		7/24/2012	8/7/2012	8/14/2012	8/21/2012	8/28/2012	9/4/2012	9/11/2012	9/18/2012	9/25/2012	10/2/2012
Sample Type		N	N	N	N	N	N	N	N	N	N
	Fraction										
General Parameters											
Alkalinity, bicarbonate, as CaCO3	NA	360 mg/l	350 mg/l	510 mg/l	370 mg/l	370 mg/l	550 mg/l	390 mg/l	370 mg/l	380 mg/l	380 mg/l
Alkalinity, carbonate, as CaCO3	NA	--	--	--	--	--	--	--	--	--	--
Alkalinity, total	NA	360 mg/l	350 mg/l	510 mg/l	370 mg/l	370 mg/l	550 mg/l	390 mg/l	370 mg/l	380 mg/l	380 mg/l
Carbon, dissolved organic	NA	7.5 mg/l	7.2 mg/l	4.9 mg/l	7.5 mg/l	7.8 mg/l	2.9 mg/l	3.5 mg/l	2.8 mg/l	7.4 mg/l	7.7 mg/l
Carbon, total organic	NA	7.5 mg/l	8.0 mg/l	4.6 mg/l	7.5 mg/l	7.7 mg/l	7.9 mg/l	13 mg/l	3.7 mg/l	12 mg/l	7.8 mg/l
Chloride	NA	31 mg/l	31 mg/l	23 mg/l	28 mg/l	30 mg/l	22 mg/l	31 mg/l	31 mg/l	30 mg/l	32 mg/l
Fluoride	NA	0.96 mg/l	0.75 mg/l	1.1 mg/l	0.81 mg/l	0.80 mg/l	1.3 mg/l	0.83 mg/l	0.78 mg/l	0.82 mg/l	0.77 mg/l
Nitrogen, ammonia (NH3), as N	NA	0.438 mg/l	0.520 mg/l	0.770 mg/l	0.529 mg/l	0.506 mg/l	0.718 mg/l	0.301 mg/l	0.236 mg/l	0.567 mg/l	0.512 mg/l
Nitrogen, Nitrate as N	NA	< 0.23 mg/l	< 1.0 mg/l	< 1.0 mg/l	< 1.0 mg/l	< 1.0 mg/l	< 1.0 mg/l	< 1.0 mg/l	< 1.0 mg/l	< 1.0 mg/l	< 1.0 mg/l
Nitrogen, Nitrite as N	NA	--	--	--	--	--	--	--	--	--	--
Orthophosphate, as PO4	NA	--	--	--	--	--	--	--	--	--	--
pH	NA	7.8 pH units	7.7 pH units	7.8 pH units	7.2 pH units	7.6 pH units	7.5 pH units	7.2 pH units	7.3 pH units	7.6 pH units	7.4 pH units
Phosphorus, total	NA	< 0.100 mg/l	< 0.100 mg/l	0.104 mg/l	< 0.100 mg/l	< 0.100 mg/l	1.81 mg/l	2.44 mg/l	0.608 mg/l	1.25 mg/l	< 0.100 mg/l
Silicon dioxide	NA	36.0 mg/l	33.0 mg/l	36.0 mg/l	34.8 mg/l	33.8 mg/l	35.0 mg/l	35.6 mg/l	36.6 mg/l	35.4 mg/l	35.5 mg/l
Solids, total dissolved	NA	590 mg/l	580 mg/l	1100 mg/l	580 mg/l	600 mg/l	1200 mg/l	580 mg/l	560 mg/l	600 mg/l	620 mg/l
Solids, total suspended	NA	37 mg/l	44 mg/l	54 mg/l	45 mg/l	42 mg/l	110 mg/l	53 mg/l	43 mg/l	58 mg/l	40 mg/l
Specific Conductance @ 25oC	NA	930 umhos/cm	890 umhos/cm	1600 umhos/cm	950 umhos/cm	940 umhos/cm	1600 umhos/cm	980 umhos/cm	910 umhos/cm	960 umhos/cm	970 umhos/cm
Sulfate	NA	92 mg/l	93 mg/l	390 mg/l	96 mg/l	99 mg/l	410 mg/l	110 mg/l	110 mg/l	110 mg/l	110 mg/l
Sulfide	NA	--	--	--	--	--	--	--	--	--	--
Metals											
Aluminum	Total	< 10 ug/l	< 10 ug/l	< 10 ug/l	< 10 ug/l	< 10 ug/l	< 10 ug/l	11 ug/l	< 10 ug/l	< 10 ug/l	< 10 ug/l
Arsenic	Total	4.3 ug/l	4.3 ug/l	4.9 ug/l	4.2 ug/l	4.3 ug/l	2.8 ug/l	18 ug/l	8.2 ug/l	8.8 ug/l	4.1 ug/l
Barium	Total	99 ug/l	130 ug/l	210 ug/l	130 ug/l	130 ug/l	140 ug/l	340 ug/l	160 ug/l	200 ug/l	130 ug/l
Boron	Total	0.28 mg/l	0.27 mg/l	0.38 mg/l	0.28 mg/l	0.29 mg/l	0.29 mg/l	0.40 mg/l	0.48 mg/l	0.27 mg/l	0.28 mg/l
Cadmium	Total	--	--	--	--	--	--	--	--	--	--
Calcium	Total	63 mg/l	71 mg/l	100 mg/l	73 mg/l	73 mg/l	72 mg/l	88 mg/l	90 mg/l	70 mg/l	66 mg/l
Cobalt	Total	0.44 ug/l	0.45 ug/l	0.53 ug/l	0.46 ug/l	0.45 ug/l	0.41 ug/l	0.54 ug/l	0.46 ug/l	0.43 ug/l	0.42 ug/l
Copper	Total	15 ug/l	3.1 ug/l	5.1 ug/l	1.8 ug/l	1.9 ug/l	3.0 ug/l	1.9 ug/l	2.5 ug/l	1.4 ug/l	46 ug/l
Iron	Dissolved	15 mg/l	19 mg/l	21 mg/l	18 mg/l	18 mg/l	16 mg/l	16 mg/l	15 mg/l	18 mg/l	18 mg/l
Iron	Total	15 mg/l	19 mg/l	23 mg/l	19 mg/l	19 mg/l	17 mg/l	70 mg/l	29 mg/l	37 mg/l	17 mg/l
Lead	Total	2.0 ug/l	0.73 ug/l	0.76 ug/l	0.23 ug/l	0.31 ug/l	0.65 ug/l	0.23 ug/l	0.38 ug/l	< 0.20 ug/l	18 ug/l
Magnesium	Total	76 mg/l	71 mg/l	160 mg/l	73 mg/l	73 mg/l	74 mg/l	150 mg/l	180 mg/l	71 mg/l	68 mg/l
Manganese	Dissolved	1300 ug/l	1700 ug/l	1600 ug/l	1800 ug/l	1800 ug/l	1600 ug/l	930 ug/l	840 ug/l	1700 ug/l	1800 ug/l
Manganese	Total	1300 ug/l	1700 ug/l	1800 ug/l	1800 ug/l	1800 ug/l	1500 ug/l	1400 ug/l	970 ug/l	1800 ug/l	1900 ug/l
Mercury	Total	--	--	--	--	--	--	--	--	--	--
Nickel	Total	< 0.50 ug/l	< 0.50 ug/l	< 0.50 ug/l	< 0.50 ug/l	< 0.50 ug/l	2.8 ug/l	1.5 ug/l	< 0.50 ug/l	< 0.50 ug/l	< 0.50 ug/l
Potassium	Total	4.2 mg/l	3.5 mg/l	7.6 mg/l	3.8 mg/l	3.5 mg/l	4.1 mg/l	7.5 mg/l	8.7 mg/l	3.3 mg/l	3.4 mg/l
Selenium	Total	< 1.0 ug/l	< 1.0 ug/l	< 1.0 ug/l	< 1.0 ug/l	< 1.0 ug/l	< 1.0 ug/l	< 1.0 ug/l	< 1.0 ug/l	< 1.0 ug/l	< 1.0 ug/l
Silicon	Total	18 mg/l	19 mg/l	20 mg/l	19 mg/l	19 mg/l	16 mg/l	23 mg/l	21 mg/l	20 mg/l	17 mg/l
Sodium	Total	33 mg/l	32 mg/l	67 mg/l	34 mg/l	32 mg/l	34 mg/l	60 mg/l	69 mg/l	31 mg/l	30 mg/l
Strontium	Total	320 ug/l	280 ug/l	530 ug/l	290 ug/l	290 ug/l	300 ug/l	490 ug/l	560 ug/l	310 ug/l	320 ug/l
Thallium	Total	--	--	--	--	--	--	--	--	--	--
Vanadium	Total	1.5 ug/l	1.8 ug/l	0.94 ug/l	1.8 ug/l	1.8 ug/l	1.1 ug/l	7.4 ug/l	1.2 ug/l	3.5 ug/l	1.6 ug/l
Zinc	Total	16 ug/l	5.6 ug/l	7.4 ug/l	5.5 ug/l	< 5.0 ug/l	6.6 ug/l	5.5 ug/l	9.4 ug/l	10 ug/l	45 ug/l

Location		Well Discharge	Well Discharge
Date		10/16/2012	10/30/2012
Sample Type		N	N
	Fraction		
General Parameters			
Alkalinity, bicarbonate, as CaCO3	NA	**560 mg/l**	**360 mg/l**
Alkalinity, carbonate, as CaCO3	NA	--	--
Alkalinity, total	NA	--	--
Carbon, dissolved organic	NA	--	--
Carbon, total organic	NA	**2.8 mg/l**	**6.74 mg/l**
Chloride	NA	**22 mg/l**	**30 mg/l**
Fluoride	NA	**1.4 mg/l**	**0.68 mg/l**
Nitrogen, ammonia (NH3), as N	NA	< 0.500 mg/l	**0.530 mg/l**
Nitrogen, Nitrate as N	NA	--	--
Nitrogen, Nitrite as N	NA	--	--
Orthophosphate, as PO4	NA	--	--
pH	NA	**7.7 pH units**	**7.2 pH units**
Phosphorus, total	NA	**0.211 mg/l**	**0.345 mg/l**
Silicon dioxide	NA	**37.5 mg/l**	**33.3 mg/l**
Solids, total dissolved	NA	**1200 mg/l**	**590 mg/l**
Solids, total suspended	NA	**71 mg/l**	**12 mg/l**
Specific Conductance @ 25oC	NA	**1600 umhos/cm**	**960 umhos/cm**
Sulfate	NA	**380 mg/l**	**120 mg/l**
Sulfide	NA	--	--
Metals			
Aluminum	Total	--	--
Arsenic	Total	**8.0 ug/l**	**3.3 ug/l**
Barium	Total	**140 ug/l**	**120 ug/l**
Boron	Total	**0.46 mg/l**	**0.30 mg/l**
Cadmium	Total	--	--
Calcium	Total	**89 mg/l**	**68 mg/l**
Cobalt	Total	**0.41 ug/l**	**0.36 ug/l**
Copper	Total	**2.0 ug/l**	**2.1 ug/l**
Iron	Dissolved	**10 mg/l**	**12 mg/l**
Iron	Total	**24 mg/l**	**12 mg/l**
Lead	Total	**0.23 ug/l**	**0.27 ug/l**
Magnesium	Total	**180 mg/l**	**79 mg/l**
Manganese	Dissolved	**910 ug/l**	**1500 ug/l**
Manganese	Total	**920 ug/l**	**1600 ug/l**
Mercury	Total	--	--
Nickel	Total	< 0.50 ug/l	< 0.50 ug/l
Potassium	Total	**8.5 mg/l**	**3.7 mg/l**
Selenium	Total	< 1.0 ug/l	< 1.0 ug/l
Silicon	Total	**20 mg/l**	**17 mg/l**
Sodium	Total	**65 mg/l**	**33 mg/l**
Strontium	Total	**510 ug/l**	**310 ug/l**
Thallium	Total	--	--
Vanadium	Total	**0.96 ug/l**	**1.2 ug/l**
Zinc	Total	**7.9 ug/l**	**9.1 ug/l**

Table 3 Treated Water Quality Targets

Chemical Name	Total or Dissolved	Units	Potential Maximum Treated Water Concentrations at Discharge Location	
			SD-006	SD-026
General Parameters				
Alkalinity, bicarbonate as CaCO3	NA	mg/L	---[1] 250[4]	---[1] 250[4]
Alkalinity, total	NA	mg/L		
Biochemical Oxygen Demand (5-day)	NA	mg/L		
Carbon, dissolved organic	NA	mg/L		
Carbon, total organic	NA	mg/L		
Chemical Oxygen Demand	NA	mg/L		
Chloride	NA	mg/L	230[4]	230[4]
Cyanide	NA	mg/L	0.0052[4]	0.0052[4]
Fluoride	NA	mg/L	2[4]	---[1]
Hardness, total as CaCO3	NA	mg/L	---[1] 250[4]	---[1] 250[4]
Nitrogen, ammonia as N	NA	mg/L	0.04[4]	0.04[4]
Nitrogen, Nitrate	NA	mg/L		
Nitrogen, Nitrite	NA	mg/L		
Phosphate, ortho	NA	mg/L		
Phosphorus, total	NA	mg/L		
Solids, total dissolved	NA	mg/L	700[4]	700[4]
Solids, total suspended	NA	mg/L	20 (30)	30 (60)
Sulfate	NA	mg/L	10[3]	10[3]
Sulfide	NA	mg/L		
pH, standard units	NA	SU	6.5 - 8.5	6.5 - 8.5
Dissolved oxygen	NA	mg/L		
Redox (oxidation potential)	NA	mV		
Salinity (total)	NA	mg/L	---[1]	---[1]
Specific Conductance umhos@ 25oC	NA	umho/cm	---[1]	1000
Temperature, degrees C	NA	degC	---[1]	
Turbidity	NA	NTU	25	25[4]
Chronic Whole Effluent Toxicity (WET) Test - IC25	NA	%	100	100
Metals				
Aluminum	Total	ug/L	125[4]	125[4]
Antimony	Total	ug/L	31[4]	31[4]
Arsenic	Total	ug/L	53[4]	53[4]
Barium	Total	ug/L		
Beryllium	Total	ug/L		
Boron	Total	ug/L	500[4]	---[1]
Cadmium	Total	ug/L		
Calcium	Total	ug/L		---[1]
Chromium	Total	ug/L	11[5]	11[5]
Cobalt	Total	ug/L	5[4]	---[1]
Copper	Total	ug/L	30[4]	30[4]
Iron	Total	ug/L	1000 (2000)[2]	300[4]
Lead	Total	ug/L	19[4]	19[4]
Magnesium	Total	ug/L		---[1]
Manganese	Total	ug/L		---[1]
Mercury	Total	ug/L	---[1]	---[1]
Molybdenum	Total	ug/L		---[1]
Nickel	Total	ug/L		
Palladium	Total	ug/L		
Platinum	Total	ug/L		
Potassium	Total	ug/L		---[1]
Selenium	Total	ug/L	5[4]	5[4]
Silica	Dissolved	mg/L		
Silica	Total	mg/L		
Silver	Total	ug/L	1[4]	1[4]
Sodium	Total	ug/L		---[1]
Strontium	Total	ug/L		
Thallium	Total	ug/L	0.56[4]	0.56[4]
Titanium	Total	ug/L		
Zinc	Total	ug/L	388[4]	388[4]

Table 4 Greensand Filter Removal Rates

		TSS			Total Fe			Total Mn		
	Sample Date	Feed Tank Effluent	GSF Effluent	% Removal	Feed Tank Effluent	GSF Effluent	% Removal	Feed Tank Effluent	GSF Effluent	% Removal
Phase 3 - Optimization	05/10/2012	12	2	>83%	6300	25	>99.6%		1.50	
	05/14/2012	6.8	2	>71%	5100	25	>99.5%		9.10	
	05/21/2012	7.6	2	>74%	5400	25	>99.5%		5.40	
	05/29/2012	12	2	>83%	6400	25	>99.6%		880	
	06/04/2012	12	2	>83%	6800	25	>99.6%		440	
	06/11/2012	22	2	>91%	7900	25	>99.7%		610	
	06/19/2012	22	2	>91%	11000	25	>99.8%	1200	630	47.5%
	06/26/2012	10	2	>80%	4400	25	>99.4%	1200	210	82.5%
Phase 4 - Steady State	07/05/2012	20	2	>90%	6700	25	>99.6%	1100	86	92.2%
	07/10/2012	21	2	>90%	11000	25	>99.8%	1200	380	68.3%
	07/17/2012	42	2	>95%	18000	25	>99.9%	1100	170	84.5%
	07/24/2012	14	2	>86%	8200	25	>99.7%	1100	220	80.0%
	08/07/2012	37	2	>95%	20000	25	>99.9%	1400	89	93.6%
	08/14/2012	36	2	>94%	17000	25	>99.9%	1400	54	96.1%
	08/21/2012	27	2	>93%	12000	25	>99.8%	1500	31	97.9%
	08/28/2012	35	2	>94%	19000	25	>99.9%	1600	51	96.8%
	09/04/2012	14	2	>86%	5500	25	>99.5%	1400	71	94.9%
	09/11/2012	10	2	>80%	5500	25	>99.5%	950	15	98.4%
	09/18/2012	20	2	>90%	8600	59	99.3%	1200	15	98.8%
	09/25/2012	34	2	>94%	16000	25	>99.8%	1400	22	98.4%
	10/02/2012	29	2	>93%	16000	25	>99.8%	1600	24	98.5%
	10/16/2012	20	2	>90%	8500	25	>99.7%	1400	47	96.6%
	10/30/2012	8	2	>75%	4500	25	>99.4%	1300	56	95.7%

Table 5 Greensand Filter Water Quality

		Phase 3 - Optimization							
Location		Pretreated Effluent	Pretreated Effluent	Pretreated Effluent	Pretreated Effluent	Pretreated Effluent	Pretreated Effluent	Pretreated Effluent	Pretreated Effluent
Date		5/10/2012	5/14/2012	5/21/2012	5/29/2012	6/4/2012	6/11/2012	6/19/2012	6/26/2012
Sample Type		N	N	N	N	N	N	N	N
	Fraction								
General Parameters									
Alkalinity, bicarbonate, as CaCO3	NA	450 mg/l	430 mg/l	410 mg/l	390 mg/l	390 mg/l	390 mg/l	410 mg/l	420 mg/l
Alkalinity, carbonate, as CaCO3	NA	< 20 mg/l	< 20 mg/l	< 20 mg/l	< 20 mg/l	< 20 mg/l	< 20 mg/l	--	--
Alkalinity, total	NA	450 mg/l	430 mg/l	410 mg/l	390 mg/l	390 mg/l	390 mg/l	410 mg/l	420 mg/l
Carbon, dissolved organic	NA	3.3 mg/l	3.1 mg/l	4.1 mg/l	7.3 mg/l	4.8 mg/l	4.9 mg/l	4.6 mg/l	4.4 mg/l
Carbon, total organic	NA	3.1 mg/l	3.3 mg/l	3.8 mg/l	9.4 mg/l	4.6 mg/l	4.9 mg/l	4.2 mg/l	4.3 mg/l
Chloride	NA	23 mg/l	24 mg/l	25 mg/l	26 mg/l	27 mg/l	28 mg/l	28 mg/l	26 mg/l
Fluoride	NA	1.3 mg/l	1.4 mg/l	1.3 mg/l	1.1 mg/l	1.0 mg/l	1.0 mg/l	1.2 mg/l	1.3 mg/l
Nitrogen, ammonia (NH3), as N	NA	< 0.500 mg/l	< 0.500 mg/l	< 0.500 mg/l	0.262 mg/l	0.234 mg/l	0.313 mg/l	0.317 mg/l	0.284 mg/l
Nitrogen, Nitrate as N	NA	< 0.20 mg/l	< 0.20 mg/l	< 0.045 mg/l	< 0.045 mg/l	< 0.045 mg/l	< 0.045 * mg/l	< 0.23 mg/l	< 1.0 mg/l
Nitrogen, Nitrite as N	NA	< 0.20 mg/l	< 0.20 mg/l	< 0.061 mg/l	< 0.061 mg/l	< 0.061 mg/l	< 0.061 mg/l	--	--
Orthophosphate, as PO4	NA	< 0.20 mg/l	< 0.20 mg/l	< 0.20 mg/l	< 0.20 mg/l	< 0.20 mg/l	< 0.20 mg/l	--	--
pH	NA	7.8 pH units	7.9 pH units	7.7 pH units	7.6 pH units	7.6 pH units	7.7 pH units	7.7 pH units	7.5 pH units
Phosphorus, total	NA	0.010 mg/l	0.010 mg/l	< 0.010 mg/l	< 0.100 mg/l	< 0.100 mg/l	< 0.100 mg/l	< 0.100 mg/l	< 0.100 mg/l
Silicon dioxide	NA	20.0 mg/l	25.0 mg/l	32.7 mg/l	32.5 mg/l	45.3 * mg/l	36.8 mg/l	36.9 mg/l	37.3 mg/l
Solids, total dissolved	NA	980 mg/l	910 mg/l	830 mg/l	860 mg/l	730 mg/l	690 mg/l	710 mg/l	910 mg/l
Solids, total suspended	NA	< 4.0 mg/l	< 4.0 mg/l	< 4.0 mg/l	< 4.0 mg/l	< 4.0 mg/l	< 4.0 mg/l	< 4.0 mg/l	< 4.0 mg/l
Specific Conductance @ 25oC	NA	1200 umhos/cm	1500 umhos/cm	1200 umhos/cm	1100 umhos/cm	990 umhos/cm	1100 umhos/cm	1200 umhos/cm	1200 umhos/cm
Sulfate	NA	290 mg/l	330 mg/l	280 mg/l	230 mg/l	180 mg/l	180 mg/l	230 mg/l	290 mg/l
Sulfide	NA	< 0.12 mg/l	< 0.12 mg/l	< 0.12 mg/l	< 0.12 mg/l	< 0.12 mg/l	< 0.12 mg/l	--	--
Metals									
Aluminum	Total	< 10 ug/l	< 10 ug/l	< 10 ug/l	< 10 ug/l	< 10 ug/l	< 10 ug/l	< 10 ug/l	< 10 ug/l
Arsenic	Total	1.1 ug/l	< 1.0 ug/l	1.0 ug/l	1.1 ug/l	< 1.0 ug/l	< 1.0 ug/l	< 1.0 ug/l	< 1.0 ug/l
Barium	Total	11 ug/l	9.0 ug/l	28 ug/l	37 ug/l	44 ug/l	51 ug/l	55 ug/l	51 ug/l
Boron	Total	0.41 mg/l	0.41 mg/l	0.38 mg/l	0.35 mg/l	0.32 mg/l	0.33 mg/l	0.33 mg/l	0.36 mg/l
Cadmium	Total	< 0.20 ug/l	< 0.20 ug/l	< 0.20 ug/l	< 0.20 ug/l	< 0.20 ug/l	< 0.20 ug/l	--	--
Calcium	Total	68 mg/l	69 mg/l	74 mg/l	72 mg/l	70 mg/l	75 mg/l	72 mg/l	78 mg/l
Cobalt	Total	< 0.20 ug/l	0.20 ug/l	< 0.20 ug/l	0.24 ug/l	< 0.20 ug/l	0.26 ug/l	0.21 ug/l	< 0.20 ug/l
Copper	Total	2.0 ug/l	2.8 ug/l	2.0 ug/l	2.6 ug/l	< 0.50 ug/l	2.6 ug/l	2.1 ug/l	2.3 ug/l
Iron	Dissolved	< 0.050 mg/l	< 0.050 mg/l	< 0.050 mg/l	< 0.050 mg/l	< 0.050 mg/l	< 0.050 mg/l	< 0.050 mg/l	< 0.050 mg/l
Iron	Total	< 0.050 mg/l	< 0.050 mg/l	< 0.050 mg/l	< 0.050 mg/l	< 0.050 mg/l	< 0.050 mg/l	< 0.050 mg/l	< 0.050 mg/l
Lead	Total	< 0.20 ug/l	1.1 ug/l	0.42 ug/l	< 0.20 ug/l	< 0.20 ug/l	0.56 ug/l	0.33 ug/l	0.57 ug/l
Magnesium	Total	130 mg/l	130 mg/l	120 mg/l	99 mg/l	87 mg/l	89 mg/l	100 mg/l	120 mg/l
Manganese	Dissolved	1.1 ug/l	0.95 ug/l	0.95 ug/l	900 ug/l	440 ug/l	620 ug/l	560 ug/l	200 ug/l
Manganese	Total	1.5 ug/l	9.1 ug/l	5.4 ug/l	880 ug/l	440 ug/l	610 ug/l	630 ug/l	210 ug/l
Nickel	Total	2.6 ug/l	2.9 ug/l	2.2 ug/l	2.7 ug/l	< 0.50 ug/l	0.70 ug/l	2.5 ug/l	2.5 ug/l
Potassium	Total	8.0 mg/l	8.9 mg/l	7.9 * mg/l	6.0 mg/l	6.0 mg/l	5.8 mg/l	6.4 mg/l	7.6 mg/l
Selenium	Total	2.2 ug/l	1.9 ug/l	1.7 ug/l	2.0 ug/l	< 1.0 ug/l	2.2 ug/l	1.9 ug/l	< 1.0 ug/l
Silicon	Total	17 mg/l	17 mg/l	17 mg/l	16 mg/l	16 mg/l	18 mg/l	16 mg/l	17 mg/l
Sodium	Total	63 mg/l	64 mg/l	62 mg/l	51 mg/l	45 mg/l	46 mg/l	49 mg/l	56 mg/l
Strontium	Total	400 ug/l	410 ug/l	420 ug/l	360 ug/l	330 ug/l	330 ug/l	420 ug/l	460 ug/l
Thallium	Total	< 0.20 ug/l	< 0.20 ug/l	< 0.20 ug/l	< 0.20 ug/l	< 0.20 ug/l	< 0.20 ug/l	--	--
Vanadium	Total	< 0.50 ug/l	< 0.50 ug/l	< 0.50 ug/l	< 0.50 ug/l	< 0.50 ug/l	< 0.50 ug/l	< 0.50 ug/l	< 0.50 ug/l
Zinc	Total	< 5.0 ug/l	5.2 ug/l	< 5.0 ug/l	< 5.0 ug/l	< 5.0 ug/l	5.8 ug/l	< 5.0 ug/l	5.8 ug/l

		Phase 4 - Longer-Term Operation														
Location		Pretreated Effluent	Pretreated Effluent	Pretreated Effluent	Pretreated Effluent	Pretreated Effluent	Pretreated Effluent	Pretreated Effluent	Pretreated Effluent	Pretreated Effluent	Pretreated Effluent	Pretreated Effluent	Pretreated Effluent	Pretreated Effluent	Pretreated Effluent	Pretreated Effluent
Date		7/5/2012	7/10/2012	7/17/2012	7/24/2012	8/7/2012	8/14/2012	8/21/2012	8/28/2012	9/4/2012	9/11/2012	9/18/2012	9/25/2012	10/2/2012	10/16/2012	10/30/2012
Sample Type		N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
	Fraction															
General Parameters																
Alkalinity, bicarbonate, as CaCO3	NA	420 mg/l	420 mg/l	430 mg/l	450 mg/l	410 mg/l	410 mg/l	410 mg/l	410 mg/l	410 mg/l	550 mg/l	490 mg/l	440 mg/l	410 mg/l	470 mg/l	440 mg/l
Alkalinity, carbonate, as CaCO3	NA	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Alkalinity, total	NA	420 mg/l	420 mg/l	430 mg/l	450 mg/l	410 mg/l	410 mg/l	410 mg/l	410 mg/l	410 mg/l	550 mg/l	490 mg/l	440 mg/l	410 mg/l	--	--
Carbon, dissolved organic	NA	4.6 mg/l	4.8 mg/l	4.6 mg/l	4.0 mg/l	5.0 mg/l	5.0 mg/l	5.1 mg/l	5.5 mg/l	5.7 mg/l	3.4 mg/l	3.8 mg/l	4.7 mg/l	5.2 mg/l	--	--
Carbon, total organic	NA	4.2 mg/l	4.8 mg/l	4.4 mg/l	4.1 mg/l	4.8 mg/l	5.2 mg/l	4.8 mg/l	5.0 mg/l	5.2 mg/l	3.0 mg/l	3.8 mg/l	4.5 mg/l	5.3 mg/l	--	--
Chloride	NA	27 mg/l	27 mg/l	26 mg/l	26 mg/l	28 mg/l	29 mg/l	28 mg/l	28 mg/l	28 mg/l	22 mg/l	25 mg/l	27 mg/l	29 mg/l	26 mg/l	27 mg/l
Fluoride	NA	1.3 mg/l	1.2 mg/l	1.2 mg/l	1.3 mg/l	1.0 mg/l	0.87 mg/l	0.99 mg/l	0.91 mg/l	0.92 mg/l	1.5 mg/l	1.2 mg/l	1.2 mg/l	0.93 mg/l	1.2 mg/l	1.2 mg/l
Nitrogen, ammonia (NH3), as N	NA	0.326 mg/l	0.287 mg/l	0.300 mg/l	0.320 mg/l	0.352 mg/l	0.433 mg/l	0.404 mg/l	0.409 mg/l	0.370 mg/l	0.219 mg/l	0.331 mg/l	0.334 mg/l	0.390 mg/l	< 0.500 mg/l	< 0.500 mg/l
Nitrogen, Nitrate as N	NA	< 0.23 mg/l	< 0.23 mg/l	< 0.23 mg/l	< 0.23 mg/l	< 1.0 mg/l	< 1.0 mg/l	< 1.0 mg/l	< 1.0 mg/l	< 1.0 mg/l	< 1.0 mg/l	< 1.0 mg/l	< 1.0 mg/l	< 1.0 mg/l	--	--
Nitrogen, Nitrite as N	NA	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Orthophosphate, as PO4	NA	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
pH	NA	7.6 pH units	7.6 pH units	7.7 pH units	7.8 pH units	8.1 pH units	7.7 pH units	8.0 pH units	7.8 pH units	7.8 pH units	7.8 pH units	7.9 pH units	7.8 pH units	7.7 pH units	7.9 pH units	7.5 pH units
Phosphorus, total	NA	< 0.100 mg/l	< 0.100 mg/l	< 0.100 mg/l	< 0.100 mg/l	< 0.100 mg/l	< 0.100 mg/l	< 0.100 mg/l	< 0.100 mg/l	< 0.100 mg/l	< 0.100 mg/l	< 0.100 mg/l	< 0.100 mg/l	< 0.100 mg/l	< 0.100 mg/l	< 0.100 mg/l
Silicon dioxide	NA	36.2 mg/l	37.5 mg/l	35.8 mg/l	35.8 mg/l	34.4 mg/l	32.0 mg/l	35.4 mg/l	32.0 mg/l	34.5 mg/l	39.9 mg/l	38.1 mg/l	36.7 mg/l	38.0 mg/l	37.0 mg/l	35.2 mg/l
Solids, total dissolved	NA	790 mg/l	680 mg/l	840 mg/l	940 mg/l	770 mg/l	710 mg/l	730 mg/l	720 mg/l	690 mg/l	1300 mg/l	950 mg/l	1000 mg/l	710 mg/l	920 mg/l	900 mg/l
Solids, total suspended	NA	< 4.0 mg/l	< 4.0 mg/l	< 4.0 mg/l	< 4.0 mg/l	< 4.0 mg/l	< 4.0 mg/l	< 4.0 mg/l	< 4.0 mg/l	< 4.0 mg/l	< 4.0 mg/l	< 4.0 mg/l	< 4.0 mg/l	< 4.0 mg/l	< 4.0 mg/l	< 4.0 mg/l
Specific Conductance @ 25oC	NA	1200 umhos/cm	1200 umhos/cm	1300 umhos/cm	1300 umhos/cm	1100 umhos/cm	1100 umhos/cm	1200 umhos/cm	1100 umhos/cm	1100 umhos/cm	1600 umhos/cm	1300 umhos/cm	1200 umhos/cm	1100 umhos/cm	1400 umhos/cm	1300 umhos/cm
Sulfate	NA	220 mg/l	240 mg/l	260 mg/l	300 mg/l	200 mg/l	150 mg/l	210 mg/l	160 mg/l	180 mg/l	450 mg/l	340 mg/l	240 mg/l	190 mg/l	270 mg/l	280 mg/l
Sulfide	NA	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Metals																
Aluminum	Total	< 10 ug/l	< 10 ug/l	< 10 ug/l	< 10 ug/l	< 10 ug/l	< 10 ug/l	< 10 ug/l	< 10 ug/l	< 10 ug/l	< 10 ug/l	< 10 ug/l	< 10 ug/l	< 10 ug/l	--	--
Arsenic	Total	< 1.0 ug/l	< 1.0 ug/l	< 1.0 ug/l	< 1.0 ug/l	< 1.0 ug/l	< 1.0 ug/l	< 1.0 ug/l	< 1.0 ug/l	< 1.0 ug/l	< 1.0 ug/l	< 1.0 ug/l	< 1.0 ug/l	< 1.0 ug/l	< 1.0 ug/l	< 1.0 ug/l
Barium	Total	46 ug/l	48 ug/l	54 ug/l	48 ug/l	48 ug/l	52 ug/l	51 ug/l	54 ug/l	45 ug/l	41 ug/l	39 ug/l	34 ug/l	40 ug/l	55 ug/l	35 ug/l
Boron	Total	0.36 mg/l	0.34 mg/l	0.38 mg/l	0.38 mg/l	0.33 mg/l	0.30 mg/l	0.33 mg/l	0.33 mg/l	0.30 mg/l	0.45 mg/l	0.40 mg/l	0.35 mg/l	0.33 mg/l	0.37 mg/l	0.36 mg/l
Cadmium	Total	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Calcium	Total	75 mg/l	75 mg/l	78 mg/l	80 mg/l	76 mg/l	76 mg/l	77 mg/l	75 mg/l	75 mg/l	90 mg/l	86 mg/l	78 mg/l	71 mg/l	80 mg/l	78 mg/l
Cobalt	Total	< 0.20 ug/l	< 0.20 ug/l	< 0.20 ug/l	< 0.20 ug/l	< 0.20 ug/l	< 0.20 ug/l	< 0.20 ug/l	< 0.20 ug/l	< 0.20 ug/l	< 0.20 ug/l	< 0.20 ug/l	< 0.20 ug/l	< 0.20 ug/l	< 0.20 ug/l	< 0.20 ug/l
Copper	Total	2.1 ug/l	2.8 ug/l	3.1 ug/l	2.5 ug/l	2.1 ug/l	2.5 ug/l	1.7 ug/l	1.8 ug/l	2.0 ug/l	2.1 ug/l	1.8 ug/l	1.5 ug/l	1.5 ug/l	1.8 ug/l	2.9 ug/l
Iron	Dissolved	< 0.050 mg/l	< 0.050 mg/l	< 0.050 mg/l	< 0.050 mg/l	< 0.050 mg/l	< 0.050 mg/l	< 0.050 mg/l	< 0.050 mg/l	< 0.050 mg/l	< 0.050 mg/l	< 0.050 mg/l	< 0.050 mg/l	< 0.050 mg/l	--	--
Iron	Total	< 0.050 mg/l	< 0.050 mg/l	< 0.050 mg/l	< 0.050 mg/l	< 0.050 mg/l	< 0.050 mg/l	< 0.050 mg/l	< 0.050 mg/l	< 0.050 mg/l	< 0.050 mg/l	0.059 mg/l	< 0.050 mg/l	< 0.050 mg/l	< 0.050 mg/l	< 0.050 mg/l
Lead	Total	0.41 ug/l	0.51 ug/l	0.93 ug/l	0.35 ug/l	0.34 ug/l	0.40 ug/l	0.27 ug/l	< 0.20 ug/l	< 0.20 ug/l	0.22 ug/l	0.21 ug/l	< 0.20 ug/l	0.35 ug/l	0.44 ug/l	0.51 ug/l
Magnesium	Total	110 mg/l	100 mg/l	120 mg/l	120 mg/l	99 mg/l	96 mg/l	100 mg/l	91 mg/l	93 mg/l	170 mg/l	140 mg/l	110 mg/l	92 mg/l	120 mg/l	120 mg/l
Manganese	Dissolved	99 ug/l	380 ug/l	170 ug/l	230 ug/l	85 ug/l	55 ug/l	31 ug/l	50 ug/l	72 ug/l	15 ug/l	15 ug/l	22 ug/l	24 ug/l	--	--
Manganese	Total	86 ug/l	380 ug/l	170 ug/l	220 ug/l	89 ug/l	54 ug/l	31 ug/l	51 ug/l	71 ug/l	15 ug/l	15 ug/l	22 ug/l	24 ug/l	47 ug/l	56 ug/l
Nickel	Total	0.54 ug/l	2.5 ug/l	0.80 ug/l	0.55 ug/l	< 0.50 ug/l	< 0.50 ug/l	< 0.50 ug/l	< 0.50 ug/l	0.56 ug/l	< 0.50 ug/l	< 0.50 ug/l	< 0.50 ug/l	< 0.50 ug/l	0.93 ug/l	1.0 ug/l
Potassium	Total	7.4 mg/l	6.7 mg/l	7.4 mg/l	7.9 mg/l	6.1 mg/l	6.1 mg/l	6.4 mg/l	5.4 mg/l	6.5 mg/l	12 mg/l	8.6 mg/l	7.2 mg/l	5.3 mg/l	7.8 mg/l	7.0 mg/l
Selenium	Total	< 1.0 ug/l	1.6 ug/l	< 1.0 ug/l	< 1.0 ug/l	< 1.0 ug/l	< 1.0 ug/l	< 1.0 ug/l	< 1.0 ug/l	< 1.0 ug/l	< 1.0 ug/l	< 1.0 ug/l	< 1.0 ug/l	< 1.0 ug/l	< 1.0 ug/l	< 1.0 ug/l
Silicon	Total	17 mg/l	17 mg/l	17 mg/l	17 mg/l	18 mg/l	18 mg/l	17 mg/l	17 mg/l	16 mg/l	18 mg/l	17 mg/l	18 mg/l	17 mg/l	16 mg/l	17 mg/l
Sodium	Total	51 mg/l	50 mg/l	54 mg/l	57 mg/l	46 mg/l	45 mg/l	45 mg/l	40 mg/l	43 mg/l	76 mg/l	59 mg/l	49 mg/l	39 mg/l	51 mg/l	50 mg/l
Strontium	Total	390 ug/l	360 ug/l	410 ug/l	420 ug/l	350 ug/l	360 ug/l	340 ug/l	330 ug/l	350 ug/l	530 ug/l	430 ug/l	410 ug/l	370 ug/l	420 ug/l	410 ug/l
Thallium	Total	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Vanadium	Total	< 0.50 ug/l	< 0.50 ug/l	< 0.50 ug/l	< 0.50 ug/l	< 0.50 ug/l	< 0.50 ug/l	< 0.50 ug/l	< 0.50 ug/l	< 0.50 ug/l	< 0.50 ug/l	< 0.50 ug/l	< 0.50 ug/l	< 0.50 ug/l	< 0.50 ug/l	< 0.50 ug/l
Zinc	Total	< 5.0 ug/l	5.3 ug/l	6.7 ug/l	< 5.0 ug/l	< 5.0 ug/l	< 5.0 ug/l	< 5.0 ug/l	< 5.0 ug/l	< 5.0 ug/l	< 5.0 ug/l	23 ug/l	< 5.0 ug/l	6.5 ug/l	5.6 ug/l	5.5 ug/l

Table 6 Greensand Filter Backwash Water Quality

	Location	**Green Sand Filt Back**	**Green Sand Filt Back**	**Green Sand Filt Back**	**Green Sand Filt Back**	**Green Sand Filt Back**	**Green Sand Filt Back**
	Date	**5/14/2012**	**5/29/2012**	**6/26/2012**	**7/10/2012**	**10/8/2012**	**10/15/2012**
	Sample Type	**N**	**N**	**N**	**N**	**N**	**N**
	Fraction						
General Parameters							
Alkalinity, bicarbonate, as CaCO3	NA	**790 mg/l**	**400 mg/l**	**610 mg/l**	**530 mg/l**	**460 mg/l**	**560 mg/l**
Alkalinity, carbonate, as CaCO3	NA	< 20 mg/l	< 20 mg/l	--	--	--	--
Alkalinity, total	NA	**790 mg/l**	**400 mg/l**	**610 mg/l**	**530 mg/l**	--	--
Carbon, total organic	NA	**67 mg/l**	**32 mg/l**	**46 mg/l**	**90 mg/l**	**25 mg/l**	**36 mg/l**
Chemical Oxygen Demand	NA	**820 mg/l**	**68 mg/l**	**210 mg/l**	**650 mg/l**	--	--
Chloride	NA	**24 mg/l**	**27 mg/l**	**25 mg/l**	**27 mg/l**	**29 mg/l**	**28 mg/l**
Fluoride	NA	**1.3 mg/l**	**1.1 mg/l**	**1.3 mg/l**	**1.2 mg/l**	**0.84 mg/l**	**1.1 mg/l**
Nitrogen, ammonia (NH3), as N	NA	**0.788 mg/l**	**0.399 mg/l**	**0.352 mg/l**	**0.494 mg/l**	**0.627 mg/l**	**0.577 mg/l**
Nitrogen, Nitrate as N	NA	< 0.20 mg/l	< 0.22 mg/l	< 1.0 mg/l	< 0.23 mg/l	--	--
Nitrogen, Nitrite as N	NA	< 0.20 mg/l	< 0.30 mg/l	--	--	--	--
Orthophosphate, as PO4	NA	< 0.20 mg/l	< 0.20 mg/l	--	--	--	--
pH	NA	**7.6 pH units**	**7.5 pH units**	**7.5 pH units**	**7.4 pH units**	**7.5 pH units**	**7.4 pH units**
Phosphorus, total	NA	**7.61 mg/l**	**1.35 mg/l**	**1.53 mg/l**	**1.64 mg/l**	**0.738 mg/l**	**0.907 mg/l**
Silicon dioxide	NA	--	**30.0 mg/l**	--	--	--	--
Solids, total dissolved	NA	**900 mg/l**	**1900 mg/l**	**880 mg/l**	**600 mg/l**	**750 mg/l**	**990 mg/l**
Solids, total suspended	NA	**3000 mg/l**	**780 mg/l**	**1900 mg/l**	**1400 mg/l**	**600 mg/l**	**1000 mg/l**
Specific Conductance @ 25oC	NA	**1300 umhos/cm**	**1100 umhos/cm**	**1300 umhos/cm**	**1100 umhos/cm**	**1100 umhos/cm**	**1500 umhos/cm**
Sulfate	NA	**300 mg/l**	**220 mg/l**	**280 mg/l**	**260 mg/l**	**180 mg/l**	**240 mg/l**
Sulfide	NA	< 0.12 mg/l	< 0.12 mg/l	--	--	--	--
Metals							
Aluminum	Total	**0.86 mg/l**	**0.20 mg/l**	**0.22 mg/l**	**0.15 mg/l**	--	--
Arsenic	Total	**0.19 mg/l**	**0.081 mg/l**	**0.18 mg/l**	**0.17 mg/l**	**51 ug/l**	**82 ug/l**
Barium	Total	**4.2 mg/l**	**0.81 mg/l**	**2.7 mg/l**	**3.0 mg/l**	--	--
Boron	Total	**0.62 mg/l**	**0.38 mg/l**	**0.46 mg/l**	**0.42 mg/l**	**0.33 mg/l**	**0.42 mg/l**
Cadmium	Total	**0.0041 mg/l**	< 0.0010 mg/l	--	--	--	--
Calcium	Total	**190 mg/l**	**100 mg/l**	**120 mg/l**	**130 mg/l**	**93 mg/l**	**110 mg/l**
Cobalt	Total	**0.044 mg/l**	< 0.0050 mg/l	**0.030 mg/l**	**0.023 mg/l**	**5.9 ug/l**	**12 ug/l**
Copper	Total	**0.28 mg/l**	< 0.020 mg/l	**0.064 mg/l**	**0.11 mg/l**	**13 ug/l**	**57 ug/l**
Iron	Dissolved	< 0.050 mg/l	< 0.050 mg/l	< 0.050 mg/l	< 0.050 mg/l	< 0.050 mg/l	--
Iron	Total	**650 mg/l**	**310 mg/l**	**370 mg/l**	**640 mg/l**	**230 mg/l**	**320 mg/l**
Lead	Total	< 0.030 mg/l	< 0.0030 mg/l	< 0.0030 mg/l	< 0.0030 mg/l	< 1.0 ug/l	**5.0 ug/l**
Magnesium	Total	**150 mg/l**	**100 mg/l**	**120 mg/l**	**110 mg/l**	**91 mg/l**	**110 mg/l**
Manganese	Dissolved	< 0.020 mg/l	**1.1 mg/l**	**0.21 mg/l**	**0.50 mg/l**	**2100 ug/l**	--
Manganese	Total	**88 mg/l**	**6.5 mg/l**	**110 mg/l**	**82 mg/l**	**36000 ug/l**	**76000 ug/l**
Nickel	Total	< 0.025 mg/l	< 0.0050 mg/l	< 0.0050 mg/l	< 0.0050 mg/l	< 2.5 ug/l	< 2.5 ug/l
Potassium	Total	**10 mg/l**	**6.6 mg/l**	**8.2 mg/l**	**7.6 mg/l**	**5.2 mg/l**	**7.0 mg/l**
Selenium	Total	< 0.020 mg/l	< 0.020 mg/l	< 0.020 mg/l	< 0.020 mg/l	< 5.0 ug/l	< 5.0 ug/l
Silicon	Total	**130 mg/l**	**47 mg/l**	**79 mg/l**	**91 mg/l**	**41 mg/l**	**49 mg/l**
Sodium	Total	**54 mg/l**	**54 mg/l**	**56 mg/l**	**50 mg/l**	**38 mg/l**	**49 mg/l**
Strontium	Total	**2.6 mg/l**	**0.67 mg/l**	**1.0 mg/l**	**1.1 mg/l**	--	--
Thallium	Total	< 0.040 mg/l	< 0.040 mg/l	--	--	--	--
Vanadium	Total	**0.046 mg/l**	**0.024 mg/l**	**0.053 mg/l**	**0.044 mg/l**	**19 ug/l**	**28 ug/l**
Zinc	Total	**0.33 mg/l**	**0.021 mg/l**	**0.030 mg/l**	**0.048 mg/l**	**46 ug/l**	**81 ug/l**

Table 7 RO Permeate Water Quality

		Phase 3 - Optimization							
	Location	**RO Permeate**	**RO Permeate**	**RO Permeate**	**RO Permeate**	**RO Permeate**	**RO Permeate**	**RO Permeate**	**RO Permeate**
	Date	**5/10/2012**	**5/14/2012**	**5/21/2012**	**5/29/2012**	**6/4/2012**	**6/11/2012**	**6/19/2012**	**6/26/2012**
	Sample Type	**N**	**N**	**N**	**N**	**N**	**N**	**N**	**N**
	Fraction								
General Parameters									
Alkalinity, bicarbonate, as CaCO3	NA	< 20 mg/l	< 20 mg/l	< 20 mg/l	< 20 mg/l	< 20 mg/l	< 20 mg/l	< 20 mg/l	< 20 mg/l
Alkalinity, carbonate, as CaCO3	NA	< 20 mg/l	< 20 mg/l	< 20 mg/l	< 20 mg/l	< 20 mg/l	< 20 mg/l	--	--
Alkalinity, total	NA	< 20 mg/l	< 20 mg/l	< 20 mg/l	< 20 mg/l	< 20 mg/l	< 20 mg/l	< 20 mg/l	< 20 mg/l
Carbon, total organic	NA	< 1.5 mg/l	< 1.5 mg/l	< 1.5 mg/l	< 1.5 mg/l	< 1.5 mg/l	< 1.5 mg/l	< 1.5 mg/l	< 1.5 mg/l
Chloride	NA	**0.24 mg/l**	**0.30 mg/l**	**0.35 mg/l**	**0.29 mg/l**	**0.26 mg/l**	**0.31 mg/l**	**0.34 mg/l**	**0.26 mg/l**
Fluoride	NA	< 0.050 mg/l	< 0.050 mg/l	< 0.050 mg/l	< 0.050 mg/l	< 0.050 mg/l	< 0.050 mg/l	< 0.050 mg/l	< 0.050 mg/l
Nitrogen, ammonia (NH3), as N	NA	< 0.500 mg/l	< 0.500 mg/l	< 0.500 mg/l	< 0.200 mg/l	< 0.200 mg/l	< 0.200 mg/l	< 0.200 mg/l	< 0.200 mg/l
Nitrogen, Nitrate as N	NA	< 0.20 mg/l	< 0.20 mg/l	**0.076 mg/l**	< 0.045 mg/l	< 0.045 mg/l	< 0.045 mg/l	< 0.045 mg/l	< 0.20 mg/l
Nitrogen, Nitrite as N	NA	< 0.20 mg/l	< 0.20 mg/l	< 0.061 mg/l	< 0.061 mg/l	< 0.061 mg/l	< 0.061 mg/l	--	--
Orthophosphate, as PO4	NA	< 0.20 mg/l	< 0.20 mg/l	< 0.20 mg/l	< 0.20 mg/l	< 0.20 mg/l	< 0.20 mg/l	--	--
pH	NA	**5.8 pH units**	**5.7 pH units**	**5.7 pH units**	**5.7 pH units**	**5.7 pH units**	**5.8 pH units**	**5.8 pH units**	**5.8 pH units**
Phosphorus, total	NA	< 0.010 mg/l	< 0.010 mg/l	< 0.010 mg/l	< 0.100 mg/l	< 0.100 mg/l	< 0.100 mg/l	< 0.100 mg/l	< 0.100 mg/l
Silicon dioxide	NA	--	--	< 0.500 mg/l	< 0.500 mg/l	--	--	--	--
Solids, total dissolved	NA	**40 mg/l**	**10 mg/l**	< 10 mg/l	< 10 h mg/l	**26 mg/l**	< 10 mg/l	< 10 mg/l	< 10 mg/l
Solids, total suspended	NA	< 4.0 mg/l	< 4.0 mg/l	< 4.0 mg/l	< 4.0 mg/l	< 4.0 mg/l	< 4.0 mg/l	< 4.0 mg/l	< 4.0 mg/l
Specific Conductance @ 25oC	NA	**79 umhos/cm**	**13 umhos/cm**	**11 umhos/cm**	**10 umhos/cm**	**10 umhos/cm**	**11 umhos/cm**	< 10 umhos/cm	**11 umhos/cm**
Sulfate	NA	**0.74 mg/l**	**0.88 mg/l**	**0.76 mg/l**	**0.49 mg/l**	**0.42 mg/l**	**0.40 mg/l**	**0.43 mg/l**	**0.59 mg/l**
Sulfide	NA	< 0.12 mg/l	< 0.12 mg/l	< 0.12 mg/l	< 0.12 mg/l	< 0.12 mg/l	< 0.12 mg/l	--	--
Metals									
Aluminum	Total	< 10 ug/l	< 10 ug/l	< 10 ug/l	< 10 ug/l	< 10 ug/l	< 10 ug/l	< 10 ug/l	< 10 ug/l
Arsenic	Total	< 1.0 ug/l	< 1.0 ug/l	< 1.0 ug/l	< 1.0 ug/l	< 1.0 ug/l	< 1.0 ug/l	< 1.0 ug/l	< 1.0 ug/l
Barium	Total	< 0.20 ug/l	< 0.20 ug/l	< 0.20 ug/l	< 0.20 ug/l	< 0.20 ug/l	< 0.20 ug/l	< 0.20 ug/l	< 0.20 ug/l
Boron	Total	**0.20 mg/l**	**0.22 mg/l**	**0.21 mg/l**	**0.19 mg/l**	**0.18 mg/l**	**0.19 mg/l**	**0.18 mg/l**	**0.19 mg/l**
Cadmium	Total	< 0.20 ug/l	< 0.20 ug/l	< 0.20 ug/l	< 0.20 ug/l	< 0.20 ug/l	< 0.20 ug/l	--	--
Calcium	Total	< 1.0 mg/l	< 1.0 mg/l	< 1.0 mg/l	< 1.0 mg/l	< 1.0 mg/l	< 1.0 mg/l	< 1.0 mg/l	< 1.0 mg/l
Cobalt	Total	< 0.20 ug/l	< 0.20 ug/l	< 0.20 ug/l	< 0.20 ug/l	< 0.20 ug/l	< 0.20 ug/l	< 0.20 ug/l	< 0.20 ug/l
Copper	Total	< 0.50 ug/l	< 0.50 ug/l	< 0.50 ug/l	< 0.50 ug/l	< 0.50 ug/l	< 0.50 ug/l	< 0.50 ug/l	< 0.50 ug/l
Iron	Total	< 0.050 mg/l	< 0.050 mg/l	< 0.050 mg/l	< 0.050 mg/l	< 0.050 mg/l	< 0.050 mg/l	< 0.050 mg/l	< 0.050 mg/l
Lead	Total	< 0.20 ug/l	< 0.20 ug/l	< 0.20 ug/l	< 0.20 ug/l	< 0.20 ug/l	< 0.20 ug/l	< 0.20 ug/l	< 0.20 ug/l
Magnesium	Total	< 1.0 mg/l	< 1.0 mg/l	< 1.0 mg/l	< 1.0 mg/l	< 1.0 mg/l	< 1.0 mg/l	< 1.0 mg/l	< 1.0 mg/l
Manganese	Total	< 0.50 ug/l	< 0.50 ug/l	< 0.50 ug/l	**1.1 ug/l**	**0.68 ug/l**	**0.94 ug/l**	**0.56 ug/l**	< 0.50 ug/l
Mercury	Total	< 0.500 ng/l	< 0.500 ng/l	< 0.500 ng/l	< 0.500 ng/l	--	--	--	--
Nickel	Total	< 0.50 ug/l	< 0.50 ug/l	**0.70 ug/l**	< 0.50 ug/l	< 0.50 ug/l	< 0.50 ug/l	< 0.50 ug/l	< 0.50 ug/l
Potassium	Total	< 1.0 mg/l	< 1.0 mg/l	< 1.0 mg/l	< 1.0 mg/l	< 1.0 mg/l	< 1.0 mg/l	< 1.0 mg/l	< 1.0 mg/l
Selenium	Total	< 1.0 ug/l	< 1.0 ug/l	< 1.0 ug/l	< 1.0 ug/l	< 1.0 ug/l	< 1.0 ug/l	< 1.0 ug/l	< 1.0 ug/l
Silicon	Total	< 0.25 mg/l	< 0.25 mg/l	< 0.25 mg/l	< 0.25 mg/l	< 0.25 mg/l	< 0.25 mg/l	< 0.25 mg/l	< 0.25 mg/l
Sodium	Total	**1.2 mg/l**	**1.4 mg/l**	**1.7 mg/l**	**1.2 mg/l**	**1.5 mg/l**	**1.6 mg/l**	**1.2 mg/l**	**1.5 mg/l**
Strontium	Total	< 1.0 ug/l	< 1.0 ug/l	< 1.0 ug/l	< 1.0 ug/l	< 1.0 ug/l	< 1.0 ug/l	< 1.0 ug/l	< 1.0 ug/l
Thallium	Total	< 0.20 ug/l	< 0.20 ug/l	< 0.20 ug/l	< 0.20 ug/l	< 0.20 ug/l	< 0.20 ug/l	--	--
Vanadium	Total	< 0.50 ug/l	< 0.50 ug/l	< 0.50 ug/l	< 0.50 ug/l	< 0.50 ug/l	< 0.50 ug/l	< 0.50 ug/l	< 0.50 ug/l
Zinc	Total	< 5.0 ug/l	< 5.0 ug/l	< 5.0 ug/l	< 5.0 ug/l	< 5.0 ug/l	< 5.0 ug/l	< 5.0 ug/l	< 5.0 ug/l

Location Date Sample Type	Fraction	Phase 4 - Longer-Term Operation														
		RO Permeate 7/5/2012 N	RO Permeate 7/10/2012 N	RO Permeate 7/17/2012 N	RO Permeate 7/24/2012 N	RO Permeate 8/7/2012 N	RO Permeate 8/14/2012 N	RO Permeate 8/21/2012 N	RO Permeate 8/28/2012 N	RO Permeate 9/4/2012 N	RO Permeate 9/11/2012 N	RO Permeate 9/18/2012 N	RO Permeate 9/25/2012 N	RO Permeate 10/2/2012 N	RO Permeate 10/16/2012 N	RO Permeate 10/30/2012 N
General Parameters																
Alkalinity, bicarbonate, as CaCO3	NA	< 20 mg/l	410 ** mg/l	< 20 mg/l	< 20 mg/l	< 20 mg/l	< 20 mg/l	< 20 mg/l	< 20 mg/l	< 20 mg/l	< 20 mg/l	< 20 mg/l	< 20 mg/l	< 20 mg/l	< 20 mg/l	< 20 mg/l
Alkalinity, carbonate, as CaCO3	NA	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Alkalinity, total	NA	< 20 mg/l	410 ** mg/l	< 20 mg/l	< 20 mg/l	< 20 mg/l	< 20 mg/l	< 20 mg/l	< 20 mg/l	< 20 mg/l	< 20 mg/l	< 20 mg/l	< 20 mg/l	< 20 mg/l	--	--
Carbon, total organic	NA	< 1.5 mg/l	4.6 ** mg/l	< 1.5 mg/l	< 1.5 mg/l	< 1.5 mg/l	< 1.5 mg/l	< 1.5 mg/l	< 1.5 mg/l	< 1.5 mg/l	< 1.5 mg/l	< 1.5 mg/l	< 1.5 mg/l	< 1.5 mg/l	--	--
Chloride	NA	0.30 mg/l	28 ** mg/l	0.29 mg/l	0.28 mg/l	0.26 mg/l	0.27 mg/l	0.28 mg/l	0.29 mg/l	0.33 mg/l	0.31 mg/l	0.31 mg/l	0.31 mg/l	0.35 mg/l	0.35 mg/l	0.31 mg/l
Fluoride	NA	< 0.050 mg/l	1.2 ** mg/l	< 0.050 mg/l	< 0.050 mg/l	< 0.050 mg/l	< 0.050 mg/l	< 0.050 mg/l	< 0.050 mg/l	< 0.050 mg/l	< 0.050 mg/l	< 0.050 mg/l	< 0.050 mg/l	< 0.050 mg/l	< 0.050 mg/l	< 0.050 mg/l
Nitrogen, ammonia (NH3), as N	NA	< 0.200 mg/l	0.292 ** mg/l	< 0.200 mg/l	< 0.200 mg/l	< 0.200 mg/l	< 0.200 mg/l	< 0.200 mg/l	< 0.200 mg/l	< 0.200 mg/l	< 0.200 mg/l	< 0.200 mg/l	< 0.200 mg/l	< 0.200 mg/l	< 0.500 mg/l	< 0.500 mg/l
Nitrogen, Nitrate as N	NA	< 0.045 mg/l	< 0.045 mg/l	< 0.045 mg/l	< 0.045 mg/l	< 0.20 mg/l	< 0.20 mg/l	< 0.20 mg/l	< 0.20 mg/l	< 0.20 mg/l	< 0.045 mg/l	< 0.20 mg/l	< 0.20 mg/l	< 0.20 mg/l	--	--
Nitrogen, Nitrite as N	NA	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Orthophosphate, as PO4	NA	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
pH	NA	5.8 pH units	7.6 ** pH units	5.5 pH units	5.7 pH units	5.7 pH units	5.8 pH units	5.9 pH units	5.5 pH units	5.5 pH units	5.8 pH units	5.9 pH units	5.8 pH units	5.8 pH units	6.8 pH units	6.3 pH units
Phosphorus, total	NA	< 0.100 mg/l	0.115 mg/l	< 0.100 mg/l	< 0.100 mg/l	< 0.100 mg/l	< 0.100 mg/l	< 0.100 mg/l	< 0.100 mg/l	< 0.100 mg/l	< 0.100 mg/l	< 0.100 mg/l	< 0.100 mg/l	< 0.100 mg/l	--	--
Silicon dioxide	NA	--	35.4 ** mg/l	--	--	--	--	--	--	--	--	--	--	--	--	--
Solids, total dissolved	NA	< 10 mg/l	630 ** mg/l	< 10 mg/l	< 10 mg/l	< 10 mg/l	< 10 mg/l	< 10 mg/l	< 10 mg/l	< 10 mg/l	< 10 mg/l	< 10 mg/l	< 10 mg/l	< 10 mg/l	< 10 mg/l	< 10 mg/l
Solids, total suspended	NA	< 4.0 mg/l	< 4.0 mg/l	< 4.0 mg/l	< 4.0 mg/l	< 4.0 mg/l	< 4.0 mg/l	< 4.0 mg/l	< 4.0 mg/l	< 4.0 mg/l	< 4.0 mg/l	< 4.0 mg/l	< 4.0 mg/l	< 4.0 mg/l	--	--
Specific Conductance @ 25oC	NA	12 umhos/cm	1200 ** umhos/cm	12 umhos/cm	11 umhos/cm	11 umhos/cm	10 umhos/cm	< 10 umhos/cm	11 umhos/cm	13 umhos/cm	14 umhos/cm	13 umhos/cm	10 umhos/cm	11 umhos/cm	14 umhos/cm	12 umhos/cm
Sulfate	NA	0.56 mg/l	250 ** mg/l	0.62 mg/l	0.57 mg/l	0.43 mg/l	0.37 mg/l	0.38 mg/l	0.35 mg/l	0.45 mg/l	0.98 mg/l	0.74 mg/l	0.60 mg/l	0.44 mg/l	0.62 mg/l	0.67 mg/l
Sulfide	NA	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Metals																
Aluminum	Total	< 10 ug/l	< 10 ug/l	< 10 ug/l	< 10 ug/l	< 10 ug/l	< 10 ug/l	< 10 ug/l	< 10 ug/l	< 10 ug/l	< 10 ug/l	< 10 ug/l	< 10 ug/l	< 10 ug/l	--	--
Arsenic	Total	< 1.0 ug/l	< 1.0 ug/l	< 1.0 ug/l	< 1.0 ug/l	< 1.0 ug/l	< 1.0 ug/l	< 1.0 ug/l	< 1.0 ug/l	< 1.0 ug/l	< 1.0 ug/l	< 1.0 ug/l	< 1.0 ug/l	< 1.0 ug/l	< 1.0 ug/l	< 1.0 ug/l
Barium	Total	< 0.20 ug/l	< 0.20 ug/l	< 0.20 ug/l	< 0.20 ug/l	< 0.20 ug/l	< 0.20 ug/l	< 0.20 ug/l	< 0.20 ug/l	< 0.20 ug/l	< 0.20 ug/l	< 0.20 ug/l	< 0.20 ug/l	< 0.20 ug/l	--	--
Boron	Total	0.22 mg/l	0.19 mg/l	0.23 mg/l	0.23 mg/l	0.18 mg/l	0.17 mg/l	0.18 mg/l	0.18 mg/l	0.18 mg/l	0.28 mg/l	0.22 mg/l	0.20 mg/l	0.18 mg/l	0.22 mg/l	0.21 mg/l
Cadmium	Total	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Calcium	Total	< 1.0 mg/l	< 1.0 mg/l	< 1.0 mg/l	< 1.0 mg/l	< 1.0 mg/l	< 1.0 mg/l	< 1.0 mg/l	< 1.0 mg/l	< 1.0 mg/l	< 1.0 mg/l	< 1.0 mg/l	< 1.0 mg/l	< 1.0 mg/l	< 1.0 mg/l	< 1.0 mg/l
Cobalt	Total	< 0.20 ug/l	< 0.20 ug/l	< 0.20 ug/l	< 0.20 ug/l	< 0.20 ug/l	< 0.20 ug/l	< 0.20 ug/l	< 0.20 ug/l	< 0.20 ug/l	< 0.20 ug/l	< 0.20 ug/l	< 0.20 ug/l	< 0.20 ug/l	< 0.20 ug/l	< 0.20 ug/l
Copper	Total	< 0.50 ug/l	< 0.50 ug/l	< 0.50 ug/l	< 0.50 ug/l	< 0.50 ug/l	1.4 ug/l	< 0.50 ug/l	< 0.50 ug/l	< 0.50 ug/l	< 0.50 ug/l	< 0.50 ug/l	< 0.50 ug/l	1.0 ug/l	< 0.50 ug/l	1.0 ug/l
Iron	Total	< 0.050 mg/l	< 0.050 mg/l	< 0.050 mg/l	< 0.050 mg/l	< 0.050 mg/l	< 0.050 mg/l	< 0.050 mg/l	< 0.050 mg/l	< 0.050 mg/l	< 0.050 mg/l	< 0.050 mg/l	< 0.050 mg/l	< 0.050 mg/l	< 0.050 mg/l	< 0.050 mg/l
Lead	Total	< 0.20 ug/l	< 0.20 ug/l	< 0.20 ug/l	< 0.20 ug/l	< 0.20 ug/l	< 0.20 ug/l	< 0.20 ug/l	< 0.20 ug/l	< 0.20 ug/l	< 0.20 ug/l	< 0.20 ug/l	< 0.20 ug/l	< 0.20 ug/l	< 0.20 ug/l	< 0.20 ug/l
Magnesium	Total	< 1.0 mg/l	< 1.0 mg/l	< 1.0 mg/l	< 1.0 mg/l	< 1.0 mg/l	< 1.0 mg/l	< 1.0 mg/l	< 1.0 mg/l	< 1.0 mg/l	< 1.0 mg/l	< 1.0 mg/l	< 1.0 mg/l	< 1.0 mg/l	< 1.0 mg/l	< 1.0 mg/l
Manganese	Total	< 0.50 ug/l	< 0.50 ug/l	< 0.50 ug/l	< 0.50 ug/l	< 0.50 ug/l	< 0.50 ug/l	< 0.50 ug/l	< 0.50 ug/l	< 0.50 ug/l	< 0.50 ug/l	< 0.50 ug/l	< 0.50 ug/l	< 0.50 ug/l	< 0.50 ug/l	< 0.50 ug/l
Mercury	Total	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Nickel	Total	< 0.50 ug/l	< 0.50 ug/l	< 0.50 ug/l	< 0.50 ug/l	< 0.50 ug/l	< 0.50 ug/l	< 0.50 ug/l	< 0.50 ug/l	< 0.50 ug/l	< 0.50 ug/l	< 0.50 ug/l	< 0.50 ug/l	< 0.50 ug/l	< 0.50 ug/l	< 0.50 ug/l
Potassium	Total	< 1.0 mg/l	< 1.0 mg/l	< 1.0 mg/l	< 1.0 mg/l	< 1.0 mg/l	< 1.0 mg/l	< 1.0 mg/l	< 1.0 mg/l	< 1.0 mg/l	< 1.0 mg/l	< 1.0 mg/l	< 1.0 mg/l	< 1.0 mg/l	< 1.0 mg/l	< 1.0 mg/l
Selenium	Total	< 1.0 ug/l	< 1.0 ug/l	< 1.0 ug/l	< 1.0 ug/l	< 1.0 ug/l	< 1.0 ug/l	< 1.0 ug/l	< 1.0 ug/l	< 1.0 ug/l	< 1.0 ug/l	< 1.0 ug/l	< 1.0 ug/l	< 1.0 ug/l	< 1.0 ug/l	< 1.0 ug/l
Silicon	Total	< 0.25 mg/l	< 0.25 mg/l	< 0.25 mg/l	< 0.25 mg/l	< 0.25 mg/l	< 0.25 mg/l	< 0.25 mg/l	< 0.25 mg/l	< 0.25 mg/l	< 0.25 mg/l	< 0.25 mg/l	< 0.25 mg/l	< 0.25 mg/l	< 0.25 mg/l	< 0.25 mg/l
Sodium	Total	1.7 mg/l	1.6 mg/l	1.7 mg/l	1.8 mg/l	1.4 mg/l	1.2 mg/l	1.2 mg/l	1.5 mg/l	1.8 mg/l	1.9 mg/l	1.6 mg/l	1.4 mg/l	1.3 mg/l	1.9 mg/l	1.7 mg/l
Strontium	Total	< 1.0 ug/l	< 1.0 ug/l	< 1.0 ug/l	< 1.0 ug/l	< 1.0 ug/l	< 1.0 ug/l	< 1.0 ug/l	< 1.0 ug/l	< 1.0 ug/l	< 1.0 ug/l	< 1.0 ug/l	< 1.0 ug/l	< 1.0 ug/l	--	--
Thallium	Total	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Vanadium	Total	< 0.50 ug/l	< 0.50 ug/l	< 0.50 ug/l	< 0.50 ug/l	< 0.50 ug/l	< 0.50 ug/l	< 0.50 ug/l	< 0.50 ug/l	< 0.50 ug/l	< 0.50 ug/l	< 0.50 ug/l	< 0.50 ug/l	< 0.50 ug/l	< 0.50 ug/l	< 0.50 ug/l
Zinc	Total	< 5.0 ug/l	6.8 ug/l	< 5.0 ug/l	< 5.0 ug/l	< 5.0 ug/l	< 5.0 ug/l	< 5.0 ug/l	< 5.0 ug/l	< 5.0 ug/l	< 5.0 ug/l	< 5.0 ug/l	< 5.0 ug/l	< 5.0 ug/l	< 5.0 ug/l	< 5.0 ug/l

Table 8 **RO Concentrate Water Quality**

Location		RO Concentrate	RO Concentrate	RO Concentrate	RO Concentrate	RO Concentrate	RO Concentrate	RO Concentrate	RO Concentrate	RO Concentrate	RO Concentrate
Date		5/10/2012	5/14/2012	5/21/2012	5/29/2012	6/4/2012	6/11/2012	6/19/2012	6/26/2012	7/5/2012	7/10/2012
Sample Type		N	N	N	N	N	N	N	N	N	N
	Fraction										
General Parameters											
Alkalinity, bicarbonate, as CaCO3	NA	**1600 mg/l**	**1700 mg/l**	**1600 mg/l**	**1500 mg/l**	**1300 mg/l**	**1300 mg/l**	**1300 mg/l**	**1400 mg/l**	**1300 mg/l**	**1400 mg/l**
Alkalinity, carbonate, as CaCO3	NA	< 20 mg/l	< 20 mg/l	< 20 mg/l	< 20 mg/l	< 20 mg/l	< 20 mg/l	--	--	--	--
Alkalinity, total	NA	**1600 mg/l**	**1700 mg/l**	**1600 mg/l**	**1500 mg/l**	**1300 mg/l**	**1300 mg/l**	**1300 mg/l**	**1400 mg/l**	**1300 mg/l**	**1400 mg/l**
Carbon, total organic	NA	**13 mg/l**	**12 mg/l**	**14 mg/l**	**35 mg/l**	**16 mg/l**	**17 mg/l**	**14 mg/l**	**14 mg/l**	**15 mg/l**	**16 mg/l**
Chemical Oxygen Demand	NA	< 50 mg/l	< 50 mg/l	< 50 mg/l	< 50 mg/l	< 50 mg/l	< 50 mg/l	--	--	--	--
Chloride	NA	**100 mg/l**	**96 mg/l**	**100 mg/l**	**110 mg/l**	**95 mg/l**	**98 mg/l**	**88 mg/l**	**83 mg/l**	**89 mg/l**	**89 mg/l**
Fluoride	NA	**5.1 mg/l**	**4.7 mg/l**	**4.7 mg/l**	**4.2 mg/l**	**3.4 mg/l**	**3.3 mg/l**	**3.7 mg/l**	**4.2 mg/l**	**4.1 mg/l**	**3.9 mg/l**
Nitrogen, ammonia (NH3), as N	NA	**0.560 mg/l**	< 0.500 mg/l	**0.773 mg/l**	**0.917 mg/l**	**0.887 mg/l**	**1.10 mg/l**	**0.998 mg/l**	**1.01 mg/l**	**0.971 mg/l**	**0.998 mg/l**
Nitrogen, Nitrate as N	NA	< 1.0 h* mg/l	< 1.0 h mg/l	< 0.23 mg/l	< 0.22 mg/l	< 0.22 mg/l	< 0.23 mg/l	< 0.23 mg/l	< 1.0 mg/l	< 0.23 mg/l	< 0.23 mg/l
Nitrogen, Nitrite as N	NA	< 1.0 h mg/l	< 1.0 h mg/l	< 0.30 mg/l	< 0.30 mg/l	< 0.30 mg/l	< 0.30 mg/l	--	--	--	--
Orthophosphate, as PO4	NA	< 0.20 mg/l	< 0.20 mg/l	< 0.20 mg/l	< 0.20 mg/l	< 0.20 mg/l	< 0.20 mg/l	--	--	--	--
pH	NA	**8.0 pH units**	**7.9 pH units**	**7.9 pH units**	**7.8 pH units**	**7.7 pH units**	**7.8 pH units**	**7.9 pH units**	**7.8 pH units**	**7.8 pH units**	**7.7 pH units**
Phosphorus, total	NA	**0.032 mg/l**	**0.030 mg/l**	**0.022 mg/l**	< 0.100 mg/l	< 0.100 mg/l	< 0.100 mg/l	< 0.100 mg/l	**0.276 mg/l**	< 0.100 mg/l	< 0.100 mg/l
Silicon dioxide	NA	--	--	**107 mg/l**	**122 mg/l**	--	--	--	--	--	**124 mg/l**
Solids, total dissolved	NA	**3800 mg/l**	**3600 mg/l**	**3200 mg/l**	**6500 mg/l**	**2400 mg/l**	**2300 mg/l**	**2300 mg/l**	**3500 mg/l**	**2700 mg/l**	**2700 mg/l**
Solids, total suspended	NA	**4.0 mg/l**	< 4.0 mg/l	< 4.0 mg/l	**4.8 mg/l**	< 4.0 mg/l	< 4.0 mg/l	< 4.0 mg/l	**6.8 mg/l**	**4.4 mg/l**	< 4.0 mg/l
Specific Conductance @ 25oC	NA	**3900 umhos/cm**	**3700 umhos/cm**	**3600 umhos/cm**	**3400 umhos/cm**	**2800 umhos/cm**	**2800 umhos/cm**	**3100 umhos/cm**	**3500 umhos/cm**	**3300 umhos/cm**	**3300 umhos/cm**
Sulfate	NA	**1200 mg/l**	**1200 mg/l**	**1100 mg/l**	**890 mg/l**	**620 mg/l**	**580 mg/l**	**750 mg/l**	**920 mg/l**	**790 mg/l**	**800 mg/l**
Sulfide	NA	--	< 0.12 mg/l	< 0.12 mg/l	< 0.12 mg/l	< 0.12 mg/l	< 0.12 mg/l	--	--	--	--
Metals											
Aluminum	Total	< 10 ug/l	< 10 ug/l	< 10 ug/l	< 10 ug/l	< 10 ug/l	< 10 ug/l	< 10 ug/l	< 10 ug/l	< 10 ug/l	< 10 ug/l
Arsenic	Total	**3.7 ug/l**	**3.3 ug/l**	**3.2 ug/l**	**4.0 ug/l**	**1.6 ug/l**	**3.0 ug/l**	**2.4 ug/l**	**2.2 ug/l**	**1.8 ug/l**	**2.9 ug/l**
Barium	Total	**42 ug/l**	**35 ug/l**	**100 ug/l**	**150 ug/l**	**150 ug/l**	**170 ug/l**	**180 ug/l**	**190 ug/l**	**150 ug/l**	**160 ug/l**
Boron	Total	**1.0 mg/l**	**0.95 mg/l**	**0.85 mg/l**	**0.84 mg/l**	**0.64 mg/l**	**0.65 mg/l**	**0.68 mg/l**	**0.72 mg/l**	**0.69 mg/l**	**0.72 mg/l**
Cadmium	Total	< 0.20 ug/l	< 0.20 ug/l	< 0.20 ug/l	< 0.20 ug/l	< 0.20 ug/l	< 0.20 ug/l	--	--	--	--
Calcium	Total	**270 mg/l**	**270 mg/l**	**280 mg/l**	**280 mg/l**	**230 mg/l**	**250 mg/l**	**230 mg/l**	**250 mg/l**	**240 mg/l**	**250 mg/l**
Cobalt	Total	**0.67 ug/l**	**0.65 ug/l**	**0.51 ug/l**	**0.86 ug/l**	**0.35 ug/l**	**0.80 ug/l**	**0.64 ug/l**	**0.53 ug/l**	**0.40 ug/l**	**0.56 ug/l**
Copper	Total	**6.4 ug/l**	**6.3 ug/l**	**8.3 ug/l**	**9.2 ug/l**	**1.4 ug/l**	**6.4 ug/l**	**5.4 ug/l**	**5.5 ug/l**	**5.4 ug/l**	**6.5 ug/l**
Iron	Total	< 0.050 mg/l	< 0.050 mg/l	< 0.050 mg/l	< 0.050 mg/l	< 0.050 mg/l	**0.14 mg/l**	< 0.050 mg/l	< 0.050 mg/l	< 0.050 mg/l	< 0.050 mg/l
Lead	Total	< 0.20 ug/l	< 0.20 ug/l	< 0.20 ug/l	< 0.20 ug/l	< 0.20 ug/l	**0.20 ug/l**	< 0.20 ug/l	< 0.20 ug/l	**0.26 ug/l**	< 0.20 ug/l
Magnesium	Total	**500 mg/l**	**510 mg/l**	**460 mg/l**	**390 mg/l**	**290 mg/l**	**300 mg/l**	**320 mg/l**	**380 mg/l**	**340 mg/l**	**360 mg/l**
Manganese	Total	**5.5 ug/l**	**6.3 ug/l**	**6.7 ug/l**	**3500 ug/l**	**1700 ug/l**	**2100 ug/l**	**1900 ug/l**	**660 ug/l**	**250 ug/l**	**1200 ug/l**
Nickel	Total	**8.9 ug/l**	**8.2 ug/l**	**4.3 ug/l**	**9.8 ug/l**	**0.50 ug/l**	**2.3 ug/l**	**7.1 ug/l**	**6.7 ug/l**	**0.69 ug/l**	**6.3 ug/l**
Potassium	Total	**35 mg/l**	**38 mg/l**	**34 mg/l**	**27 mg/l**	**21 mg/l**	**21 mg/l**	**23 mg/l**	**27 mg/l**	**25 mg/l**	**24 mg/l**
Selenium	Total	**6.6 ug/l**	**6.5 ug/l**	**4.3 ug/l**	**7.3 ug/l**	**2.4 ug/l**	**7.9 ug/l**	**5.6 ug/l**	**2.5 ug/l**	**2.5 ug/l**	**5.3 ug/l**
Silicon	Total	**67 mg/l**	**65 mg/l**	**66 mg/l**	**60 mg/l**	**53 mg/l**	**59 mg/l**	**52 mg/l**	**56 mg/l**	**58 mg/l**	**58 mg/l**
Sodium	Total	**270 mg/l**	**280 mg/l**	**250 mg/l**	**220 mg/l**	**170 mg/l**	**160 mg/l**	**180 mg/l**	**200 mg/l**	**180 mg/l**	**180 mg/l**
Strontium	Total	**1700 ug/l**	**1600 ug/l**	**1600 ug/l**	**1400 ug/l**	**1200 ug/l**	**1200 ug/l**	**1200 ug/l**	**1400 ug/l**	**1300 ug/l**	**1200 ug/l**
Thallium	Total	< 0.20 ug/l	< 0.20 ug/l	< 0.20 ug/l	< 0.20 ug/l	< 0.20 ug/l	< 0.20 ug/l	--	--	--	--
Vanadium	Total	< 0.50 ug/l	< 0.50 ug/l	< 0.50 ug/l	**0.59 ug/l**	< 0.50 ug/l	< 0.50 ug/l	**0.61 ug/l**	< 0.50 ug/l	**0.56 ug/l**	**0.62 ug/l**
Zinc	Total	**6.5 ug/l**	**6.2 ug/l**	**6.8 ug/l**	**13 ug/l**	**11 ug/l**	**11 ug/l**	**9.6 ug/l**	**8.3 ug/l**	**5.4 ug/l**	**8.2 ug/l**

Location Date Sample Type		RO Concentrate 7/17/2012 N	RO Concentrate 7/24/2012 N	RO Concentrate 8/7/2012 N	RO Concentrate 8/14/2012 N	RO Concentrate 8/21/2012 N	RO Concentrate 8/28/2012 N	RO Concentrate 9/4/2012 N	RO Concentrate 9/11/2012 N	RO Concentrate 9/18/2012 N	RO Concentrate 9/25/2012 N
	Fraction										
General Parameters											
Alkalinity, bicarbonate, as CaCO3	NA	**1400 mg/l**	**1500 mg/l**	**1300 mg/l**	**1300 mg/l**	**1400 mg/l**	**1200 mg/l**	**1400 mg/l**	**1700 mg/l**	**1800 mg/l**	**1500 mg/l**
Alkalinity, carbonate, as CaCO3	NA	--	--	--	--	--	--	--	--	--	--
Alkalinity, total	NA	**1400 mg/l**	**1500 mg/l**	**1300 mg/l**	**1300 mg/l**	**1400 mg/l**	**1200 mg/l**	**1400 mg/l**	**1700 mg/l**	**1800 mg/l**	**1500 mg/l**
Carbon, total organic	NA	**14 mg/l**	**13 mg/l**	**16 mg/l**	**18 mg/l**	**17 mg/l**	**18 mg/l**	**19 mg/l**	**9.3 mg/l**	**14 mg/l**	**16 mg/l**
Chemical Oxygen Demand	NA	--	--	--	--	--	--	--	--	--	--
Chloride	NA	**82 mg/l**	**87 mg/l**	**92 mg/l**	**94 mg/l**	**96 mg/l**	**93 mg/l**	**96 mg/l**	**71 mg/l**	**82 mg/l**	**89 mg/l**
Fluoride	NA	**4.0 mg/l**	**4.0 mg/l**	**3.2 mg/l**	**3.0 mg/l**	**3.3 mg/l**	**2.9 mg/l**	**3.1 mg/l**	**4.3 mg/l**	**3.7 mg/l**	**3.4 mg/l**
Nitrogen, ammonia (NH3), as N	NA	**0.937 mg/l**	**1.01 mg/l**	**1.13 mg/l**	**1.22 mg/l**	**1.35 mg/l**	**1.31 mg/l**	**1.26 mg/l**	**0.672 mg/l**	**1.05 mg/l**	**1.10 mg/l**
Nitrogen, Nitrate as N	NA	< 0.23 mg/l	< 0.23 mg/l	< 1.0 mg/l	< 1.0 mg/l	< 1.0 mg/l	< 1.0 mg/l	< 1.0 mg/l	< 1.0 mg/l	< 1.0 mg/l	< 1.0 mg/l
Nitrogen, Nitrite as N	NA	--	--	--	--	--	--	--	--	--	--
Orthophosphate, as PO4	NA	--	--	--	--	--	--	--	--	--	--
pH	NA	**7.5 pH units**	**7.8 pH units**	**7.9 pH units**	**7.8 pH units**	**7.8 pH units**	**7.6 pH units**	**7.8 pH units**	**7.8 pH units**	**8.0 pH units**	**7.9 pH units**
Phosphorus, total	NA	< 0.100 mg/l	< 0.100 mg/l	< 0.100 mg/l	< 0.100 mg/l	< 0.100 mg/l	< 0.100 mg/l	< 0.100 mg/l	< 0.100 mg/l	**0.365 mg/l**	**0.396 mg/l**
Silicon dioxide	NA	--	--	--	--	--	--	--	--	--	--
Solids, total dissolved	NA	**2900 mg/l**	**3100 mg/l**	**2500 mg/l**	**2400 mg/l**	**2700 mg/l**	**2200 mg/l**	**2400 mg/l**	**3900 mg/l**	**4200 mg/l**	**2700 mg/l**
Solids, total suspended	NA	< 4.0 mg/l	< 4.0 mg/l	< 4.0 mg/l	< 4.0 mg/l	< 4.0 mg/l	**4.0 mg/l**	**4.4 mg/l**	< 4.0 mg/l	< 4.0 mg/l	**4.0 mg/l**
Specific Conductance @ 25oC	NA	**3500 umhos/cm**	**3700 umhos/cm**	**3200 umhos/cm**	**3200 umhos/cm**	**3400 umhos/cm**	**3000 umhos/cm**	**3300 umhos/cm**	**4400 umhos/cm**	**3700 umhos/cm**	**3700 umhos/cm**
Sulfate	NA	**920 mg/l**	**950 mg/l**	**660 mg/l**	**590 mg/l**	**740 mg/l**	**570 mg/l**	**630 mg/l**	**1400 mg/l**	**1100 mg/l**	**820 mg/l**
Sulfide	NA	--	--	--	--	--	--	--	--	--	--
Metals											
Aluminum	Total	< 10 ug/l	< 10 ug/l	< 10 ug/l	< 10 ug/l	< 10 ug/l	< 10 ug/l	< 10 ug/l	< 10 ug/l	< 10 ug/l	< 10 ug/l
Arsenic	Total	**2.1 ug/l**	**2.3 ug/l**	**1.7 ug/l**	**1.8 ug/l**	**1.6 ug/l**	**1.6 ug/l**	**1.6 ug/l**	**1.5 ug/l**	**1.5 ug/l**	**1.6 ug/l**
Barium	Total	**180 ug/l**	**170 ug/l**	**170 ug/l**	**180 ug/l**	**180 ug/l**	**190 ug/l**	**150 ug/l**	**130 ug/l**	**130 ug/l**	**110 ug/l**
Boron	Total	**0.75 mg/l**	**0.76 mg/l**	**0.72 mg/l**	**0.60 mg/l**	**0.70 mg/l**	**0.67 mg/l**	**0.58 mg/l**	< 1.0 mg/l	**0.79 mg/l**	**0.73 mg/l**
Cadmium	Total	--	--	--	--	--	--	--	--	--	--
Calcium	Total	**260 mg/l**	**270 mg/l**	**260 mg/l**	**240 mg/l**	**270 mg/l**	**250 mg/l**	**250 mg/l**	**300 mg/l**	**280 mg/l**	**260 mg/l**
Cobalt	Total	**0.38 ug/l**	**0.37 ug/l**	**0.34 ug/l**	**0.34 ug/l**	**0.44 ug/l**	**0.36 ug/l**	**0.40 ug/l**	**0.37 ug/l**	**0.43 ug/l**	**0.36 ug/l**
Copper	Total	**5.6 ug/l**	**6.2 ug/l**	**5.2 ug/l**	**4.2 ug/l**	**4.6 ug/l**	**4.4 ug/l**	**5.1 ug/l**	**5.7 ug/l**	**4.9 ug/l**	**3.9 ug/l**
Iron	Total	< 0.050 mg/l	< 0.050 mg/l	< 0.050 mg/l	< 0.050 mg/l	< 0.050 mg/l	< 0.050 mg/l	< 0.050 mg/l	< 0.50 mg/l	< 0.050 mg/l	< 0.050 mg/l
Lead	Total	< 0.20 ug/l	< 0.20 ug/l	< 0.20 ug/l	< 0.20 ug/l	< 0.20 ug/l	< 0.20 ug/l	< 0.20 ug/l	< 0.20 ug/l	< 0.20 ug/l	< 0.20 ug/l
Magnesium	Total	**400 mg/l**	**420 mg/l**	**330 mg/l**	**300 mg/l**	**360 mg/l**	**310 mg/l**	**320 mg/l**	**580 mg/l**	**450 mg/l**	**380 mg/l**
Manganese	Total	**450 ug/l**	**420 ug/l**	**270 ug/l**	**220 ug/l**	**100 ug/l**	**170 ug/l**	**240 ug/l**	**42 ug/l**	**45 ug/l**	**62 ug/l**
Nickel	Total	**0.56 ug/l**	< 0.50 ug/l	< 0.50 ug/l	< 0.50 ug/l	< 0.50 ug/l	< 0.50 ug/l	**1.2 ug/l**	**1.4 ug/l**	< 0.50 ug/l	< 0.50 ug/l
Potassium	Total	**27 mg/l**	**30 mg/l**	**22 mg/l**	**22 mg/l**	**26 mg/l**	**20 mg/l**	**24 mg/l**	**32 mg/l**	**31 mg/l**	**26 mg/l**
Selenium	Total	**2.5 ug/l**	**2.2 ug/l**	**2.0 ug/l**	**2.5 ug/l**	**2.5 ug/l**	**2.5 ug/l**	**2.6 ug/l**	**1.6 ug/l**	**2.0 ug/l**	**2.3 ug/l**
Silicon	Total	**59 mg/l**	**58 mg/l**	**60 mg/l**	**58 mg/l**	**58 mg/l**	**58 mg/l**	**55 mg/l**	**55 mg/l**	**57 mg/l**	**60 mg/l**
Sodium	Total	**190 mg/l**	**210 mg/l**	**160 mg/l**	**150 mg/l**	**180 mg/l**	**150 mg/l**	**160 mg/l**	**220 mg/l**	**200 mg/l**	**180 mg/l**
Strontium	Total	**1500 ug/l**	**1500 ug/l**	**1200 ug/l**	**1200 ug/l**	**1200 ug/l**	**1100 ug/l**	**1100 ug/l**	**1800 ug/l**	**1600 ug/l**	**1400 ug/l**
Thallium	Total	--	--	--	--	--	--	--	--	--	--
Vanadium	Total	< 0.50 ug/l	< 0.50 ug/l	**0.61 ug/l**	**0.52 ug/l**	**0.51 ug/l**	**0.58 ug/l**	< 0.50 ug/l	< 0.50 ug/l	< 0.50 ug/l	< 0.50 ug/l
Zinc	Total	**5.9 ug/l**	**6.0 ug/l**	< 5.0 ug/l	**5.2 ug/l**	**5.5 ug/l**	< 5.0 ug/l	**5.2 ug/l**	**7.9 ug/l**	**9.0 ug/l**	**8.5 ug/l**

Location Date Sample Type		RO Concentrate 10/2/2012 N	RO Concentrate 10/16/2012 N	RO Concentrate 10/30/2012 N
	Fraction			
General Parameters				
Alkalinity, bicarbonate, as CaCO3	NA	**1400 mg/l**	**1600 mg/l**	**1500 mg/l**
Alkalinity, carbonate, as CaCO3	NA	--	--	--
Alkalinity, total	NA	**1400 mg/l**	--	--
Carbon, total organic	NA	**19 mg/l**	--	--
Chemical Oxygen Demand	NA	--	--	--
Chloride	NA	**96 mg/l**	**90 mg/l**	**89 mg/l**
Fluoride	NA	**3.1 mg/l**	**4.4 mg/l**	**3.6 mg/l**
Nitrogen, ammonia (NH3), as N	NA	**1.24 mg/l**	**1.12 mg/l**	**1.01 mg/l**
Nitrogen, Nitrate as N	NA	< 1.0 mg/l	--	--
Nitrogen, Nitrite as N	NA	--	--	--
Orthophosphate, as PO4	NA	--	--	--
pH	NA	**7.8 pH units**	**8.0 pH units**	**7.9 pH units**
Phosphorus, total	NA	**0.433 mg/l**	--	--
Silicon dioxide	NA	--	--	--
Solids, total dissolved	NA	**2300 mg/l**	**3200 mg/l**	**3200 mg/l**
Solids, total suspended	NA	< 4.0 mg/l	--	--
Specific Conductance @ 25oC	NA	**3300 umhos/cm**	**3700 umhos/cm**	**3700 umhos/cm**
Sulfate	NA	**630 mg/l**	**1100 mg/l**	**960 mg/l**
Sulfide	NA	--	--	--
Metals				
Aluminum	Total	< 10 ug/l	--	--
Arsenic	Total	**1.4 ug/l**	< 5.0 ug/l	**1.4 ug/l**
Barium	Total	**130 ug/l**	**200 ug/l**	**120 ug/l**
Boron	Total	**0.67 mg/l**	**0.74 mg/l**	< 1.0 mg/l
Cadmium	Total	--	--	--
Calcium	Total	**240 mg/l**	**270 mg/l**	**260 mg/l**
Cobalt	Total	**0.44 ug/l**	< 1.0 ug/l	**0.45 ug/l**
Copper	Total	**3.6 ug/l**	**6.4 ug/l**	**5.8 ug/l**
Iron	Total	< 0.050 mg/l	< 0.050 mg/l	< 0.50 mg/l
Lead	Total	< 0.20 ug/l	< 1.0 ug/l	< 0.20 ug/l
Magnesium	Total	**300 mg/l**	**420 mg/l**	**420 mg/l**
Manganese	Total	**71 ug/l**	**150 ug/l**	**200 ug/l**
Nickel	Total	< 0.50 ug/l	< 2.5 ug/l	**1.6 ug/l**
Potassium	Total	**18 mg/l**	**28 mg/l**	**23 mg/l**
Selenium	Total	**2.2 ug/l**	< 5.0 ug/l	**2.1 ug/l**
Silicon	Total	**56 mg/l**	**58 mg/l**	**57 mg/l**
Sodium	Total	**130 mg/l**	**180 mg/l**	**160 mg/l**
Strontium	Total	**1200 ug/l**	**1400 ug/l**	**1400 ug/l**
Thallium	Total	--	--	--
Vanadium	Total	**0.52 ug/l**	< 2.5 ug/l	< 0.50 ug/l
Zinc	Total	**10 ug/l**	< 25 ug/l	**8.2 ug/l**

Table 9 Average RO Removal Rates – No Metals Added

	Fraction	Percent Reduction
General Parameters		
Alkalinity, bicarbonate, as CaCO3	NA	> 97.7%
Alkalinity, total	NA	> 97.6%
Carbon, total organic	NA	> 82.7%
Chloride	NA	98.9%
Fluoride	NA	> 97.8%
Nitrogen, ammonia (NH3), as N	NA	> 68.6%
Silicon dioxide	NA	> 99.2%
Solids, total dissolved	NA	> 99.1%
Specific Conductance @ 25oC	NA	98.8%
Sulfate	NA	99.8%
Metals		
Arsenic	Total	> 53.0%
Barium	Total	> 99.7%
Boron	Total	43.6%
Calcium	Total	> 99.3%
Cobalt	Total	> 55.6%
Copper	Total	> 83.5%
Lead	Total	> 73.9%
Magnesium	Total	> 99.5%
Manganese	Total	> 98.5%
Nickel	Total	> 75.4%
Potassium	Total	> 92.8%
Selenium	Total	> 73.8%
Silicon	Total	> 99.3%
Sodium	Total	97.0%
Strontium	Total	> 99.9%
Zinc	Total	> 62.1%

- Where “>” (greater than) is indicated, the permeate concentration was often less than the method reporting limit. Half of the method reporting limit was used to calculate the percent removal in those cases.

Table 10 Comparison of Measured and Modeled RO Permeate Quality

		7/5/2012		8/7/2012		10/2/2012	
	Location	**Measured RO Permeate**	**Modeled Permeate**	**Measured RO Permeate**	**Modeled Permeate**	**Measured RO Permeate**	**Modeled Permeate**
	Fraction						
General Parameters							
Alkalinity, bicarbonate, as CaCO3	NA	< 20 mg/l	13.2 mg/l	< 20 mg/l	11.3 mg/l	< 20 mg/l	9.6 mg/l
Chloride	NA	0.30 mg/l	0.41 mg/l	0.26 mg/l	0.28 mg/l	0.35 mg/l	0.12 mg/l
Fluoride	NA	< 0.050 mg/l	0.03 mg/l	< 0.050 mg/l	0.02 mg/l	< 0.050 mg/l	0.02 mg/l
pH	NA	5.8 pH units	5.97 pH units	5.7 pH units	6.32 pH units	5.8 pH units	5.93 pH units
Solids, total dissolved	NA	< 10 mg/l	16.92 mg/l	< 10 mg/l	14.43 mg/l	< 10 mg/l	12.1 mg/l
Sulfate	NA	0.56	0.60	0.43	0.50	0.44	0.41
Metals							
Boron	Total	0.22 mg/l	0.24 mg/l	0.18 mg/l	0.21 mg/l	0.18 mg/l	0.21 mg/l
Calcium	Total	< 1.0 mg/l	1.28 mg/l	< 1.0 mg/l	1.18 mg/l	< 1.0 mg/l	0.95 mg/l
Magnesium	Total	< 1.0 mg/l	0.76 mg/l	< 1.0 mg/l	0.63 mg/l	< 1.0 mg/l	0.59 mg/l
Potassium	Total	< 1.0 mg/l	0.56 mg/l	< 1.0 mg/l	0.44 mg/l	< 1.0 mg/l	0.32 mg/l
Sodium	Total	1.7 mg/l	1.42 mg/l	1.4 mg/l	1.16 mg/l	1.3 mg/l	0.88 mg/l

Table 11 RO CIP Waste Quality

Location Date Sample Type		High pH Cleaning 7/31/2012 N	Low pH Cleaning 7/30/2012 N
	Fraction		
General Parameters			
Alkalinity, bicarbonate, as CaCO3	NA	**160 mg/l**	< 20 mg/l
Alkalinity, total	NA	**370 mg/l**	< 20 mg/l
Chemical Oxygen Demand	NA	**350 mg/l**	**4100 mg/l**
Chloride	NA	**5.8 mg/l**	**10 mg/l**
Fluoride	NA	**0.17 mg/l**	**1.1 mg/l**
Nitrogen, ammonia (NH3), as N	NA	< 0.200 mg/l	< 0.200 mg/l
Nitrogen, Nitrate as N	NA	< 0.20 * mg/l	< 0.20 h mg/l
pH	NA	**10 pH units**	**3.3 pH units**
Phosphorus, total	NA	**0.490 mg/l**	**0.216 mg/l**
Solids, total dissolved	NA	**790 mg/l**	**5300 mg/l**
Solids, total suspended	NA	< 4.0 mg/l	< 4.0 mg/l
Specific Conductance @ 25oC	NA	**1100 umhos/cm**	**1500 umhos/cm**
Sulfate	NA	**180 mg/l**	**110 mg/l**
Metals			
Aluminum	Total	**17 ug/l**	**390 ug/l**
Arsenic	Total	**1.7 ug/l**	**16 ug/l**
Barium	Total	**6.9 ug/l**	**1100 ug/l**
Boron	Total	**0.22 mg/l**	**0.32 mg/l**
Calcium	Total	**12 mg/l**	**280 mg/l**
Cobalt	Total	< 0.20 ug/l	**11 ug/l**
Copper	Total	**24 ug/l**	**250 ug/l**
Iron	Total	**0.29 mg/l**	**16 mg/l**
Lead	Total	**0.92 ug/l**	**50 ug/l**
Magnesium	Total	**14 mg/l**	**53 mg/l**
Manganese	Total	**54 ug/l**	**58000 ug/l**
Nickel	Total	**0.58 ug/l**	**25 ug/l**
Potassium	Total	**1.9 mg/l**	**4.0 mg/l**
Selenium	Total	< 1.0 ug/l	< 10 ug/l
Silicon	Total	**6.7 mg/l**	**8.7 mg/l**
Sodium	Total	**260 mg/l**	**21 mg/l**
Strontium	Total	**46 ug/l**	**880 ug/l**
Vanadium	Total	**0.75 ug/l**	**15 ug/l**
Zinc	Total	**9.8 ug/l**	**140 ug/l**

Table 12 VSEP CIP Waste Quality

		NLR 505	Hot Water Flush	NLR 505
	Location	**VSEP CIP**	**VSEP CIP**	**VSEP CIP**
	Date	**10/16/2012**	**10/31/2012**	**11/7/2012**
	Sample Type	**N**	**N**	**N**
	Fraction			
General Parameters				
Alkalinity, bicarbonate, as CaCO3	NA	**30 mg/l**	**98 mg/l**	**120 mg/l**
Alkalinity, total	NA	**810 mg/l**	**98 mg/l**	**720 mg/l**
Chemical Oxygen Demand	NA	**1800 mg/l**	**1800 mg/l**	**1800 mg/l**
Chloride	NA	< 2.0 mg/l	< 2.0 mg/l	< 2.0 mg/l
Fluoride	NA	< 0.50 mg/l	< 0.50 mg/l	< 0.50 mg/l
Nitrogen, ammonia (NH3), as N	NA	< 0.500 mg/l	< 0.500 mg/l	< 0.500 mg/l
Orthophosphate, as PO4	NA	**6.9 h mg/l**	**3.3 mg/l**	**3.8 mg/l**
pH	NA	**12 pH units**	**7.1 pH units**	**11 pH units**
Phosphorus, total	NA	**351 mg/l**	**324 mg/l**	**274 mg/l**
Solids, total dissolved	NA	**3200 mg/l**	**650 mg/l**	**2700 mg/l**
Solids, total suspended	NA	**4.4 mg/l**	< 4.0 mg/l	**5.6 mg/l**
Specific Conductance @ 25oC	NA	**2800 umhos/cm**	**570 umhos/cm**	**2500 umhos/cm**
Sulfate	NA	**18 mg/l**	**4.5 mg/l**	**18 mg/l**
Metals				
Aluminum	Total	< 50 ug/l	**92 ug/l**	**76 ug/l**
Arsenic	Total	< 5.0 ug/l	< 5.0 ug/l	< 5.0 ug/l
Barium	Total	**2.4 ug/l**	**1000 ug/l**	**60 ug/l**
Boron	Total	< 1.0 mg/l	**0.31 mg/l**	**0.30 mg/l**
Calcium	Total	< 10 mg/l	**1.5 mg/l**	**2.0 mg/l**
Cobalt	Total	< 1.0 ug/l	< 1.0 ug/l	< 1.0 ug/l
Copper	Total	**220 ug/l**	**220 ug/l**	**250 ug/l**
Iron	Total	< 0.50 mg/l	**0.17 mg/l**	**0.69 mg/l**
Lead	Total	**18 ug/l**	**25 ug/l**	**15 ug/l**
Magnesium	Total	< 10 mg/l	**2.5 mg/l**	**3.1 mg/l**
Manganese	Total	**4.2 ug/l**	**7.8 ug/l**	**20 ug/l**
Nickel	Total	**2.7 ug/l**	< 2.5 ug/l	< 2.5 ug/l
Potassium	Total	**12 mg/l**	**14 mg/l**	**12 mg/l**
Selenium	Total	< 5.0 ug/l	< 5.0 ug/l	< 5.0 ug/l
Silicon	Total	**15 mg/l**	**11 mg/l**	**12 mg/l**
Sodium	Total	**880 mg/l**	**790 mg/l**	**760 mg/l**
Strontium	Total	**6.5 ug/l**	**100 ug/l**	**13 ug/l**
Vanadium	Total	< 2.5 ug/l	< 2.5 ug/l	< 2.5 ug/l
Zinc	Total	**140 ug/l**	**160 ug/l**	**120 ug/l**

Table 13 VSEP Permeate Water Quality

Location		VSEP Permeate	VSEP Permeate	VSEP Permeate	VSEP Permeate	VSEP Permeate	VSEP Permeate	VSEP Permeate	VSEP Permeate	VSEP Permeate	VSEP Permeate
Date		8/28/2012	9/5/2012	9/11/2012	9/12/2012	9/13/2012	9/14/2012	9/17/2012	9/18/2012	9/19/2012	9/20/2012
Sample Type		N	N	N	N	N	N	N	N	N	N
	Fraction										
General Parameters											
Alkalinity, bicarbonate, as CaCO3	NA	< 20 mg/l	22 mg/l	24 mg/l	62 mg/l	< 20 mg/l	< 20 mg/l	20 mg/l	< 20 mg/l	21 mg/l	< 20 mg/l
Alkalinity, total	NA	< 20 mg/l	22 mg/l	24 mg/l	62 mg/l	< 20 mg/l	< 20 mg/l	20 mg/l	< 20 mg/l	21 mg/l	< 20 mg/l
Carbon, total organic	NA	2.3 mg/l	< 1.5 mg/l	< 1.5 mg/l	< 1.5 mg/l	< 1.5 mg/l	< 1.5 mg/l	< 1.5 mg/l	< 1.5 mg/l	1.6 mg/l	1.5 mg/l
Chloride	NA	17 mg/l	5.6 mg/l	4.5 mg/l	4.3 mg/l	3.7 mg/l	3.2 mg/l	4.7 mg/l	4.0 mg/l	11 mg/l	33 mg/l
Fluoride	NA	0.098 mg/l	0.16 mg/l	0.11 mg/l	0.22 mg/l	0.15 mg/l	0.16 mg/l	0.21 mg/l	0.25 mg/l	0.18 mg/l	0.19 mg/l
Nitrogen, ammonia (NH3), as N	NA	0.251 mg/l	< 0.200 mg/l	< 0.200 mg/l	< 0.200 mg/l	< 0.200 mg/l	< 0.200 mg/l	< 0.200 mg/l	< 0.200 mg/l	< 0.200 mg/l	< 0.200 mg/l
Nitrogen, Nitrate as N	NA	< 0.20 mg/l	< 0.20 mg/l	< 0.20 mg/l	< 0.20 h mg/l	< 0.20 h mg/l	< 0.20 h mg/l	< 0.20 mg/l	< 0.20 mg/l	< 0.20 * mg/l	< 0.20 mg/l
pH	NA	6.9 pH units	6.7 pH units	5.8 pH units	5.7 pH units	5.2 pH units	5.3 pH units	5.4 pH units	5.3 pH units	5.2 pH units	5.2 pH units
Phosphorus, total	NA	< 0.100 mg/l	< 0.100 mg/l	< 0.100 mg/l	< 0.100 mg/l	< 0.100 mg/l	< 0.100 mg/l	< 0.100 mg/l	< 0.100 mg/l	< 0.100 mg/l	< 0.100 mg/l
Solids, total dissolved	NA	140 mg/l	< 200 mg/l	64 mg/l	120 mg/l	83 mg/l	52 mg/l	70 mg/l	62 mg/l	100 mg/l	120 mg/l
Solids, total suspended	NA	< 4.0 mg/l	< 4.0 mg/l	< 4.0 mg/l	< 4.0 mg/l	< 4.0 mg/l	< 4.0 mg/l	< 4.0 mg/l	< 4.0 mg/l	< 4.0 mg/l	< 4.0 mg/l
Specific Conductance @ 25oC	NA	110 umhos/cm	100 umhos/cm	100 umhos/cm	170 umhos/cm	120 umhos/cm	91 umhos/cm	120 umhos/cm	100 umhos/cm	140 umhos/cm	180 umhos/cm
Sulfate	NA	3.9 mg/l	12 mg/l	14 mg/l	34 mg/l	22 mg/l	16 mg/l	24 mg/l	20 mg/l	22 mg/l	10 mg/l
Metals											
Aluminum	Total	< 10 ug/l	< 10 ug/l	< 10 ug/l	< 10 ug/l	< 10 ug/l	< 10 ug/l	< 10 ug/l	< 10 ug/l	< 10 ug/l	< 10 ug/l
Arsenic	Total	< 1.0 ug/l	< 1.0 ug/l	< 1.0 ug/l	< 1.0 ug/l	< 1.0 ug/l	< 1.0 ug/l	< 1.0 ug/l	< 1.0 ug/l	< 1.0 ug/l	< 1.0 ug/l
Barium	Total	1.8 ug/l	1.4 ug/l	1.4 ug/l	1.6 ug/l	1.3 ug/l	0.83 ug/l	1.3 ug/l	0.98 ug/l	1.4 ug/l	1.8 ug/l
Boron	Total	0.36 mg/l	0.40 mg/l	0.37 mg/l	0.53 mg/l	0.36 mg/l	0.36 mg/l	0.42 mg/l	0.41 mg/l	0.40 mg/l	0.39 mg/l
Calcium	Total	2.5 mg/l	2.3 mg/l	2.5 mg/l	3.7 mg/l	2.8 mg/l	1.8 mg/l	2.6 mg/l	2.0 mg/l	3.1 mg/l	4.0 mg/l
Cobalt	Total	< 0.20 ug/l	< 0.20 ug/l	< 0.20 ug/l	< 0.20 ug/l	< 0.20 ug/l	< 0.20 ug/l	< 0.20 ug/l	< 0.20 ug/l	< 0.20 ug/l	< 0.20 ug/l
Copper	Total	0.60 ug/l	0.88 ug/l	0.97 ug/l	1.3 ug/l	0.73 ug/l	1.0 ug/l	0.79 ug/l	1.0 ug/l	0.83 ug/l	1.2 ug/l
Iron	Total	< 0.050 mg/l	< 0.050 mg/l	< 0.050 mg/l	< 0.050 mg/l	< 0.050 mg/l	< 0.050 mg/l	< 0.050 mg/l	< 0.050 mg/l	< 0.050 mg/l	< 0.050 mg/l
Lead	Total	< 0.20 ug/l	< 0.20 ug/l	< 0.20 ug/l	< 0.20 ug/l	< 0.20 ug/l	< 0.20 ug/l	< 0.20 ug/l	< 0.20 ug/l	< 0.20 ug/l	< 0.20 ug/l
Magnesium	Total	2.7 mg/l	3.1 mg/l	3.5 mg/l	7.5 mg/l	4.9 mg/l	3.0 mg/l	4.1 mg/l	3.2 mg/l	5.1 mg/l	5.8 mg/l
Manganese	Total	1.4 ug/l	1.3 ug/l	21 ug/l	1.4 ug/l	0.59 ug/l	< 0.50 ug/l	< 0.50 ug/l	0.86 ug/l	0.66 ug/l	0.60 ug/l
Nickel	Total	< 0.50 ug/l	< 0.50 ug/l	0.53 ug/l	< 0.50 ug/l	< 0.50 ug/l	< 0.50 ug/l	< 0.50 ug/l	< 0.50 ug/l	< 0.50 ug/l	< 0.50 ug/l
Potassium	Total	2.2 mg/l	1.7 mg/l	1.9 mg/l	2.8 mg/l	2.0 mg/l	1.6 mg/l	2.0 mg/l	1.6 mg/l	2.2 mg/l	3.1 mg/l
Selenium	Total	< 1.0 ug/l	< 1.0 ug/l	< 1.0 ug/l	< 1.0 ug/l	< 1.0 ug/l	< 1.0 ug/l	< 1.0 ug/l	< 1.0 ug/l	< 1.0 ug/l	< 1.0 ug/l
Silicon	Total	1.9 mg/l	2.1 mg/l	2.2 mg/l	2.5 mg/l	1.7 mg/l	1.6 mg/l	2.2 mg/l	1.9 mg/l	1.8 mg/l	1.7 mg/l
Sodium	Total	13 mg/l	13 mg/l	12 mg/l	19 mg/l	12 mg/l	10 mg/l	13 mg/l	11 mg/l	15 mg/l	19 mg/l
Strontium	Total	11 ug/l	9.3 ug/l	11 ug/l	20 ug/l	14 ug/l	8.6 ug/l	12 ug/l	10 ug/l	16 ug/l	19 ug/l
Vanadium	Total	< 0.50 ug/l	< 0.50 ug/l	< 0.50 ug/l	< 0.50 ug/l	< 0.50 ug/l	< 0.50 ug/l	< 0.50 ug/l	< 0.50 ug/l	< 0.50 ug/l	< 0.50 ug/l
Zinc	Total	< 5.0 ug/l	< 5.0 ug/l	< 5.0 ug/l	< 5.0 ug/l	< 5.0 ug/l	< 5.0 ug/l	< 5.0 ug/l	< 5.0 ug/l	< 5.0 ug/l	< 5.0 ug/l

	Location	VSEP Permeate	VSEP Permeate	VSEP Permeate	VSEP Permeate	VSEP Permeate	VSEP Permeate	VSEP Permeate	VSEP Permeate	VSEP Permeate	VSEP Permeate
	Date	9/24/2012	9/25/2012	9/26/2012	9/27/2012	10/1/2012	10/2/2012	10/3/2012	10/4/2012	10/8/2012	10/9/2012
	Sample Type	N	N	N	N	N	N	N	N	N	N
	Fraction										
General Parameters											
Alkalinity, bicarbonate, as CaCO3	NA	**20 mg/l**	< 20 mg/l	< 20 mg/l	**28 mg/l**	< 20 mg/l	< 20 mg/l	< 20 mg/l	< 20 mg/l	< 20 mg/l	< 20 mg/l
Alkalinity, total	NA	**20 mg/l**	< 20 mg/l	< 20 mg/l	**28 mg/l**	< 20 mg/l	< 20 mg/l	< 20 mg/l	< 20 mg/l	--	--
Carbon, total organic	NA	< 1.5 mg/l	< 1.5 mg/l	< 1.5 mg/l	**1.6 mg/l**	< 1.5 mg/l	< 1.5 mg/l	< 1.5 mg/l	< 1.5 mg/l	--	--
Chloride	NA	**40 mg/l**	**38 mg/l**	**35 mg/l**	**4.4 mg/l**	**3.8 mg/l**	**4.6 mg/l**	**3.8 mg/l**	**5.0 mg/l**	**4.6 mg/l**	**3.8 mg/l**
Fluoride	NA	**0.17 mg/l**	**0.15 mg/l**	**0.14 mg/l**	**0.13 mg/l**	**0.16 mg/l**	**0.18 mg/l**	**0.15 mg/l**	**0.16 mg/l**	**0.15 mg/l**	**0.11 mg/l**
Nitrogen, ammonia (NH3), as N	NA	< 0.200 mg/l	< 0.200 mg/l	< 0.200 mg/l	< 0.200 mg/l	< 0.200 mg/l	< 0.200 mg/l	< 0.200 mg/l	< 0.200 mg/l	< 0.200 mg/l	< 0.200 mg/l
Nitrogen, Nitrate as N	NA	< 0.20 h mg/l	< 0.20 mg/l	< 0.20 h mg/l	< 0.20 h mg/l	< 0.20 h mg/l	< 0.20 mg/l	< 0.20 * mg/l	< 0.20 mg/l	--	--
pH	NA	**6.0 pH units**	**5.6 pH units**	**5.7 pH units**	**5.6 pH units**	**5.8 pH units**	**5.6 pH units**	**5.5 pH units**	**5.5 pH units**	**5.4 pH units**	**5.2 pH units**
Phosphorus, total	NA	< 0.100 mg/l	< 0.100 mg/l	< 0.100 mg/l	< 0.100 mg/l	< 0.100 mg/l	< 0.100 mg/l	< 0.100 mg/l	< 0.100 mg/l	< 0.100 mg/l	< 0.100 mg/l
Solids, total dissolved	NA	**140 mg/l**	**160 mg/l**	**110 mg/l**	**100 mg/l**	**160 mg/l**	**170 mg/l**	**75 mg/l**	**100 mg/l**	**51 mg/l**	**64 mg/l**
Solids, total suspended	NA	< 4.0 mg/l	< 4.0 mg/l	< 4.0 mg/l	< 4.0 mg/l	< 4.0 mg/l	< 4.0 mg/l	< 4.0 mg/l	< 4.0 mg/l	--	--
Specific Conductance @ 25oC	NA	**190 umhos/cm**	**180 umhos/cm**	**170 umhos/cm**	**80 umhos/cm**	**89 umhos/cm**	**98 umhos/cm**	**79 umhos/cm**	**92 umhos/cm**	**94 umhos/cm**	**72 umhos/cm**
Sulfate	NA	**9.9 mg/l**	**7.8 mg/l**	**9.7 mg/l**	**12 mg/l**	**12 mg/l**	**18 mg/l**	**11 mg/l**	**17 mg/l**	**18 mg/l**	**11 mg/l**
Metals											
Aluminum	Total	< 10 ug/l	< 10 ug/l	< 10 ug/l	< 10 ug/l	< 10 ug/l	< 10 ug/l	< 10 ug/l	< 10 ug/l	--	--
Arsenic	Total	< 1.0 ug/l	< 1.0 ug/l	< 1.0 ug/l	< 1.0 ug/l	< 1.0 ug/l	< 1.0 ug/l	< 1.0 ug/l	< 1.0 ug/l	< 1.0 ug/l	< 1.0 ug/l
Barium	Total	**2.0 ug/l**	**1.5 ug/l**	**1.8 ug/l**	**0.63 ug/l**	**0.69 ug/l**	**1.0 ug/l**	**0.75 ug/l**	**1.2 ug/l**	--	--
Boron	Total	**0.42 mg/l**	**0.44 mg/l**	**0.42 mg/l**	**0.40 mg/l**	**0.37 mg/l**	**0.38 mg/l**	**0.37 mg/l**	**0.38 mg/l**	**0.36 mg/l**	**0.35 mg/l**
Calcium	Total	**4.4 mg/l**	**3.5 mg/l**	**4.0 mg/l**	**1.3 mg/l**	**1.2 mg/l**	**1.9 mg/l**	**1.4 mg/l**	**2.0 mg/l**	**2.3 mg/l**	**1.4 mg/l**
Cobalt	Total	< 0.20 ug/l	< 0.20 ug/l	< 0.20 ug/l	< 0.20 ug/l	< 0.20 ug/l	< 0.20 ug/l	< 0.20 ug/l	< 0.20 ug/l	< 0.20 ug/l	< 0.20 ug/l
Copper	Total	**1.3 ug/l**	**1.6 ug/l**	**1.4 ug/l**	**1.7 ug/l**	**1.0 ug/l**	**0.69 ug/l**	**0.91 ug/l**	**1.6 ug/l**	**1.9 ug/l**	**0.95 ug/l**
Iron	Total	< 0.050 mg/l	< 0.050 mg/l	< 0.050 mg/l	< 0.050 mg/l	< 0.050 mg/l	< 0.050 mg/l	< 0.050 mg/l	< 0.050 mg/l	< 0.050 mg/l	< 0.050 mg/l
Lead	Total	< 0.20 ug/l	< 0.20 ug/l	< 0.20 ug/l	< 0.20 ug/l	< 0.20 ug/l	< 0.20 ug/l	< 0.20 ug/l	< 0.20 ug/l	< 0.20 ug/l	< 0.20 ug/l
Magnesium	Total	**6.2 mg/l**	**4.9 mg/l**	**5.4 mg/l**	**2.0 mg/l**	**1.8 mg/l**	**2.7 mg/l**	**2.0 mg/l**	**2.7 mg/l**	**3.0 mg/l**	**2.0 mg/l**
Manganese	Total	**0.96 ug/l**	**2.1 ug/l**	**1.3 ug/l**	< 0.50 ug/l	**0.53 ug/l**	**1.6 ug/l**	**0.59 ug/l**	**3.1 ug/l**	**5.3 ug/l**	**2.3 ug/l**
Nickel	Total	< 0.50 ug/l	< 0.50 ug/l	< 0.50 ug/l	< 0.50 ug/l	< 0.50 ug/l	< 0.50 ug/l	< 0.50 ug/l	< 0.50 ug/l	< 0.50 ug/l	< 0.50 ug/l
Potassium	Total	**3.7 mg/l**	**3.5 mg/l**	**3.3 mg/l**	**1.5 mg/l**	**1.2 mg/l**	**1.5 mg/l**	**1.2 mg/l**	**1.4 mg/l**	**1.4 mg/l**	**1.2 mg/l**
Selenium	Total	< 1.0 ug/l	< 1.0 ug/l	< 1.0 ug/l	< 1.0 ug/l	< 1.0 ug/l	< 1.0 ug/l	< 1.0 ug/l	< 1.0 ug/l	< 1.0 ug/l	< 1.0 ug/l
Silicon	Total	**2.0 mg/l**	**1.9 mg/l**	**1.8 mg/l**	**1.6 mg/l**	**1.7 mg/l**	**1.9 mg/l**	**1.8 * mg/l**	**2.2 mg/l**	--	--
Sodium	Total	**21 mg/l**	**22 mg/l**	**19 mg/l**	**10 mg/l**	**9.2 mg/l**	**10 mg/l**	**9.6 mg/l**	**11 mg/l**	**11 mg/l**	**8.9 mg/l**
Strontium	Total	**22 ug/l**	**17 ug/l**	**19 ug/l**	**6.6 ug/l**	**6.5 ug/l**	**9.2 ug/l**	**6.6 ug/l**	**9.9 ug/l**	**9.9 ug/l**	**6.1 ug/l**
Vanadium	Total	< 0.50 ug/l	< 0.50 ug/l	< 0.50 ug/l	< 0.50 ug/l	< 0.50 ug/l	< 0.50 ug/l	< 0.50 ug/l	< 0.50 ug/l	< 0.50 ug/l	< 0.50 ug/l
Zinc	Total	< 5.0 ug/l	< 5.0 ug/l	< 5.0 ug/l	< 5.0 ug/l	< 5.0 ug/l	< 5.0 ug/l	< 5.0 ug/l	**6.0 ug/l**	< 5.0 ug/l	< 5.0 ug/l

Location Date Sample Type		VSEP Permeate 10/10/2012 N	VSEP Permeate 10/11/2012 N	VSEP Permeate 10/15/2012 N	VSEP Permeate 10/16/2012 N	VSEP Permeate 10/17/2012 N	VSEP Permeate 10/18/2012 N	VSEP Permeate 10/23/2012 N	VSEP Permeate 10/31/2012 N	VSEP Permeate 11/7/2012 N
	Fraction									
General Parameters										
Alkalinity, bicarbonate, as CaCO3	NA	< 20 mg/l	< 20 mg/l	**22 mg/l**	**21 mg/l**	**21 mg/l**	< 20 mg/l	**24 mg/l**	**26 mg/l**	**25 mg/l**
Alkalinity, total	NA	--	--	--	--	--	--	--	--	--
Carbon, total organic	NA	--	--	--	--	--	--	--	--	**4.72 mg/l**
Chloride	NA	**2.8 mg/l**	**5.3 mg/l**	**5.5 mg/l**	**5.4 mg/l**	**5.2 mg/l**	**4.9 mg/l**	**4.3 mg/l**	**3.7 mg/l**	**4.3 mg/l**
Fluoride	NA	**0.19 mg/l**	**0.15 mg/l**	**0.21 mg/l**	**0.24 mg/l**	**0.25 mg/l**	**0.20 mg/l**	**0.19 mg/l**	**0.11 mg/l**	**0.094 mg/l**
Nitrogen, ammonia (NH3), as N	NA	< 0.500 mg/l	< 0.500 mg/l	< 0.500 mg/l	< 0.500 mg/l	< 0.500 mg/l	< 0.500 mg/l	< 0.500 mg/l	< 0.500 mg/l	< 0.500 mg/l
Nitrogen, Nitrate as N	NA	--	--	--	--	--	--	--	--	--
pH	NA	**5.2 pH units**	**5.4 pH units**	**5.5 pH units**	**5.7 pH units**	**5.4 pH units**	**5.9 pH units**	**5.7 pH units**	**5.6 pH units**	**5.8 pH units**
Phosphorus, total	NA	< 0.100 mg/l	< 0.100 mg/l	< 0.100 mg/l	< 0.100 mg/l	< 0.100 mg/l	< 0.100 mg/l	< 0.100 mg/l	< 0.100 mg/l	< 0.100 mg/l
Solids, total dissolved	NA	**59 mg/l**	**33 mg/l**	**92 mg/l**	**70 mg/l**	**34 mg/l**	**88 mg/l**	**49 mg/l**	**65 mg/l**	**32 mg/l**
Solids, total suspended	NA	--	--	--	--	--	--	--	--	--
Specific Conductance @ 25oC	NA	**63 umhos/cm**	**96 umhos/cm**	**110 umhos/cm**	**120 umhos/cm**	**120 umhos/cm**	**130 umhos/cm**	**99 umhos/cm**	**93 umhos/cm**	**87 umhos/cm**
Sulfate	NA	**7.1 mg/l**	**17 mg/l**	**19 mg/l**	**21 mg/l**	**23 mg/l**	**25 mg/l**	**20 mg/l**	**15 mg/l**	**14 mg/l**
Metals										
Aluminum	Total	--	--	--	--	--	--	--	--	--
Arsenic	Total	< 1.0 ug/l	< 1.0 ug/l	< 1.0 ug/l	< 1.0 ug/l	< 1.0 ug/l	< 1.0 ug/l	< 1.0 ug/l	< 1.0 ug/l	< 1.0 ug/l
Barium	Total	--	--	--	--	--	--	--	--	--
Boron	Total	**0.34 mg/l**	**0.38 mg/l**	**0.46 mg/l**	**0.47 mg/l**	**0.45 mg/l**	**0.47 mg/l**	**0.46 mg/l**	**0.43 mg/l**	**0.40 mg/l**
Calcium	Total	< 1.0 mg/l	**2.2 mg/l**	**2.0 mg/l**	**2.3 mg/l**	**2.3 mg/l**	**2.5 mg/l**	**2.0 mg/l**	**1.8 mg/l**	**1.8 mg/l**
Cobalt	Total	< 0.20 ug/l	< 0.20 ug/l	< 0.20 ug/l	< 0.20 ug/l	< 0.20 ug/l	< 0.20 ug/l	< 0.20 ug/l	< 0.20 ug/l	< 0.20 ug/l
Copper	Total	**3.1 ug/l**	**1.6 ug/l**	**0.67 ug/l**	< 0.50 ug/l	< 0.50 ug/l	**0.54 ug/l**	**0.75 ug/l**	< 0.50 ug/l	**0.76 ug/l**
Iron	Total	< 0.050 mg/l	< 0.050 mg/l	< 0.050 mg/l	< 0.050 mg/l	< 0.050 mg/l	< 0.050 mg/l	< 0.050 mg/l	< 0.050 mg/l	< 0.050 mg/l
Lead	Total	< 0.20 ug/l	< 0.20 ug/l	< 0.20 ug/l	< 0.20 ug/l	< 0.20 ug/l	< 0.20 ug/l	< 0.20 ug/l	< 0.20 ug/l	< 0.20 ug/l
Magnesium	Total	**1.3 mg/l**	**3.0 mg/l**	**3.1 mg/l**	**3.5 mg/l**	**3.8 mg/l**	**4.3 mg/l**	**3.4 mg/l**	**3.2 mg/l**	**3.0 mg/l**
Manganese	Total	**0.93 ug/l**	**2.9 ug/l**	**1.3 ug/l**	**2.8 ug/l**	**1.5 ug/l**	**1.2 ug/l**	**0.90 ug/l**	**0.93 ug/l**	**2.0 ug/l**
Nickel	Total	< 0.50 ug/l	< 0.50 ug/l	< 0.50 ug/l	< 0.50 ug/l	< 0.50 ug/l	< 0.50 ug/l	< 0.50 ug/l	< 0.50 ug/l	< 0.50 ug/l
Potassium	Total	**1.1 mg/l**	**1.5 mg/l**	**1.8 mg/l**	**2.0 mg/l**	**2.1 mg/l**	**2.2 mg/l**	**1.9 mg/l**	**1.8 mg/l**	**1.9 mg/l**
Selenium	Total	< 1.0 ug/l	< 1.0 ug/l	< 1.0 ug/l	< 1.0 ug/l	< 1.0 ug/l	< 1.0 ug/l	< 1.0 ug/l	< 1.0 ug/l	< 1.0 ug/l
Silicon	Total	--	--	--	--	--	--	--	--	--
Sodium	Total	**8.8 mg/l**	**11 mg/l**	**14 mg/l**	**15 mg/l**	**15 mg/l**	**15 mg/l**	**14 mg/l**	**13 mg/l**	**12 mg/l**
Strontium	Total	**4.1 ug/l**	**9.6 ug/l**	**9.5 ug/l**	**11 ug/l**	**11 ug/l**	**13 ug/l**	**10 ug/l**	**8.5 ug/l**	**8.5 ug/l**
Vanadium	Total	< 0.50 ug/l	< 0.50 ug/l	< 0.50 ug/l	< 0.50 ug/l	< 0.50 ug/l	< 0.50 ug/l	< 0.50 ug/l	< 0.50 ug/l	< 0.50 ug/l
Zinc	Total	< 5.0 ug/l	< 5.0 ug/l	< 5.0 ug/l	< 5.0 ug/l	< 5.0 ug/l	< 5.0 ug/l	< 5.0 ug/l	< 5.0 ug/l	< 5.0 ug/l

Table 14 Average VSEP Removal Rates (Concentration – Based) – No Metals Added

Parameter	Recovery		
	80%	85%	90%
Alkalinity, bicarbonate, as CaCO3	>98.5%	>98.0%	>96.3%
Carbon, total organic	>91.3%	>89.0%	NA
Chloride	96.2%	95.1%	95.0%
Fluoride	95.7%	95.2%	95.6%
Nitrogen, ammonia (NH3), as N	>84.3%	>86.1%	>80.9%
Phosphorus, total	>49.2%	>84.0%	>92.6%
Solids, total dissolved	>92.9%	>96.1%	98.2%
Sulfate	99.2%	99.2%	99.0%
Aluminum	ND	ND	NA
Arsenic	>67.4%	>66.5%	ND
Barium	99.1%	99.1%	NA
Boron	42.2%	39.9%	39.2%
Calcium	>99.3%	99.2%	99.2%
Cobalt	>74.0%	>74.7%	ND
Copper	78.3%	>80.8%	>89.6%
Iron	ND	ND	ND
Lead	ND	ND	ND
Magnesium	99.4%	99.1%	99.1%
Manganese	86.7%	98.7%	99.1%
Nickel	62.1%	>90.8%	>91.1%
Potassium	93.0%	91.8%	92.8%
Selenium	>74.6%	>77.8%	ND
Silicon	96.5%	96.6%	NA
Sodium	93.6%	91.8%	92.1%
Strontium	99.4%	99.2%	99.2%
Vanadium	>56.9%	>51.9%	ND
Zinc	>77.0%	>76.3%	ND

- Where “>” (greater than) is indicated, the permeate concentration was often less than the method reporting limit. Half of the method reporting limit was used to calculate the percent removal in those cases.
- ND = Parameter not detected either VSEP feed or permeate
- NA = Parameter was not analyzed in VSEP permeate

Table 15 Average VSEP Removal Rates (Mass-Based) – No Metals Added

Parameter	Recovery		
	80%	85%	90%
Alkalinity, bicarbonate, as CaCO3	>98.8%	>98.3%	>96.6%
Carbon, total organic	>93.0%	>90.6%	NA
Chloride	97.0%	95.8%	95.5%
Fluoride	96.6%	95.9%	96.0%
Nitrogen, ammonia (NH3), as N	>87.5%	>88.2%	>82.8%
Phosphorus, total	>59.4%	>86.4%	>93.3%
Solids, total dissolved	>94.3%	>96.7%	98.4%
Sulfate	99.3%	99.3%	99.1%
Aluminum	ND	ND	NA
Arsenic	>73.9%	>71.5%	ND
Barium	99.3%	99.3%	NA
Boron	53.8%	48.9%	45.3%
Calcium	>99.5%	99.3%	99.3%
Cobalt	>79.2%	>78.5%	ND
Copper	82.7%	>83.7%	>90.7%
Iron	ND	ND	ND
Lead	ND	ND	ND
Magnesium	99.5%	99.3%	99.2%
Manganese	89.3%	98.9%	99.2%
Nickel	69.7%	>92.2%	>92.0%
Potassium	94.4%	93.0%	93.5%
Selenium	>79.7%	>81.1%	ND
Silicon	97.2%	97.1%	ND
Sodium	94.9%	93.0%	92.9%
Strontium	99.5%	99.3%	99.3%
Vanadium	>65.5%	>59.1%	ND
Zinc	>81.6%	>79.9%	ND

- Where “>” (greater than) is indicated, the permeate concentration was often less than the method reporting limit. Half of the method reporting limit was used to calculate the percent removal in those cases.
- ND = Parameter not detected either VSEP feed or permeate
- NA = Parameter was not analyzed in VSEP permeate

Table 16 VSEP Concentrate Water Quality

	Location	VSEP Concentrate	VSEP Concentrate	VSEP Concentrate	VSEP Concentrate	VSEP Concentrate	VSEP Concentrate	VSEP Concentrate	VSEP Concentrate	VSEP Concentrate	VSEP Concentrate
	Date	8/28/2012	9/5/2012	9/11/2012	9/12/2012	9/13/2012	9/14/2012	9/17/2012	9/18/2012	9/19/2012	9/20/2012
	Sample Type	N	N	N	N	N	N	N	N	N	N
	Fraction										
General Parameters											
Alkalinity, bicarbonate, as CaCO3	NA	1000 mg/l	2000 mg/l	2400 mg/l	2400 mg/l	1700 mg/l	2100 mg/l	1200 mg/l	1100 mg/l	2600 mg/l	2500 mg/l
Alkalinity, total	NA	1000 mg/l	2000 mg/l	2400 mg/l	2400 mg/l	1700 mg/l	2100 mg/l	1200 mg/l	1100 mg/l	2600 mg/l	2500 mg/l
Carbon, total organic	NA	47 mg/l	83 mg/l	94 mg/l	54 mg/l	83 mg/l	--	80 mg/l	70 mg/l	70 mg/l	58 mg/l
Chloride	NA	3100 mg/l	530 mg/l	300 mg/l	290 mg/l	340 mg/l	390 mg/l	430 mg/l	420 mg/l	1500 mg/l	3300 mg/l
Fluoride	NA	11 mg/l	13 mg/l	10 mg/l	19 mg/l	14 mg/l	16 mg/l	17 mg/l	16 mg/l	19 mg/l	17 mg/l
Nitrogen, ammonia (NH3), as N	NA	4.51 mg/l	5.16 mg/l	3.29 mg/l	2.78 mg/l	3.55 mg/l	3.07 mg/l	4.66 mg/l	5.04 mg/l	2.05 mg/l	1.81 mg/l
Nitrogen, Nitrate as N	NA	< 2.0 mg/l	< 2.0 mg/l	< 2.0 mg/l	< 2.0 h mg/l	< 2.0 h mg/l	< 2.0 h mg/l	< 2.0 mg/l	< 2.0 mg/l	< 2.0 mg/l	< 2.0 mg/l
pH	NA	6.8 pH units	6.8 pH units	6.9 pH units	6.8 pH units	6.6 pH units	6.8 pH units	6.4 pH units	6.5 pH units	6.6 pH units	6.7 pH units
Phosphorus, total	NA	3.51 mg/l	2.34 mg/l	0.295 mg/l	2.29 mg/l	1.41 mg/l	1.31 mg/l	1.97 * mg/l	1.06 mg/l	4.89 mg/l	3.95 mg/l
Solids, total dissolved	NA	23000 mg/l	14000 mg/l	10000 mg/l	20000 mg/l	15000 mg/l	16000 mg/l	19000 mg/l	16000 mg/l	24000 mg/l	24000 mg/l
Solids, total suspended	NA	11 mg/l	21 mg/l	9.2 mg/l	16 mg/l	15 mg/l	18 mg/l	14 mg/l	20 mg/l	84 mg/l	66 mg/l
Specific Conductance @ 25oC	NA	14000 umhos/cm	12000 e umhos/cm	9900 umhos/cm	15000 umhos/cm	12000 umhos/cm	13000 e umhos/cm	14000 e umhos/cm	13000 e umhos/cm	15000 e umhos/cm	16000 e umhos/cm
Sulfate	NA	2100 mg/l	7400 mg/l	4000 mg/l	9100 mg/l	8500 mg/l	8900 mg/l	11000 mg/l	8300 mg/l	8800 mg/l	4400 mg/l
Metals											
Aluminum	Total	< 50 ug/l	< 50 ug/l	< 50 ug/l	< 50 ug/l	< 50 ug/l	< 50 ug/l	< 50 ug/l	< 50 ug/l	< 50 ug/l	< 50 ug/l
Arsenic	Total	6.2 ug/l	8.2 ug/l	5.6 ug/l	6.9 ug/l	7.0 ug/l	7.4 ug/l	8.6 ug/l	7.8 ug/l	7.8 ug/l	< 5.0 ug/l
Barium	Total	810 ug/l	280 ug/l	330 ug/l	400 ug/l	250 ug/l	520 ug/l	380 ug/l	420 ug/l	510 ug/l	560 ug/l
Boron	Total	1.4 mg/l	1.5 mg/l	1.2 mg/l	2.0 mg/l	2.0 mg/l	2.1 mg/l	2.1 mg/l	2.0 mg/l	2.3 mg/l	2.0 mg/l
Cadmium	Total	< 1.0 ug/l	< 1.0 ug/l	< 1.0 ug/l	< 1.0 ug/l	< 1.0 ug/l	< 1.0 ug/l	< 1.0 ug/l	< 1.0 ug/l	< 1.0 ug/l	< 1.0 ug/l
Calcium	Total	1100 mg/l	860 mg/l	920 mg/l	1200 mg/l	1000 mg/l	1200 mg/l	860 mg/l	890 mg/l	1400 mg/l	1200 mg/l
Cobalt	Total	2.3 ug/l	1.6 ug/l	2.2 ug/l	1.6 ug/l	1.8 ug/l	1.9 ug/l	1.7 ug/l	1.6 ug/l	2.7 ug/l	2.2 ug/l
Copper	Total	26 ug/l	270 ug/l	350 ug/l	240 ug/l	200 ug/l	230 ug/l	230 ug/l	320 ug/l	380 ug/l	790 ug/l
Iron	Total	< 0.050 mg/l	< 0.50 mg/l	< 0.50 mg/l	< 0.50 mg/l	< 0.50 mg/l	< 0.50 mg/l	< 0.50 mg/l	< 0.50 mg/l	< 0.50 mg/l	< 0.50 mg/l
Lead	Total	1.9 ug/l	< 1.0 ug/l	2.1 ug/l	1.1 ug/l	1.5 ug/l	2.0 ug/l	1.4 ug/l	< 1.0 ug/l	2.0 ug/l	1.1 ug/l
Magnesium	Total	1200 mg/l	1500 mg/l	1200 mg/l	2300 mg/l	1800 mg/l	1900 mg/l	2100 mg/l	1900 mg/l	2200 mg/l	1900 mg/l
Manganese	Total	580 ug/l	520 ug/l	7100 ug/l	320 ug/l	150 ug/l	190 ug/l	140 ug/l	370 ug/l	210 ug/l	140 ug/l
Nickel	Total	< 2.5 ug/l	17 ug/l	37 ug/l	13 ug/l	17 ug/l	5.0 ug/l	9.8 ug/l	10 ug/l	27 ug/l	11 ug/l
Potassium	Total	90 mg/l	92 mg/l	77 mg/l	140 mg/l	100 mg/l	120 mg/l	130 mg/l	110 mg/l	130 mg/l	110 mg/l
Selenium	Total	10 ug/l	12 ug/l	8.5 ug/l	7.5 ug/l	9.2 ug/l	9.7 ug/l	11 ug/l	10 ug/l	10 ug/l	8.1 ug/l
Silicon	Total	240 mg/l	240 mg/l	170 mg/l	230 mg/l	240 mg/l	240 mg/l	250 mg/l	260 mg/l	280 mg/l	260 mg/l
Sodium	Total	600 mg/l	640 mg/l	480 mg/l	920 mg/l	710 mg/l	780 mg/l	850 mg/l	770 mg/l	890 mg/l	750 mg/l
Strontium	Total	5100 ug/l	4300 ug/l	4200 ug/l	6900 ug/l	5100 ug/l	6000 ug/l	5000 ug/l	1000 ug/l	7400 ug/l	6400 ug/l
Thallium	Total	< 1.0 ug/l	< 1.0 ug/l	< 1.0 ug/l	< 1.0 ug/l	< 1.0 ug/l	< 1.0 ug/l	< 1.0 ug/l	< 1.0 ug/l	< 1.0 ug/l	< 1.0 ug/l
Vanadium	Total	< 2.5 ug/l	2.8 ug/l	< 2.5 ug/l	< 2.5 ug/l	< 2.5 ug/l	< 2.5 ug/l	2.5 ug/l	< 2.5 ug/l	< 2.5 ug/l	< 2.5 ug/l
Zinc	Total	75 ug/l	250 ug/l	110 ug/l	71 ug/l	110 ug/l	87 ug/l	77 ug/l	79 ug/l	110 ug/l	88 ug/l

Location		VSEP Concentrate	VSEP Concentrate	VSEP Concentrate	VSEP Concentrate	VSEP Concentrate	VSEP Concentrate	VSEP Concentrate	VSEP Concentrate	VSEP Concentrate
Date		9/24/2012	9/25/2012	9/26/2012	9/27/2012	10/1/2012	10/2/2012	10/3/2012	10/4/2012	10/8/2012
Sample Type		N	N	N	N	N	N	N	N	N
	Fraction									
General Parameters										
Alkalinity, bicarbonate, as CaCO3	NA	**1900 mg/l**	**1700 mg/l**	**2000 mg/l**	**2100 mg/l**	**1200 mg/l**	**1100 mg/l**	**1500 mg/l**	**1300 mg/l**	**1400 mg/l**
Alkalinity, total	NA	**1900 mg/l**	**1700 mg/l**	**2000 mg/l**	**2100 mg/l**	**1200 mg/l**	**1100 mg/l**	**1500 mg/l**	**1300 mg/l**	--
Carbon, total organic	NA	**58 mg/l**	**48 mg/l**	**69 mg/l**	**96 mg/l**	**100 mg/l**	**110 mg/l**	**99 mg/l**	**120 mg/l**	**100 mg/l**
Chloride	NA	**4800 mg/l**	**4600 mg/l**	**4100 mg/l**	**560 mg/l**	**480 mg/l**	**510 mg/l**	**520 mg/l**	**640 mg/l**	**540 mg/l**
Fluoride	NA	**18 mg/l**	**18 mg/l**	**19 mg/l**	**18 mg/l**	**16 mg/l**	**17 mg/l**	**16 mg/l**	**8.5 mg/l**	**15 mg/l**
Nitrogen, ammonia (NH3), as N	NA	**4.83 mg/l**	**4.88 mg/l**	**3.31 mg/l**	**5.35 * mg/l**	**6.74 mg/l**	**6.89 mg/l**	**6.56 mg/l**	**7.66 mg/l**	**7.12 mg/l**
Nitrogen, Nitrate as N	NA	< 2.0 h mg/l	< 2.0 mg/l	< 2.0 h mg/l	< 2.0 h mg/l	< 2.0 h mg/l	< 2.0 mg/l	< 2.0 mg/l	< 2.0 mg/l	--
pH	NA	**6.7 pH units**	**7.0 pH units**	**6.6 pH units**	**6.8 pH units**	**6.5 pH units**	**6.5 pH units**	**6.7 pH units**	**6.5 pH units**	**6.7 pH units**
Phosphorus, total	NA	**1.86 mg/l**	**3.95 mg/l**	**0.796 mg/l**	**3.93 mg/l**	**2.02 mg/l**	**3.21 mg/l**	**2.03 mg/l**	**3.49 mg/l**	**4.39 mg/l**
Solids, total dissolved	NA	**17000 mg/l**	**16000 mg/l**	**15000 mg/l**	**19000 mg/l**	**17000 mg/l**	**20000 mg/l**	**15000 mg/l**	**15000 mg/l**	**18000 mg/l**
Solids, total suspended	NA	**22 mg/l**	**20 mg/l**	**60 mg/l**	**20 mg/l**	**20 mg/l**	**26 mg/l**	**82 mg/l**	**84 mg/l**	**66 mg/l**
Specific Conductance @ 25oC	NA	**19000 e umhos/cm**	**20000 e umhos/cm**	**20000 e umhos/cm**	**15000 e umhos/cm**	**14000 e umhos/cm**	**15000 e umhos/cm**	**14000 e umhos/cm**	**15000 e umhos/cm**	**14000 e umhos/cm**
Sulfate	NA	**4600 mg/l**	**4800 mg/l**	**6000 mg/l**	**10000 mg/l**	**9600 mg/l**	**11000 mg/l**	**9400 mg/l**	**2300 mg/l**	**9800 mg/l**
Metals										
Aluminum	Total	< 50 ug/l	< 50 ug/l	< 100 ug/l	< 100 ug/l	< 100 ug/l	< 100 ug/l	< 100 ug/l	< 100 ug/l	--
Arsenic	Total	< 5.0 ug/l	< 5.0 ug/l	< 10 ug/l	< 10 ug/l	< 10 ug/l	**10 ug/l**	< 10 ug/l	**10 ug/l**	**8.0 ug/l**
Barium	Total	**360 ug/l**	**370 ug/l**	**680 ug/l**	**650 ug/l**	**250 ug/l**	**430 ug/l**	**430 ug/l**	**450 ug/l**	**270 ug/l**
Boron	Total	**2.0 mg/l**	**2.1 mg/l**	**2.3 mg/l**	**2.3 mg/l**	**2.0 mg/l**	**2.1 mg/l**	**2.1 mg/l**	**2.1 mg/l**	**2.0 mg/l**
Cadmium	Total	< 1.0 ug/l	< 1.0 ug/l	< 2.0 ug/l	< 2.0 ug/l	< 2.0 ug/l	< 2.0 ug/l	< 2.0 ug/l	< 2.0 ug/l	--
Calcium	Total	**1300 mg/l**	**1400 mg/l**	**1500 mg/l**	**1400 mg/l**	**880 mg/l**	**1000 mg/l**	**1200 mg/l**	**1100 mg/l**	**930 mg/l**
Cobalt	Total	**2.5 ug/l**	**2.9 ug/l**	**3.5 ug/l**	**2.5 ug/l**	**2.3 ug/l**	**2.8 ug/l**	**2.6 ug/l**	**2.6 ug/l**	**1.8 ug/l**
Copper	Total	**610 ug/l**	**1200 ug/l**	**730 ug/l**	**220 ug/l**	**180 ug/l**	**160 ug/l**	**120 ug/l**	**150 ug/l**	**110 ug/l**
Iron	Total	< 0.50 mg/l	< 0.50 mg/l	< 0.50 mg/l	< 0.50 mg/l	< 0.50 mg/l	< 0.50 mg/l	< 0.50 mg/l	< 0.50 mg/l	< 0.50 mg/l
Lead	Total	**2.8 ug/l**	**2.6 ug/l**	**3.5 ug/l**	**5.7 ug/l**	**2.6 ug/l**	**3.2 ug/l**	**3.6 ug/l**	**2.7 ug/l**	**1.7 ug/l**
Magnesium	Total	**2000 mg/l**	**2100 mg/l**	**2100 mg/l**	**2000 mg/l**	**1800 mg/l**	**1900 mg/l**	**1800 mg/l**	**1900 mg/l**	**1900 mg/l**
Manganese	Total	**190 ug/l**	**870 ug/l**	**420 ug/l**	**360 ug/l**	**400 ug/l**	**1100 ug/l**	**410 ug/l**	**2000 ug/l**	**3300 ug/l**
Nickel	Total	**8.2 ug/l**	**34 ug/l**	**51 ug/l**	**16 ug/l**	**15 ug/l**	**13 ug/l**	**8.7 ug/l**	**7.7 ug/l**	**8.2 ug/l**
Potassium	Total	**110 mg/l**	**110 mg/l**	**120 mg/l**	**120 mg/l**	**99 mg/l**	**120 mg/l**	**93 mg/l**	**100 mg/l**	**97 mg/l**
Selenium	Total	**7.9 ug/l**	**7.5 ug/l**	< 10 ug/l	**12 ug/l**	**15 ug/l**	**16 ug/l**	**15 ug/l**	**17 ug/l**	**13 ug/l**
Silicon	Total	**290 mg/l**	**280 mg/l**	**320 mg/l**	**320 mg/l**	**300 mg/l**	**320 mg/l**	**290 mg/l**	**340 mg/l**	**320 mg/l**
Sodium	Total	**790 mg/l**	**830 mg/l**	**820 mg/l**	**820 mg/l**	**710 mg/l**	**790 mg/l**	**750 mg/l**	**820 mg/l**	**770 mg/l**
Strontium	Total	**7000 ug/l**	**7400 ug/l**	**8000 ug/l**	**7500 ug/l**	**5200 ug/l**	**5500 ug/l**	**5600 ug/l**	**5500 ug/l**	**4900 ug/l**
Thallium	Total	< 1.0 ug/l	< 1.0 ug/l	< 2.0 ug/l	< 2.0 ug/l	< 2.0 ug/l	< 2.0 ug/l	< 2.0 ug/l	< 2.0 ug/l	--
Vanadium	Total	< 2.5 ug/l	< 2.5 ug/l	< 5.0 ug/l	< 5.0 ug/l	< 5.0 ug/l	< 5.0 ug/l	< 5.0 ug/l	< 5.0 ug/l	**3.3 ug/l**
Zinc	Total	**79 ug/l**	**240 ug/l**	**140 ug/l**	**80 ug/l**	**84 ug/l**	**110 ug/l**	**120 ug/l**	**200 ug/l**	**150 ug/l**

Location Date Sample Type		VSEP Concentrate 10/9/2012 N	VSEP Concentrate 10/10/2012 N	VSEP Concentrate 10/11/2012 N	VSEP Concentrate 10/15/2012 N	VSEP Concentrate 10/16/2012 N	VSEP Concentrate 10/17/2012 N	VSEP Concentrate 10/18/2012 N	VSEP Concentrate 10/23/2012 N	VSEP Concentrate 10/31/2012 N	VSEP Concentrate 11/7/2012 N
	Fraction										
General Parameters											
Alkalinity, bicarbonate, as CaCO3	NA	**1800 mg/l**	**1100 mg/l**	**2700 mg/l**	**2300 mg/l**	**2200 mg/l**	**2000 mg/l**	**2300 mg/l**	**3000 mg/l**	**4500 mg/l**	**3500 mg/l**
Alkalinity, total	NA	--	--	--	--	--	--	--	--	--	--
Carbon, total organic	NA	**130 mg/l**	**81 mg/l**	**150 mg/l**	**160 mg/l**	**120 mg/l**	**110 mg/l**	**87 mg/l**	**82 mg/l**	**78.7 mg/l**	--
Chloride	NA	**630 mg/l**	**410 mg/l**	**700 mg/l**	**680 mg/l**	**660 mg/l**	**580 mg/l**	**530 mg/l**	**480 mg/l**	**490 mg/l**	**490 mg/l**
Fluoride	NA	**17 mg/l**	**14 mg/l**	**18 mg/l**	**25 mg/l**	**27 mg/l**	**24 mg/l**	**25 mg/l**	**23 mg/l**	**21 mg/l**	**18 mg/l**
Nitrogen, ammonia (NH3), as N	NA	**7.70 mg/l**	**6.26 mg/l**	**10.3 mg/l**	**8.79 mg/l**	**7.93 mg/l**	**6.51 mg/l**	**5.54 mg/l**	**5.22 mg/l**	**5.46 mg/l**	**5.10 mg/l**
Nitrogen, Nitrate as N	NA	--	--	--	--	--	--	--	--	--	--
pH	NA	**6.9 pH units**	**6.6 pH units**	**7.1 pH units**	**6.8 pH units**	**7.0 pH units**	**6.8 pH units**	**6.8 pH units**	**7.1 pH units**	**7.2 pH units**	**7.5 pH units**
Phosphorus, total	NA	**2.41 mg/l**	**3.68 mg/l**	**6.01 mg/l**	**6.29 * mg/l**	**6.11 mg/l**	**5.52 mg/l**	**5.19 mg/l**	**4.36 mg/l**	**3.73 mg/l**	**4.08 mg/l**
Solids, total dissolved	NA	**22000 mg/l**	**14000 mg/l**	**18000 mg/l**	**14000 mg/l**	**15000 mg/l**	**22000 mg/l**	**25000 mg/l**	**22000 mg/l**	**21000 mg/l**	**18000 mg/l**
Solids, total suspended	NA	**50 mg/l**	**16 mg/l**	**460 mg/l**	**530 mg/l**	**500 mg/l**	**340 mg/l**	**250 mg/l**	**390 mg/l**	**97 mg/l**	**18 mg/l**
Specific Conductance @ 25oC	NA	**15000 e umhos/cm**	**12000 e umhos/cm**	**16000 e umhos/cm**	**18000 e umhos/cm**	**19000 umhos/cm**	**18000 e umhos/cm**	**18000 umhos/cm**	**16000 e umhos/cm**	**16000 e umhos/cm**	**14000 e umhos/cm**
Sulfate	NA	**11000 mg/l**	**7900 mg/l**	**12000 mg/l**	**14000 mg/l**	**15000 mg/l**	**15000 mg/l**	**15000 mg/l**	**12000 mg/l**	**10000 mg/l**	**8400 mg/l**
Metals											
Aluminum	Total	--	--	--	--	--	--	--	--	--	--
Arsenic	Total	**8.2 ug/l**	**7.0 ug/l**	**11 ug/l**	**13 ug/l**	**12 ug/l**	**10 ug/l**	**9.0 ug/l**	**9.5 ug/l**	**6.8 ug/l**	**7.1 ug/l**
Barium	Total	**300 ug/l**	**600 ug/l**	**500 ug/l**	**570 ug/l**	**360 ug/l**	**420 ug/l**	**480 ug/l**	**490 ug/l**	**610 ug/l**	**510 ug/l**
Boron	Total	**2.2 mg/l**	**1.8 mg/l**	**2.3 mg/l**	**2.6 mg/l**	**2.7 mg/l**	**2.4 mg/l**	**2.6 mg/l**	**2.3 mg/l**	**2.4 mg/l**	**2.2 mg/l**
Cadmium	Total	--	--	--	--	--	--	--	--	--	--
Calcium	Total	**1300 mg/l**	**1100 mg/l**	**1200 mg/l**	**830 mg/l**	**920 mg/l**	**900 mg/l**	**990 mg/l**	**1300 mg/l**	**1400 mg/l**	**1400 mg/l**
Cobalt	Total	**2.4 ug/l**	**1.9 ug/l**	**2.2 ug/l**	**2.6 ug/l**	**2.5 ug/l**	**1.8 ug/l**	**1.7 ug/l**	**1.9 ug/l**	**2.4 ug/l**	**2.1 ug/l**
Copper	Total	**92 ug/l**	**71 ug/l**	**87 ug/l**	**160 ug/l**	**120 ug/l**	**69 ug/l**	**63 ug/l**	**62 ug/l**	**45 ug/l**	**48 ug/l**
Iron	Total	< 0.50 mg/l	< 0.50 mg/l	< 0.50 mg/l	< 0.50 mg/l	< 0.50 mg/l	< 0.50 mg/l	< 0.50 mg/l	< 0.50 mg/l	< 0.50 mg/l	< 0.50 mg/l
Lead	Total	**5.6 ug/l**	**5.3 ug/l**	**3.9 ug/l**	**2.9 ug/l**	**2.8 ug/l**	**1.6 ug/l**	**1.6 ug/l**	**3.7 ug/l**	**1.7 ug/l**	**2.5 ug/l**
Magnesium	Total	**2000 mg/l**	**1500 mg/l**	**2400 mg/l**	**3000 mg/l**	**3100 mg/l**	**2900 mg/l**	**2900 mg/l**	**2600 mg/l**	**2300 mg/l**	**2000 mg/l**
Manganese	Total	**2300 ug/l**	**630 ug/l**	**3700 ug/l**	**1200 ug/l**	**2200 ug/l**	**1100 ug/l**	**760 ug/l**	**460 ug/l**	**580 ug/l**	**1400 ug/l**
Nickel	Total	**5.0 ug/l**	**3.9 ug/l**	**6.4 ug/l**	**17 ug/l**	**14 ug/l**	**8.6 ug/l**	**8.1 ug/l**	**7.5 ug/l**	**12 ug/l**	**11 ug/l**
Potassium	Total	**110 mg/l**	**81 mg/l**	**130 mg/l**	**170 mg/l**	**190 mg/l**	**170 mg/l**	**170 mg/l**	**150 mg/l**	**140 mg/l**	**130 mg/l**
Selenium	Total	**15 ug/l**	**11 ug/l**	**18 ug/l**	**21 ug/l**	**18 ug/l**	**14 ug/l**	**13 ug/l**	**12 ug/l**	**8.7 ug/l**	**11 ug/l**
Silicon	Total	**360 mg/l**	**250 mg/l**	**420 mg/l**	**380 mg/l**	**410 mg/l**	**360 mg/l**	**330 mg/l**	**290 mg/l**	**280 mg/l**	**260 mg/l**
Sodium	Total	**860 mg/l**	**610 mg/l**	**1000 mg/l**	**1200 mg/l**	**1300 mg/l**	**1200 mg/l**	**1100 mg/l**	**1000 mg/l**	**960 mg/l**	**830 mg/l**
Strontium	Total	**6700 ug/l**	**5200 ug/l**	**13000 ug/l**	**6000 ug/l**	**5900 ug/l**	**6200 ug/l**	**6700 ug/l**	**7700 ug/l**	**7300 ug/l**	**6100 ug/l**
Thallium	Total	--	--	--	--	--	--	--	--	--	--
Vanadium	Total	< 2.5 ug/l	< 2.5 ug/l	**3.7 ug/l**	< 5.0 ug/l	< 5.0 ug/l	< 2.5 ug/l	< 2.5 ug/l	< 2.5 ug/l	< 2.5 ug/l	< 2.5 ug/l
Zinc	Total	**130 ug/l**	**85 ug/l**	**100 ug/l**	**120 ug/l**	**140 ug/l**	**99 ug/l**	**77 ug/l**	**63 ug/l**	**75 ug/l**	**54 ug/l**

Table 17 Modeled Lime Dose for Effluent Stabilization

Addition	Chemical	Optimal Dose (mg/L)	Optimal Final pH	$CaCO_3$ SI Final
Lime and CO_2	$Ca(OH)_2$	130	7.3	0.10
	CO_2	77		

Table 18 Summary of Lime Addition Bench Test Results

Parameter	Total or Dissolved	Units	Control	Unstabilized Permeate	Dose 2	Dose 3	Dose 4	Dose 5	Dose 6
Hydrated Lime Dose, as $Ca(OH)_2$	NA	mg/L		0	65	98	130	195	260
Alkalinity, bicarbonate, as CaCO3	NA	mg/L	NA	<20	80	100	130	160	200
Alkalinity, total	NA	mg/L	NA	<20	80	100	130	160	200
Chloride	NA	mg/L	NA	0.83	0.89	0.84	0.78	0.77	0.78
Fluoride	NA	mg/L	NA	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050
Nitrogen, ammonia (NH3), as N	NA	mg/L	NA	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20
pH	NA	SU	NA	6.1	7.4	7.6	7.9	7.8	7.9
Turbidity	NA	NTU	NA	0.0	7.0	11.0	44.9	193.0	253.0
Phosphorus, total	NA	mg/L	NA	<0.10	<0.10	0.11	<0.10	<0.10	<0.10
Silicon dioxide	NA	mg/L	NA	1.0	1.5	1.7	1.8	2.3	2.8
Solids, total dissolved	NA	mg/L	NA	<10	240	280	210	220	230
Solids, total suspended	NA	mg/L	NA	<4.0	4.4	4.4	24.0	10.0	140.0
Sulfate	NA	mg/L	NA	4.0	4.2	4.2	3.7	3.7	3.7
Aluminum	Total	µg/L	NA	<10	120	180	230	390	470
Antimony	Total	µg/L	NA	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20
Arsenic	Total	µg/L	NA	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
Boron	Total	mg/L	NA	0.24	0.24	0.24	0.24	0.23	0.24
Cadmium	Total	µg/L	NA	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20
Calcium	Total	mg/L	NA	<1.0	29	44	57	86	110
Chromium (VI)	Total	mg/L	NA	<0.020	<0.020	<0.020	<0.020	<0.020	<0.020
Cobalt	Total	µg/L	NA	<0.20	<0.20	<0.20	<0.20	0.23	0.28
Copper	Total	µg/L	NA	0.8	0.9	<0.50	0.79	0.85	1.0
Iron	Total	mg/L	NA	<0.05	0.08	0.12	0.18	0.25	0.32
Lead	Total	µg/L	NA	<0.050	<0.20	<0.20	<0.20	<0.20	<0.20
Manganese	Total	µg/L	NA	<0.5	2.00	2.90	4.0	5.9	7.3
Mercury	Total	ng/L	NA	<0.100	<0.100	0.33	0.134	0.123	0.155
Molybdenum	Total	µg/L	NA	<0.20	<0.20	0.26	0.41	0.31	0.27
Nickel	Total	µg/L	NA	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50
Potassium	Total	mg/L	NA	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
Selenium	Total	µg/L	NA	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
Silicon	Total	mg/L	NA	0.36	0.62	0.76	0.87	1.1	1.3
Sodium	Total	mg/L	NA	3.3	3.5	3.3	3.1	3.1	3.1
Thallium	Total	µg/L	NA	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20
Zinc	Total	µg/L	NA	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0
WET Test Results									
Survival	NA	%	100	90	100	100	100	100	90
Reproduction	NA	#/female	14.4	7.7	12.2	14	14.6	13.8	10.9
Calculated Indices									
LSI	NA	NA	NA	-4.56	-0.76	-0.29	0.25	0.41	0.72
SI	NA	NA	NA	-4.48	-0.61	-0.16	0.34	0.48	0.76

Table 19 Summary of Limestone Bed Contactor Bench Test Results

				Rate 1			Rate 2			Rate 3			Raw
Parameter	**Total or Dissolved**	**Units**	**Comtrol**	**Caustic**	**No Treatment**	**Sparge**	**Caustic**	**No Treatment**	**Sparge**	**Caustic**	**No Treatment**	**Sparge**	**Untreated Permeate**
Hydraulic Loading Rate	NA	gpm/sf	NA	2.4	2.4	2.4	3.6	3.6	3.6	4.8	4.8	4.8	NA
Alkalinity, bicaronate, as CaCO3	NA	mg/l	NA	110	120	110	110	110	100	110	110	92	< 20
pH	NA	pH units	NA	7.8	7.7	7.9	7.8	7.8	7.9	7.9	7.8	7.9	7.7
Phosporus, total	NA	mg/l	NA	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100
Solids, total dissolved	NA	mg/l	NA	69	77	71	85	120	52	58	57	76	< 10
Solids, total suspended	NA	mg/l	NA	< 4.0	< 4.0	< 4.0	< 4.0	< 4.0	7	29	< 5.0	5.6	< 4.0
Sulfate	NA	mg/l	NA	3.1	3.3	3.1	3.1	3.2	3.1	3.1	3.3	3.1	3
Final Turbidity	NA	NTU	NA	5.5	7.2	3.1	4.5	7.3	5.7	53	12.5	10.6	0
Metals													
Aluminum	Total	ug/l	NA	21	13	14	15	13	15	88	20	25	< 10
Antimony	Total	ug/l	NA	< 0.20	< 0.20	< 0.20	< 0.20	< 0.20	< 0.20	< 0.20	< 0.20	< 0.20	< 0.20
Arsenic	Total	ug/l	NA	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
Cadmium	Total	ug/l	NA	< 0.20	< 0.20	< 0.20	< 0.20	< 0.20	< 0.20	< 0.20	< 0.20	< 0.20	< 0.20
Calcium	Total	mg/l	NA	47	47	45	43	42	43	60	42	42	< 1.0
Chromium, exavalent	NA	mg/l	NA	< 0.020	< 0.020	< 0.020	< 0.020	< 0.020	< 0.020	< 0.020	< 0.020	< 0.020	< 0.020
Cobalt	Total	ug/l	NA	< 0.20	< 0.20	< 0.20	< 0.20	< 0.20	< 0.20	< 0.20	< 0.20	< 0.20	< 0.20
Copper	Total	ug/l	NA	0.66	< 0.50	< 0.50	< 0.50	< 0.50	< 0.50	< 0.50	< 0.50	< 0.50	0.52
Iron	Total	mg/l	NA	< 0.050	< 0.050	< 0.050	< 0.050	< 0.050	< 0.050	0.058	< 0.050	< 0.050	< 0.050
Lead	Total	ug/l	NA	< 0.20	< 0.20	< 0.20	< 0.20	< 0.20	< 0.20	0.49	< 0.20	0.2	< 0.20
Manganese	Total	ug/l	NA	5.5	3	4.5	4.3	3.1	3.7	12	3.9	4.4	0.95
Molydenum	Total	ug/l	NA	0.38	0.66	0.46	0.39	0.59	0.6	0.41	0.59	0.6	< 0.20
Nickel	Total	ug/l	NA	0.55	0.69	< 0.50	< 0.50	< 0.50	< 0.50	< 0.50	< 0.50	< 0.50	< 0.50
Selenium	Total	ug/l	NA	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
Silicon	Total	mg/l	NA	0.49	0.47	0.45	0.46	0.45	0.46	0.71	0.49	0.5	0.44
Tallium	Total	ug/l	NA	< 0.20	< 0.20	< 0.20	< 0.20	< 0.20	< 0.20	< 0.20	< 0.20	< 0.20	< 0.20
Zinc	Total	ug/l	NA	< 5.0	< 5.0	< 5.0	< 5.0	< 5.0	< 5.0	< 5.0	< 5.0	< 5.0	< 5.0
WET Test Results													
Survival	NA	%	100	100	100	100	100	100	100	90	100	100	90
Reproduction	NA	#/female	19.3	13.6	16.5	16.6	12	12.8	14.5	10	12.9	12	11.1
Calculated Indices													
LSI	NA	NA	NA	0.00	0.00	0.10	0.00	0.00	0.10	0.30	0.00	0.00	-3.00
SI	NA	NA	NA	0.1967	0.1333	0.2777	0.1624	0.1533	0.222	0.387	0.1533	0.1704	-2.7851

Table 20 Stock Solution 1 Composition

Stock Solution 1 - Arsenic, cobalt, copper, nickel, and zinc	
Copper sulfate pentahydrate	$CuSO_4$-5H_2O
Target influent Cu concentration	700 µg/L
Stock solution Cu concentration	700 mg/L
Stock solution salt concentration	2,750 mg/L
Mass of copper salt required for 20 gal	165.0 g
Cobalt chloride hexahydrate	$CoCl_2$-6H_2O
Target influent Co concentration	150 µg/L
Stock solution Co concentration	150 mg/L
Stock solution Co salt concentration	606 mg/L
Mass of cobalt salt required for 20 gal	36.3 g
Nickel chloride hexahydrate	$NiCl_2$-6H_2O
Target influent Ni concentration	1300 µg/L
Stock solution Ni concentration	1,300 mg/L
Stock solution salt concentration	5,265 mg/L
Mass of nickel salt required for 20 gal	315.9 g
Sodium arsenite	$NaAsO_2$
Target influent As concentration	100 µg/L
Stock solution As concentration	100 mg/L
Stock solution salt concentration	173 mg/L
Mass of arsenic salt required for 20 gal	10.4 g
Zinc sulfate heptahydrate	$ZnSO_4$-7H_2O
Target influent Zn concentration	300 µg/L
Stock solution Zn concentration	300 mg/L
Stock solution salt concentration	1, 319 mg/L
Mass of zinc salt required for 20 gal	79.2 g

Table 21 Stock Solution 2 Composition

Stock Solution 2 - Selenium	
Sodium selenite	Na_2SeO_3
Target influent selenium concentration	10 µg/L
Stock solution selenium concentration	10 mg/L
Stock solution salt concentration	22 mg/L
Mass of salt required for 20 gal	1.3 g

Table 22 **Stock Solution 3 Composition**

Stock Solution 3 - Lead	
Lead nitrate	$Pb(NO_3)_2$
Target influent lead concentration	100 µg/L
Stock solution lead concentration	100 mg/L
Stock solution salt concentration	160 mg/L
Mass of salt required for 20 gal	9.6 g

Table 23 Summary of Metals Seeding Test Results

		Fraction	Alkalinity, total NA	pH NA	Solids, total dissolved NA	Arsenic Total	Cobalt Total	Copper Total	Lead Total	Nickel Total	Selenium Total	Zinc Total
Location	lab_sample_id	Date										
Pretreated Effluent	1205772-01	12/7/12 11:15 AM	480 mg/l	7.7 pH units	960 mg/l	< 1.0 ug/l	< 0.20 ug/l	2.6 ug/l	--	< 2.5 ug/l	--	8.9 ug/l
Pretreated Effluent	1205772-05	12/7/12 11:15 AM	500 mg/l	7.8 pH units	1000 mg/l	< 1.0 ug/l	< 0.20 ug/l	2.2 ug/l	--	0.91 ug/l	--	5.3 ug/l
Pretreated Effluent	1205787-01	12/8/12 10:30 AM	480 mg/l	8.0 pH units	1200 mg/l	< 1.0 ug/l	< 0.20 ug/l	2.8 ug/l	--	0.69 ug/l	--	5.3 ug/l
Pretreated Effluent	1205787-05	12/8/12 10:30 AM	460 mg/l	7.7 pH units	1000 mg/l	< 1.0 ug/l	< 0.20 ug/l	2.1 ug/l	--	1.1 ug/l	--	6.2 ug/l
Pretreated Effluent	1205787-09	12/9/12 10:00 AM	470 mg/l	7.5 pH units	1100 mg/l	< 1.0 ug/l	< 0.20 ug/l	2.5 ug/l	--	0.96 ug/l	--	5.4 ug/l
Pretreated Effluent	1205772-13	12/10/12 9:00 AM	430 mg/l	7.6 pH units	860 mg/l	--	--	--	--	--	< 1.0 ug/l	--
Pretreated Effluent	1205787-15	12/10/12 9:00 AM	440 mg/l	7.4 pH units	970 mg/l	--	--	--	--	--	< 1.0 ug/l	--
Pretreated Effluent	1205786-01	12/11/12 10:00 AM	430 mg/l	7.6 pH units	960 mg/l	--	--	--	--	--	< 1.0 ug/l	--
Pretreated Effluent	1205786-05	12/11/12 10:00 AM	450 mg/l	7.6 pH units	980 mg/l	--	--	--	--	--	< 1.0 ug/l	--
Pretreated Effluent	1205835-01	12/13/12 7:00 AM	450 mg/l	7.8 pH units	1000 mg/l	--	--	--	0.23 ug/l	--	--	--
Pretreated Effluent	1205835-05	12/13/12 7:00 AM	450 mg/l	7.7 pH units	970 mg/l	--	--	--	0.24 ug/l	--	--	--
Pretreated Effluent	1205874-01	12/14/12 10:30 AM	450 mg/l	8.0 pH units	1000 mg/l	--	--	--	0.44 ug/l	--	--	--
Pretreated Effluent	1205874-05	12/14/12 10:30 AM	450 mg/l	7.6 pH units	940 mg/l	--	--	--	0.26 ug/l	--	--	--
RO Feed	1205772-02	12/7/12 11:15 AM	490 mg/l	7.7 pH units	700 mg/l	170 ug/l	210 ug/l	990 ug/l	--	1700 ug/l	--	630 ug/l
RO Feed	1205772-06	12/7/12 11:15 AM	500 mg/l	7.8 pH units	890 mg/l	160 ug/l	200 ug/l	940 ug/l	--	1700 ug/l	--	580 ug/l
RO Feed	1205787-02	12/8/12 10:30 AM	490 mg/l	7.8 pH units	1100 mg/l	200 ug/l	220 ug/l	1200 ug/l	--	1800 ug/l	--	750 ug/l
RO Feed	1205787-06	12/8/12 10:30 AM	460 mg/l	7.8 pH units	1100 mg/l	96 ug/l	160 ug/l	550 ug/l	--	1300 ug/l	--	320 ug/l
RO Feed	1205787-10	12/9/12 10:00 AM	460 mg/l	7.8 pH units	1100 mg/l	100 ug/l	180 ug/l	570 ug/l	--	1400 ug/l	--	360 ug/l
RO Feed	1205772-14	12/10/12 9:00 AM	430 mg/l	7.5 pH units	660 mg/l	--	--	--	--	--	14 ug/l	--
RO Feed	1205787-16	12/10/12 9:00 AM	450 mg/l	7.4 pH units	920 mg/l	--	--	--	--	--	13 ug/l	--
RO Feed	1205786-02	12/11/12 10:00 AM	430 mg/l	7.7 pH units	920 mg/l	--	--	--	--	--	13 ug/l	--
RO Feed	1205786-06	12/11/12 10:00 AM	440 mg/l	7.6 pH units	990 mg/l	--	--	--	--	--	13 ug/l	--
RO Feed	1205835-02	12/13/12 7:00 AM	450 mg/l	8.3 pH units	1100 mg/l	--	--	--	150 ug/l	--	--	--
RO Feed	1205835-06	12/13/12 7:00 AM	460 mg/l	7.8 pH units	1000 mg/l	--	--	--	140 ug/l	--	--	--
RO Feed	1205874-02	12/14/12 10:30 AM	460 mg/l	7.7 pH units	960 mg/l	--	--	--	150 ug/l	--	--	--
RO Feed	1205874-06	12/14/12 10:30 AM	470 mg/l	7.7 pH units	950 mg/l	--	--	--	150 ug/l	--	--	--
RO Permeate	1205772-04	12/7/12 11:15 AM	< 20 mg/l	6.2 pH units	< 10 mg/l	31 ug/l	0.27 ug/l	1.6 ug/l	--	2.1 ug/l	--	< 5.0 ug/l
RO Permeate	1205772-08	12/7/12 11:15 AM	< 20 mg/l	7.1 pH units	< 10 mg/l	28 ug/l	0.27 ug/l	3.1 ug/l	--	2.2 ug/l	--	< 5.0 ug/l
RO Permeate	1205787-04	12/8/12 10:30 AM	< 20 mg/l	7.0 pH units	< 10 mg/l	32 ug/l	0.28 ug/l	2.5 ug/l	--	2.3 ug/l	--	< 5.0 ug/l
RO Permeate	1205787-08	12/8/12 10:30 AM	< 20 mg/l	6.0 pH units	18 mg/l	23 ug/l	0.24 ug/l	1.3 ug/l	--	1.9 ug/l	--	< 5.0 ug/l
RO Permeate	1205787-12	12/9/12 10:00 AM	< 20 mg/l	5.9 pH units	12 mg/l	26 ug/l	0.29 ug/l	2.0 ug/l	--	2.4 ug/l	--	< 5.0 ug/l
RO Permeate	1205772-16	12/10/12 9:00 AM	< 20 mg/l	5.7 pH units	< 10 mg/l	--	--	--	--	--	< 1.0 ug/l	--
RO Permeate	1205787-17	12/10/12 9:00 AM	< 20 mg/l	5.5 pH units	17 mg/l	--	--	--	--	--	< 1.0 ug/l	--
RO Permeate	1205786-04	12/11/12 10:00 AM	< 20 mg/l	5.6 pH units	< 10 mg/l	--	--	--	--	--	< 1.0 ug/l	--
RO Permeate	1205786-08	12/11/12 10:00 AM	< 20 mg/l	5.6 pH units	< 10 mg/l	--	--	--	--	--	< 1.0 ug/l	--
RO Permeate	1205835-04	12/13/12 7:00 AM	< 20 mg/l	6.1 pH units	44 mg/l	--	--	--	< 0.20 ug/l	--	--	--
RO Permeate	1205835-08	12/13/12 7:00 AM	< 20 mg/l	6.5 pH units	33 mg/l	--	--	--	< 0.20 ug/l	--	--	--
RO Permeate	1205874-04	12/14/12 10:30 AM	< 20 mg/l	6.6 pH units	< 10 mg/l	--	--	--	0.27 ug/l	--	--	--
RO Permeate	1205874-08	12/14/12 10:30 AM	< 20 mg/l	6.2 pH units	< 10 mg/l	--	--	--	0.20 ug/l	--	--	--
RO Concentrate	1205787-03	12/8/12 10:30 AM	1700 mg/l	7.8 pH units	3800 mg/l	400 ug/l	620 ug/l	4300 ug/l	--	6300 ug/l	--	2200 ug/l
RO Concentrate	1205787-07	12/8/12 10:30 AM	1600 mg/l	7.8 pH units	3600 mg/l	310 ug/l	540 ug/l	2000 ug/l	--	4800 ug/l	--	1200 ug/l
RO Concentrate	1205787-11	12/9/12 10:00 AM	1600 mg/l	7.7 pH units	3600 mg/l	330 ug/l	590 ug/l	2000 ug/l	--	4800 ug/l	--	1200 ug/l
RO Concentrate	1205772-15	12/10/12 9:00 AM	1500 mg/l	7.8 pH units	2800 mg/l	--	--	--	--	--	66 ug/l	--
RO Concentrate	1205787-18	12/10/12 9:00 AM	1500 mg/l	7.7 pH units	3400 mg/l	--	--	--	--	--	63 ug/l	--
RO Concentrate	1205786-03	12/11/12 10:00 AM	1500 mg/l	7.7 pH units	3400 mg/l	--	--	--	--	--	61 ug/l	--
RO Concentrate	1205786-07	12/11/12 10:00 AM	1500 mg/l	7.8 pH units	3400 mg/l	--	--	--	--	--	61 ug/l	--
RO Concentrate	1205835-03	12/13/12 7:00 AM	1500 mg/l	7.9 pH units	3700 mg/l	--	--	--	530 ug/l	--	--	--
RO Concentrate	1205835-07	12/13/12 7:00 AM	1600 mg/l	7.8 pH units	3500 mg/l	--	--	--	440 ug/l	--	--	--
RO Concentrate	1205874-03	12/14/12 10:30 AM	1600 mg/l	7.8 pH units	3400 mg/l	--	--	--	520 ug/l	--	--	--
RO Concentrate	1205874-07	12/14/12 10:30 AM	1600 mg/l	7.8 pH units	3300 mg/l	--	--	--	530 ug/l	--	--	--
RO Concentrate	1205772-03	12/7/12 11:15 AM	1700 mg/l	7.8 pH units	3800 mg/l	360 ug/l	590 ug/l	3200 ug/l	--	5400 ug/l	--	2000 ug/l
RO Concentrate	1205772-07	12/7/12 11:15 AM	970 mg/l	7.8 pH units	3600 mg/l	340 ug/l	590 ug/l	3100 ug/l	--	5700 ug/l	--	2100 ug/l
VSEP Feed	1205772-09	12/8/12 7:00 AM	850 mg/l	6.4 pH units	4200 mg/l	420 ug/l	660 ug/l	3100 ug/l	--	5400 ug/l	--	2000 ug/l
VSEP Feed	1205772-10	12/9/12 7:00 AM	620 mg/l	6.2 pH units	4500 mg/l	420 ug/l	720 ug/l	2400 ug/l	--	5100 ug/l	--	2200 ug/l
VSEP Feed	1205786-09	12/11/12 12:30 PM	680 mg/l	6.4 pH units	4000 mg/l	--	--	--	--	--	47 ug/l	--
VSEP Feed	1205804-01	12/12/12 7:00 AM	730 mg/l	6.4 pH units	3900 mg/l	--	--	--	--	--	49 ug/l	--
VSEP Feed	1205874-09	12/14/12 7:00 AM	610 mg/l	6.4 pH units	3700 mg/l	--	--	--	460 ug/l	--	--	--
VSEP Feed	1205874-12	12/15/12 7:00 AM	860 mg/l	6.5 pH units	4500 mg/l	--	--	--	570 ug/l	--	--	--
VSEP Permeate	1205772-12	12/8/12 12:30 PM	34 mg/l	5.5 pH units	76 mg/l	160 ug/l	9.4 ug/l	42 ug/l	--	73 ug/l	--	18 ug/l
VSEP Permeate	1205787-14	12/9/12 12:30 PM	26 mg/l	5.3 pH units	130 mg/l	120 ug/l	5.9 ug/l	22 ug/l	--	47 ug/l	--	12 ug/l
VSEP Permeate	1205786-11	12/11/12 12:30 PM	25 mg/l	5.3 pH units	120 mg/l	--	--	--	--	--	1.0 ug/l	--
VSEP Permeate	1205804-03	12/12/12 12:30 PM	22 mg/l	6.3 pH units	120 mg/l	--	--	--	--	--	1.0 ug/l	--
VSEP Permeate	1205874-11	12/14/12 12:00 PM	26 mg/l	5.5 pH units	100 mg/l	--	--	--	3.2 ug/l	--	--	--
VSEP Permeate	1205874-14	12/15/12 12:30 PM	22 mg/l	5.2 pH units	37 mg/l	--	--	--	1.1 ug/l	--	--	--
VSEP Concentrate	1205772-11	12/8/12 12:30 PM	4800 mg/l	7.1 pH units	24000 mg/l	2100 ug/l	4500 ug/l	21000 ug/l	--	36000 ug/l	--	13000 ug/l
VSEP Concentrate	1205787-13	12/9/12 12:30 PM	3300 mg/l	6.9 pH units	24000 mg/l	1100 ug/l	3600 ug/l	13000 ug/l	--	29000 ug/l	--	11000 ug/l
VSEP Concentrate	1205786-10	12/11/12 12:30 PM	2700 mg/l	6.9 pH units	22000 mg/l	--	--	--	--	--	310 ug/l	--
VSEP Concentrate	1205804-02	12/12/12 12:30 PM	2800 mg/l	6.9 pH units	21000 mg/l	--	--	--	--	--	310 ug/l	--
VSEP Concentrate	1205874-10	12/14/12 12:00 PM	3500 mg/l	7.1 pH units	21000 mg/l	--	--	--	3000 ug/l	--	--	--
VSEP Concentrate	1205874-13	12/15/12 12:30 PM	3600 mg/l	7.0 pH units	26000 mg/l	--	--	--	3200 ug/l	--	--	--

Table 24 **Metals Seeding Test RO Removal Rates**

	Stock Solution 1		Stock Solution 2			Stock Solution 3				
	12/7/2012		12/10/2012	12/11/2012		12/13/2012		12/14/2012		
Parameter	***Sample 1***	***Sample 2***	***Sample 1***	***Sample 2***	***Sample 3***	***Sample 1***	***Sample 2***	***Sample 3***	***Sample 4***	**Average Reduction**
As	81.76%	82.50%								82.13%
Co	99.87%	99.87%								99.87%
Cu	99.84%	99.67%								99.75%
Ni	99.88%	99.87%								99.87%
Pb						>99.93%	>99.93%	99.82%	99.87%	>99.89%
Se			>96.43%	>96.15%	>96.15%					>96.25%
Zn	>99.60%	>99.57%								>99.59%

- Where “>” (greater than) is indicated, the permeate concentration was less than the method reporting limit. Half of the method reporting limit was used to calculate the percent removal in those cases.

Table 25 **Metals Seeding Test VSEP Removal Rates (Concentration-Based)**

	Stock Solution 1		Stock Solution 2		Stock Solution 3		
	12/8/2012	12/9/2012	12/11/2012	12/12/2012	12/14/2012	12/15/2012	
Parameter	***Batch 1***	***Batch 2***	***Batch 1***	***Batch 2***	***Batch 1***	***Batch 2***	**Average Removal**
As	61.90%	71.43%					66.67%
Co	98.58%	99.18%					98.88%
Cu	98.65%	99.08%					98.86%
Ni	98.65%	99.08%					98.86%
Pb					99.30%	99.81%	99.56%
Se			97.87%	97.96%			97.92%
Zn	98.30%	98.82%					98.56%

Table 26 Metals Seeding Test Estimated Blended Permeate Water Quality

	Average Permeate Concentrations (ug/L)				
Parameter	**RO**	**VSEP**	**Blend**	**Class 2B WQS**	
As	29.5	140	48.9	53	
Co	0.27	7.65	1.6	5	
Cu	2.4	32	7.5	9.8	(assumes total hardness of 100 mg/L as CaCO3)
Ni	2.2	60	12.3	158	(assumes total hardness of 100 mg/L as CaCO3)
Pb	0.2	2.15	0.5	3.2	(assumes total hardness of 100 mg/L as CaCO3)
Se	0.5	1	0.6	5	
Zn	2.5	15	4.7	106	(assumes total hardness of 100 mg/L as CaCO3)

Red values are half the reporting limit.
Blend concentration based on 80% RO recovery and 85% VSEP recovery

Table 27 Summary of Arsenic Removal Test Results

Fraction			Alkalinity, total NA	pH NA	Solids, total dissolved NA	Arsenic Total
Location	**lab_sample_id**	**Date**				
Feed Tank Effluent	1205928-01	12/19/12 7:30 AM	**450 mg/l**	**8.0 pH units**	**910 mg/l**	**64 ug/l**
Feed Tank Effluent	1205928-05	12/19/12 9:00 AM	**450 mg/l**	**7.8 pH units**	**900 mg/l**	**67 ug/l**
Feed Tank Effluent	1205928-09	12/19/12 10:30 AM	**450 mg/l**	**7.6 pH units**	**1100 mg/l**	**370 ug/l**
RO Concentrate	1205928-03	12/19/12 7:30 AM	**1500 mg/l**	**7.7 pH units**	**3000 mg/l**	< 5.0 ug/l
RO Concentrate	1205928-07	12/19/12 9:00 AM	**1500 mg/l**	**7.7 pH units**	**3100 mg/l**	< 5.0 ug/l
RO Concentrate	1205928-11	12/19/12 10:30 AM	**1500 mg/l**	**7.7 pH units**	**3000 mg/l**	< 5.0 ug/l
RO Feed	1205928-02	12/19/12 7:30 AM	**450 mg/l**	**7.7 pH units**	**890 mg/l**	< 1.0 ug/l
RO Feed	1205928-06	12/19/12 9:00 AM	**460 mg/l**	**7.5 pH units**	**890 mg/l**	< 1.0 ug/l
RO Feed	1205928-10	12/19/12 10:30 AM	**450 mg/l**	**7.8 pH units**	**910 mg/l**	**1.2 ug/l**
RO Permeate	1205928-04	12/19/12 7:30 AM	< 20 mg/l	**6.8 pH units**	< 10 mg/l	< 1.0 ug/l
RO Permeate	1205928-08	12/19/12 9:00 AM	< 20 mg/l	**6.8 pH units**	< 10 mg/l	< 1.0 ug/l
RO Permeate	1205928-12	12/19/12 10:30 AM	< 20 mg/l	**6.6 pH units**	< 10 mg/l	< 1.0 ug/l

Table 28 Greensand Filter Arsenic Removal Rates

	As Removal
Sampling event 1	> 99.22%
Sampling event 2	> 99.25%
Sampling event 3	99.68%
Average	99.38%

Table 29 Metals Removal Literature Review Summary

Element	Influent	Effluent	Max Rejection	Median rejection	Temp	Membrane	System Recovery	Test Type	Source
Aluminum			99.90%						Pure water Products
Aluminum	80 µg/L	<MDL	>99.9%		Room			Bench	Reference (11)
Antimony	18.2 µg/L		>99%	99%	N/A	TFC RO		Bench Scale	Reference (12)
Antimony	50 mg/L			99.2%	N/A		80%	Bench Scale	Reference (13)
Cadmium	0.23 mg/L		99%		Room	Toray		Pilot	Reference (16)
Cadmium	500 mg/L		99.40%		Room	Polyamide	80%	Full Scale	Reference (15)
Chromium	NA	1.5 mg/L		>99%	20C	Polyamide	50-80%	Pilot	Reference (16)
Chromium (III)	0.29 mg/L	<MDL	>99%	98%	Room	Filmtec	10.40%	Pilot	Reference (16)
Chromium (III)	1.23 mg/L		99%	99%	Room	Hydranautics	10.70%	Pilot	Reference (16)
Chromium (VI)	NA			99.50%	20C	Polyamide	63%	Full Scale	Reference (17)
Chromium (VI)	0.61 mg/L			98%	Room	Toray		Pilot	Reference (16)
Mercury	0.026 mg/l	<MDL	>98%		Room	DuPont	50%	Pilot	Reference (16)
Mercury	0.076 mg/L		22%	16%	Room	Dow	59%	Pilot	Reference (16)
Mercury	6µg/L		99.9%		Room	Polyamide		Bench Scale	Reference (19)
Thallium			90-100%						Reference (20)

Table 30 Oxidation Pretreatment Test Conditions

Batch #	HDS Metals Screening		Sulfate Precipitation Screening	
	Iron Solids, %	pH, std units	Gypsum Solids, %	pH, std units
Pre-Treated Water	1	9	10	12
Untreated Water	1	9	10	12

Table 31 Summary of Oxidation Pretreatment Test Results

Dissolved Constituents, ug/L	VSEP Concentrate	HDS Metals-Treated		Gypsum Precipitation-Treated	
		Oxidative Pre-Treatment	No Oxidative Pre-Treatment	Oxidative Pre-Treatment	No Oxidative Pre-Treatment
Sulfate	9,200,000			1,800,000	2,200,000
Aluminum	<50			<50	<50
Antimony	<1.0				
Arsenic	8	<5.0	<5.0		
Beryllium	<1.0	<1.0	<1.0		
Boron	1.8	<1.0	<1.0		
Chromium	22	8.3	8		
Cobalt	2.7	3.4	2.7		
Copper	260	67	60		
Iron	<0.5	<0.5	<0.5		
Lead	2	<1.0	<1.0		
Manganese	180	<2.5	3		
Nickel	23	15	19		
Selenium	11	7.3	8.3		
Zinc	100	<50	<50		

Table 32 Comparison of Stock Solutions and Future Mine Site WWTF Influent Concentrations

Solution		Metal Salt Formula	Stock Concentration (mg/L)	90th Percentile Concentration (mg/L)	Concentration Possible Using Specified Stock Solution (mg/L)	Volume Of Stock Solution to Add (ml of stock/Liter of Water)
Solution #1	Cobalt	$CoCl_2*6H_2O$	150	0.47	2.09	13.9
Solution #1	Copper	$CuSO_4*5H_2O$	700	9.76	9.76	13.9
Solution #1	Nickel	$NiCl_2*6H_2O$	1300	6.59	18.12	13.9
Solution #1	Arsenic	$NaAsO_2$	100	0.63	1.39	13.9
Solution #1	Zinc	$ZnSO_4*7H_2O$	300	0.15	0.15	13.9
Solution #2	Selenium	Na_2SeO_3	22	0.06	0.011	0.5
Solution #3	Lead	$Pb(NO_3)_2$	100	0.81	0.81	8.1

Table 33 HDS Test Conditions

Batch #	Jar A		Jar B		Jar C		Jar D	
	Ferric Hydroxide Solids, %	pH, std units	Ferric Hydroxide Solids, %	pH, std units	Ferric Hydroxide Solids, %	pH, std units	Ferric Hydroxide Solids, %	pH, std units
1	0.05	7	0.05	8	0.05	9	0.05	10
2	0.5	7	0.5	8	0.5	9	0.5	10
3	1.5	7	1.5	8	1.5	9	1.5	10

Table 34 HDS Test Analytes

Dissolved Metals List	As, Sb, Be, B, Cr, Co, Cu, Fe, Pb, Mn, Ni, Se, Zn
Total Metals List	Co, As, Fe

Table 35 Gypsum Test Conditions

Batch #	Gypsum Solids, %	pH, std units
1	0.1	12
2	1	12
3	10	12

Table 36 Summary of HDS Bench Test Results

Sample	pH	Rxn Time (min)	Fe Solids (%)	Sb	As	Be	B	Cr	Co	Cu	Fe	Pb	Mn	Ni	Se	Zn
Raw	NA	NA	NA	--	1200	--	1.7	20	1800	7500	0.50	730	170	14000	18	2500
1	7	30	0.05	2.0	610	1.0	--	14	1600	1100	0.25	2.2	160	13000	10.0	510
2	7	30	0.50	2.0	47	1.0	--	11	170	130	0.25	1.1	79	6000	7.1	46
3	7	30	1.50	2.0	14	1.0	--	12	31	110	0.25	1.2	29	1600	5.0	34
4	7	60	0.05	2.0	560	1.0	--	14	1400	830	0.25	2.3	160	13000	9.7	140
5	7	60	0.50	2.0	41	1.0	--	11	100	130	0.25	1.1	54	4700	6.7	37
6	7	60	1.50	2.0	12	1.0	--	12	21	100	0.25	1.1	20	1200	5.0	34
7	8	30	0.05	2.0	770	1.0	--	15	1000	840	0.25	5.2	110	10000	12.0	57
8	8	30	0.50	2.0	53	1.0	--	12	93	120	0.25	1.0	25	3300	8.5	34
9	8	30	1.50	2.0	13	1.0	--	14	20	110	0.25	1.0	15	810	6.4	35
10	8	60	0.05	2.0	630	1.0	--	16	1000	800	0.25	4.2	120	9900	11.0	62
11	8	60	0.50	2.0	37	1.0	--	12	68	110	0.25	1.0	20	2700	6.8	34
12	8	60	1.50	2.0	9	1.0	--	15	12	99	0.25	1.0	9.6	530	5.0	51
13	9	30	0.05	--	440	--	1.1	14	28	94	0.25	1.1	3.8	810	11.0	29
14	9	30	0.50	--	38	--	1.1	20	11	95	0.25	1.0	0.25	350	8.6	33
15	9	30	1.50	--	7	--	0.9	22	3.5	97	0.25	1.0	0.25	56	8.0	34
16	9	60	0.05	--	370	--	1.0	14	22	79	0.25	1.0	0.25	530	9.6	30
17	9	60	0.50	--	24	--	1.1	24	8.5	97	0.25	1.0	0.25	230	9.8	25
18	9	60	1.50	--	6.2	--	0.87	22	3.5	93	0.25	1.0	0.25	46	5.5	42
19	10	30	0.05	--	34	--	0.5	20	7	84	0.25	1.0	0.25	65	11.0	25
20	10	30	0.50	--	16	--	0.5	22	3.7	83	0.25	1.0	0.25	27	8.5	26
21	10	30	1.50	--	7.6	--	1.0	24	3	92	0.25	1.0	0.25	29	7.4	28
22	10	60	0.05	--	17	--	1.0	22	7	80	0.25	1.0	0.25	41	9.1	25
23	10	60	0.50	--	13	--	1.0	25	4.1	79	0.25	1.0	0.25	25	10.0	26
24	10	60	1.50	--	7	--	1.0	24	3	89	0.25	1.0	0.25	28	7.9	30

Results in RED reflect the reporting limit of the instrumentation.
All units are ug/L EXCEPT Fe/B, which are mg/L

Not requested on CoC or formally cancelled.

Table 37 Summary of HDS Settling Test Results

Sample	pH	Settling Time (min)	Total As, ug/L	Total Co, ug/L	Total Fe, ug/L
37	7	2	140	800	1300
38	7	4	61	120	150
39	7	6	30	70	62
40	8	2	82	140	220
41	8	4	27	47	57
42	8	6	20	34	28
43	9	2	41	64	99
44	9	4	16	13	14
45	9	6	14	10	10
46	10	2	26	36	47
47	10	4	9	5.6	6.8
48	10	6	7.7	3.7	2.1

Table 38 Summary of Gypsum Precipitation Bench Test Results

Sample	pH	Reaction Time (min)	Solids (%)	Dissolved Al, ug/L	Dissolved Ca, ug/L	Dissolved Alk, mg/L	Dissolved SO4, mg/L
25	12	30	0.10	3900	4900	11000	2100
26	12	30	1.00	5300	9800	16000	1900
27	12	30	10.00	7500	8800	12000	4400
28	12	60	0.10	3600	4700	6300	2100
29	12	60	1.00	5500	9200	8600	1800
30	12	60	10.00	8000	7800	1100	4300

Table 39 Summary of Gypsum Precipitation Settling Test Results

Sample	pH	Settling Time, min	Solids (%)	Total Al, ug/L	Total Ca, mg/L	Total SO4, mg/L
31	NA	2	0.10	2600	3200	4200
32	NA	4	0.10	2500	3100	4400
33	NA	6	0.10	2500	3100	3300
34	NA	2	1.00	3800	7200	2800
35	NA	4	1.00	3800	6300	2200
36	NA	6	1.00	3500	6100	3600

Table 40 Comparison of Pilot Plant Influent and Estimated Future Influent Water Qualities

	Mine Site WWTF(1)			Plant Site WWTP(2)				Plant Site Pilot Testing Program(3,4,5)						
	Year 75 Annual Average Concentrations (mg/L)			Year 20 Annual Average Concentrations (mg/L)		Year 20 Annual Maximum Concentrations (mg/L)		SD004 (mg/L)			Pilot Test Well (mg/L)			Metals Seeding And Arsenic Removal Tests (mg/L)
Parameter	***P10***	***P50***	***P90***	***Mean***	***P90***	***Mean***	***P90***	***Min***	***Max***	***Ave***	***Min***	***Max***	***Ave***	***Ave***
Ag	0.0002	0.0002	0.0002	0.00019	0.0002	0.0002	0.0002	NA	NA	NA	NA	NA	NA	NA
Al	0.0009	0.0014	0.0021	0.0035	0.0044	0.0073	0.012	<0.010	<0.010	<0.010	<0.010	0.022	0.0083	NA
As	0.0092	0.0122	0.0196	0.064	0.069	0.069	0.073	0.002	0.02	0.004	0.0028	0.018	0.007	0.17
B	0.10	0.10	0.10	0.11	0.12	0.12	0.12	0.45	0.54	0.49	0.27	0.50	0.38	NA
Ca	56.3	63.9	80.1	293	376	311	401	88	100	94	63	100	80	NA
Cd	0.0010	0.0015	0.0036	0.0023	0.0039	0.0024	0.0042	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	NA
Cl	10	12	15	35	40	37	42	20	24	21	21	32	26	NA
Co	0.014	0.028	0.061	0.048	0.096	0.051	0.10	0.00079	0.0016	0.00097	0.00036	0.00086	0.00053	0.21
Cr	0.0033	0.0034	0.0037	0.0074	0.0078	0.0078	0.0081	NA	NA	NA	NA	NA	NA	NA
Cu	0.12	0.24	0.65	0.48	0.63	0.49	0.66	<0.0005	0.0072	0.0028	0.00085	0.046	0.0083	0.97
Mg	19.7	21.7	26.7	147	162	152	167	150	200	184	68	190	128	NA
Ni	0.22	0.38	0.67	0.64	1.19	0.68	1.26	<0.0005	0.0035	0.0011	<0.0005	0.0029	0.0011	1.7
Pb	0.0069	0.0086	0.012	0.064	0.069	0.070	0.074	<0.0002	0.021	0.0017	<0.0002	0.018	0.0019	0.15
Sb	0.0085	0.0096	0.0124	0.017	0.019	0.017	0.029	NA	NA	NA	NA	NA	NA	NA
Se	0.0002	0.0025	0.0035	0.0056	0.0072	0.0059	0.0076	<0.001	0.002	0.001	<0.001	0.0022	0.0008	0.013
Tl	0.0001	0.0001	0.0001	0.0002	0.0002	0.0002	0.00021	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	NA
Zn	0.08	0.10	0.22	0.173	0.26	0.18	0.27	<0.005	0.03	0.006	0.0025	0.048	0.013	0.61

(1) Preliminary output, Model Version: AWMP Version 4.0, Run Date: 12/09/12, concentrations are the dissolved fraction
(2) Plant Site GoldSim model output, October 2012
(3) Preliminary data from pilot test program, 5/2012 through 10/2012; concentrations are total concetrations. Metals seeding and As removal test data were collected 12/2012.
(4) NA = not analyzed
(5) Where analytical results were less than the method reporting limit, half the reporting limit was used to calculate the averages.

Table 41 Analytical Data Notes and Qualifiers

Qualifier	Definition
--	Not analyzed/not available.
b	Potential false positive value based on blank data validation procedures.
e	Estimated value, exceeded the instrument calibration range.
h	EPA recommended sample preservation, extraction or analysis holding time was exceeded.
j	Reported value is less than the stated laboratory quantitation limit and is considered an estimated value.
*	Estimated value, QA/QC criteria not met.
**	Unusable value, QA/QC criteria not met.
N	Sample Type: Normal
FD	Sample Type: Field Duplicate

Figures

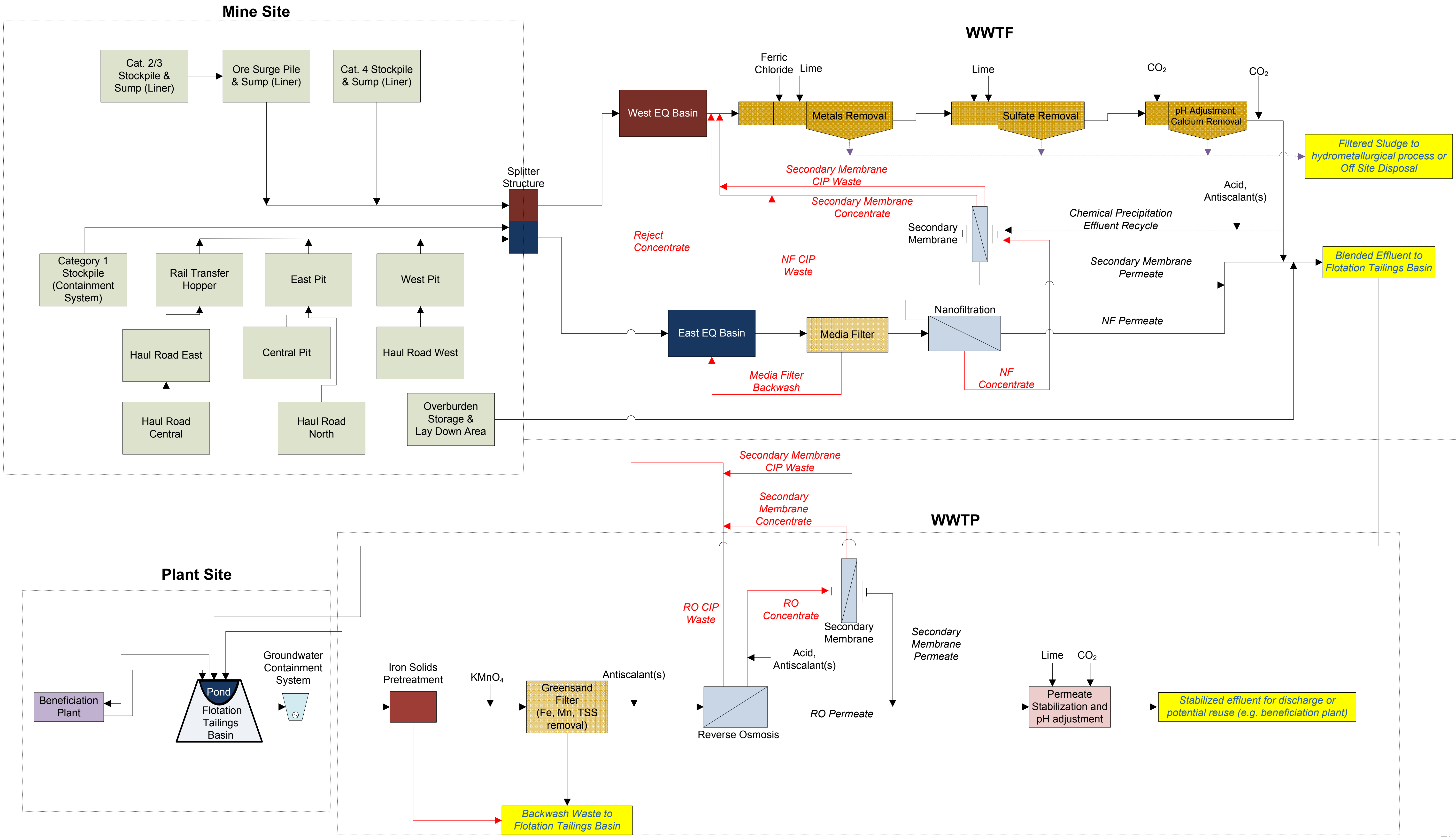
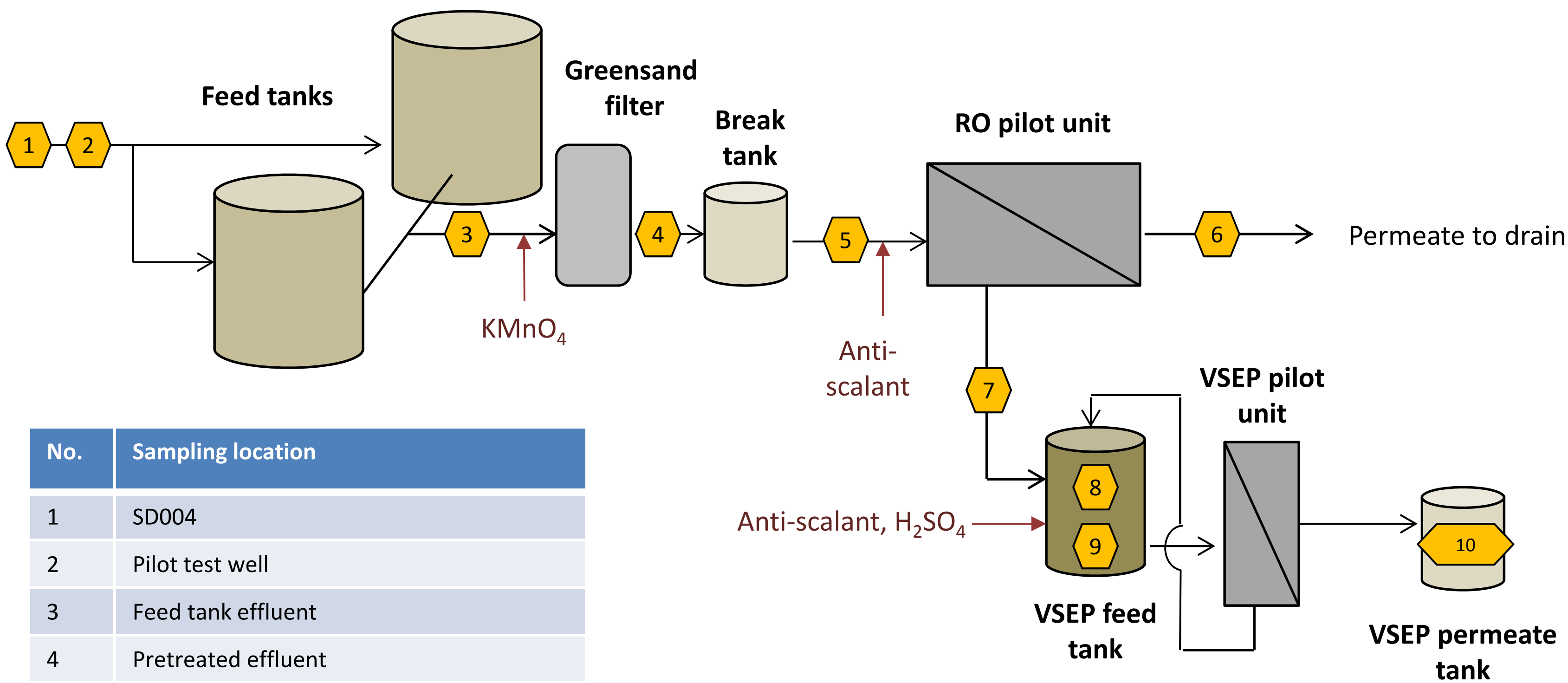


Figure 1
Water Treatment
Overall Flow Sheet-Operations
NorthMet Project
Poly Met Mining, Inc.
Hoyt Lakes, MN

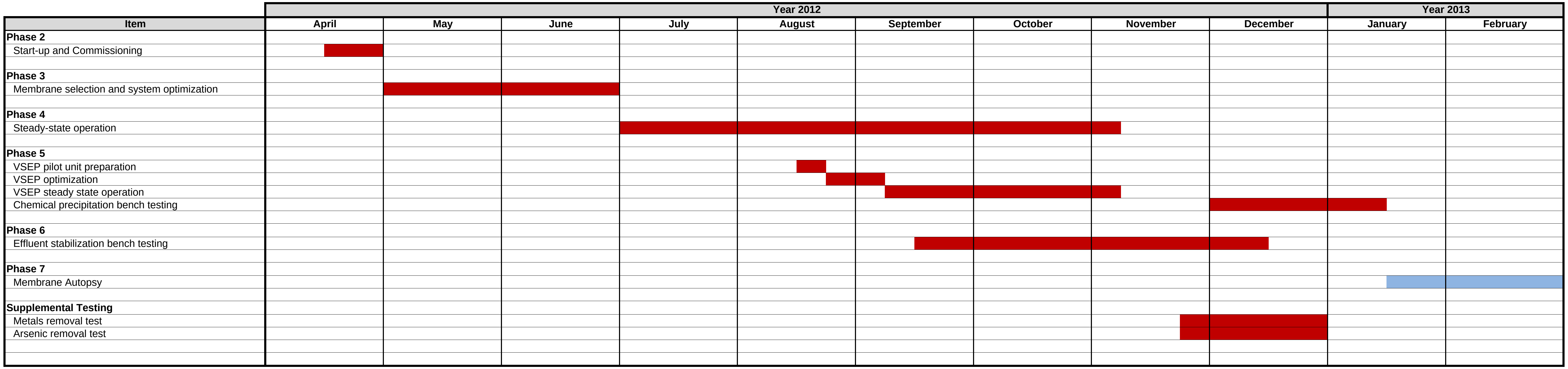
Figure 2. Pilot Testing Program Components and Sampling Locations



No.	Sampling location
1	SD004
2	Pilot test well
3	Feed tank effluent
4	Pretreated effluent
5	RO feed
6	RO permeate
7	RO concentrate
8	VSEP feed (beginning of batch)
9	VSEP concentrate (end of batch)
10	VSEP permeate (end of batch)

Sampling location

Figure 3. Testing Schedule



This conceptual milestone schedule is subject to modification depending on the results of the pilot-scale testing.

Notes:

Tasks completed as of report's cover date

Tasks to-be completed as of report's cover date

Existing Surface Discharges

Existing Groundwater Wells

Pilot Test Well

0 2,000 4,000
Feet

Figure 4
SITE LAYOUT
NorthMet Project
Poly Met Mining, Inc.
Hoyt Lakes, MN

Figure 5. Influent Dissolved Solids, Total Hardness, and Sulfate Concentrations

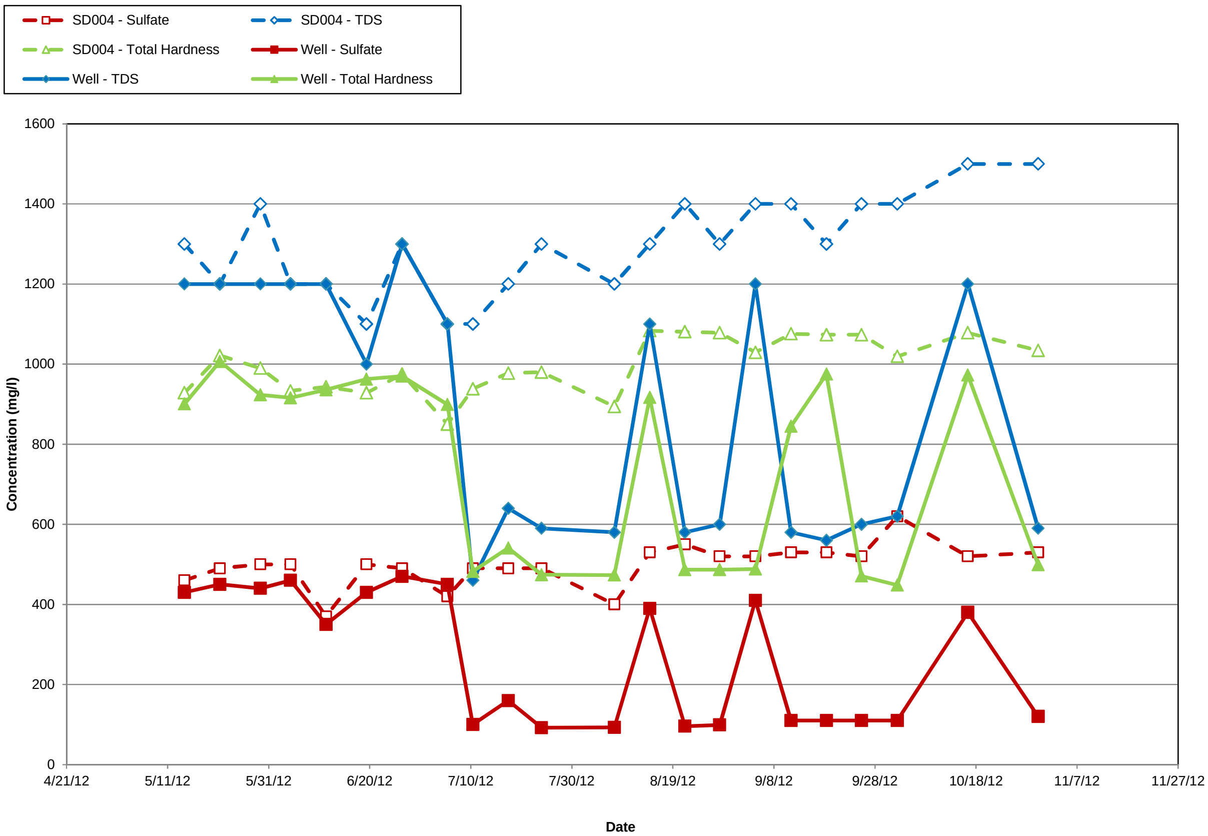


Figure 6. Influent Iron and Manganese Concentrations

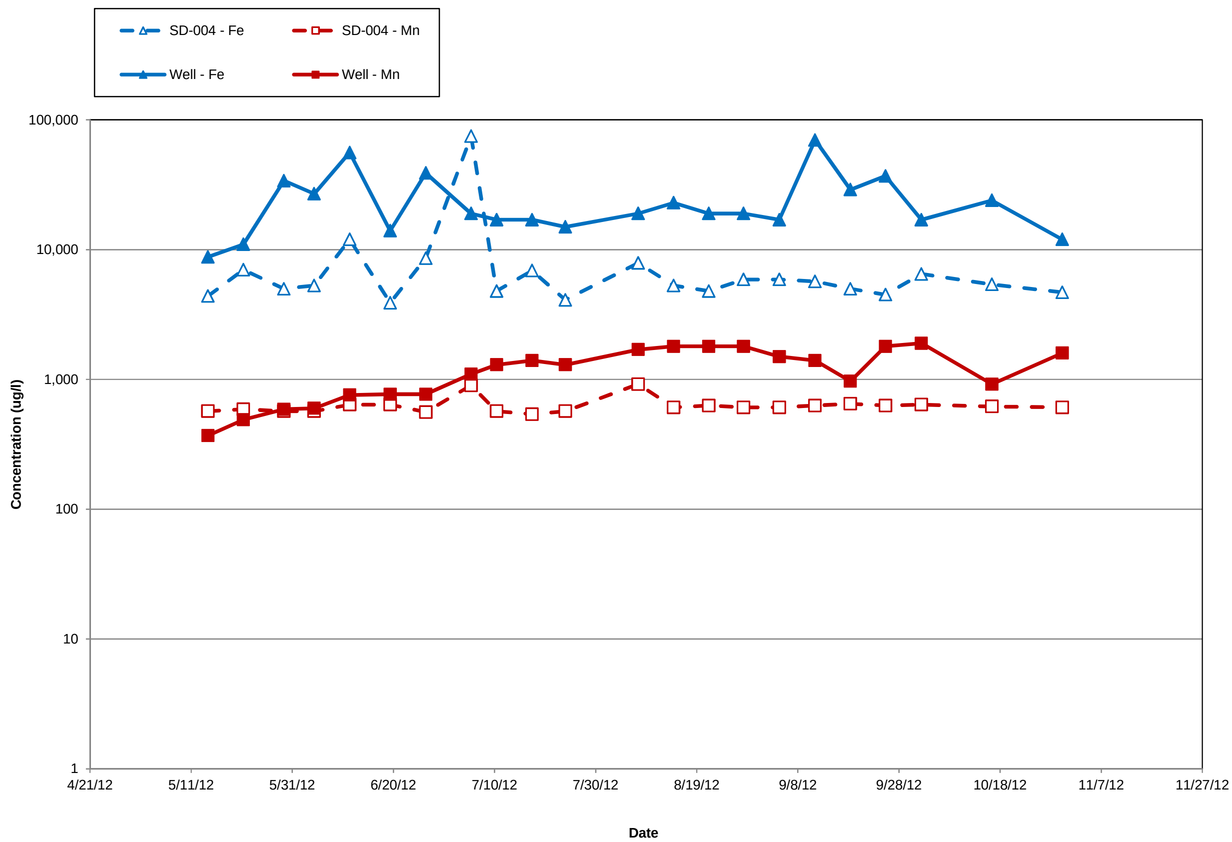


Figure 7. Greensand Filter Pilot Unit

Figure 8. Permanganate Dose Optimization

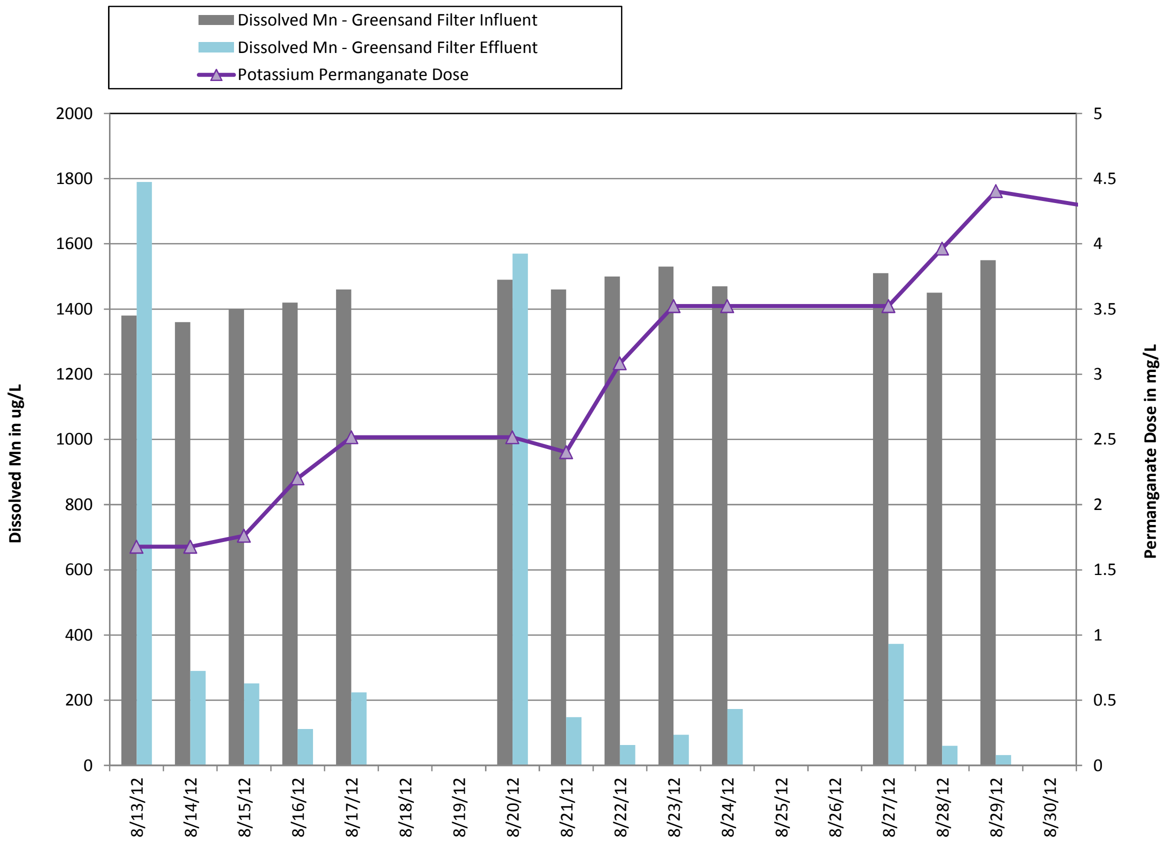


Figure 9. RO Pilot Unit

Figure 10. RO Feed-to-Concentrate Pressure Drop

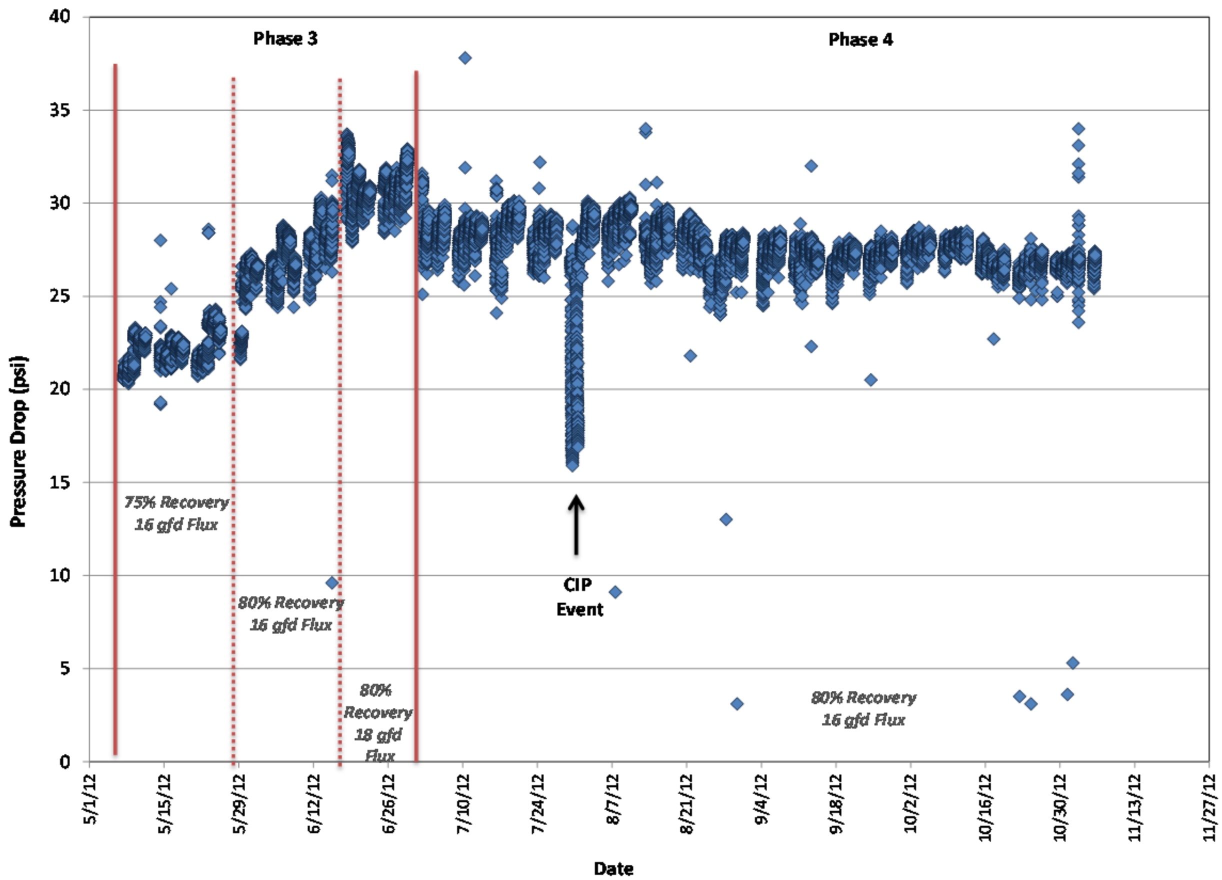


Figure 11. RO Feed Pressure

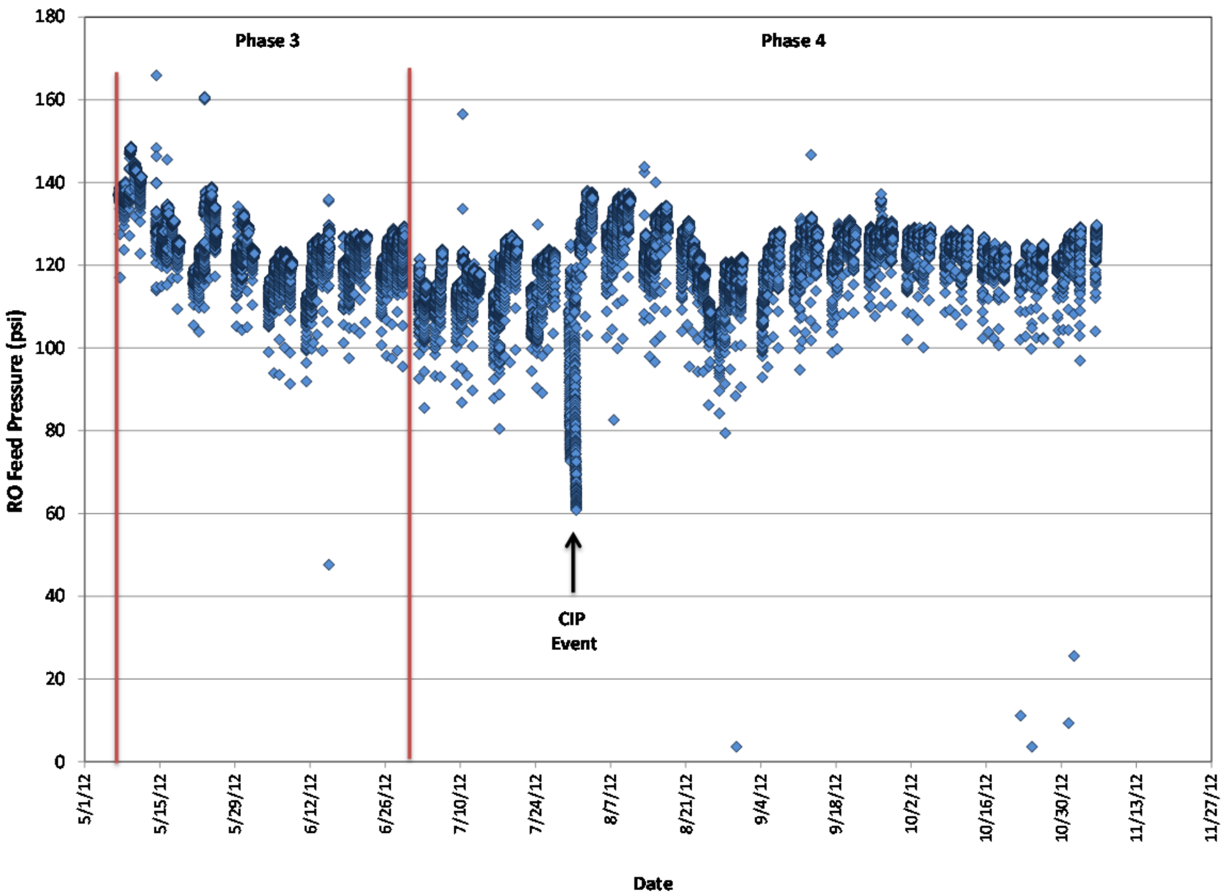


Figure 12. Sulfate Removal by the RO Process

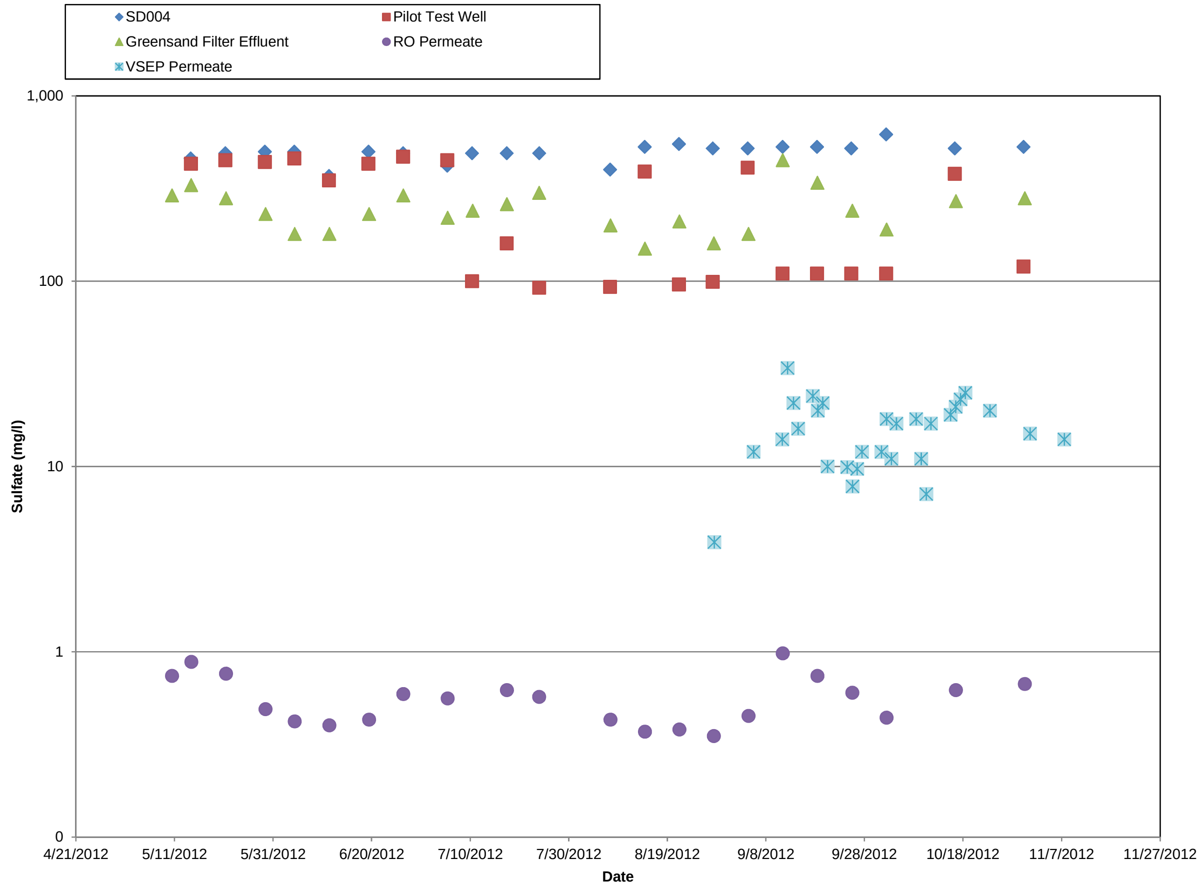


Figure 13. Total Dissolved Solids by the RO Process

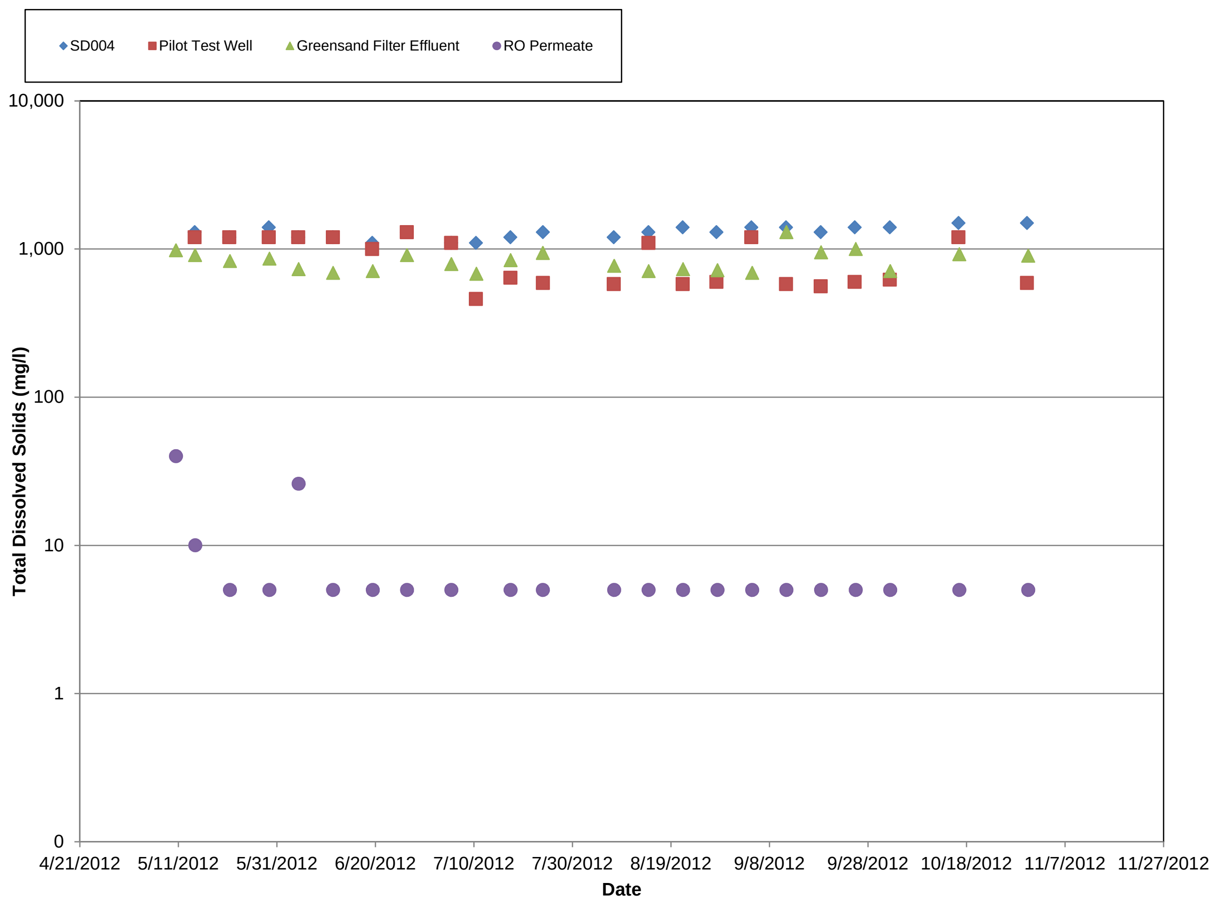


Figure 14. Comparison of Measured and Modeled RO Permeate Sulfate Concentrations

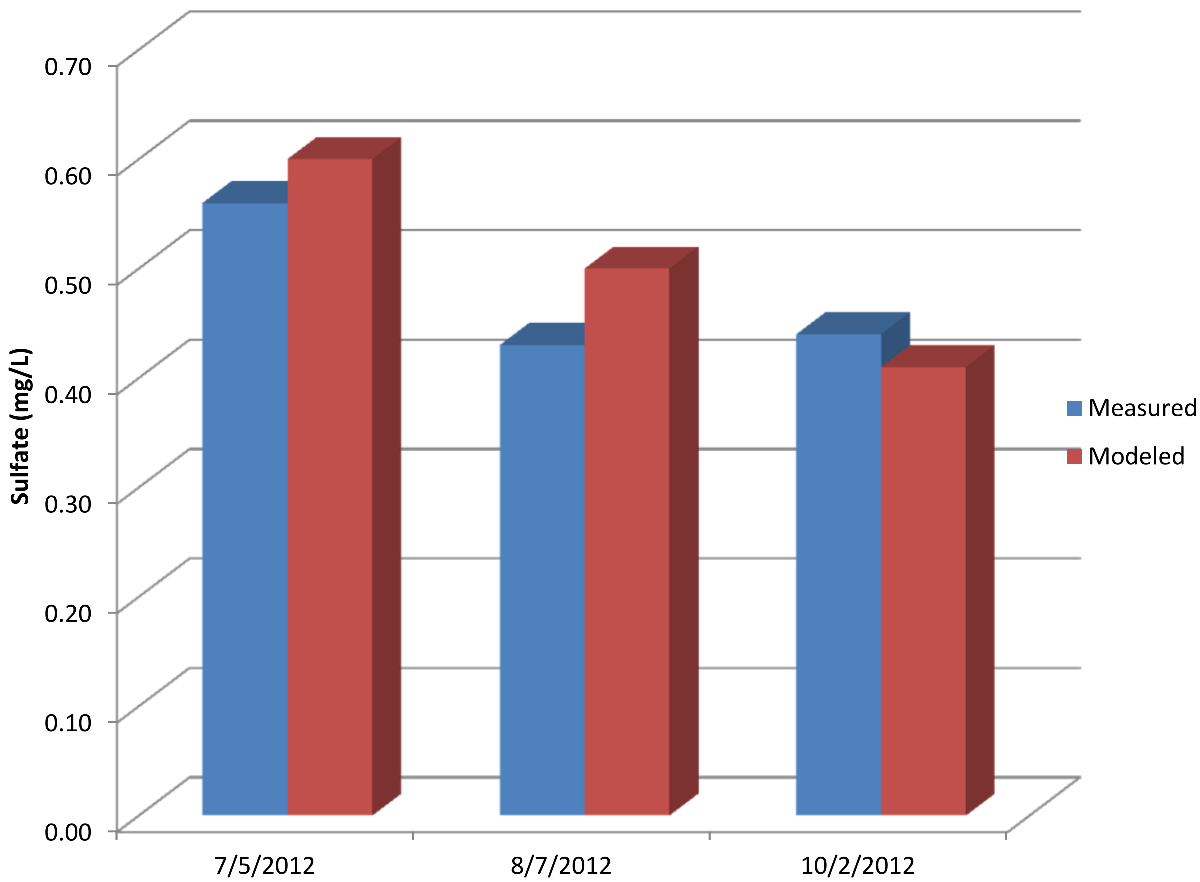


Figure 15. VSEP Pilot Unit

Figure 16. Initial VSEP Pretreatment Optimization

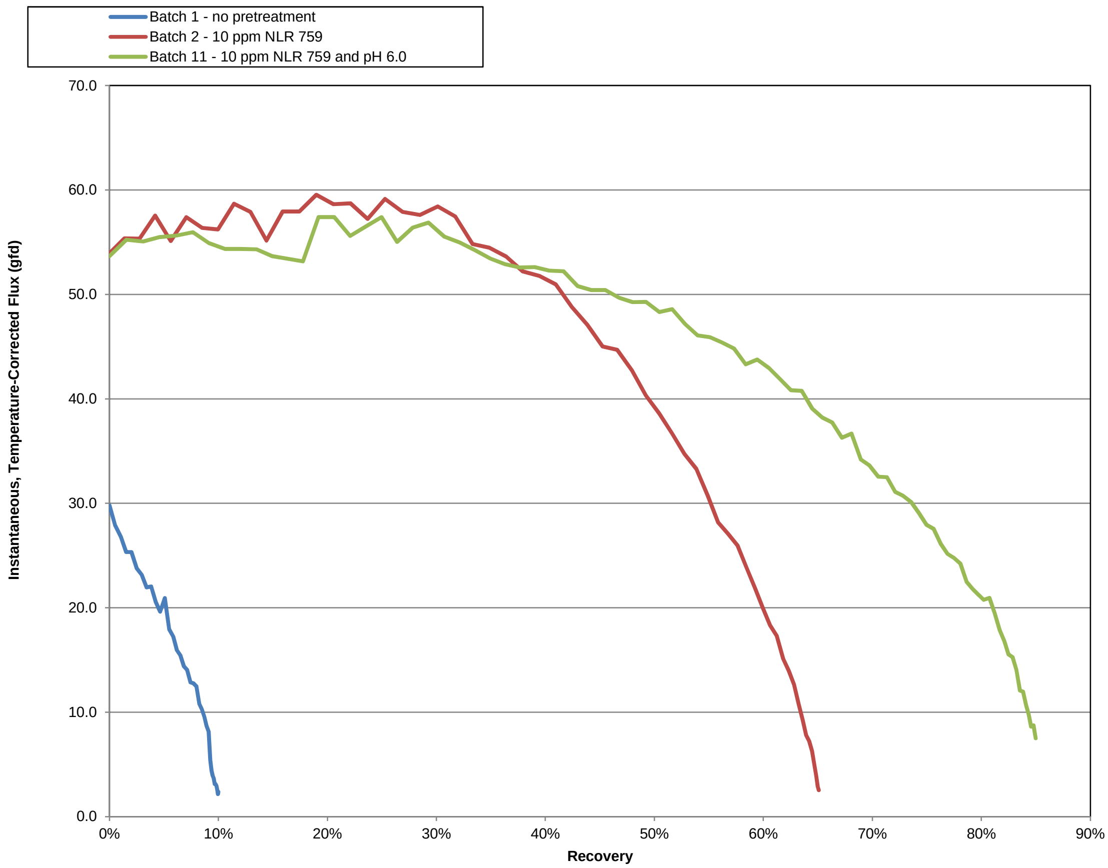


Figure 17. VSEP Operation with Hydrochloric and Sulfuric Acids

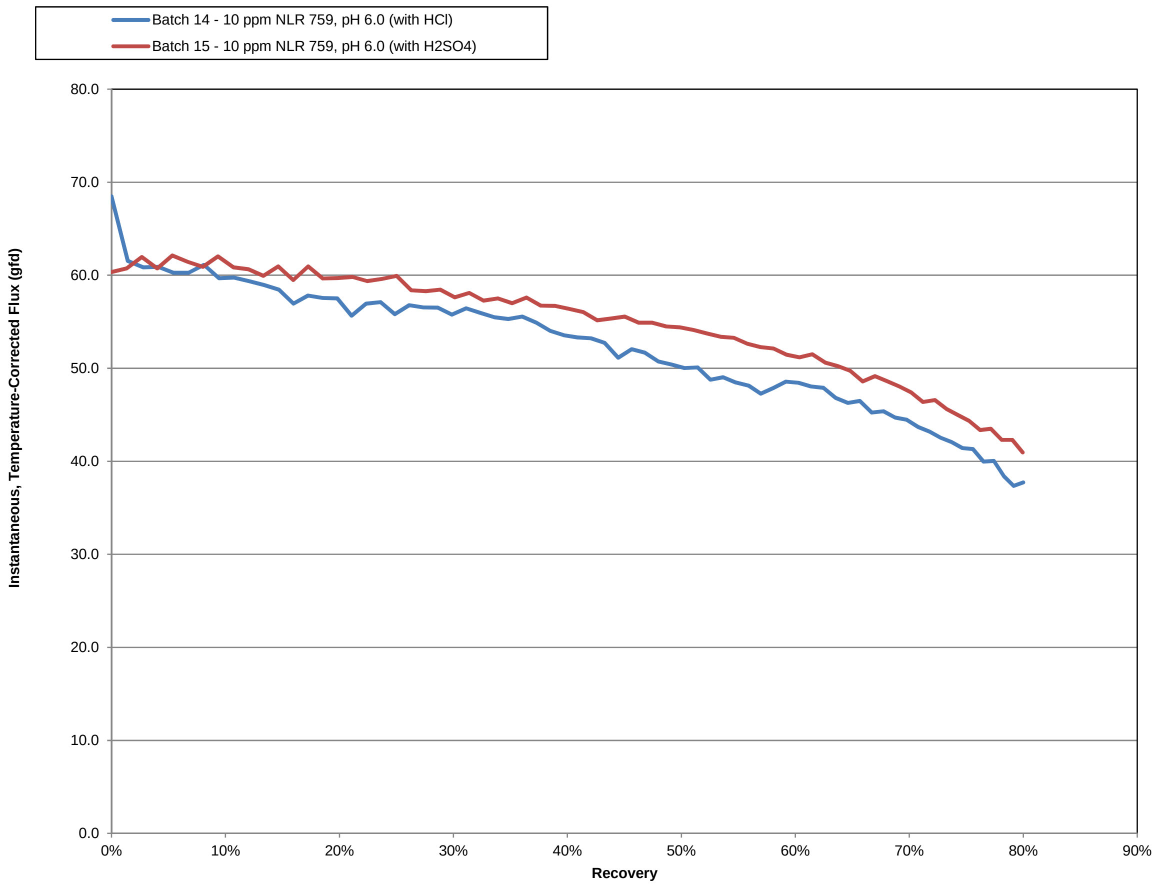


Figure 18. Comparison of the Effects of pH Adjustment Timing on VSEP Flux and Recovery

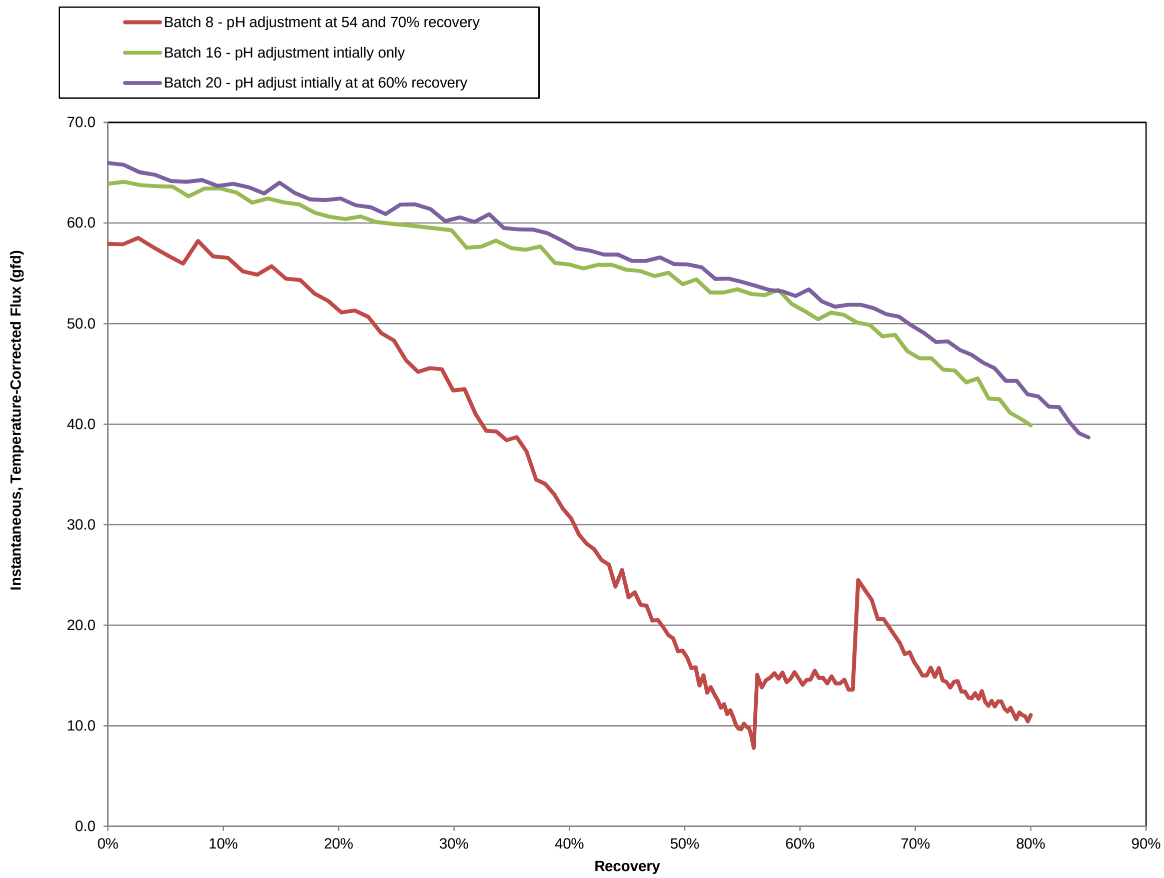


Figure 19. Effect of Degree of pH Adjustment on VSEP Flux and Recovery

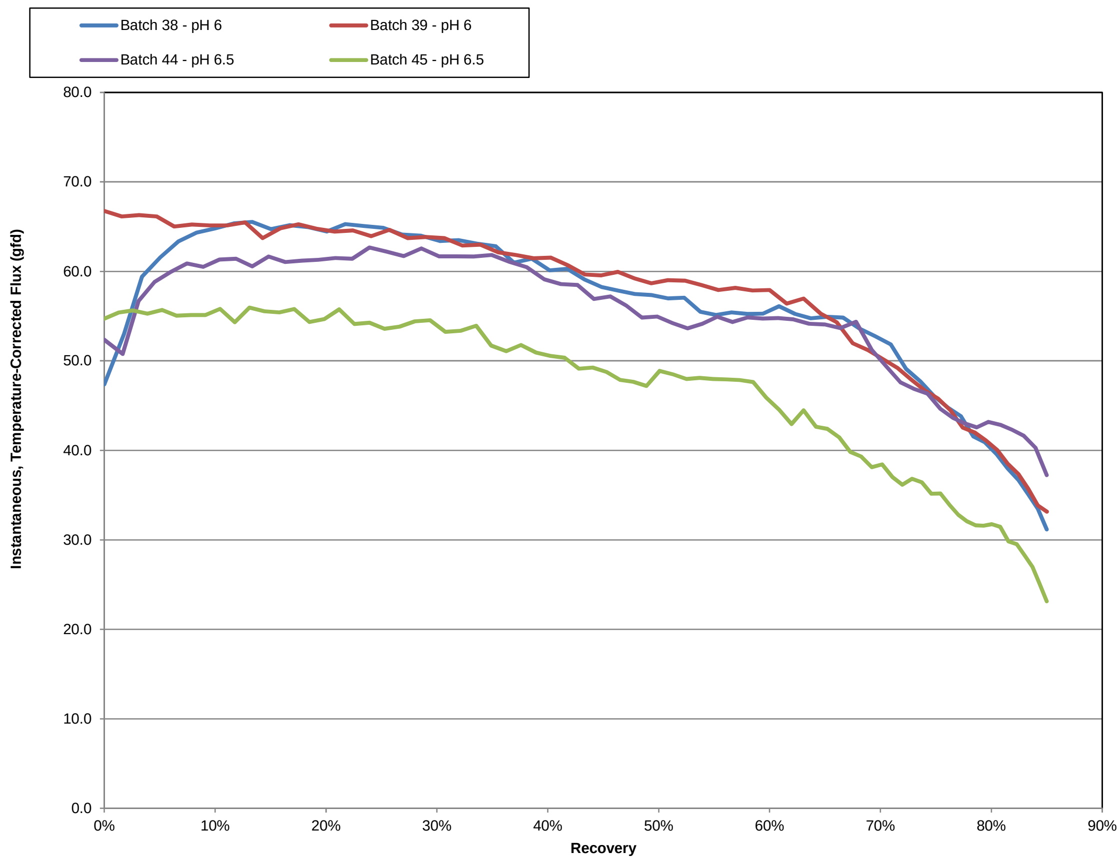


Figure 20. VSEP Recovery Optimization

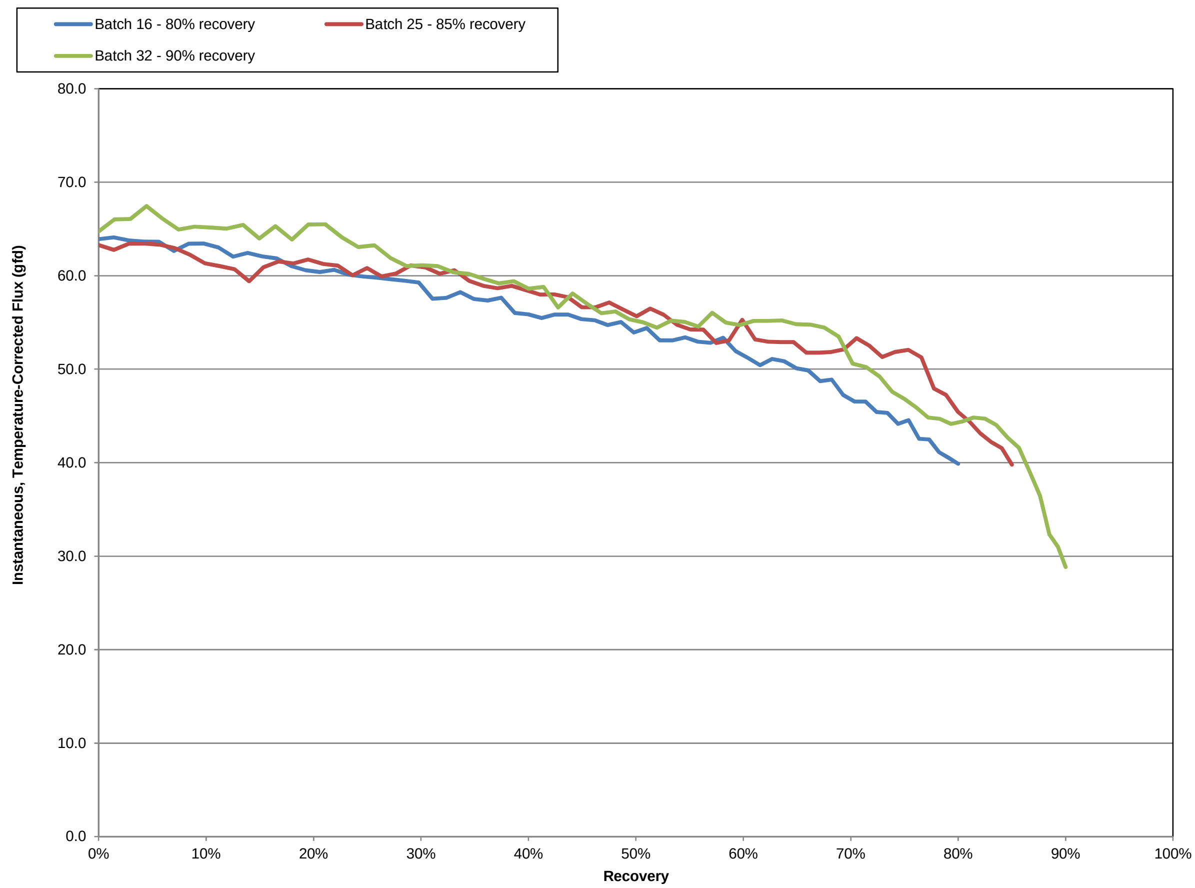


Figure 21. Lime Addition WET Test Results

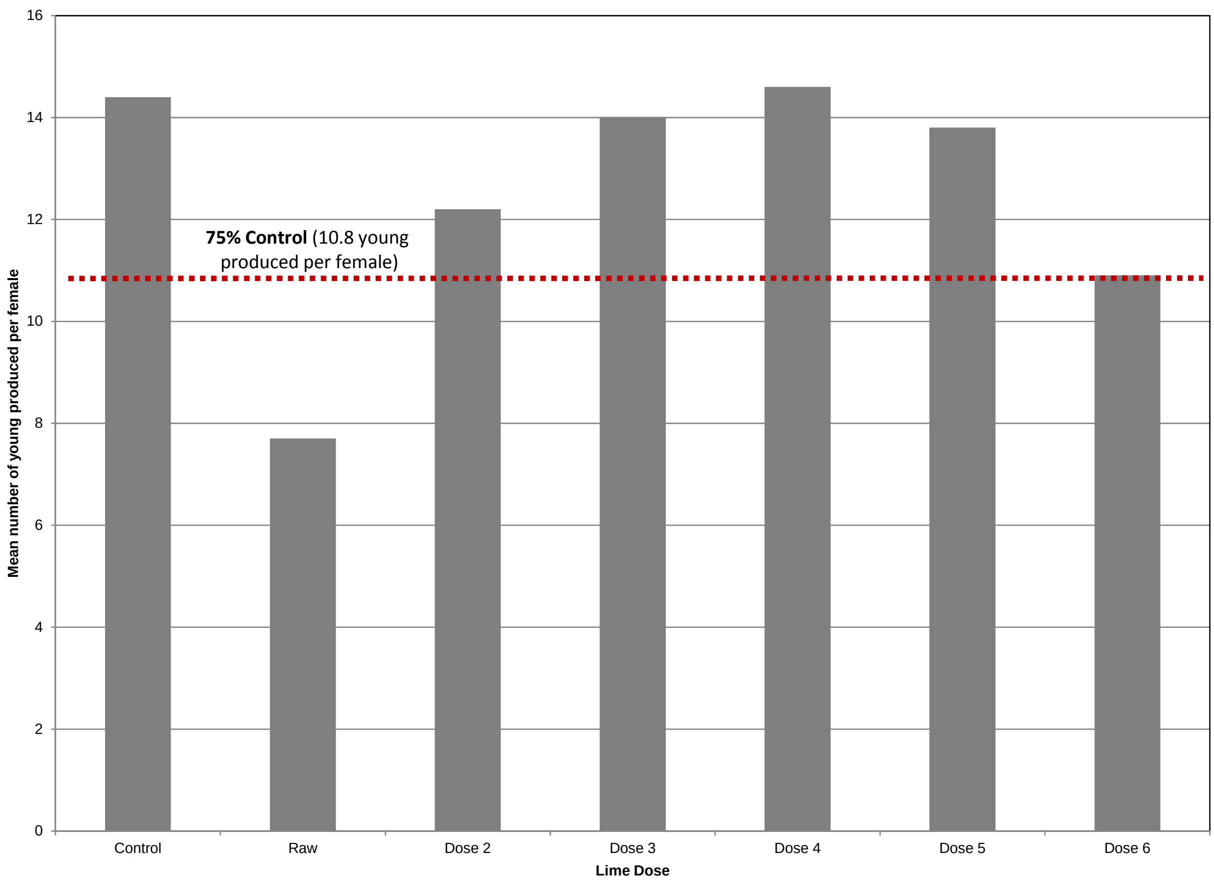


Figure 22. Limestone Bed Contactor Columns

Upflow columns

Puri-Cal RO media

Figure 23. Limestone Bed Contactor Tests

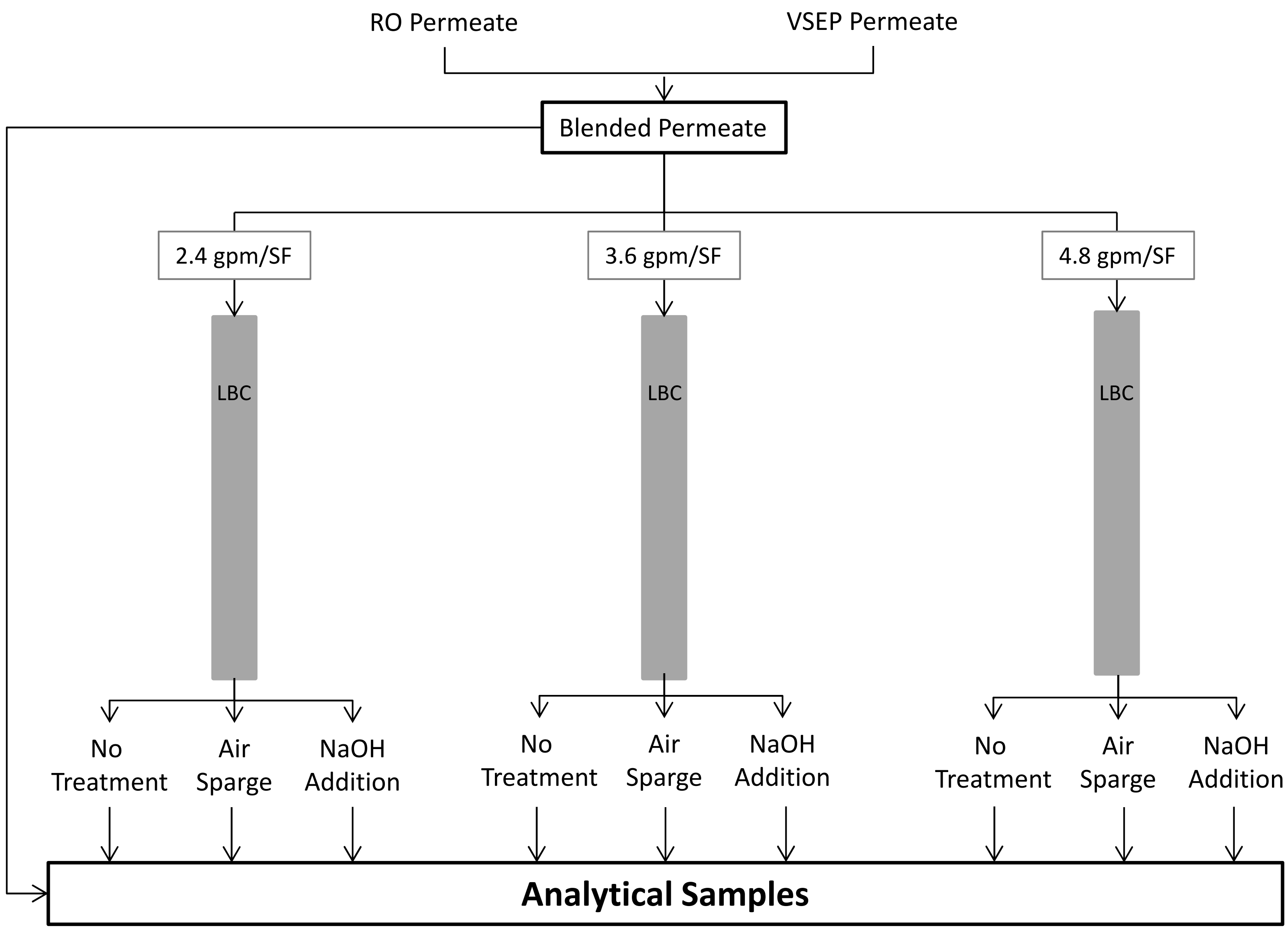


Figure 24. Limestone Bed Contactor WET Test Results

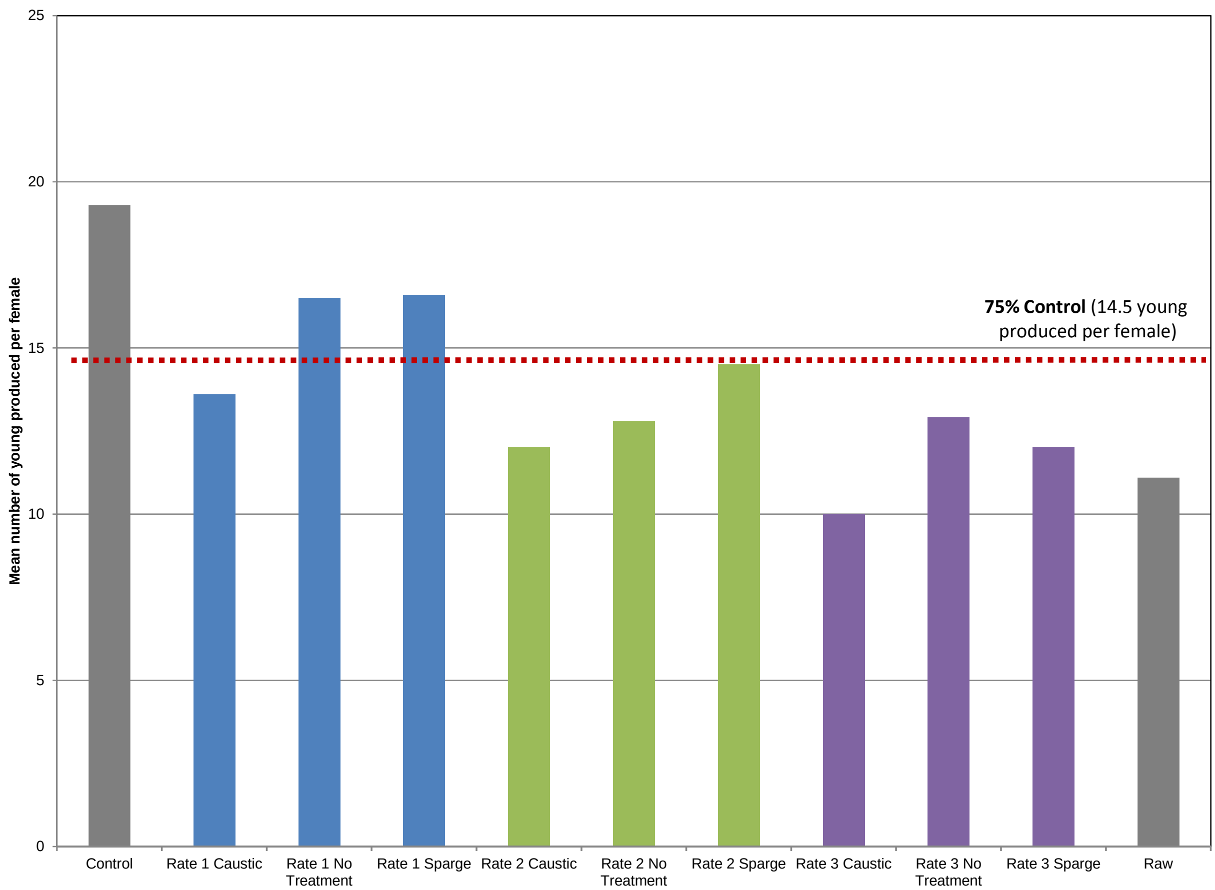
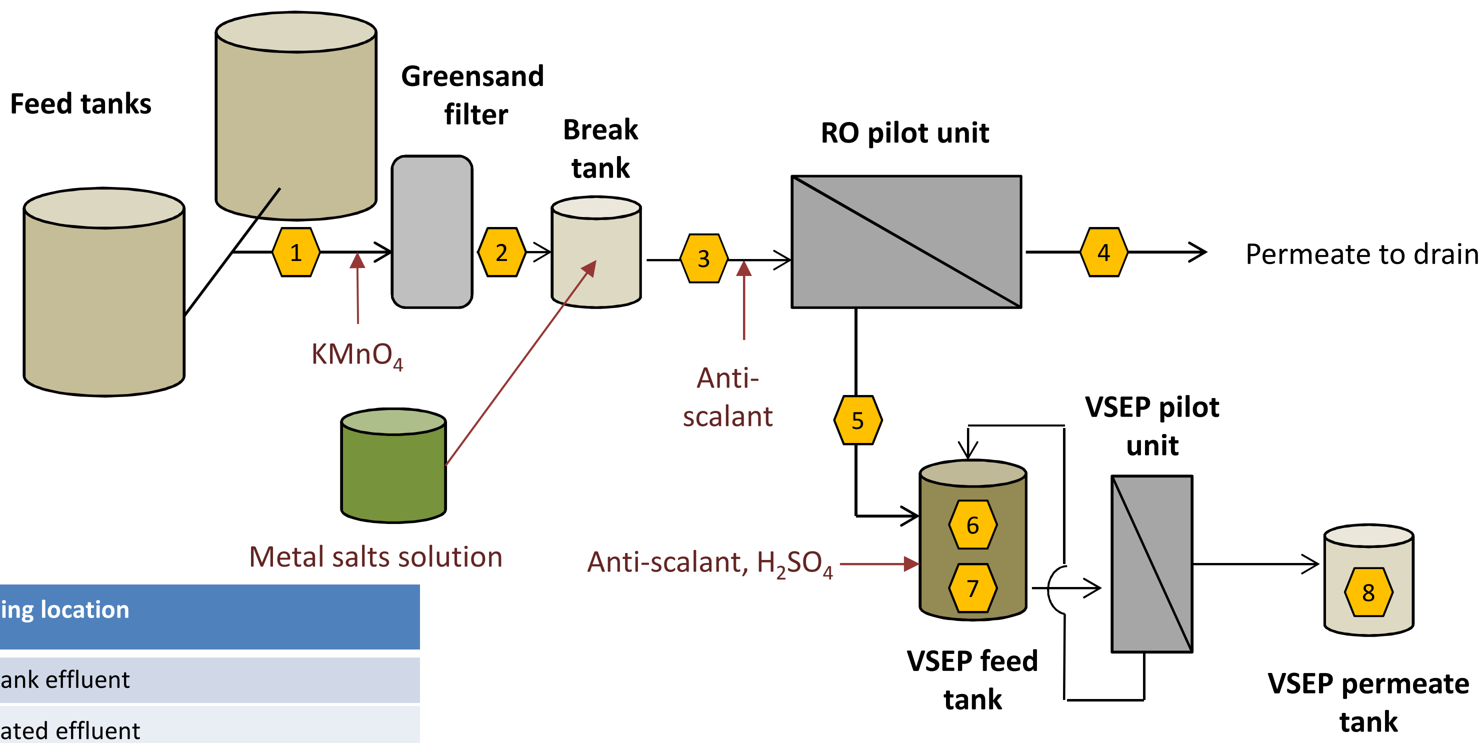


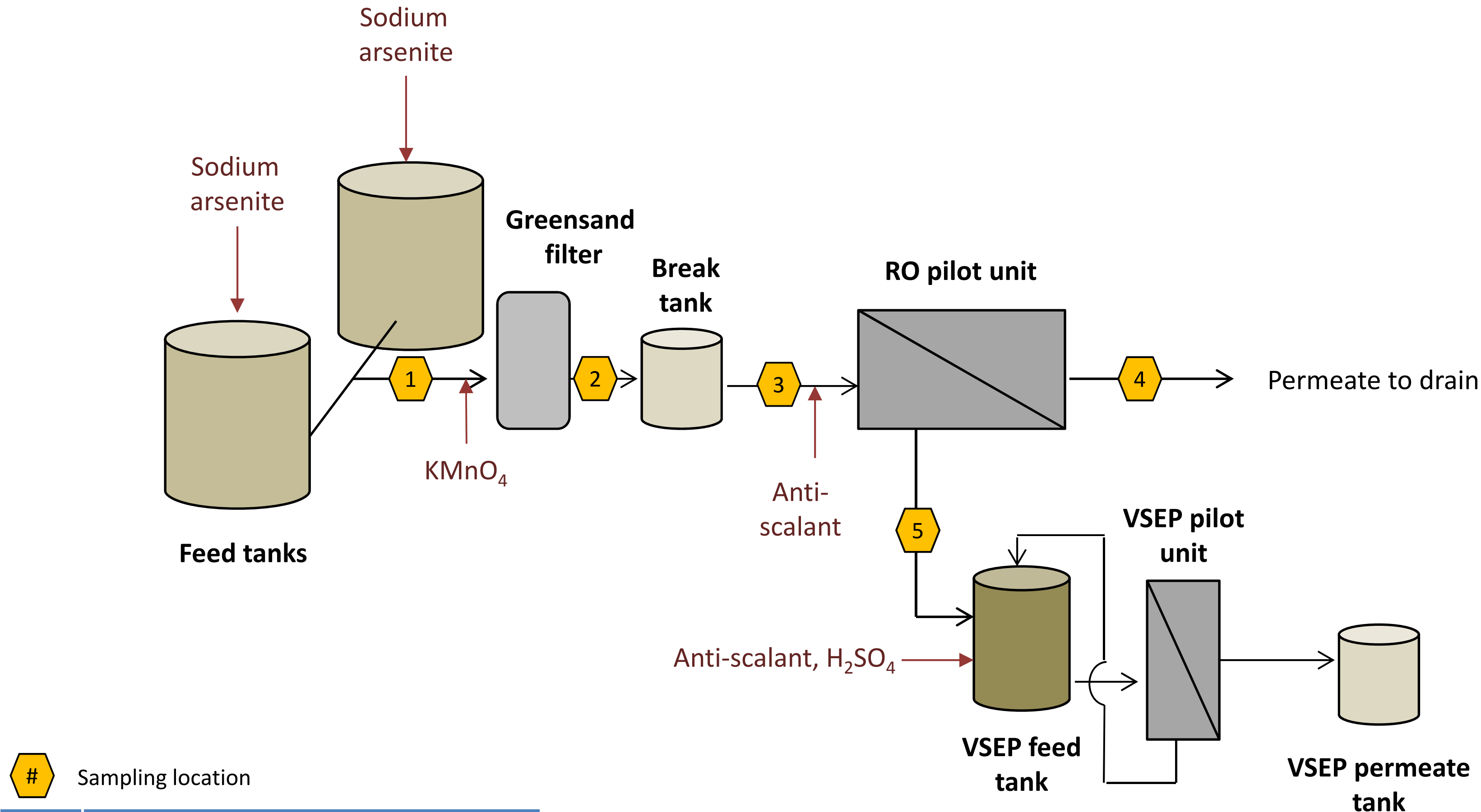
Figure 25. Metals Seeding Test Illustration



No.	Sampling location
1	Feed tank effluent
2	Pretreated effluent
3	RO feed
4	RO permeate
5	RO concentrate
6	VSEP feed (beginning of batch)
7	VSEP concentrate (end of batch)
8	VSEP permeate (end of batch)

Sampling location

Figure 26. Arsenic Removal Test Illustration



No.	Sampling location
1	Feed tank effluent
2	Pretreated effluent
3	RO feed
4	RO permeate
5	RO concentrate

Figure 27. HDS Test Results for Arsenic

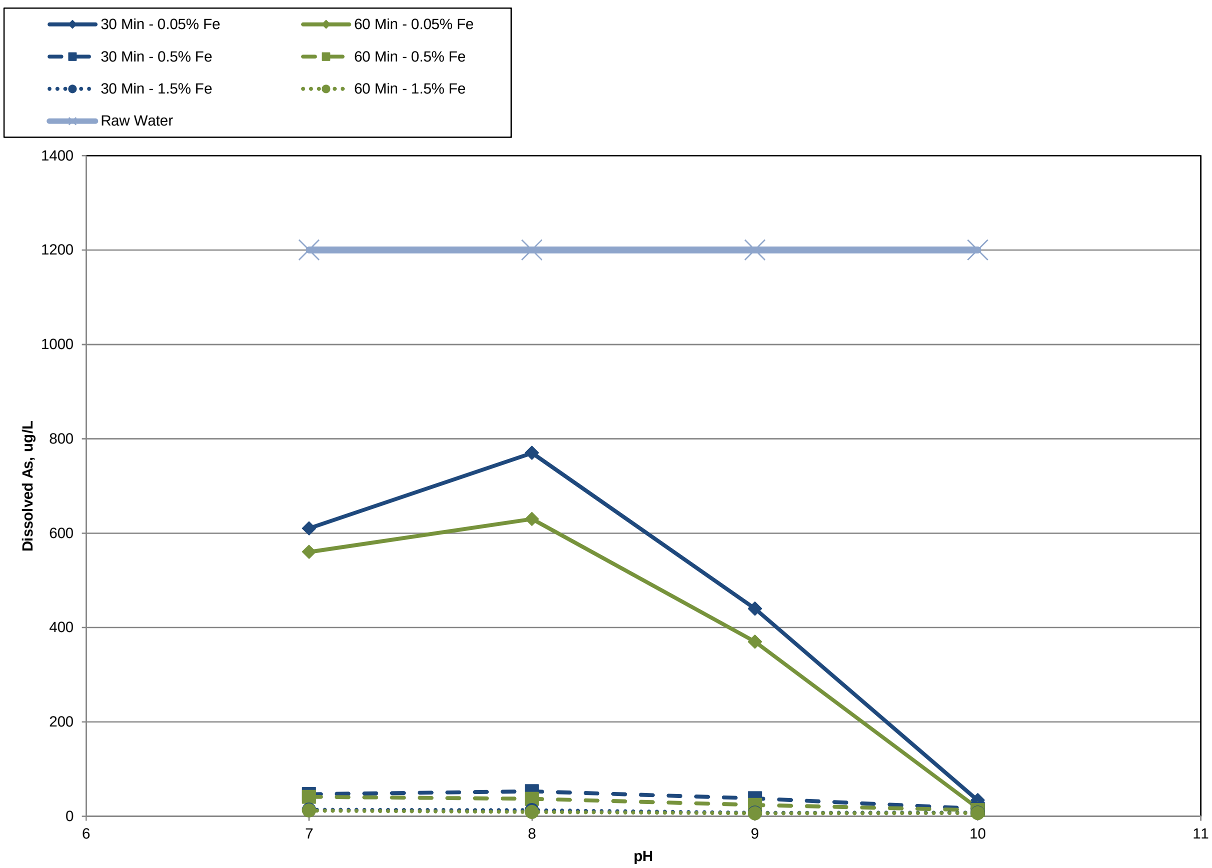


Figure 28. HDS Test Results for Chromium

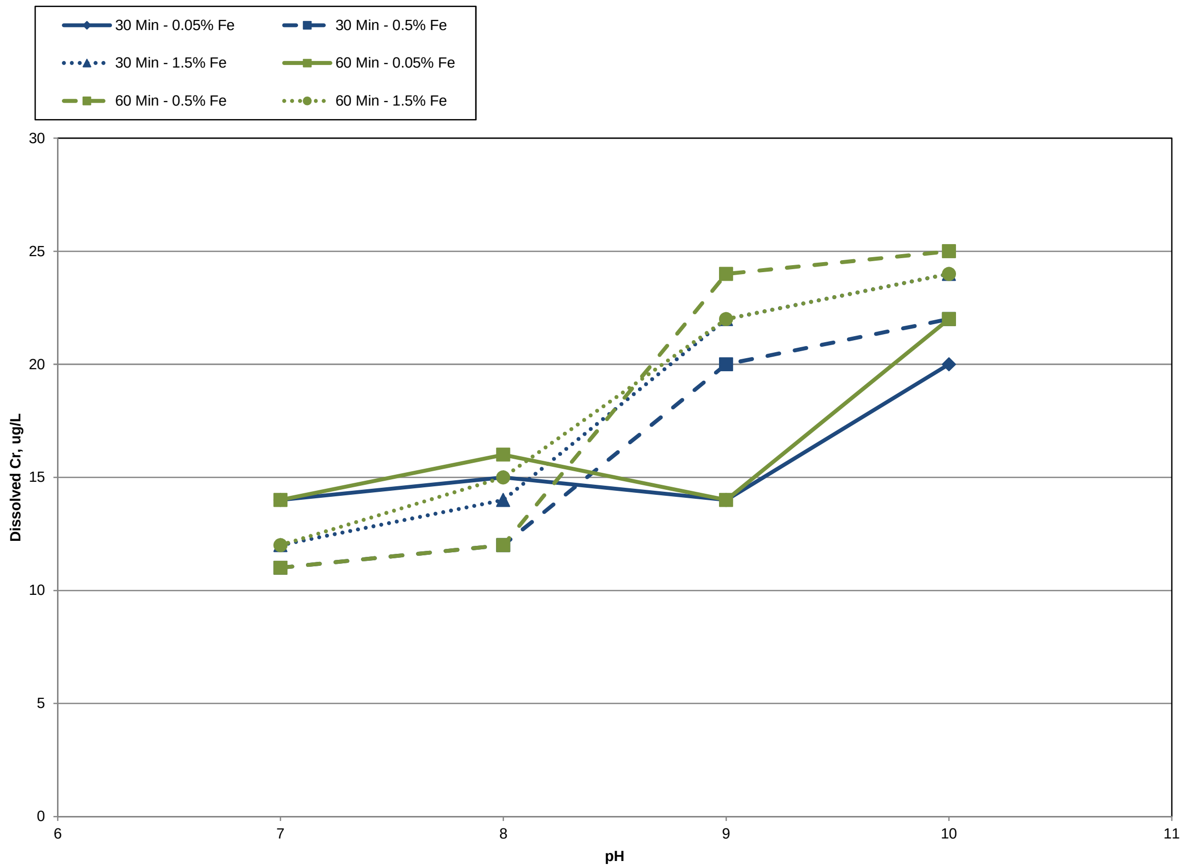


Figure 29. HDS Test Results for Cobalt

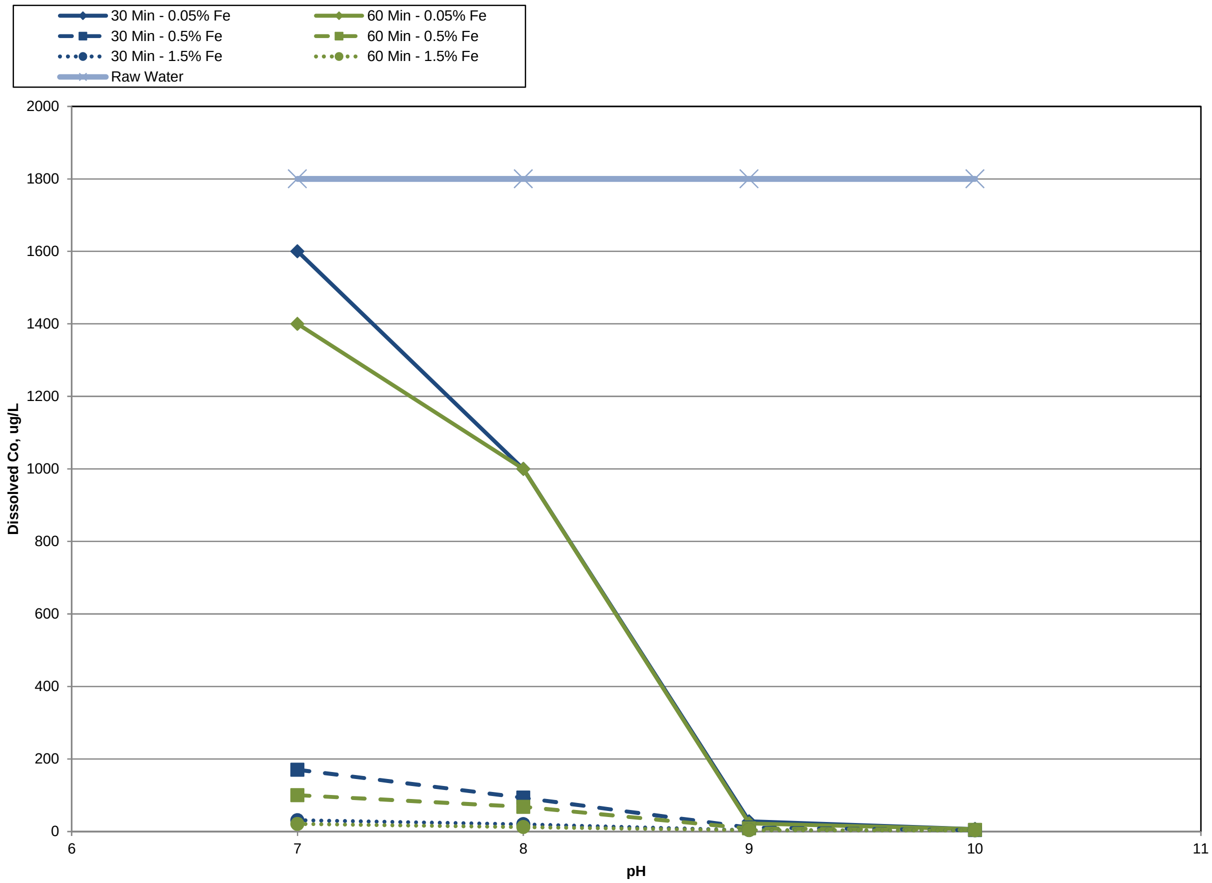


Figure 30. HDS Test Results for Copper

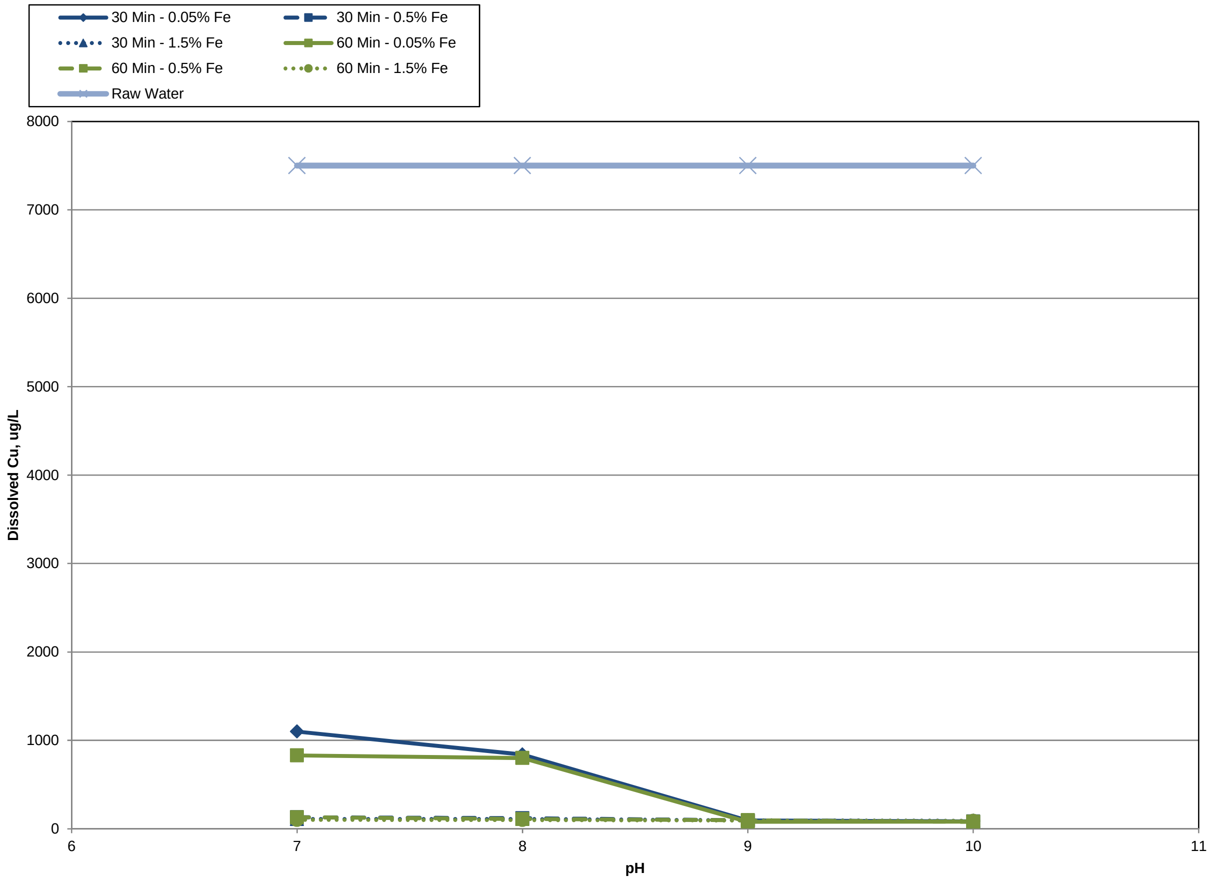


Figure 31. HDS Test Results for Lead

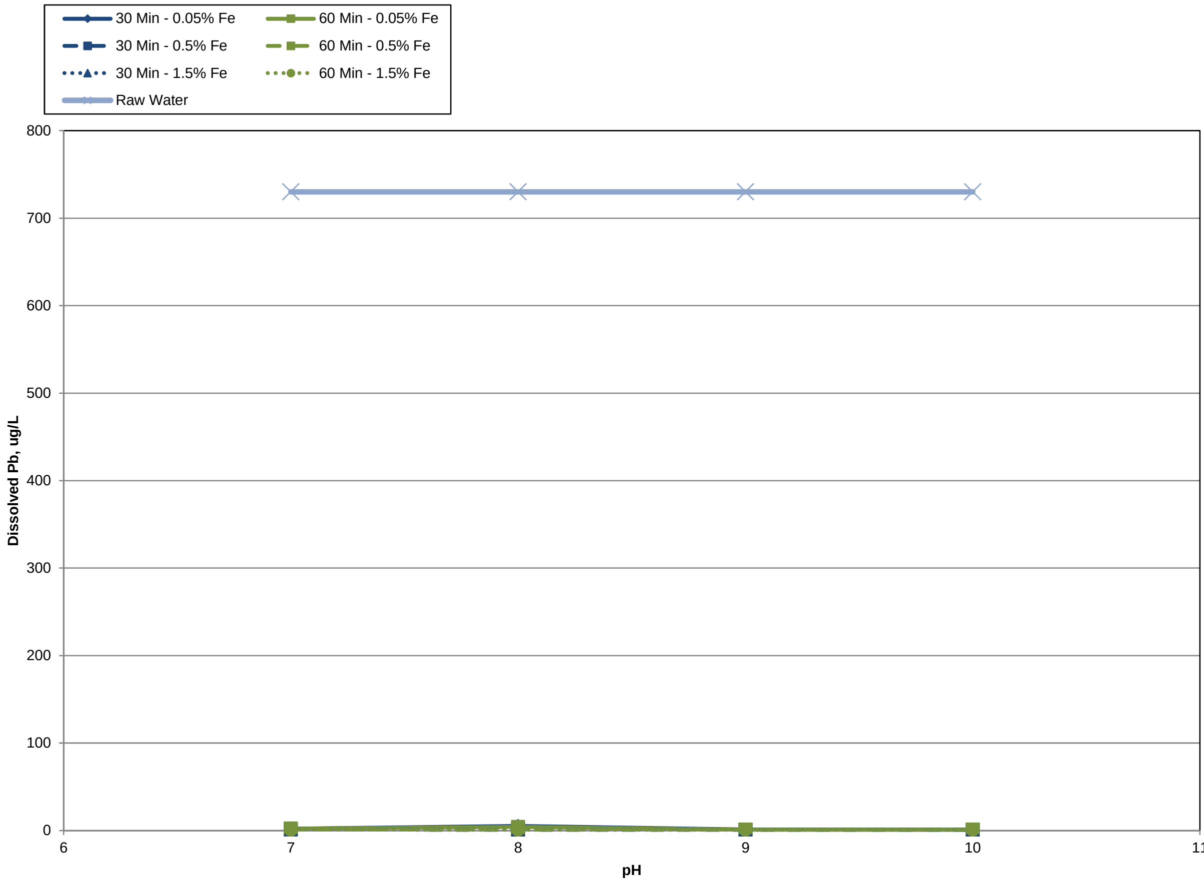


Figure 32. HDS Test Results for Manganese

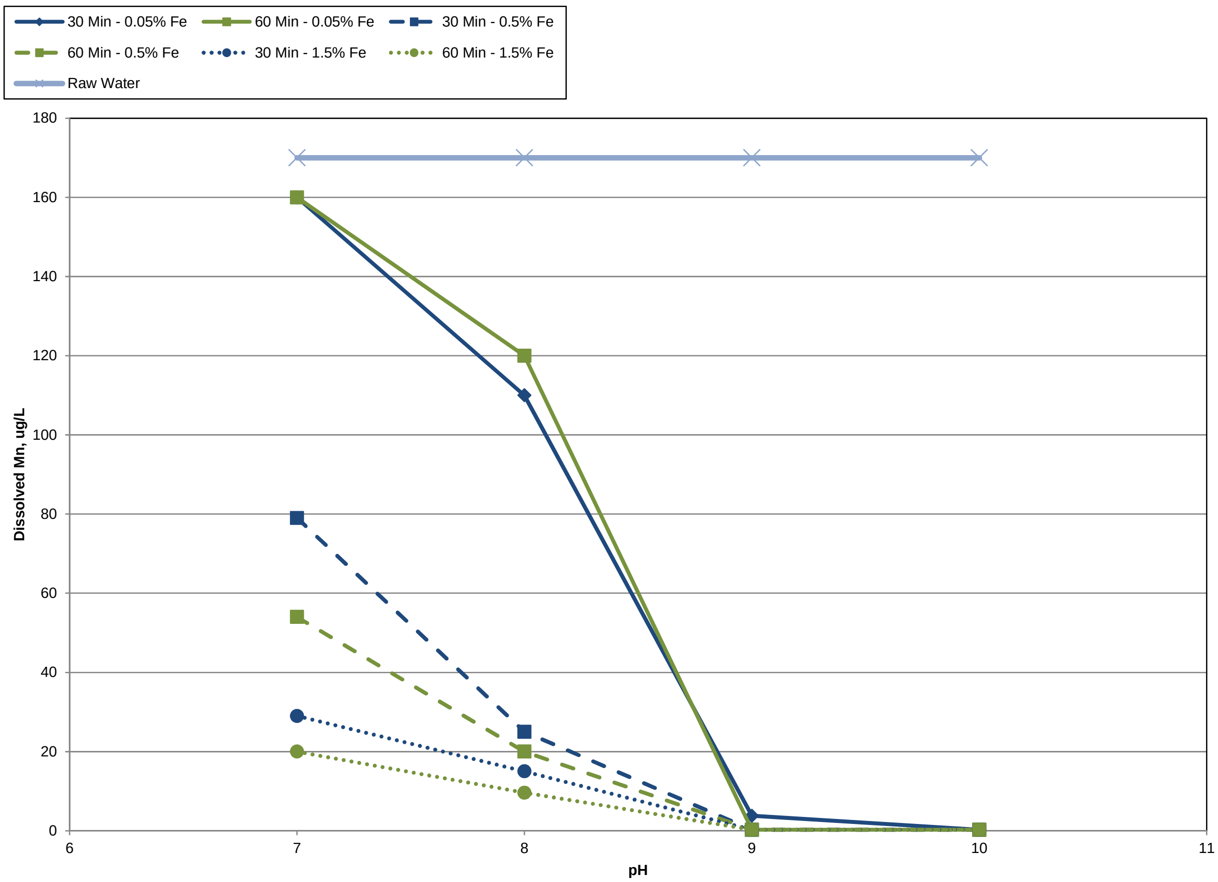


Figure 33. HDS Test Results for Nickel

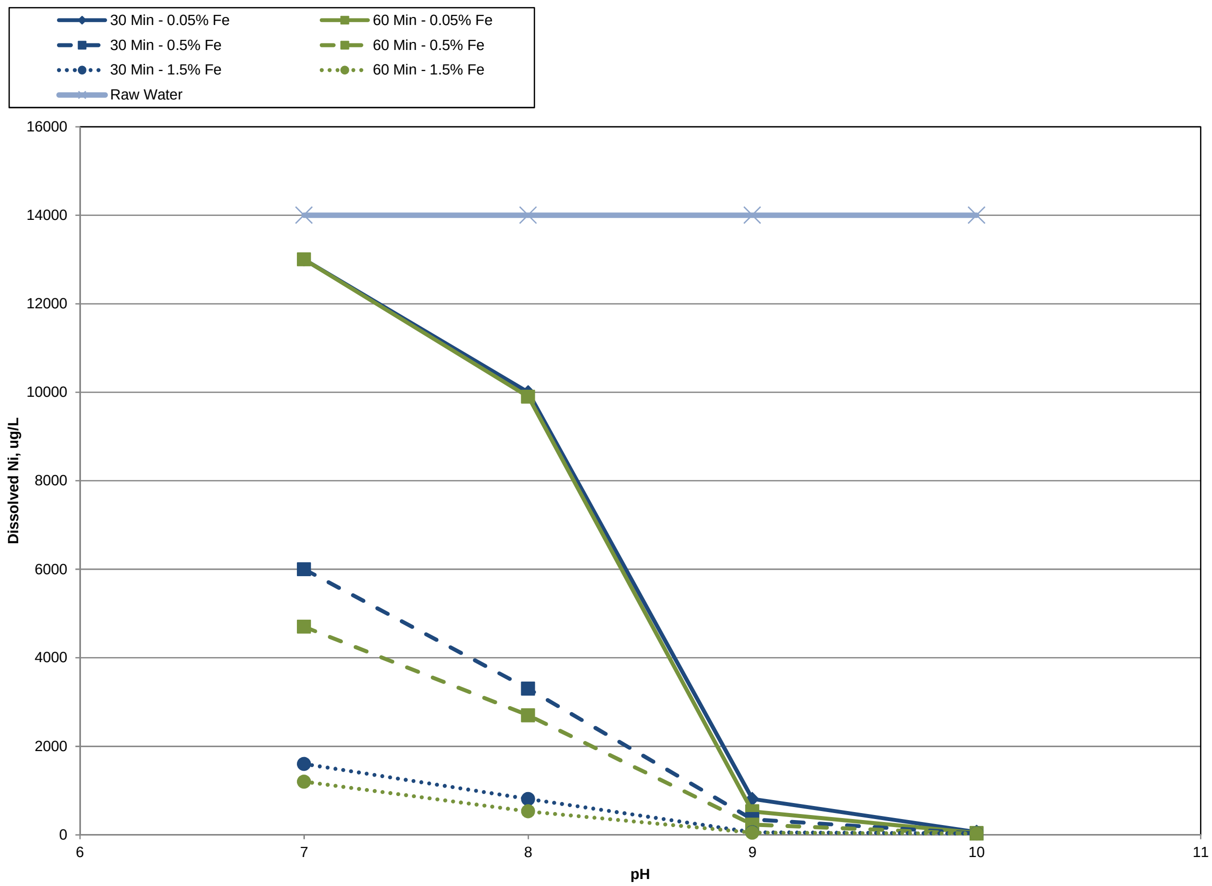


Figure 34. HDS Test Results for Selenium

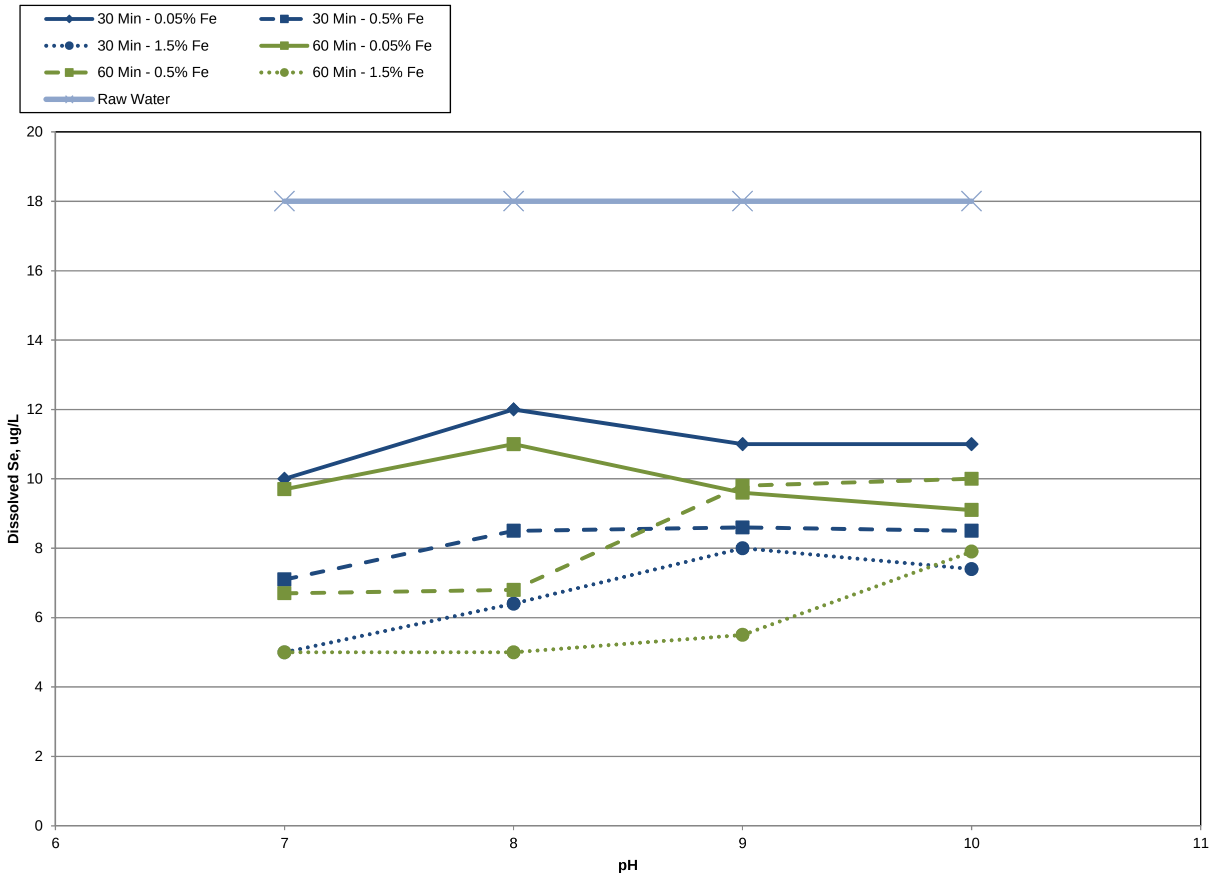


Figure 35. HDS Test Results for Zinc

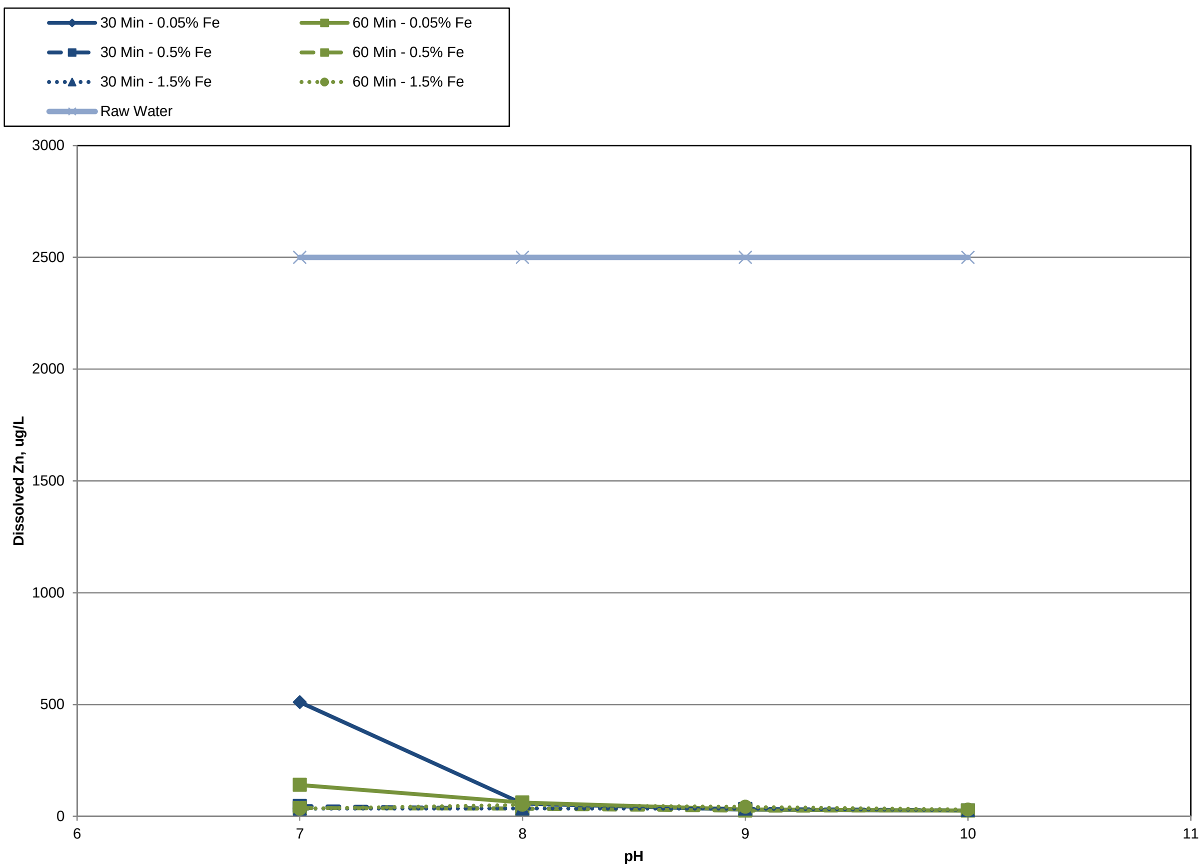


Figure 36. HDS Metals Settling, pH 7

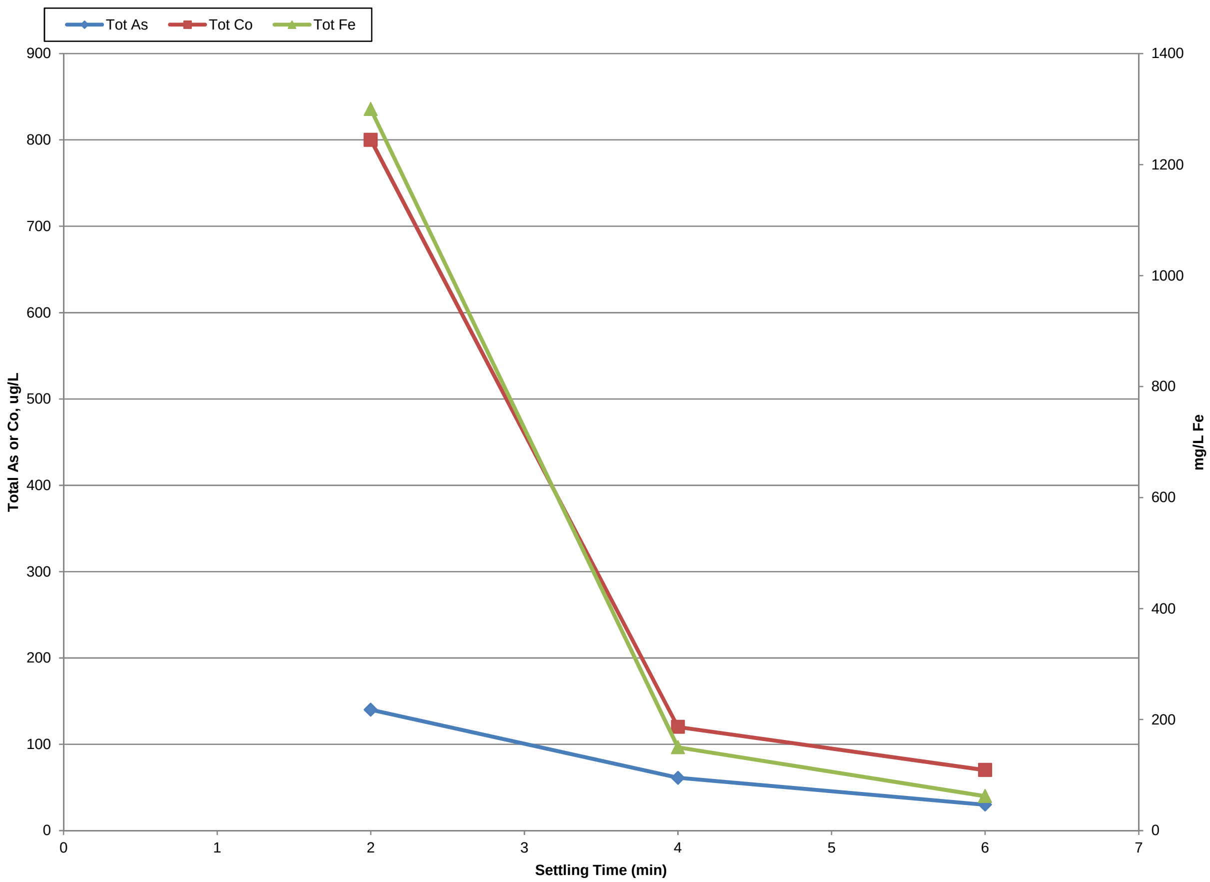


Figure 37. HDS Metals Settling, pH 8

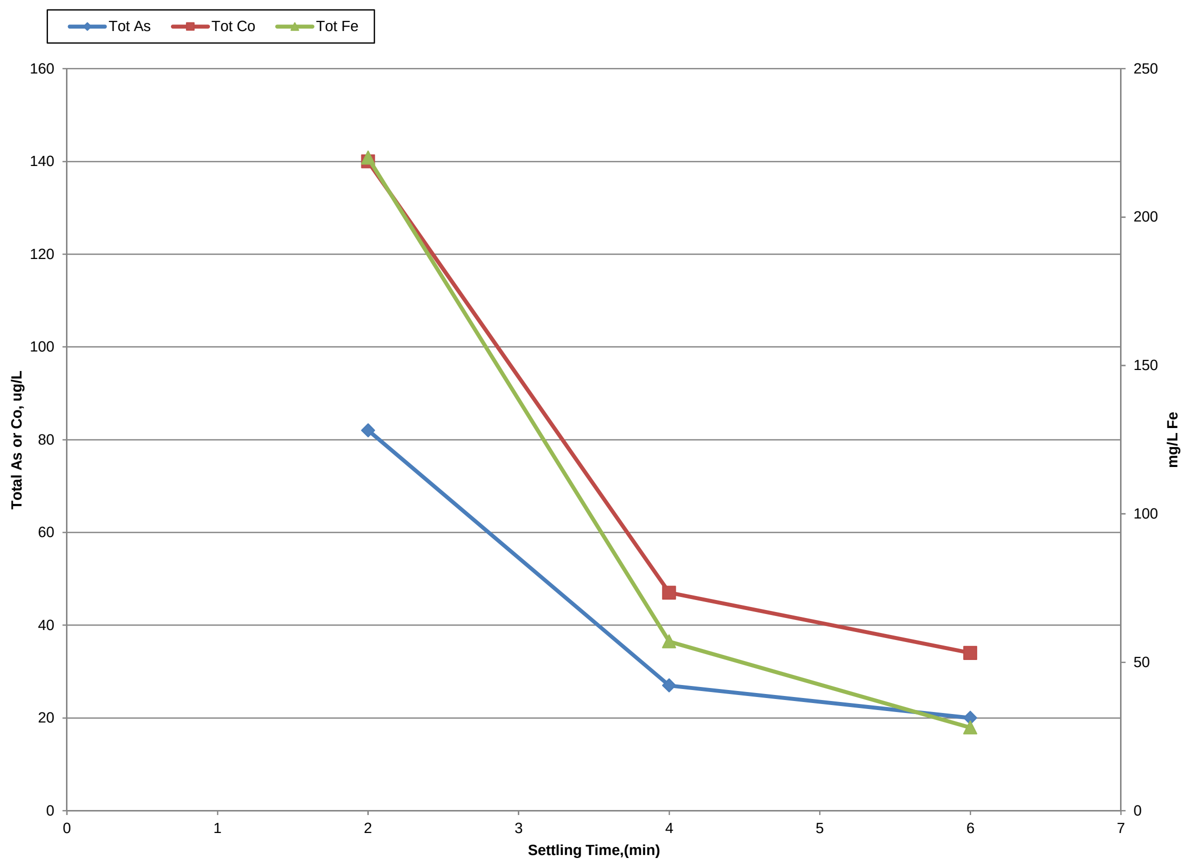


Figure 38. HDS Metals Settling, pH 9

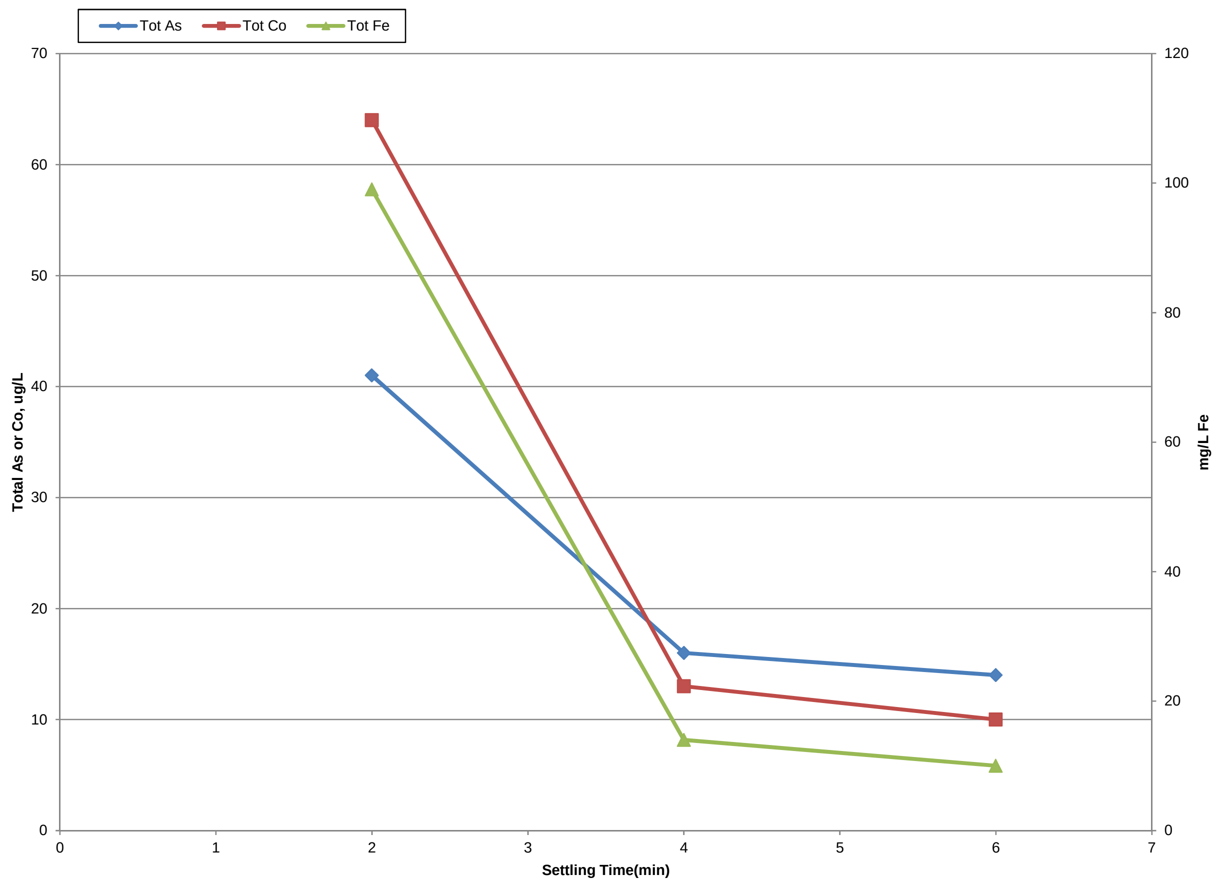
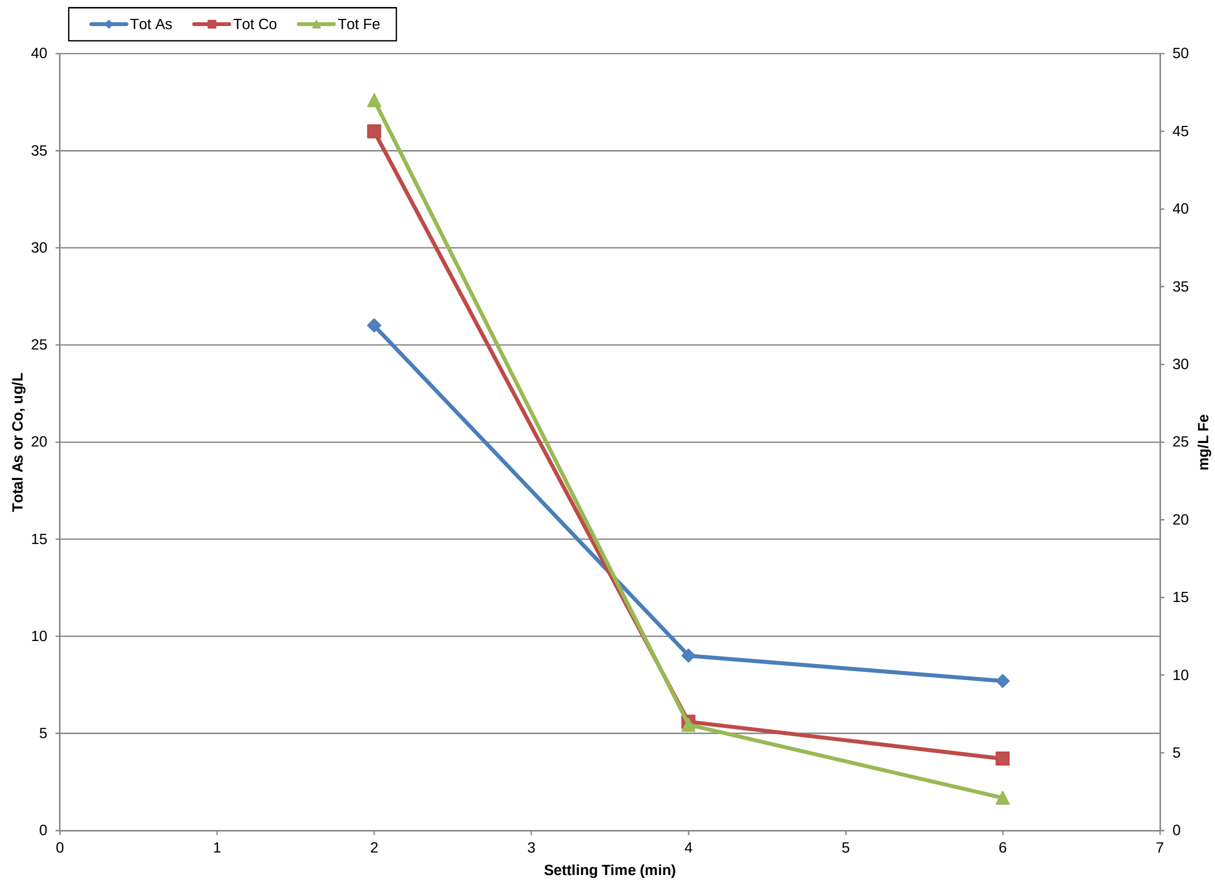


Figure 39. HDS Metals Settling, pH 10



Appendices

Appendix A

Pilot Test Well Evaluation

Technical Memorandum

To: Paul Brunfelt, Poly Met Mining, Inc.
From: Adam Janzen, Jeré Mohr
Subject: Results from Tailings Basin Pilot Well Pumping Test and Water Level Monitoring
Date: January 8, 2013
Project: 23/69-C08
c: Jim Scott, Poly Met Mining, Inc.

Introduction

In January 2012 a pumping test was conducted on a new well located on the north side of the former LTV Steel Mining Company tailings basin near Hoyt Lakes, MN. The new well (the "pilot well") was installed to support on-going water treatment evaluations. Drawdown data were collected from the pilot well and nearby monitoring wells GW-006, GW-012, and a piezometer as shown on Figure 1. The objectives of the aquifer testing were to determine the maximum sustainable pumping rate for the pilot well and to produce information on groundwater level responses to hydraulic stresses (i.e. pumping) at the site. These responses provide insight into hydrogeologic factors such as the interconnection between the native material under the tailings basin and the wetlands to the north, hydraulic parameter values (e.g. hydraulic conductivity and storativity), and heterogeneities within the aquifer.

This memorandum describes the methods used to collect the pumping test data, the data analysis procedures, and a compilation of the results of the data analysis in comparison to existing hydrogeological data for the tailings basin. Long-term groundwater monitoring data collected from the pilot well, GW-006, and the piezometer through early January 2013 are also presented and discussed.

Aquifer Test Sequence

The aquifer testing was conducted generally as described in the original specifications (Barr, 2011), with appropriate changes due to site conditions and unexpected difficulties with the pumping well. The pilot well (Minnesota Department of Health unique ID #786386) was used as the pumping well. Water levels were monitored in the pumping well and at three monitoring wells:

- GW-006 (MDH #625042) , a well downslope and approximately 110 feet north of the pilot well;
- a piezometer (no MDH tag) slightly upslope and approximately 11 feet southwest of the pilot well; and
- GW-012 (MDH #767968), a well in the wetlands about 1 mile northeast of the pumping well.

Water level measurements were collected using LevelTROLL dataloggers/pressure transducers with logarithmic frequency in the pumping well, GW-006, and the piezometer, and every 5 minutes at GW-012. Manual water level measurements were collected during the pumping phase and the recovery phase to supplement automated measurements whenever feasible. GW-012 was monitored to provide information on water level fluctuations outside the area of influence of the aquifer test so that background water level fluctuations could be filtered out of the data collected at the other observation wells if necessary.

The pumping well is screened from 31 to 71 feet through silty sand (31-68') and bedrock (68-71'). GW-006 is completed in the same geologic unit(s) as the pumping well. No construction data is available for the piezometer, but based on the stratigraphy at the nearby pumping well and the measured depth of the piezometer (32.5' below top of riser) it appears to be screened in the tailings. Figure 2 shows an approximate cross-section of the geology through these three wells and boring RS-29 (drilled in 2009).

The primary components of the aquifer testing process were:

1. Step-drawdown Test

A formal step-drawdown test was planned as per the specifications, but two attempts to perform one on January 17 and January 25 were both significantly affected by a leaking pitless adaptor in the well. A limited amount of drawdown data without leakage in the well was collected on January 25 after the problem was resolved. This data showed that a pumping rate of 10 gallons per minute (gpm) might be sustainable, but that 15 gpm would be too high. Based on this information and the client's desire to find the maximum sustainable pumping rate for the well, a pumping rate of 11 gpm was selected for the constant-rate pumping test.

2. Background Monitoring

Background water level data were collected in the pumping well, piezometer, and GW-006 between January 18 and January 25.

3. Constant-rate Test

The constant rate pumping test commenced at 08:30 on January 26, 2012, at a rate of approximately 10.6 gpm. Flow rate measurements were collected using a bucket and stopwatch. Periodic flow measurements were collected throughout the test to make sure the pumping rate remained constant. The flow rate was reduced twice during the test, which is discussed in the results section.

4. Recovery/Post-test Monitoring

Pumping was stopped at 08:50 on January 27, 2012. The post-test monitoring was concluded once the water level in the pumping well recovered to 95% of the maximum drawdown level, as prescribed in the test specifications. The transducer in GW-012 was removed at 12:22 on January 27, 2012. Electronic monitoring of water levels continues in the pilot well, GW-006, and the piezometer. The most current data included in this memo is from January 4, 2013.

Results

Pumping rates during the constant-rate test are shown on Figure 3 along with a summary of the drawdown data collected from the monitoring locations. The drawdown in the pumping well seemed to be stabilizing by late morning on January 26, but as the day progressed drawdown continued to increase at an increasing rate. The LevelTROLL in the pumping well was located approximately 64 feet below the top of casing and directly above the pump; the pump was throttled back when the depth to water in the well reached 60 feet to prevent drawing air into the pump. The pumping rate was first reduced to approximately 8.5 gpm at 16:08 on January 26. A similar increase in drawdown was observed again during the evening, and the rate was reduced to approximately 6.5 gpm at 23:15 on January 26. As shown in Figure 3, the drawdown did not stabilize at this rate and continued to increase until the pump was turned off.

Data Analysis

Data obtained from the constant-rate test have been evaluated using conventional analytical methods to obtain values for hydraulic conductivity and storativity. A summary of the values for these parameters that have been obtained from this work are summarized in Table 1. Data were analyzed using AQTESOLV version 4.5 Professional (Hydrosolv, 2007). The procedures for data analyses using time-drawdown analytical solutions and distance-drawdown methods are discussed in this section.

General Data Trends

As shown in Figure 3, responses to pumping were apparent at both GW-006 and the piezometer. No response to pumping in the pilot well was apparent at GW-012. The changes in pumping rate are seen in the data from GW-006 but not in the piezometer data. The total drawdown in the piezometer was only approximately 3 inches during the test. Because the piezometer appears to be screened in a different unit from the pumping well and GW-006, the piezometer data was not analyzed. Initial examination of the raw test data does not appear to show any external influences not related to pumping that caused water level fluctuations at the monitoring locations.

Time-drawdown Analysis

The Theis (1935) solution for pumping in a confined aquifer was selected for the analysis of the data from GW-006. A confined aquifer solution was chosen because of the layering identified from the well logs and the different responses observed between GW-006 and the piezometer during the pumping test, as noted previously. The Theis solution allows for estimation of transmissivity and storativity of the aquifer using time-drawdown data from pumping tests. The values of these two parameters are adjusted to find a solution that provides an optimum fit to the field data.

Both the pumping period and the recovery period data collected at GW-006 were analyzed using the Theis solution. Analysis of the pumping data resulted in estimates of 1,100 ft^2/day for transmissivity and 0.0061 for storativity. Assuming an average aquifer thickness of 40 feet (silty sand is 37 feet thick at pilot well, about 43 feet thick at GW-006), the estimated hydraulic conductivity is 28 ft/day. Analysis of the recovery data (or residual drawdown) from GW-006 using the Theis solution resulted in similar estimates of 1,100 ft^2/day for transmissivity (28 ft/day for hydraulic conductivity) and 0.0052 for storativity. AQTESOLV plots for these (and all other analyses) are included as Attachment A.

Data collected from the pumping well during the first 3 hours of the test (before the water level began to decrease rapidly) was also analyzed in AQTESOLV. A good fit to this data was achieved using the Papadopulos-Cooper (1967) solution, which includes wellbore storage effects to better match the initial response. This analysis gave estimates of 160 ft^2/day for transmissivity and 0.0001 for storativity. Using a thickness of 40 feet, the hydraulic conductivity was estimated as 4 ft/day. These values are nearly an order of magnitude less than the results from the GW-006 analysis.

Distance-drawdown Analysis

The pumping well data were analyzed using the Cooper-Jacob (1946) distance-drawdown method to provide an additional estimate of transmissivity and storativity. The Cooper-Jacob method fits a straight line to a semilog plot of drawdown versus time. Omitting the nonlinear early-time data from the Papdopulos-Cooper analysis and fitting a straight line to the remaining data gave estimates of 130 ft^2/day for transmissivity and 0.0020 for storativity. The storativity estimate is similar to the GW-006 analysis, while the hydraulic conductivity (again assuming a thickness of 40 feet) of 3 ft/day is similar to the Papadopulos-Cooper pumping well analysis.

Discussion of Results

Variation of Conductivity Estimates

The hydraulic conductivity values estimated from the constant-rate test analysis fall within the range of 0.03 – 300 ft/day for silty sand, and the storativity values are close to the expected range of 0.005 to 0.00005 for confined aquifers (Freeze and Cherry, 1979). Barr conducted a series of single-well pumping tests in wells around the tailings basin in 2009, and obtained a range of hydraulic conductivity values from 1 to 50 ft/day (Barr, 2009). The new estimates from the pilot well testing are all within this range.

Barr conducted a single-well pumping test in GW-006 on May 4, 2009, and obtained hydraulic conductivity estimates of 10 and 6 ft/day from pumping and recovery data, respectively (Barr, 2009). These values are much lower than those obtained from the analysis of the GW-006 data from the 24-hour test, and a bit higher than the values from the pumping well (pilot well) analysis. In general, it is preferable to analyze drawdown data from an observation well rather than from the pumping well. This minimizes the effects of well inefficiencies on the analysis, and provides parameter estimates that are averaged over a larger volume of the aquifer. Due to spatial heterogeneity, the hydraulic conductivity may be similar near the pumping well and near GW-006, but may differ by orders of magnitude elsewhere in the aquifer. Thus the hydraulic conductivity estimates from the 24-hour test with GW-006 as an observation well may better reflect the conductivity of the aquifer as a whole.

Aquifer Boundaries and Flow Regime

The late time data collected during an aquifer test can provide insights into the flow regime of an aquifer and the presence of hydraulic boundaries. For example, encountering an aquifer boundary that supplies water to the aquifer (e.g. river, lake, or leakage boundary) will result in observed drawdown that is less than would be predicted by a Theis-type response. A low permeability boundary will result in more observed drawdown than would be predicted with a Theis-type response. The large increases in drawdown in the pumping well that prompted flow rate reductions do not fit expected Theis behavior and suggest the presence of a low permeability boundary within the aquifer, likely near the pumping well.

Another possible explanation for the difference in hydraulic conductivity estimates between the pumping well and observation well analyses is hydraulic connection with the wetlands. This would result in lower-than-expected drawdowns at GW-006 when pumping at the pilot well, and lower-than-expected drawdowns at GW-006 would correspond to a higher hydraulic conductivity estimate from the GW-006 data. Such boundary effects would be most pronounced during the latter part of the pumping period, and, as shown in the AQTESOLV plot of the GW-006 pumping period analysis in Attachment A, the Theis solution with the higher transmissivity fits the observed drawdown data better at late times than at early times. If a connection with the wetland is influencing the drawdowns at GW-006, a Theis curve with a lower transmissivity should fit the early time data better. However, this is not the case; a higher transmissivity (1,800 ft^2/day instead of 1,100 ft^2/day) is needed to better match the early time data. Therefore, the data do not conclusively show whether or not the native material under the tailings basin is hydraulically connected with the wetlands.

Maximum Pumping Rate

This pumping test indicated that the maximum sustainable long-term pumping rate for the pilot well is likely less than 6.5 gpm. The well was pumped at a rate of 6.5 gpm for a period of approximately 9 hours at the end of the aquifer test, and drawdown in the well was continuing to increase throughout this period. The fact that the drawdown in the pumping well did not stabilize, even at a relatively low pumping rate, suggests that a low permeability boundary may be present within the aquifer. Further investigation would be necessary to better characterize the location and properties of this boundary.

Long-Term Water Level Monitoring

As noted above, electronic monitoring of groundwater levels in the pilot well, GW-006, and the piezometer continued well after the conclusion of the aquifer testing. Figure 4 shows the water elevation record in these three wells from the start of the constant rate test at 8:30 on January 26, 2012 through late morning on January 4, 2013. The onset of regular pumping of the pilot well in May 2012 for the water treatment pilot testing is clearly evident in Figure 4, with the large fluctuations in water levels in the pilot well corresponding to a cyclical pumping pattern. For most of the pumping periods from May until mid-July, the pilot well was apparently pumped dry or nearly dry; the bottom of the pilot well is at an approximate elevation of 1442 feet, and the pressure sensor is mounted just above the submersible pump, which sits at the bottom. After mid-July the pumping levels did not approach the bottom of the well, which may be due to reduced pumping rates during this time period.

The natural flow direction appears to be towards the north, away from the tailing basin, as water levels are consistently highest in the piezometer and lowest at GW-006 during non-pumping periods, though the water level in GW-006 was higher than the water level in the pilot well from mid-March to late-April and again for short periods in late-May and mid-June, the latter of which may correspond to rainfall events. During pumping periods, the flow direction between GW-006 and the pilot well is reversed, as the lower water levels in the pilot well relative to GW-006 induce flow to the south towards the pilot well. Figure 5 presents the same data as shown on Figure 4, but its vertical scale has been adjusted to show more detail for GW-006 and the piezometer. Both GW-006 and the piezometer clearly respond to pumping in the pilot well, and all three wells show similar patterns of water level fluctuations during non-pumping periods. GW-006 is completed in the native unconsolidated deposits, and although it is not screened in wetland deposits, it is located adjacent to extensive wetland areas near the toe of the tailings basin. Water levels at GW-006 likely reflect hydraulic conditions in the adjacent wetlands. The clear drawdown observed at GW-006 in response to operation of the pilot test well suggests that long-term operation of the pilot-test well would likely affect water levels in the adjacent wetlands, at least while the well is being actively pumped. Water levels at GW-006 do appear to recover relatively rapidly after pumping ceases.

Summary and Conclusions

Analysis of the constant-rate pumping test data provided additional insights into the aquifer system. Transmissivity estimates using the data from GW-006 were 1,100 and 1,100 ft^2/day, and 130 and 160 ft^2/day using the pumping well data. Using an average aquifer thickness of 40 feet, these correspond to hydraulic conductivities of 28 and 28 ft/day and 3 and 4 ft/day, respectively. Storativity values were 0.0061 and 0.0052 from the GW-006 analysis and 0.0001 and 0.0020 from the pumping well analysis. The estimates from the GW-006 analysis are expected to better reflect average aquifer values, while the pumping well estimates are likely more localized and may be affected by frictional losses in the well. A low permeability boundary appears to be located within the aquifer. Long-term monitoring of the water levels in the pilot well, GW-006, and the piezometer shows strong correlations between water level fluctuations in the three wells, suggesting that there is a good hydraulic connection between these wells.

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Table 1

Hydraulic conductivity (K) and storativity (S) estimates from analysis of 24-hour test data.

PolyMet Mining Corp.

Data Source	Period Analyzed	Analysis Method	K (ft/day)	S (dimensionless)
GW-006	Pumping	Theis	28	0.0061
GW-006	Recovery	Theis	28	0.0052
Pumping Well	Pumping	Papadopulos-Cooper	4	0.0001
Pumping Well	Pumping	Cooper-Jacob	3	0.0020

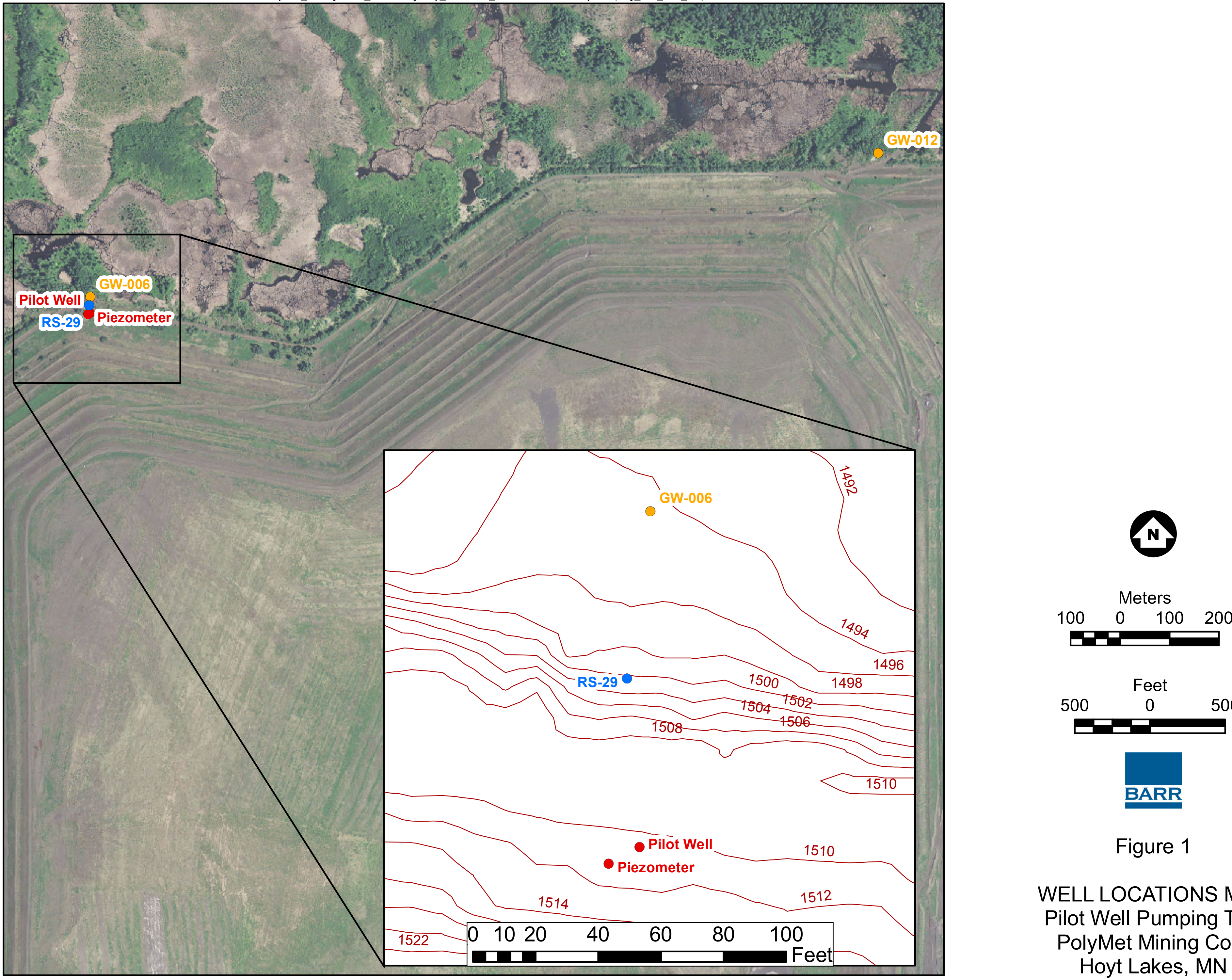


Figure 1

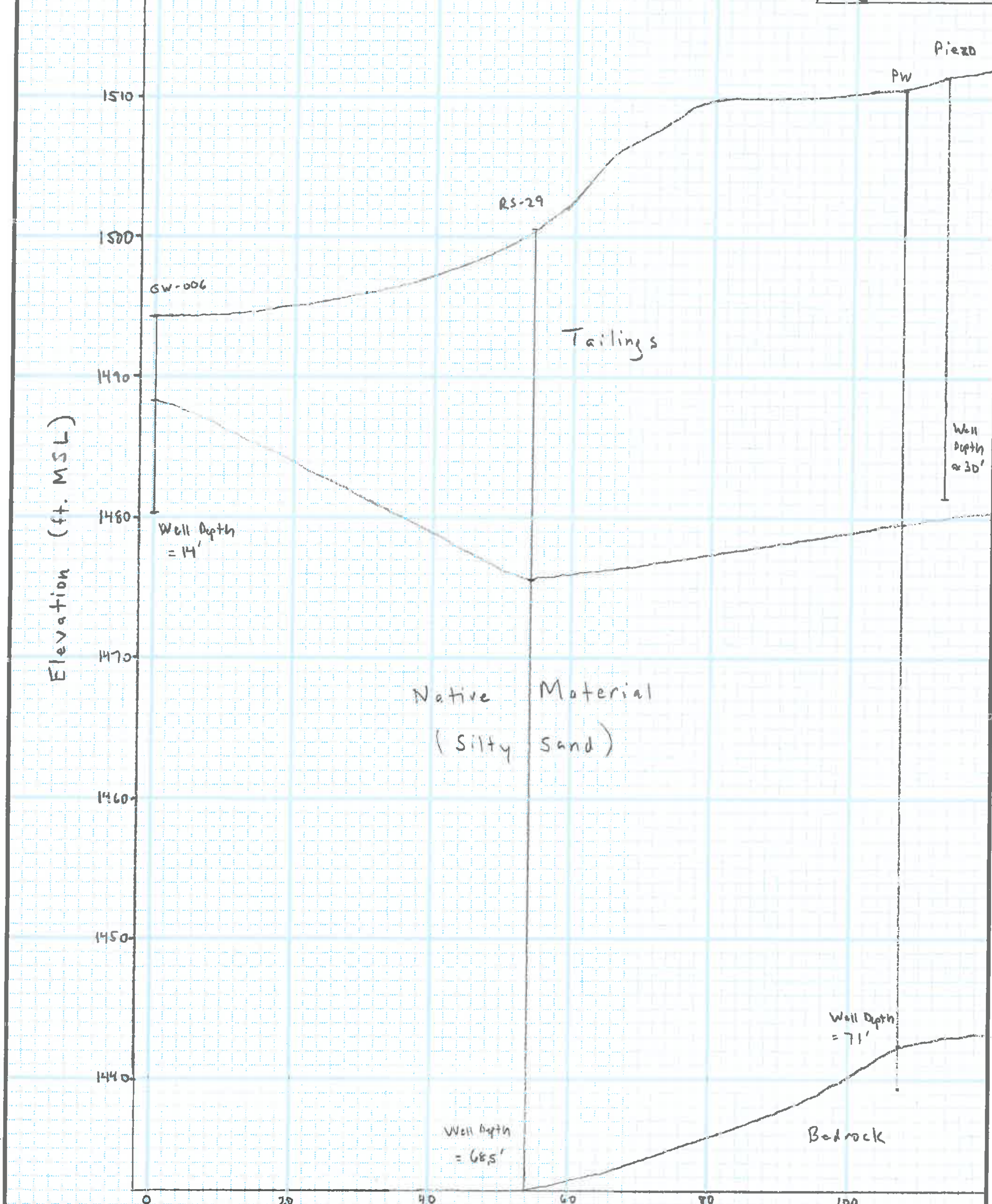
WELL LOCATIONS MAP
Pilot Well Pumping Test
PolyMet Mining Corp
Hoyt Lakes, MN

BARR

MINNEAPOLIS, MINNESOTA - HIBBING, MINNESOTA
DULUTH, MINNESOTA
ANN ARBOR, MICHIGAN - JEFFERSON CITY, MISSOURI

COMPUTED	CHECKED	SUBMITTED	DATE 2/23/2012	SHEET NO. 1/1
BY AKJ	BY	TO	PROJECT NAME PolyMet	
DATE 2/23/12	DATE	DATE	PROJECT NUMBER 23/69-0862	
			SUBJECT Pumping Test Wells X-Section	

Figure 2



10 Squares per Inch

H:RLG\INHOUSE\COMPPADS.CDR

REV. 12/1/98

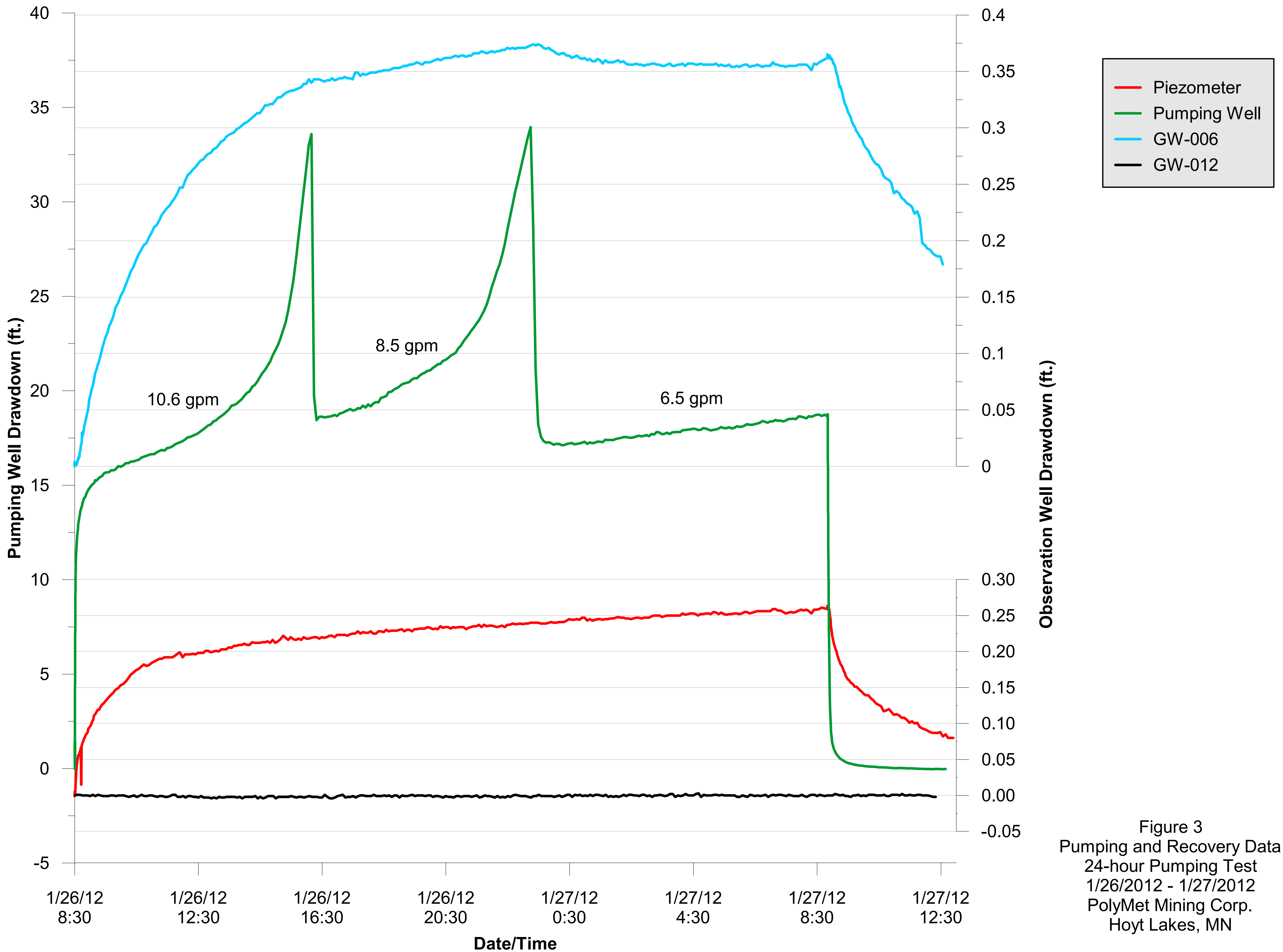


Figure 3
Pumping and Recovery Data
24-hour Pumping Test
1/26/2012 - 1/27/2012
PolyMet Mining Corp.
Hoyt Lakes, MN

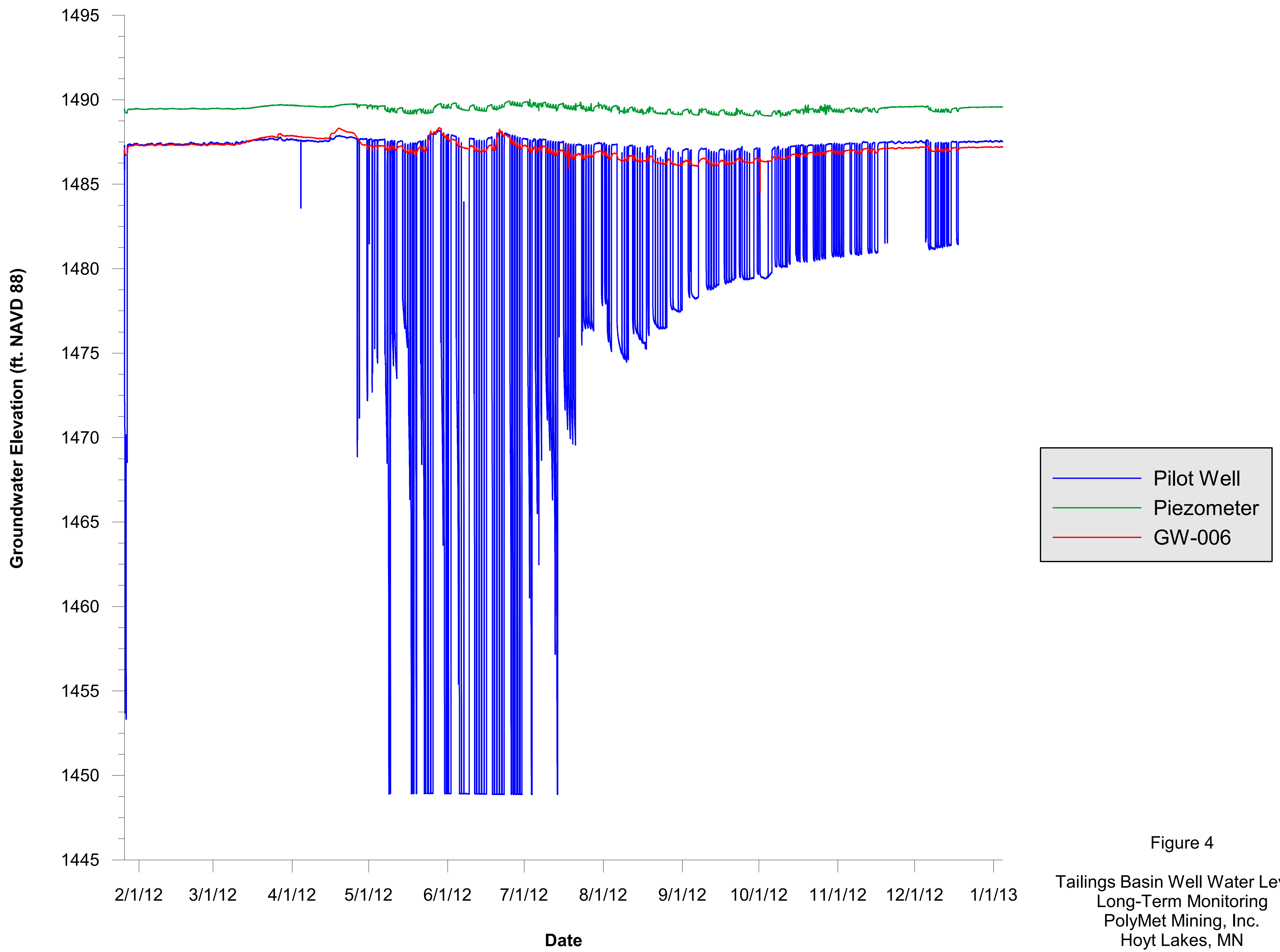


Figure 4

Tailings Basin Well Water Levels
Long-Term Monitoring
PolyMet Mining, Inc.
Hoyt Lakes, MN

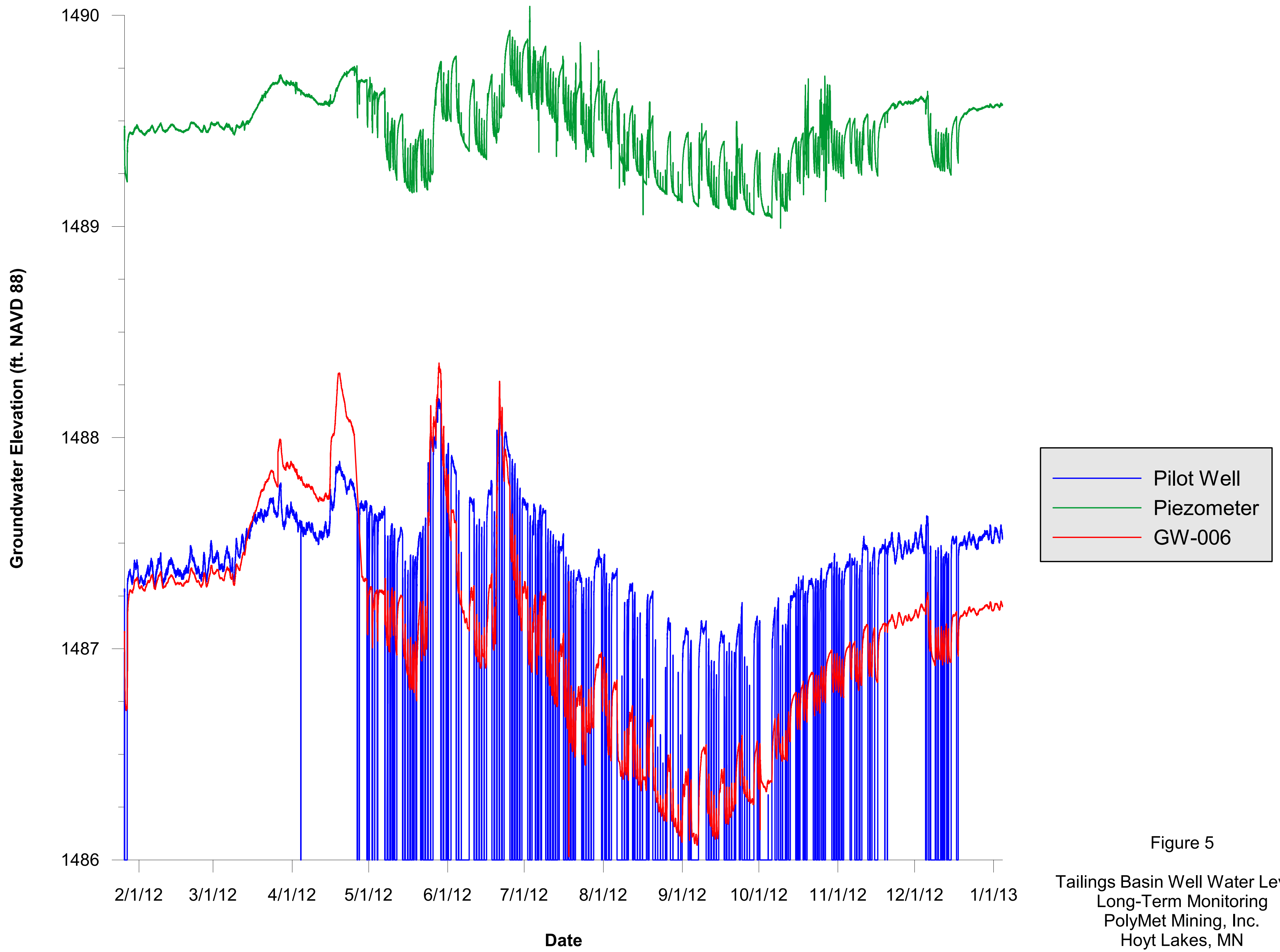
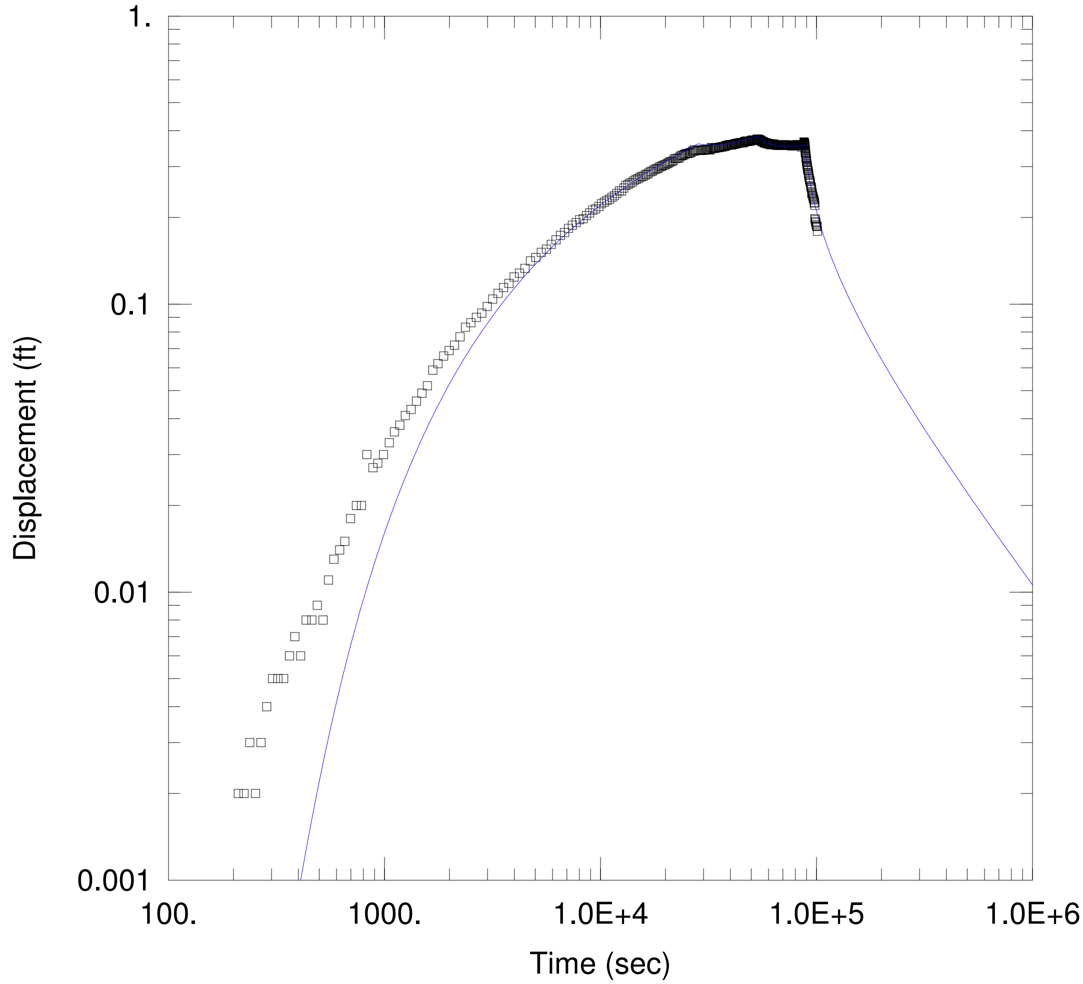


Figure 5

Tailings Basin Well Water Levels
Long-Term Monitoring
PolyMet Mining, Inc.
Hoyt Lakes, MN

Attachment A

AQTESOLV Plots



WELL TEST ANALYSIS

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Date: 02/24/12 Time: 09:11:30

PROJECT INFORMATION

Company: Barr Engineering
Client: PolyMet
Project: 23690862
Location: Hoyt Lakes, MN
Test Well: Pumping Well
Test Date: 01/26/2012

WELL DATA

Pumping Wells

Well Name	X (ft)	Y (ft)
Pumping Well	0	0

Observation Wells

Well Name	X (ft)	Y (ft)
□ GW-006	-110	0

SOLUTION

Aquifer Model: Confined

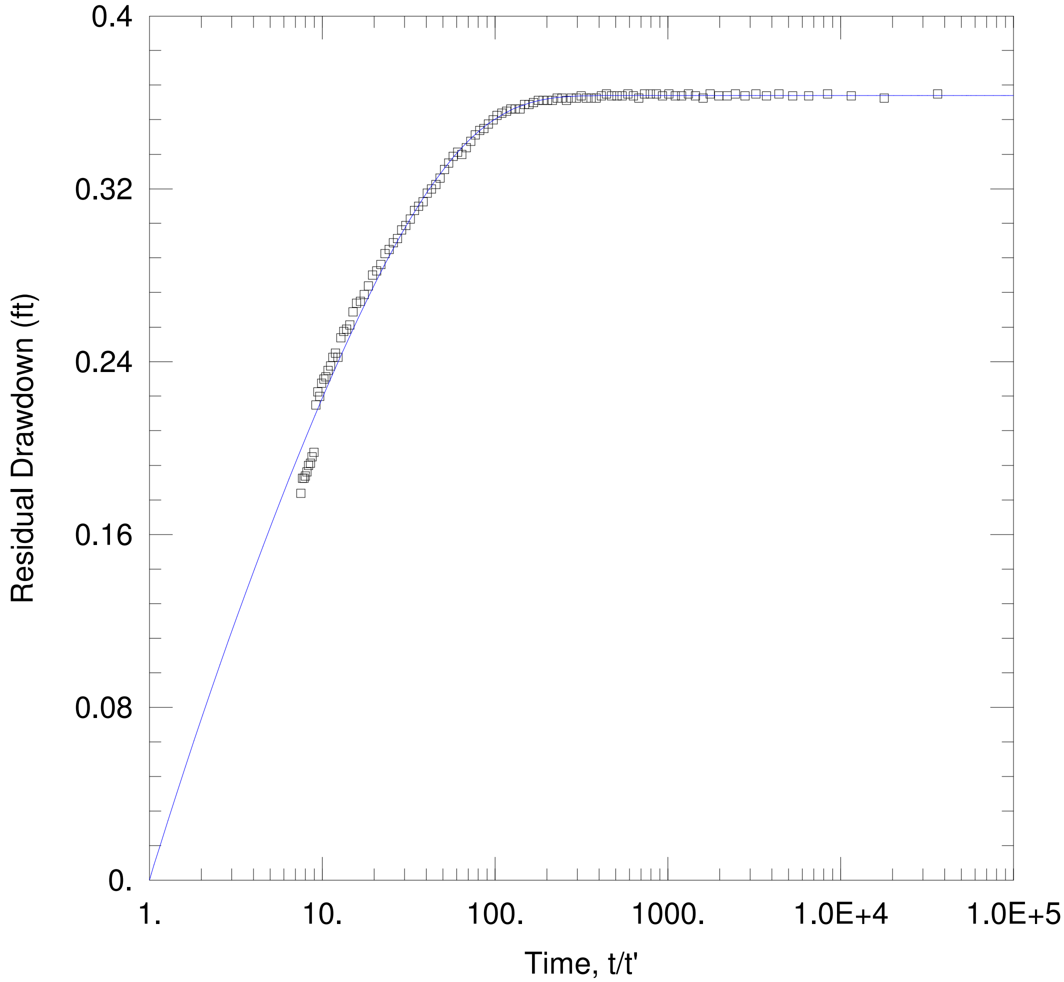
Solution Method: Theis

T = 1103.7 ft^2/day

Kz/Kr = 0.1

S = 0.006096

b = 40. ft



WELL TEST ANALYSIS

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PROJECT INFORMATION

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Client: PolyMet
Project: 23690862
Location: Hoyt Lakes, MN
Test Well: Pumping Well
Test Date: 01/26/2012

WELL DATA

Pumping Wells

Well Name	X (ft)	Y (ft)
Pumping Well	0	0

Observation Wells

Well Name	X (ft)	Y (ft)
□ GW-006	-110	0

SOLUTION

Aquifer Model: Confined

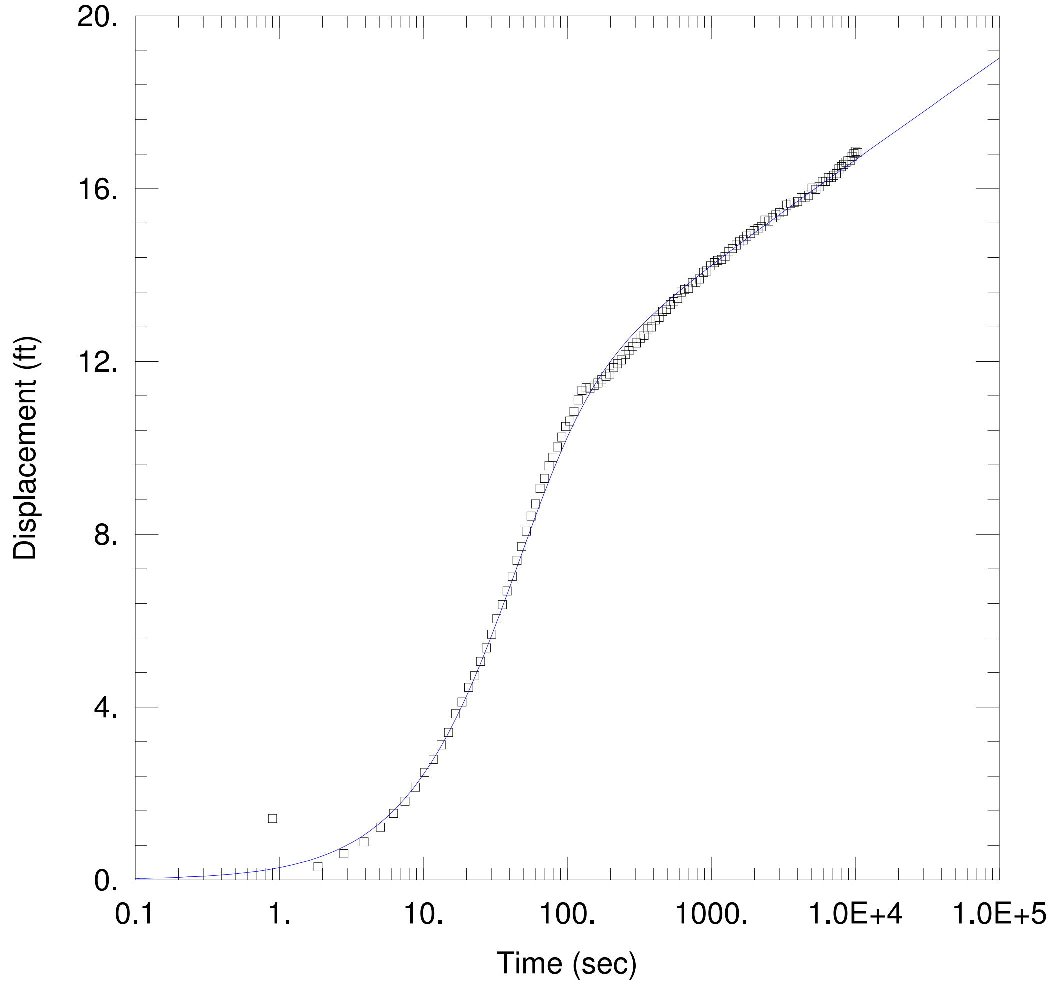
Solution Method: Theis

T = 1135.6 ft^2/day

S = 0.005159

Kz/Kr = 0.1

b = 40. ft



WELL TEST ANALYSIS

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Date: 02/24/12 Time: 09:04:08

PROJECT INFORMATION

Company: Barr Engineering
Client: PolyMet
Project: 23690862
Location: Hoyt Lakes, MN
Test Well: PW
Test Date: 01/26/2012

AQUIFER DATA

Saturated Thickness: 40. ft Anisotropy Ratio (Kz/Kr): 0.1

WELL DATA

Pumping Wells

Well Name	X (ft)	Y (ft)
Pumping Well	0	0

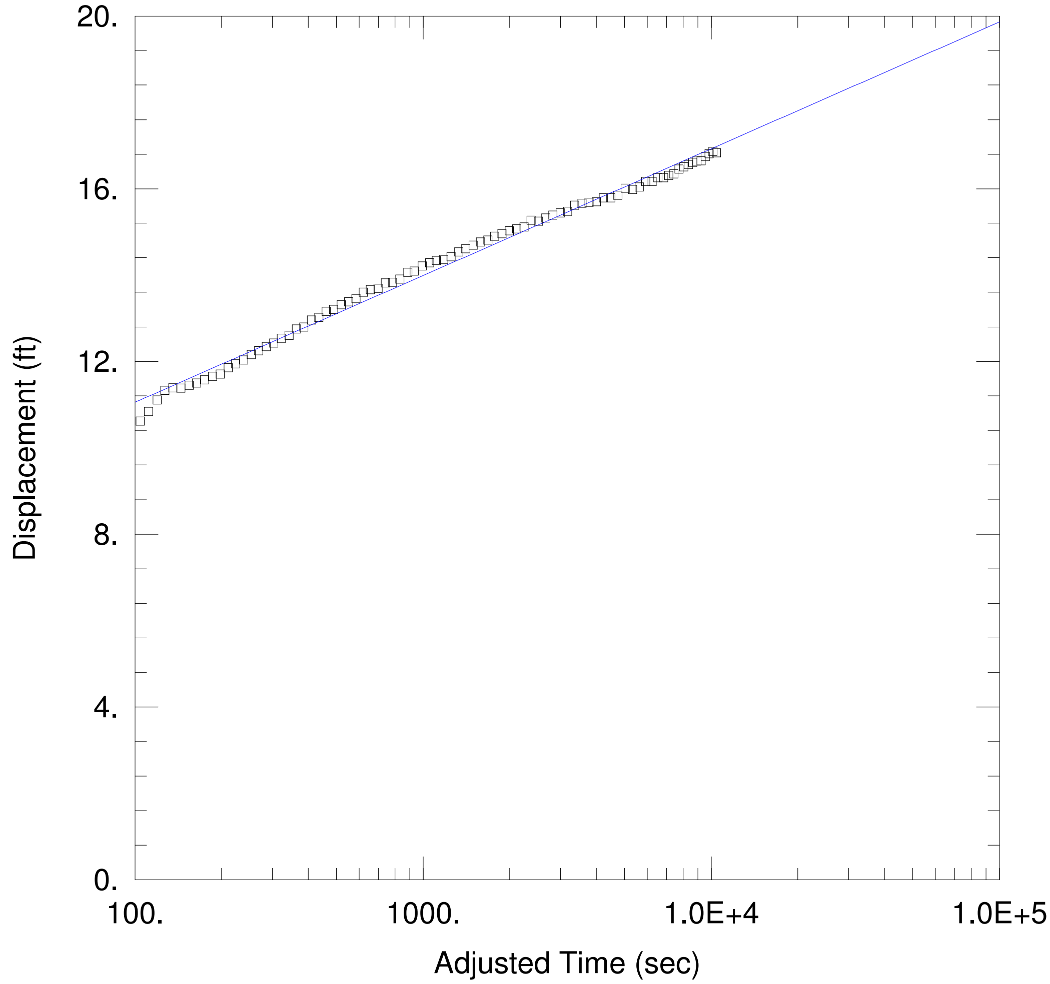
Observation Wells

Well Name	X (ft)	Y (ft)
□ Pumping Well	0	0

SOLUTION

Aquifer Model: Confined Solution Method: Papadopulos-Cooper

T = 159.2 ft^2/day S = 0.0001178
r(w) = 0.167 ft r(c) = 0.167 ft



WELL TEST ANALYSIS

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Date: 02/24/12 Time: 09:03:49

PROJECT INFORMATION

Company: Barr Engineering
Client: PolyMet
Project: 23690862
Location: Hoyt Lakes, MN
Test Well: PW
Test Date: 01/26/2012

AQUIFER DATA

Saturated Thickness: 40. ft Anisotropy Ratio (Kz/Kr): 0.1

WELL DATA

Pumping Wells

Well Name	X (ft)	Y (ft)
Pumping Well	0	0

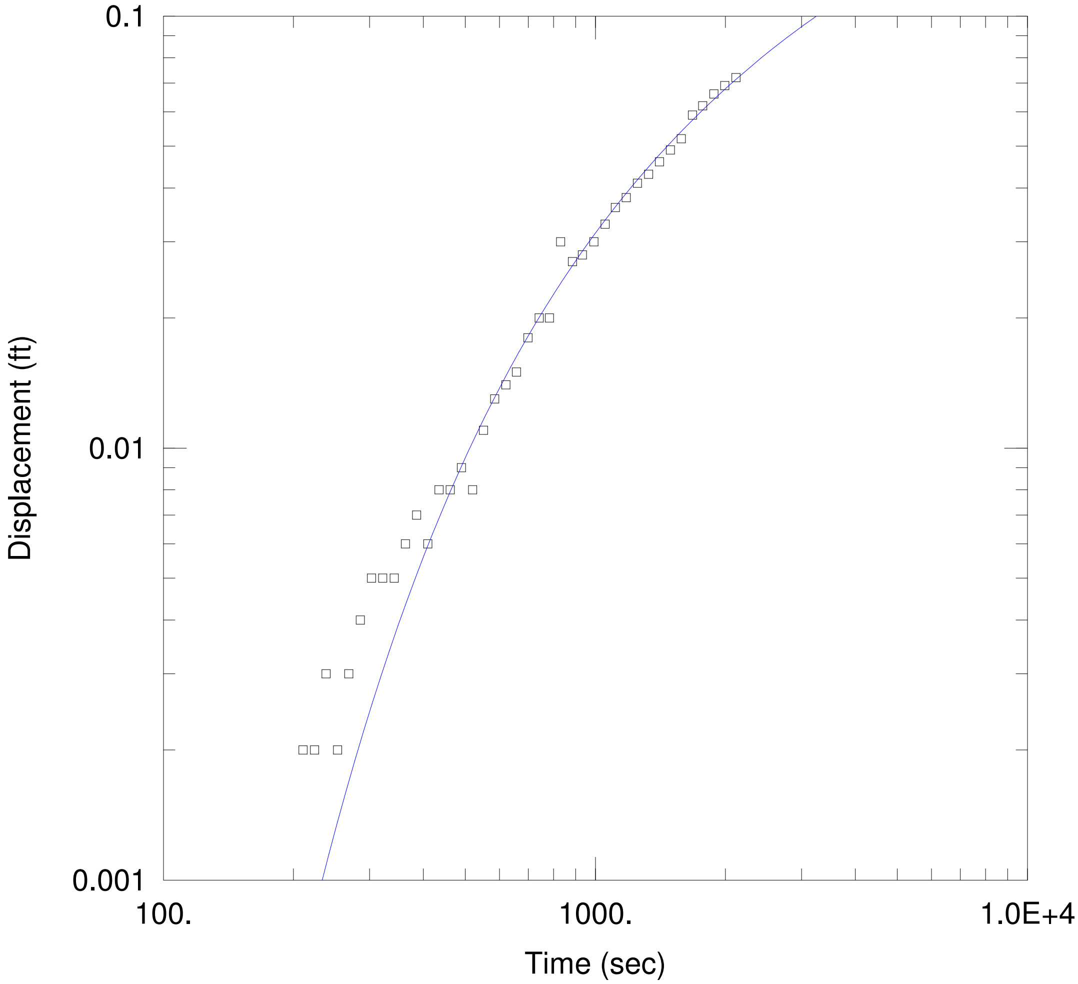
Observation Wells

Well Name	X (ft)	Y (ft)
□ Pumping Well	0	0

SOLUTION

Aquifer Model: Confined Solution Method: Cooper-Jacob

T = 127.4 ft^2/day S = 0.002037



WELL TEST ANALYSIS

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PROJECT INFORMATION

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Client: PolyMet
Project: 23690862
Location: Hoyt Lakes, MN
Test Well: Pumping Well
Test Date: 01/26/2012

WELL DATA

Pumping Wells

Well Name	X (ft)	Y (ft)
Pumping Well	0	0

Observation Wells

Well Name	X (ft)	Y (ft)
□ GW-006	-110	0

SOLUTION

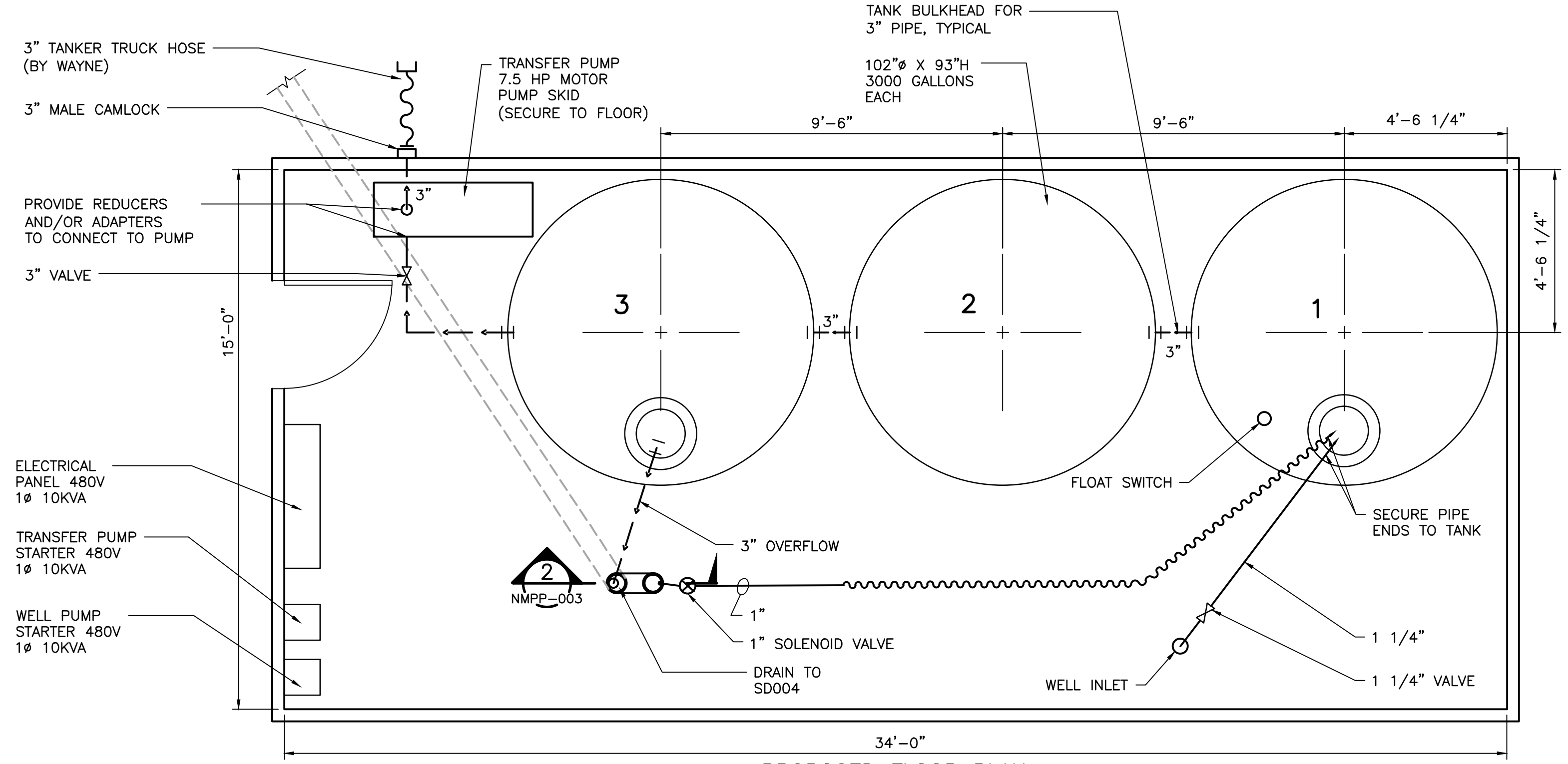
Aquifer Model: Confined

Solution Method: Theis

T = 1840.3 ft^2/day
S = 0.005107
Kz/Kr = 0.1
b = 40. ft

Appendix B

Pilot Test Facility Information

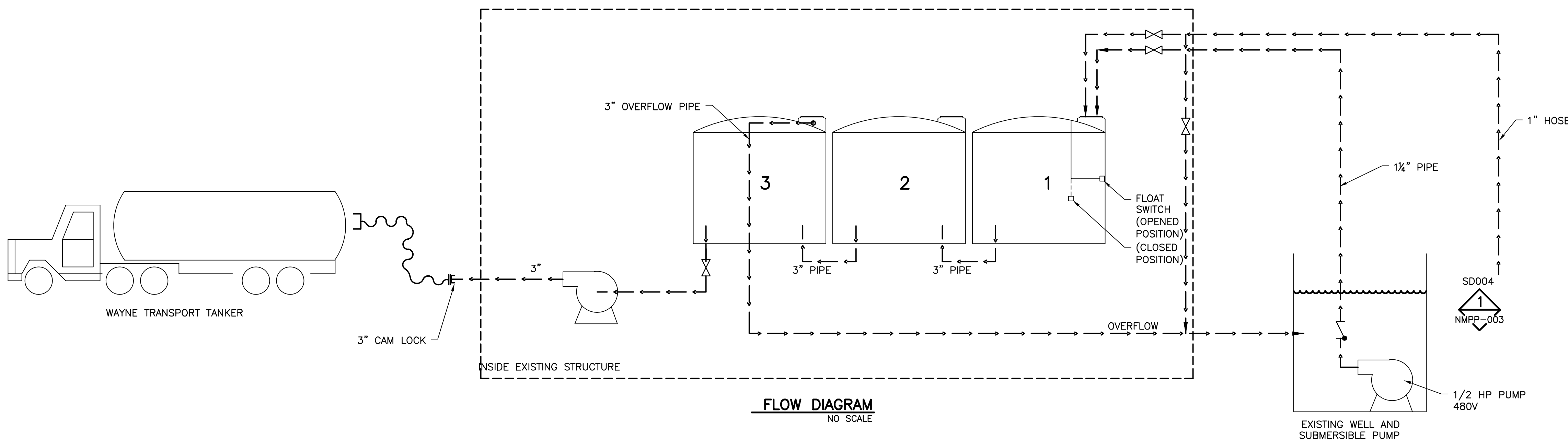


PROPOSED FLOOR PLAN

0 1 2 3 4 5 6
SCALE

NOTES:

1. VENT TANKS THROUGH TOP ACCESSWAY OR PROVIDE VENT IN TANK TOP.
2. REFER TO SHEET NMPP-004 FOR FLOOR REINFORCEMENT TO SUPPORT TANKS.
3. LEVEL CONTROL FLOAT TO BE INSTALLED IN TANK 3.
4. SEE ELECTRICAL SCHEMATIC NMPP-005 FOR POWER AND CONTROL REQUIREMENTS.
5. 3" PIPING – SCHEDULE 40 PVC OR EQUAL.



FLOW DIAGRAM
NO SCALE

POLYMET DRAWING REVIEW
☒ APPROVED
☐ APPROVED AS NOTED
☐ REVISE AND RESUBMIT
BY: PAUL BRUNFELT DATE:4/13/2012

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ISSUED	REV	DATE	SDE	PEM
PRELIMINARY	A	4/3/12	–	–
APPROVED FOR CONSTRUCTION	0	4/13/12	–	–

NOT APPROVED FOR CONSTRUCTION UNLESS SIGNED AND DATED. DESTROY ALL PRINTS BEARING EARLIER DATE AND/OR REV.NO.

I HEREBY CERTIFY THAT THIS PLAN, SPECIFICATION, OR REPORT WAS PREPARED BY ME OR UNDER MY DIRECT SUPERVISION AND THAT I AM A DULY LICENSED PROFESSIONAL ENGINEER UNDER THE LAWS OF THE STATE OF MINNESOTA.

SIGNATURE ____________
PRINTED NAME ____________
DATE ______ REG. NO. ______

DRAWN: KRM	DATE: 3/15/12
CHECKED: –	DATE: –
BARR PROJECT NO.: 23/69-1302	
SCALE: AS SHOWN	

PLANT DRAWING NUMBER:

TAILING BASIN
PILOT PLANT ON SITE STORAGE
GENERAL ARRANGEMENTS

POLYMET MINING CORPORATION
NORTHMET PROJECT
HOYT LAKES, MINNESOTA

BARR ENGINEERING COMPANY
3128 14TH AVENUE EAST
HIBBING, MN
55746
Ph: 1-800-225-1966
Fax: (218) 262-3460
www.barr.com

DWG. NO. NMPP-001 REV 0

CADD USER: Adeptuser FILE: \\ADEPTXPHIB\HIBBING PW IN\565439ED-135B-4E7D-B3C2-447D10DAB133\41C6324F-456C-43E7-8959-4737DF600891\23691302_NMPP001.DWG PLOT SCALE: 1:2 PLOT DATE: 4/13/2012 3:26 PM

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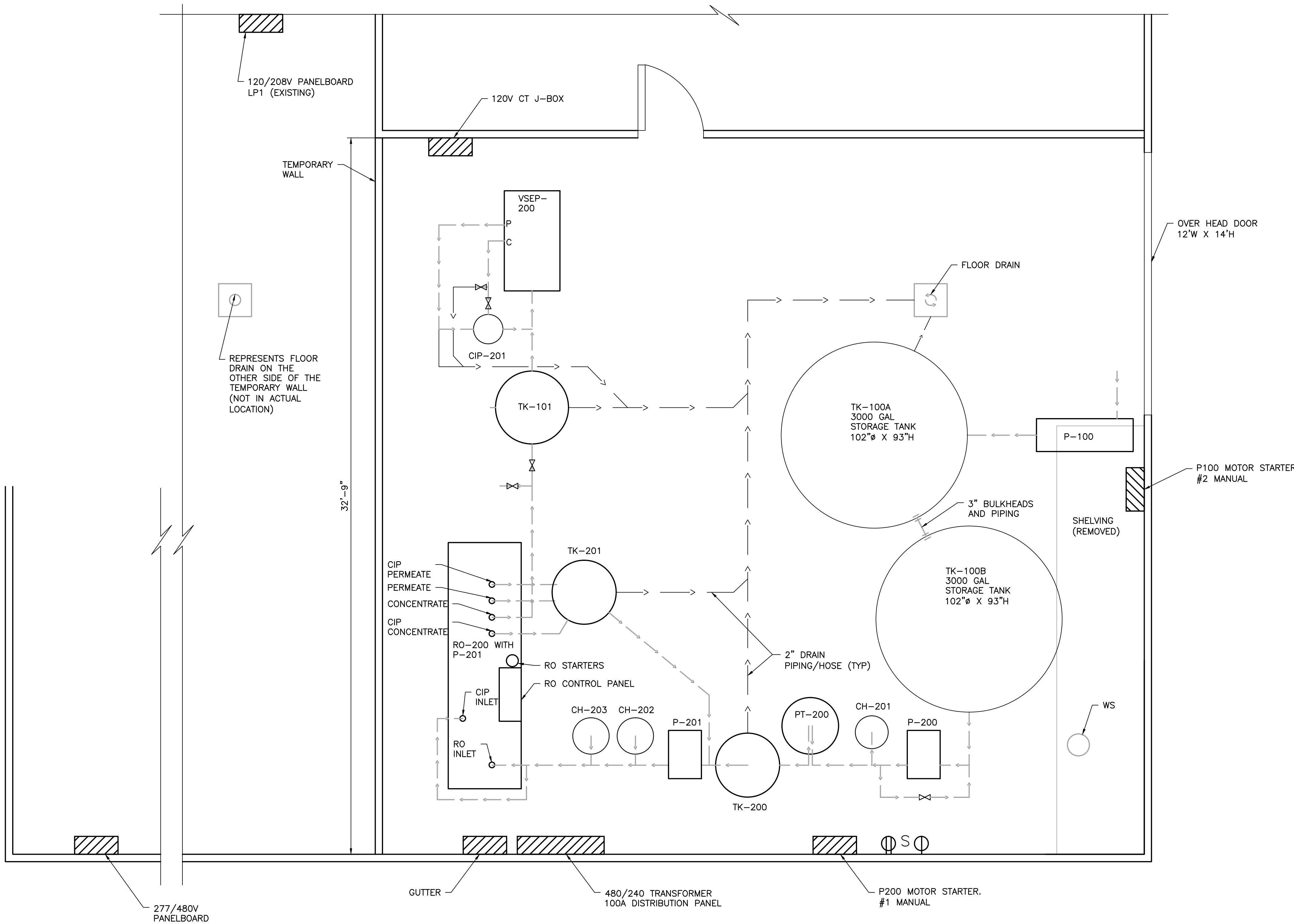

LEGEND:
P – PIPING
TK – TANK
CH – CHEMICAL FEED
PT – PRETREATMENT
RO – RO PILOT SKID
CIP – CIP TANK
VSED – VSED PILOT SKID

NOTES:
1. SEE G.E. DRAWINGS FOR PIPING SIZES.
2. "100" ITEMS BY POLYMET. "200" ITEMS BY G.E./OTHERS.

PROPOSED FLOOR PLAN

0 1 2 3 4 5 6
SCALE

N

POLYMET DRAWING REVIEW
☒ APPROVED
☐ APPROVED AS NOTED
☐ REVISE AND RESUBMIT
BY: PAUL BRUNFELT DATE: 4/13/2012

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APPROVED FOR CONSTRUCTION	0	4/13/12	–	–
NOT APPROVED FOR CONSTRUCTION UNLESS SIGNED AND DATED. DESTROY ALL PRINTS BEARING EARLIER DATE AND/OR REV.NO.				

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SIGNATURE ____________
PRINTED NAME ____________
DATE ________ REG. NO. ________

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CHECKED: –	DATE: –
BARR PROJECT NO.: 23/69-1302	
SCALE: AS SHOWN	

PLANT DRAWING NUMBER:

WAYNE SITE
WASTE WATER TREATMENT PILOT PLANT
GENERAL ARRANGEMENTS

POLYMET MINING

POLYMET MINING CORPORATION
NORTHMET PROJECT
HOYT LAKES, MINNESOTA

BARR

BARR ENGINEERING COMPANY
3128 14TH AVENUE EAST
HIBBING, MN.
55746
Ph: 1-800-225-1966
Fax: (218) 262-3460
www.barr.com

DWG. NO. NMPP-002 REV 0

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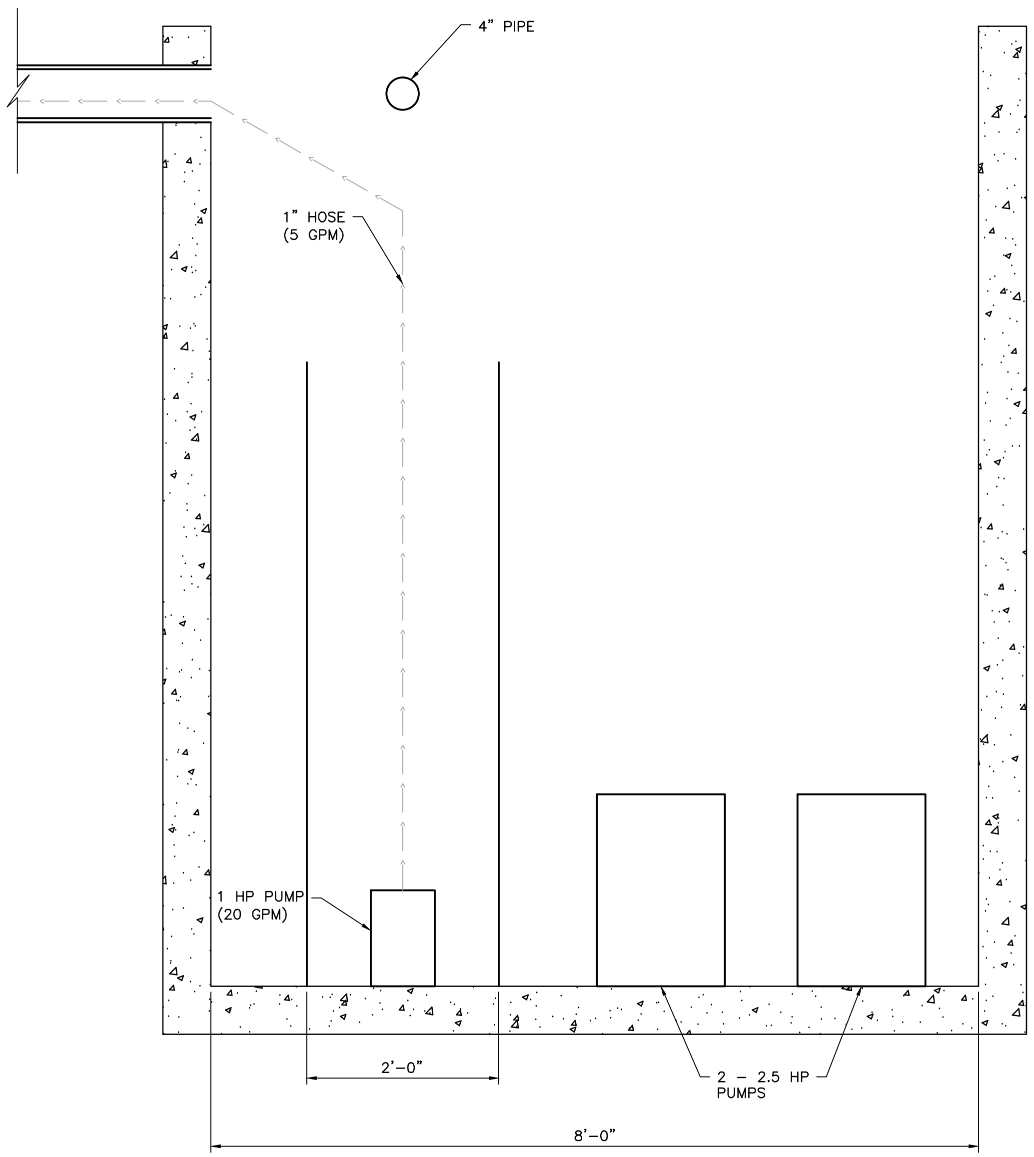

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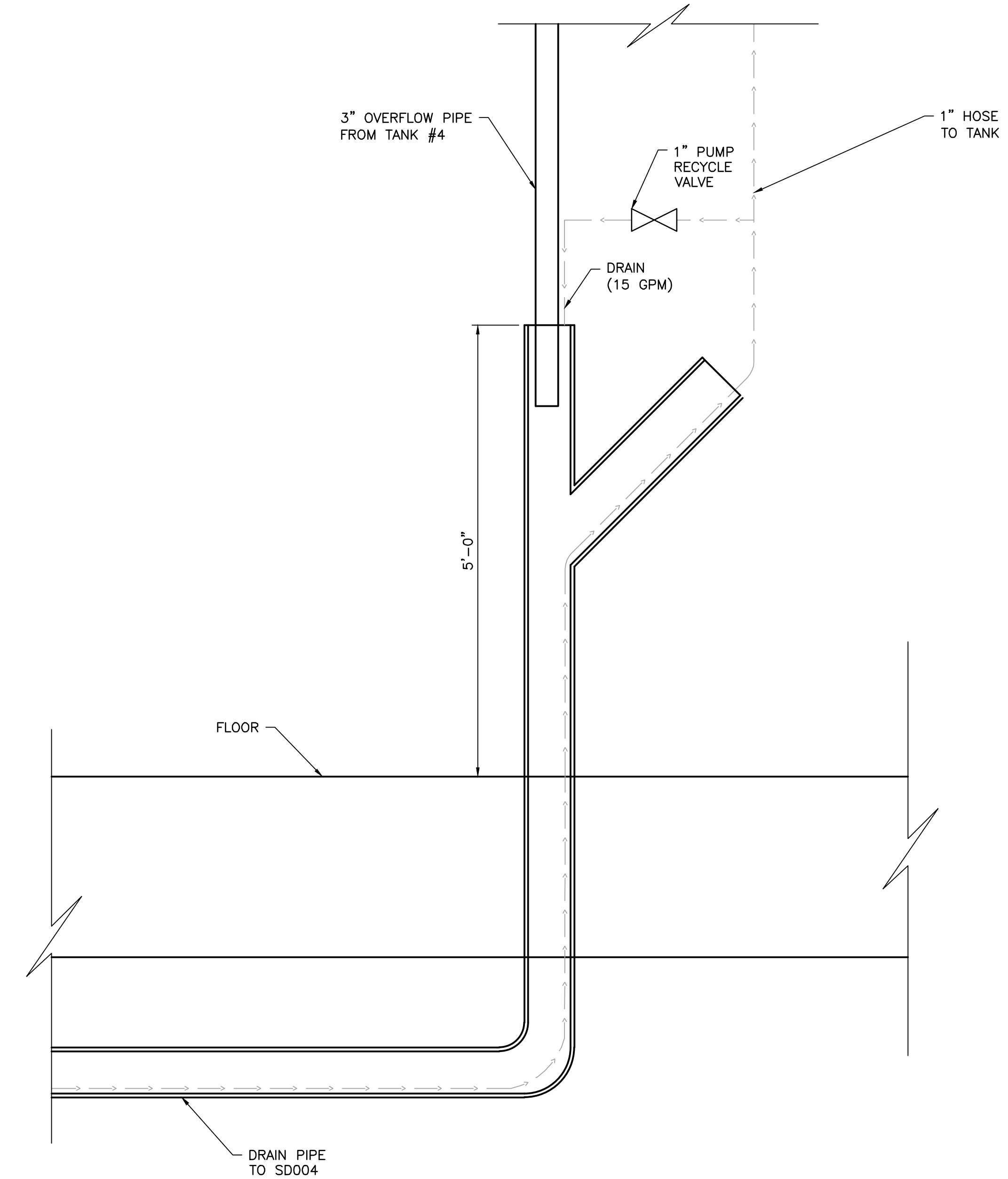

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☒ APPROVED	
☐ APPROVED AS NOTED	
☐ REVISE AND RESUBMIT	
BY: PAUL BRUNFELT	DATE: 4/13/2012

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NOT APPROVED FOR CONSTRUCTION UNLESS SIGNED AND DATED. DESTROY ALL PRINTS BEARING EARLIER DATE AND/OR REV.NO.

I HEREBY CERTIFY THAT THIS PLAN, SPECIFICATION, OR REPORT WAS PREPARED BY ME OR UNDER MY DIRECT SUPERVISION AND THAT I AM A DULY LICENSED PROFESSIONAL ENGINEER UNDER THE LAWS OF THE STATE OF MINNESOTA.

SIGNATURE ______

PRINTED NAME ______

DATE ______ REG. NO. ______

DRAWN: KRM	DATE: 3/27/12
CHECKED: –	DATE: –
BARR PROJECT NO.: 23/69-1302	
SCALE: AS SHOWN	

PLANT DRAWING NUMBER:

TAILINGS BASIN
PILOT PLANT ON SITE STORAGE
DETAILS

POLYMET MINING

POLYMET MINING CORPORATION
NORTHMET PROJECT
HOYT LAKES, MINNESOTA

BARR

BARR ENGINEERING COMPANY
3128 14TH AVENUE EAST
HIBBING, MN.
55746
Ph: 1-800-225-1966
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DWG. NO. NMPP-003 REV 0

CADD USER: Adeptuser FILE: \\ADEPTXPHIB\HIBBING PW IN\565439ED-135B-4E7D-B3C2-447010DAB133\3E3A7642-7EBD-4708-B3F8-DB068AD2BE9\23691302_NMPP003.DWG PLOT SCALE: 1:2 PLOT DATE: 4/13/2012 3:26 PM

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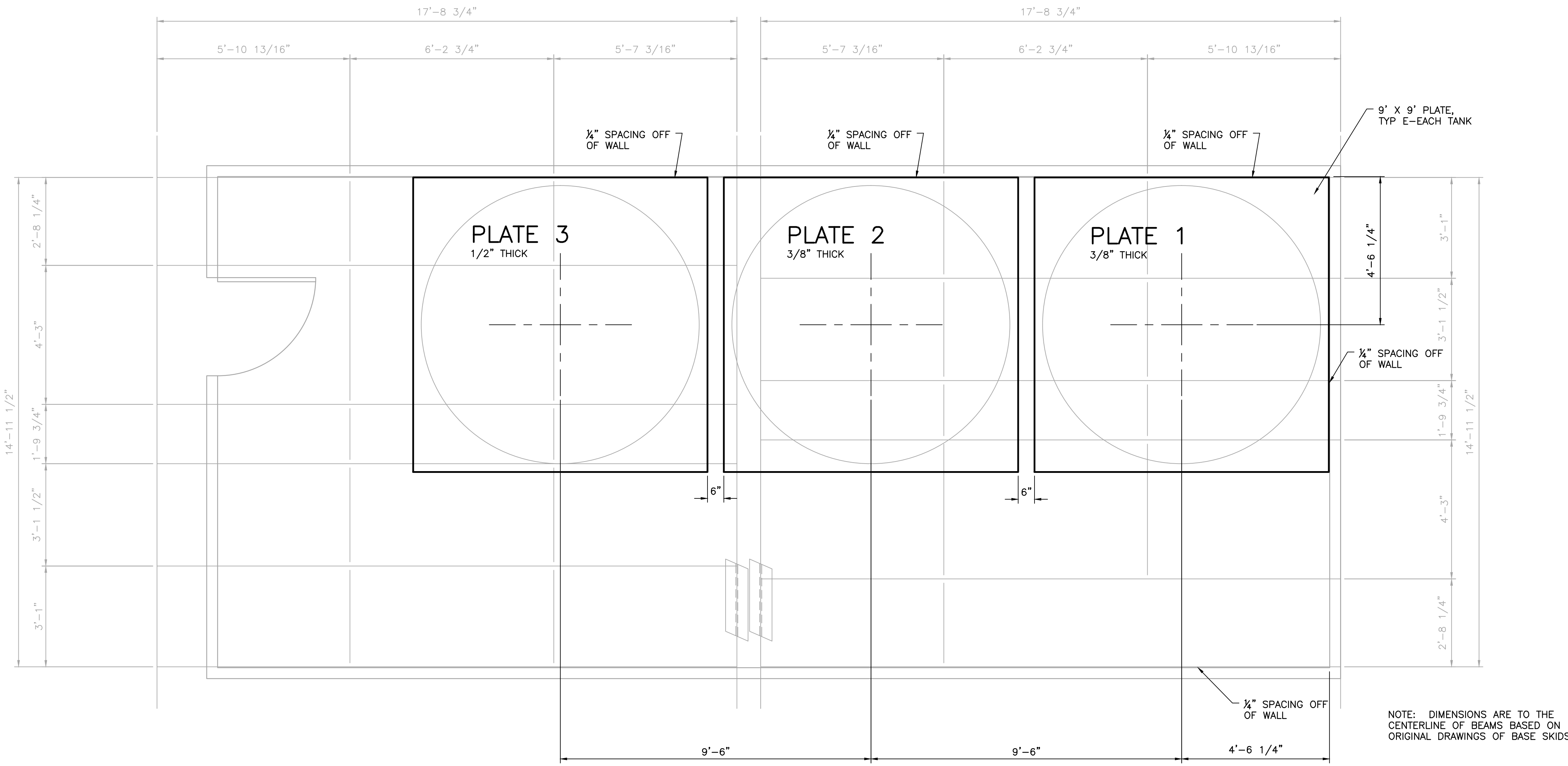

NOTE: DIMENSIONS ARE TO THE CENTERLINE OF BEAMS BASED ON ORIGINAL DRAWINGS OF BASE SKIDS

FLOOR DETAIL AT TAILINGS BASIN SITE

0 1 2 3 4 5
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POLYMET DRAWING REVIEW

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- ☐ APPROVED AS NOTED
- ☐ REVISE AND RESUBMIT

BY: PAUL BRUNFELT DATE: 4/13/2012

REV NO	DATE	REVISIONS	BY	CHKR
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CHECKED: –	DATE: –
BARR PROJECT NO.: 23/69-1302	
SCALE: AS SHOWN	

PLANT DRAWING NUMBER:

TAILINGS BASIN PILOT PLANT ON SITE STORAGE TANK REINFORCEMENT

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NORTHMET PROJECT
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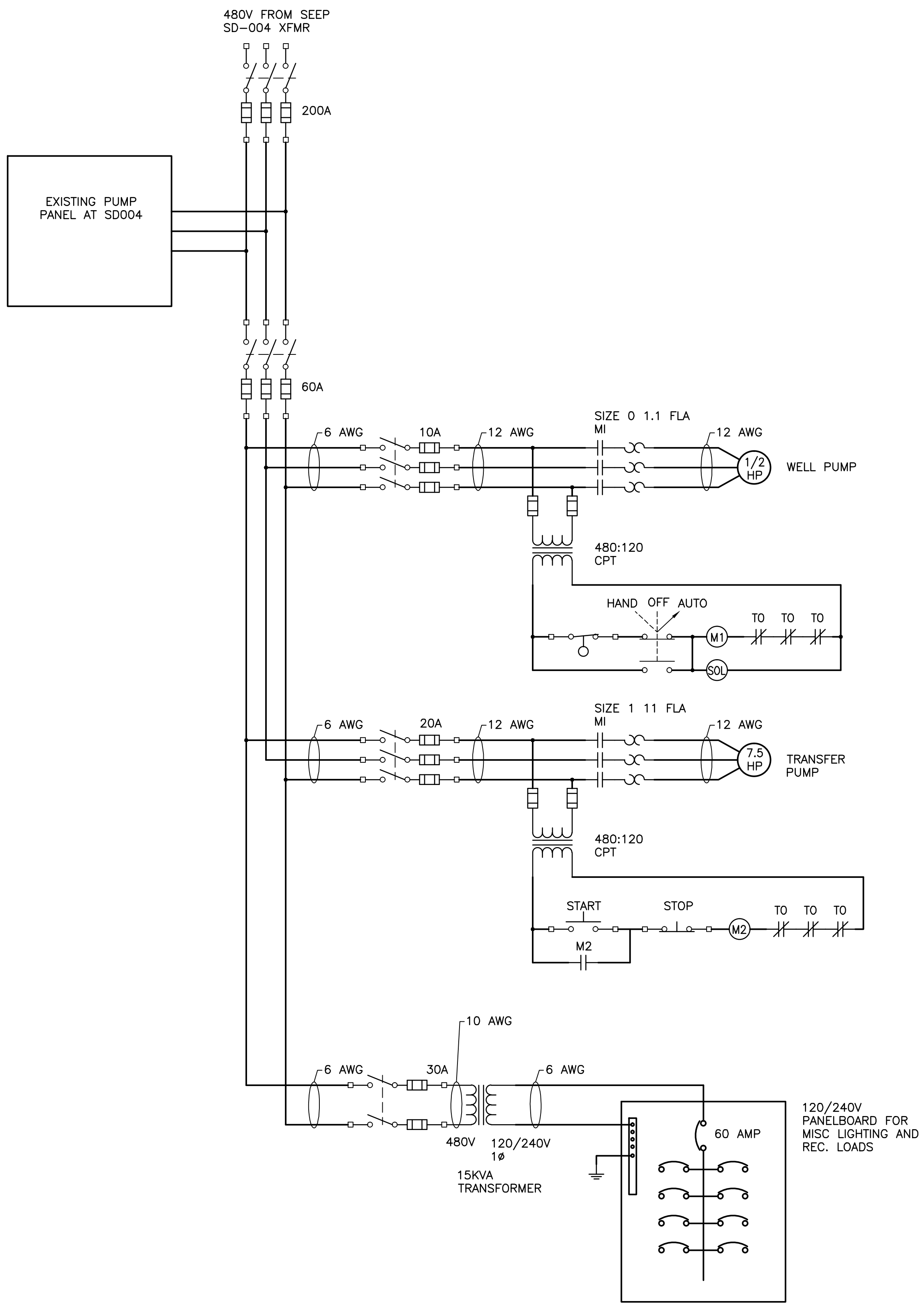

POLYMET DRAWING REVIEW

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- [ ] APPROVED AS NOTED
- [ ] REVISE AND RESUBMIT

BY: PAUL BRUNFELT DATE: 4/13/2012

REV NO	DATE	REVISIONS	BY	CHKR
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SCALE: AS SHOWN

PLANT DRAWING NUMBER:

TAILINGS BASIN
PILOT PLANT ON SITE STORAGE
ELECTRICAL SCHEMATIC

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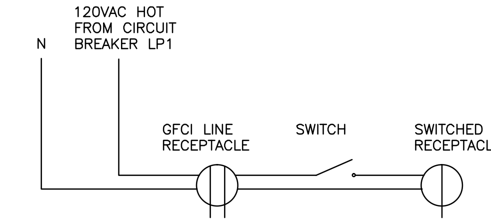

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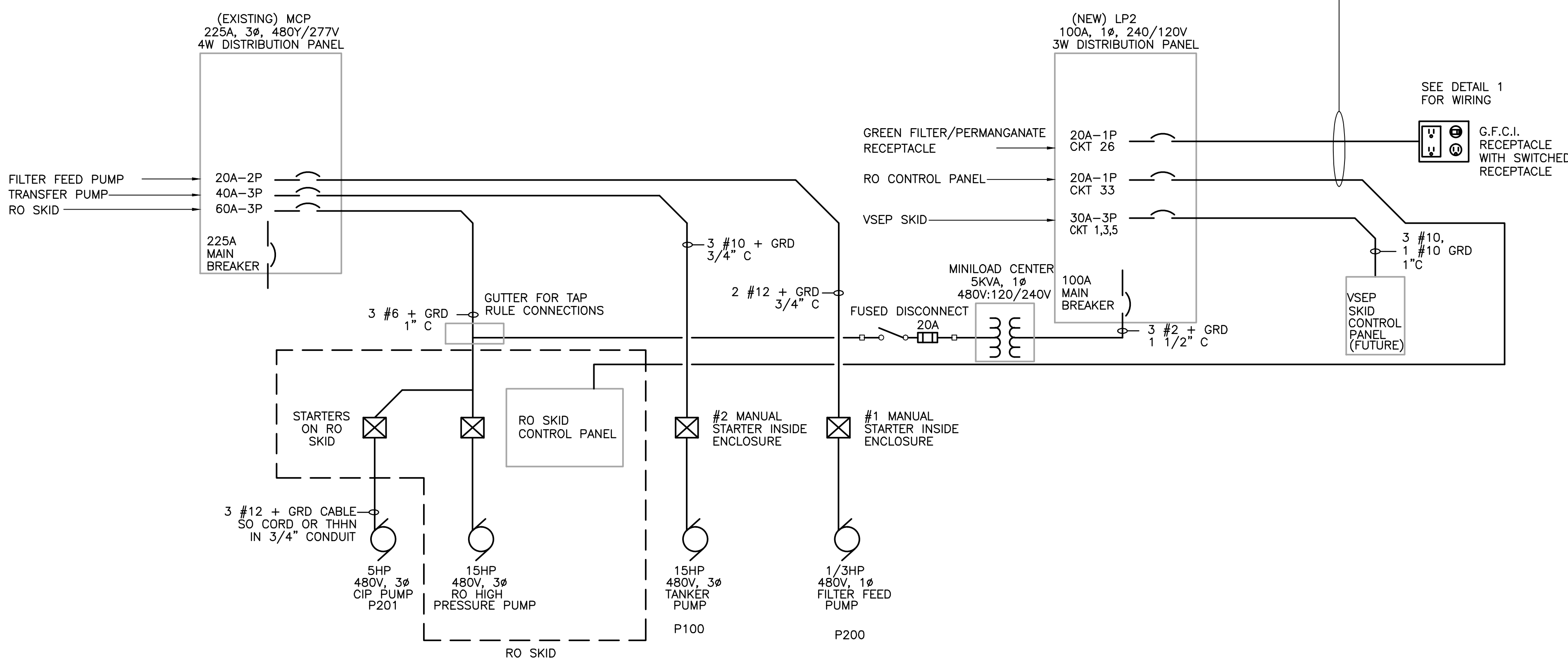

ELECTRICAL SYSTEM DIAGRAM
NO SCALE

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☐ APPROVED AS NOTED	
☐ REVISE AND RESUBMIT	
BY: PAUL BRUNFELT	DATE: 4/13/2012

REV NO	DATE	REVISIONS	BY	CHKR
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BARR PROJECT NO.: 23/69-1302	
SCALE: AS SHOWN	

PLANT DRAWING NUMBER:

WAYNE SITE
WASTE WATER TREATMENT PILOT PLANT
ELECTRICAL SYSTEM DIAGRAM

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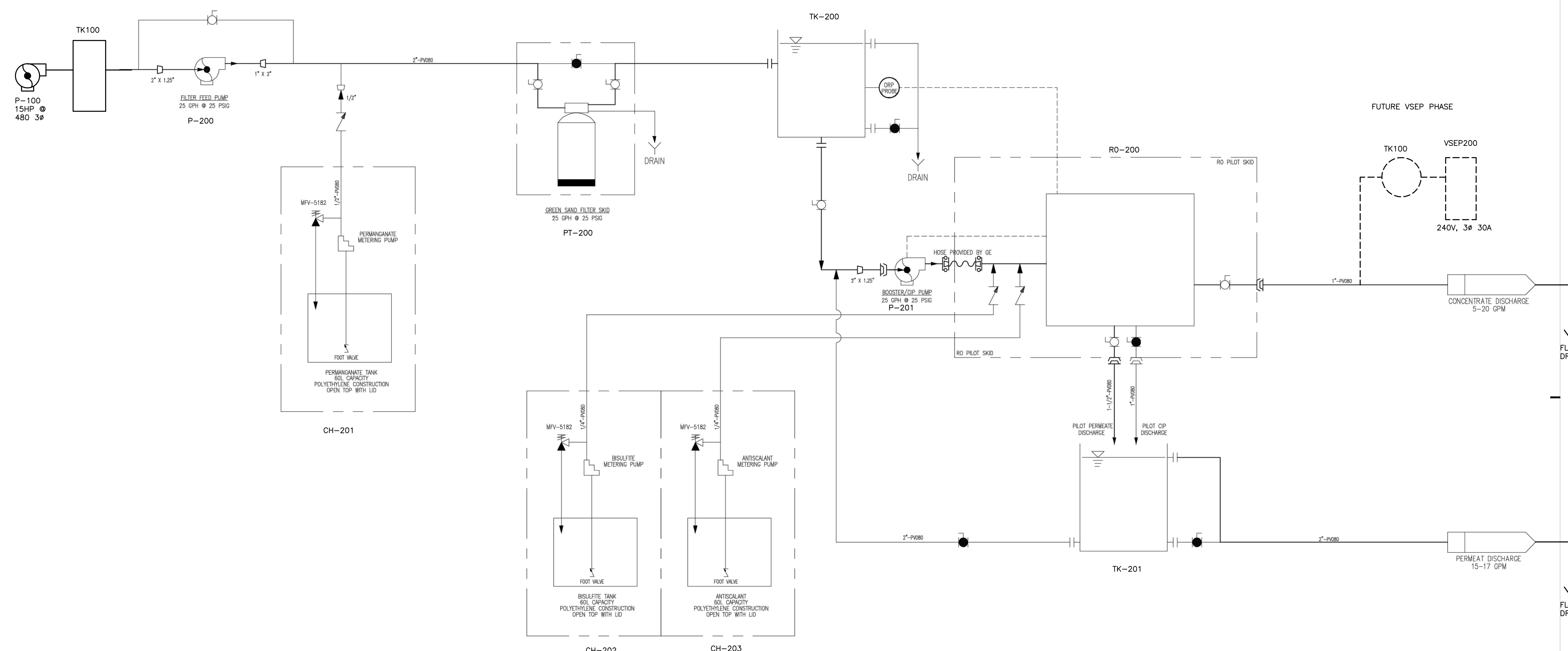

FEED PUMP	PERMANGANTE PUMP	MEDIA FILTER	BISULFITE PUMP	ANTISCALANT PUMP	RO CONTROLS EQUIPMENT	RO PILOT PUMPS CONNECTION
208/440V / 4.25/1.95A / 1Ph / 60Hz	115V / 1A / 1Ph / 60Hz	115V / 15A / 1Ph / 60Hz	115V / 1A / 1Ph / 60Hz CAN BE PLUGGED INTO RO PILOT OR SEPARATE SUPPLY	115V / 1A / 1Ph / 60Hz CAN BE PLUGGED INTO RO PILOT OR SEPARATE SUPPLY	115V / 15A / 1Ph / 60Hz	460V / 60A / 3Ph / 60 Hz

POLYMET DRAWING REVIEW

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- ☐ APPROVED AS NOTED
- ☐ REVISE AND RESUBMIT

BY: PAUL BRUNFELT DATE: 4/13/2012

REV NO	DATE	REVISIONS	BY	CHKR
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BARR PROJECT NO.: 23/69-1302	
SCALE: AS SHOWN	

PLANT DRAWING NUMBER:

WAYNE SITE
WASTE WATER TREATMENT PLAN
PIPING AND INSTRUMENT DIAGRAM

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NORTHMET PROJECT
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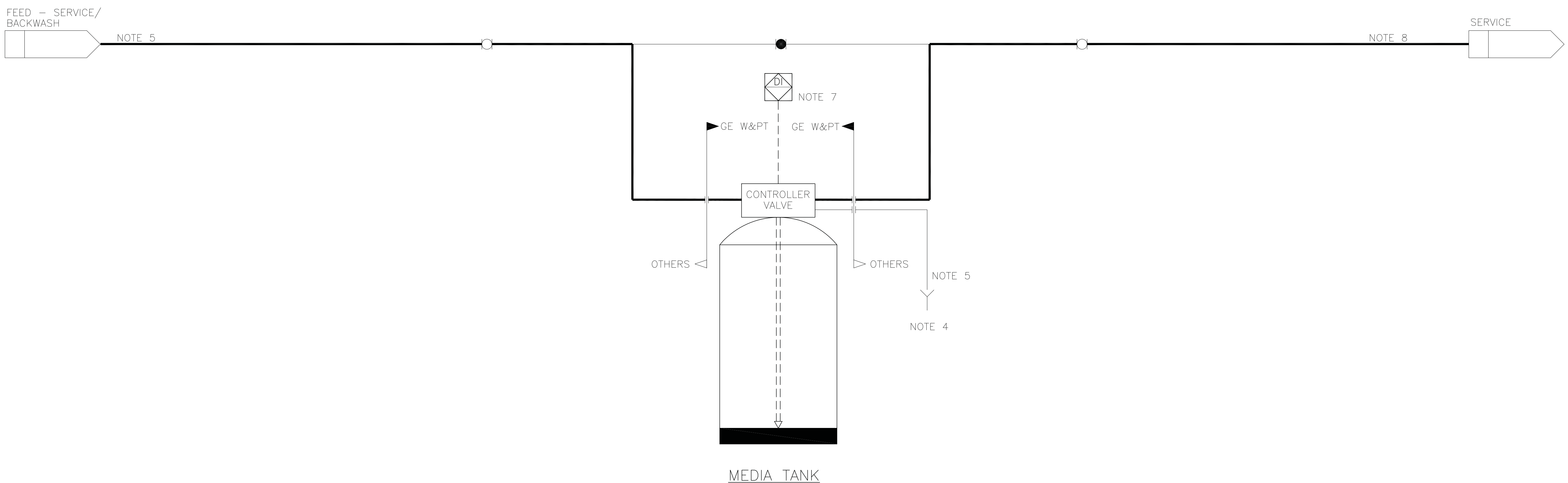
INCHES 1 2

Appendix C

GE Greensand Filter and Reverse Osmosis Pilot Unit Information



SYSTEM INFORMATION (EACH)				
TANK SIZE (IN.);	SERVICE (GPM): NOTE 5	BACKWASH(GPM): NOTE 5	INLET/OUTLET CONNECTIONS SIZE (IN):	DRAIN CONNECTION SIZE (IN):
10	1.5–5	6	1.0 SPG	0.75 MPT
14	3–9	10	1.0 SPG	0.75 MPT
21	6–18	25	2.0 SPG	1.5 SPG
30	15–45	50	2.0 SPG	2.0 MPT
36	20–60	75	2.0 SPG	2.5 MPT

NOTE:

1. MANUAL VALVES AND PIPING IN CUSTOMER SCOPE OF SUPPLY.
2. WATER PRESSURE 25 PSI MINIMUM AND 125 PSI MAXIMUM.
3. A 120 VOLT ELECTRICAL OUTLET SHOULD BE PROVIDED WITHIN 10 FEET OF EQUIPMENT.
4. REFER TO INSTALLATION MANUAL FOR INSTALLATION INSTRUCTION. TO MEET SANITARY REQUIREMENTS, THE DRAIN LINE MUST BE PIPED TO AN OPEN DRAIN WHERE FLOW (DURING REGENERATION) CAN BE OBSERVED AND AN AIR GAP CAN BE MAINTAINED IN ACCORDANCE WITH LOCAL PLUMBING CODES.
5. FEED LINE AND DRAIN LINE SHALL BE SIZED FOR BACKWASH FLOW.
6. MEDIA SHIPPED LOOSE AND LOADED ON SITE BY CUSTOMER.
7. CONTROLLER IS PROVIDED WITH SWITCH FOR EQUIPMENT LOCKOUT DURING REGENERATION.
8. NO AUTOMATIC UNFILTERED WATER BYPASS DURING REGENERATION
9. REFERENCE P&ID LEGEND PAGE: 1301227

REV	DESCRIPTION	ECO	DWN	APVD	DATE	CHKD
A	INITIAL RELEASE	13308	–	–	–	–

TOLERANCES UNLESS NOTED
DECIMALS ANGLES
.X ± ±
.XX ±
.XXX ±
FRAC ±

DRAWN BY GRK	DATE 28Jun07	
CHECKED BY RLD	DATE 21Sep07	
APPROVED BY PWG	DATE 21Sep07	
APPROVED BY	DATE	

GE
Water & Process Technologies
GLOBAL HEADQUARTERS : TREVOSE, PA USA +1-215-355-3300 WWW.GEWATER.COM

CLIENT/JOB

FILE

DWG DESCRIPTION
PIPING & INSTRUMENTATION DIAGRAM
CARBON, FRP, SINGLE

MATERIAL/BOM NO.

SIZE D
DRAWING NO. 1303222
REV A
PROJECT
SCALE NONE
SHEET 1 OF 1

P/N 1161662–RGP01

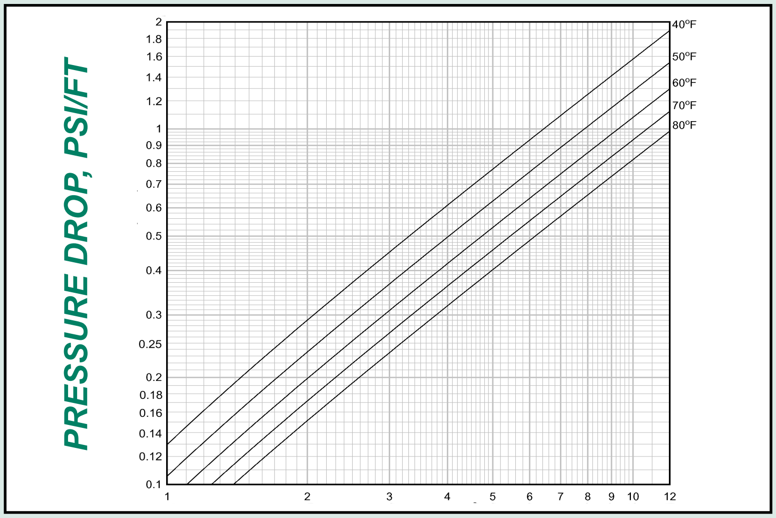
Inversand Company
SINCE 1925
226 Atlantic Avenue, P.O. 650 • Clayton, NJ 08312
Phone 856-881-2345 Fax 856-881-6859
Email: info@inversand.com • www.inversand.com

GREENSANDplus™

Performance Media for Water Filtration

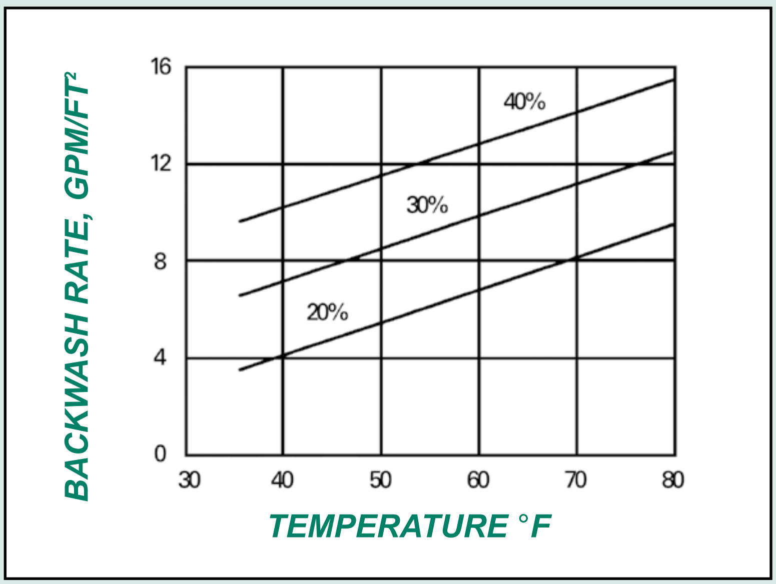
Removes iron, manganese, hydrogen sulfide, arsenic and radium.

GREENSANDPLUS PRESSURE DROP (CLEAN BED)



FLOW RATE (GPM/FT²)

BED EXPANSION DURING BACKWASHING



GreensandPlus™ is a black filter media used for removing soluble iron, manganese, hydrogen sulfide, arsenic and radium from groundwater supplies.

The manganese dioxide coated surface of GreensandPlus acts as a catalyst in the oxidation reduction reaction of iron and manganese.

The silica sand core of GreensandPlus allows it to withstand waters that are low in silica, TDS and hardness without breakdown.

GreensandPlus is effective at higher operating temperatures and higher differential pressures than standard manganese greensand. Tolerance to higher differential pressure can provide for longer run times between backwashes and a greater margin of safety.

Systems may be designed using either vertical or horizontal pressure filters, as well as gravity filters.

GreensandPlus is a proven technology for iron, manganese, hydrogen sulfide, arsenic and radium removal. Unlike other media, there is no need for extensive preconditioning of filter media or lengthy startup periods during which required water quality may not be met.

GreensandPlus is an exact replacement for manganese greensand. It can be used in CO or IR applications and requires no changes in backwash rate or times or chemical feeds.

GreensandPlus has the WQA Gold Seal Certification for compliance with NSF/ANSI 61. Packaging is available in 1/2 cubic foot bags or 1 metric ton (2,205 lbs) bulk sacks.

PHYSICAL CHARACTERISTICS

Physical Form
Black, nodular granules shipped in a dry form

Apparent Density
88 pounds per cubic foot net (1410.26 kg/m3)

Shipping Weight
90 pounds per cubic foot gross (1442.31 kg/m3)

Specific Gravity
Approximately 2.4

Porosity
Approximately 0.45

Screen Grading (dry)
18 X 60 mesh

Effective Size
0.30 to 0.35 mm

Uniformity Coefficient
Less than 1.60

pH Range
6.2-8.5 (see General Notes)

Maximum Temperature
No limit

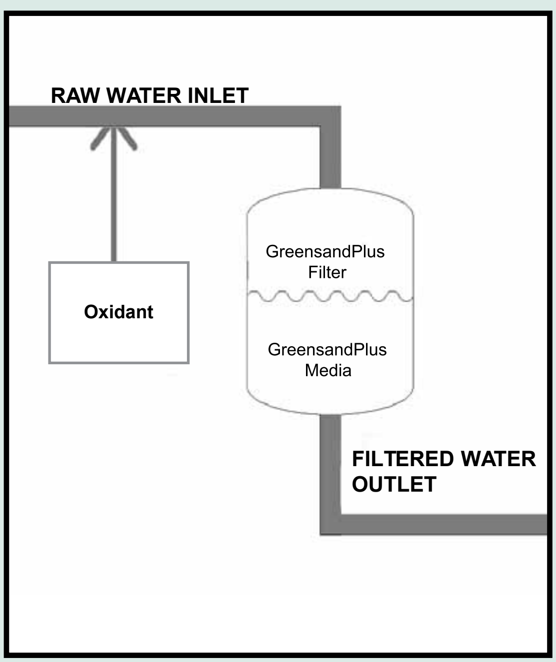
Backwash Rate
Minimum 12 gpm/sq. ft. at 55ºF
(29.4 m/hr @ 12.78*C) (see expansion chart)

Service Flow Rate
2 – 12 gpm/sq. ft. (4.9m/hr - 29.4 m/hr)

Minimum Bed Depth
15 inches (381 mm) of each media for dual media beds or 30 inches minimum (762 mm) of GreensandPlus alone.

METHOD OF OPERATION CO

GreensandPlus: Catalytic Oxidation (CO)



Catalytic Oxidation (CO) operation is recommended in applications where iron removal is the main objective in well waters with or without the presence of manganese. This method involves the feeding of a predetermined amount of chlorine (Cl_2) or other strong oxidant directly to the raw water before the GreensandPlus Filter.

Chlorine should be fed at least 10-20 seconds upstream of the filter, or as far upstream of the filter as possible to insure adequate contact time. A free chlorine residual carried through the filter will maintain GreensandPlus in a continuously regenerated condition.

For operation using chlorine, the demand can be estimated as follows:

mg/L Cl_2 = (1 x mg/L Fe) + (3 x mg/L Mn) + (6x mg/L H_2S) + (8 x mg/L NH_3)

SUGGESTED OPERATING CONDITIONS

Bed Type

Dual media; anthracite 15-18 in. (381 mm-457 mm) and GreensandPlus 15-24 in. (381 mm - 610 mm)

Capacity

700-1200 grains of oxidized iron and manganese/sq.ft. of bed area based on oxidant demand and operation to iron break through or dp limitations.

Backwash

Sufficient rate using treated water to produce 40% bed expansion until waste water is clear, or for 10 minutes, whichever occurs first.

Air/Water Scour

Optional using 0.8-2.0 cfm/sq. ft. (15 m/hr -37 m/hr) with a simultaneous treated water backwash at 4.0-4.5 gpm/sq. ft. (9.8 m/hr - 11.03 m/hr)

Raw Water Rinse

At normal service flow rate for 3 minutes or until effluent is acceptable.

Flow Rate

Recommended flow rates with CO operation are 2-12 gpm/sq. ft. (4.9 m/hr - 29.4 m/hr). High concentrations of iron and manganese usually require lower flow rates for equivalent run lengths. Higher flow rates can be considered with low concentrations of iron and manganese. For optimizing design parameters, pilot plant testing is recommended.The run length between backwashes can be estimated as follows:

What is the run length for a water containing 1.7 mg/L iron and 0.3 mg/L manganese at a 4 gpm/sq. ft. service rate:

Contaminant loading
= (1 x mg/L Fe) + (2 x mg/L Mn)
= (1 x 1.7) + (2 x 0.3)
= (2.3 mg/L or 2.3/17.1 = 0.13 grains/gal. (gpg)

At 1,200 grains / sq. ft. loading ÷ 0.13 gpg = 9,230 gal./sq. ft.

At 4 gpm / sq. ft. service rate 9,230/4 = 2,307 min.

The backwash frequency is approximately every 32-38 hours of actual operation.

The Intermittent regeneration (IR) operation is available for certain applications. Contact your Inversand representative for additional information.

GENERAL NOTES

pH

Raw waters having natural pH of 6.2 or above can be filtered through GreensandPlus without pH correction. Raw waters with a pH lower than 6.2 should be pH-corrected to 6.5-6.8 before filtration. Additional alkali should be added following the filters if a pH higher than 6.5-6.8 is desired in the treated water. This prevents the possible adverse reaction and formation of a colloidal precipitate that sometimes occurs with iron and alkali at a pH above 6.8.

Initial Conditioning of GreensandPlus

GreensandPlus media must be backwashed prior to adding the anthracite cap. The GreensandPlus backwash rate must be a minimum of 12 gpm/sq. ft. @ 55 °F.

This initial backwash could last for up to 60 minutes to thoroughly remove the fine dust. After backwashing is complete, the GreensandPlus must be conditioned. Mix 0.5 gal. (1.9 L) of 6% household bleach or

Initial Conditioning of GreensandPlus

0.2 gal (0.75 L) of 12% sodium hypochlorite for every 1 cu. ft. (28.3 L cu. m) of GreensandPlus into 6.5 gallons (25 L) of water.

Drain the filter enough to add the diluted chlorine mix. Apply the diluted chlorine to the filter being sure to allow the solution to contact the GreensandPlus media. Let soak for a minimum of 4 hours, then rinse to waste until the “free” chlorine residual is less than 0.2 mg/L. The GreensandPlus is now ready for service.

Radium and Arsenic Removal Using GreensandPlus

The GreensandPlus CO process has been found to be successful in removing radium and arsenic from well water. This occurs via adsorption onto the manganese and/or iron precipitates that are formed. For radium removal, soluble manganese must be present in or added to the raw water for removal to occur. Arsenic removal requires iron to be present in or added to the raw water to accomplish removal. Pilot plant testing is recommended in either case.

REFERENCES

USA

American Water Company, CA
San Jacinto, CA
City of Tallahassee, FL
Adedge Technologies, Inc., Buford, GA
City of Mason City, IL
City of Goshen, IN
City of Hutchinson, KS
City of Burlington, MA
Dedham Water Co., MA
Raynham Center, MA
Northbrook Farms, MD
Sykesville, MD
Tonka Equipment Company, Plymouth, MN
City of New Bern, NC
Onslow County, NC
Hungerford & Terry, Inc., Clayton, NJ
Fort Dix, NJ
Jackson Twsp. MUA, NJ

USA

Churchill County, NV
Suffolk County Water Authority, NY
City of Urbana, OH
Roberts Filter Group, Darby, PA

International

Watergroup, Saskatoon, SK Canada
BI Pure Water, Surrey, BC Canada
Sydney, Nova Scotia, Canada
PT Besflo Prima, Jakarta, Indonesia
Eurotrol, Milanese, Italy
Gargon Industrial, Mexico City, Mexico
Filtration Tech, Auckland, New Zealand
Alamo Water Poland, Izabelin, Poland
Aquatrol Company, Moscow, Russia
Impulse Group, St. Petersburg, Russia
Brenntag Nordic, Taby, Sweden
Nema Kimya, Istanbul, Turkey
Minh Tam, Ho Chi Minh City, Vietnam

The manufacturing of GreensandPlus is an ongoing, 24/7 process to ensure the highest quality water treatment media.

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C USA

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E:info@inversand.com •**www.inversand.com**

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AK LE Series

High Flow Low Energy Brackish Water RO Elements

The A-Series family of proprietary thin-film reverse osmosis membrane is characterized by high flux and high sodium chloride rejection. AK LE brackish water elements are selected when high rejection, high flow and ultra-low operating pressures are desired.

The AK LE element is a low energy high flow element for beverage, light commercial, residential and general industrial applications. AK LE Series elements feature a Fiberglass outer wrap.

Table 1: Element Specification

Membrane	Thin-film membrane (TFM*)

Model	Average permeate flow gpd (m3/day)[1,2]	Average NaCl rejection[1,2]	Minimum NaCl rejection[1,2]
AK-90 LE	2800 (10.6)	99.3%	99.0%
AK-400 LE	12300 (46.6)	99.3%	99.0%
AK-440 LE	13500 (51.1)	99.3%	99.0%

[1] Average salt rejection after 24 hours operation. Individual flow rate may vary +25%/-15%.
[2] Testing conditions: 500ppm NaCl solution at 115psi (793kPa) operating pressure, 77°F (25°C), pH7 and 15% recovery.

Model	Active area ft² (m²)	Outer wrap	Part number
AK-90 LE	90 (8.4)	Fiberglass	3056683
AK-400 LE	400 (37.2)	Fiberglass	3056684
AK-440 LE	440 (40.9)	Fiberglass	3056685

Table 2: Operating and CIP parameters

Typical Operating Pressure	110 psi (758 kPa)
Typical Operating Flux	10-20GFD (15-35LMH)
Maximum Operating Pressure	400 psi (2,758 kPa)
Maximum Temperature	Continuous operation: 122°F (50°C) Clean-In-Place (CIP): 122°F (50°C)
pH range	Optimum rejection: 7.0-7.5, Continuous operation 4.0-11.0, Clean-In-Place (CIP): 2.0-11.5
Maximum Pressure Drop	Over an element: 12 psi (83 kPa) Per housing: 50 psi (345 kPa)
Chlorine Tolerance	1,000+ ppm-hours, dechlorination recommended
Feedwater[3]	NTU < 1 SDI < 5

[3] SDI is measured on a non-linear scale using a 0.45 micron filter paper. Additionally, finer colloids, particulates and microorganisms that pass through the filter paper and not measured in the SDI test, will potentially foul the RO element. For performance consistency and project warranty, please use Winflows projection software and consult your Filters with Membranes representative.

Figure 1a: Element Dimensions Diagram – Male

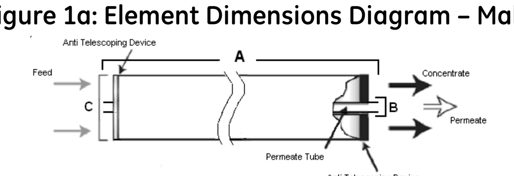


Figure 1b: Element Dimensions Diagram – Female

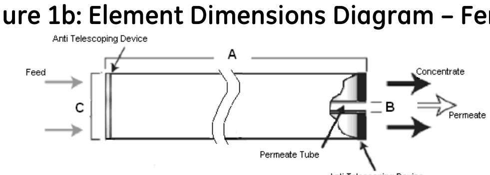
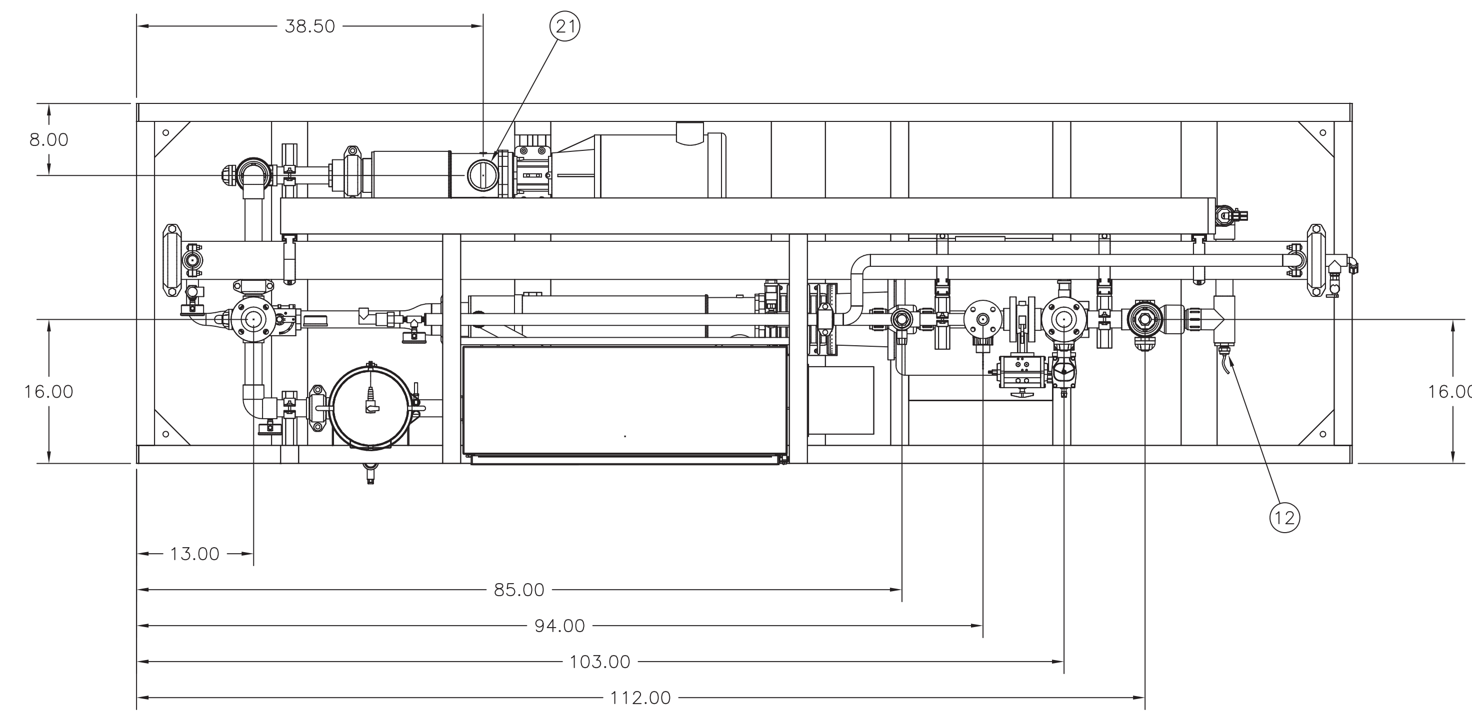
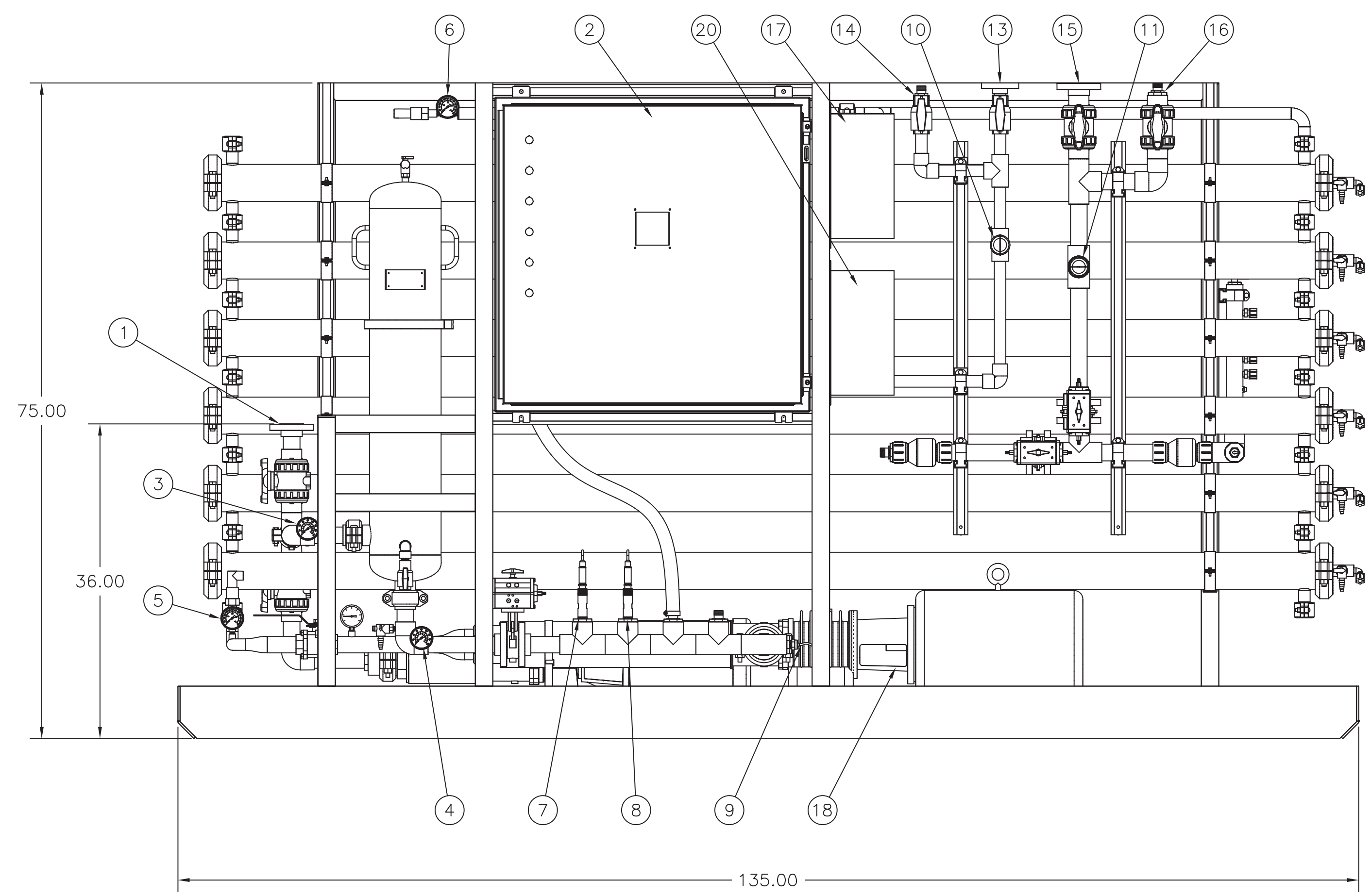


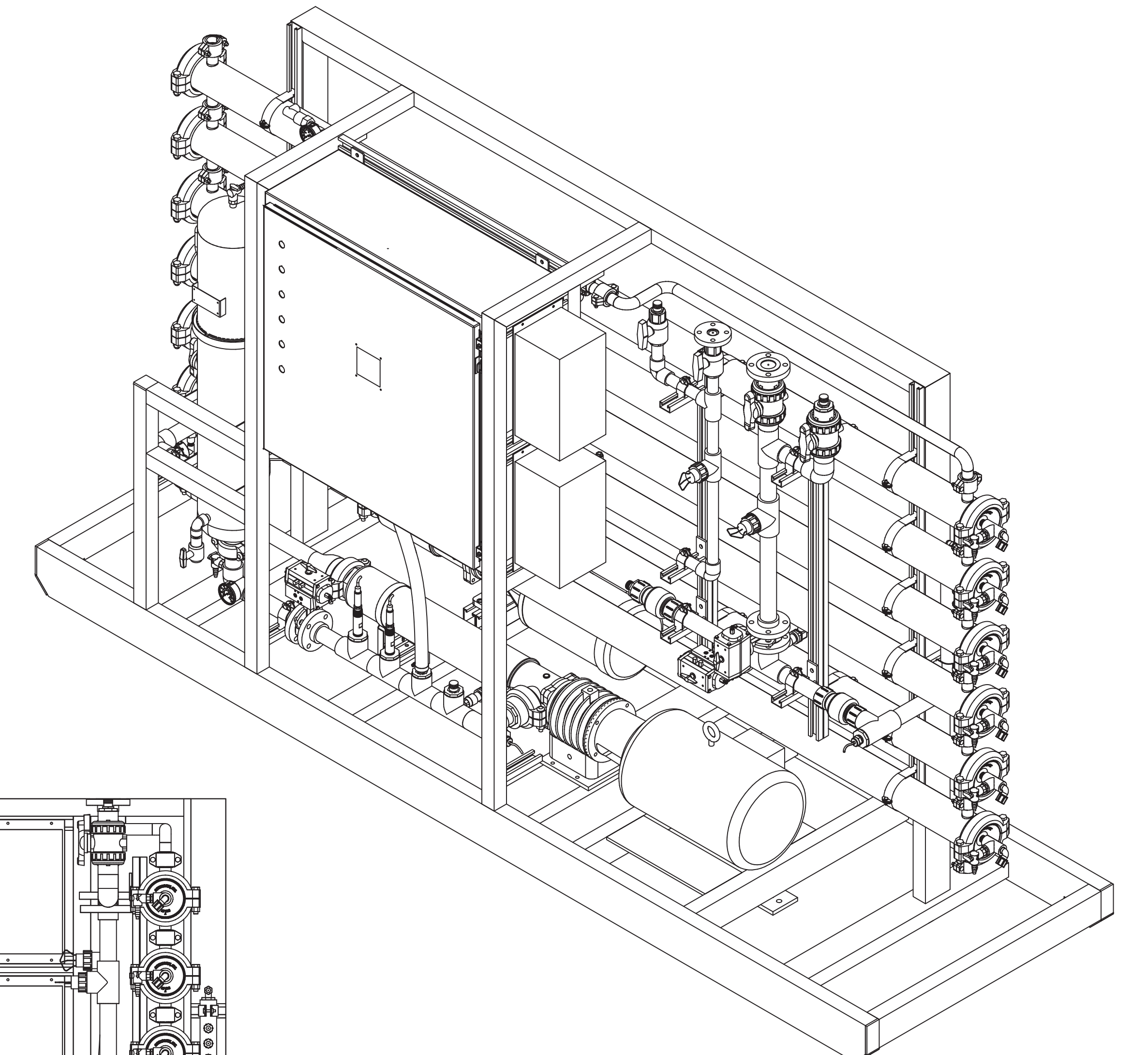
Table 3: Dimensions and Weights

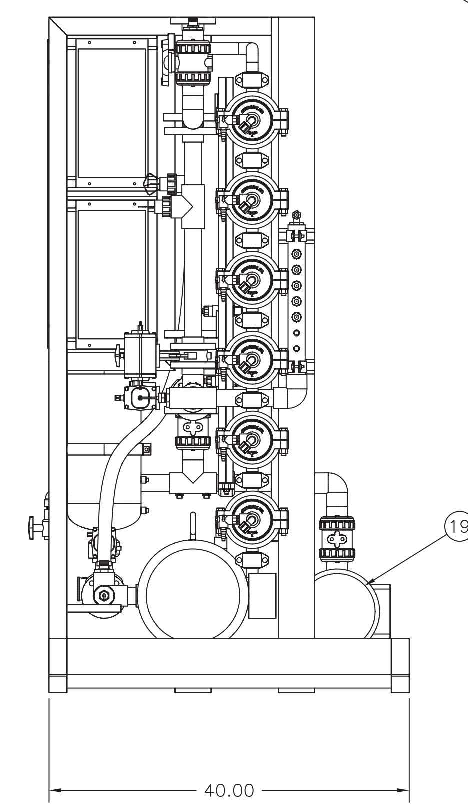
Model[1]	Type	Dimensions, inches (cm)			Boxed Weight lbs (kg)
		A	B[2]	C	
AK-90 LE	Male	40.0 (101.6)	0.75 (1.90)	3.9 (9.9)	9 (4)
AK-400 LE	Female	40.0 (101.6)	1.125 (2.86)	7.9 (20.1)	35 (16)
AK-440 LE	Female	40.0 (101.6)	1.125 (2.86)	7.9 (20.1)	35 (16)

REVISION HISTORY						
REV	ZONE	DESCRIPTION	ECO	DWN	DATE	APVD
A	–	INITIAL RELEASE	–	–	–	–









LEGEND

1. INLET, 1.50" FLANGE
2. ELECTRICAL ASSEMBLY
3. PRE–FILTER PRESSURE GAUGE, 1–160 PSIG
4. POST–FILTER PRESSURE GAUGE, 1–160 PSIG
5. PRIMARY PRESSURE GAUGE/TRANSMITTER, 1–600 PSIG
6. FINAL PRESSURE GAUGE/TRANSMITTER, 1–600 PSIG
7. INLET ORP, THORNTON 770MAX
8. INLET pH, THORNTON 770MAX
9. INLET CONDUCTIVITY, THORNTON 770MAX
10. CONCENTRATE FLOWMETER, THORNTON 770MAX
11. PERMEATE FLOWMETER, THORNTON 770MAX
12. PERMEATE CONDUCTIVITY, THORNTON 770MAX
13. CONCENTRATE OUTLET, 1.00" FLANGE
14. CONCENTRATE OUTLET CIP, 1.00" HOSEBARB
15. PERMEATE OUTLET, 1.50" FLANGE
16. PERMEATE OUTLET CIP, 1.00" HOSEBARB
17. RO MOTOR STARTER ASSEMBLY
18. RO PUMP AND MOTOR, SS5512KZA W/ 15 HP, TEFC
19. CIP PUMP AND MOTOR, SS5503G W/ 5 HP, TEFC
20. CIP MOTOR STARTER ASSEMBLY
21. CIP INLET, 3.00" VICTAULIC

GE Osmonics
GE Water Technologies
5951 CLEARWATER DRIVE, MINNETONKA, MN 55343–8995 (952) 933–2277
WWW.GEWATER.COM

MATERIAL SEE BOM	TOLERANCES UNLESS NOTED FRAC ± DECIMALS .X ± .XX ± .50 .XXX ± ANGLES ± 1°		TITLE	DWG, RO, PES–18 PALL PILOT SYSTEM
FINISH				
ORDER NO.	DWN PDT	DATE 18Jan05		
CUSTOMER	CHKD BRB	DATE 19Jan05	SIZE D, THIRD ANGLE	DWG NO/PN 2300026A–951 — REV A
CUSTOMER LOC.	APVD JSS	DATE 17Jan05		
DO NOT SCALE	APVD	DATE	SCALE 3/32	FILE TYPE ACR2004 — SHEET 1 OF 1

P/N 1161662 REV–D PG–1/2

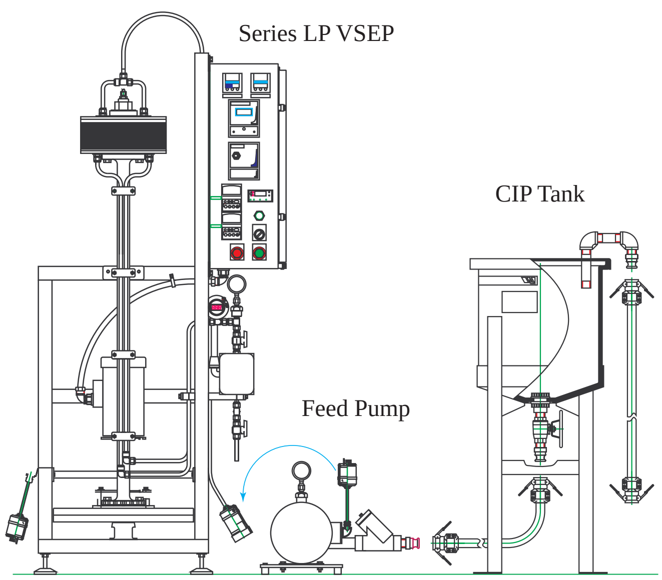
Appendix D

New Logic Research VSEP Pilot Unit Information

VSEP - Vibratory Shear Enhanced Process

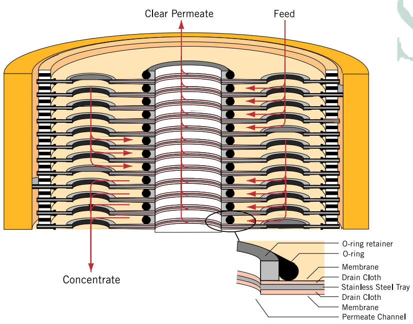
Description:

The V✧SEP Filtration System incorporates the patented Vibrating Membrane Filtration Technology. The key ingredient that comes from the vibrational oscillation is highly focused shear energy at the membrane surface. The combination of this plus pressure creates a non-fouling, high yielding, and efficient way of filtration for previously difficult separation applications. Throughputs of up to 225,000 GPD per module, (based on 150 GFD) are possible with a footprint of only 16 SF (1.5 m2). Torsional vibration created by an induced wobble in an opposing mass creates the necessary shear at the membrane.



Series LP V✧SEP Equipment Set Up

Filter Pack Cross Section



Series LP

The pilot scale VSEP unit is known as the *Series L/P*. This unit is inter-convertible between pilot (P), and laboratory modes (L). In the laboratory L mode, the system acts as a *Series L* with 0.4785 ft^2 of membrane area. However, in pilot P mode, with the addition of a small membrane stack, the membrane area is 16.44 ft^2. For most Microfiltration and Ultrafiltration applications, the Series L/P will filter between 62.5 and 125 gallons per hour (236-473 liters per hour). For Nanofiltration and RO applications, the system will filter approximately 25 to 94 gallons per hour (95-356 liters per hour). These ranges will vary according to feed material, pressure, temperature, and membrane selection.

Specifications:

1] Filter Pack

Membrane:	Reverse Osmosis-Microfiltration
Membrane Area:	16.8 square ft. (1.5 m2)
Max. Temperature:	up to 284 °F (140°C)
Allowable Ph Range:	1-14
Elastomers (O-rings):	EPDM,(Options for Buna, Viton)
Wetted Steel Trays:	304 .018 Gauge Stainless Steel

2] Piping

Maximum Pressure:	600 psi
Process Piping:	1/2" 316L Stainless Steel
Clean in Place Tank:	15 Gallon Polyethylene
Flow Control Valves:	Parker 12Z-PR4-VT-SS

3] Vibration System

Motor:	Baldor, 2HP, 3525 RPM
Speed Controller:	"ABB" ACS400501635
Maximum Decibels:	65

4] Electrical Specifications:

Power Supply Voltage:	240VAC 3 Phase 50/60Hz
Full Load Amp Rating:	30 Amps
Normal Load Amps:	9-26 Amps
Pressure Sensors:	Wika 0-600 Analog Gauge

5] Feed Pump Specifications:

Feed Pump Type:	Hydra-Cell M-10MRSEHHC
Power Supply Voltage:	240VAC 3 Phase 50/60Hz
Motor:	Baldor, 5HP, 1725 RPM, TEFC
Pressure Relief:	Wanner Bypass C22ADBESSEF

6] Pre-Screen Bag Filter:

Filter Housing Type:	316 SS Y-Strainer
Filter Size:	100 Mesh
Capacity:	10 GPM Each

7] Operating Site Conditions:

Equipment Rating:	NEMA 4, Indoor/Outdoor
Ambient Temperature:	5 - 37℃
Storage Temperature:	2 - 70℃ (Protect from Freezing)
Relative Humidity:	<95%, non-condensing
Elevation:	3300 ft max without derating

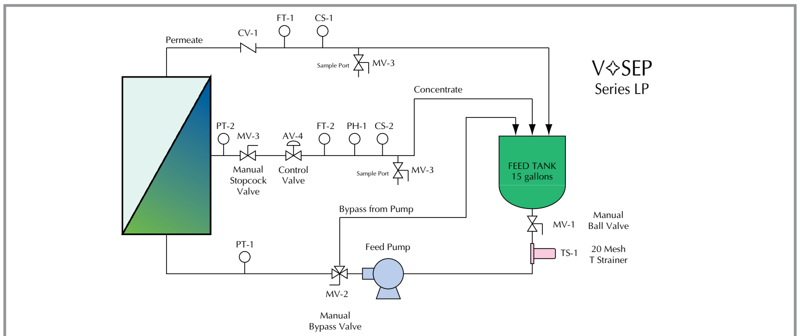
8] Instrumentation:

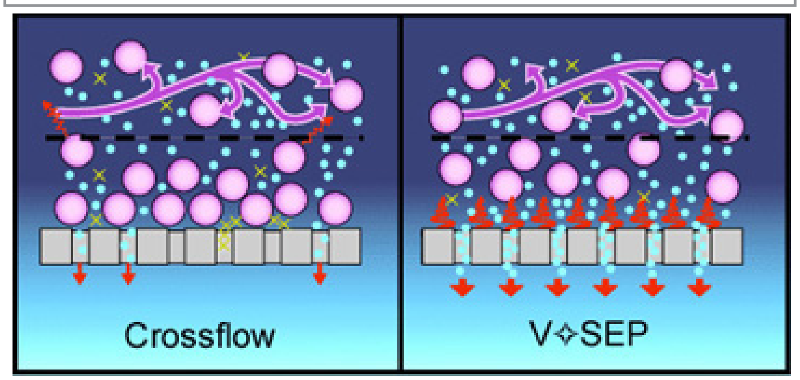
Temperature:	Ashcroft Digital Thermometer
pH:	Oakton Model EW-27011-11
Conductivity:	Myron L Company Model 758

VSEP Applications:

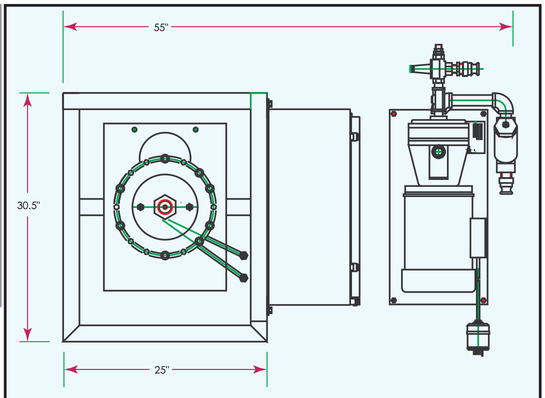
- Ultrapure Water
- Industrial Wastewater
- Chemical Processing
- Mineral Slurry Dewatering
- Glycol Recovery
- Waste Oil Recycling
- Phosphate Clarification
- Pulp & Paper Closed Loop
- Water Recycling
- Mining
- Oil Production & Processing
- Ethanol Production
- Polymer & Pigment Diafiltration
- Latex Concentration
- Laundry Wastewater Recycling
- Scrubber Blowdown

Typical Simplified Flow Diagram:



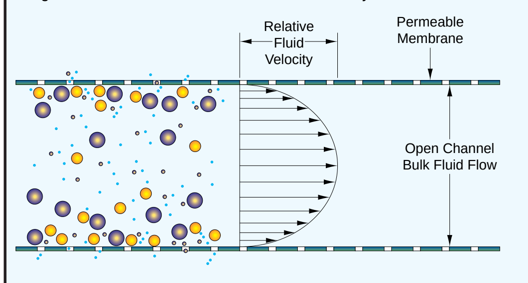


Footprint:

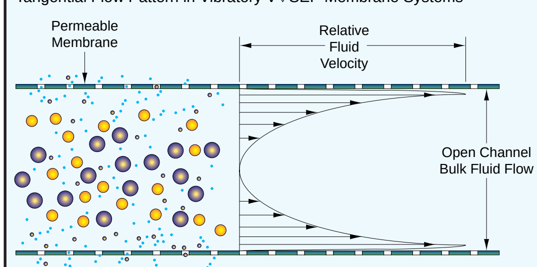


VSEP Series LP Footprint Drawing
(Tank not Shown)

Tangential Flow Pattern in Crossflow Membrane Systems



Tangential Flow Pattern in Vibratory V✧SEP Membrane Systems



NEW LOGIC'S FILTRATION SYSTEM MEMBRANES THAT CAN DO THIS ....

- ✔ Discriminating Molecular Separation
- ✔ Create a high solids concentrate in a **single pass**
- ✔ Separate any Liquid / Solid stream that flows
- ✔ Recovery of valuable chemical products
- ✔ Reduce operating costs and plant size
- ✔ Replace expensive, traditional processes*

(*Flocculation, Sedimentation, Vacuum Filtration, Centrifugation, Evaporation, Etc.)

New Logic Research
1295 67th Street, Emeryville, CA 94608
1-800-BUY VSEP
510-655-7305 tel
510-655-7307 fax

For more information, visit our website:

www.vsep.com

NLR doc 300-40

Subject to change without notice

Appendix E

Limestone Information

COLUMBIA RIVER CARBONATES
P.O. Box 2350 – 300 North Pekin Road
Woodland, Washington 98674
TEL: (360) 225 – 6505
FAX: (360) 225 – 5082
WATS: (800) 735 – 6690

Puri-Cal™ RO

DATA SHEET

Puri-Cal™ RO

Typical Physical Characteristics

Moisture (%)	< 0.2
Specific Gravity	2.7

Typical Chemical Analysis

$CaCO_3$ (%)	> 95
$MgCO_3$ (%)	< 3
Acid Insoluble (%)	< 2

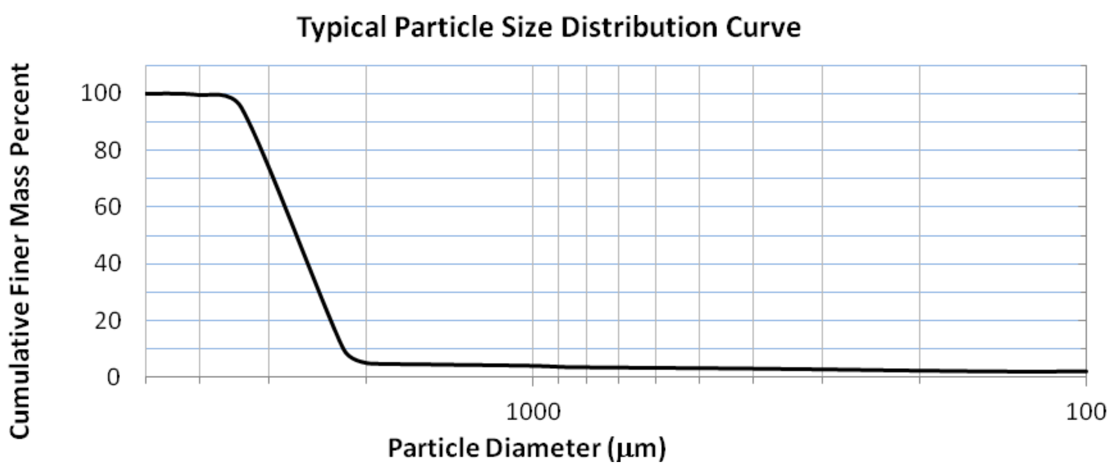
CAS# 1317-65-3

Certified to NSF/ANSI 60

MUL 400 gm/L

Typical Size Distribution

6% Plus 6 mesh (U.S. Standard)
5% Minus 10 mesh (U.S. Standard)



Revised by Leif Backstrom
June 2012

Material Safety Data Sheet

SECTION 1 – PRODUCT INFORMATION

Product: Calcium Carbonate (Limestone)

Trade Names: Puri-Cal™, Puri-Cal™ C, Puri-Cal™ RO

Chemical Formula: Primarily Calcium Carbonate ($CaCO_3$)

CAS #: 1317 – 65 – 3

Manufacturer: COLUMBIA RIVER CARBONATES

Address: P.O. Box 2350, 300 N. Pekin Road, Woodland, WA 98674

Telephone: (360) 225-6505

Emergency Phone: (800) 424-9300 (CHEMTREC)

Certified to NSF/ANSI 60

SECTION 2 – HAZARDOUS INGREDIENTS

Ingredients:	Wt. %(typical):	CAS#:	Exposure Limits (TWA) mg/m^3:	
Limestone	>99.0	1317 – 65 – 3	ACGIH TLV	Inhalable dust, 10 [for PNOS] Respirable dust, 3 [for PNOS]
			OSHA PEL:	Total dust, 15 Respirable dust, 5
Silica, quartz (naturally-occurring component of limestone)	<0.75	14808 – 60 – 7	OSHA PEL:	Total dust, 30 / % silica + 2
Silica, respirable quartz (naturally-occurring component of limestone) – typical value	< 0.35	14808 – 60 – 7	ACGIH TLV:	Respirable dust, 0.025
			OSHA PEL:	Respirable dust, 10 / % silica + 2

SECTION 3 – PHYSICAL DATA

Appearance and Odor: White powder – no odor.
Solubility in Water: 0.0014 g/100 ml @ 25 degrees Celcius.
Specific Gravity; (of solids) 2.71 g/ml.
Maximum Use Level: 400 gm/l.

SECTION 4 - FIRE & EXPLOSION DATA

Flash Point: Non-Flammable.
Extinguishing Media: Not Applicable.
Special Fire Fighting Procedures: None.
Unusual Fire & Explosion Hazards: None.

SECTION 5 – REACTIVITY DATA

Stability: Stable.
Reactivity in Water: None.
Incompatibility (Material to Avoid): Reacts with acids and liberates carbon dioxide. Ignites on contact with fluorine. Also incompatible with alum and ammonium salts.
Hazardous Polymerization: Will not occur.
Hazardous Decomposition Products: Thermal decomposition can produce calcium oxide and carbon dioxide.

SECTION 6 – TOXILOGICAL PROPERTIES

EFFECTS AND HAZARDS OF ACUTE EXPOSURE:

Inhalation: Dust may irritate the respiratory tract. Symptoms include sneezing and slight nose irritation.

Eye Contact: Irritation. Symptoms include watering and irritation.

Skin Contact: Repeated or prolonged exposure may have a drying effect on the skin, and may also cause irritation.

Ingestion: Ingestion of very large quantities may result in intestinal obstruction and/or constipation.

EFFECTS AND HAZARDS OF CHRONIC EXPOSURE:

Chronic exposure to limestone dust at concentrations exceeding occupational exposure limits may cause pneumoconiosis (lung disease). This product contains crystalline silica (quartz) as an impurity. Chronic exposure to crystalline silica dust at concentrations exceeding occupational exposure limits may cause silicosis. The NTP's Ninth Report on Carcinogens lists crystalline silica (respirable size) as a known human carcinogen. IARC concluded that there is sufficient evidence in humans for the carcinogenicity of inhaled (respirable) crystalline silica.

SECTION 7 – FIRST AID MEASURES

Eye Contact: Flush thoroughly with water. If irritation persists, seek medical attention.

Skin Contact: Wash with mild soap and warm water.

Inhalation: Remove to fresh air. Obtain medical advice if required.

Ingestion: Never give anything by mouth if victim is rapidly losing consciousness or is unconscious or convulsing. Rinse mouth thoroughly with water. Do not induce vomiting. Drink 8 to 10 ounces (240 to 300 ml)of water to dilute material in stomach. Obtain medical advice immediately.

SECTION 8 – PREVENTATIVE MEASURES

Spills/Leaks: Measures should be taken to minimize and protect against airborne dust during cleanup operations, including use of respiratory protective equipment if necessary.

Disposal: From a waste perspective, this product is not considered hazardous and may be disposed of as solid waste in accordance with applicable federal, state, provincial, and local regulations.

Handling: Administrative and/or engineering control methods such as, but not limited to, process enclosure and exhaust ventilation may be necessary to control dust exposures. Supply sufficient replacement air to make up for air removed by exhaust systems. If engineering controls and work practices are not effective in controlling exposures, appropriate personal protective equipment including a NIOSH/OSHA approved dust respirator should be worn. Appropriate eye protection should be worn. Selection of all personal protective equipment should be performed by an Industrial Hygienist or other qualified professional.

HAZARDOUS MATERIAL IDENTIFICATION SYSTEM (National Paint & Coatings Association):

CATEGORY	RATING
Health	**1***
Flammability	**0**
Physical Hazard	**0**

SECTION 9 –REGULATORY INFORMATION

TSCA: This product primarily is natural calcium carbonate from limestone ore which is listed on the U.S. EPA TSCA inventory under Limestone, CAS# 1317-65-3. In addition, all other ingredients and/or processing aids are also on the TSCA inventory.

DSL: BY virtue of its status as a "substance occurring in nature", ground limestone is considered to be on the Canadian Domestic Substances List. In addition, all other ingredients and/or processing aids are also on the DSL.

CONEG: Being derived from limestone ore, this product may contain incidental trace levels of naturally occurring metals. However, no metals are intentionally added and this product complies with the CONEG requirement of <100 ppm of Cd, Cr^{+6}, Pb, and Hg.

ODCs: This product does not contain, nor is it produced with, any U.S. EPA-defined Class I or Class II ozone-depleting chemicals.

FDA: This product may be used as an indirect food additive in food packaging applications under 21 CFR (FDA) 174.5, 175.300, and 178.3297. It does not qualify as a substance permitted for direct addition to human food or animal feed.

SECTION 10 – PREPARATION INFORMATION

Prepared by Technical Support Group

The information contained herein has been compiled by Columbia River Carbonates from sources it considers reliable, and is accurate to the best of Columbia River Carbonates' knowledge. Before using the product identified hereon, the foregoing MSDS and the product label should be read carefully. The information contained herein relates only to the product identified hereon, and does not relate to its use in combination with any other material or in any process. Customers are encouraged to conduct their won tests concerning the use of the product identified hereon as each customer's manner and conditions of use and handling may involve additional considerations. Columbia River Carbonates assumes and shall incur no liability for any damages, losses, injures, costs, or consequential damages that may result from the uses or misuse of the product identified hereon, and the recipient assumes all of such liability.