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CATION EXCHANGE PRETREATMENT STUDIES FOR HIGH RECOVERY - YUMA DESALTING PLANT

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16. ABSTRACT

The main purpose of the High Recovery Test Program was to obtain feasibility design data for cation exchange softening to allow a greater fractional recovery of desalted product water at the YDP (Yuma Desalting Plant). Compared to the original YDP design with 70-percent desalting recovery, additional removal of calcium in the desalting feed would allow recoveries over 90 percent. The sole chemical regeneration solution for the IX (ion exchange) process during steady-state operation would be the sodium-rich reject brine from the desalting equipment. Pilot plant equipment to test this process was operated at the YDTF (Yuma Desalting Test Facility) and consisted of an IX unit and an electrodialyzer to supply reject-brine regenerant for the IX experiments. Because the reject-brine contained major concentrations of sulfate, gypsum scale occurred in the resin bed under certain IX operating conditions. Scaling occurred especially when the water temperatures were about 30 °C in the summer. Scaling did not occur with water temperatures of 15 °C in the winter. Gypsum scale buildup in the resin bed could be avoided by regeneration with a high upward flow rate causing a fluidized bed. Reuse of regenerant was also beneficial. Multiple regression analysis of the IX data delineated the importance of several control variables in the IX experiments, including regeneration concentration, flow rate, volume, and temperature. The major response variable was the specific calcium resin capacity divided by the IX cycle duration. This number is inversely proportional to the design resin requirement. Results show that the ion exchange high recovery pretreatment process is highly feasible, and that it is technically possible to achieve high recovery in the YDP. Numerous recommendations for a plant design are given and future studies are noted.

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CATION EXCHANGE PRETREATMENT STUDIES FOR HIGH RECOVERY — YUMA DESALTING PLANT

by

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October 1983

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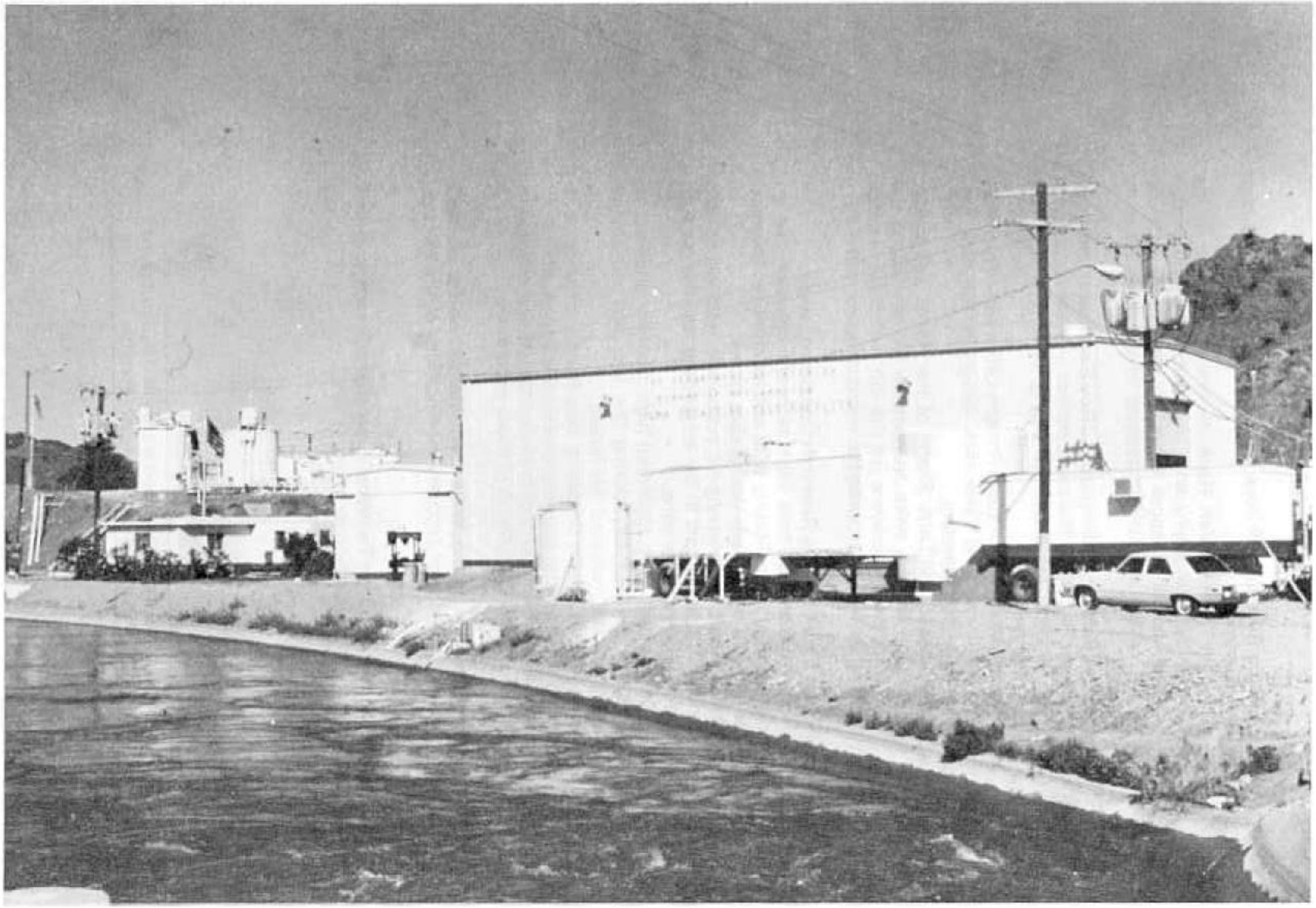
SI METRIC

As the Nation's principal conservation agency, the Department of the Interior has responsibility for most of our nationally owned public lands and natural resources. This includes fostering the wisest use of our land and water resources, protecting our fish and wildlife, preserving the environmental and cultural values of our national parks and historical places, and providing for the enjoyment of life through outdoor recreation. The Department assesses our energy and mineral resources and works to assure that their development is in the best interests of all our people. The Department also has a major responsibility for American Indian reservation communities and for people who live in Island Territories under U.S. Administration.



Frontispiece.—View of Yuma Desalting Test Facility in summer 1979 showing ion exchange trailer in center and electrodialysis trailer at right.

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- **Cornelis "Kees" Van Hoek**, technical specialist in the Chemistry, Petrography, and Chemical Engineering Section of the Applied Sciences Branch (now retired), provided much advice on various aspects of the high recovery studies,
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- **Ron Hudson**, full-time high recovery operator, did an outstanding job collecting data and samples for chemical analysis — particularly during data cycles,
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- **Mike Olewski** was appointed high recovery engineer in place of Paul Laverty during the last few months of operation and reviewed this report,
- **Rick Amalfi**, Yuma Desalting Test Facility chemist, was responsible for the accurate chemical analyses, and
- Numerous other test facility personnel who contributed to the successful completion of these experiments.

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Richard N. Walters of the Technical Publications Branch, provided final editing and preparation for printing.

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INTRODUCTION

Application of cation exchange softening as pretreatment is applicable where calcium must be removed from feed water to prevent gypsum scaling in a desalting unit or other device such as a wet cooling tower in which there is a concentrated waste stream. A high removal efficiency for calcium is particularly necessary when calcium and sulfate are major ions in the feed water and a high desalting recovery (ratio of product flow to feed flow) is required. These two conditions often occur in the desalting of inland brackish waters where environmentally acceptable disposal of a reject brine is necessary.

Disposal of reject brine—usually in evaporation ponds or by injecting into deep wells—can be one of the most expensive features of a desalting project. Thus, high recovery is a determinant in minimizing the reject brine flow and the cost of brine disposal. The YDP (Yuma Desalting Plant) will be rather unique compared to other inland desalting applications in that the reject brine from the YDP will be conveyed by canal for disposal to the Gulf of California. Higher recovery in the YDP would be used solely to achieve a higher yield of product water. There is no brine disposal cost factor for high recovery at the YDP.

This final report describes the background, experimental methodology, results, recommendations and conclusions of a pilot plant study of cation exchange pretreatment to desalting at the YDTF (Yuma Desalting Test Facility) in 1978-79. This report consolidates an analysis of data contained in monthly and weekly reports from the YDTF in the time period of March 1978 through September 1979 (plus November 1979 monthly) published by the site contractor, PRC (Planning Research Corporation). A requirement of the cation exchange softener operation was that the desalting reject brine should provide the sole source of cation exchange regenerant chemical at process equilibrium conditions. Some 50 different operating conditions for exchange cycles were run. Data were analyzed in a way to better understand the phenomena occurring in this ion exchange process and to provide information for a high recovery feasibility design for the prototype YDP.

Feed water to the ion exchanger was provided by a solids contact reactor and dual media gravity filters. High pH lime softening was required (for desalting by reverse osmosis but not by electrodialysis) to reduce silica concentrations below the levels achieved by other similar reactors in operation at the YDTF. Data and other information on the reactor and filters (Train IV, see subsec. Pilot Plant Equipment) are contained in another report [1].[1]

The Bureau of Reclamation desalting group of the Mechanical Branch, Division of Design, noted that testing of high recovery desalting would not be necessary. It was stated that extrapolation of lower recovery desalting data from YDTF and manufacturers' data would be sufficient for a feasibility design of high recovery desalting. Thus, the high recovery tests program did not include experimental desalting requirements other than to provide reject brine for regeneration in cation exchange experiments. Incidental data for the electrodialyzer used to generate reject brine regenerant are in Appendix E—**Electrodialyzer Operational Data**.

[1]Numbers in brackets refer to the **Bibliography**.

SUMMARY

Phase 1 — Exploratory Experiments

Results of the initial exploratory experiments (Phase 1) include the following:

1. After several serious mechanical and electrical equipment problems were solved, the cation exchanger and ED (electrodialysis) were operated successfully with closed loop regeneration in which desalting reject provided the sole cation exchange regenerant. This process included a successful system for recycling regenerant.

2. Operable ranges for the independent variables later used in Phase 2 were established. This included a high value of fresh regenerant (ED reject brine) concentrations of 50 g/L TDS (total dissolved solids) or about 95 percent desalting recovery with a feed water of lime-treated Wellton-Mohawk Project irrigation drainage water.

3. The *specific resin capacity* for calcium removal was about 20 percent less when the regenerant was 26.7 g/L TDS ED reject brine than when the regenerant was 3.0 percent NaCl under the same operating conditions.

4. A reliable accurate method, for automatically sensing *calcium breakthrough* of the cation exchange resin was not found. Periodic manual operator titration was used in all remaining experiments to sense the termination of the *service* or *exhaustion mode*.

5. Quite surprisingly, *gypsum* ($CaSO_4 \cdot 2H_2O$) *scaling* did not occur in the resin bed during regeneration under a wide range of operating conditions. Rather, gypsum precipitation was properly confined to the regenerant recycling system. Numerous previous investigations of cation exchange softeners regenerated with high sulfate solutions (discussed in this report) had shown that special measures were necessary to control resin scaling by gypsum. Fall and winter temperatures were always cool and, thus, the impact of warmer temperatures on gypsum scaling rates had not been observed during Phase 1.

Phase 2 — Response-surface Experiments

A three-level, four-variable experimental design with 27 observations was run in Phase 2 to establish a response surface for the major dependent variable, the **TWRC** (time-weighted resin capacity) and the control variables. Three additional screening runs using a feed water backwash rather than recycled regenerant, two additional runs using a lower calcium breakthrough point for service, and one run using SHMP (sodium hexmetaphosphate) addition to the regenerant were completed also in Phase 2. Unfortunately 2 of the 27 response-surface observations resulted in outlying performance (high residuals in the statistical data analysis) as a result of hurrying the experiments to meet program time constraints. Specifically, during these two runs, insufficient numbers of conditioning cycles were allowed for chemical equilibrium in the recycled regenerant system to have been established, which required deletion of those two observations from the data analysis.

Gypsum scaling of the resin occurred during regeneration in many Phase 2 experiments with control variable levels similar to those in Phase 1 when no scaling had been observed. It was established clearly in a limited bench scale experiment that temperature was an important uncontrolled independent variable and that higher midyear temperatures promoted this gypsum scaling. Permanent harm to resin properties was not detected from gypsum scaling, for the resin capacity had fully recovered after NaCl regeneration.

During some screening experiments, advantage was not found in lowering the maximum allowed calcium *breakthrough concentration* as a means to increase resin capacity. Advantages for using recycled regenerant were demonstrated. Conversely, one of the three runs using feed water for backwash rather than recycled regenerant was the only cycle condition in Phase 2 that could not be operated closed loop (without added NaCl regenerant).

Phase 3 — Additional Experiments

Several test methods were performed in additional experiments (Phase 3) to control gypsum scaling of the resin that was observed during regeneration in Phase 2 during high regenerant temperatures. Successful methods included:

- Filtration of gypsum crystallites from recycled regenerant,
- Higher regeneration flow rates (up to a limit), and
- Addition of SHMP (a scale inhibitor) to the regenerants.

It was found that addition of SHMP is not necessary, however, if recycled regenerants and high regeneration flow rates are used (24 L/min with 340 mm inside diameter, 0.1 m^3 volume resin bed). The use of SHMP here would be costly in any case. Very poor cation exchange performance was observed when injection of air was tried to destratify the resin bed prior to regeneration.

Multiple Regression Analyses

An analysis of the 25 response-surface observations showed that fresh regeneration flow rate, TDS concentration, and the volume of recycled regenerant were the significant variables affecting **TWRC**. The TWRC is the *specific cation exchange capacity* of the resin for calcium in equivalents per liter *divided by the total cycle time* in minutes. TWRC is inversely proportional to the design resin requirement. An equation was developed relating TWRC with fresh regeneration flow rate, fresh regenerant TDS concentration, and recycled regenerant volume.

An analysis of 28 observations that include Phases 2 and 3 data shows that increasingly higher fresh regeneration flow rates improve performance up to some limit, which was not precisely defined. A statistical analysis of semiquantitative gypsum *scaling intensities* in the resin bed—based on visual observations noted in the operators' log together with data from Phases 2 and 3—substantiated that gypsum scaling of the resin was progressively more severe as regenerant concentration and temperature increased and regenerant flow rate decreased. However, this scaling intensity had zero correlation with TWRC, the most important IX performance parameter. Mitigation of scaling occurred when either the regenerant concentration or temperature were lowered or when the regenerant flow rate was increased.

The mean and standard deviations of TWRC in all the experiments were 1.23 ± 0.27 meq/(L·min). A rather low (22 percent) relative standard deviation for all observations illustrates that TWRC is determined largely by the total exchange capacity of the cation exchange resin and the relative constant feed water composition during these experiments.

Gypsum Settling Tests

Limited experiments described in this report provide data for use in designing a regenerant recycling system. The gypsum settled at faster rates than was observed for calcium carbonate in lime softening jar tests at the YDTF.

Microbiological Growth

High plugging factors were noted in ED feed water. Various analyses indicated that uncontrolled microbiological growth was responsible for organic by-products in the water. Chlorine residual was not maintained in the IX (ion exchange) feed, IX product, ED feed, or IX regenerants. Chlorine was removed because of low tolerance of the IX resins to chlorine. Detrimental effects from this biological activity toward IX or ED performance were not noted—other than minor clumping of IX resin beads caused by the microbiological by-products. However, there could be a detrimental effect of microbiological products on RO (reverse osmosis) performance if RO were used as the desalting process. Resin manufacturers recommend storing resin in a strong (10 percent) NaCl solution and periodically flushing the resin bed with formaldehyde solution when needed as a means of controlling such microbiological growth. The IX product water fed to an RO also should be disinfected.

Design Recommendations

Based on the experimental results, a recommended set of operating conditions were developed for cation exchange pretreatment systems for the YDP operated at high recovery. Important operating conditions provide for control of gypsum scaling of the cation exchange resin and maximum **TWRC**. These operating conditions include using high regeneration upflow rates producing about 50-percent bed expansion and using recycled regenerant. Common gel-type cation exchange resin is recommended. Common piping for the IX feed and regenerant effluent would eliminate the possibility of gypsum scale accumulating in the regenerant effluent piping which results from the supersaturated calcium sulfate. With common piping, any small scale accumulation from the regenerant effluent becomes redissolved in the IX feed during each cycle. The use of SHMP as a scale inhibitor is not needed in RO feed water after IX pretreatment if advantage is taken of the low calcium leakage of the IX process; this would result in cost savings for SHMP of about $1 million annually for the YDP. Further process improvements could result from using a packed bed during at least a portion of the regeneration rather than a fluidized bed and using higher exhaustion flow rates, but this would require further IX testing.

Testing and demonstration of an IX bed with brine regeneration at Yuma should be modeled to obtain performance of a prototype system because of the importance of flow distribution in controlling gypsum scaling of the resin. Comparisons of RO and ED desalination should include the pretreatment advantage of ED that silica generally is not concentrated by ED and often does not require pretreatment removal prior to ED. In using lime softening, a lower lime dosage—when silica removal is not needed—yields a lower calcium concentration in the IX feed resulting in a smaller, more effective IX system.

Future refinement of this IX process should include systematic studies of the effect of feed water composition and recovery. It would help define the feasibility of IX for different sites and applications. Such studies should include the mechanism of gypsum precipitation kinetics as a function of temperature and its effect on the IX process. A computer program would be developed from such work which would yield the equipment capacity and recommended IX cycle conditions from an input of the feed water composition, feed water flow, and desalting recovery.

Also, there is great potential that the use of cation exchange softening prior to RO can reduce the rate of colloidal membrane fouling through the stabilization of colloids in the RO feed water. A high level of softening retards colloid coagulation and membrane fouling which occurs during the RO desalting process. This area needs further research and practical demonstration.

CONCLUSIONS

Using cation exchange softening as a pretreatment for high recovery desalination with only the desalting reject brine as the cation exchange regenerant has been demonstrated successfully for possible inclusion to the Yuma Desalting Plant. It is believed that, in these experiments, temperature was demonstrated for the first time to be very important in the potential for gypsum scaling of the resin when using sulfate-containing brine regenerants. Scaling can be controlled—at least it was at the Yuma Desalting Test Facility—by using high regeneration upflow rates and recycled regenerant volumes. However, when gypsum scaling did occur during less favorable operating conditions, the resin capacity did not seem to be affected by the scale, and any trace of gypsum scale was removed after several cycles using NaCl regenerant. Disinfecting the IX product and possibly the IX resin is recommended to avoid high plugging factors in the desalting feed water caused by slime resulting from microbiological growth.

Moreover, cation exchange softening could provide a very successful pretreatment system for the YDP with several process advantages over the major pretreatment alternative—lime-soda softening. With cation exchange:

- High cost of soda and importing it would be avoided,
- Less sludge would be formed that requires disposal, and
- Pretreatment system would be less susceptible to possible upsets of the sludge blanket in the reactor-clarifier.

BACKGROUND

Existing Yuma Desalting Plant Design

Construction of the YDP was authorized by Congress in Public Law 93-320 [2] to meet the requirements of a treaty signed by the United States of America and the Republic of Mexico [3]. The YDP will reduce the salinity from the WM (Wellton-Mohawk) Irrigation and Drainage District having a projected salinity of 3200 mg/L TDS (total dissolved solids) to provide Mexico with irrigation water of satisfactory quality from the Colorado River. Public Law 93-320 requires that the technology in the YDP be advanced but commercially available.

Presently, the YDP is being designed for a product water capacity of 4.2 m^3/s (96 000 000 gal/d). The nominal product water recovery will be about 70 percent, which is based largely on economic analyses by the desalting equipment suppliers. At design capacity, YDP will be capable of producing a product water salinity of 264 mg/L TDS or less. An 82-km-long bypass canal will convey reject brine (about 30 percent of the feed water) to the Gulf of California. In a competitive bid procedure-completed in October 1978—spiral wound RO (using cellulose acetate membranes) was the desalting process selected for YDP based on cost and performance.

The purpose of testing at the YDTF [4] has been for providing data for the selection and design of the YDP pretreatment and desalting equipment [5]. Pretreatment testing at YDTF led to the selection of partial lime softening for YDP. Extensive testing of membrane desalting culminated in 1980 (after the present study) with the proof testing for final acceptance of prototype RO systems for the YDP. The expected average WM brine canal raw and lime-treated water compositions for the YDP (table 1) are similar but not identical to present water at the YDTF. (Note that the lime-treated water composition in Table 1 does not include the necessary addition of acid prior to desalting.)

High Recovery Design Requirements

In addition to authorizing the YDP, Public Law 93-320 requires that measures for replacing the quantity of water wasted in the plant's reject brine be identified and reported to Congress [2]. An engineering study [6] was done to indicate the most feasible methods of obtaining higher recoveries while reducing the brine volume. This study indicated that the best approach for achieving higher recoveries would be to change the existing pretreatment and desalting plant design. To achieve 90 percent recovery at the same feed rate would require about 50 percent more membrane area through additional desalting equipment. Osmotic pressure of the brine limits the recovery of RO to about 90 percent or less for WM water at the upper limit of allowable pressure in the existing cellulose acetate RO modules to about 3100 kPa (450 lb/in^2). Recoveries of greater than 90 percent with RO would require the addition of a tail-end plant such as an evaporation brine concentrator or high-pressure RO with seawater-type membranes, which could significantly increase the project cost. Electrodialysis probably could be operated as a tail-end process at a recovery of 95 percent without much change in the standard type of hardware; however, energy costs would be high. Other desalting processes were considered and eliminated because they were either too costly or would be incompatible with the existing YDP design.

The partial lime pretreatment system generally has provided satisfactory water quality at the YDTF for membrane desalting at recoveries up to about 80 percent. However, testing at recoveries

Table 1. — *Canal and lime-softened water compositions projected for the YDP for 70 percent recovery operation*

Constituent	Canal water mg/L	*Pretreated water mg/L
Calcium	258	145
Magnesium	90	85
Sodium	739	739
Potassium	9	9
Strontium	258	145
Bicarbonate	385	19
Chloride	870	870
Sulfate	1011	1011
Nitrate	1	1
Phosphate	<1	<1
Silica	25	23
Iron	<1	<0.06
Manganese	1	<0.1
pH	8.1	9.5
TDS (ions summation)	3392	2904

* After 200 mg/L lime dosage as 90-percent calcium oxide

above 80 percent at YDTF generally resulted in accelerated performance degradation—usually attributable to gypsum scaling. (These prebid testing data are still considered proprietary by the desalting equipment suppliers.) This is a direct result of the inherent limitations in the chemistry of the partial lime softening process [7], which uses lime only to remove that portion of calcium related to *temporary hardness* (equivalent to bicarbonate present) but not the calcium related to *permanent hardness.* This amounts to less than half of the calcium in WM water (table 1). Soda ash can be added besides the lime to remove the permanent hardness [7] allowing further recovery before gypsum precipitation. Silica scaling of RO membranes would be expected also at high recoveries. Thus, an improved pretreatment system to remove more calcium and silica would be needed for higher water recoveries in the YDP.

High Recovery Pretreatment Selection

Pretreatment selected for achieving high recovery would use the same lime-softening and clarification equipment as the 70-percent recovery plant. It would use additional lime to raise the pH to about 10.2 to precipitate magnesium for silica reduction followed by IX softening with strong acid cation exchange resin to remove additional calcium. A comparison between the existing system design and the possible higher recovery system is on figures 1 and 2. Major new equipment for high recovery would include the IX, additional desalting equipment, and tankage. As shown on figure 2, the IX process would use the desalting reject brine as the source of salt for regenerating the cation exchange resin and probably recycle this regenerant. The use of imported NaCl chemical as regenerant would make IX pretreatment unfeasible because of the high chemical cost.

Alternatively, conventional lime-soda softening also could provide the required pretreatment. Lime-soda softening would use essentially the same equipment as the existing partial lime softening. However, the chemical costs for soda ash would be great. Chemical costs with the IX process would be much less, but capital costs of IX would be high [6, 8]. Lime-soda softening was not tested at YDTF.

Calculations were used to determine the maximum allowable levels of calcium ion and silica in the pretreated WM water for RO operation without scaling at high recoveries. Computer calculation [9]

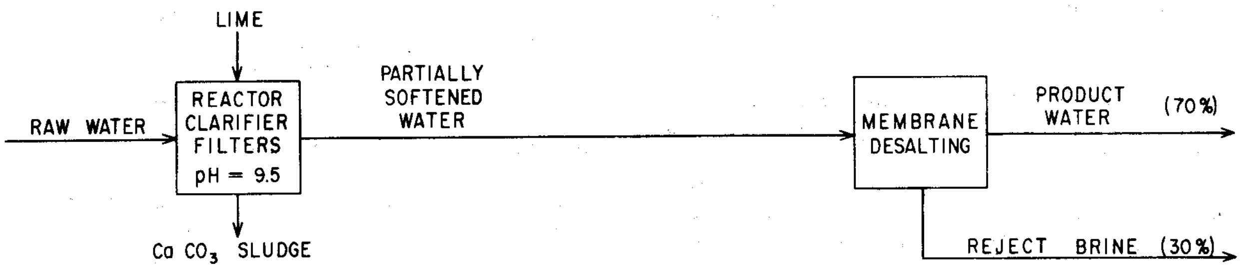


Figure 1.—Existing Yuma Desalting Plant design.

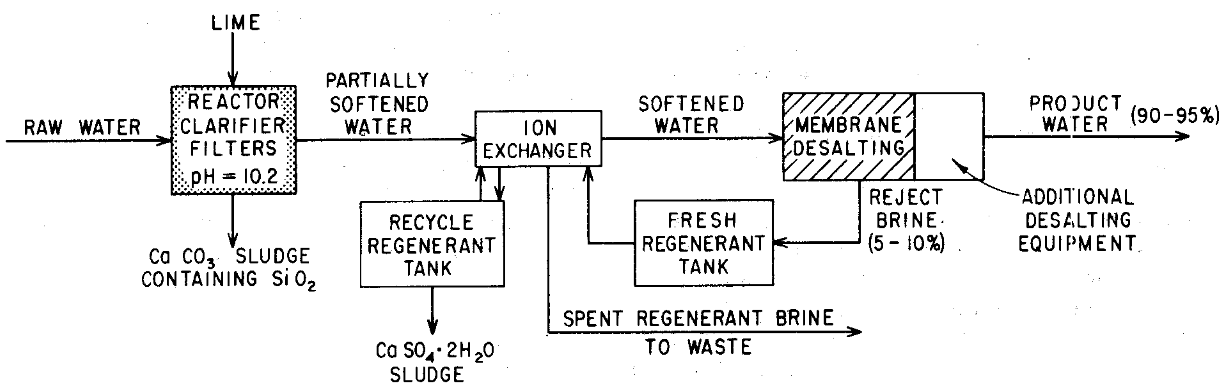


Figure 2.—Possible modifications to YDP for achieving high recovery.

were used to estimate the maximum calcium concentration in WM water without the addition of SHMP scale inhibitor for equilibrium gypsum precipitation in the RO brine. These results gave an upper limit of about 35 mg/L Ca^{+2} at 90-percent desalting recovery and 17 mg/L Ca^{+2} at 95-percent recovery. The allowable maximum dissolved silica levels—assuming a 120 mg/L saturation concentration in the brine—are about 12 mg/L at 90-percent recovery and about 6 mg/L at 95-percent recovery. These do not account for concentration polarization that would additionally lower the above concentration limits by roughly 20-percent for the case of spiral-wound RO, but this 20-percent reduction can be offset by SHMP addition, which retards the rate of gypsum precipitation. Because ED does not concentrate SiO_2, only the Ca^{+2} limit applies, and SiO_2 removal by the pretreatment for ED alone would be unnecessary, which is one obvious advantage of ED over RO. (This means that high lime softening for SiO_2 removal would not be necessary for ED pretreatment. Unfortunately, in the high recovery feasibility design there was an erroneous assumption that SiO_2 removal would be necessary for both ED and RO.) Strontium also would need to be removed in the pretreatment for recoveries above about 85 percent to avoid strontium sulfate scaling in RO and ED. Strontium removal is achieved readily in a cation exchange softener.

There were no previous IX data for softening WM water prior to the present study. Experimental data have been collected from pilot plant IX testing of several other brackish waters with somewhat similar compositions to that of WM water for which successful IX softening was achieved [10, 11, 12]. In each case, reject desalting brine was used as the IX regenerant.

IX Process Considerations

Certain basic differences in the cation exchange softening cycles have evolved between using desalting reject brine regeneration in high recovery desalting pretreatment applications (table 2) as compared to using the common NaCl regeneration. (Numerous sources of information on standard Na cycle softening are available [13, 14, 15].) A special emphasis for high recovery is placed on eliminating an unnecessary wastage of water from the process, for not to do so results in an overall net loss in product water recovery for the combined pretreatment-desalting system. Also, because the average amount of new regenerant available per cycle is fixed by the average amount of water produced during exhaustion per cycle that is concentrated as reject by the desalting process, the regenerant is recycled to be used more than once. This recycling technique was first demonstrated on a pilot scale at the Firebaugh Facility of the Water Resources Division of the State of California [12].

Table 2. — *Comparison between IX softening cycles, NaCl regeneration and desalting reject brine regeneration.*

Mode	Input	Output
A. *NaCl Regeneration Used in Standard Cation Exchange Softening*		
Exhaustion	Feed water	Product
Backwash	Feed water	Waste
Regeneration	NaCl solution	Waste
Drain	Air vent	Waste
Slow rinse	Feed water	Waste
Fast rinse	Feed water	Waste
B. *Regeneration with Desalting Reject Brine for High Recovery Pretreatment*		
Exhaustion	Feed water	Product
Drain 1	Air vent	Product
Regeneration I	Recycled regenerant	Waste
Regeneration 2	Recycled regenerant	Used regenerant
Regeneration 3	Fresh desalting brine	Used regenerant
Drain 2	Air vent	Used regenerant
Rinse (slow)	Feed water	Recycled (optional)

An additional and most important change from usual NaCl regeneration is that to use desalting reject brine as the regenerant, regeneration is carried out upflow having different amounts of bed expansion and fluidization depending on the upflow velocity and water temperature. This is done because regenerant effluent nearly always is supersaturated with calcium sulfate to some extent-a consequence of the high amounts of calcium eluted from the cation exchange resin during regeneration and the high concentrations of sulfate in the desalting reject. It would probably by impossible to operate at all under similar conditions of calcium sulfate supersaturation if it were not for the fact that calcium sulfate precipitation and scaling takes time to form [16]. Fortunately, using a sufficiently high regeneration flow rate can cause the supersaturated spent regenerant to be removed from the column containing the cation exchange resin before scaling occurs there. The fluidized bed aids in removing any just-formed gypsum crystallites to be removed from the bed.

Another advantage results from counterflow operation which is exhaustion and regeneration in opposite flow directions. Because the fully exhausted resin containing the highest concentration of absorbed calcium ion is at the top of the resin bed, when the *breakthrough of* calcium just occurs at the bottom of the bed, upflow regeneration minimizes the average depth of bed through which the eluting calcium ions must pass. In turn, this minimizes the average contact time between the resin and the eluting regenerant supersaturated in calcium sulfate. Another advantage of counterflow operation is that the initial leakage from the column during exhaustion consists of water in equilibrium with the most fully regenerated resin at the bottom of the bed, which results in lower calcium leakage than with coflow operation—which is exhaustion and regeneration in the same flow direction. Poorer IX performance during downflow (coflow) reject brine regeneration as compared to during upflow (counterflow) regeneration has been documented in several reports [10, 17]. A general discussion of this process in terms of ionic equilibria and conservation of Na^+ by regenerant recycling is contained in Appendix I–**How Does This Cation Exchange Softening Process Succeed?**

EXPERIMENTAL METHODOLOGY

Pilot Plant Equipment

The YDTF experimental equipment for the IX tests consisted of:

- a solids contact reactor-clarifier and dual media filters for partial lime pretreatment,
- the IX pilot plant,
- an electrodialyzer,
- a regenerant recycling system, and
- various interconnecting water storage tanks, piping and pumps.

Raw water (saline irrigation return flow) was pumped from the WM main conveyance channel into a grit basin. Primary chlorine (about 6mg/L dosage) was applied at the grit basin inlet. The grit basin (fig. 3) had a settling basin where the more coarse suspended material settled before the influent entered the lime-treatment system. At times, a trashrake, shown in figure 4, was used at the inlet from the canal to contain large floating weeds from the influent.

The lime-treatment system consisted of a 3.0-meter-diameter solids contact reactor-clarifier (fig. 5) called Train IV followed by a filter. This reactor was an internal sludge-recirculation type manufactured by Eimco (Envirotech Corp.). Generally, it was operated using a 114-L/min throughput. Water from the grit basin was combined with lime slurry to maintain a pH of 10.4 in the reaction zone for silica removal, and 7.5 mg/L of $Fe_2(SO_2)_3$ was added presumably to improve process stability and clarification. The effluent was acidified to a pH of about 7.0 with H_2SO_4 prior to filtration by Filter 9B. Filter media consisted of layers of anthracite coal, silica sand, and a grated gravel support. Further information on Train IV plus Filter 9B is available [1].

Most IX system components were located in an air-conditioned van. Tanks and some piping and

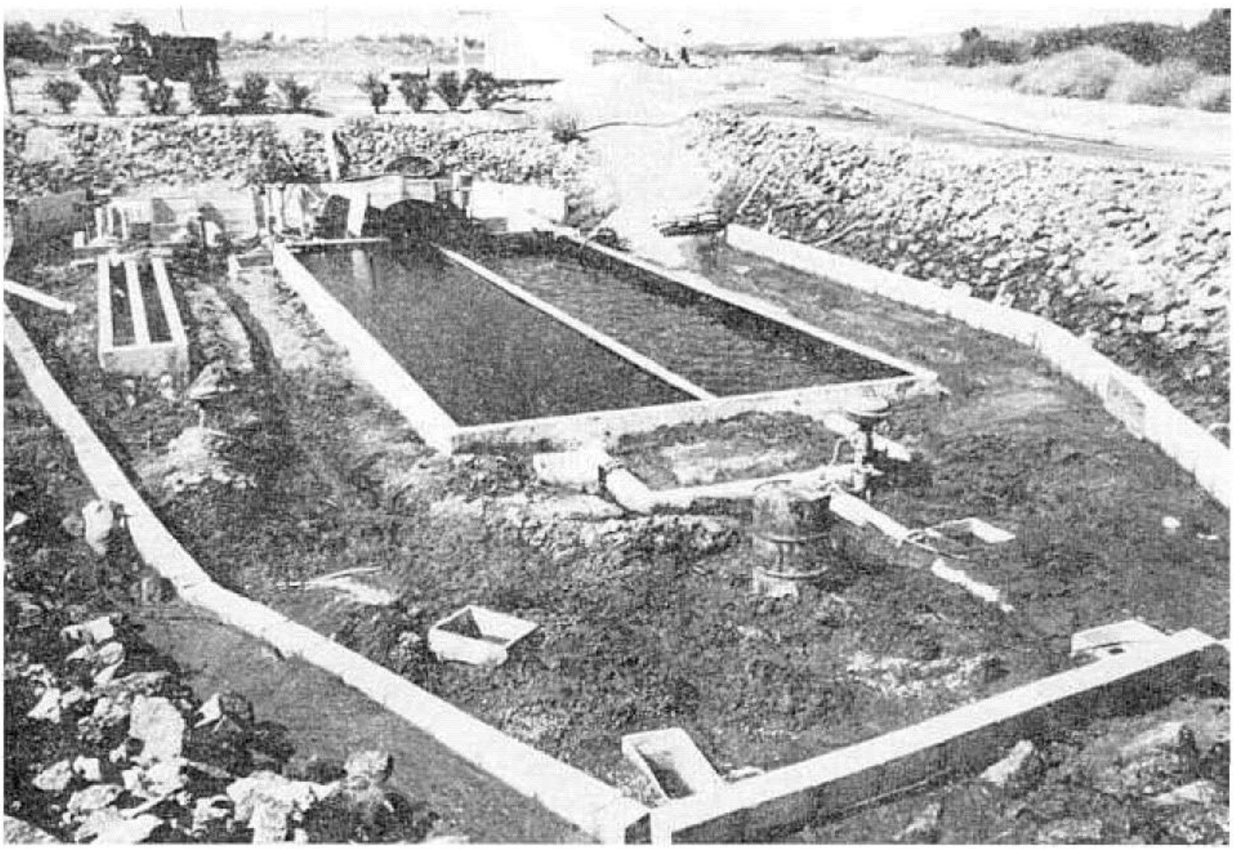


Figure 3.—Grit basin. P801-D-80050

pumps were located outside (fig. 6). Layout drainage (figs. 7, 8, 9) and a simplified flow schematic (fig. 10) show the interrelations with components. The IX pilot plant contained two transparent acrylic columns, 2.5 meters high and 0.34 meter inside diameter, each charged with about 0.10 cubic meters of Amberlite 200 macroreticular cation exchange resin (fig. 11). Resin bead size was 1.18 to 300 μm diameter (No. 16 to No. 50 U.S.A. Standard Sieve) and bed depth was about 1 meter. Most of the IX process was controlled by a microprocessor operating roughly 35 electric motor-activated valves (fig. 12) and 4 pumps (fig. 6). The length of each step or mode in an IX cycle was controlled by either time duration by microprocessor clock, volume of water throughput, or calcium breakthrough concentration in the exhaustion effluent. Operators (on duty 24 hours per day) measured and adjusted flow rates, measured tank volumes, physically titrated samples of the IX exhaustion effluent to monitor for the calcium *breakthrough* concentration, made other readings and measurements, collected samples for the YDTF Chemical Laboratory, and recorded observations on data sheets and in logs.

The ED was Ionics, Inc. Aquamite V model with Mark II stack containing two electrical stages and four hydraulic stages, 250 total cell pairs having polarity reversal, and a nominal feed capacity of 38 L/min. It was operated to achieve a range of TDS concentrations in the reject brine of 20 to 50 g/L. An ED was selected in preference to an RO for experimental convenience. When the pilot plant equipment was ordered, selection of YDP desalting equipment from among the RO and ED

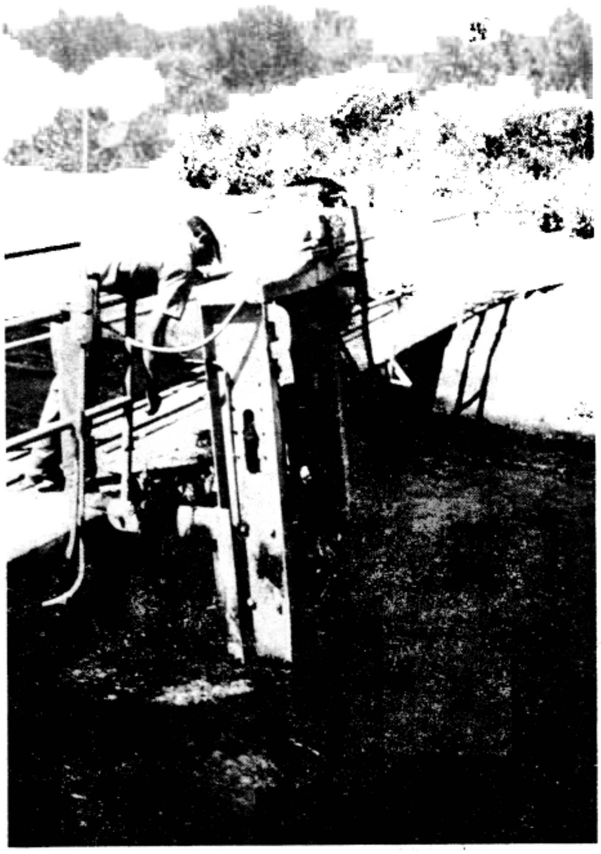


Figure 4.—Canal intake trashrake. P801-D-80049

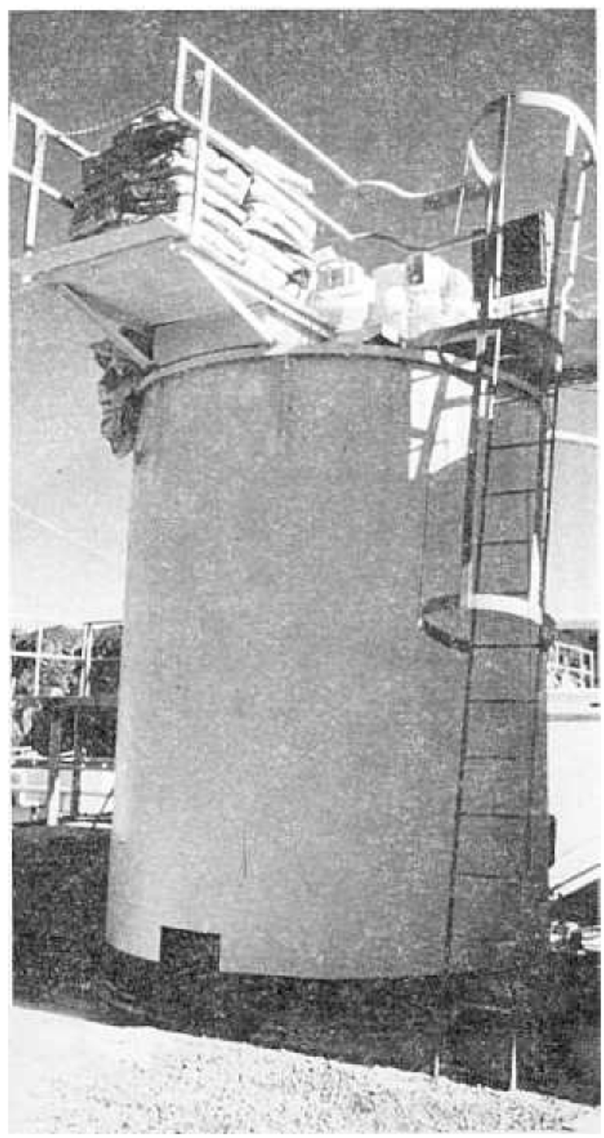


Figure 5.—Train IV solids contact reactor-clarifier P801-D-80051

processes had not been completed. Results of these IX experiments should have been substantially the same if an RO had been used instead of an ED unit. The high lime treatment using Train IV was used to provide low silica water to the IX-ED as would be required by an RO, even though this was not needed for the pilot plant ED.

Experimental Procedures

The following measurements were made during each cycle:

- Volume of water throughput during each mode was determined from volumetric data obtained by measuring the cross-sectional area and the differential levels of water in the appropriate tank. Height of water in a tank was measured usually using a sight tube and a rule.
- Regenerant volumes usually were metered using tanks 1 or 2, which were filled automatically upon microprocessor command up to the preset height of an adjustable probe sensor from one of the larger regenerant storage tanks.
- Volumetric flow rates were measured usually with Signet-brand, paddle-wheel-type flowmeters. The lowest regeneration flow rates (3 L/min in 25-mm pipe) were toc low to give a response from these flowmeters and had to be measured manually using a 1000-millimeter graduated cylinder and a stopwatch. Flowmeter readings were checked frequently with measured differential tank volumes and elapsed times.
- IX column effluent and ED product and brine conductivities were monitored continuously using inline sensors.

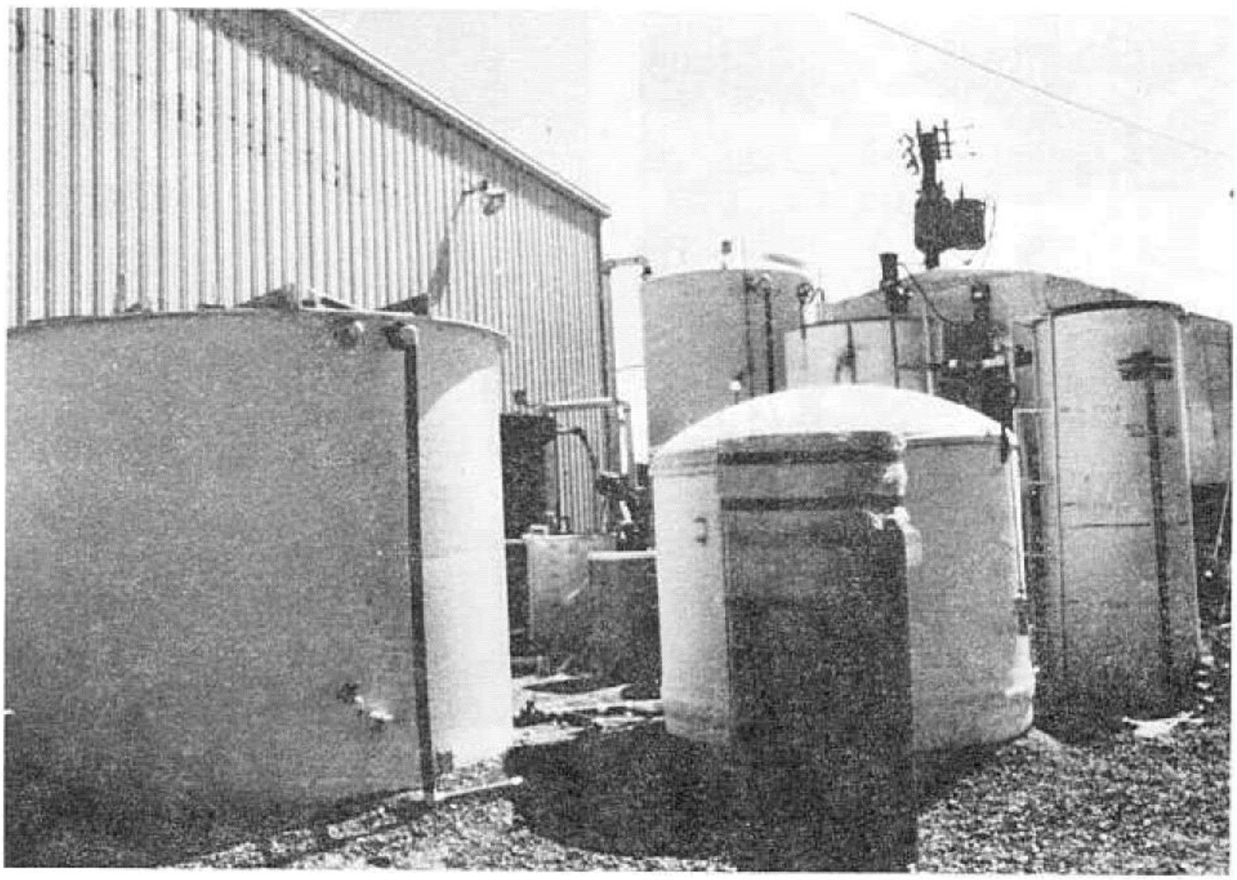


Figure 6.—Tanks for ion exchange pilot plant. P801-D-80052

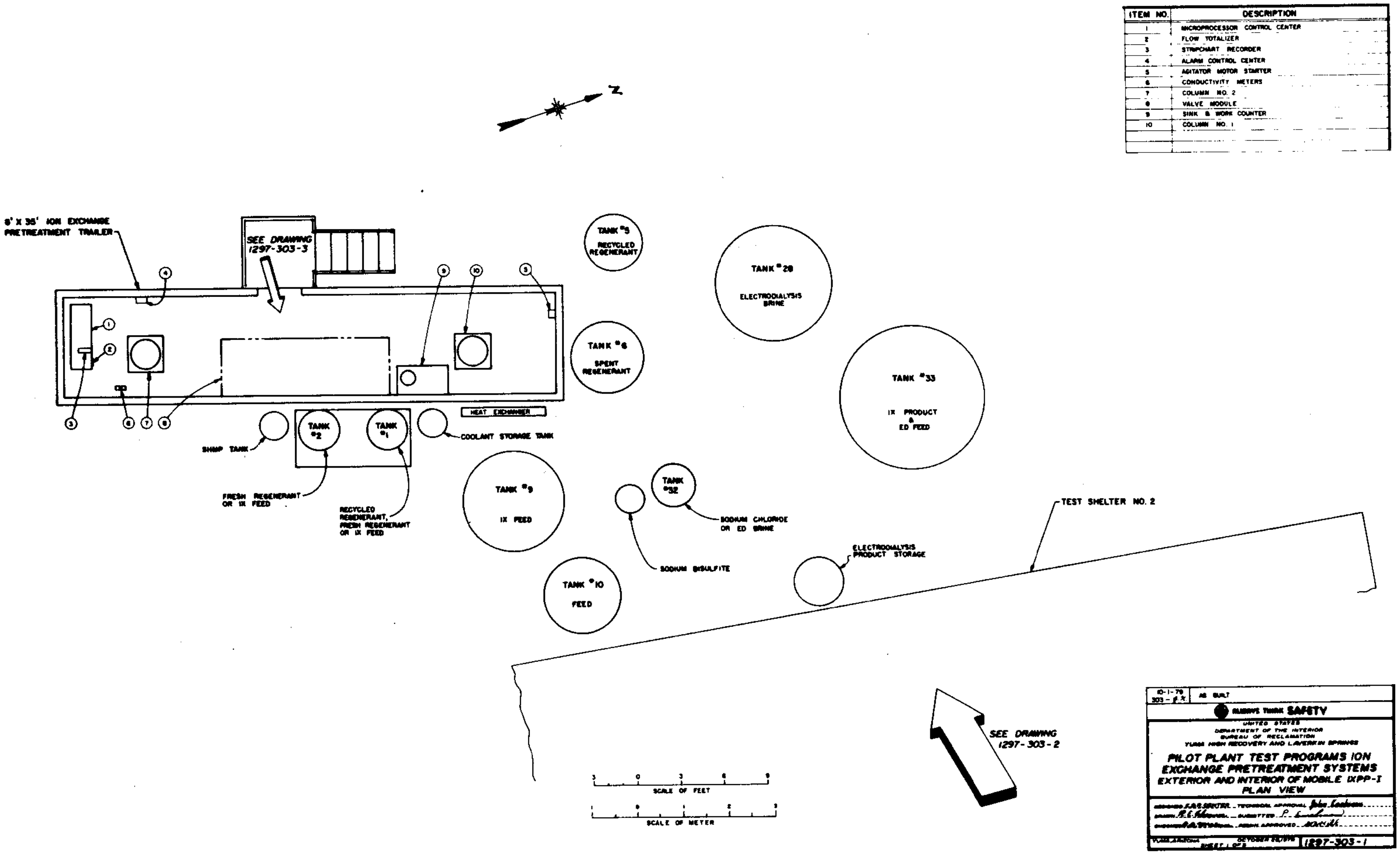


Figure 7.—Pilot plant plan view.

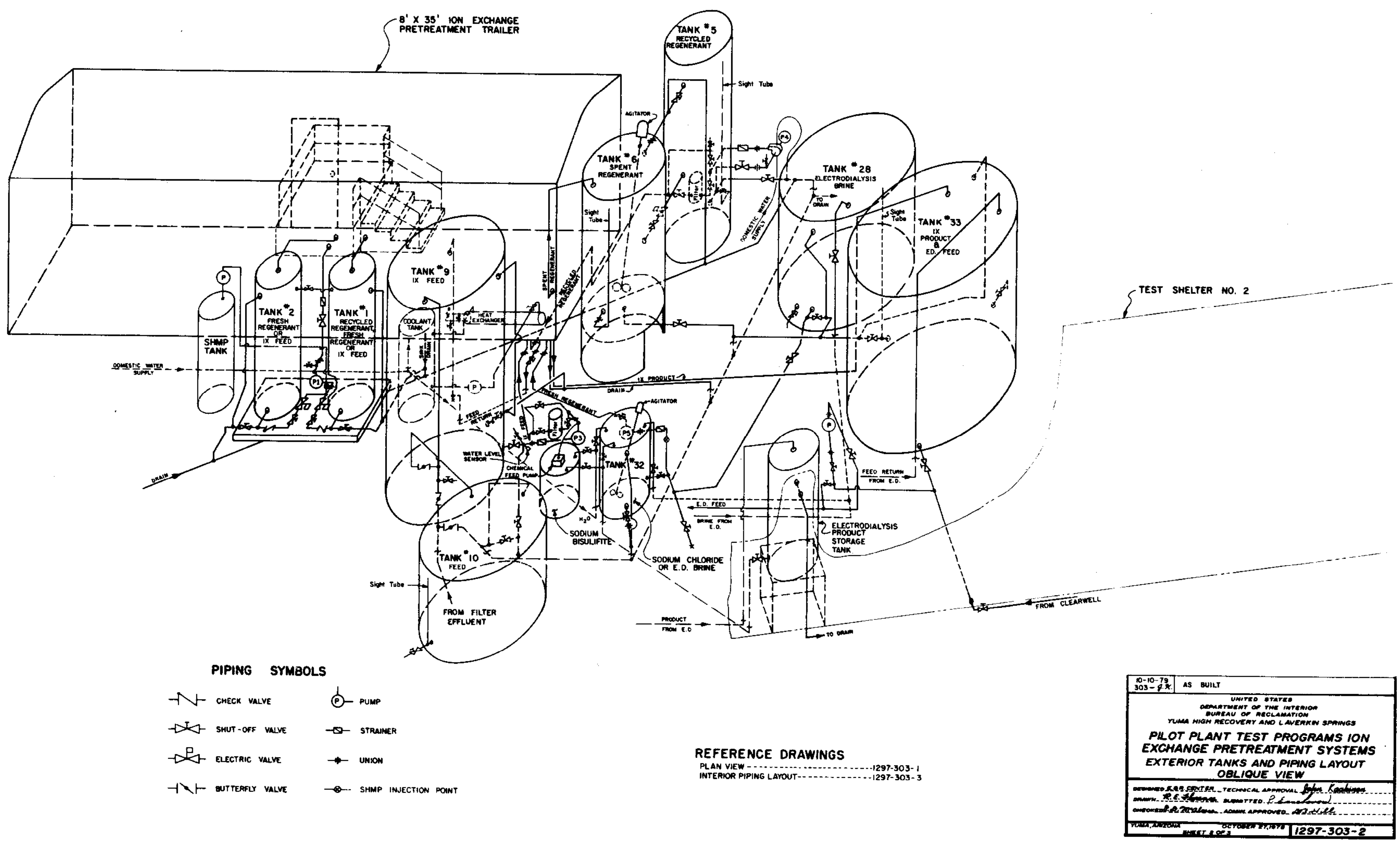


Figure 8.—Pilot plant oblique view.

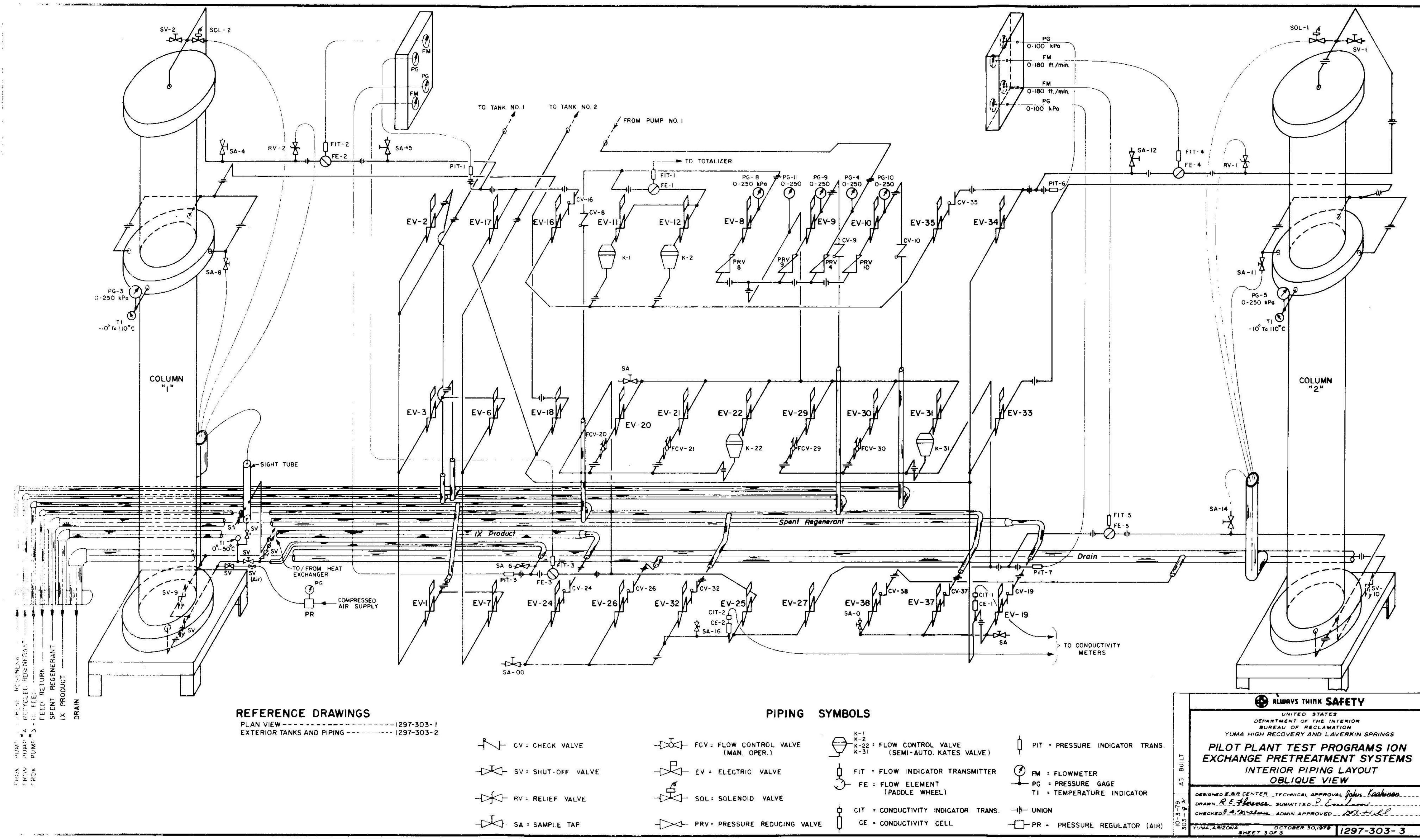
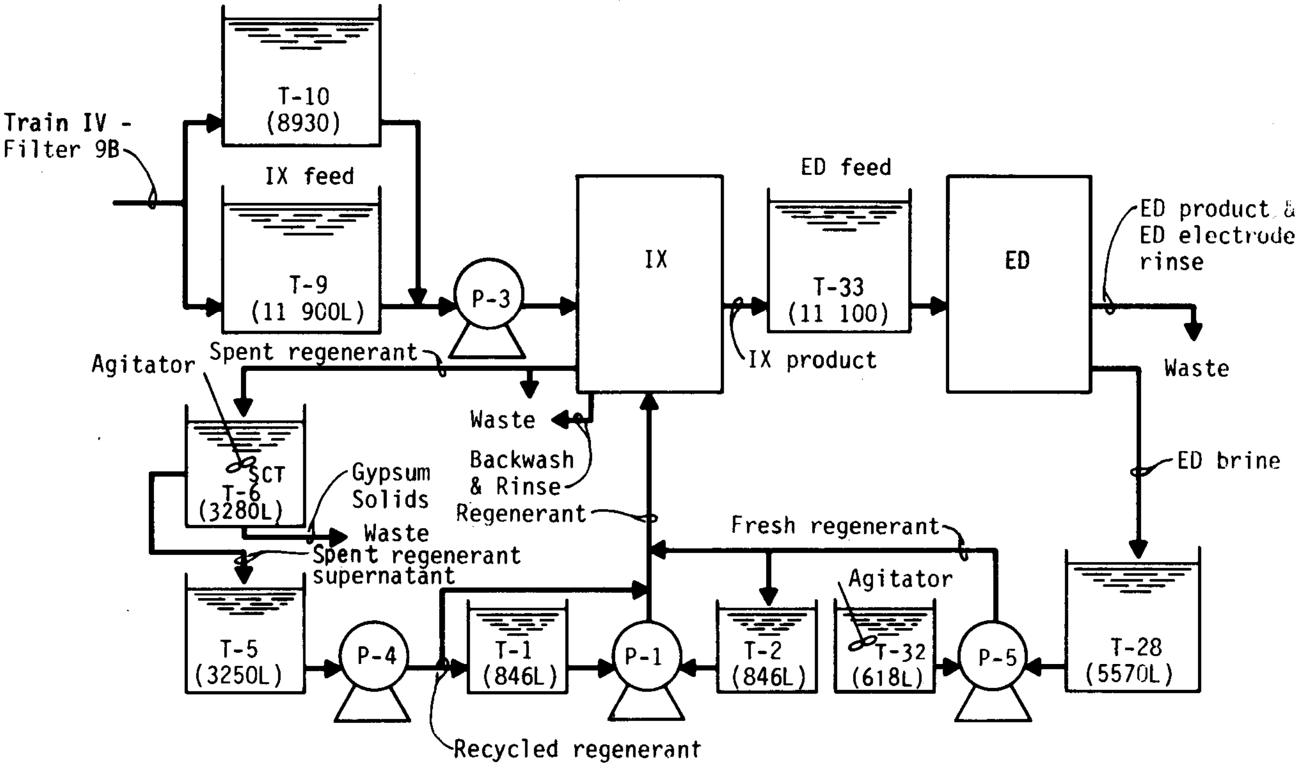


Figure 9.—Ion exchange layout.



Pumps

P-1 Regenerant
P-3 IX feed
P-4 Recycled regenerant transfer
P-5 Fresh regenerant transfer

Processes

IX Ion exchanger
ED Electrodialyzer
SCT Solids contact tank (T-6) (Calcium sulfate precipitator for recycling regenerant)

Tanks

T-1 Recycled regenerant (metering)
T-2 Fresh regenerant (metering)
T-5 Recycled regenerant
T-9 IX feed
T-10 IX feed
T-28 ED brine
T-32 Sodium chloride solutioning
T-33 IX product/ED feed

Figure 10.—Simplified flow diagram of ion exchange—electrodialysis pilot plant.

During formal data collection cycles, individual samples were collected and analyzed for calcium, magnesium, and sodium. Composite samples were made and analyzed for all major anions and cations plus TDS by summation of ions in the YDTF chemical laboratory using standard analytical methods.

- Calcium and total hardness were monitored during IX operation by the operators using EDTA titrations to determine the IX calcium *breakthrough* point to terminate the exhaustion mode and to monitor water compositions in the process tanks.

Desalting recovery was related to TDS concentration (mg/L) in the reject brine by:

$$R = \frac{C_f - C_e}{C_f - C_p} (100) \qquad (1)$$

where

R = desalting recovery in percent,

C_f = TDS Concentration of reject brine (fresh IX regenerant),

C_e = TDS concentration of desalting feed (IX exhaustion effluent), and

C_p = TDS concentration of desalting product.

Equation 1 can be derived from the mass balances of water and total dissolved solids and the definition of desalting recovery—product flow divided by feed flow. In the equation, usually a product salinity of 427 mg/L and feed salinity of 3300 mg/L were assumed for daily operation of the ED and IX regeneration. The 3300 mg/L feed salinity corresponds to an average for the water at YDTF during the experiments. The 427-mg/L product salinity was an estimate for RO product water in the YDP for projected high recovery operating conditions. During IX data reduction, recoveries were calculated

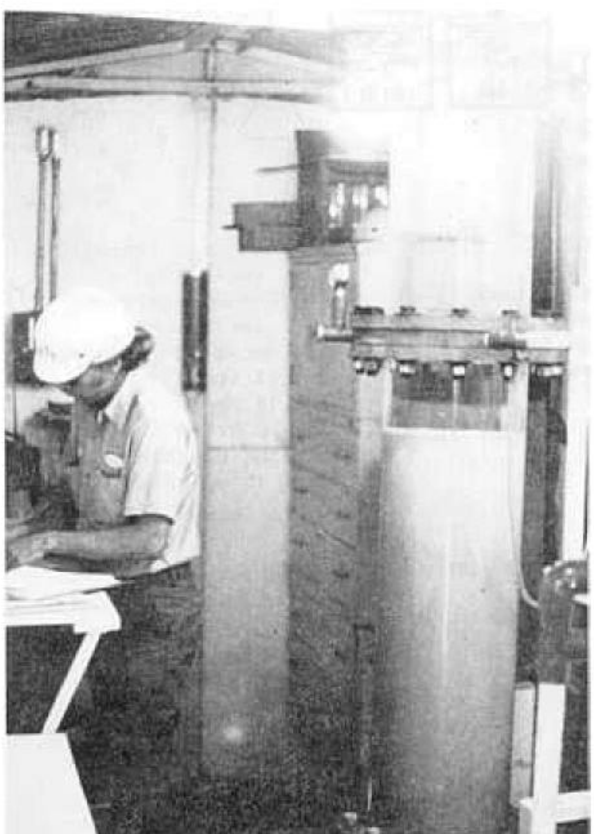


Figure 11.—Acrylic column containing cation exchange resin.
P801-D-80053

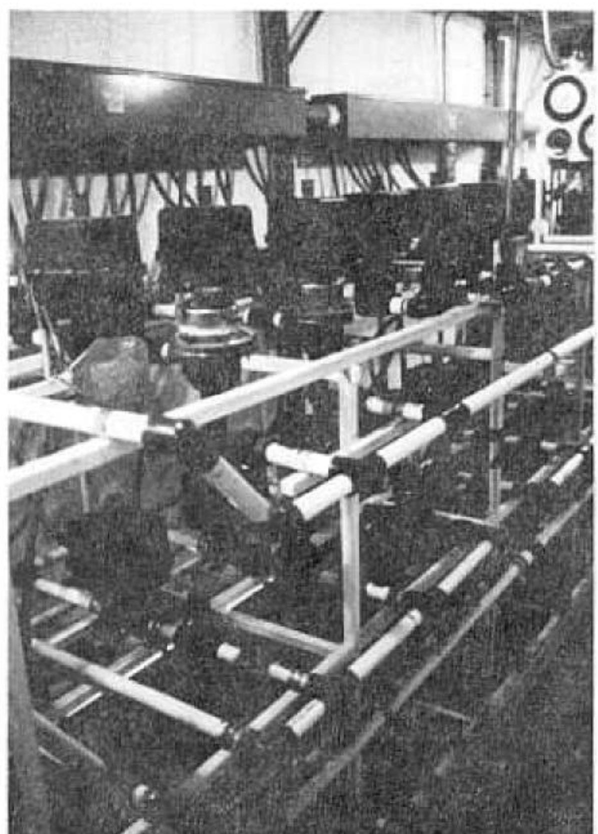


Figure 12.—Motorized valves, control valves, and pipe rack.
P801-D-80054

from salinity measurements of the ED feed, product, and brine determined in the Chemistry Laboratory using the preceding equation, not from flow rate measurements — which generally are subject to greater error. Brine concentration was determined operationally by evaporation at 103 °C in the YDTF Chemistry Laboratory — usually daily — because more than a week was required to obtain summation of ions TDS data. There was consistent agreement between TDS by evaporation and TDS by summation of ions. Generally, the IX experiments were run at three different levels of ED brine concentration, which were established in the exploratory experiments: 20, 35, and 50 g/L of TDS corresponding to calculated recoveries of 85.5, 91.8, and 94.3 percent, respectively.

For a closed loop process (no imported regeneration chemicals), the new regenerant volume available per cycle normally would be limited and equal to the volume of ED reject brine generated per cycle—on the average. This fresh regenerant volume V_f' used was balanced with the volume theoretically made V_f' calculated from the IX exhaustion volume V_e and the ED desalting recovery R (as a decimal fraction) calculated from TDS concentrations using the expression $V_f' = V_e\ (1 - R)$. A trial and error approach toward a balance of volumes was necessary because the exhaustion volume V_e is affected somewhat by the amount of regenerant being used. In each experimental run, an initial fresh regenerant volume V_f was intuitively selected and used. After at least three similar IX cycles to obtain an equilibrium condition using this V_f, a theoretical V_f' available was calculated and compared to V_f. If the values of V_f and V_f' did not agree within 10 percent, a new V_f was selected and the process repeated until approximate equality between V_f and V_f' was achieved.

The limitation in fresh regenerant volume generated by the ED per IX cycle was overcome by recycling regenerant. The regenerant recycling system, consisting of tank 6 and tank 5 (fig. 13), functioned as follows:

Regenerant effluent was pumped into tank 6. This used regenerant was probably always supersaturated in calcium sulfate from the fact that there were both high concentrations of sulfate in the desalting reject and high concentrations of eluted calcium in the used regenerant.

- During the regeneration, a residual of gypsum crystals was maintained in suspension in tank 6 through the use of an agitator. This agitation was used to promote rapid desupersaturation of the calcium sulfate.

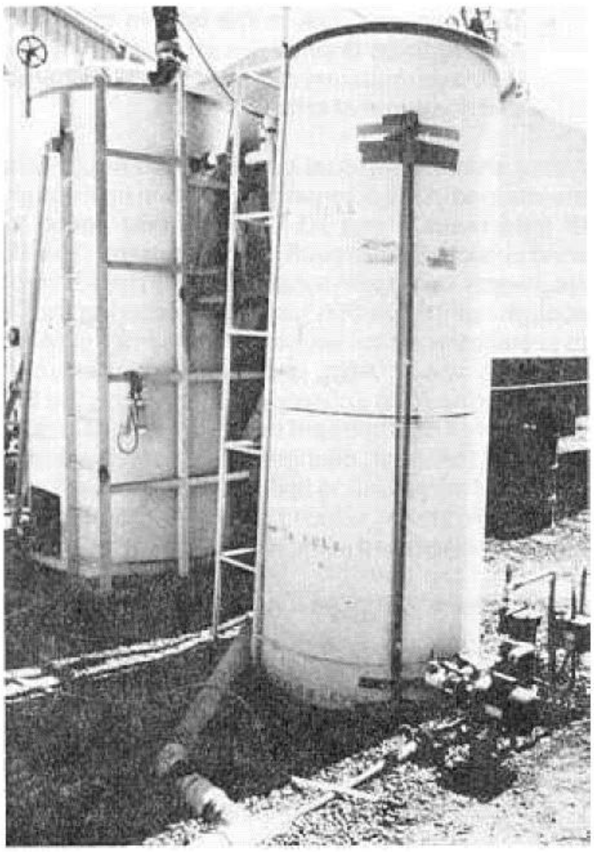


Figure 13.—Regenerant recycling system consisting of tank 6 (left) with agitator for calcium sulfate desupersaturation and storage tank 5 (right). P801-D-80055

- At least an hour prior to the next use of recycled regenerant in the subsequent cycle, the agitator was turned off to allow the crystals to settle to the bottom of tank 6. (Some data on settling rates for these gypsum crystals are given in **RESULTS**—subsection Gypsum Settling Tests).

- The clear supernatant from tank 6 was transferred by gravity flow to tank 5 for temporary storage just before its use as recycled regenerant.

- The effluent from tank 5 was filtered also just prior to use as regenerant during some of the later Phase 3 experiments.

- The gypsum solids in the bottom of tank 6 needed to be drained out infrequently since their accumulation rate was small compared to the volume of tank 6.

A free chlorine residual averaging 0.5 mg/L was maintained in the pretreatment system up through IX feed tanks 9 and 10. Chlorine was added to control biological growth in the system. The IX feed water was dechlorinated through injection of sodium sulfite solution just before entering the IX to protect the cation exchange resin from gradual oxidative attack. Also, dechlorination prevented any chlorine from subsequently attacking the ED membranes downstream which were sensitive to chlorine. However, dechlorination did allow some biological microfouling to develop in the resin and in ED feed water, which yielded a high plugging factor, as discussed in the **RESULTS** of this report.

Independent Variables

During development of the test program, four experimental independent (control variables) were selected as being probably the most important. They were:

- Fresh regenerant concentration,
- Fresh regenerant flow rate,
- Recycled regenerant flow rate, and
- Recycled regenerant volume.

The fresh regenerant concentration determines a desalting recovery for a particular pair of feed and product concentrations and the fresh regenerant volume (as just discussed). Thus, desalting recovery and fresh regenerant volume are not independent variables. The effects of other variables such as resin bed height and exhaustion flow rate can be predicted from resin manufacturers' data [18, 19] and books on IX design [13, 14, 15]. This is not the case for the four experimental independent variables listed above.

Calcium *breakthrough* concentration for exhaustion was fixed also by the fresh regenerant (ED reject brine) concentration. The *breakthrough* concentration was calculated [9] as the calcium concentration where calcium sulfate saturation would be reached in the ED reject brine at a given desalting recovery. The average calcium *leakage* (concentration in the IX exhaustion effluent) during the entire exhaustion always was less than a third of the calcium *breakthrough* concentration. Thus, the feed to the ED was always conservatively far below the value which would actually yield any calcium sulfate precipitation in the brine. Additionally, two special experiments were run in Phase 2 using lower calcium breakthrough concentrations than the corresponding calculated calcium sulfate saturation value.

Normally, temperature is a relatively less important variable in cation exchange softening. Usually, it only significantly affects—in predictable ways—the amount of bed expansion during backwash and the hydraulic pressure drop through the resin bed. Temperature, has never been reported to have an important effect in any of the previous mentioned studies using reject brine regeneration. Likewise, temperature was not perceived to be important as a result of the exploratory experiments run at YDTF in late 1978 during cool ambient and water temperatures. But, during the second experimental phase in late spring of 1979, as the ambient temperatures near Yuma increased, it was found that gypsum scaling of the resin occurred whenever there was a combination of high regenerant concentration, a low regeneration flow rate, and high water temperatures. The temperature variable (largely uncontrolled in these experiments) is discussed extensively in the **RESULTS**.

The effect of several other discrete control variables were studied. They included:

- Type of backwash water (lime-pretreated water versus recycled regenerant),
- Addition of SHMP to the regenerants to retard gypsum precipitation,
- Filtration of recycled regenerant, and
- Use of air injection to mix and destratify the IX bed between regeneration and service.

Dependent Variables

A major dependent or response variable is *specific resin capacity* in eq/L, which is the number of equivalents of ions absorbed per liter of resin in the *exhaustion* mode of an IX cycle. In the present IX process, the primary interest is the absorbed calcium ion. But for design purposes, the *specific resin capacity* indicates only a partial description of total resin use and requirements. When comparing different IX cycle conditions, especially with different regeneration procedures or where the exhaustion flow rate is a variable, the total cycle time necessary to accomplish the required softening is important also because the lower the cycle time, the more frequent is the completion of a cycle wherein the absorptive capacity of the resin is utilized. Thus, a different quantity (**TWRC** time-weighted resin capacity) was defined as the *specific resin capacity* divided by total cycle duration. The amount of resin required in a plant design is inversely proportional to the **TWRC**.[2] The **TWRC** was selected as the major dependent variable in the reduction of data and in the selection of recommended IX cycle conditions.

Leakage or slippage of calcium (the average effluent concentration during exhaustion) is another dependent variable of interest in IX. But, since the calcium *leakage* in these experiments was always so much lower than the previously determined allowable leakage rates, only the calcium resin capacity or **TWRC** were of consequence as dependent variables in the data analyses.

Experimental Design

Experimentation was performed in three phases. The first was the exploratory phase that had five objectives:

1. To operate the IX and ED integrally for the first time with regenerant recycling and to correct mechanical and operational problems in the system.

2. To operate the IX using 10-percent NaCl solution as the regenerant to establish baseline performance with which to compare performance using desalting reject brine as the regenerant.

3. To evaluate different methods of terminating the exhaustion including:

    —automatically monitored effluent,
    —hardness,
    —in-line effluent conductivity,
    —exhaustion duration, and
    —exhaustion volume,

    and to compare each of these methods to operators' manual sampling and titrametric calcium analyses of the exhaustion effluent.

4. To establish operating characteristics and their limits (particularly highest recovery) of the ED using IX-softened WM feed water.

5. To establish limits of upper and lower values for the four control variables used in Phase 2 experiments.

Phase 2 experiments (for feasibility design purposes) were for the primary purpose of developing the response of the major dependent variable (TWRC) to the significant independent variables.

A statistical design [20] was selected rather than the classical or unplanned approach because of several advantages for a planned statistical design, particularly for a multivariable study. Probably the most important benefit of a statistical design is that more information is obtained per test run as compared to an unplanned approach, which is desirable because time, money, and manpower usually are limited. An organized statistical design approach results in data that is much easier to analyze and interpret (usually statistically). Another advantage is that the reliability of the data can be expressed in terms of experimental and analytical variation (or error), which gives more credibility to the results and conclusions. Finally, the interactions among multiple experimental variables are defined better, which allows more reliable predictions of the response variables in regimes not covered directly by the experimental conditions.

A Box-Behnken [20] experimental design was selected. The Box-Behnken design is efficient to obtain data for a statistical and multiple regression analyses. The analyses yield equations and graphs relating the dependent response variables with the independent control variables, which are useful in the design of an ion exchange process.

For four independent variables the Box-Behnken design requires 27 observations or test runs including three midpoint replicates. For each observation, each of four independent variables was assigned one of three levels (a low, high, or a midpoint that is a mean of the low and high values)

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[2] The volume of working resin required in a plant design can be calculated from

$$V_{resin} = \frac{Q_p (C_{ei} - C_{ea})}{\text{TWRC}}$$

where
V_{resin} = volume of ion exchange resin in L
Q_p = steady-state IX plant capacity in L/min
C_{ei} = IX influent calcium concentration in meq/L
C_{ea} = IX effluent calcium concentration in meq/L
TWRC = time-weighted resin capacity for calcium removal in meq/(L·min)

according to the sequence dictated by the experimental design. The pattern for this design is in table 3 [20]. The order of performing each observation was established randomly except for the following constraint. Observations were ordered into six groups during which brine concentration was kept at a single level for four to seven observations. The order within each of the six groups was random. The groups were formed to reduce the total time required to make new concentrations of fresh and recycled regenerants in chemical equilibrium with the system whenever the concentrations were changed, since each concentration change would require up to 2 weeks. In addition to 27 Box-Behnken observations, Phase 2 experiments include:

Table 3 — *Four variable Box-Behnken — three blocks of nine points*

x_1	x_2	x_3	x_4
Block 1			
+1	+1	0	0
+1	-1	0	0
-1	+1	0	0
-1	-1	0	0
0	0	+1	+1
0	0	+1	-1
0	0	-1	+1
0	0	-1	-1
0	0	0	0
Block 2			
+1	0	0	+1
+1	0	0	-1
-1	0	0	+1
-1	0	0	-1
0	+1	+1	0
0	+1	-1	0
0	-1	+1	0
0	-1	-1	0
0	0	0	0
Block 3			
+1	0	+1	0
+1	0	-1	0
-1	0	+1	0
-1	0	-1	0
0	+1	0	+1
0	+1	0	-1
0	-1	0	+1
0	-1	0	-1
0	0	0	0

In this representation each of the independent variables (x_1 through x_4) has three levels: a high +1, a low -1, and a middle 0. Note that the center point condition (0, 0, 0, 0) occurs three times.

- Two observations to measure effects of changing the maximum allowable calcium concentration of the effluent used as an indication when to terminate exhaustion, often called the *breakthrough point.*

- Three observations to study use of a feed water backwash (the standard IX procedure) instead of recycled regenerant, and

- One observation to evaluate SHMP addition to the fresh regenerant for retarding calcium sulfate precipitation.

In Phase 3, the nine experiments were designed to study additional process variables and higher fresh regenerant flow rates as determined from **RESULTS**—Phase 2. New process variables included:

- using filtration for gypsum crystallites in recycling regenerant,

- air mixing for destratifying the resin bed between regeneration and rinse, and

- addition of SHMP to both fresh and recycled regenerants.

Most Phase 3 experiments were included to study methods for controlling resin scaling by gypsum that occurred during hot summer temperatures of the Phase 2 study. Gypsum scaling of the resin was not observed under any combination of operating conditions during cool winter ambient temperatures of Phase 1.

RESULTS

Results of the three experimental phases are presented here. Detailed data and descriptions are in the appendixes. Multiple regression analysis of the data are given with the **TWRC** as the dependent variable. Optimum IX operating conditions were determined. Further data analyses were done to define combinations of control conditions and temperature when gypsum scaling of the cation exchange resin did not occur.

Phase I Exploratory Experiments

The first several months beginning in March 1978 were spent in resolving equipment malfunctions. Major equipment problems are noted in appendix F. Successful Phase 1 operation began in late September 1978. Detailed data and a chronological description of these exploratory experiments are in appendix B. Key Phase 1 findings follow.

Baseline NaCl Cycles. — Results of cycle 1.03.28 indicate a calcium RC (specific resin capacity) of 0.188 eq/L (equivalents of calcium removed per liter of resin). This was typical when 3.0-percent NaCl regenerant was used for the operating conditions established including a normal feed water backwash and no regenerant recycling. This run established a baseline performance for which results from cycle 2.01.09 were compared.

Cycle 2.01.09 used ED reject brine for regenerant having a concentration of 26.7 g/L TDS. All other operational conditions of cycle 2.01.09 were similar to cycle 1.03.28. For cycle 2.01.09, the resin capcity was 0.149 eq/L, or 21 percent less than that of 1.03.28. This difference was not surprising since the ED reject brine contained calcium that would tend to oppose the regeneration effect caused by the sodium in ED reject. The amount of regenerant used in cycle 2.01.09 was about 50 percent greater than what could be made by concentrating the exhaustion volume per cycle. All further Phase 1 experiments were operated under closed loop constraints whereby a main requirement was to balance the fresh regenerant used with the ED reject brine made per cycle.

Upon initial exploratory operation of the Ionics Aquamite V electrodialyzer, it was found that the maximum possible brine concentration was nearly 60 g/L TDS for safe operation of the ED with the installed membranes, configuration, and feed water. Under this ED operation, almost all makeup to the internally recirculating concentrate loop was from normally occuring leakages from dilute to concentrate cells and mixing of streams during polarity reversal. The 60 g/L high value would not be possible when either feed water TDS or feed water temperature would drop because they both do seasonally. Thus, 50 g/L TDS was selected as a conservative maximum. Operational data for the ED are in appendix E.

Recycling Regenerant. —Procedures for recycling regenerant were developed during Phase 1. Regenerant effluent from IX generally is supersaturated with calcium sulfate when sulfate-containing reject brine is used as the regenerant. The purpose of tank 6 and tank 5 (fig. 13) was to allow this used supersaturated regenerant to be recycled. Desupersaturation was accomplished by allowing the spent regenerant to approach a saturated condition by batch mixing followed by crystallite settling in tank 6. Gypsum solids from previous IX cycles were retained in the bottom of tank 6 to speed nucleation and precipitation. After the gypsum crystals had settled, clear supernatant in tank 6 was transferred to tank 5 for temporary storage and later use as recycled regenerant in the subsequent regeneration.

Attempt was not made to optimize mixing and settling times during the exploratory tests. Mixing and settling times were determined solely by the available time while maintaining normal IX operation. For example, in cycle 2.02.174 the agitator in tank 6 was operated during the 3-minute draindown of regenerant from the IX column following regeneration. The settling was allowed to occur during the 10-minute rinse and during the first 60 minutes of the service mode. The gravity transfer of recycled regenerant from tank 6 to tank 5 was allowed to continue during the remainder of service, or for 111 minutes. The concentration of major ions and TDS in tank 28 (fresh regenerant or ED brine) and tank 6 (used or spent regenerant after mixing and settling) following cycle 2.01.174, which was typical, are given in table 4.

A hypothetical, completely supersaturated composition flow in tank 6 is given also in table 4 for cycle 2.01.174. This supersaturated composition was estimated by the following calculations:

1. A total supersaturated calcium concentration flow into tank 6 before any precipitation formation was calculated from a balance of the total major cation (sodium, magnesium, and

Table 4.—*Recycling regenerant following cycle 2.01.174—November 27, 1978 (TDS includes some minor constituents not listed)*

Ion	Tank 28 Measured		Tank 6 Measured		Tank 6 Supersaturated*		Tank 6 Saturated 20 °C	
	mg/L	meq/L	mg/L	meq/L	mg/L	meq/L	mg/L	meq/L
Ca	113	5.65	1 570	78.5	4 880	244	1 400	60
Mg	239	19.6	1 295	106	1 300	106	1 300	106
Na	18 100	789	10 700	464	10 700	464	10 700	464
SO_4	15 000	313	5 040	105	13 000	270	4 600	96
Cl	17 800	503	19 400	548	19 400	548	19 400	548
TDS	51 500	—	38 100	—	49 400	—	37 500	—

*A hypothetical condition, assuming no calcium sulfate (gypsum) precipitated, was calculated as follows (see text for explanation):

(Ca) = 789 + 19.6 + 5.65 - 464 - 106 = 244 meq/L from a cation balance between tank 28 and tank 6; thus, prior to $CaSO_4$ precipitation, tank 6 had 244 - 78.5 = 165.5 meq/L more Ca and SO_4 than was measured.

(SO_4) = 105 + 165.5 = 270 meq/L.

TDS = 38 100 + 13 000 - 5040 + 4880 - 1570 = 49 400 mg/L; as a check: TDS = 38 100 + (165.5) 68 = 49 400 mg/L.

calcium) concentrations in meq/L between tank 6 and tank 28. That is, in regeneration 3, the regenerant from tank 28 exchanges cations with the resin in that the total equivalents leaving the resin bed flowing into tank 6 equals the total equivalents entering from tank 28—provided that no dilution by other water occurs, which is the present case. Furthermore, the dissolved magnesium and sodium concentrations measured in samples from tank 6 should not change from the influence of calcium sulfate precipitation. Thus, the supersaturated calcium concentration in tank 6 is calculated as the value whereby the total major cations in tank 6 would be equal to those in tank 28.

2. The sulfate concentration into tank 6 was increased by the same number of meq/L as the calcium was increased, because calcium and sulfate precipitate as gypsum in equivalent amounts.

3. The supersaturated TDS in tank 6 was increased by the mg/L increase in calcium and sulfate.

Also, in table 4 are concentrations of calcium, sulfate, and TDS at saturation and 20 °C in tank 6, which were estimated using a computer program (app. G).

Table 4 values indicate that about 68 percent (166 meq/L) of calcium was removed in tank 6. The theoretical maximum removal at 20 °C is 71 percent or 174 meq/L. Thus, the actual removal values correspond to nearly 95 percent complete desupersaturation. Interpreted another way, about 165.5 meq/L [actually about 14 g/L as gypsum ($CaSO_4{\cdot}2H_2O$) or 11 g/L of $CaSO_4$] were removed during recycling, and also the TDS decreased by about 11 g/L. The theoretical amount removed to complete saturation would be nearly 12 g/L of $CaSO_4$. Since 250 liters of fresh regenerant were used and recycled during cycle 2.01.174 (neglecting draindown losses, which were significant in the pilot plant), the total $CaSO_4$ precipitated was about actually 2.8 kg or theoretically 3.0 kg per cycle. This mass of precipitate per cycle is small compared to the 3280-kg water capacity of tank 6.

In any case, there had been problems with scaling in tank 5 and in the filter, pump, and piping downstream of tank 5, which indicates that complete desupersaturation had not occurred. Some of this additional precipitation could be attributed to diurnal changes in water temperature after leaving tank 6, which causes the gypsum solubility to change. Further investigation of this problem occurred during the Phase 2 experiments.

Sensing Exhaustion Breakthrough.—Different methods of automatically sensing exhaustion breakthrough were evaluated. Each was discarded because of one or more shortcomings. A total hardness analyzer (Hach Chemical Company model 1714) was tested but found unreliable, mainly because the breakthrough concentrations were much greater than its accuracy range, and a separate dilution system could not be operated reliably. The IX effluent conductivity measurements were found to be deficient in sensitivity to changes in calcium to sodium ionic ratio that occur at breakthrough. Exhaustion duration and exhaustion volume varied too much among individual cycles at the same conditions to be used as a reliable service end point during these experiments. Therefore, manual operator titration for calcium was the only method used successfully for detecting calcium breakthrough concentrations in all the Phase 2 and Phase 3 experiments.

Control Variable Levels Established for Phase 2.—Results of the exploratory testing phase were analyzed to provide *high* and *low* levels for the control variables in the response-surface experiments. These results showed that the IX-ED system could operate satisfactorily at any combination of selected high and low levels of the four control variables.

The four major independent control variables in the response-surface variables, three-level Box-Behnken design variables, and two additional screening variables (two levels each) are listed in table 5. Each of the four response-surface control variables has a *midpoint* value which is the high and low mean values. The reasoning of selecting each of these variable levels follows.

Table 5.—*Phase 2 control variables*

Control variable	Units	Low	High	Midpoint
Response-surface control variables				
Fresh regenerant concentration	g/L TDS	20	50	35
Fresh regenerant flow rate	L/min	3.0	8.0	5.5
Recycled regenerant flow rate (Reg. 2)	L/min	8.0	24	16
Recycled regenerant volume (Reg. 2)	L	0	1600	800
Screening control variables (no midpoints)				
Service termination point for calcium	meq/L	1.5	4.5	
Type of backwash water	—	Feedwater	Recycled regenerant	

Fresh regenerant concentration was measured in samples from the reject brine storage tank 28 by the summation of major ions determined by chemical analyses. The TDS by evaporation was used only for daily operational settings of ED desalting recovery and, thus, fresh regenerant volume.

Desalting recovery was calculated most accurately from the TDS of the desalting feed, product, and brine using equation 1 rather than flow rates—as noted previously. Because feed and product did not vary greatly in these experiments, recovery was predominantly a function of brine concentration. As previously noted, the 50-g/L high regenerant concentration level was the highest concentration that could be reliably achieved by the present ED unit (including a safety factor in case of a slightly lower feed TDS or feed water temperatures). The 20-g/L low level was derived from a practical lower limit of high recovery of about 85 percent. There would be no need for IX besides lime softening if the recovery were much less than 85 percent.

Fresh regenerant flow rate was investigated. The high level of 8.0 L/min approached the highest value for which satisfactory IX operation can be achieved when there was no recycled regenerant. A higher flow rate could be used with recycled regenerant, but higher flow rates without using recycled regenerant gave a less efficient regeneration resulting in progressively smaller service volumes and, consequently, less producible fresh regenerant from the desalting reject than the regeneration consumed. A balanced experimental design required that the system should operate at steady-state with the highest fresh regenerant flow rate and no recycled regenerant. The low level of 3.0 L/min was determined to be the lowest that would be practical. With lower flow rates the time spent in regeneration would become excessive relative to the exhaustion time when all of the softening is done. It is noted that gypsum scaling in the resin was observed even at such low regeneration flow rates during Phase 1.

Practical recycled regeneration flow rate levels were established experimentally. The high flow level of recycled regenerant of 24 L/min gave about 50-percent resin bed expansion, depending on water temperature, with the present 340-mm-inside-diameter columns. The 8.0-L/min low level was the lowest that could still give a reasonable recycled regeneration time for the recycled regenerant volumes that were used.

Recycled regenerant volume was defined in these experiments as the additional volume after the initial 240 L (24.0 L/min for 10 min) of recycled regenerant used for backwash water. The low level of zero liter was the minimum while retaining the backwash. The 1600-L maximum was the usable remaining tank 5 capacity in addition to the 240 L of backwash.

Exhaustion termination point was the maximum peak calcium concentration leakage allowed in the effluent during exhaustion. The peak calcium effluent concentration was used as the indication that the cation exchange resin was close to its calcium absorption capacity at the conditions of the IX cycle. The value of the exhaustion termination point was selected to be a function of the brine concentration or desalting recovery. This reflects the varying requirements for the allowable calcium in desalting unit feed to prevent calcium sulfate scaling in the reject brine stream within the desalting unit for different brine concentration factors. The termination points for 20-, 35-, and 50-g/L brine concentrations were 4.5, 3.0, and 1.5 meq/L of calcium, respectively. These calcium concentrations are values estimated by computer calculations [9] corresponding to calcium sulfate saturation in the desalting reject. Exhaustion termination point controlled by the accumulated average calcium concentration of the total effluent of service would have been ideal; however, this value would be difficult to measure practically. Thus, these calcium breakthrough points were conservatively low because the mean leakage during exhaustion was far below these maximum values allowed at breakthrough.

Note that the exhaustion termination point affects quality of fresh regenerant that is made from IX exhaustion effluent. A higher termination point implies a greater exhaustion water volume—other conditions being equal—but the higher calcium content of the resulting brine creates a less favorable regenerant composition. Limited screening runs in Phase 2 were designed to indicate whether these interactions would be significant to overall performance.

Backwash water type was the final control variable selected for Phase 2 experiments. The IX feed water and recycled regenerant were to be compared during the 10-minute, 50-percent-bed-expansion backwash. This variable is, of course, a discrete variable rather than a continuous variable.

Having selected this set of control variables and their high and low levels for use in the Phase 2 response-surface experimental design, Phase 1 exploratory experiments concluded in December 1978.

Phase 2 Response-Surface Experiments

As presented in the previous section, Phase 1 exploratory experimental results were used in the design of the Phase 2 response-surface experiments. Phase 2 started in January 1979 and concluded at the end of August 1979. About a month of testing was lost in April caused by equipment problems–primarily with the ED–which are described in appendix F.

Experimental Design.—The original Phase 2 experimental design (table 6) had the following three features:

1. A four-control variable, three-level BoxBehnken design (table 3) was used to develop the response-surface specific resin capacity and **TWRC** as a function of:

- fresh regenerant concentration,
- fresh regenerant flow rate,
- recycled regenerant flow rate, and
- recycled regenerant volume.

The 27 runs were numbered 3.01.00 through 3.27.00 without a suffix, and each IX cycle in a run was designated in sequence by the last two digits of the run number. The runs were divided into three blocks to cancel out the potential effects of external uncontrolled variables.

Specifically, each IX regeneration consisted of three steps:

Step 1.—A *backwash* of 24 L/min (nominally 50-percent resin bed expansion) for 10 minutes using recycled regenerant with the column effluent going to waste.

Step 2.—Regeneration with recycled regenerant with the flow rates and volumes listed in table 6 (note that zero volume also was included) with the effluent going to the regenerant recycling system.

Step 3.—Regeneration with fresh ED brine regenerant of specified concentration with the effluent to be recycled.

Table 6. — *Phase 2 — High recovery ion exchange screening-response surface experimental design*

Block	Run number, No.	Fresh regenerant concen-tration, mg/L TDS	Nominal desalting recovery,* percent	Fresh regenerant flow rate, L/min	Step 2 recycled regenerant flow rate, L/min	Step 2 recycled regenerant volume, L	Calcium exhaustion termination point, meq/L
1	3.01.00C	20 000	85.5	8.0	16.0	800	1.5
	3.02.00C	20 000	85.5	3.0	16.0	800	1.5
	3.01.00	20 000	85.5	8.0	16.0	800	4.5
	3.02.00	20 000	85.5	3.0	16.0	800	4.5
	3.03.00	35 000	91.8	5.5	8.0	1600	3.0
	3.04.00	35 000	91.8	5.5	8.0**	0	3.0
CP	3.05.00	35 000	91.8	5.5	16.0	800	3.0
	3.06.00	35 000	91.8	5.5	24.0	1600	3.0
	3.07.00	35 000	91.8	5.5	24.0**	0	3.0
	3.07.00B	35 000	91.8	5.5	NA	NA	3.0
	3.08.00	50 000	94.3	3.0	16.0	800	1.5
	3.09.00	50 000	94.3	8.0	16.0	800	1.5
2	3.10.00	50 000	94.3	5.5	16.0	1600	1.5
	3.11.00	50 000	94.3	5.5	16.0**	0	1.5
	3.11.00B	50 000	94.3	5.5	NA	NA	1.5
	3.12.00	35 000	91.8	3.0	8.0	800	3.0
	3.13.00	35 000	91.8	3.0	24.0	800	3.0
CP	3.14.00	35 000	91.8	5.5	16.0	800	3.0
	3.15.00	35 000	91.8	8.0	8.0	800	3.0
	3.16.00	35 000	91.8	8.0	24.0	800	3.0
	3.17.00C	20 000	85.5	5.5	16.0	1600	1.5
	3.18.00C	20 000	85.5	5.5	16.0**	0	1.5
	3.19.00C	20 000	85.5	5.5	8.0	800	1.5
	3.20.00C	20 000	85.5	5.5	24.0	800	1.5
	3.17.00	20 000	85.5	5.5	16.0	1600	4.5
	3.18.00	20 000	85.5	5.5	16.0**	0	4.5
	3.18.00B	20 000	85.5	5.5	NA	NA	4.5
3	3.19.00	20 000	85.5	5.5	8.0	800	4.5
	3.20.00	20 000	85.5	5.5	24.0	800	4.5
	3.21.00	35 000	91.8	3.0	16.0	1600	3.0
	3.22.00	35 000	91.8	8.0	16.0**	0	3.0
CP	3.23.00	35 000	91.8	5.5	16.0	800	3.0
	3.24.00	35 000	91.8	8.0	16.0	1600	3.0
	3.25.00	35 000	91.8	3.0	16.0**	0	3.0
	3.26.00	50 000	94.3	5.5	8.0	800	1.5
	3.27.00	50 000	94.3	5.5	24.0	800	1.5

* Dependent upon brine concentration assuming a feed of 3300 mg/L TDS and a product of 473 mg/L TDS.

** Actual setting unimportant since zero volume throughput in step 2.

CP — Center point condition repeated three times gives estimate of experimental variability.

B — Run number designation for feed water backwash and no regenerant recycle.

C — Run number designation for low exhaustion termination point for calcium of 1.5 meq/L for 20 000 mg/L TDS brine concentration.

NA — Not applicable because recycled regenerant was not used when there was a feed water backwash.

The volume of fresh regenerant used per cycle was theoretically balanced with the amount of ED brine made per cycle. It was calculated from the desalting recovery and the average exhaustion volume as described earlier in **Experimental Methodology.** The calcium exhaustion termination concentration was a direct function of the brine concentation or desalting recovery, which realistically reflects desalting equipment feed requirements.

Upon completion of the design experiments, data were analyzed by multiple regression to give a statistical analysis and a second order polynomial expression involving the four control variables. They were plotted parametrically. These are presented and discussed in later sections.

2. Three screening runs designated by suffix B use a feed water backwash rather than recycled regenerant. These runs were used to indicate whether there was a significant IX performance difference between using feed water or recycled regenerant for backwash.

3. A lower exhaustion termination point (expressed as meq/L calcium in the IX product effluent) was used as an additional screening variable for six runs designated by suffix C. These were all run at the lowest brine concentration or desalting recovery. Data resulting from these runs were used to assess if the exhaustion termination point significantly affected the total resin requirements in an IX design.

During the experiments, the following were held constant:

- exhaustion flow rate of 30 L/min,
- a single rinse of 15 L/min for 10 minutes,
- draindown after exhaustion or feed-water backwash,
- draindown after regeneration, and
- the method of recycling regenerant.

Of course, other operating methods were applied when sodium chloride regeneration was used to make ED feed water for new fresh regenerant production, when the regenerant concentration was changed or when regenerant was lost under nonequilibrium operating conditions.

Numerical Data.—A summary of results from the response-surface experimental runs is given in table 7. Detailed data for each run are in appendix C. Each data cycle was preceded by three or more cycles at the same operating conditions to establish a system equilibrium.

This completed design (table 7) departed from the original planned design (table 6) in three ways. First, runs 3.17.00C through 3.20.00C (additional runs not contained in the basic Box-Behnken design) were deleted because of a shortage of time. The purpose of these runs was to determine the response as a result of varying the IX exhaustion calcium breakthrough concentration. Sufficient information for this purpose was obtained from runs 3.10.32C and 3.02.12C. Second, runs 3.26.00 and 3.27.00 were done out of the original order as 3.26.12D and 3.27.25D. This was done also to save time (2 weeks or more) by avoiding having to remake new volumes of the highest concentration fresh and recycled regenerants in chemical equilibrium with the IX-ED process if the original schedule had been followed. Third, run 3.18.12E was added. In this run, SHMP (100 mg/L) was added to the fresh regenerant (21.8-g/L of TDS) to test the effect of SHMP on gypsum precipitation in the column and the response of IX performance. Run 3.18.12E is discussed in a later section *(SHMP Addition to Regenerants)* along with two other runs in Phase 3 (4.04.07E and 4.06.07F) during which SHMP also was added to the regenerants.

Calcium Breakthrough Point. — Results show that increasing the calcium breakthrough point above the levels that normally were used in these experiments would increase the specific calcium resin capacity significantly but not the **TWRC.** this is evident in comparing resin capacities of runs 3.01.32C and 3.02.12C with 3.01.15 and 3.02.08, respectively (table 7). The former two runs used a 1.5-meq/L calcium breakthrough point, and the latter two used the normal 4.5-meq/L calcium breakthrough point. Comparisons among these runs do not support an advantage from a higher breakthrough point for increasing **TWRC.**

Source of Backwash Water. — Thee greatest benefit of using recycled regenerant rather than feed water for backwash is that the overall water recovery of the combined pretreatment-desalting system process is higher if feed water is not wasted for backwash. However, when using the recycled regenerant, IX resin capacities are higher, particularly at very high desalting recoveries. Run 3.11B proved to be the only run which was not self-sustaining; in other words, not as much regenerant was produced as was used. An equilibrium could not be reached as service volumes

Table 7. — *Summary of response-surface experimental design*

Cycle No.	Date	Fresh regen. conc., g/L TDS	Fresh regen. flow, L/min	Recycled regen. flow, L/min	Recycled regen. volume, L	Fresh regen. temp., °C	Resin capacity, eq-Ca/L	Resin capacity, eq-TH/L	Duration, exhaustion min	Duration, cycle min	Exhaustion fraction of cycle time	TWRC, meq-Ca/(L·min)
	1979											
3.10.32C	Jan 27	22.3	8.00	14.6	800	12.5	0.328	0.511	176	350	0.50	0.94
3.02.12C	Feb 1	20.4	3.15	14.5	800	15.2	.419	.636	203	563	.36	.74
3.01.15	8	20.6	7.18	14.5	800	15.7	.544	.647	322	577	.56	.94
3.02.08	14	20.0	3.01	14.8	800	19.5	.451	.554	226	615	.37	.73
3.03.28	Mar 3	33.9	5.85	7.96	1600	16.7	.570	.794	238	584	.41	.98
3.04.23	12	33.5	5.44	8.0	0	20.1	.506	.657	182	303	.60	1.67
3.05.15	17	32.8	5.51	15.6	800	19.0	.466	.667	204	367	.56	1.27
3.06.13	21	33.3	5.52	23.7	1600	18.8	.582	.731	246	448	.55	1.30
3.07.04	22	32.9	5.42	24.0	0	18.9	.466	.612	189	307	.60	1.52
3.07.04B	23	34.3	5.49	N/A	N/A	21.5	.513	.690	180	299	.61	1.72
3.08.77	May 2	51.3	3.16	16.2	800	22.0	.346	.520	158	318	.50	1.09
3.09.10	4	52.0	8.02	16.5	800	27.0	.469	.616	171	278	.62	1.69
3.10.15	9	50.3	5.59	16.6	1600	22.3	.526	.766	208	397	.52	1.32
3.11.12	12	51.8	5.49	16.0	0	24.2	.342	.537	152	228	.67	1.50
3.11.—B	N/A	50.0	5.5	N/A	N/A		run not self-sustaining so never completed successfully					
3.26.12D	26	52.1	5.48	7.82	800	28.0	.456	.527	185	367	.50	1.24
3.27.25D	June 2	53.4	5.42	24.2	800	28.0	.369	.497	162	270	.60	1.37
3.12.09	6	35.7	3.09	8.06	800	28.7	.399	.536	175	445	.39	0.90
3.13.08	8	33.9	2.96	24.6	800	31.5	.398	.544	183	394	.46	1.01
3.14.10	11	33.0	5.47	16.3	792	31.9	.442	.565	190	346	.55	1.28
3.15.08	13	33.7	7.93	8.06	792	35.8	.477	.581	193	373	.52	1.28
3.16.06	15	36.1	8.01	24.3	791	33.5	.483	.594	193	307	.63	1.58
3.17.08	18	20.2	5.49	17.3	1595	28.4	.473	.597	231	530	.44	.89
3.18.09	21	20.0	5.38	16.0	0	27.8	.441	.541	213	420	.51	1.05
3.18.13B	25	20.6	5.47	N/A	N/A	30.2	.392	.471	176	341	.52	1.15
3.19.09	28	19.4	5.42	8.77	800	35.0	.429	.518	180	440	.41	.98
3.20.10	July 2	19.6	5.58	23.1	805	32.0	.452	.557	200	433	.46	1.04
3.18.21E	9	21.8	5.40	N/A	N/A	30.3	.380	.488	189	353	.54	1.08
3.21.56	Aug 2	33.9	3.00	16.1	1588	36.5	.607	.737	245	571	.43	1.06
3.22.12	6	33.8	7.68	16.0	0	33.2	.426	.537	186	279	.67	1.53
3.23.33	22	34.4	5.51	16.2	794	29.5	.655	.815	336	546	.62	1.20
3.24.11	25	34.6	7.92	15.5	1573	30.8	.690	.867	346	561	.62	1.23
3.25.10	29	33.3	3.04	16.0	0	29.5	.336	.468	211	384	.55	.88

became progressively smaller as fresh regenerant volumes were adjusted lower to match the volume of rejected ED brine produced per cycle. This is demonstrated by the data noted in table 8. This run used feed water backwash and the highest concentration fresh regenerant, 50 g/L corresponding to a recovery of 94.3 percent, which also means that a total volume of fresh regenerant available per exhaustion volume was the lowest. Run 3.11.12 was comparable to 3.11B except that recycled regenerant (240 L) was used for backwash (called regeneration 1 when recycled regenerant was used).

A comparison between runs 3.18.09 and 3.18.13B (20-g/L TDS regenerant level) indicated a higher **TWRC** using recycled regenerant for backwash. But another comparison between runs 3.07.04 and 3.07.04B (35-g/L regenerant level) indicated lower **TWRC** using the recycled regenerant. However, the difference in **TWRC** in each pair is not great compared to experimental variability of all the runs. Thus, while it cannot be concluded that **TWRC** always is greater when using recycled regenerant for backwash, it is clear that to maintain an overall high water recovery with the IX process (not to waste feed water for backwash, although this backwash water could be recycled to some degree) and to be able to operate closed loop successfully at very high recoveries (94 percent and above at Yuma), recycled regenerant must be used for the backwash.

Gypsum Precipitation During Regeneration. — As previously mentioned, gypsum ($CaSO_4 \cdot 2H_2O$) precipitation in the IX column—during regeneration—was first observed during test runs in the spring and summer of 1979. Various symptoms, depending upon severity, included:

- Milkiness in the upflow regeneration effluent above the bed (fig. 14)

Table 8. — *Volumes and concentrations of IX fresh regenerant and exhaustion waters for conditioning cycles of run 3.11.00B (May 1979)*

Cycle No. 3.1100B Run No.	Date	Fresh regenerant volume V_f, L	Estimated fresh regenerant TDS, mg/L	Exhaustion volume V_e, L	Estimated ED feed TDS, mg/L	R, %	Ratio, $\frac{V_f}{(1-R)V_e}$
	May						
08	14	250	53 330	4080	3330	95	1.14
09	14	251	53 330	2900	3330	95	1.60
10	14	251	53 330	2840	3330	95	1.64
11	14	252	53 330	2490	3330	95	1.89
12	15	251	52 520	2790	3630	94	1.48
13	15	250	52 520	2760	3630	94	1.49
31	21	99	53 120	1140	3480	94	1.52
32	21	115	53 120	890*	3480	94	2.27
33	21	117	53 120	1160	3480	94	1.77
34	22	114	52 580	1070	3540	94	1.81
35	22	115	52 580	1100	3540	94	1.77
36	22	122	52 580	1160	3540	94	1.78
37**	22	121	52 580	3100	3540	94	0.66
38**	22	122	52 580	1650	3540	94	1.25
39**	22	122	52 580	1140	3540	94	1.39

Instrumentation and symbols:

V_f : Fresh regenerant volume is measured by the change in supply tank (T-28) water level.

V_e : Exhaustion volume is measured by a Signet flow totalizer.

TDS: Total dissolved solids concentration of ED feed is estimated from electrical conductivity (Beckman RC-18A). TDS of fresh regenerant is determined by evaporation (103 °C) in the chemical laboratory.

R: Percentage desalting water recovery based on the ED feed TDS concentration, fresh regenerant TDS concentration, and a projected design TDS concentration of 473 mg/L in the desalting product (see equation 1 in **Experimental Methodology**).

* No unusual condition explaining this early breakthrough was reported; however, it is not rare to see anomalous performance in initial cycles following a change in operating conditions.

** Cycles conducted using column 2 in the IX pilot plant to verify the performance trend observed using IX column I in previous cycles.

- Clumping of resin beads
- Channeling of water around these clumps particularly evident during upflow
- Unevenness of the top surface of the resin bed which normally is uniform (fig. 15)
- Cementation by gypsum of approximately the top one-third of the resin bed
- White powder (gypsum) settling onto the bed surface from the regenerant effluent (fig. 16)
- Plugging by gypsum scale of the upper column distributor and upper effluent piping.

The identification of the white precipitate as gypsum was verified by X-ray diffraction at the E&R Center. Some of the worst symptoms occurred in run 3.11B, which (previously described) was the only run scheduled that could not be completed successfully.

Because, under very similar conditions, successful cycles were completed with no visible gypsum precipitation in November 1978, a brief bench scale screening investigation was undertaken to identify whether temperature—an uncontrolled variable related to the season—was contributing to the gypsum precipitation. For this purpose, two simple laboratory glass columns about 25 mm in diameter were each loaded to a depth of about 300 mm with exhausted cation exchange resin from column 2 of the pilot plant. Each of these small resin beds were regenerated with portions of the fresh regenerant from tank 28 used in run 3.11B using upflow velocities comparable to those used in run 3.11B. Regenerant into one column named "A" was cooled in a refrigerated water bath to 15°C (similar to the temperatures during the Phase 1 experiments in November). Regenerant into "B" (the other column) was warmed to 30°C (comparable to the temperature occurring during run 3.11B). The following results were obtained.

1. Observable precipitation phenomena (channeling, cementing, blanketing) in column "A" during the cycle conducted using 15 °C regenerant, was slight and qualtitatively comparable to that observed during pilot plant column operation under similar circumstances during November 1978. That is, the only gypsum precipitation symptoms observed were the very fine crystallites that were carried out of the column in the spent regenerant above the resin bed.

2. Precipitation occurring in column "B," during the two cycles using 30 °C regenerant, was visually comparable to the precipitation observed in the pilot plant column operation during May 1979. That is, symptoms of cementing of the top one-third of the resin bed were observed. Channeling of the regenerant flow, cementing of resin into loosely coalesced clumps, and blanketing of precipitate on the resin bed surface were observed, and all remained well into the exhaustion mode. Symptoms of cementing were more severe during a second cycle than during the first cycle.

3. The specific resin capacity for exchanging calcium was estimated from titration data for calcium in exhaustion effluent samples. Capacities were:

Column "A" — regenerant temperature 15 °C	0.5 eq/L
Column "B" — regenerant temperature 30 °C	
Cycle No. 1	0.50 eq/L
Cycle No. 2	0.43 eq/L

Thus, the bench scale screening investigation clearly demonstrated the effect of two levels of regenerant solution temperature (15 and 30 °C) on the occurrence of visual gypsum precipitation phenomena. Further IX bench tests were not done.

Therefore, it was substantiated that temperature was a major variable (uncontrolled) in these experiments. Temperature dependency had not been reported in any previous work of which the authors were familiar. Several months later, the authors obtained an article alluding to the importance of temperature in affecting gypsum scaling when sulfuric acid is used to regenerate cation exchangers [21].

Another brief experiment using the IX pilot plant demonstrated that the inability to complete run 3.11B was not due to a possible gradual degradation in performance of the resin in column 1 such as could be caused from repeated resin scaling. Column 2 was operated for several cycles under similar conditions using the same influent solutions as used in column 1. Prior to this, column 2 had been used almost exclusively to provide feed periodically to the ED for makeup brine, and in the 17 preceding cycles (with column 2) 12-percent NaCl was the regenerant. The resulting performance of column 2 under conditions of run 3.11B duplicated the trends in performance of column 1

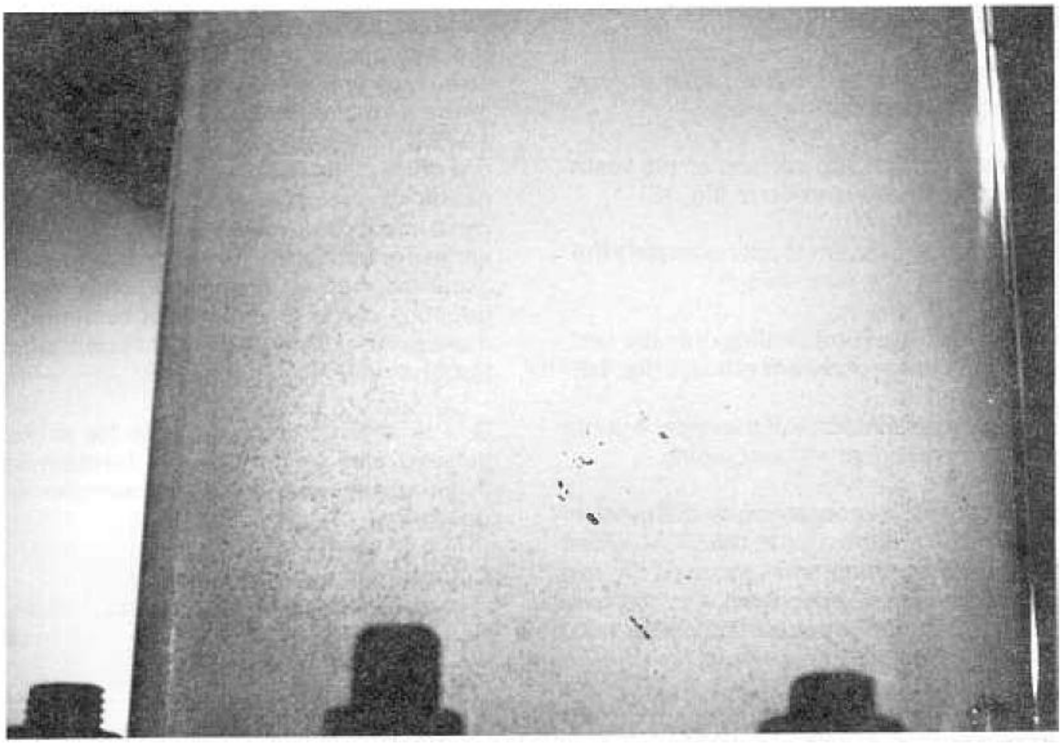

Figure 14.—Suspended gypsum crystals above resin bed formed during upflow regeneration. P801-D-80056

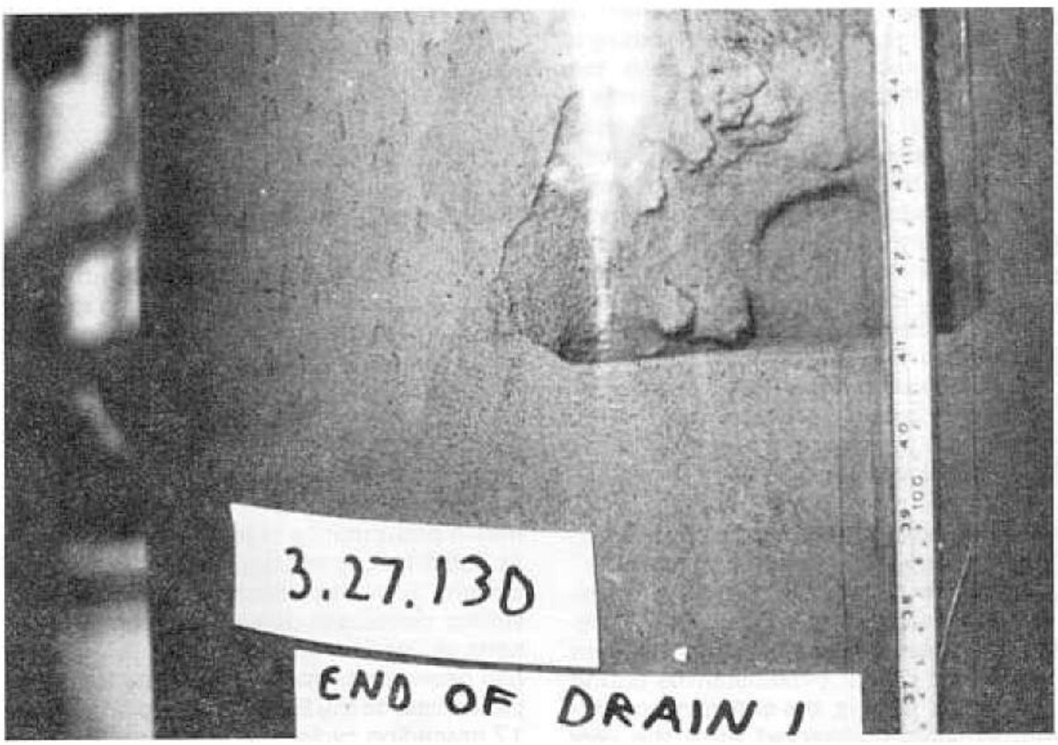

Figure 15.—Severe resin clumping and uneveness in the resin profile at the top of the bed due to cementation by precipitated gypsum. P801-D-80057.

(table 8). That is, self-sustaining operation of column 2 was not achieved, and the same gypsum scaling symptoms as for column 1 were observed. Thus, the nonself-sustaining IX behavior observed could not be attributed to degradation of the resin in column 1 as possibly could be suspected from repeated gypsum scaling. Furthermore, it was consistently observed that gypsum scaling symptoms disappeared and cation exchange capacity was restored following several cycles with NaCl regeneration. Thus, gypsum scaling of the resin was shown to be reversible.

It was qualitatively observed that:

— high regenerant concentrations,

— high regenerant temperatures,

— low fresh regenerant flow rates, and

— low volumes of recycled regenerant

contributed to the severity of gypsum scaling. Additional experiments in Phase 3 were designed to address conditions for controlling the gypsum scaling. A semiquantitative statistical analysis of these gypsum scaling phenomena is given later in the subsection entitled: *Statistical analysis of resin scaling potential.*

Phase 3 Experiments

Following completion of the Phase 2 response-surface experimental design, a third phase of experimentation was begun. Phase 3 runs were primarily for the purpose of studying methods of controlling the gypsum precipitation in the IX column. It occurred during brine regeneration with certain combinations of the control variables and high regenerant temperatures during Phase 2.

Since only about 1 month (Sept. 1979) was the maximum time available for these additional experiments, the scope of the experiments was limited to encompass several well-defined operating procedures:

- higher fresh regenerant flow rates,
- filtration of the recycled regenerant prior to entering the IX column to exclude the introduction of any gypsum crystallites,
- the addition of SHMP to both fresh and recycled regenerants, and
- mixing the resin bed with compressed air during backwash.

Considerable time was saved by running all of these experiments using the midpoint level of TDS concentration (about 35 g/L) of fresh regenerant thereby eliminating the need to make new tankfulls of other concentration regenerants. A statistically based experimental design was not possible because of the time limitation, but where possible, data from Phase 3 were later combined with Phase 2 data in the statistical analyses.

Numerical Data. — Phase 3 experimental run conditions and the principal results of each data cycle are summarized in table 9. Each data cycle was preceded by generally three cycles at the same conditions to establish an equilibrium. (detailed data for each IX run are in app. D).

The specific purpose, a description, and partial results of each run follows.

The two cycles 4.01.39 and 4.01.51 were designed to explore gypsum-scaling severity with different fresh regenerant flow rates using no recycled regenerant and feed water for the backwash. A much greater amount of visible gypsum precipitation and resin scaling was qualitatively observed using a fresh regenerant flow rate of 8.2 L/min (run 4.01.51) as compared to using 10.2 L/min (run 4.01.39). Note that the fresh regenerant temperature (uncontrolled) was nearly 5 °C lower while the lower fresh regenerant flow rate was used. Thus, a direct comparison between these two runs in terms of resin scaling due to the effect of fresh regenerant flow rate is possible. Under the prevailing levels of the other control variables, the threshold for severe gypsum-salinity was at about a 9-L/min fresh regenerant flow rate.

High Regenerant Flow Rates. — In the next three runs, fresh regenerant flow rate was increased further. These three runs also included use of the highest volume of recycled regenerant (1600 L). Starting with run 4.02.34 and for the remainder of the Phase 3 experiments, a 10-μm porosity cartridge filter located in the effluent line from T-5 was used to remove any remaining suspended gypsum crystallites from recycled regenerant. The use of this filter had been discontinued early in Phase 2. This filtration resulted in an apparent improvement in **TWRC** (comparing runs 4.02.27 and 4.02.42); however, the difference is not significant statistically. In addition, the regeneration effluent above the resin was crystal clear while using the filter,

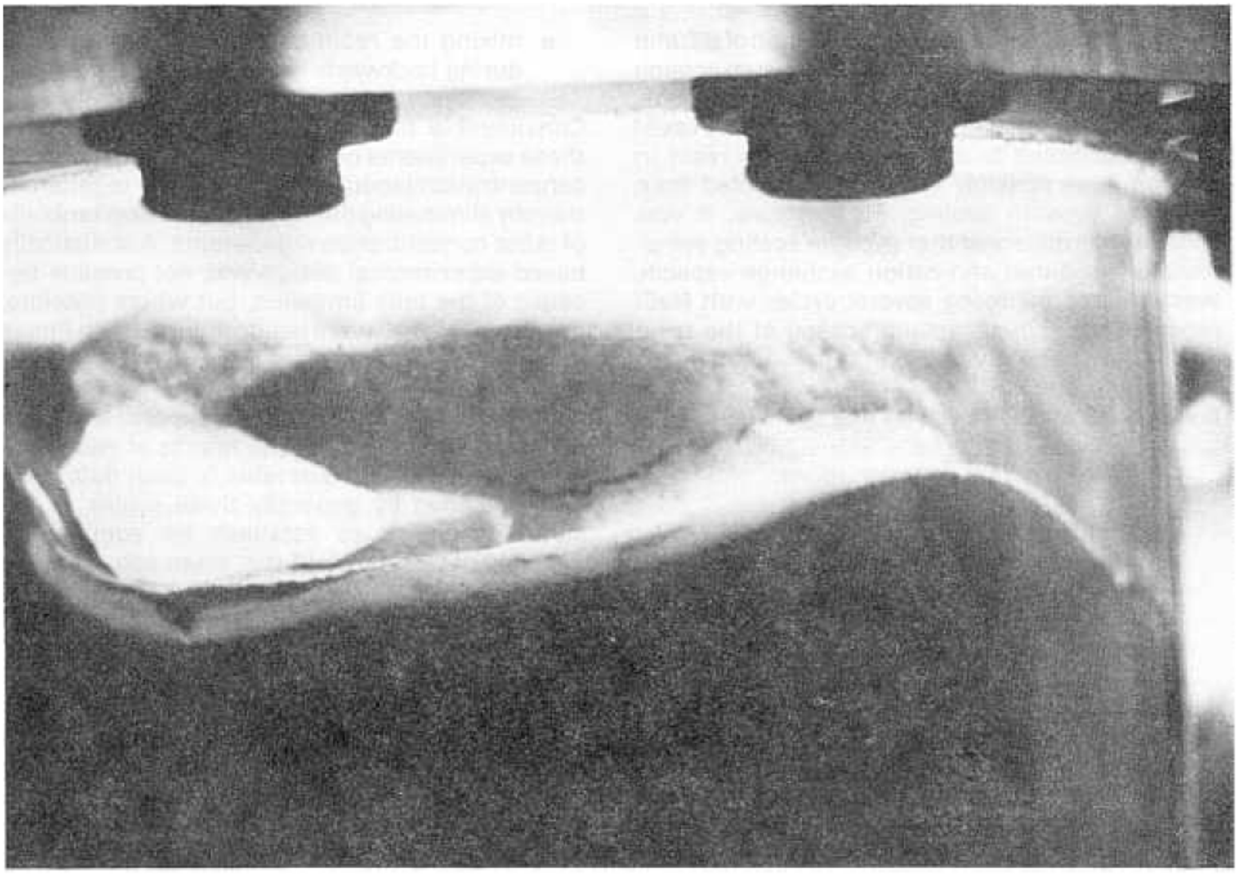

Figure 16.—Top of resin bed covered by gypsum crystals and a sheet of gypsum scale fallen from the upper distributor following a flow stoppage. P801-D-80058

Table 9. *Summary of additional IX runs to test methods for avoiding calcium sulfate scaling of resin (Sept. 1979)*

Cycle No.	Date	Fresh regen. conc., g/L TDS	Fresh regen. flow, L/min	Recycled regen. flow, L/min	Recycled regen. volume, L	Fresh regen. temp., °C	Resin capacity, eq-Ca/L	Resin capacity, eq-TH/L	Exhaustion duration, min	Cycle duration, min	Exhaustion fraction of cycle time	**TWRC,*** *meq-Ca* (L·min)
	Sept.											
4.01.39	9	33.4	10.17	NA	NA	29.5	0.292	0.383	131	194	0.68	1.51
4.01.51	11	33.7	8.25	NA	NA	24.0	.317	.438	134	208	.64	1.52
4.02.27	16	32.3	24.4	23.6	1600	30.9	.446	.606	217	331	.66	1.35
4.02.34	18	34.4	12.8	23.2	1600	28.0	.539	.679	225	360	.62	1.49
4.02.42	20	33.4	24.0	23.8	1600	28.7	.503	.625	231	346	.67	1.45
4.03.13B	22	32.7	5.40	NA	NA	30.4	.262	.353	110	197	.56	1.33
4.04.07E	24	32.8	5.56	NA	NA	29.2	.332	.394	130	215	.60	1.50
4.05.09B	25	32.1	5.66	NA	NA	33.3	.187	.244	82	152	.54	1.23
4.06.07F	26	33.1	5.60	15.8	800	30.0	.514	.654	210	379	.56	1.36

* **TWRC** = time-weighted resin capacity.
NA = not applicable

but without the filter the regenerant effluent was cloudy with gypsum crystallites. Gypsum scaling symptoms in the resin bed were not observed in any of these three runs using the high fresh regenerant flow rates whether or not the cartridge filter was used, thus demonstrating a desired benefit from using high fresh regenerant flow rates and a fluidized bed. Data from these three runs were combined with Phase 2 data in the statistical analyses.

Cycle 4.03.13B was run to establish a baseline operation using a midpoint fresh regenerant flow rate, no recycled regenerant (a feed water backwash), and a high regenerant temperature (33 °C). Control conditions for this run were the same as for cycle 3.07.04B when the regenerant temperature was 22 °C. Results of the two subsequent runs were compared with results of cycle 4.03.13B for the purpose of screening two major process variations described as follows.

Air Mixing the Resin Bed. — Run 4.05.00B conditions contained air mixing of the resin bed during backwash. This air mixing procedure was suggested for trial by a consultant — Dr. Robert Kunin[3] — in regard to the high recovery experiments. The purpose for injecting air in the bottom of the column during backwash was to cause violent mixing of the bed and a more or less random, nonstratification of resin beads in the bed. This could release any possible accumulated gypsum crystals remaining after exhaustion (if any) and also moderate the high calcium concentration gradient in the regenerant effluent during elution. However, cycle 4.05.09B resulted in the lowest resin capacity and smallest service volumes of any cycle in the entire test program (table 9). This run can be compared directly to 4.03.13B, which was operated at the same conditions except for the air mix. Apparently, the air mixing resulted in high calcium leakage and an early breakthrough concentration. Moreover, air mixing evidently negated one of the inherent advantages of counterflow operation—low leakage—which is especially important when the regenerant volume is limited and the regenerant composition is less than ideal. Thus, this procedure cannot be recommended for the present IX process.

SHMP Addition to Regenerants. — In cycle 4.04.07E, 100 mg/L of SHMP was metered into the fresh regenerant prior to the regenerant pump P-5 (fig. 8). Conditions were otherwise similar to cycle 4.03.13B. The purpose of SHMP addition was to try to retard the rate of gypsum precipitation in the column during brine regeneration. This procedure did prevent gypsum precipitation in the column and apparently caused a modest increase in the resin capacity.

Cycle 3.18.21E, run in Phase 2 but not discussed earlier, had the same flow conditions as cycle 4.04.07E with the 100-mg/L SHMP addition to the fresh regenerant, but the fresh regenerant concentration was at the low level (20 g/L nominal). Performance of cycle 3.18.21E can be compared directly to that of cycle 3.18.13B, which was performed without the SHMP addition. The SHMP caused the regenerant effluent to be clearer. However, the differences in resin capacity and **TWRC** between cycle 3.18.21E and cycle 3.18.13B are insignificant.

In cycle 4.06.07F, 100 mg/L of SHMP was added to the fresh regenerant, which subsequently carried over into the recycled regenerant. Otherwise, control conditions were similar to those of cycle 3.14.10. The regenerant effluent of cycle 4.06.07F contained finer pinpoint gypsum crystallites and the resin showed no scaling symptoms. There was also a slight improvement in resin capacity and **TWRC** with the SHMP. But the SHMP dramatically interferred with the regenerant recycling process: recycled regenerant contained 1660 mg/L of Ca with SHMP during cycle 4.06.07F versus 1150 mg/L of Ca without SHMP. This higher calcium concentration should cause the recycled regenerant to be less effective, but this was not observed in the overall performance.

Thus, it is noted that the addition of SHMP to regenerant — in the four runs tested — gave marginal improvement in IX performance. However, SHMP would be a multimillion dollar yearly cost in a large IX installation such as the YDP. Higher **TWRC** was found without SHMP addition when high regenerant flow rates and recycled regenerant volumes were used such as in the three cycles of the 4.02 series. Therefore, SHMP addition to the regenerant is not needed for proper IX operation and can be rejected for the Yuma Desalting Plant due to cost.

Multiple Regression Analysis of IX Data

Data from Phase 2 (table 7) were mathematically analyzed by multiple regression. Runs with suffixes B, C, and E were not included in these analyses

[3] Personal communication with R. Kunin, consultant, formerly of Rohm and Haas, Inc., 1318 Moon Drive, Yardley, Pennsylvania.

because they were separate process screening runs in addition to the Box-Behnken design (table 3). There were 27 runs or observations included in the basic response-surface portion of the experimental design.

Regression analyses [22] were performed on a Hewlett-Packard model 9825 desktop computer using a packaged program (Stepwise Regression, part 09825-15041). The selected dependent (response) variable was sometimes the specific resin capacity (**RC**, eq/L of calcium), but more often the time-weighted resin capacity (**TWRC**, meq/(L·min) of calcium) was used. The independent variables in the second order regression included all linear, cross-product, and squared terms for the four experimental control variables:

- Fresh regenerant TDS concentration (g/L)
- Fresh regenerant flow rate (L/min)
- Recycled regenerant flow rate (L/min)
- Recycled regenerant volume (L)

and for the uncontrolled variable:

- Fresh regenerant temperature (°C).

Outlying Observations. — Preliminary regression analyses yielded residual plots indicating two outlying observations for cycles 3.23.33 and 3.24.11. By coincidence, cycle 3.23.33 was at midpoint conditions — a replicate of conditions 3.05.15 and 3.14.10. **RC** was considerably greater for both cycles 3.23.33 and 3.24.11 than predicted from smooth fits of the data from all 27 response-surface runs. It was not immediately apparent why the **RC** of cycle 3.23.33 should be about 50 percent greater than the RC's of cycles 3.05.15 and 3.14.10 run at similar operating conditions, but an explanation was suggested upon studying the compositions of the recycled regenerant. The sodium concentration in the recycled regenerant was about 20 percent greater for runs 3.23.33 and 3.24.11 as compared to other runs using 35-g/L TDS fresh regenerant (these data are in app. C). This higher than normal sodium concentration in the recycled regenerant would cause the resin to be regenerated more thoroughly resulting in higher resin capacities.

The cause for the abnormally high sodium concentration in the recycled regenerant of cycles 3.23.33 and 3.24.11 was from the nonequilibrium composition in tanks T5 and T6, which occurred after draining the tanks on August 18, 1979 to remove algae growth. Tanks T5 and T6 were filled then with fresh regenerant, which naturally had a greater concentration of sodium than recycled regenerant. An insufficient number of IX conditioning cycles (just five before 3.23.33) were allowed before test cycles were run. The result was that the chemical compositions in tanks T5 and T6 had not reached a proper chemical equilibrium with the remainder of the IX process.

Because the results of cycles 3.23.33 and 3.24.11 were substantially different from the results of other cycles, and because a plausible explanation for some of their deviation due to experimental bias was found, these runs were dropped from further regression analysis. This left 25 observations analyzed from the original response-surface design.

Results From 25 Observations. — Variations among runs from the 25 Phase 2 experiments were found to be fairly low considering the wide ranges of the independent variables. The calcium **TWRC** mean and standard deviations were 1.20 ± 0.27 meq/(L·min) which yield a relative standard deviation of 22.5 percent. For the normal calcium resin capacity, the mean and standard deviations were 0.46 ± 0.07 eq/L with a relative standard deviation of 16 percent. Apparently, **TWRC** is determined primarily by the total capacity of the cation exchange resin and the feed water composition — which were constant during these experiments — and not by the control variables within the ranges tested.

A correlation matrix for these data is given in table 10. Because the correlation coefficients among the independent variables C, Q_f, Q_r, V_r, *and* T_f are less than 0.07, these control variables are shown to be truly independent, which verifies their selection and analysis as independent variables. **RC** is affected strongly and positively by V_r (0.599) but weakly by the other independent variables. **TWRC** increases considerably with increasing Q_f (0.606) and C_f (0.538) and decreases to a relatively lesser extent with increasing V_r (–0.314). These statistical relations also are demonstrated by the following results of multiple linear regression analysis.

Table 10.—*Correlation matrix for 25 observations — Phase 2 response-surface experimental design*

	C_f	Q_f	Q_r	V_r	T_f	**RC**
Q_f	0.053					
Q_r	.034	-0.010				
V_r	.006	-.064	0.019			
T_f	-.056	.048	.031	-0.046		
RC	-.274	.260	-.092	.599	-.242	
TWRC	.538	.606	.189	-.314	-.006	0.034

Symbol	*Variable name*	*Units*
C_f	Fresh regenerant concentration	g/L
Q_f	Fresh regenerant flow rate	L/min
Q_r	Recycled regenerant flow rate	L/min
V_r	Recycled regenerant volume	L
T_f	Fresh regenerant temperature	°C
RC	Resin capacity for calcium	eq/L
TWRC	Time-weighted resin capacity for calcium	meq/(L·min)

Regression analysis gave the following least-squares-method equation:

$$\mathbf{TWRC} = 0.0946\,Q_f + 0.0122\,C_f - 0.000\,142\,V_r + 3.80 \qquad (2)$$

where

TWRC = time-weighted calcium resin capacity in meq/(L·min)

Q_f = fresh regenerant flow rate in L/min

C_f = fresh regenerant TDS concentration in g/L, and

V_r = recycled regenerant volume in L in addition to the 240 L used as backwash.

The **F** test [22, 23] was used to judge which independent variables were the most significant for inclusion in the equation. In the stepwise regression, the **F** values to remove a term in the equation above were 22.0 for Q_f, 18.3 for C_f, and 5.6 for V_r. The higher the **F** value, the more significant the term. For 24 degrees of freedom, an **F** value greater than about 2 indicates significance at the 95-percent confidence level, which also applies to the other regression equations that follow. The R^2 of the fit is 0.70. The standard error is 0.14 meq/(L·min) or 11.7 percent based on the mean **TWRC**. This equation is valid for Q_f between 3 and 8 L/min. Figure 17 shows some plots of this equation plus data points with V_r = 800 L. Because V_r had a relatively smaller effect on **TWRC** (a decrease in **TWRC** of 0.12 meq/(L·min) with an increase in V_r of 800 L), a plot showing **TWRC** versus V_r is not included in this report.

A regression analysis of **RC** (calcium resin capacity, not time-weighted) as the dependent variable shows the importance of V_r on **RC** for the 25 low Q_f runs.

$$\mathbf{RC} = 5.52 \times 10^{-8}\,V_r^2 + 0.0148\,Q_f - 0.00181\,C_f + 0.395 \qquad (3)$$

R^2 for this fit is 0.62. Standard error of the fit is 0.047 eq/L or 10 percent relative to the mean **RC** of 0.463 eq/L for the 25 observations. The **F** value to remove a term is 26.4 for V_r^2, 6.05 for Q_f, and 4.51 for C_f. This high **F** value for V_r^2 agrees with the relatively high correlation (0.599) between V_r and **RC** in table 10. Lines generated by the above equation are plotted on figure 18, which shows how **RC** increased with V_r. The physical significance of the second order V_r^2 term being more significant than a first order V_r term is that one would expect the increase in **RC** with V_r to curve and level off rather than continue to rise as the resin approaches chemical equilibrium with recycled regenerant at very high V_r.

Results From 28 Observations. — Further regression analysis was performed on data from the 25 response-surface runs from Phase 2 plus the inclusion of the 3 additional runs from Phase 3 in which higher fresh regenerant flow rates were used. The three additional runs included 4.02.27, 4.02.34, and 4.02.42 (table 9) with fresh regenerant flow rates of about 24, 12, and 24 L/min, respectively. Runs 4.02.34 and 4.02.42 used filtered recycled regenerant; whereas, 4.02.27 and the 25 response-surface runs used only sedimentation of gypsum crystals in tank T6 to remove gypsum

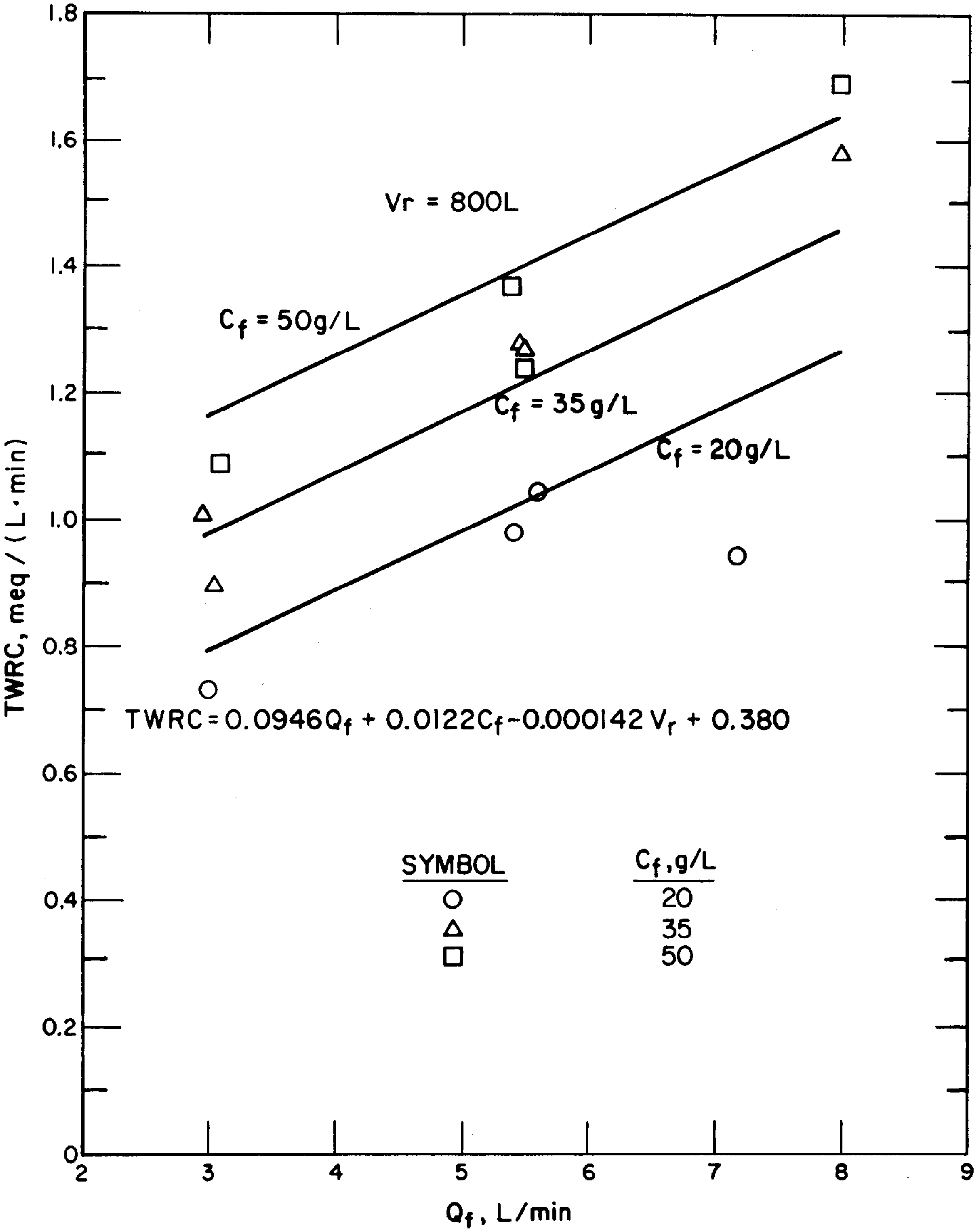

Figure 17.—**TWRC** versus fresh regenerant flow rate and TDS concentration for 25 Phase 2 observations. The equation is based on all 25 observations. However, the curves and data points are only for V_r equals 800 L.

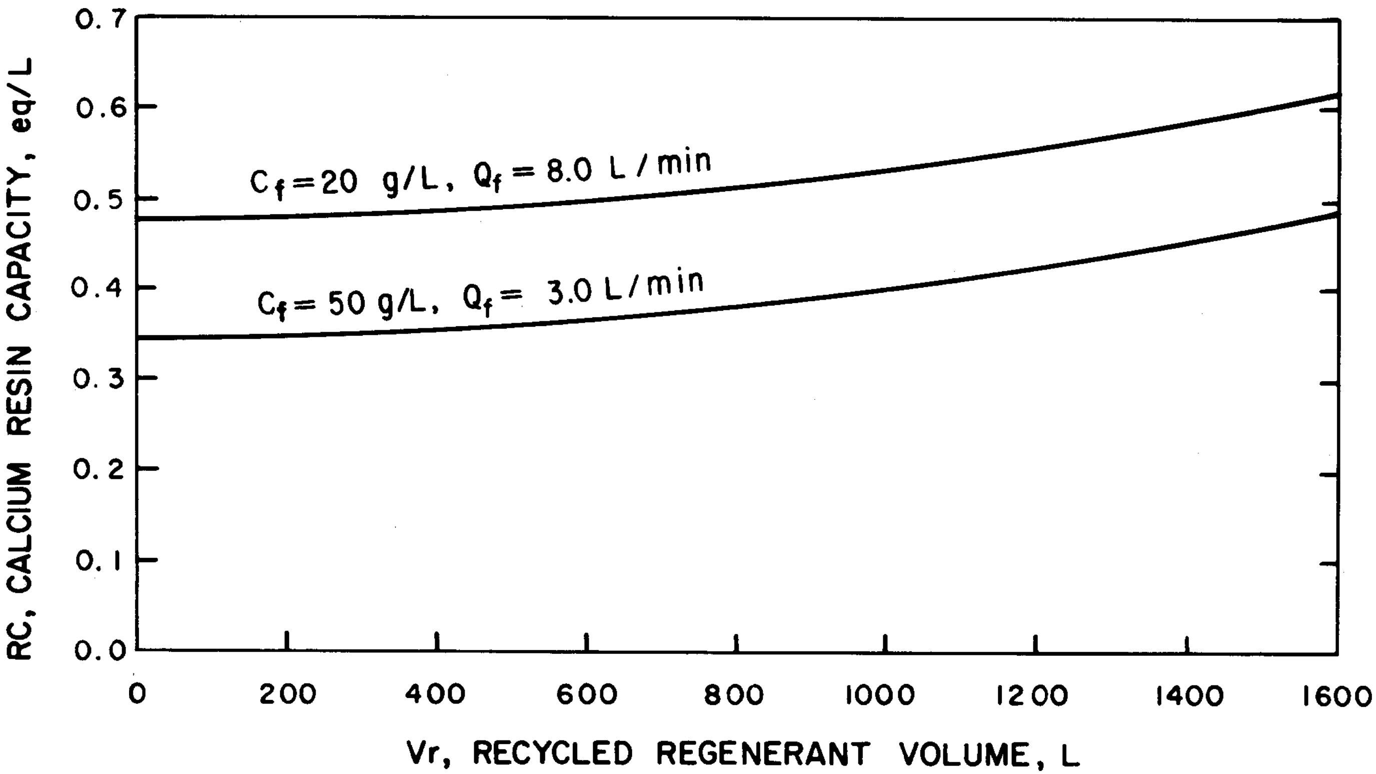

Figure 18.—Resin capacity versus fresh regenerant volume for 25 Phase 2 observations.

precipitates in the regenerant recycling process. While the filter visually clarified the recycled regenerant, the IX performance with the filter was not significantly different without the filter in relation to the **TWRC**. For this reason, all 28 runs were analyzed together. Basic statistics for the 28 runs resulted in mean and standard deviations of 1.23 ± 0.27 meq/(L·min) for **TWRC** and 0.46 ± 0.07 eq/L for normal calcium resin capacity, respectively, which are nearly identical to the corresponding values previously calculated for the 25 response-surface observations.

Regression analysis of the 28 observations with **TWRC** as the dependent variable yielded similar results to those for the 25 observations. The primary addition was a second order term for V_r in the least-squares-method equation.

$$\mathbf{TWRC} = 0.133\,Q_f - 0.00392\,Q_f^2 + 0.0123\,C_f - 0.000149\,V_r + 0.294 \qquad (4)$$

R^2 for this fit is 0.73. Standard error of the fit is 0.151 meq/(L·min), or 12 percent relative to the mean **TWRC**. The **F** to delete a term in this fit is 25.8 for Q_f^2, 20.6 for C_f, 17.2 for Q_f^2, and 7.2 for V_r. Curvature caused by the second order term is shown on figure 19 for C_f=35 g/L and V_r=1600 L; the dashed lines are the standard error or one standard deviation (67 percent confidence level for a normal error distribution) for the intercept (Q_f=0) value of the fit. The standard error for the fit is lower towards the midpoint of Q_f [22], which was not calculated. A maximum occurs at Q_f = 17 L/min on figure 19, but the data and fit are insufficient to indicate whether this is the true location of a maximum.

The regression analyses showed an increase in **RC** with V_r (equation 3 and fig. 18) but a decrease in **TWRC** with V_r (equation 4). This results because the **RC** is increased by a larger V_r to a lesser fraction than the fractional increase in cycle time caused by the larger time required to pass the larger V_r through the resin bed. Thus, because **TWRC** is the quotient of **RC** dividend by cycle time, an increased V_r can decrease **TWRC**.

The occurrence of a maximum in **TWRC** versus Q_f by equation 4 can be explained. Increase in **TWRC** with increasing Q_f and C_f occurs mainly because of a decreased cycle time, specifically a decreased regeneration time. The regeneration time decreases with C_f because higher C_f corresponds to higher desalting recovery and less volume of fresh regenerant, which yields shorter regeneration time for a given Q_f.

A drop off in the **TWRC** with increasingly higher Q_f and a maximum in the **TWRC** occur because the contact time for regeneration by mass transfer with finite rates will decrease resulting in lower resin capacities. Yet there are real limits in the amount that cycle time can be minimized as illustrated by equation 5 that follows. One additional practical limit for IX flow rates is the hydraulic pressure drop across the resin bed, IX column, and piping, which could lead to uneconomical equipment and energy costs when using much higher flow rates (per volume of resin) than those that were tested.

Effects of the independent variables on the cycle time can be illustrated clearly by the following derived equation:

$$t_c = \frac{V_e}{Q_e} + \frac{V_e\,(C_e - C_p)}{Q_f\,(C_f - C_p)} + \frac{V_r}{Q_r} + t_o \qquad (5)$$

where

t_c = cycle time in min
V_e = exhaustion volume in L
Q_e = exhaustion flow rate in L/min
Q_f = fresh regeneration flow rate in L/min
C_e, C_p, and C_f are the TDS concentrations of desalting feed (IX exhaustion effluent), product, and reject (fresh IX regenerant), respectively, which together yield a term expressing one minus the desalting recovery from equation 1
V_r = recycled regeneration volume in L
Q_r = recycled regeneration flow rate in L/min
t_o = time for other cycle steps, almost always 25 minutes during the present experiments for backwash, rinse, and drains.

The first term on the right-hand side of equation 5 is the exhaustion time in minutes, the second term is the fresh regeneration time, and the third term is the recycled regeneration time. Note that the cycle time decreases with increased exhaustion flow rate Q_e. Experiments were all run with Q_e equals 30 L/min.

A regression analysis with cycle time t_c as the dependent variable was done on the 28 experimental IX observations. Independent variable combinations selected for the fit were $(Q_f \cdot C_f)^{-1}$ and V_r/Q_r because the combinations occur in equation 5. Results are shown on figure 20, which illustrates the effects of C_f, Q_f, V_r, and Q_r on experimental cycle time. The curves on figure 20 cannot be calculated directly from equation 5 without the experimental data because V_e (nearly proportional to the resin capacity) is determined experimentally and

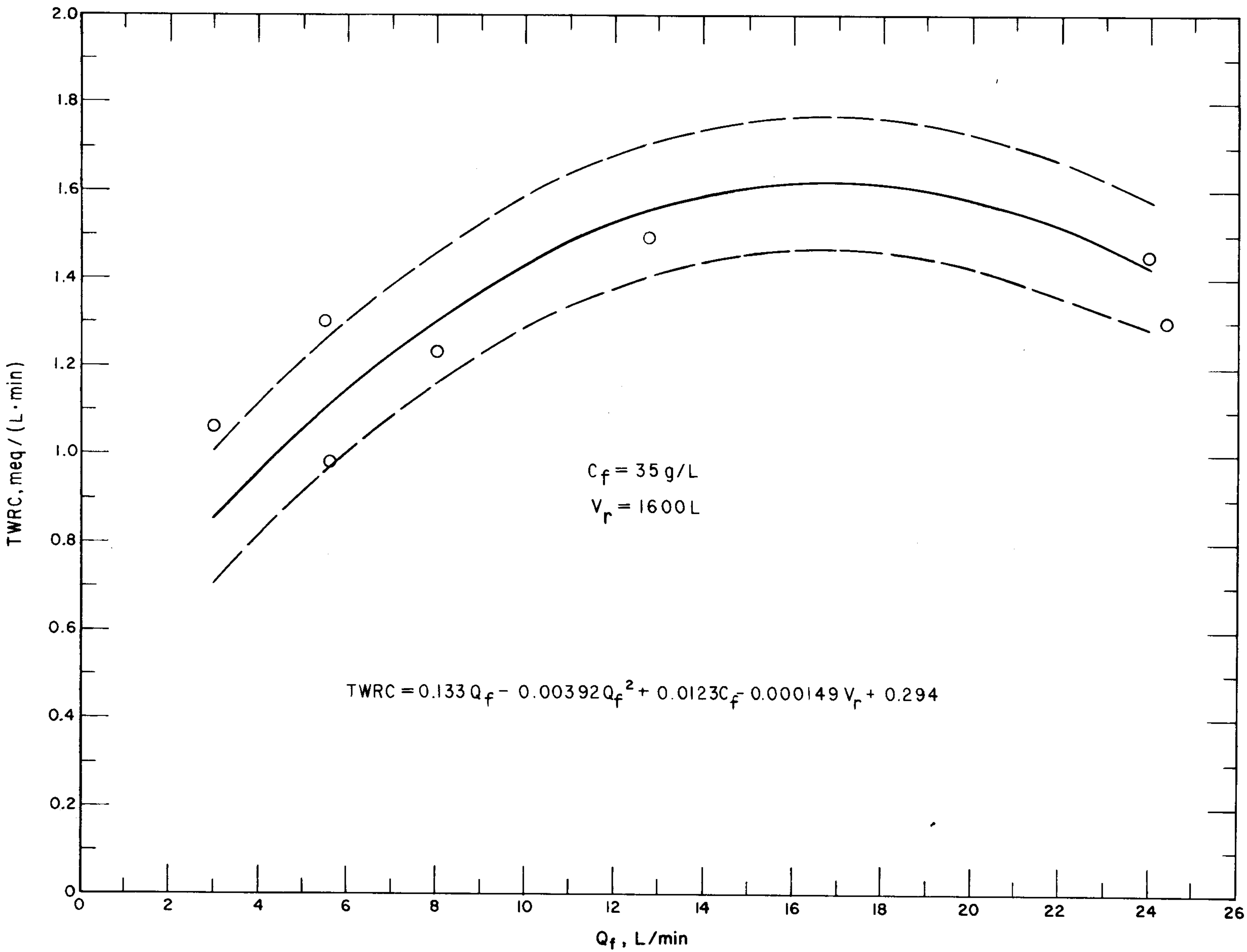

Figure 19.—**TWRC** versus fresh regenerant flow rate for 28 observations from Phases 2 and 3. Equation was based on all 28 observations. The curve and data points are for C_f equals 35 g/L and V_r equals 1600 L.

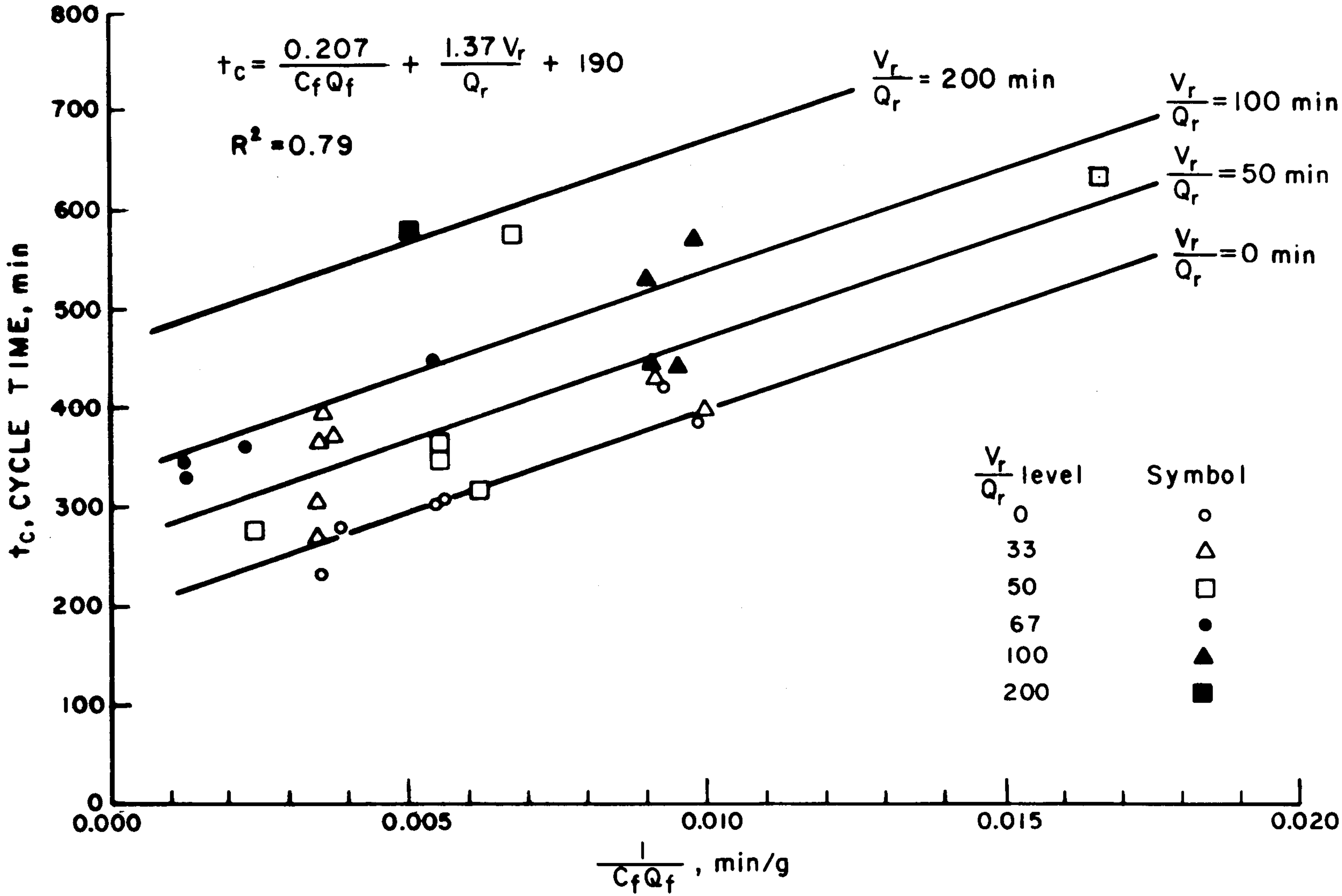

Figure 20.—Regression fit of IX cycle time versus IX operating variables.

cannot be accurately predicted from the independent variables alone.

Analyzing Effects of Calcium Sulfate Supersaturation and Gypsum Scaling of Resin

The regeneration effluent probably was nearly always supersaturated in calcium sulfate. This was a result of high levels of calcium eluting from the cation exchange resin during regeneration plus the high concentrations of sulfate present. Even the recycled regeneration influent (for Regenerations 1 and 2) to some extent was supersaturated depending upon the efficiency of the regenerant recycling system as shown in table 4. Ideally, the recycling system should completely desupersaturate the spent regenerant, but in the YDTF tests there was not opportunity to design and operate an optimal system because of the variable constraints imposed by experimentation with different levels of ion exchange operation. The fresh brine regenerant was, of course, always below saturation, as is required to prevent scaling in the desalting unit. The severity of calcium sulfate scaling the cation exchange resin was observed only qualitatively. Under many operating conditions there was not apparent scaling. The least severe scaling consisted of some minor cementing of resin beads near the top of the IX column during regeneration. The minor cementing would disappear during rinse or early during exhaustion.

The most severe resin scaling consisted of cementation of the entire top one-third of the ion exchange bed. The top surface of the resin would be severely mountainous rather than normally flat. Sometimes cavities would form below the top surface of the bed allowing one to see entirely through the bed. Cementation would remain throughout exhaustion. However, the bottom third of the bed always tended to remain normally uncemented, except that sometimes an occasional clump of finer beads would occur there as described previously under: *Gypsum Precipitation During Regeneration*.

The more severe resin scaling would be accompanied also by plugging of the top screen of the column. But more often–with severe scaling–there would be gypsum "snow" forming in regenerant effluent in the top of the column above the bed. This fine white powder would form a layer less than a few millimeters thick on top of the bed at the end of regeneration and draindown. The thin white layer would redissolve soon during rinse or exhaustion.

Statistical Analysis of Resin Scaling Potential. — In an attempt to quantify effects of resin scaling, a computer program (app. G) was used to estimate the amount of CSS, calcium sulfate supersaturation in:

- RRI, recycled regeneration influent,
- RRE, recycled regeneration effluent, and
- FRE, fresh regeneration effluent,

for Phases 2 and 3 experimental runs. These data are given in table 11. The CSS is the amount of calcium sulfate that would precipitate (as gypsum) at chemical equilibrium at 25 °C. Negative values indicate unsaturated solutions.

Some of the data were combined with other data from the 25 observations of the response-surface experiments (table 7) and analyzed using basic statistics. A correlation matrix is shown in table 12. The strongly positive correlation (0.67) between the supersaturations of RRE and RRI is indicative that inefficient desupersaturation of RRI affects RRE supersaturation. But supersaturation of RRI and RRE were correlated only slightly with that of FRE. Negative correlations between the supersaturation of RRI and fresh regenerant concentration (–0.480) and regenerant temperature (–0.411) are consistent with the known kinetics of calcium sulfate precipitation [16] as it would occur in the regenerant recycling system. That is, more efficient recycling (greater calcium sulfate desupersaturation and precipitation kinetics rates) is favored by high initial calcium and sulfate concentrations, by the longer residence times in the agitated recycling tank T-6, and by higher regenerant temperatures.

The greatest supersaturation generally occurred in the fresh regeneration effluent as table 12 indicates. The highest supersaturation of FRE occurred at the highest brine concentrations (correlation coefficient of 0.661). Indeed, the most severe calcium sulfate scaling of the cation exchange resin was observed at the highest desalting recoveries. However, it was observed that the resin scaling was alleviated largely by using large volumes of recycled regenerant. This qualitative observation is consistent with the negative correlation (–0.608) between FRE supersaturation and recycled regenerant volume.

The quantitative importance of these CSS values is involved in the kinetics of gypsum precipitation. A published laboratory study showed that the rate of gypsum precipitation is proportional to the square of the molar concentration of calcium sulfate to be deposited before equilibrium is reached [16]. This molar concentration corresponds to the CSS values in table 11.

Table 11.—*Degree of calcium sulfate supersaturation — in recycled regeneration influent* RRI *and effluent* RRE *and fresh regeneration effluent* FRE†

Run No.	RRI	RRE	FRE	SI*
3.01.15	5.96	17.7	8.27	0
3.02.08	6.17	13.9	7.12	0
3.03.28	2.92	17.5	7.86	0
3.04.23	4.00	17.3	26.0	0
3.05.15	9.90	16.1	13.4	0
3.06.13	2.05	11.2	13.4	0
3.07.04	4.37	14.0	26.6	0
3.07.04B	-	-	40.3	0
3.08.77	-1.84	7.44	20.5	10
3.09.10	-0.96	7.48	27.3	10
3.10.15	-1.80	13.5	19.8	10
3.11.12	0.16	16.3	41.4	10
3.26.12D	-1.08	12.2	19.3	10
3.27.25D	-1.65	8.13	21.5	10
3.12.09	-1.18	6.33	12.3	5
3.13.08	0.58	8.43	12.0	5
3.14.10	-0.61	6.59	10.8	10
3.15.08	-2.29	11.0	15.7	10
3.16.06	0.11	10.5	22.8	10
3.17.08	-0.26	12.3	5.37	5
3.18.09	-1.97	4.54	13.9	5
3.18.13B	-	-	16.5	0
3.19.09	1.72	9.48	2.09	0
3.20.10	1.82	9.04	6.46	0
3.18.21E	-	-	22.5	0
3.21.56	1.91	16.6	6.75	5
3.22.12	1.17	12.8	28.6	5
3.23.33	5.18	24.4	14.7	5
3.24.11	8.16	19.0	12.8	0
3.25.10	6.86	16.3	25.7	0
4.01.39	-	-	34.6	5
4.01.51	-	-	42.2	5
4.02.27	3.58	20.1	9.19	0
4.02.34	1.20	17.3	9.68	0
4.02.42	2.30	23.6	10.3	0
4.03.13B	-	-	32.1	5
4.04.07E	-	-	40.9	0
4.05.09B	-	-	31.0	0
4.06.07F	18.6	33.4	26.5	0

† Numerical values are the predicted amounts of gypsum ($CaSO_4 \cdot 2H_2O$) in millimoles per liter that would precipitate at equilibrium at 25 °C. Missing values occur where recycled regenerant was not used.

* The degrees of gypsum scaling intensity (SI) of the resin bed were derived from visual descriptions in the operators' log assigning arbitrary grades of 0 for no visible scale, 5 for slight to moderate symptoms of scaling, and 10 to severe scaling as defined in the text.

Gypsum Scaling Intensity. — An approach used to try to qualify the severity of resin scaling was to establish a grade for each experimental run based on operators' qualitative visual observations as recorded in their log. Three grades of gypsum scaling intensity (**SI**) were assigned.

- A value for **SI** of 10 was assigned when symptoms of severe gypsum scaling of the resin were noted. These included:

  —cementation of resin beads, flow channelling, and sometimes the formation of cavities in the top 300 to 600 mm of the resin bed (figs. 15 and 16)

  —formation of volcano-like cones on the top surface of the bed during regeneration with fresh desalting brine

  —cloudiness of the regeneration effluent in the column above the resin and settling of white gypsum crystals on the top of the resin bed (fig. 14).

- An intermediate value for **SI** of 5 was assigned when these symptoms were less severe and confined to the top 300 mm or less of the resin bed.

- A value for **SI** of 0 was assigned when the symptom of the presence of gypsum was not observed.

The arithmetic range for **SI** of 0 to 10 was arbitrary, and it was not shown that half of the mass of gypsum scale was present at an **SI** of 5 as was present when **SI** was 10, which implies a linear relation. But because quantitative measurement of gypsum scale was not made, these **SI** values do provide a means to generalize according to visual conditions when gypsum scaling did and did not occur. The individual values of the grades are listed in the last column of table 11.

Another unusual observed symptom, which could be misinterpreted as gypsum scaling, was the formation of loosely cemented clumps of fine resin beads at various bed depths. However, various tests indicate that these clumps probably were caused by microbiologically produced slime. This aspect is discussed in a following section: Microbiological Growth Causing High Plugging Factors.

Table 12.—*Gypsum scaling factors — correlations among variables for 25 response-surface experimental observations*

	C	Q_f	Q_r	V_r	T_f	RRE	RRI	FRE	**RC**	**TWRC**
Q_f	0.053									
Q_r	.034	-0.010								
V_r	.006	-.064	0.019							
T_f	-.056	.048	.031	-0.046						
RRE	-.064	.019	-.220	.029	-0.439					
RRI	-.480	-.211	.013	-.197	-.411	0.667				
FRE	.661	.240	.134	-.608	-.098	.136	-0.105			
RC	-.274	.260	-.092	.599	-.242	.391	.208	-0.430		
TWRC	.538	.606	.189	-.314	-.006	.022	-.195	.724	0.034	
SI	.699	.232	.046	.064	.397	-.440	-.810	.393	-.295	0.001

Symbol	*Variable name*	*Units*
C	Fresh regenerant concentration, TDS	g/L
Q_f	Fresh regenerant flow rate	L/min
Q_r	Recycled regenerant flow rate	L/min
V_r	Recycled regenerant volume	L
T_f	Fresh regenerant temperature	°C
RRE	Recycled regeneration effluent calcium sulfate supersaturation	m moles/L
RRI	Recycled regeneration influent calcium sulfate supersaturation	m moles/L
FRE	Fresh regeneration effluent calcium sulfate supersaturation	m moles/L
RC	Resin capacity for calcium	eq/L
TWRC	Time-weighted resin capacity for calcium	meq/(L·min)
SI	Scaling intensity	dimensionless

A regression analysis was performed on these intensity data. For the RS runs from Phase 2 the following equation was formed:

$$\mathbf{SI} = 0.01\ T_f C_f - 5$$

where

$\mathbf{SI}$ = gypsum scaling intensity,
T_f = fresh regenerant temperature, and
C_f = fresh regenerant concentration.

It is notable the fresh regenerant flow rate, Q_f, did not appear as a significant control variable affecting scaling in the range of Q_f from 3 to 8 L/min.

Upon analyzing 28 runs which included values of Q_f up to 24 L/min, a different analysis emerged. The effect of Q_f was significant in lowering the observed gypsum scaling intensity of the resin. The following equation was generated by multiple regression:

$$\mathbf{SI} = 0.011\ T_f - 0.25\ Q_f - 3.8$$

Curves using this equation are plotted in figure 21. Along the lines where **SI** = 0 and to the upper left on the graph, gypsum scaling was not perceived at the labeled temperatures. A progressively greater amount of gypsum scaling tended to occur away from these **SI** = 0 lines toward the lower right on the graph. Dashed lines indicate moderate amounts of gypsum scale intensity with **SI** = 5. Only at the high temperature of T_f=35 °C does a line for severe scaling, **SI** = 10, appear within the bounds of the graph. Thus, figure 21 graphically illustrates the gypsum scaling intensity as a function of the three significant independent variables and demonstrates how scaling can be avoided with low fresh regenerant concentrations, high regeneration flow rates, and low temperatures.

Despite the apparent desirability for smooth IX operation to avoid gypsum scaling of the cation exchange resin, data do not support an improved **TWRC** if gypsum scaling is avoided. No correlation existed between **TWRC** and scaling intensity (table 12). Thus, the net effect of gypsum scaling on the cation exchange performance of the resin are apparently not important. However, the effects of scaling on the hydraulics of the resin bed and piping are of concern and need to be addressed in an IX design.

Gypsum Settling Tests

In response to a request from the Division of Design (E&R Center), settling tests for gypsum were done

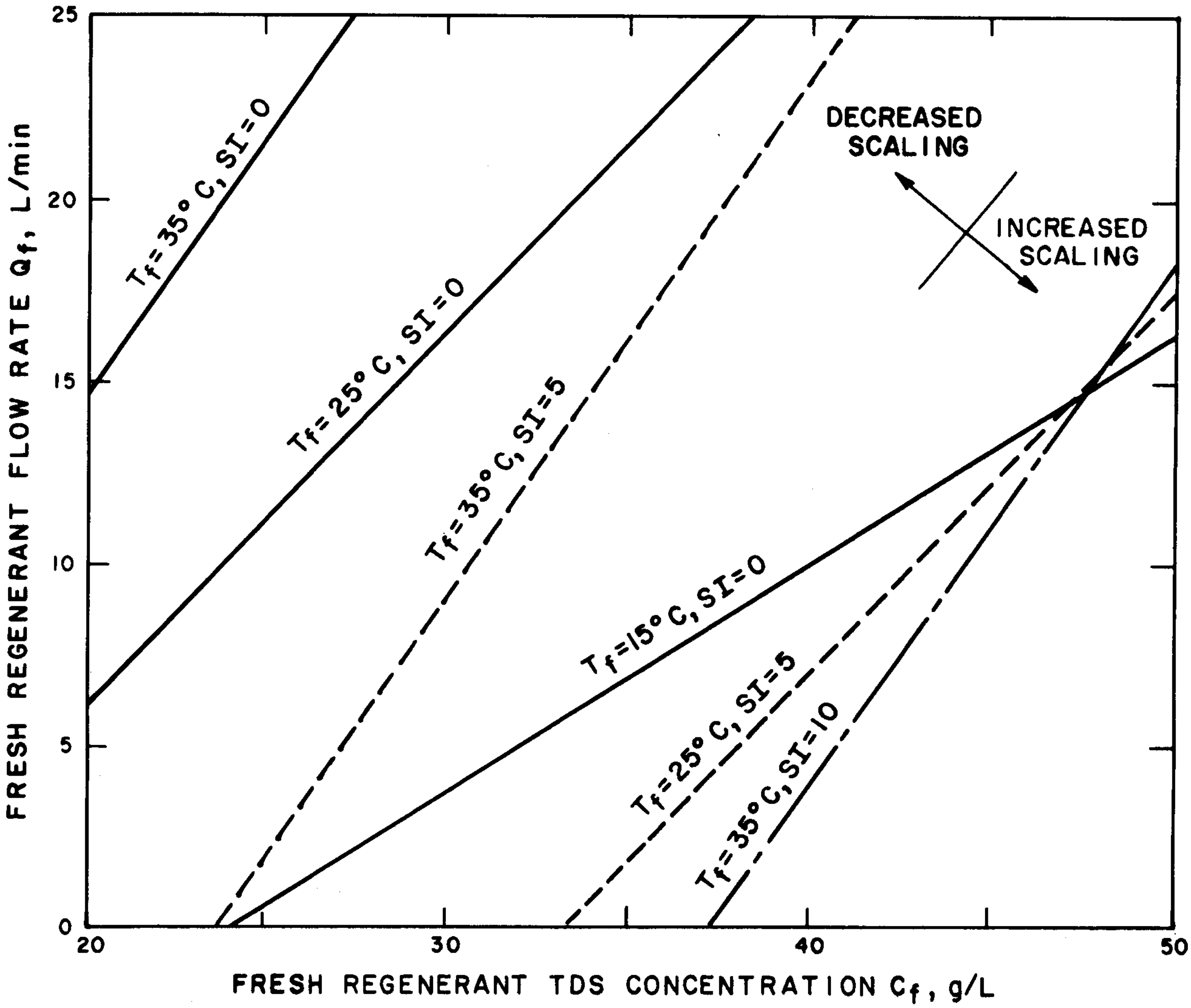

Figure 21.—Profile of gypsum scaling intensity as a function of fresh regenerant concentration, flow rate, and temperature.

on an agitated suspension of the spent regenerant being recycled in tank 6. The purpose for the data was for a feasibility design of a regenerant recycling system for high recovery in the YDP. The suspension of gypsum contained 1.7 percent solids, calculated from a suspended solids analysis of 17.3 g/L as gypsum in a 30-g/L TDS solution. Temperature of the water in tank 6 was 28 °C. Since new spent regenerant had not entered tank 6 for several hours, chemical equilibrium was assumed. Six samples were collected at 5-minute intervals in 1000-mL glass volumetric cylinders from the side of tank 6 during agitation. Clarity of the solution was recorded by photography and measured by syphoning 100-mL aliquots from the 500-mL level of the cylinders and analyzing these samples for turbidity.

Results are given in table 13. They indicate that nearly maximum clarity of the solution (turbidity less than 100 JTU) was achieved in less than 20 minutes of settling time, but that the solutions were already relatively clear in 11 minutes. The photographs of this test are not reproduced here because the turbidity data adequately described the gypsum settling behavior.

Table 13. — *Gypsum settling tests — samples collected from agitated spent regenerant tank T-6 — September 29, 1979*

Cylinder No.[1]	Sampling time, a.m.	Sampling duration, min[2]	Turbidity, JTU[3]
1	9:15	35	72
2	9:20	30	82
3	9:25	25	86
4	9:30	20	82
5	9:35	15	114
6	9:40	10	175

[1] Cylinder height or the distance between the 0 and 1000 mL graduations was 362 mm.
[2] Holding time in each cylinder between spent regeneration withdrawal from tank 6 and turbidity analysis.
[3] Turbidity was measured at around 9:50 a.m. in samples from each cylinder using Monitek, Inc. model 150. Measurements were off scale (greater than 500 JTU) 5 minutes after sampling.

Microbiological Growth Causing High Plugging Factors

High plugging factors were measured in the feed water to the ED during much of the high recovery test program as shown on figure 22. Plugging factor (specifically defined in app. A) is a measure of the rate of plugging of a 0.45 μm-pore-size membrane filter caused by substances in the water and is presumably a measure of the desalting membrane fouling potential of the water. There was not a maximum plugging factor requirement for the ED test unit as there is sometimes for RO. Degradation in ED or IX performance was not noticeable during nearly 1 year of experimentation. The high plugging factors were suspected of being from a biological source, which could be controlled effectively by chlorination, if required. There was no immediate concern to try methods to lower the plugging factor in the ED feed water. By contrast, during earlier testing at YDTF, it was recalled that Ionics, Inc. (proprietary data) had periodic problems from the buildup of biological slimes in their ED stack using low plugging factor, lime-pretreated feed water. Because of slimes, periodic chemical cleaning was required to limit increases in pressure drop through their stack. Such a problem did not occur in the high recovery ED. Nor was there any problem which can be attributed to an inadequacy in the IX pretreatment of the ED feed water. (Other equipment problems with the ED unrelated to feed water quality as given in app. F.)

In the experiments at YDTF, there was no disinfection of the water downstream of the feed to the IX. The lime-treated water was dechlorinated just prior to the IX to protect the cation exchange resin from oxidation by residual chlorine. Thus, the resin bed, piping, and storage tank 33 for IX product water (ED feed water) were never treated to limit biological growth. Also, they were not completely drained and cleaned for about a year.

Because of the concern of the Division of Design (E&R Center) and the authors' desire to characterize the substances in the water which caused the high plugging factors — which probably would be important in RO operation — a limited investigation was done to identify the cause of high plugging factors in ED feed water. It included a contact[4] having experience with plugging factors under OWRT (Office of Water Research and Technology) contracts on IX-RO operation at Roswell, New Mexico, and their RO testing of biological effects from seawater at St. Croix, Virgin Islands. Additionally, specially collected samples of the high plugging factor pads were analyzed by the U.S. Geological Survey using SEM (scanning electron microscopy) including elemental X-ray spectra. Other pads were sent for special analyses for biological materials as described later in this section.

[4] Personal communication with A.B. Mindler, Group Leader — Permutit Research and Development Center, of Permutit Company, Princeton, New Jersey.

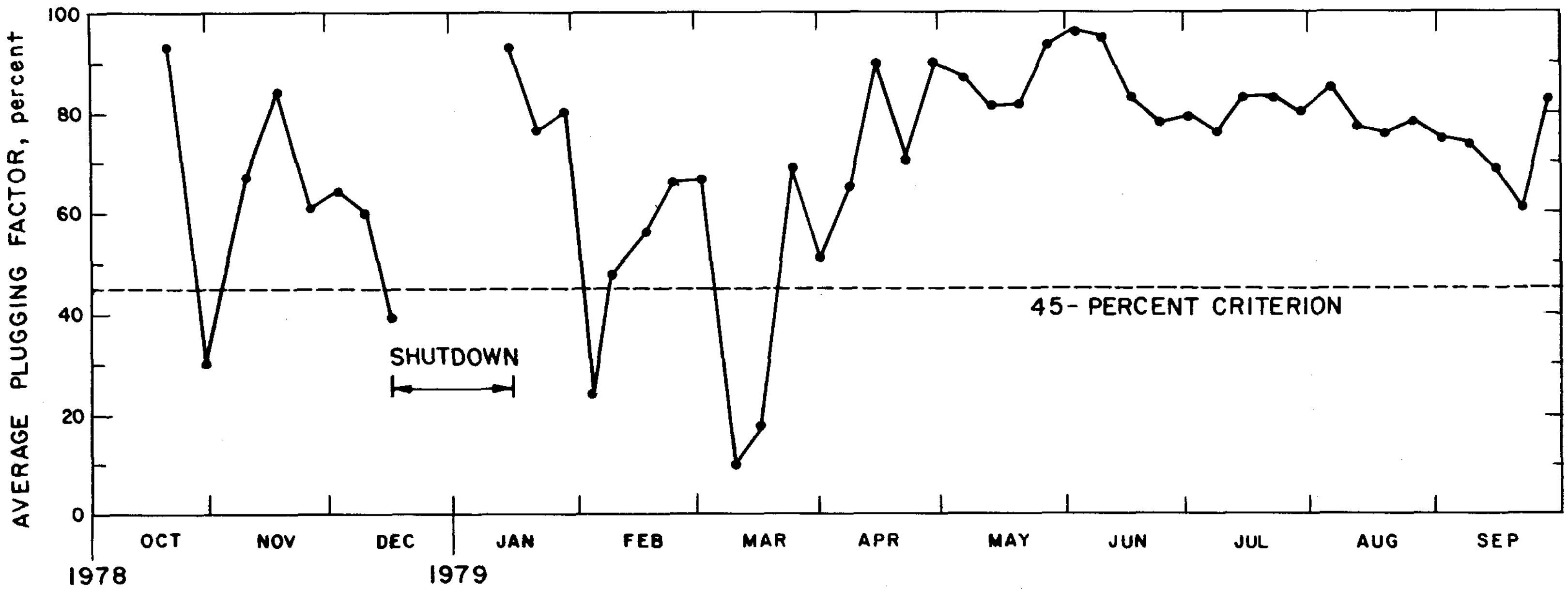

Figure 22.—Weekly average plugging factor in ED feed water.

The group leader at Permutit Company related Permutit's experience with high plugging factors. In general, they foresee a gradual increase of about 2 in the silting index (corresponding to a plugging factor increase of 30 percent for a 15-minute reading) when chlorination of RO feed water is ceased. This increased plugging factor has been shown to result from biological growths in the water, especially periphytic (surface attaching) bacteria, which produce a glycoprotein polymer allowing them to attach to the inside of pipes and tanks. Glycoprotein material excreted by bacteria is the slime that is often the cause of high plugging factors.

At Roswell, N.Mex., Permutit Company tested the same IX process with synthesized Wellton Mohawk Canal water that the authors tested at YDTF [17]. However, Permutit Company rechlorinated the IX product water and maintained a residual of chlorine in the IX product tank and feed to their RO to control biological growth. Their pilot plant was enclosed in a building. As a result, all of the plugging factors they measured in the IX product-RO feed were 50 percent or less.

Under another OWRT contract, Permutit Company ran tests at St. Croix, Virgin Islands, to study the effects of biological materials fouling RO membranes [24]. The RO feed water was filtered and chlorinated seawater. A Permutit Company subcontractor[5] identified a number of periphytic bacteria and their byproducts which contribute strongly to high plugging factors. Permutit Company found an acceleration in bacteria growth in water which was allowed to sit without flow in their system.

To specifically characterize the material causing high plugging factors in ED feed, three special plugging factor measurements were made (on Sept. 28, 1978) on the ED feed (IX product after storage in tank 33) and lime-treated filter 9B effluent—which became IX feed water after storage and dechlorination. The volume of water passed through in each 15-minute test and the mass of material collected on each 0.45-μm pore size cellulose acetate filter were specially measured.

One filter each for ED feed water and filter 9B effluent were run by SEM, and another filter for ED feed water plus copies of the electron micrographs were sent the Permutit Company's subcontractor for biological characterization.

[5] H. Winters, Professor of Biology, Fairleigh Dickinson University, Teaneck, New Jersey.

The SEM's on figures 23 through 32 were taken by the U.S. Geological Survey at the Denver Federal Center. They include micrographs of unused cellulose acetate filters (figs. 23 and 24). The five micrographs of the low plugging factor, filter-9B-effluent filters (figs. 25 through 29) show stringy material and a few discrete particles resting on the filters surfaces. The X-ray spectra analyses of an individual string and group of strings indicated no elements detectable with an atomic number greater than 10 (corresponding to sodium) that suggest organic material consisting of elements such as C, H, O, N, etc.

Particles shown on figure 29 vary in composition; the top particle gave a peak only for Si, the bottom particle contained Si, Al, and Fe, but the second particle from the top contained no detectable element greater than atomic number 10 (organic?).

The three micrographs of the high plugging factor, ED feed water filters (figs. 30 through 32) show a definite mass of material almost completely covering over the Millipore surfaces and pores, obviously the cause of the high plugging factors. This material had no detectable spectral for elements greater than atomic number 10, which again indicates organic material and completely rules out any common inorganic precipitate such as gypsum, calcite, etc. Diatoms are shown, which gave off only the X-ray peaks for Si, one of the major constituents of diatoms. The other particles contained such elements as Si, Al, and Fe, which would be indicative of inorganic particles.

Dr. Winters[5] (hired as a consultant to the Bureau) interpreted the SEM's and the results of organic chemical analysis of the ED feed water Millipore filter. He concluded that the stringy material and at least some of the discrete particles were probably bacteriological in nature. The large mass of material on filters from ED feed water consisted primarily of protein and hexose carbohydrate, which are building blocks of various materials contained in and produced by bacteria. Also, Dr. Winters incubated a sample of the cationic exchange resin collected at YDTF and microscopically found slime-producing bacteria and protozoa.

Further information on periphytic bacteria is covered in references [25, 26, and 27].

Thus, all of the evidence indicates that the high plugging factors in the ED feed were due to slime-like material of a bacteriological nature which quickly plug the Millipore filters. Significant inorganic material such as gypsum was not detected. Bacterial growth occurred in the resin bed, piping, and IX product tank. The microbiological growth and resulting high plugging factors can be controlled effectively by chlorinating the IX product as demonstrated by low plugging factor performance of this same IX process by Permutit Company at Roswell, New Mexico. Occasional flushing of the resin bed with formaldehyde solution when needed is recommended by resin manufacturers. Furthermore, whenever the IX is shut down for more than a few days, the resin should be kept in a 10-percent NaCl solution to stop microbiological growth.

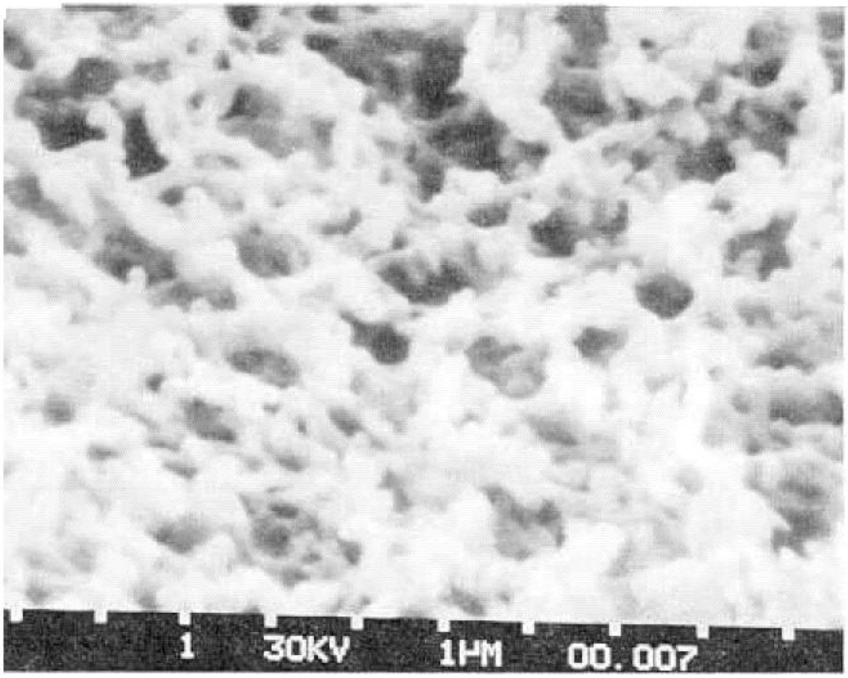

Figure 23.—Unused millipore filter-1. Note 1μm distance scale. No elements detected with atomic number greater than 10. P801-D-80059

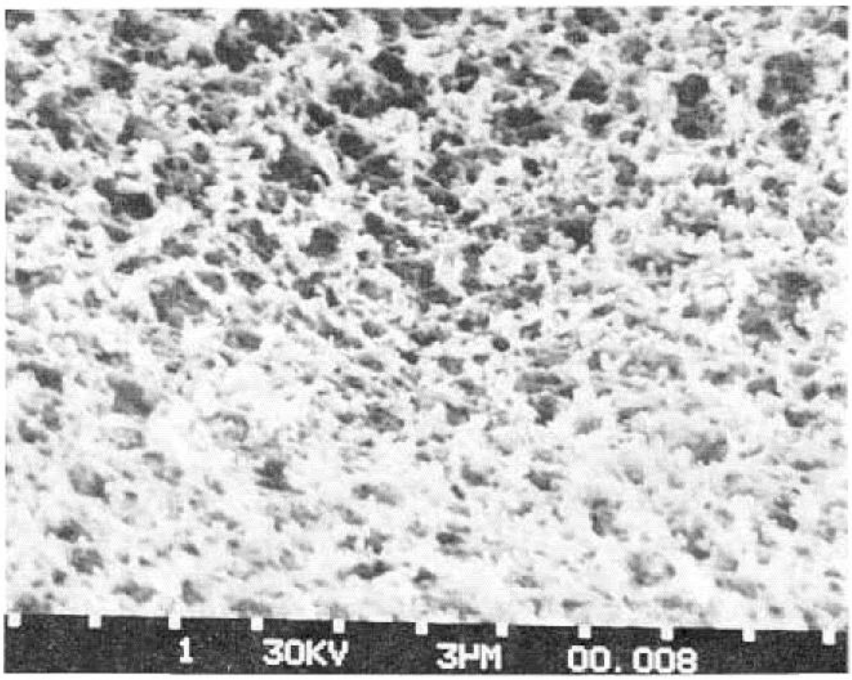

Figure 24.—Unused millipore filter-2. P801-D-80060

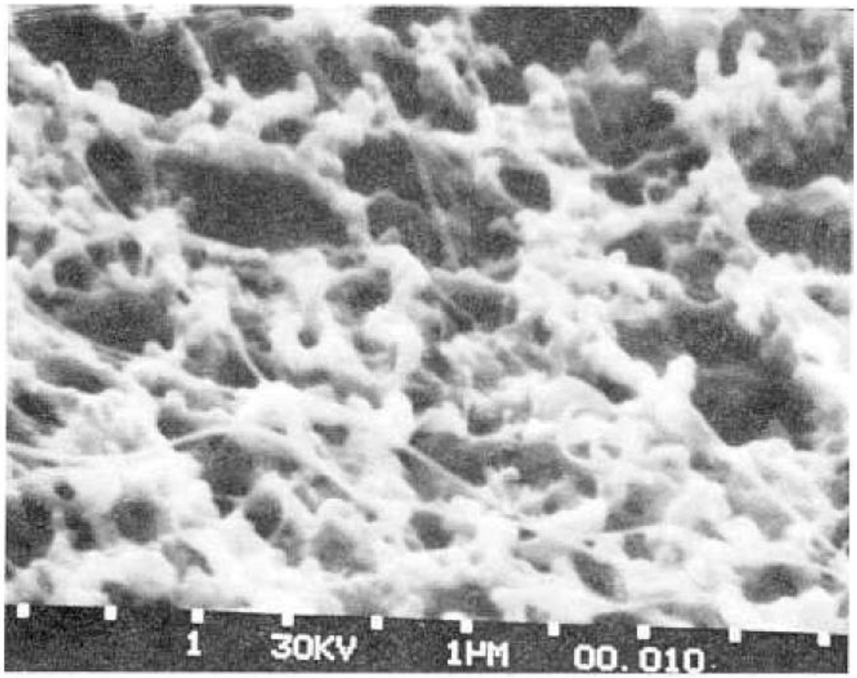

Figure 25.—Filter 9B effluent-1, plugging factor = 14 percent. Note filamentous material — suggesting bacterial appendages. P801-D-80061

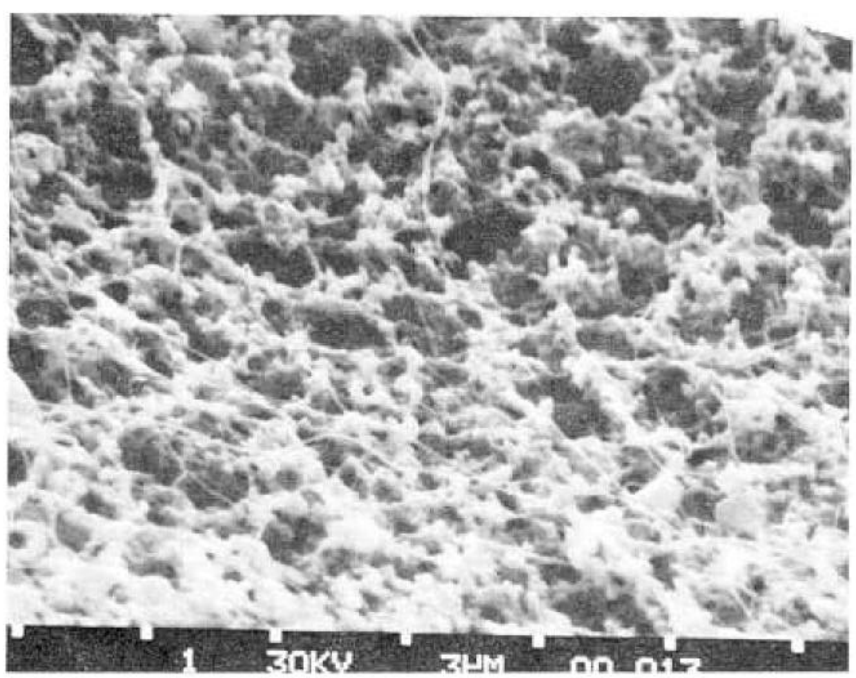

Figure 26.—Filter 9B effluent-2, plugging factor = 14 percent. P801-D-80062

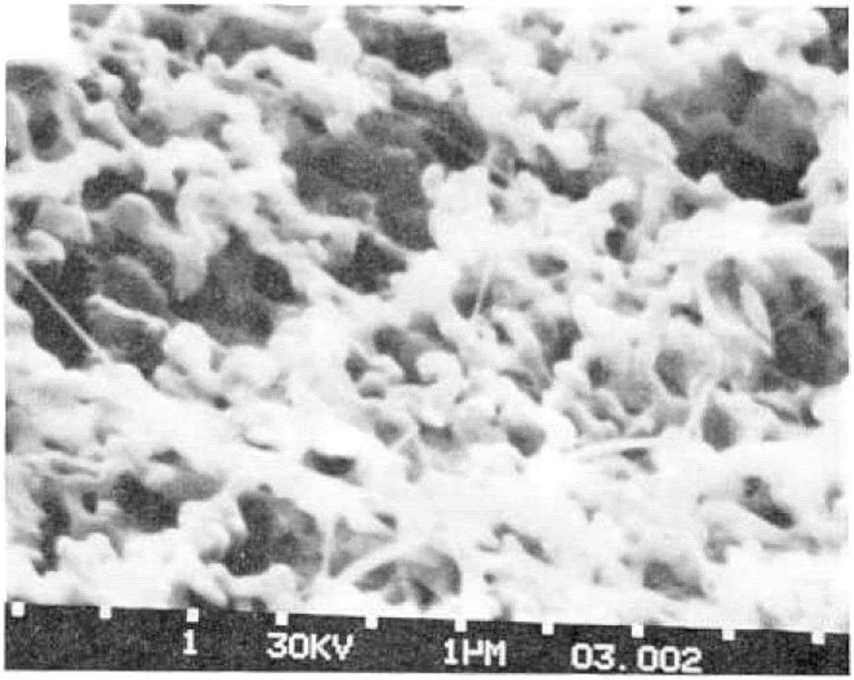

Figure 27.—Filter 9B effluent-3, plugging factor = 14 percent. P801-D-80063

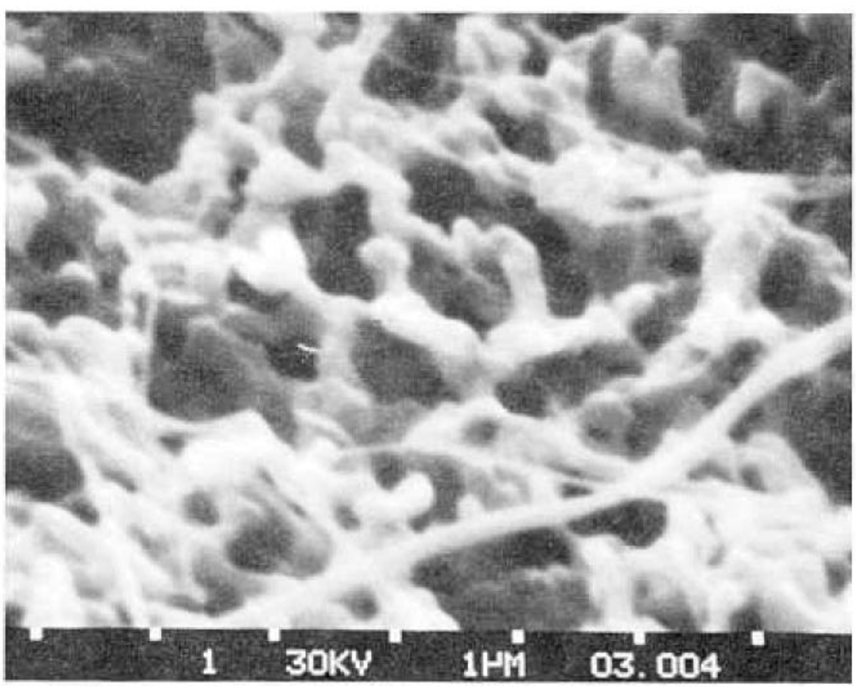

Figure 28.—Filter 9B effluent-4, plugging factor = 14 percent. Large filament has no detectable element above atomic number 10 — suggesting organic material. P801-D-80064

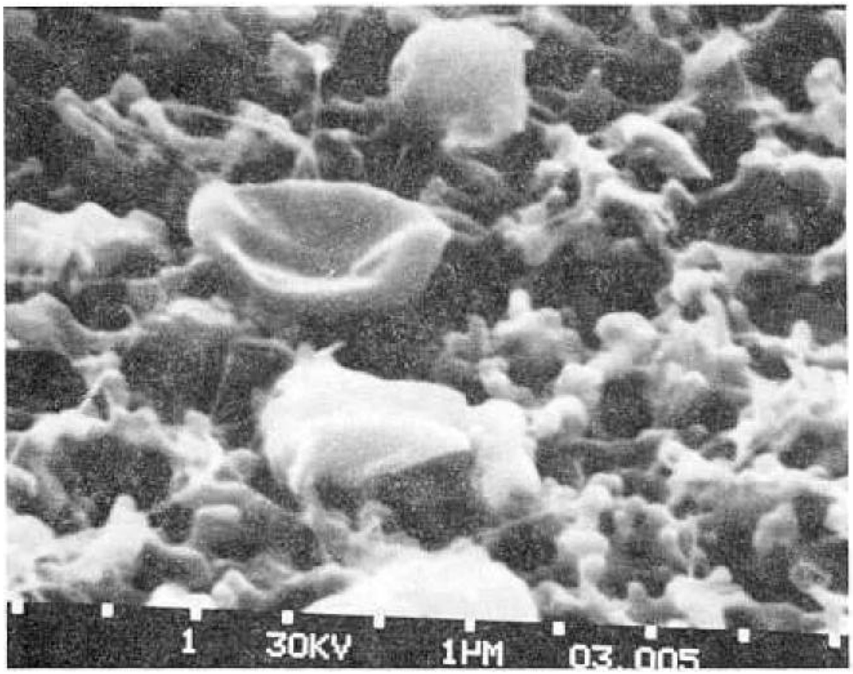

Figure 29.—Filter 9B effluent-5, plugging factor = 11 percent. Top particle showed only Si. Second particle from top showed no element with an atomic number above 10 — suggesting bacteria. Bottom particle contained Si, Al, and Fe. P801-D-80065

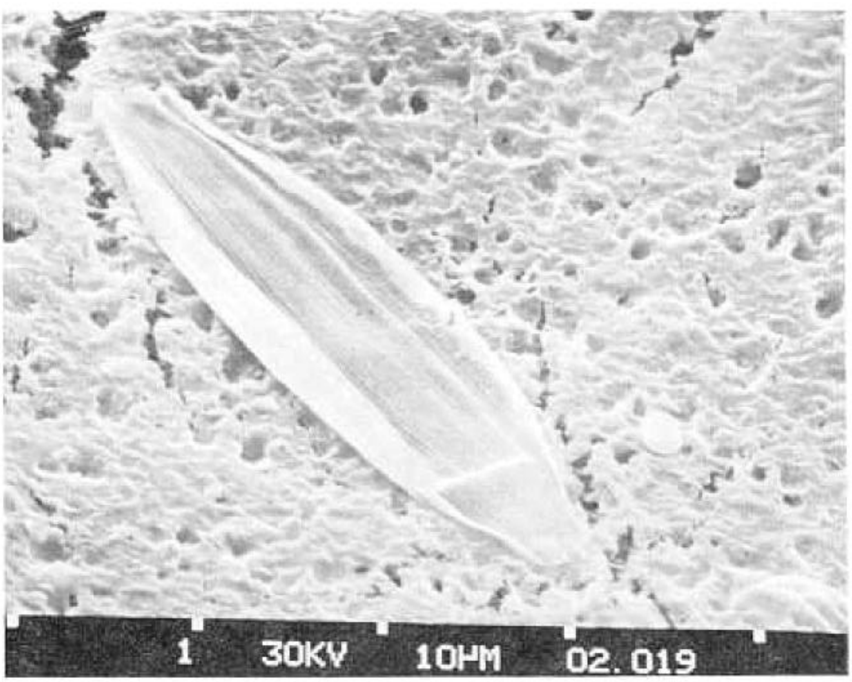

Figure 30.—ED feed-1, plugging factor = 75 percent. Note diatom (Si)^0 and possible mineral particle (Al, Si) to the right. P801-D-80066

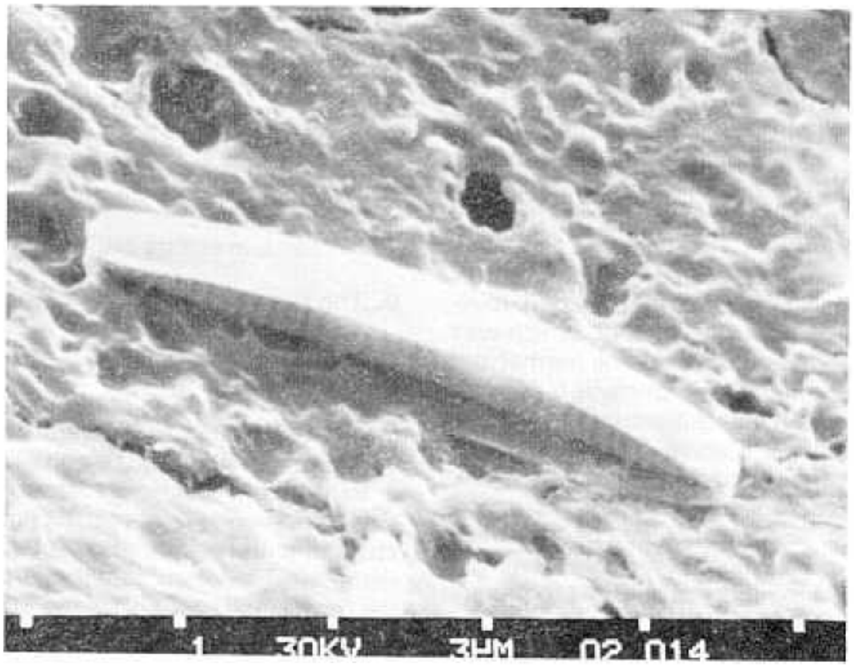

Figure 31.—ED feed-2, plugging factor = 75 percent. Note piece of diatom (Si). P801-D-80067

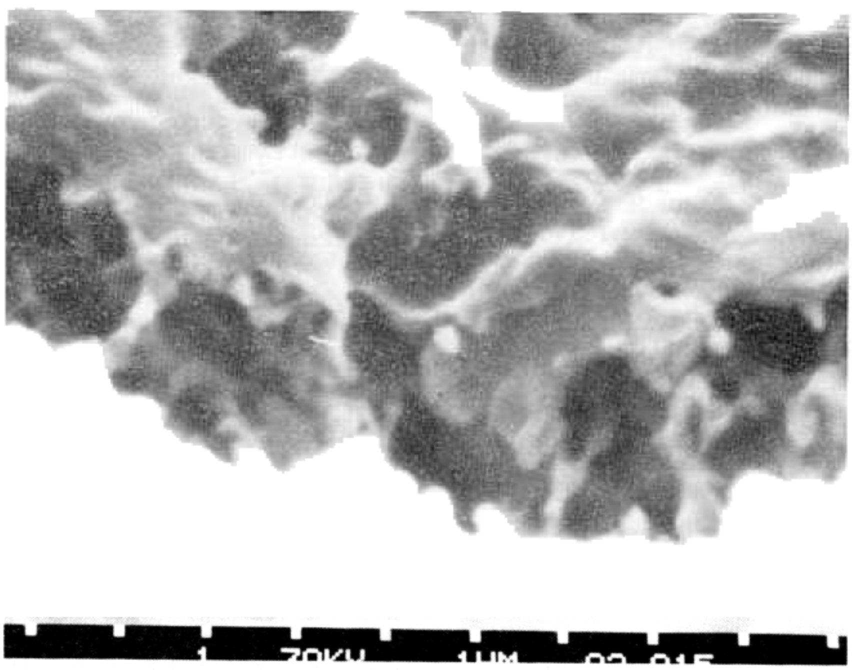

Figure 32.—ED feed-3, plugging factor = 75 percent. Note crack in surface coating over filter. It probably formed during SEM sample preparation. P801-D-80068

RECOMMENDATIONS

Recommended Ion Exchange Cycle

Based on analysis of IX data, a recommended IX cycle with about 92 percent desalting recovery is given in table 14. The conditions in table 14 are based on data from YDTF in which 0.10 m^3 of Amberlite 200 resin in a 1.1-m-deep bed was used. From figure 19, which was based on a fit of the IX data, the predicted **TWRC** is 1.42 meq/(L·min). Using other results from run 4.02.42, which was similar to the recommended cycle, the normal (not time-weighted) specific resin capacity is 0.47 eq/L of Ca^{+2}. Average water compositions for run 4.02.42 are given in table 15. Curves for major cation concentrations versus bed volume in the rinse, service, and regenerant effluents are shown on figures 33 and 34. The **TWRC** might be increased using a higher exhaustion flow rate than was tested, but at this time it is not possible to predict the amount of increase in **TWRC**.

A further modification of the tested IX cycle as listed in table 14 is that the rinse effluent should not be sent to waste as in common ion exchange operation. This would lower overall process water recovery. The first portion of rinse effluent, about one-half of a bed volume, should be recycled as regenerant. The remaining portion prior to service should be recycled to the feed of the lime-treatment system, which would require a fractionally larger pretreatment capacity to reprocess the recycled portion of the rinse effluent.

The recommended resin type is the common gel-type cation exchange resin made a sulfonated styrene-divinyl benzene copolymer used in countless water softeners and in demineralization. Manufacturers' designations for reference only include:

- Amberlite IR-120 (Rohm and Haas)
- Duolite C-20 (Diamond Shamrock)
- Dowex HCR (Dow Chemical)
- Ionac C-249 (Sybron)
- Permutit Q100
- Others equally suitable

The reason that this common gel-type is recommended over the macroreticular-type tested at YDTF is:

1. Cost is lower for the gel-type.
2. Availability is greater for the gel-type.
3. Resin capacity is about 8 percent higher for the gel-type so the amount of resin required is about 8 percent less.
4. There is less potential for problems due to calcium sulfate scaling with the gel-type.
5. The higher physical strength of the macroreticular-type resin is not needed in the present application.

Gypsum-scale-free operation was demonstrated clearly using high regenerant flow rates and regenerant recycling, and this also can be expected in a large plant. But in a case of an emergency situation, such as if regenerant flow were suddenly stopped with regenerant still in contact with the resin because of an equipment or power failure, the resin could become scaled. The macroreticular resin contains pores inside which calcium sulfate precipitate conceivably could form, although this has not been proved. Gel-type resin does not have pores, for the gel beads have a smooth solid spherical surface into and out which the cations diffuse but not the anions (sulfate). Thus, since any calcium sulfate scale formed in a gel-type resin bed would exist outside the beads, the scale could be dissolved more easily by rinsing with feed water a solution containing 10-percent sodium chloride or most rapidly with hydrochloric acid. This was demonstrated successfully in later tests of saline water at LaVerkin Springs in southwestern Utah using gel type resin (Dowex HCR but other brands are equal) [28]. The resin capacity also would be 10 to 15 percent greater in a large plant (2-m-deep resin beds) compared to the present experiments (1-m-deep beds) because the performance would be more efficient in a deeper IX bed. The compounding of these factors (8 percent improvement for gel-type resin and 10 percent increase from greater bed depth) results in a projected resin capacity of 0.55 eq/L Ca^{+2}. The conditions in table 14 do not include these correction factors, which would increase resin capacity and exhaustion throughput volume.

The previous high recovery feasibility design [6, 8] used a conservative estimate of resin capacity less than that found in the present experiments. In the design, limits also were assumed on the possible recoveries with self-sustaining IX operation using only fresh brine regeneration. It was presumed that if the sodium ion concentrations in the reject brine were less than 10 g/L (about 91-percent recovery),

Table 14. — *Recommend IX cycle. A cycle with 35 g/L TDS reject brine regenerant, based on a resin bed volume BV of 100 L and bed depth of 1 m of cation exchange resin, regenerant temperature less than 31 °C*

Mode name	Input	Output	Throughput volume, BV	Duration, min
Exhaustion	IX feed	RO feed	68.0	228
Drain 1	—	RO feed	0.4	2
Regeneration 1	Recycled reg.	Waste	2.5[1]	10
Regeneration 2	Recycled reg.	Reg. recycle	15.8[2]	68
Regeneration 3	RD reject	Reg. recycle	5.4[2]	23
Drain 2	—	Reg. recycle	0.6	3
Rinse	IX feed	Reg./feed recycle	1.3	10

Total cycle time .... 344 min
Resin capacity .... 0.47 eq/L of Ca^{+2}
Time-weighted resin capacity .... 1.4 meq/(L-min) of Ca^{+2}
Calcium removal efficiency .... 90 percent

[1] Volume and flow rate to maintain a 50-percent bed expansion for 10 minutes.
[2] Based on a 24 L/min flow rate.

self sustaining IX operations would not be possible, and supplemental sodium chloride would need to be added to the reject brine regenerant. Also, in this design it was assumed that 92.89 percent was the maximum recovery achievable because the volume of regenerant available at higher recoveries was insufficient. Experiments at YDTF have shown that these two conservative assumptions are incorrect. Self-sustaining operation was demonstrated consistently over a range of 85.5- to 94.3- percent nominal desalting recovery. Only one of the 42 Phase 2 and Phase 3 IX runs was not self-sustaining. That was run 3.11B, which used the highest recovery (94.3 percent, 50-g/L TDS) regenerant brine and feed water backwash with no recycled regenerant. The use of recycled regenerant in all other IX runs eliminated this limitation of low fresh regenerant volumes, which accompany the highest recovery operations. The 6.7-g/L sodium concentration in the 20-g/L TDS fresh regenerant (85.5-percent recovery) was still more than adequate to regenerate the cation exchange resin, and there was not evidence that this concentration was close to a lower limit for a completely closed loop operation without supplemental sodium chloride. Information in appendix I sheds light on the behavior of this IX process.

Further Design Suggestions

For recoveries less than about 90 percent there is not apparent justification for the addition of SHMP to desalting unit feed considering the low calcium effluent of the ion exchange. The SHMP ending in the reject brine would also slow the rate of recycling the regenerant, although even with SHMP, reuse of regenerant is recommended. Savings in SHMP costs would be about $1 million annually for the YDP if SHMP was not used. Generally, SHMP use for high recovery is not recommended.

Consideration also should be given to only passing a portion of the lime-treated water through the IX. The fraction of water which would bypass the IX would be blended prior to the RO with the remaining fraction treated by IX. The fraction treated by IX would be determined by the allowable calcium in the RO feed, a function of desalting recovery. For example, using the values in table 14 and 15 for the recommended cycle at 91.8-percent recovery, which requires less than about 29 mg/L average calcium in the feed for gypsum scale at equilibrium, 95 percent of the water would require IX treatment and the other 5 percent could bypass the IX. For lower desalting recoveries, the bypass could be greater. Whether SHMP in the RO feed is to be used under such a scheme can be considered also. Because the size of the IX equipment is proportional to the fraction of the flow passed through the IX, considerable cost savings would result from the partial IX treatment. The resin capacity of the IX also would be evidently greater than in the present experiments under such a scheme. This is because the entire desalting plant reject would be available as regenerant whereas only a portion of the desalting feed water would have been softened by IX.

There are several recommendations for controlling biological growth in the IX system. The suggestions are based on resin manufacturers' recommendations. Chlorine residual in the feed to the IX should

Table 15. — *Composite water compositions in mg/L during cycle 4.02.42*

Constituent	Regenerant 1 and 2 influent	Regenerant 1 effluent	Regenerant 2 effluent	Regenerant 3 influent	Regenerant 3 effluent	Rinse and exhaustion influent	Rinse effluent	Exhaustion effluent
Silica	2.4	2.4	2.6	3.4	2.8	3.5	3.0	3.5
Calcium	1 030	1 590	1 490	167	1 000	168	332	21.8
Magnesium	602	600	738	254	484	46.4	194	31.0
Sodium	8 230	4 660	7 730	11 500	9 530	841	7 070	1100
Potassium	57	36	53	83	60	7.4	44	11.8
Strontium	25	25	31	3.6	25	2.1	5.0	0.4
Bicarbonate	97.6	68.3	122.0	119.6	146.4	26.8	89.3	29.8
Sulfate	5 500	4 120	6 080	9 420	8 220	930	5 800	950
Chloride	12 440	8 640	12 580	12 080	12 040	1054	7 970	1106
TDS*	27 984	19 742	28 827	33 631	31 508	3079	21 507	3254

* TDS (total dissolved solids) calculated by summing the concentrations of the components.

be kept at or near zero, because the cumulative effect of higher chlorine levels would result in gradual deterioration of the cation exchange resin. Disinfection should be maintained in the IX product. All tanks and piping should be drained if the IX system is shut down for more than about a month. Resin can be stored long term in-place in a 10- to 15-percent sodium chloride solution, which will inhibit biological growth in the resin bed and serve as regenerant when the IX is restarted. If biological growth should occur at any time in the resin bed, backwashing and rinsing with a 1-percent formaldehyde solution will sanitize the bed. Alternatively, the resin bed also can be flushed safely with a caustic solution to remove any slime buildup that might occur.

Gypsum scaling of regenerant effluent piping could occur due to the supersaturated regenerant effluent. It is best eliminated by collecting the spent regenerant just above the resin bed and by using minimum pipe diameters and lengths to speed the spent regenerant to the regenerant recycling system. For minimum retention time of regenerant effluent in the piping the best location for regenerant recycling is adjacent to the ion exchangers. Keeping the residence time of the spent regenerant low should minimize gypsum scaling since it takes some time for precipitation and scaling to begin. The piping also should be drained and flushed with a small volume of feed water at the end of regeneration. But probably the most effective means to prevent a gypsum buildup in the piping is to design for common flow of IX feed water and regenerant effluent. In pilot plant locations, of such common piping, there was never a buildup of scale, for any gypsum adhering to piping during regeneration was readily redissolved during rinse and exhaustion.

Future Development Studies for Yuma High Recovery

While data contained in this report may be sufficient for an experienced IX designer to develop a YDP-type high recovery IX pretreatment design, additional study would probably yield a more optimal final design.

Operation of a full-size IX bed would verify sizing up to a large bed regenerated with RO reject brine, which has never been specifically demonstrated. This could include different flow distributor designs if necessary. Regenerant effluent piping design could include the recommendations presented in the previous section on methods of eliminating

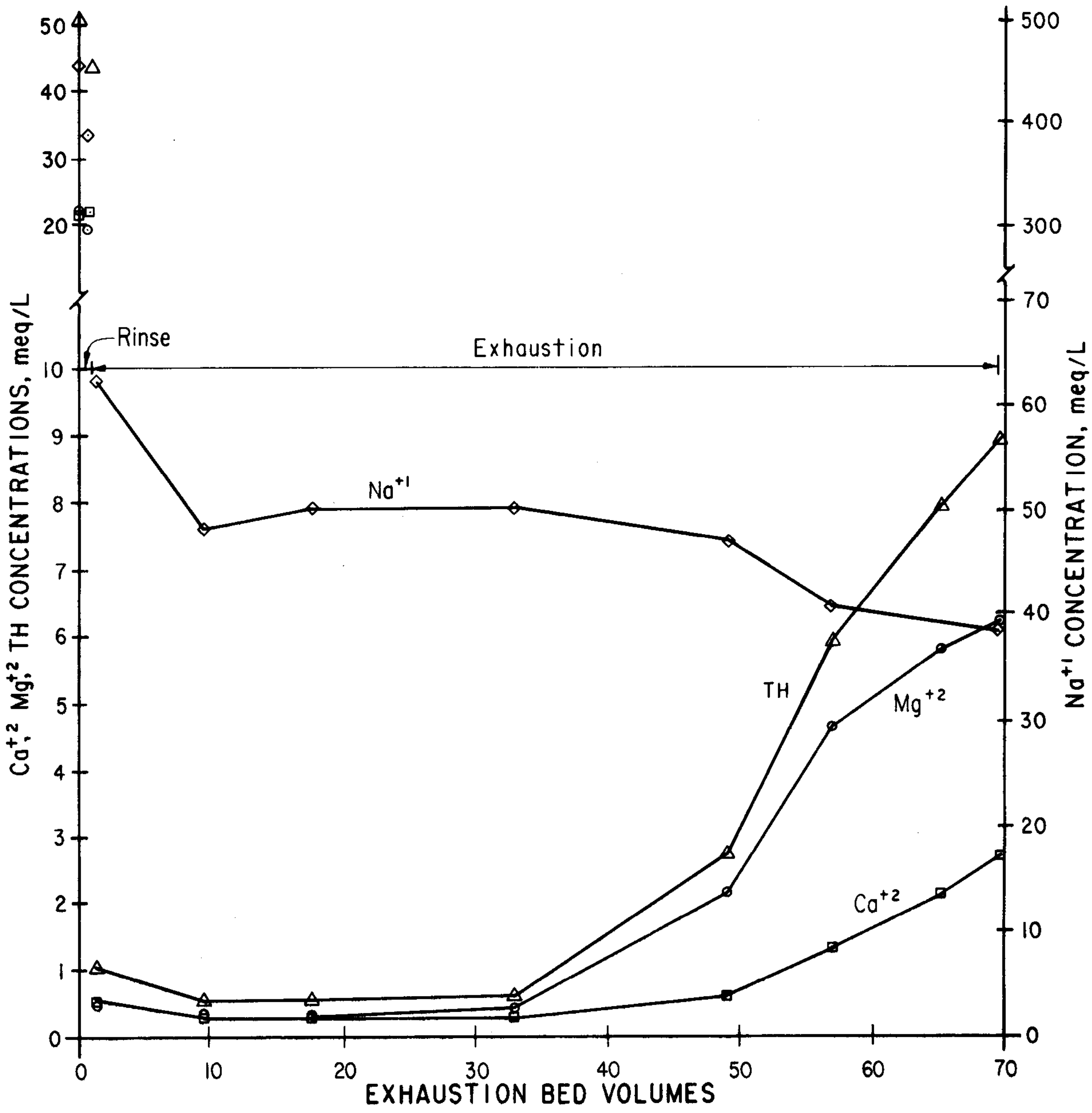

Figure 33.—Major cation concentrations in IX rinse and exhaustion effluents in cycle 4.04.42.

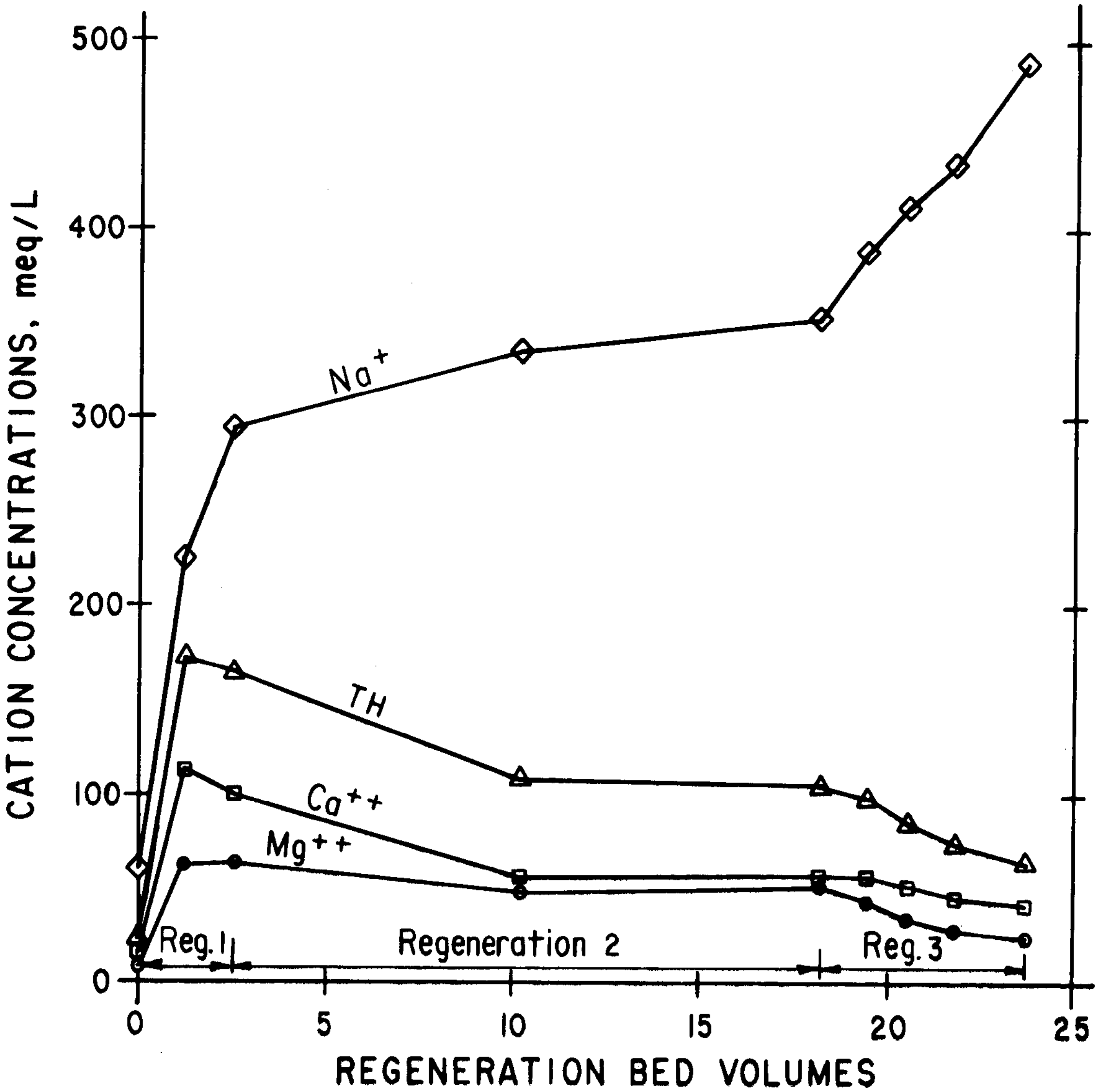

Figure 34.—Major cation concentrations in IX regeneration effluent in cycle 4.04.42.

gypsum-scale buildup inside the piping. Recommended methods for stopping microbiological growth to keep plugging factors low also could be demonstrated. Data should be collected to predict the effect of higher exhaustion flow rates on **TWRC**. Testing of continuous ion exchangers should be considered, also.

A resin hold down procedure to maintain a compact resin bed during upflow regeneration [29] has been demonstrated successfully at LaVerkin Springs [28]. The procedure uses a low-pressure compressed air flow from above the bed to hold down expansion while regenerant flowing upward from the bottom of the column exits through special distributor-collector piping located in the top of the bed at the middle of the column. Benefits include better contact for mass transfer between regenerant and resin and higher possible regenerant flow rates, which would yield a lower regeneration time, and higher **TWRC**. Resulting performance with a compacted bed at LaVerkin Springs showed higher resin capacities and less potential for resin scaling as compared to performance using fluidized bed regeneration. Less gypsum precipitation may occur in a compacted resin bed because the residence time of regenerant in the bed during which gypsum can form is much less than with a fluidized bed. This procedure should be tested on lime-treated Wellton Mohawk Canal water if this IX system is to be used for the Yuma Desalting Plant.

There is one significant advantage of an IX-ED combination over an IX-RO combination. Pretreatment removal of silica is not necessary for ED (unless the feed is already at silica saturation) because ED does not concentrate silica at near neutral or acidic pH when the silica is unionized. Silica removal is more often necessary for RO because RO concentrates silica, and supersaturated silica will scale the membrane and ruin it. When high-lime softening is used for silica removal for RO, additional calcium is introduced from the higher lime dosage. This additional calcium then must be removed by the IX prior to the RO. A smaller, more efficient, more economical IX system generally would be possible with ED because this additional lime for silica removal and the resulting increased calcium are unnecessary. In the high recovery feasibility design [6] the feed water requirements for RO and ED were assumed to be the same. Clearly, this is erroneous because of the different silica requirements for RO and ED and does not take this basic advantage of ED into account. It is recommended that in the future the different pretreatment requirements for silica removal be considered whenever RO and ED are compared.

General Studies

Nearly all experimental work on cation exchange softening pretreatment with reject desalting brine regeneration has used site-specific water compositions. Systematic study has not determined IX performance as a function of the water composition nor defined limits of composition to which this process is applicable. The need for such work is illustrated by the conclusion in the report of Haugseth and Beitelshees [10] that the ratio of Na to Ca in equivalents should be greater than 1.8 in the IX feed to achieve IX operation with reject brine regeneration only. This conclusion is questionable because it is based on extrapolating experimental data using only one feed water composition. Consideration was not given to either regenerant recycling nor allowance for the importance of differences in brine-feed TDS concentration as a regeneration driving force as explained in appendix I. A systematic theoretical and laboratory study could establish the composition dependency and limits of the process. Such a study should include the development of a model for predicting — by computer —ion exchange performance and required ion exchange equipment size for pretreating a particular water composition.

Such experiments would be best accomplished in small diameter (about 25 mm), 2-m-high columns, water jacketed with temperature control. Different water compositions could be made synthetically using various salts. Different regenerant temperatures could be tested.

More study in the area of gypsum precipitation kinetics would be valuable, especially under conditions similar to those in reject-brine-regenerated cation exchange. Experimental results could be used to model gypsum precipitation and scaling rates. Such a model could be useful to better define operating limits for scale control in resin and piping. The importance of water composition, temperature, mixing rate, and gypsum seed crystal composition would be important dependent variables. Use of a calcium specific ion electrode could provide nearly instantaneous calcium activity data useful in the modeling. One intriguing application could be to intentionally feed gypsum crystallites with recycled regenerant during upflow fluidized resin regeneration; the effect of this theoretically is that scaling of resins would be abated and regeneration efficiency improved. The calcium specific ion electrode may serve also as a means of measuring calcium ion breakthrough of the cation exchanger.

Controlling Colloidal Fouling of Reverse Osmosis Membranes Using Cation Exchange Softening

After the completion of these high recovery experiments, the proof testing at Yuma Desalting Test Facility showed greater water productivity decline rates of the RO units than was projected in the manufacturers' proposals. Colloids and organic materials in the feed water fouling the RO membranes may have been a contributing factor to the performance decline. Significantly better removal of colloids by the existing pretreatment scheme may not be possible and additional equipment to better remove the fouling substances may be justified. Alternatively, rather than removing additional colloids prior to RO, colloidal fouling may be controlled by stabilizing colloids to prevent their coagulation in the RO units. This stabilization could allow the colloids to pass through the RO equipment in the reject stream without fouling the membrane surface.

Presently, cation exchange softening is the only practical technique known to accomplish such colloid stabilization [32]. Softening (replacing multivalent cations with monovalent sodium and potassium) increases the double layer thickness and the effective electrical charge of the colloids. Both of these effects increase colloid stability and retard their coagulation. The *zeta* potential of colloids usually will double after a high level of softening. In obtaining thoroughly effective stabilization, softening must be nearly complete–assume to an effluent hardness level of less than 5 mg/L [32]. But even a lesser level of softening may lower the rate of colloid coagulation significantly.

Stabilizing colloids through cation exchange pretreatment remains an area needing more research and demonstration. This could prove to be another significant advantage for the use of cation exchange pretreatment for RO and ED.

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APPENDIX A — GLOSSARY

Backwash — The name of the initial upflow mode of an IX cycle following exhaustion, used to flush foreign particulate material from the resin bed and to reduce compaction of and reclassify the resin bed prior to regeneration of the cation exchange resin.

Breakthrough — Rapid increase in the concentration of the absorbed ion in the exhaustion effluent, which indicates a nearly exhausted resin with respect to that ion.

BV — Bed volume, volume of water in liters divided by the resin bed volume in liters, dimensionless.

C — Solution concentration, also the fresh regenerant (C_f) or ED reject brine concentration of total dissolved solids in mg/L, g/L, or g/m^3.

Ca — Calcium.

Ca^{++} — Calcium ion.

$CaSO_4 \cdot 2H_2O$ — Calcium sulfate dihydrate (Gypsum).

Cation exchange — Ion exchange involving positively charged ions called cations.

Cocurrent — Refers to an IX cycle with the exhaustion and regeneration operated in the same flow direction.

Countercurrent — Refers to an IX cycle with exhaustion and regeneration operated with opposite flow directions.

CSS — Calcium sulfate supersaturation, quantitatively the amount of gypsum in moles/L that would precipitate at equilibrium from a supersaturated solution of calcium sulfate.

Cycle — A set of the different sequential process steps that make up the ion exchange process.

Drain — Removal by gravity of solution from the resin bed and IX column prior to a mode to promote a faster change in effluent solution concentration at the beginning of a new ion exchange process step.

ED — Electrodialysis.

EDTA — Ethylenediaminetetraacetic acid, a white crystalline acid used as a chelating agent.

E.F. — TDS concentration of a solution in mg/L divided by electrical conductivity in μS/cm.

Electrodialysis — A desalination process driven by an electromotive force (direct-current voltage) applied to electrodes on either side of pair(s) of ion-selective membranes of opposite charge. The voltage causes ion diffusion through the membranes yielding dilute (product) and concentrate (reject) streams.

Elution — Removal of absorbed ions and replacement by co-ions from the IX resin during regeneration.

End point — Termination of exhaustion occurring at breakthrough.

Equivalents — The mass of an ion present in grams divided by its equivalent mass.

Equivalent mass — The atomic or molecular weight of an ion divided by the absolute value of the ionic charge of the ion.

eq/L — Number of equivalents of ions absorbed per liter of resin in exhaustion mode, which are the units for (specific) resin capacity. Also can be the ionic concentration in a solution in which case it is per liter of solution.

Exhaustion — Also called service; the mode of an ion exchange cycle during which feed water is being treated by ion exchange to remove one or more undesirable ions.

E&R Center — Engineering and Research Center, Bureau of Reclamation, PO Box 25007, Denver, Colorado 80225-0007.

F — A statistical measure by which to judge the significance of a term in an equation generated by multiple regression.

Formaldehyde — Colorless, toxic, water-soluble gas (CH_2O) used in aqueous solution as a disinfectant and preservative against biological growth.

FRE — Fresh regeneration effluent.

gal/d — Gallons per day.

Gel — A type of ion exchange resin consisting of rigid spheres of styrene-divinyl benzene co-polymer. The selective exchange of ions occurs at the surface of the resin beads as the ions of positive or negative charge diffuse into and out the resin beads, but not the ions of the opposite charge.

Glycoprotein — Any of a group of complex proteins containing a carbohydrate combined with a simple protein, often a product of micro-biological activity.

Gypsum — Calcium sulfate dihydrate ($CaSO_4 \cdot 2H_2O$), a solid crystalline form.

Hardness — Multivalent cations, chiefly calcium and magnesium.

Ion exchange — A process by which certain ions of a given charge are absorbed from the influent solution by an aborbent (ion exchange resin) and are replaced in the effluent solution by equivalent amounts of other ions of the same charge from the absorbent.

IX — ion exchange.

JTU — Jackson turbidity unit.

Leakage — For ions being absorbed from the feedwater during IX exhaustion, the appearance of some of those ions in the exhaustion effluent water.

Macroreticular — The physical structure of the ion exchange resin where each bead consists of a small sphere with a rigid sponge-like structure containing numerous relatively large pores into which a solution can pass in contrast to gel-type.

Mg — Magnesium.

Mg^{+2} — Magnesium ion.

Mode — One of the discrete process steps in an ion exchange cycle.

N/A — Not applicable.

Na — Sodium.

Na^+ — Sodium ion.

NaCl — Sodium chloride, common chemical (salt) used to regenerate cation exchange resin in the sodium cycle.

ND — Not detected.

Plugging factor — It is an analytical measure used to quantify the potential of a water composition to foul (decrese product water transport through) a desalting membrane. Plugging factor is computed by:

$$\text{Plugging factor} = \left(1 - \frac{t_1}{t_2}\right) 100$$

where t_1 is the time for 0.38 m of water to pass through a new 0.45-μm pore-size membrane filter at an applied pressure of 207 kPa, and t_2 is the same measurement after the test water has been passed through the filter for 15 minutes at 207 kPa of applied pressure.

Pretreatment — Water conditioning prior to desalting to prevent fouling and chemical scaling of the desalting equipment.

PVC — Polyvinyl chloride, plastic material used to make pipe, valves, pumps, etc.

Q_f — Fresh regenerant flow rate, L/min.

Q_p — Ion exchange plant capacity, L/min.

Q_r — Recycled regenerant flow rate, L/min.

R^2 — A statistical measure, the fraction of the total variation of a dependent variable which is accounted for by an equation containing independent variables.

RC — Specific resin capacity in eq/L usually for calcium removal in this report.

R — Desalting recovery, the ratio of product water volume to feed water volume expressed as a percentage. In these experiments, usually it was calculated indirectly from the ED feed TDS concentration, fresh regenerant TDS concentration, and a projected design TDS concentration of 473 mg/L in the desalted product using equation 1.

Regenerant — The chemical solution used during regeneration to return an ion exchange resin to the desired ionic form for further absorption of the ion requiring removal during service or exhaustion.

Regeneration — The mode for replacement from the ion exchange resin of the ions removed from the process solution during service or exhaustion. Performed by passing through the bed, a solution containing a high concentration of the ion desired in the resin.

Reject — The concentrated solute stream or brine of a desalting process, usually considered the waste stream.

Residual — An observed (experimental) value minus the corresponding value predicted by a best fit equation for that observation.

Resin — Here, the synthetic beads of polystyrene-divinyl benzene copolymer which are further treated chemically to give the properties of ion exchange.

Resin capacity (specific) — A quantitative measure of equivalents of ion or ions absorbed by a resin per volume (or mass) of resin, which is a function of the resin properties, the water composition, and IX operating conditions.

Reverse osmosis — A desalting process in which a semipermeable membrane is used to separate dissolved solids from water with an applied pressure greater than the osmotic pressure as the driving force.

RO — Reverse osmosis.

RRE — Recycled regeneration effluent.

RRI — Recycled regeneration influent.

RS — Response-surface experimental design.

S — Siemen.

SEM — Scanning electron microscopy.

Service — Synonymous with exhaustion, which is the preferred term.

SHMP — Sodium hexametaphosphate precipitation or scale inhibitor, used here to retard gypsum formation.

SI — Scaling intensity, a semiquantitative measure of gypsum scaling of the IX resin based on observations noted in the operators' log.

SiO_2 — Silica.

Slippage — Same as leakage.

Soda — Sodium carbonate, Na_2CO_3, or soda ash (mineral).

Softening-Removal of hardness (multivalent ions)—chiefly calcium and magnesium—from water.

SO_4^{-2} — Sulfate.

t_c — Time duration of an ion exchange cycle, min.

T_f — Fresh regenerant temperature, degrees Celcius.

TDS — Total dissolved solids in a solution, usually a concentration in mg/L, g/L, or g/m^3, determined in the laboratory by summation of individual ion analyses or by evaporation. TDS can also be estimated from a conductivity measurement.

Train IV — Name of the lime-softening-clarification system which provided partial pretreatment for the IX experiments at the YDTF.

TWRC — Time-weighted resin capacity, the specific resin capacity divided by the cycle curation in minutes, in meq/(L·min).

V_e — Exhaustion volume, L.

V_f — Fresh regenerant volume, L.

V_f' — Fresh regenerant volume theoretically predicted from V_e and R.

V_{resin} — Volume of ion exchange resin, L.

V_r — Recycled regenerant volume, L.

V_s — Service volume, L, same as V_e.

V_3 — Fresh regenerant volume, L, same as V_f.

WM — Wellton-Mohawk, refers to the irrigation district in the westernmost portion of the Gila River Valley in Arizona producing the saline irrigation drainage water which fed the Yuma Desalting Test Facility and to feed the future Yuma Desalting Plant.

YDP — Yuma Desalting Plant.

YDTF — Yuma Desalting Test Facility.

Zeta potential — A measure of the charge and mobility of collodial particles in solution. The higher the absolute value, the more likely are the colloids to remain stabilized in solution and not coagulate.

APPENDIX B — DATA FROM PHASE I

A detailed description of the results of Phase I experiments is presented in chronological order. Tables and figures describing the results of cycles 1.03.28, 2.01.09, 2.01.76, 2.01.137, 2.01.156, 2.01.174, 2.01.202, and 2.01.213 are at the end of this appendix.

Reject Brine Versus Sodium Chloride for Regeneration

The IX cycles 1.03.20 through 1.03.49 used a 3.0 percent sodium chloride regenerant and were conducted to supply feed water for the ED startup, initial ED testing, and ED production of the initial supply of 90-percent recovery desalting brine regenerant. Partially lime-treated feed water from Train V was used. Cycle 1.03.28 (table B-3) was typical of these runs with a sodium chloride regenerant.

Cycles 2.01.01 through 2.01.47 were the first exploratory experiments using the ED brine for regeneration. A backwash using feed water was used in cycles 2.01.01 through 2.01.09.

The operating conditions were similar for cycles 1.03.28 (table B-3) and 2.01.09 (table B-4). Only the regenerant composition was different. A performance comparison is possible between using 3.0-percent sodium chloride regenerant and reject brine regenerant derived from lime-softened Welton-Mohawk Canal water concentrated to 26700 mg/L. The 0.149-meq/L resin capacity for calcium removal using the ED brine as regenerant is 21 percent less than the 0.188 meq/L using 3.0 percent sodium chloride. Similarly, the resin capacity for total hardness removal (calcium plus magnesium) was 17 percent less using ED brine regenerant under these conditions. This type of difference is expected since, compared to the reject brine regenerant in 2.09.09, the sodium chloride regenerant in 1.03.28 had a 23 percent greater sodium ion concentration.

Note, however, the brine regeneration of cycle 2.09.09 was not self-sustaining in that 371 L of ED brine were used but only about 245 L of brine could be made at 90-percent recovery (2453-L exhaustion volume concentrated tenfold yields 245 L of brine). Subsequent exploratory experiments were aimed toward determining ranges of conditions during which self-sustaining brine regeneration occurred. That is, the volume of ED brine used for regeneration per cycle was balanced with the volume which could be made by concentrating the amount of IX product water made per cycle at the set desalting recovery.

Exploring Fresh Brine Regeneration Flow Rates

Starting with cycle 2.01.10, the backwash was eliminated and the entire ED brine regeneration was done at a much higher flow rate to fluidize the bed to approximately 50-percent bed expansion. This was an attempt:

- to carry out the physical requirements served by a backwash in removing fines from the bed and reclassifying the resin particles,
- to minimze any opportunity for calcium-sulfate-precipitate formation and retention in a compacted bed, and
- to eliminate the wastage of feed water in the backwash.

Feed water use for backwash has the net effect of lowering overall water recovery of the total system if the backwash effluent is not recycled.

From the small service volumes, it became apparent that the use of the 240 L of fresh regenerate was poor under these regeneration conditions. The amount of IX product-ED feed being generated through cycle 2.01.23 averaged only 1200 L. This resulted in only about 120 L of 90-percent recovery ED brine per cycle and, thus, these cycles were not nearly self-sustaining in the amount of regenerant brine that could be produced.

An effluent limit of 1.0 meq/L calcium was used to terminate the exhaustion mode up to cycle 2.01.23. In an effort to increase the exhaustion throughput volume, the effluent limit was increased to 1.4 meq/L calcium for cycles 2.01.34 through 2.01.37, but an average of only 1450 L of IX product was produced, and the average calcium level in the product increased significantly.

In further attempts to increase service throughput, the effluent limit was increased again to 2.0 meq/L and the regeneration flow rate decreased to 10 L/min for cycles 2.01.38 through 2.01.47. The results were — unexpectedly — even poorer with an average of only 750 L of IX product per cycle.

Some of this decline was probably due to the elimination of the backwash.

During this long series of cycles containing small service volumes, the stock of ED brine gradually became depleted because of the inadequate supply of IX product-ED feed for making enough regenerant brine for self-sustaining operations.

Because of an operator's mistake, the remaining stored ED brine was drained to waste. During cycles 2.01.49A through 2.01.57A, sodium chloride regenerant was used so that more ED brine could be made. This also served to return the resin in column 1 to a nearly fully-regenerated state prior to subsequent experiments at other conditions.

During cycles 2.01.58 through 2.01.77, higher recovery (93.6 percent, 42 g/L TDS) ED brine was used as fresh regenerant after a preceding mode using recycled regenerant from tank T-5. During cycles 2.01.58 through 2.01.60, all the regeneration effluent, including that from regeneration 1, was returned to tank T-6 in an effort to build up the recycled regenerant stock more rapidly. This attempt to recycle temporarily all the regenerant was discontinued when it was realized that the initial portion of regeneration effluent consisted largely of feed water in the column from the previous exhaustion mode, which was diluting the regenerant in tanks T-5 and T-6. During subsequent cycles, the first portion (at least 190 L) of the regeneration effluent was sent to waste to avoid diluting the recycled regenerant.

It should be noted that one practical limitation of the present experimental system was that about the last 90-L of fresh regenerant effluent per cycle could not be recycled because it could be drained only by gravity to waste. An additional sump and pump would have been necessary to transfer this 90-L drained up to the recycling tank. In a prototype plant, this drained regenerant should be collected and recycled.

Operating conditions for cycles 2.01.61 through 2.01.69 are summarized in table B-1. Under these conditions calcium leakage was high (2.0 meq/L or greater once equilibrium was reached) and the mean exhaustion volume was 1175 L at a calcium breakthrough point of 3.0 meq/L. These exhaustion volumes provided insufficient ED feed to provide the volume of fresh regenerant used at 90-percent recovery.

The fresh regenerant flow rate was lowered from 10 L/min to about 3 L/min starting with cycle 2.01.70. The fast rinse mode also was eliminated in all subsequent cycles because the effluent quality after the slow rinse step alone was entirely adequate for initiating the service mode. That is, by the end of the slow rinse, the calcium and sodium concentrations of the rinse effluent were lowered to levels of typical initial exhaustion effluent.

Cycle 2.01.76 (table B-5) included the first set of conditions tested which resulted in a greater volume of fresh brine generated than used for fresh regenerant. Apparently, the lower fresh regenerant flow rate was a critical control variable. It could be adjusted to give a longer contact time between the fresh regenerant and the resin and a more compact resin bed to increase cationic mass transfer rates between the regenerant and resin. The result of proper adjustment was a greater resin capacity.

These last two series of cycles indicated that the fresh regenerant flow rate had to be something less than 10 L/min with the other operating conditions specified, including no recycled regenerant, for satisfactory IX performance. This flow rate was considerably lower than expected.

Start of High Lime-softened Feed Water

During the following group of IX cycles (2.01.78 through 2.01.174), the ED was operated intermittently at about 94-percent recovery to yield a regenerant brine concentration of about 50 g/L TDS. During the initial ED testing, this concentration was found to be the highest that could be achieved reliably using the present ED configuration while anticipating the historic seasonal variation of feed salinity. (With the lowering of feed salinity, it would be more difficult for the ED to reach the highest brine concentration.) Considerable mechanical difficulties with the ED unit — particularly motorized valve and brine pump failures (see app. F) — lowered the rate of experimentation during this period.

Prior to cycle 2.01.1076A, all feed water to the IX had come from Train V and had a composition representative of the YDP operating at 70-percent desalting recovery. For cycle 2.01.106A and all subsequent cycles, the IX feed water came from Train IV operated with a higher reaction zone pH and greater retention time to promote silica removal as required for high recovery RO. This high lime-pretreated water also contains more calcium and less magnesium.

The first IX data cycle completed at the highest recovery was 2.01.137 (table B-6). A relatively small volume of recycled regenerants was used at a high flow rate, and a low fresh regenerant flow rate was used.

Owing to an operation error in collecting samples, the last two points of the exhaustion effluent concentrations of calcium and magnesium had to be salvaged from the operators' calcium and total hardness titration data; whereas, the remainder of the concentration data came from samples submitted to the YDTF Chemistry Laboratory. As a further consequence, the reported composite concentrations of the service effluent are representative of only the first 44 bed volumes, because the last portion of the service effluent (when hardness leakage was highest) was not sampled for obtaining laboratory analyses.

For cycle 2.01.137, the amount of fresh regenerant used (300 L) balanced reasonably with the brine that could be made from the exhaustion effluent (5120 L). From the TDS of the regeneration 3 influent (41 259 mg/L) and the service effluent (3141 mg/L) and by assuming a 473-mg/L product TDS in the future high recovery YDP, a recovery of 93.5 percent can be calculated using equation 1. The projected brine production for this cycle was (1 −0.935)(5120 L) = 355 L. In actuality, the present experimental ED unit had a significant portion of feed (about 1.4 L/min) lost as electrode rinse, and the product had a varying salinity (ranging 600 to 1000 μS/cm conductivity) and generally higher average TDS (roughly 500 mg/L).

Because of these losses, it was estimated that the ED unit produced about 317 L of brine under these conditions, or 5.4 percent less than the theoretical 335 L. Although, in this case, 317 L still exceeded the 300 L used; this illustrates a major reason for the occasional intervening IX cycles using sodium chloride regenerant needed to provide feed to the ED for replenishing the fresh regenerant brine stock in tank T-28. Usually, the alternate IX column 2 was used during sodium chloride regeneration to avoid disturbing the prevailing ionic equilibria conditions established in cation exchange resin of the experimental column 1.

During cycles 2.01.138 through 2.01.146, a feed water backwash replaced the use of recycled regenerant. Otherwise, the control operating conditions were the same as for cycle 2.01.137. The average exhaustion volume for cycles 2.01.141 through 2.01.148 was 4480 L. This could yield 291 L of new ED brine at 93.5-percent recovery. This was sufficiently close (within 3 percent) to the 300 L used to assume that equilibrium was achieved. Under these conditions, a data cycle was not made, but the resulting IX performance indicated that self-sustaining brine regeneration could be achieved.

After several sodium chloride-regenerated cycles using column 2 for making more ED brine to make up for gradual losses, experiments with column 1 resumed with cycles 2.01.152 through 2.01.156. A feed water backwash without regenerant recycle and a higher fresh regenerant flow rate of 7.4 L/min was used. Both of these conditions probably give a less efficient regeneration than used in cycle 2.01.137.

Estimating the recovery for cycle 2.01.156 (table B-7) at 94 percent, 277 L of brine could be made from the 4560-L service. This favorably exceeds the 250 L of fresh regenerant used. Additional ED brine was made using sodium chloride regeneration and column 2 in cycles 2.01.157 through 2.01.166A.

In cycles 2.01.167 through 2.01.174 (table B-8), a low recycled regenerant flow rate (8.0 L/min), a low fresh regenerant flow rate (3.0 L/min), and a large amount of recycled regenerant (1600 L) were used. While these conditions would allow the best cationic mass transfer between regenerant and resin, these low flow rates also were judged to cause the greatest potential for any possible gypsum-scale accumulation problem in the column due to a compact resin bed and longer regenerant residence time. Such a problem did not appear; however, but note that the water temperatures were relatively cool.

Low Concentration Brine Regeneration

A last series of exploratory cycles were conducted to find if previously determined operating limits also resulted in operable conditions with lower brine concentrations. Following IX cycle 2.01.174, all fresh and recycled brine tanks were drained to make room for a new brine composition. (Later in the program, it was found that diluting the brine with ED product was a faster method of reaching a new lower brine concentration.) The ED was operated to obtain nominally 20-g/L TDS brine. Beginning with cycle 2.01.175A, the IX resin was regenerated with sodium chloride solution to provide feed water to the ED.

Fresh ED brine regeneration began with cycle 2.01.184. During this cycle, it was established from column effluent in-line conductivity measurements that the first 240 L of spent regeneration effluent contained largely feed water retained in the column from the previous exhaustion and should be sent to waste because it would dilute recycled regenerant. Any spent regenerant after this initial 240 L could be recycled as desired. This volume will be fixed by the internal volume of any particular IX unit. Cycles 2.01.185 through 2.01.188 were used to fill spent regenerant tank T-6 with regeneration effluent.

The next series of exploratory cycles — starting with 2.01.189 — was conducted to see if self-regenerating cycles would be maintained under a set of relatively unfavorable control conditions:

- a minimum volume,
- high-flow-rate recycled regenerant step sufficient for backwash only, and
- a moderate fresh regenerant flow rate.

The approach to a satisfactory cycle equilibrium was difficult because of the requirement to balance the volume of fresh brine used to the amount generable from the service volume. The attempt to reach a balance of volumes is illustrated in table B-2 for cycles 2.01.189 through 2.01.213.

A complete set of samples and data was collected for cycles 2.01.202 (table B-9) and 2.01.213 (table B-10). Note that a good balance was reached using 850 L of fresh regenerant in cycles 2.01.203 through 2.01.205 (table B-2). The reason that samples were not collected at this condition was due to the inability at the time of operation to rapidly and accurately measure brine TDS and, thus, to accurately calculate the actual recovery. The recovery, estimated from brine conductivities, was 85.8 percent (at the time the experiments were conducted) which gave considerably higher volumes of generable brine than the 88 to 89-percent recovery — calculated later from TDS by summation of ions from chemical analyses of feed and brine samples. During Phase 2, the daily measurement of evaporative TDS in the chemistry laboratory helped solve this problem.

Thus, cycle 2.01.202 represents a condition where all the brine available was not used for regeneration, and cycle 2.01.213 was a condition where more brine was used than was generated per cycle. Exploratory tests were terminated with these data cycles since they covered the range of conditions within which brine volumes would balance.

It is interesting to compare the performance of cycles 2.01.202 and 2.01.213. The calcium and total hardness resin capacities are greater for cycle 2.01.213 than for 2.01.202 as might be expected from a more thorough regeneration. Surprisingly, the magnesium removal decreased with a greater amount of regenerant brine! Probably the equilibria among cationic species (primarily calcium, magnesium, and sodium) in the IX feed and regenerant interacted, in such a way to cause this phenomenon. However, since the IX feed composition also varied considerably during these runs—apparently due to some control problem in Train IV where the pH in the reactor greatly influenced the calcium and magnesium in the IX feed—a clear conclusion regarding the role of magnesium is not possible.

Table B-1. — *IX operating conditions — cycles 2.01.61 through 2.01.69*

Mode	Input	Output	Average duration min	Average volume L	Average flow rate L/min	Avrage bed expansion %	Average temper-ature °C
Recycled regeneration	Recycled regeneration	Waste	7	191	27	55	21.1
Recycled regeneration	Recycled regenerant	Spent regenerant	34	890	26	53	21.6
Fresh regeneration	Fresh regenerant	Spent regenerant	20	209	10	11	—
Drain	—	Waste	3	—	—	—	—
Slow rinse	Feed	Waste	10	170	17	—	—
Fast rinse	Feed	Waste	3	90	30	—	—
Exhaustion	Feed	Product	[1]39 ±18	[1]1175±534	30	—	—

[1] Mean and standard deviation of the nine cycles.

Table B-2. — *Balance between volumes of fresh regenerant used and potentially generable ED brine — cycles 2.01.189 through 2.01.213*

Cycle No.	Volumes: Fresh regenerant used L	Volumes: Exhaustion L	Volumes: [1]Generable ED brine L	[2]Ratio %
2.01.189	500	10 560	1270	39
2.09.190	500	6 960	835	60
2.01.191	500	7 960	955	52
2.01.192	500	8 140	977	51
2.01.193	500	7 880	946	53
2.01.194	500	6 590	791	63
2.01.195	500	6 160	739	68
2.01.196	500	6 650	798	63
2.01.197	500	7 320	878	57
2.01.198	500	7 320	878	57
2.01.199	500	6 050	726	69
2.01.200	500	6 190	743	67
2.01.201	500	6 620	794	63
2.01.202	500	5 730	688	73
2.01.203	850	8 430	927	92
2.01.204	850	8 200	902	94
2.01.205	850	8 090	890	96
2.01.206	1700	11 970	1320	130
2.01.207	1800	11 020	1210	150
2.01.208	1800	10 840	1190	150
2.01.209	1800	11 940	1310	140
2.01.210	1600	10 930	1200	130
2.01.211	1600	9 850	1080	150
2.01.212	1600	10 260	1130	140
2.01.213	1600	9 050	1000	160

[1] Projected *generable* volume that could be generated from the *exhaustion* volume. It is based on desalting recoveries calculated from an assumed product of 473 TDS and from brine and feed TDS measurements from cycles 2.01.202 and 2.01.213, which gave 88.0 and 89.0-percent recovery, respectively. Cycles 2.01.189 through 2.01.202 used the 88.0-percent value in the calculation and cycles 2.01.203 through 2.01.213 used 89.0 percent.

[2] $$\text{Ratio} = \frac{\text{fresh regenerate volume used}}{\text{generable ED brine volume}} (100\ \%)$$

Ion Exchange - Cycle 1.03.28

Date: 10/6/78

Purpose:
1. To produce water for operation of ED unit
2. To obtain baseline conditions using 3% sodium chloride as regenerant.

Conditions: Feedwater - similar to 70% recovery YDP
Backwash - feedwater
Regenerant - 3% sodium chloride
Service termination level - 1.0 meq/ℓ Ca^{++}

Control variable levels: Fresh regenerant concentration - 31 000 mg/ℓ TDS
Average fresh regenerant flow rate - 11.7 ℓ/min
Volume of regenerant - 421 ℓ

Standard resin bed height: 1066 mm

Resin bed volume: 97.3 ℓ

Operating Conditions

Mode	Input	Output	Duration min	Throughput volume ℓ	Throughput volume BV	Avg. flow rate ℓ/min	Avg. flow rate BV/min	Bed expansion %	Temperature °C
Backwash	Feed	Waste	10	306	3.14	30.6	0.31	50	27.3
Regeneration	Fresh regenerant	Waste	36	421	4.33	11.7	0.12	11	30.5
Drain	(Vent)	Waste	3	62	0.64	20.7	0.21	-	-
Slow rinse	Feed	Waste	13	198	2.03	15.2	0.16	-	-
Fast rinse	Feed	Waste	6	176	1.81	29.3	0.30	-	-
Service	Feed	Product	106	3421	35.2	32.3	0.33	-	-

Chemical Analyses of Significant Components in Composite Samples

Sample		Cycle influent Reg	Cycle influent Service	Cycle effluent Service	Cycle effluent Reg	Cycle effluent Slow rinse	Cycle effluent Fast rinse
pH	units	6.74	7.10	7.12	6.84	7.07	7.27
TDS (calc)	mg/ℓ	31 012	4004	4036	18 995	20 260	4080
Conductivity @ 25 °C	µS/cm	48 984	6715	6812	31 320	33 263	6948
Silica	mg/ℓ	3.0	12	13	7.0	7.0	13
Calcium	mg/ℓ	13.5	118	10.8	1134	175	6.6
Magnesium	mg/ℓ	6.34	69.4	19.39	568	113	4.47
Sodium	mg/ℓ	12 389	1257	1479	5471	7724	1526
Potassium	mg/ℓ	2.2	7.9	6.8	32	8.2	2.3
Iron, total	mg/ℓ	0.36	0.04	<0.03	<0.03	<0.03	<0.03
Strontium	mg/ℓ	0.12	1.9	<0.1	19.9	2.5	<0.1
Bicarbonate	mg/ℓ	20	29.3	30.3	22.4	27.3	32.7
Sulfate	mg/ℓ	<10	886	900	28	<10	896
Chloride	mg/ℓ	18 580	1634	1590	11 720	12 200	1612
T-alkalinity as $CaCO_3$	mg/ℓ	16.4	24	24.8	18.4	22.4	26.8
P-alkalinity as $CaCO_3$	mg/ℓ	ND	ND	ND	ND	ND	ND

Major Cation Concentrations of Samples Analyzed by Atomic Absorption

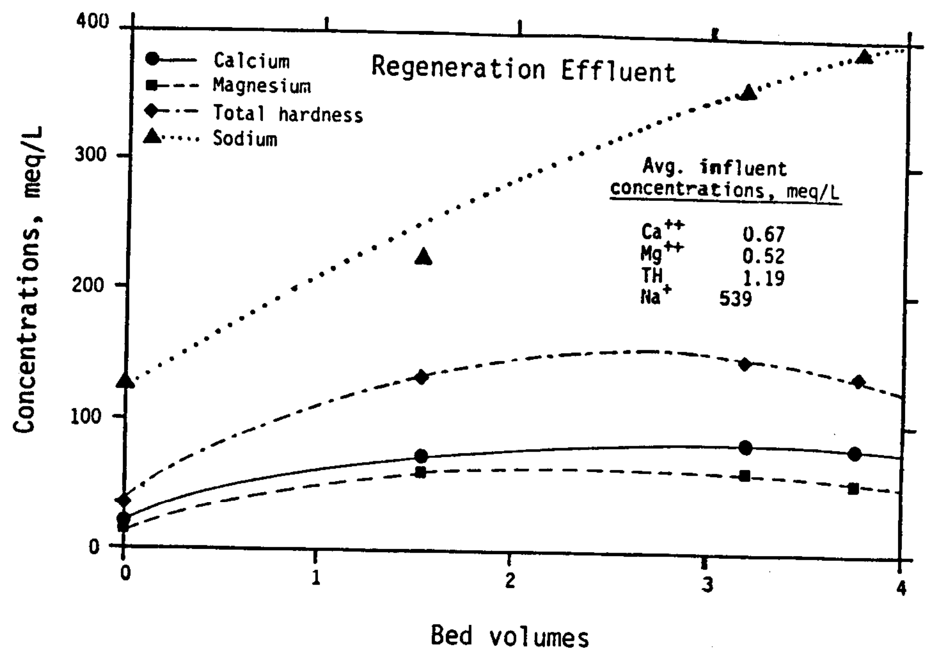
Mode	Throughput BV	Ca^{++} meq/ℓ	Mg^{++} meq/ℓ	TH* meq/ℓ	Na^{+} meq/ℓ
Regen	0	21.1	15.8	36.9	128
Regen	1.59	70.8	60.7	132	226
Regen	3.18	85.8	63.5	149	359
Regen	3.81	82.1	55.7	138	390
Rinse, slow	0	15.8	16.5	32.3	512
Rinse, slow	0.94	2.05	2.15	4.20	165
Rinse, fast	2.03	0.32	0.35	0.67	66.6
Rinse, fast	2.93	0.32	0.35	0.67	66.5
Service	3.84	0.32	0.35	0.67	65.9
Service	10.14	0.32	0.38	0.70	66.2
Service	15.12	0.34	0.43	0.77	66.1
Service	20.09	0.36	0.54	0.90	65.4
Service	25.07	0.42	0.90	1.32	65.4
Service	30.04	0.58	1.84	2.42	64.3
Service	35.02	0.79	2.89	3.68	62.7
Service	39.00	1.04	3.89	4.93	61.7

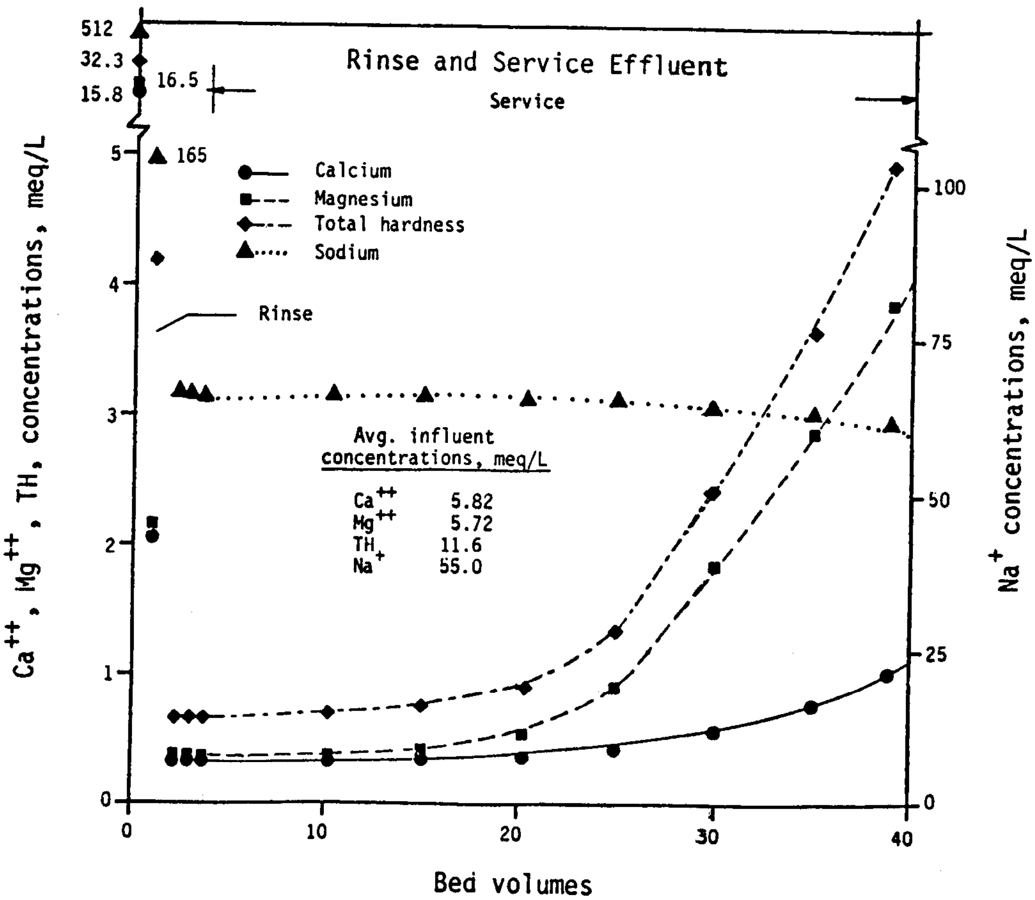
*Calculated from Ca^{++} plus Mg^{++}

Service Performance Summary

	Average concentrations, meq/ℓ			Removal	Resin capacity
	Influent	Effluent	Difference	%	eq/ℓ
Ca^{++}	5.82	0.48	5.34	92	0.188
Mg^{++}	5.72	1.21	4.51	79	0.159
TH*	11.59	1.69	9.90	85	0.348
Na^{+}	55.0	65.0	-10.0	-	-

* Calculated from Ca^{++} plus Mg^{++}


Regeneration Effluent
Calcium
Magnesium
Total hardness
Sodium
Avg. influent concentrations, meq/L
Ca++ 0.67
Mg++ 0.52
TH 1.19
Na+ 539
Concentrations, meq/L
400
300
200
100
0
0
1
2
3
4
Bed volumes


Rinse and Service Effluent
Service
Rinse
512
32.3
15.8
16.5
165
Calcium
Magnesium
Total hardness
Sodium
Avg. influent concentrations, meq/L
Ca++ 5.82
Mg++ 5.72
TH 11.6
Na+ 55.0
Ca++, Mg++, TH, concentrations, meq/L
Na+ concentrations, meq/L
5
4
3
2
1
0
100
75
50
25
0
0
10
20
30
40
Bed volumes

Ion Exchange - Cycle 2.01.09

Date: 10/13/78

Purpose: Performance comparison between use of ED brine and 3.0% NaCl regenerants

Conditions: Feedwater - similar to 70% recovery YDP
Backwash - feedwater
Regenerant - fresh ED brine
Service termination level - 0.1 meq/ℓ Ca^{++}

Control variable levels: Fresh regenerant concentration - 27 000 mg/ℓ TDS
Average fresh regenerant flow rate - 32.5 ℓ/min
Volume of fresh regenerant - 390 ℓ

Standard resin bed height: 1066 mm

Resin bed volume: 97.3 ℓ

Operating Conditions

Mode	Input	Output	Duration min	Throughput volume ℓ	Throughput volume BV	Avg. flow rate ℓ/min	Avg. flow rate BV/min	Bed expansion %	Temperature °C
Backwash	Feed	Waste	10	305	3.13	30.5	0.31	55	25.2
Regeneration	Fresh regenerant	Waste	12	390	4.01	32.5	0.33	63	27.2
Drain	(Vent)	Waste	3	62	0.64	17.6	0.18	-	-
Slow rinse	Feed	Waste	10	176	1.81	17.6	0.18	-	-
Fast rinse	Feed	Waste	3	88	0.90	29.3	0.30	-	-
Service	Feed	Product	82	2453	25.2	29.9	0.31	-	-

Chemical Analyses of Significant Components in Composite Samples

Sample		Cycle influent		Cycle effluent			
		Reg	Service	Service	Reg	Slow rinse	Fast rinse
pH	units	6.14	7.14	7.15	6.58	6.59	7.21
TDS (calc)	mg/ℓ	26 698	3532	3591	18 913	21 598	3844
Conductivity @ 25 °C	µS/cm	36 994	5703	5948	26 656	30 564	6117
Silica	mg/ℓ	17.0	15.0	16.0	16.0	16.0	16.0
Calcium	mg/ℓ	41.0	132	14.0	821	379	12.8
Magnesium	mg/ℓ	116.7	83.9	19.0	486	345	13.1
Sodium	mg/ℓ	9570	1030	1276	5428	7100	1340
Potassium	mg/ℓ	41.8	8.9	8.1	34.3	39.4	7.5
Iron, total	mg/ℓ	0.12	<0.03	<0.03	<0.03	0.04	<0.03
Strontium	mg/ℓ	1.67	2.51	0.70	13.8	6.3	0.60
Bicarbonate	mg/ℓ	27.3	28.8	27.3	29.8	28.3	24.9
Sulfate	mg/ℓ	6700	1016	1020	4600	5100	1080
Chloride	mg/ℓ	10 200	1230	1226	7500	8600	1250
T-alkalinity as $CaCO_3$	mg/ℓ	22.4	23.6	22.4	24.4	23.2	20.4
P-alkalinity as $CaCO_3$	mg/ℓ	ND	ND	ND	ND	ND	ND

Major Cation Concentrations of Samples Analyzed by Atomic Absorption

Mode	Throughput B/V	Ca^{++} meq/ℓ	Mg^{++} meq/ℓ	TH* meq/ℓ	Na^{+} meq/ℓ
Regen	0	18.4	19.2	37.6	127
Regen	0.95	26.6	32.1	58.7	159
Regen	1.91	50.9	51.9	103	261
Regen	2.86	53.9	50.1	104	310
Regen	3.81	50.8	42.1	92.9	326
Rinse, slow	0	24.6	36.2	60.8	369
Rinse, slow	0.90	13.7	20.2	33.9	250
Rinse, fast	1.81	0.65	1.09	1.74	59.0
Rinse, fast	2.26	0.60	1.01	1.61	57.4
Service	2.71	0.60	1.02	1.62	60.5
Service	7.94	0.59	1.06	1.65	56.4
Service	12.55	0.61	1.10	1.71	56.7
Service	17.16	0.61	1.19	1.80	60.4
Service	21.78	0.69	1.55	2.24	55.9
Service	24.85	0.79	2.03	2.82	55.4
Service	27.92	0.94	3.06	4.00	54.0

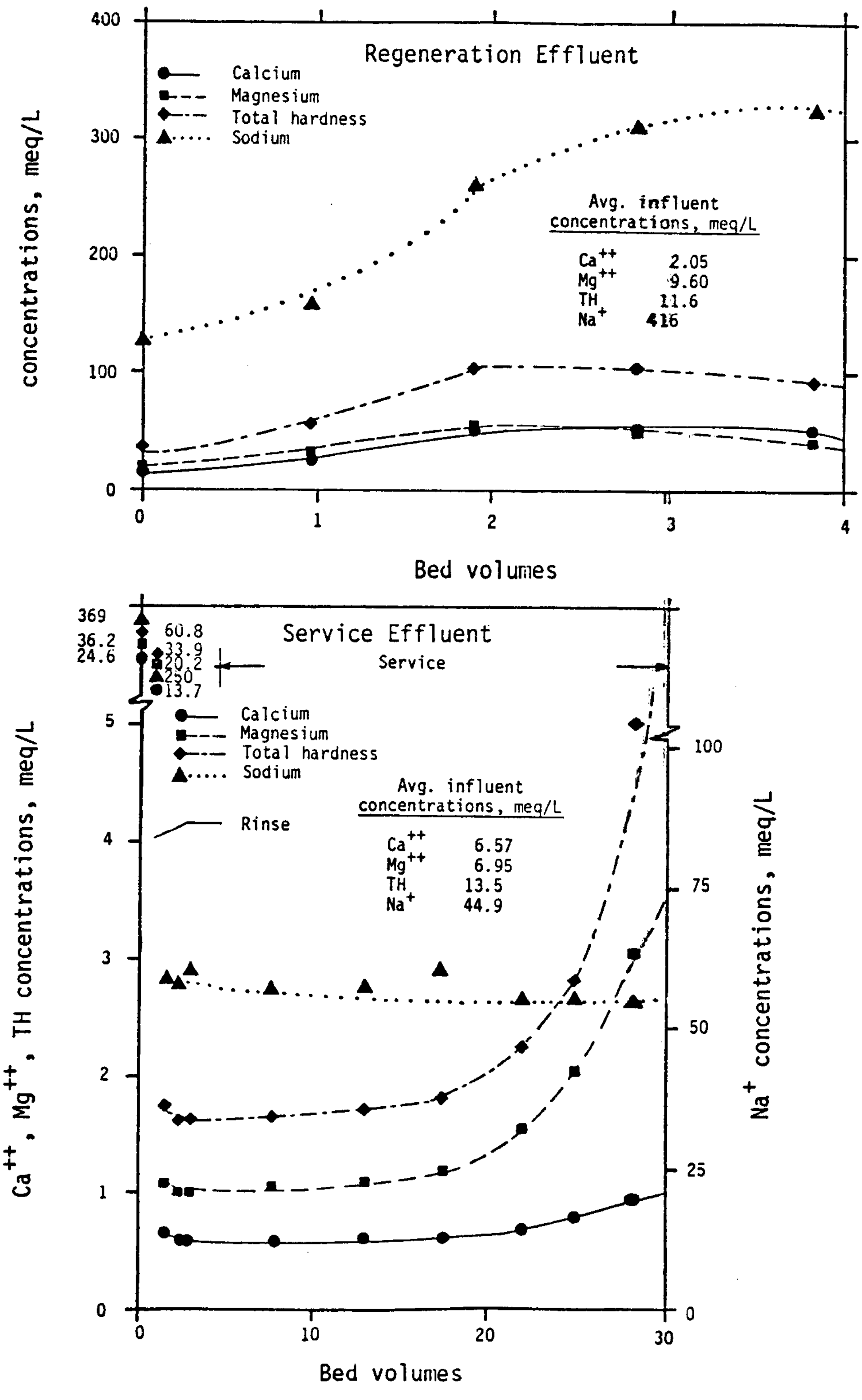
*Calculated from Ca^{++} plus Mg^{++}

Service Performance Summary

	Average concentrations, meq/ℓ			Removal	Resin capacity
	Influent	Effluent	Difference	%	eq/ℓ
Ca^{+}	6.57	0.66	5.91	90	0.149
Mg^{+}	6.95	1.40	5.55	80	0.140
TH*	13.5	2.06	11.5	85	0.289
Na^{+}	44.9	57.3	-12.3	-	-

*Calculated from Ca^{++} plus Mg^{++}

B4—4



Regeneration Effluent
Calcium
Magnesium
Total hardness
Sodium
Avg. influent concentrations, meq/L
Ca++ 2.05
Mg++ 9.60
TH 11.6
Na+ 416
concentrations, meq/L
400
300
200
100
0
0
1
2
3
4
Bed volumes
Service Effluent
Service
369
36.2
24.6
60.8
33.9
20.2
250
13.7
Calcium
Magnesium
Total hardness
Sodium
Rinse
Avg. influent concentrations, meq/L
Ca++ 6.57
Mg++ 6.95
TH 13.5
Na+ 44.9
Ca++, Mg++, TH concentrations, meq/L
Na+ concentrations, meq/L
5
4
3
2
1
0
100
75
50
25
0
0
10
20
30
Bed volumes

Ion Exchange - Cycle 2.01.76

Date: 10/27/78

Purpose: Phase I. To determine high and low values of independent variables in preparation for response surface experiments (Phase II)

Conditions: Feedwater - similar to 70% recovery YDP
Backwash - recycled regenerant
Regenerants - fresh ED brine and recycled regenerant
Service termination level - 3.0 meq/ℓ Ca^{++}

Control variable levels: Fresh regenerant concentration - 27 000 mg/ℓ TDS
Average fresh regenerant flow rate - 3.0 ℓ/min
Average recycled regenerant flow rate, Regen 2 - 26.0 ℓ/min
Volume of recycled regenerant, Regen 2 - 884 ℓ

Standard resin bed height: 1066 mm

Resin bed volume: 97.3 ℓ

Operating Conditions

Mode	Input	Output	Duration min	Throughput volume ℓ	Throughput volume BV	Avg. flow rate ℓ/min	Avg. flow rate BV/min	Bed expansion %	Temperature °C
Regeneration 1	Recycled regenerant	Waste	7	196	2.01	28.0	0.29	59	-
Regeneration 2	Recycled regenerant	Spent regenerant	34	884	9.09	26.0	0.27	53	21.0
Regeneration 3	Fresh regenerant	Spent regenerant	135	400	4.11	3.0	0.03	1.8	23.0
Drain	(Vent)	Waste	3	62	0.64	20.7	0.21	-	-
Rinse	Feed	Waste	10	165	1.70	16.5	0.17	-	-
Service	Feed	Product	164	4895	50.3	29.8	0.37	-	-

Chemical Analyses of Significant Components in Composite Samples

Sample		Cycle influent Reg 1, 2	Cycle influent Reg 3	Cycle influent Service	Cycle effluent Reg 1	Cycle effluent Reg 2	Cycle effluent Reg 3	Cycle effluent Rinse	Cycle effluent Service
pH	units	6.91	5.27	6.80	6.60	6.54	6.47	6.02	6.78
TDS (calc)	mg/ℓ	15 538	27 030	3087	11 021	15 279	20 238	16 880	3136
Conductivity @ 25 °C	μS/cm	22 119	35 826	5099	16 561	21 454	27 456	24 658	5315
Silica	mg/ℓ	18.0	20.0	14.0	15.0	17.0	18.0	16.0	14.0
Calcium	mg/ℓ	970	–	125	770	1030	1000	280	19.0
Magnesium	mg/ℓ	614	157.3	73.1	466	646	771	117.8	29.4
Sodium	mg/ℓ	3690	9060	877	2490	3340	4870	5650	1091
Potassium	mg/ℓ	289	49.3	8.5	21.4	27.2	36.8	31.3	9.7
Iron, total	mg/ℓ	<0.03	<0.04	<0.03	0.12	0.84	2.52	0.04	<0.03
Strontium	mg/ℓ	14.9	1.2	1.8	12.3	16.5	20.4	3.9	<0.2
Bicarbonate	mg/ℓ	20.5	12.69	25.86	21.47	19.52	19.52	17.08	26.84
Sulfate	mg/ℓ	4000	6900	880	2600	4100	5300	4380	880
Chloride	mg/ℓ	6200	9800	1096	4640	6100	8220	6400	1080
T-alkalinity as $CaCO_3$	mg/ℓ	16.8	10.4	21.2	17.60	16.0	16.0	14.0	22.0
P-alkalinity as $CaCO_3$	mg/ℓ	ND	ND	ND	ND	ND	ND	ND	ND

Major Cation Concentrations of Samples Analyzed by Atomic Absorption

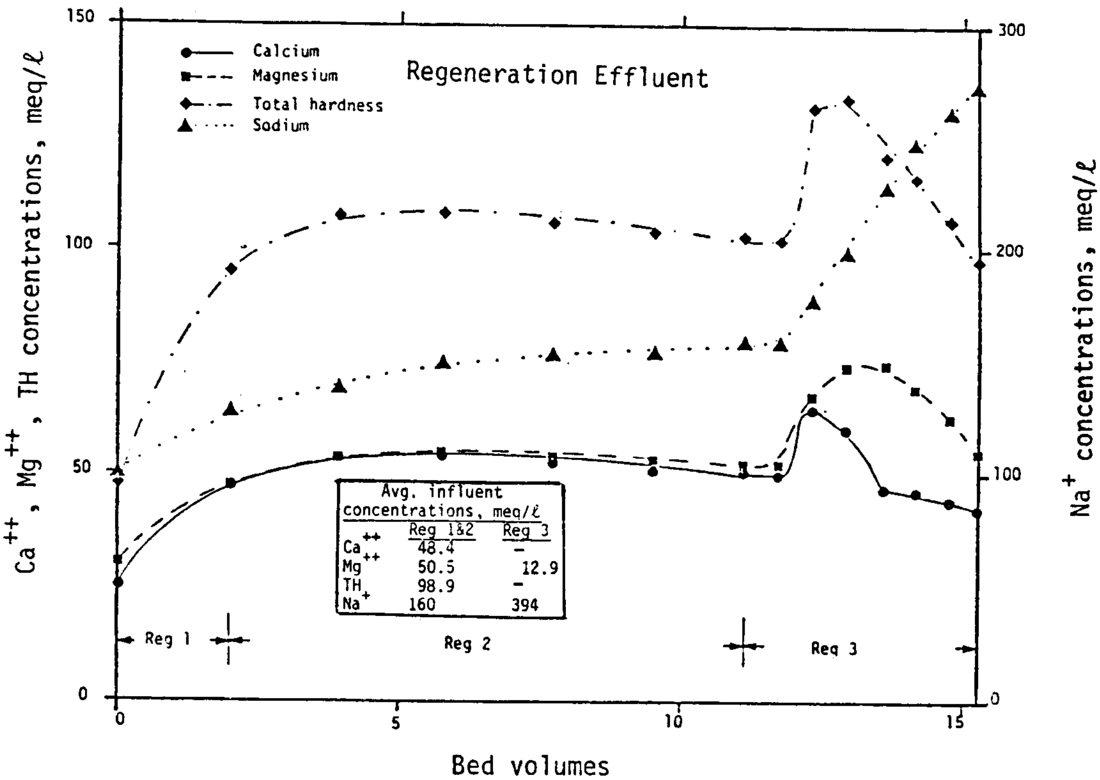
Mode	Throughput BV	Ca^{++} meq/ℓ	Mg^{++} meq/ℓ	TH* meq/ℓ	Na^{+} meq/ℓ
Regen 1	0	31.4	29.6	61.0	99.6
Regen 1/2	2.01	47.4	47.5	94.9	127
Regen 2	3.88	53.4	53.5	107	137
Regen 2	5.75	53.9	54.6	108	148
Regen 2	7.62	52.4	54.0	106	151
Regen 2	9.49	50.9	53.4	104	154
Regen 2/3	11.10	50.4	52.4	103	158
Regen 3	0.61	49.9	52.3	102	158
Regen 3	1.22	64.3	67.3	132	177
Regen 3	1.83	59.9	73.8	134	198
Regen 3	2.44	46.9	74.2	121	227
Regen 3	3.05	46.4	69.2	116	247
Regen 3	3.65	44.4	62.6	107	261
Regen 3	4.11	42.9	54.9	97.8	273
Rinse	0	22.4	17.4	39.8	374
Rinse	0.85	2.89	2.32	5.21	128
Service	1.70	0.29	0.28	0.57	51.4
Service	7.53	0.26	0.25	0.51	49.8
Service	12.13	0.26	0.27	0.53	49.6
Service	16.73	0.26	0.28	0.54	49.6
Service	21.33	0.27	0.36	0.63	49.6
Service	25.94	0.33	0.66	0.99	49.2
Service	30.54	0.45	1.39	1.84	48.2
Service	35.14	0.76	2.75	3.51	46.5
Service	39.74	1.24	4.28	5.52	44.0
Service	44.34	1.85	5.47	7.32	43.4
Service	48.94	2.59	6.28	8.87	42.0
Service	52.01	2.94	6.58	9.52	41.0

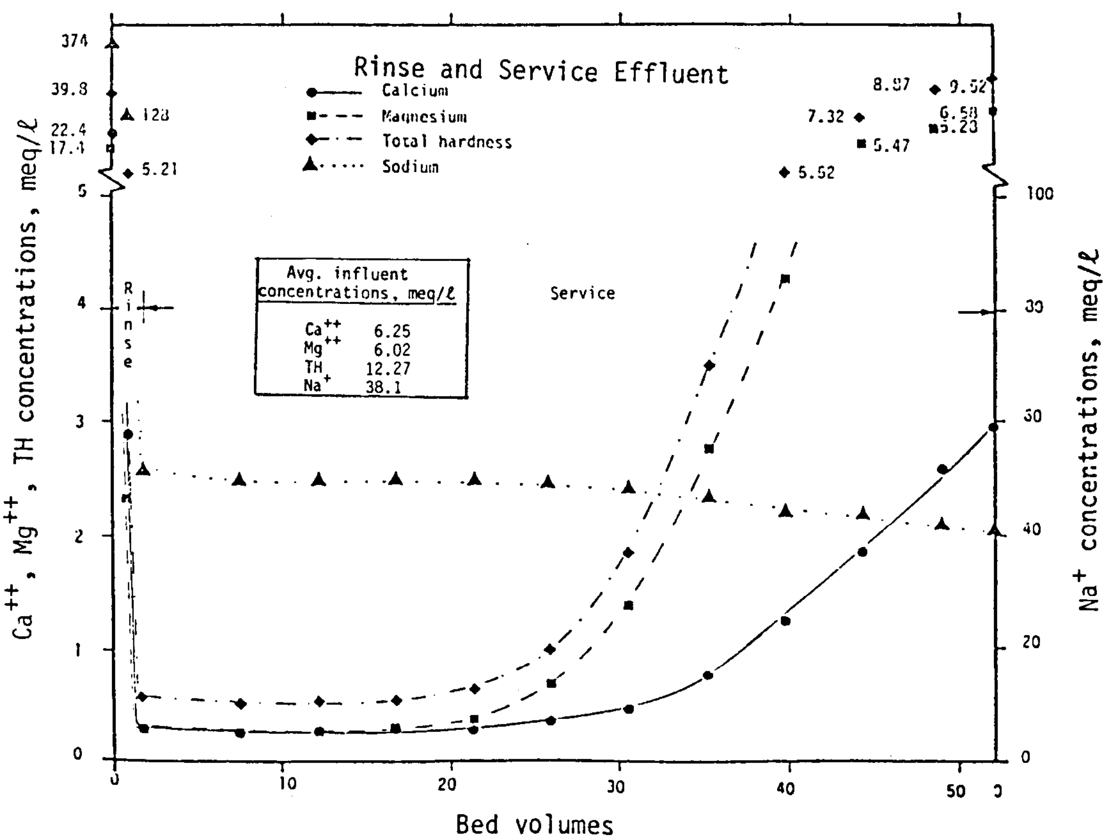
*Calculated from Ca^{++} plus Mg^{++}

Service Performance Summary

	Average concentrations, meq/ℓ			Removal	Resin capacity
	Influent	Effluent	Difference	%	eq/ℓ
Ca^{++}	6.27	0.83	5.44	87	0.273
Mg^{++}	6.06	2.14	3.92	65	0.197
TH*	12.3	2.96	9.34	76	0.470
Na^{+}	38.1	47.4	-9.3	-	-

*Calculated from Ca^{++} plus Mg^{++}


Regeneration Effluent
Calcium
Magnesium
Total hardness
Sodium
Avg. influent concentrations, meq/ℓ
Reg 1&2 Reg 3
Ca++ 48.4 –
Mg++ 50.5 12.9
TH 98.9 –
Na+ 160 394
Reg 1
Reg 2
Reg 3
Ca++, Mg++, TH concentrations, meq/ℓ
Na+ concentrations, meq/ℓ
Bed volumes


Rinse and Service Effluent
Calcium
Magnesium
Total hardness
Sodium
Avg. influent concentrations, meq/ℓ
Ca++ 6.25
Mg++ 6.02
TH 12.27
Na+ 38.1
Rinse
Service
374
39.8
22.4
128
5.21
8.97
9.52
7.32
5.47
5.52
Ca++, Mg++, TH concentrations, meq/ℓ
Na+ concentrations, meq/ℓ
Bed volumes

Ion Exchange - Cycle 2.01.137

Date: 11/15/78

Purpose: To explore a low fresh regenerant flow rate level at high recycle regenerant flow rates and a moderate recycle regenerant volume.

Conditions: Feedwater - Pretreated with high lime dosage for silica removal
Backwash - recycled regenerant
Regenerants - fresh ED brine and recycled regenerant
Service termination level - 1.0 meq/ℓ Ca^{++}

Control variable levels: Fresh regenerant concentration - 41 259 mg/ℓ TDS
Average fresh regenerant flow rate - 4.0 ℓ/min
Average recycled regenerant flow rate, Regen 2 - 23.5 ℓ/min
Volume of recycled regenerant, Regen 2 - 352 ℓ

Standard resin bed height: 1066 mm

Resin bed volume: 97.3 ℓ

Operating Conditions

Mode	Input	Output	Duration min	Throughput volume ℓ	Throughput volume BV	Avg. flow rate ℓ/min	Avg. flow rate BV/min	Bed expansion %	Temperature °C
Regeneration 1	Recycled regenerant	Waste	10	240	2.47	24.0	0.25	58	-
Regeneration 2	Recycled regenerant	Spent regenerant	15	352	3.62	23.5	0.24	58	15.5
Regeneration 3	Fresh regenerant	Spent regenerant	75	300	3.08	4.00	0.04	5.6	18.0
Drain	(Vent)	Waste	3	62	0.64	20.7	0.21	-	-
Rinse	Feed	Waste	10	160	1.64	16.0	0.16	-	-
Service	Feed	Product	163	5120	52.6	31.4	0.32	-	-

Ta~~ble 16~~

Tank Chemical Composition**

Tank	Conductivity µS/cm	Ca^{++} meq/ℓ	Mg^{++}* meq/ℓ	TH meq/ℓ
T-5	50 117	26.0	23.0	49.0
T-6	53 635	84.0	92.0	176
T-9	5 112	6.2	5.8	12.0
T-28	50 337	6.0	16.0	22.0
T-33	5 424	0.4	1.2	1.6

*Calculated from TH minus Ca^{++}
**Concentrations determined by operators' titrations

Chemical Analyses of Significant Components in Composite Samples

Sample		Cycle influent Reg 1 & 2	Cycle influent Reg 3	Cycle influent Service	Cycle effluent Reg 1	Cycle effluent Reg 2	Cycle effluent Reg 3	Cycle effluent Service	Cycle effluent Rinse
pH	units	4.16	3.54	6.90	6.12	5.74	5.62	6.55	4.29
TDS (calc)	mg/ℓ	41 187	41 259	3153	18 509	38 077	37 784	3241	7851
Conductivity @ 25 °C	µS/cm	54 042	51 784	4846	24 684	49 164	48 050	5141	10 312
Silica	mg/ℓ	4.0	2.0	4.0	3.0	4.0	3.0	4.0	3.0
Calcium	mg/ℓ	1270	47.9	113	930	1520	1300	3.6	25.0
Magnesium	mg/ℓ	999	142	71.0	633	1149	929	3.1	13.59
Sodium	mg/ℓ	12 490	14 740	921	5000	11 220	11 450	1170	2690
Potassium	mg/ℓ	90	128	8.1	38.6	78.0	84.0	9.0	19.3
Iron, total	mg/ℓ	<0.03	0.68	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03
Strontium	mg/ℓ	28.4	2.0	2.6	17.5	38.0	34.0	0.8	1.1
Bicarbonate	mg/ℓ	9.27	ND	19.52	9.76	12.20	7.32	14.64	2.44
Sulfate	mg/ℓ	7200	11 900	920	3780	5000	6840	940	2400
Chloride	mg/ℓ	19 100	14 300	1098	8100	19 060	17 140	1100	2700
T-alkalinity as $CaCO_3$	mg/ℓ	7.60	ND	16.0	8.0	10.0	6.0	12.0	2.0
P-alkalinity as $CaCO_3$	mg/ℓ	ND	ND	ND	ND	ND	ND	ND	ND

Major Cation Concentrations of Samples Analyzed by Atomic Absorption

Mode	Process stream	Throughput B/V	Ca^{++} meq/ℓ	Mg^{++} meq/ℓ	TH* meq/ℓ	Na^{+} meq/ℓ
Regen 1	Effluent	0.74	14.0	17.8	31.8	131
Regen 1	Effluent	1.97	77.8	90.9	169	287
Regen 2	Effluent	3.68	78.8	105	184	462
Regen 2	Effluent	4.88	74.4	92.4	167	496
Regen 1/2	Influent	6.09	63.4	82.2	146	543
Regen 2/3	Effluent	6.09	72.9	85.9	159	507
Regen 3	Effluent	6.30	73.4	83.6	157	514
Regen 3	Effluent	6.92	73.4	83.0	156	511
Regen 3	Effluent	7.53	74.4	82.6	157	516
Regen 3	Influent	7.57	2.39	11.7	14.1	641
Regen 3	Effluent	8.15	52.9	83.5	136	491
Regen 3	Effluent	8.76	42.4	68.6	111	512
Regen 3	Effluent	9.17	62.4	58.2	121	433
Rinse	Effluent	0	1.82	2.06	3.88	165
Rinse	Effluent	0.82	0.23	0.17	0.40	53.9
Service	Influent	1.64	5.59	6.07	11.7	39.0
Service	Effluent	1.64	0.24	0.16	0.40	52.6
Service	Effluent	5.51	0.18	0.13	0.31	50.0
Service	Effluent	10.35	0.16	0.13	0.29	49.9
Service	Effluent	15.19	0.15	0.13	0.28	50.1
Service	Effluent	20.04	0.15	0.14	0.29	50.6
Service	Effluent	24.88	0.15	0.12	0.27	50.9
Service	Influent	29.72	5.84	5.79	11.6	39.7
Service	Effluent	29.72	0.16	0.22	0.38	50.5
Service	Effluent	34.56	0.15	0.15	0.30	50.9
Service	Effluent	39.41	0.17	0.43	0.60	50.7
Service	Effluent	44.25	0.20	0.91	1.11	50.4
Service	Effluent	49.09	-	-	2.66**	-
Service	Effluent	52.32	0.70**	-	-	-
Service	Effluent	54.26	1.00**	2.28**	3.28**	-
Service	Influent	-	5.59	5.79	11.38	40.4

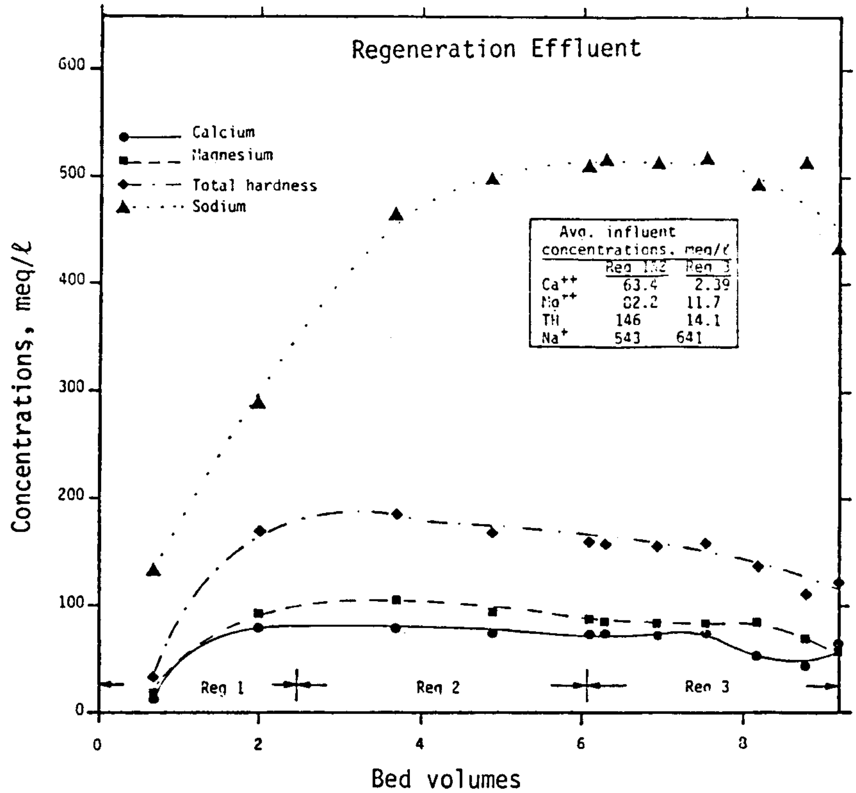
*Calculated from Ca^{++} plus Mg^{++}

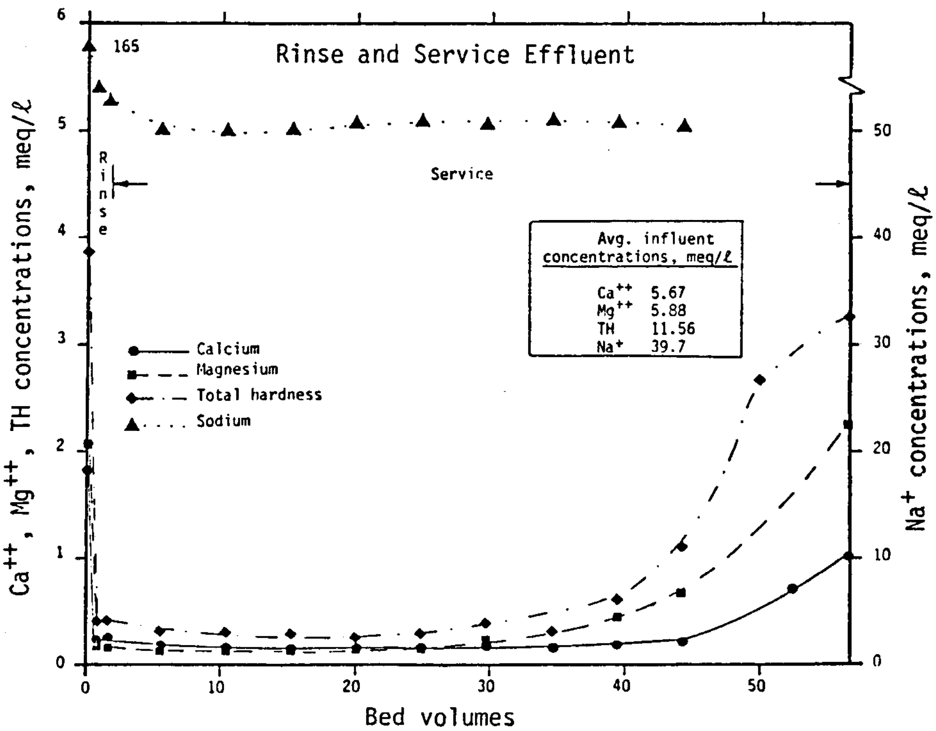
**Ca^{++} and TH from operators' titrations, Mg^{++} calculated from TH minus Ca^{++}

SERVICE PERFORMANCE SUMMARY

	Average concentrations, meq/ℓ			Removal	Resin capacity
	Influent	Effluent	Difference	%	eq/ℓ
Ca^{++}	5.67	0.23	5.44	96	0.286
Mg^{++}	5.88	0.48	5.40	92	0.284
TH*	11.56	0.78	10.78	93	0.567
Na^{+}	39.7	-	-	-	-

*Calculated from Ca^{++} plus Mg^{++}


Regeneration Effluent
Calcium
Magnesium
Total hardness
Sodium
Avg. influent concentrations, meq/ℓ
Reg 1&2 Reg 3
Ca^{++} 63.4 2.39
Mg^{++} 82.2 11.7
TH 146 14.1
Na^{+} 543 641
Concentrations, meq/ℓ
600
500
400
300
200
100
0
Reg 1
Reg 2
Reg 3
0
2
4
6
8
Bed volumes


Rinse and Service Effluent
165
Rinse
Service
Avg. influent concentrations, meq/ℓ
Ca^{++} 5.67
Mg^{++} 5.88
TH 11.56
Na^{+} 39.7
Calcium
Magnesium
Total hardness
Sodium
Ca^{++}, Mg^{++}, TH concentrations, meq/ℓ
Na^{+} concentrations, meq/ℓ
6
5
4
3
2
1
0
50
40
30
20
10
0
0
10
20
30
40
50
Bed volumes

Ion Exchange - Cycle 2.01.156

Date: 11/22/78

Purpose: To explore a high fresh regenerant flow rate at the condition of a single pass regeneration (no recycling of regenerant).

Conditions: Feedwater - pretreated with high lime dosage for silica removal
Backwash - feedwater
Regenerant - fresh ED brine
Service termination level - 1.5 meq/ℓ Ca^{++}

Control variable levels: Fresh regenerant concentration - 47 000 mg/ℓ TDS*
Average fresh regenerant flow rate - 7.4 ℓ/min
Volume of recycled regenerant, Regen 2 - 0 ℓ

Standard resin bed height: 1066 mm

Resin bed volume: 97.3 ℓ

Operating Conditions

Mode	Input	Output	Duration min	Throughput volume ℓ	Throughput volume BV	Avg. flow rate ℓ/min	Avg. flow rate BV/min	Bed expansion %	Temperature °C
Backwash	Feed	Waste	10	260	2.67	26.0	0.27	52	-
Drain	(Vent)	Waste	3	62	0.64	20.7	0.21	-	-
Regeneration	Fresh regenerant	Spent regenerant	34	250	2.57	7.35	0.08	-	-
Rinse	Feed	Waste	10	150	1.54	15.0	0.15	-	-
Service	Feed	Product	151	4560	46.9	30.2	0.31	-	-

Tank Chemical Composition

Tank	pH units	Conductivity µS/cm	Ca meq/ℓ	Mg** meq/ℓ	TH meq/ℓ
T-9	7.19	5 095	6.6	6.2	12.8
T-28	-	58 777	8.0	18.5	26.5
T-33	-	5 503	1.0	2.0	3.0

*Estimated from daily tank conductivity. A discrepancy between this conductivity, as determined by the chemical laboratory, and in-line conductivity measurements was being investigated at the end of the reporting period. Low confidence is assigned to this value at present.

**Calculated from TH minus Ca

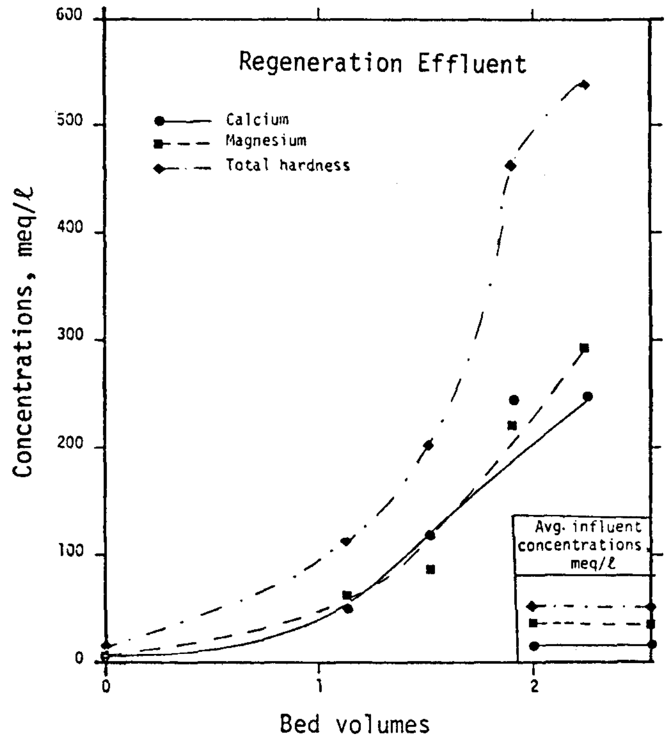
Calcium and Magnesium Concentrations Determined by Operators' Titrations

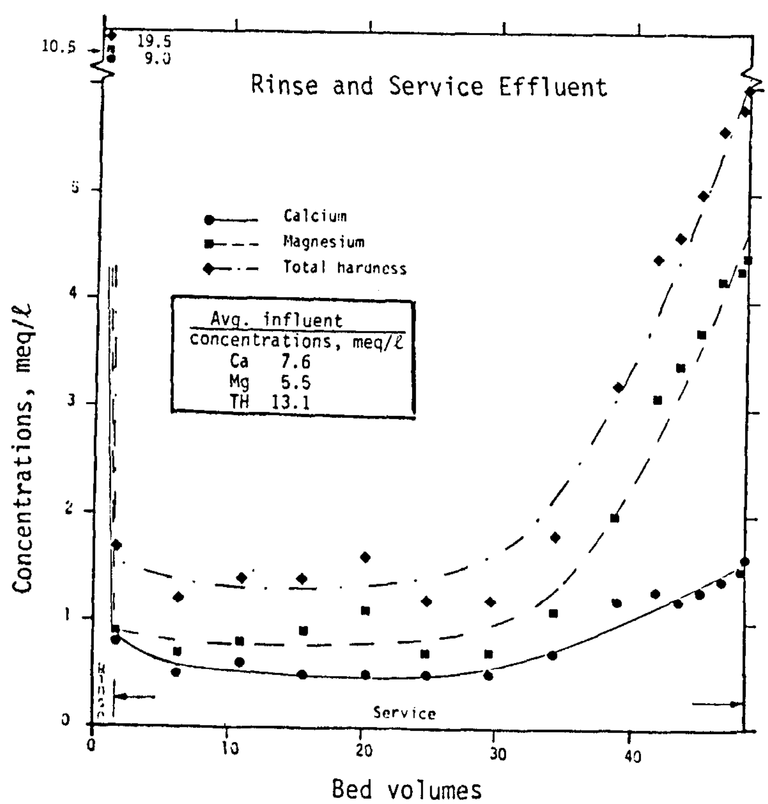
Mode	Process stream	Throughput BV	Ca^{++} meq/ℓ	Mg^{++*} meq/ℓ	TH meq/ℓ
Regen	Effluent	0.76	7.5	8.5	16.0
Regen	Effluent	1.14	51.5	61.5	113
Regen	Effluent	1.52	118	85.0	203
Regen	Effluent	1.90	244	220	464
Regen	Effluent	2.27	246	292	538
Regen	Effluent	2.57	194	63.0	257
Rinse	Effluent	0.77	9.0	10.5	19.5
Service	Influent	1.54	7.6	6.4	14.0
Service	Effluent	1.54	0.8	0.9	1.7
Service	Effluent	6.20	0.5	0.7	1.2
Service	Effluent	10.85	0.6	0.8	1.4
Service	Effluent	15.51	0.5	0.9	1.4
Service	Influent	20.16	7.6	5.2	12.8
Service	Effluent	20.16	0.5	1.1	1.6
Service	Effluent	24.82	0.5	0.7	1.2
Service	Effluent	29.47	0.5	0.7	1.2
Service	Effluent	34.13	0.7	1.1	1.8
Service	Effluent	38.78	1.2	2.0	3.2
Service	Effluent	41.88	1.3	3.1	4.4
Service	Effluent	43.43	1.2	3.4	4.6
Service	Effluent	44.98	1.3	3.7	5.0
Service	Effluent	46.54	1.4	4.2	5.6
Service	Effluent	48.09	1.5	4.3	5.8
Service	Influent	48.40	7.6	4.8	12.4
Service	Effluent	48.40	1.6	4.4	6.0

Service Performance Summary

	Average concentrations, meq/ℓ			Removal %	Resin capacity eq/ℓ
	Influent	Effluent	Difference		
Ca^{++}	7.6	0.83	6.77	89	0.317
Mg^{++*}	5.5	1.62	3.88	71	0.182
TH	13.1	2.45	10.6	81	0.499

* Calculated from TH minus Ca^{++}


Regeneration Effluent
Calcium
Magnesium
Total hardness
Avg. influent concentrations, meq/ℓ
Concentrations, meq/ℓ
600
500
400
300
200
100
0
0
1
2
Bed volumes


Rinse and Service Effluent
19.5
9.0
10.5
Calcium
Magnesium
Total hardness
Avg. influent
concentrations, meq/ℓ
Ca 7.6
Mg 5.5
TH 13.1
Concentrations, meq/ℓ
4
3
2
1
0
Service
0
10
20
30
40
Bed volumes

Ion Exchange - Cycle 2.01.174

Date: 11/27/78

Purpose: To explore performance at low fresh and recycle regeneration flow rates and high recycle regenerant volume.

Conditions: Feedwater - pretreated with high lime dosage for silica removal
Backwash - recycled regenerant
Regenerants - fresh ED brine and recycled regenerant
Service termination level - 1.5 meq/ℓ Ca^{++}

Control variable levels: Fresh regenerant concentration - 51 473 mg/ℓ TDS
Average fresh regenerant flow rate - 3.0 ℓ/min
Average recycled regenerant flow rate, Regen 2 - 8.0 ℓ/min
Volume of recycled regenerant, Regen 2 - 1384 ℓ

Standard resin bed height: 1066 mm

Resin bed volume 97.3 ℓ

Operating Conditions

Mode	Input	Output	Duration min	Throughput volume ℓ	BV	Avg. flow rate ℓ/min	BV/min	Bed expansion %	Temperature °C
Regeneration 1	Recycled regenerant	Waste	10	230	2.36	23.0	0.24	57	17.2
Regeneration 2	Recycled regenerant	Spent regenerant	173	1384	14.2	8.0	0.08	11	-
Regeneration 3	Fresh regenerant	Spent regenerant	82.5	250	2.57	3.03	0.03	2.7	16.8
Drain	(Vent)	Waste	3	62	0.64	20.7	0.21	-	-
Rinse	Feed	Waste	10	160	1.64	16.0	0.16	-	-
Service	Feed	Product	171	5080	52.2	29.7	0.31	-	-

Table 25

Tank Chemical Composition

Tank	pH units	Conductivity µS/cm	Ca^{++} meq/ℓ	Mg^{++}* meq/ℓ	TH meq/ℓ
T-5	-	49 662	84.0	102	186
T-6	-	48 992	110	126	236
T-9	7.36	4 959	8.8	5.6	14.4
T-28	-	58 830	11.0	18.0	29.0
T-33	-	5 546	0.8	1.6	2.4

*Calculated from TH minus Ca^{++}

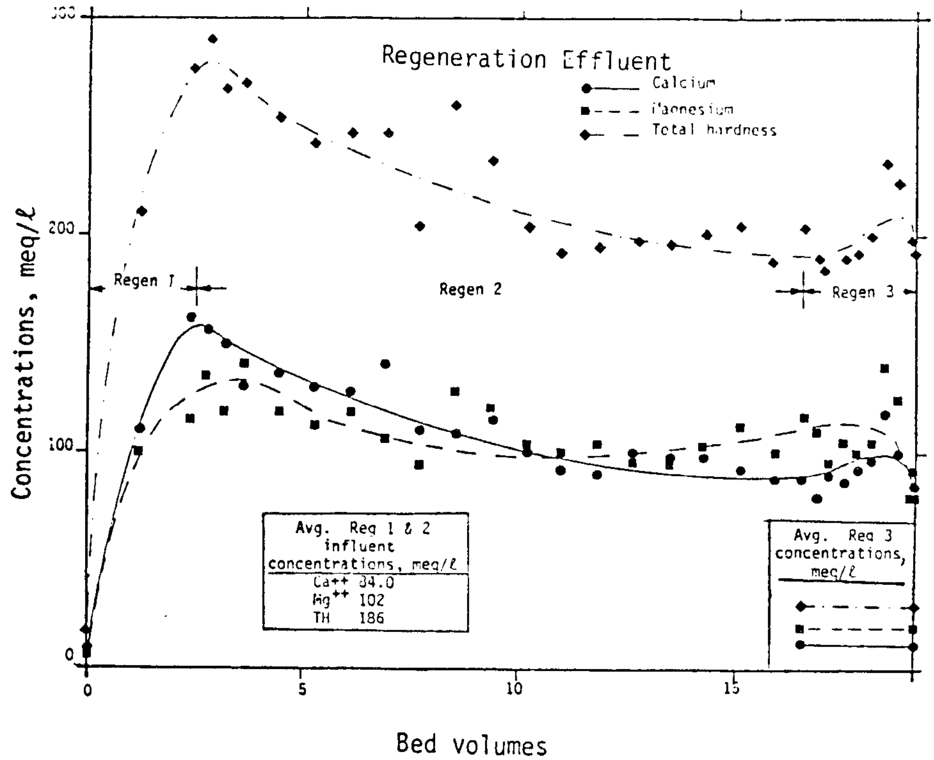
Calcium and Magnesium Concentrations Determined by Operators' Titrations

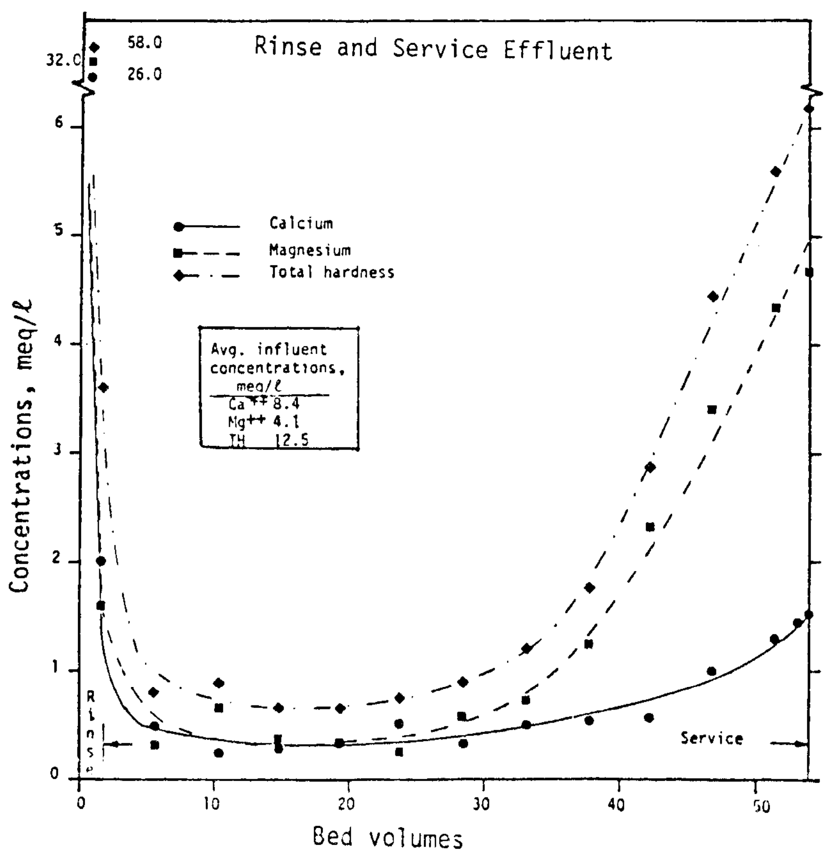
Mode	Process stream	Throughput BV	Ca^{++} meq/ℓ	Mg^{++}* meq/ℓ	TH meq/ℓ
Regen 1	Effluent	0	9.0	6.0	15.0
Regen 1	Effluent	1.18	110	100	210
Regen 1 & 2	Effluent	2.36	162	114	276
Regen 2	Effluent	2.77	156	134	290
Regen 2	Effluent	3.13	150	118	268
Regen 2	Effluent	3.59	130	140	270
Regen 2	Effluent	4.41	136	118	254
Regen 2	Effluent	5.23	130	112	242
Regen 2	Effluent	6.06	128	118	246
Regen 2	Effluent	6.88	140	106	246
Regen 2	Effluent	7.70	110	94.0	204
Regen 2	Effluent	8.52	108	152	260
Regen 2	Effluent	9.35	114	120	234
Regen 2	Effluent	10.17	100	104	204
Regen 2	Effluent	10.99	92.0	100	192
Regen 2	Effluent	11.81	90.0	104	194
Regen 2	Effluent	12.63	100	96.0	196
Regen 2	Effluent	13.46	98.0	98.0	196
Regen 2	Effluent	14.28	98.0	102	200
Regen 2	Effluent	15.10	92.0	112	204
Regen 2	Effluent	15.92	88.0	100	188
Regen 2 & 3	Effluent	16.58	88.0	116	204
Regen 3	Effluent	16.89	80.0	110	190
Regen 3	Effluent	17.20	90.0	94.0	184
Regen 3	Effluent	17.51	86.0	104	190
Regen 3	Effluent	17.83	92.0	100	192
Regen 3	Influent	18.14	9.0	21.0	30.0
Regen 3	Effluent	18.14	96.0	104	200
Regen 3	Effluent	18.45	118	116	234
Regen 3	Effluent	18.76	100	125	225
Regen 3	Effluent	19.07	92.0	106	198
Regen 3	Effluent	19.15	86.0	106	192
Rinse	Effluent	0.82	26.0	32.0	58.0
Service	Effluent	1.64	2.0	1.60	3.60
Service	Influent	5.61	8.4	4.4	12.4
Service	Effluent	5.61	0.48	0.32	0.80
Service	Effluent	10.19	0.24	0.64	0.88
Service	Effluent	14.77	0.28	0.36	0.64
Service	Effluent	19.35	0.32	0.32	0.64
Service	Influent	23.93	8.4	4.4	12.8
Service	Effluent	23.93	0.48	0.24	0.72
Service	Effluent	28.51	0.32	0.56	0.88
Service	Effluent	33.09	0.48	0.72	1.20
Service	Effluent	37.67	0.52	1.24	1.76
Service	Effluent	42.25	0.56	2.32	2.88
Service	Effluent	46.83	1.00	3.40	4.40
Service	Effluent	51.41	1.28	4.32	5.60
Service	Effluent	52.94	1.44	-	-
Service	Influent	53.86	8.4	4.0	12.4
Service	Effluent	53.86	1.52	4.68	6.20

Service Performance Summary

	Average concentrations, meq/ℓ			Removal	Resin capacity
	Influent	Effluent	Difference	%	eq/ℓ
Ca^{++}	8.4	0.61	7.79	93	0.407
Mg^{++}*	4.1	1.34	2.76	67	0.144
TH	12.5	1.95	10.6	84	0.551

*Calculated from TH minus Ca^{++}


Regeneration Effluent
Calcium
Magnesium
Total hardness
Concentrations, meq/ℓ
200
100
0
Regen 1
Regen 2
Regen 3
Avg. Reg 1 & 2 influent concentrations, meq/ℓ
Ca++ 34.0
Mg++ 102
TH 186
Avg. Reg 3 concentrations, meq/ℓ
0
5
10
15
Bed volumes


Rinse and Service Effluent
58.0
32.0
26.0
6
5
4
3
2
1
0
Calcium
Magnesium
Total hardness
Avg. influent concentrations, meq/ℓ
Ca++ 8.4
Mg++ 4.1
TH 12.5
Concentrations, meq/ℓ
Rinse
Service
0
10
20
30
40
50
Bed volumes

Ion Exchange - Cycle 2.01.202

Date: 12/4/78

Purpose: To explore a high fresh regenerant flow rate with use of recycled regenerant for backwash only.

Conditions: Feedwater - pretreated with high lime dosage for silica removal
Backwash - recycled regenerant
Regenerants - fresh ED brine and recycled regenerant
Service termination level - 4.5 meq/ℓ Ca^{++}

Control variable levels: Fresh regenerant concentration - 23 074 mg/ℓ TDS
Average fresh regenerant flow rate - 7.7 ℓ/min
Volume of recycled regenerant, Regen 2 - 0 ℓ

Standard resin bed height: 1066 mm

Resin bed volume: 97.3 ℓ

Operating Conditions

Mode	Input	Output	Duration min	Throughput volume ℓ	Throughput volume BV	Avg. flow rate ℓ/min	Avg. flow rate BV/min	Bed expansion %	Temperature °C
Regeneration 1	Recycled regenerant	Waste	10	240	2.47	24.0	0.25	61	15.0
Regeneration 3	Fresh regenerant	Spent regenerant	65	500	5.14	7.7	0.08	13	14.8
Drain	(Vent)	Waste	3	62	0.64	20.7	0.21	-	-
Rinse	Feed	Waste	10	160	1.64	16.0	0.16	-	-
Service	Feed	Product	176	5730	58.9	32.6	0.33	-	-

Tank Chemical Composition**

Tank	pH units	Conductivity µS/cm	Ca^{++} meq/ℓ	Mg^{++}* meq/ℓ	TH meq/ℓ
T-5	-	27 160	50.0	58.0	108
T-6	-	26 128	74.0	54.0	128
T-9	7.09	4 741	6.8	7.6	14.4
T-28	-	26 248	14.0	24.0	38.0
T-33	-	5 010	2.32	4.24	6.56

*Calculated from TH minus Ca^{++}
**Concentrations determined by operators' titrations

Chemical Analyses of Significant Components in Composite Samples

Sample		Cycle influent			Cycle effluent			
		Reg 1	Reg 3	Service	Reg 1	Reg 3	Rinse	Service
pH	units	7.14	6.73	7.08	7.05	7.01	7.12	7.43
TDS (calc)	mg/ℓ	21 636	23 074	3175	13 718	20 999	9765	3206
Conductivity @ 25 °C	µS/cm	27 445	28 467	4662	17 231	25 175	1648	4993
Silica	mg/ℓ	14	17	9	12	15	11	9
Calcium	mg/ℓ	1050	224	129	1020	1310	111	33.5
Magnesium	mg/ℓ	611	319	65.6	608	615	72.6	42.8
Sodium	mg/ℓ	6100	7640	907	2940	5330	2880	1060
Potassium	mg/ℓ	37.8	76.0	8.0	21.7	30.9	25.1	10.7
Iron, total	mg/ℓ	<0.03	<0.03	<0.03	<0.03	0.44	<0.03	<0.03
Strontium	mg/ℓ	19.1	3.2	2.1	17.3	22.4	1.9	0.5
Bicarbonate	mg/ℓ	37.6	71.7	26.8	51.2	70.8	43.9	26.8
Sulfate	mg/ℓ	5300	6500	930	3460	5620	2340	924
Chloride	mg/ℓ	8480	8240	1106	5600	8000	4200	1108
T-alkalinity as $CaCO_3$	mg/ℓ	30.8	58.8	22.0	42.0	58.0	36.0	22.0
P-alkalinity as $CaCO_3$	mg/ℓ	ND	ND	ND	ND	ND	ND	ND

Major Cation Concentrations of Samples Analyzed by Atomic Absorption

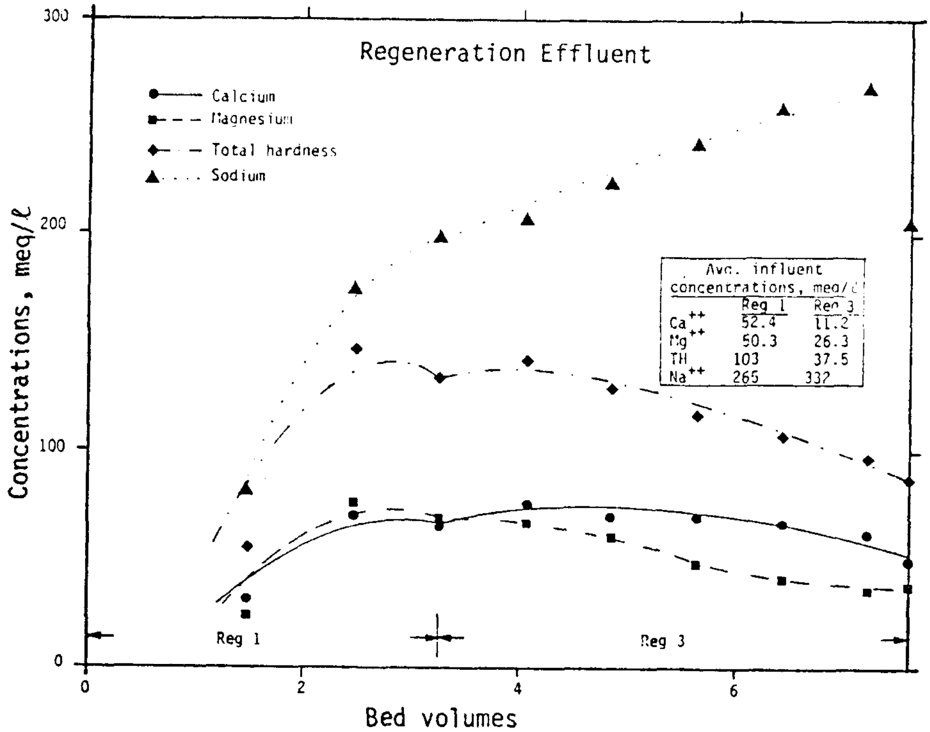
Mode	Process stream	Throughput B/V	Ca^{++} meq/ℓ	Mg^{++} meq/ℓ	TH* meq/ℓ	Na^{+} meq/ℓ
Regen 1	Influent	1.23	52.4	50.3	103	265
Regen 1	Effluent	1.48	30.9	23.9	54.8	81.0
Regen 1/3	Effluent	2.47	69.9	75.7	146	174
Regen 3	Influent	2.86	11.2	26.3	37.5	332
Regen 3	Effluent	3.26	64.9	68.0	133	198
Regen 3	Effluent	4.05	74.8	66.3	141	206
Regen 3	Effluent	4.84	69.4	59.4	129	223
Regen 3	Effluent	5.63	69.4	47.7	117	242
Regen 3	Effluent	6.42	65.9	40.7	107	258
Regen 3	Effluent	7.21	61.4	35.2	96.6	267
Regen 3	Effluent	7.61	49.9	37.6	87.5	205
Rinse	Effluent	0.82	10.1	11.2	21.3	191
Service	Effluent	1.64	0.54	0.68	1.22	52.9
Service	Influent	6.99	6.44	5.50	11.9	39.4
Service	Effluent	6.99	0.48	0.62	1.10	51.6
Service	Effluent	12.01	0.49	0.63	1.12	50.3
Service	Effluent	17.03	0.51	0.71	1.21	50.4
Service	Effluent	22.05	0.57	0.95	1.52	50.3
Service	Effluent	27.07	0.70	1.59	2.29	48.8
Service	Effluent	32.09	0.93	2.54	3.47	47.6
Service	Effluent	37.10	1.25	3.68	4.93	46.4
Service	Influent	42.12	6.34	5.43	11.8	39.4
Service	Effluent	42.12	1.70	4.67	6.37	44.5
Service	Effluent	47.14	2.20	5.41	7.61	43.3
Service	Effluent	52.16	2.79	5.98	8.77	42.3
Service	Effluent	57.13	3.29	6.23	9.52	42.6
Service	Effluent	58.85	3.64	5.25	9.39	41.4
Service	Influent	60.53	6.44	5.45	11.9	39.9
Service	Effluent	60.53	3.64	6.37	10.0	39.9

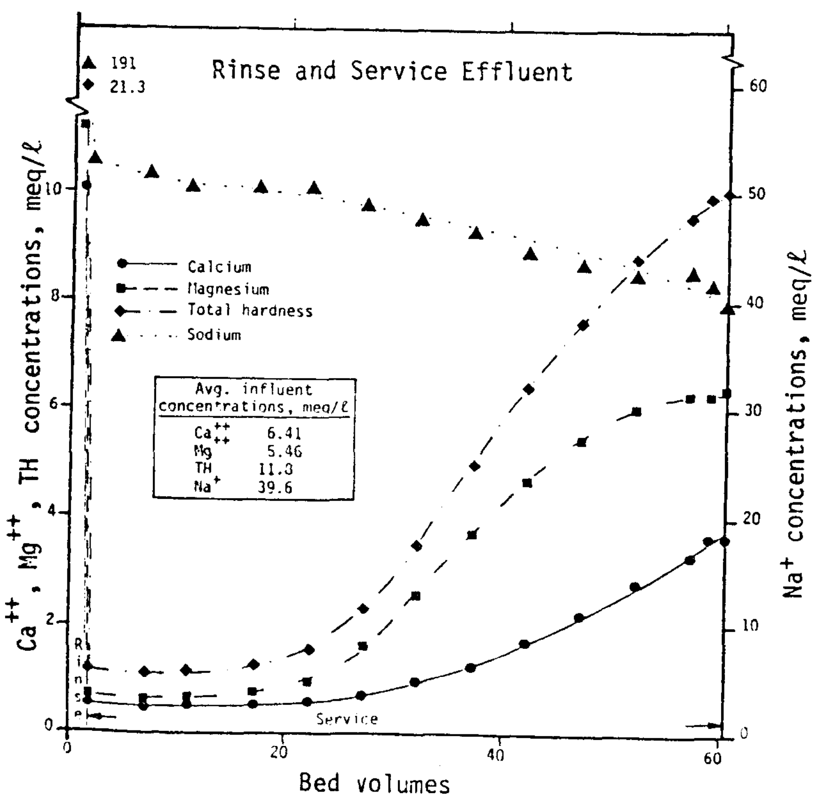
*Calculated from Ca^{++} plus Mg^{++}

SERVICE PERFORMANCE SUMMARY

	Average concentrations, meq/ℓ			Removal	Resin capacity
	Influent	Effluent	Difference	%	eq/ℓ
Ca^{++}	6.41	1.36	5.05	79	0.297
Mg^{++}	5.46	2.94	2.52	46	0.148
TH*	11.87	4.29	7.58	64	0.446
Na^{+}	39.6	47.3	-7.7	-	-

*Calculated from Ca^{++} plus Mg^{++}


Regeneration Effluent
Calcium
Magnesium
Total hardness
Sodium
Avg. influent concentrations, meq/ℓ
Reg 1 Reg 3
Ca++ 52.4 11.2
Mg++ 50.3 26.3
TH 103 37.5
Na++ 265 332
Reg 1
Reg 3
Concentrations, meq/ℓ
Bed volumes
0
100
200
300
2
4
6


Rinse and Service Effluent
191
21.3
Calcium
Magnesium
Total hardness
Sodium
Avg. influent concentrations, meq/ℓ
Ca++ 6.41
Mg++ 5.46
TH 11.3
Na+ 39.6
Rinse
Service
Ca++, Mg++, TH concentrations, meq/ℓ
Na+ concentrations, meq/ℓ
Bed volumes
0
2
4
6
8
10
20
40
60
10
30
50

Ion Exchange - Cycle 2.01.213

Date: 12/11/78

Purpose: To explore a high fresh regenerant flow rate with use of recycled regenerant for backwash only.

Conditions: Feedwater - Pretreated with high lime dosage for silica removal
Backwash - recycled regenerant
Regenerants - fresh ED brine and recycled regenerant
Service termination level - 4.5 meq/ℓ Ca^{++}

Control variable levels: Fresh regenerant concentration - 24 864 mg/ℓ TDS
Average fresh regenerant flow rate - 7.8 ℓ/min
Volume of recycled regenerant, Regen 2 - 0 ℓ

Standard resin bed height: 1066 mm

Resin bed volume: 97.3 ℓ

Operating Conditions

Mode	Input	Output	Duration min	Throughput volume ℓ	Throughput volume BV	Avg. flow rate ℓ/min	Avg. flow rate BV/min	Bed expansion %	Temperature °C
Regeneration 1	Recycled regenerant	Waste	10	240	2.47	24.0	0.25	64	12.0
Regeneration 3	Fresh regenerant	Spent regenerant	205	1600	16.4	7.79	0.08	14	13.8
Drain	(Vent)	Waste	3	62	0.64	20.7	0.21	-	-
Rinse	Feed	Waste	10	170	1.75	17.0	0.17	-	-
Service	Feed	Product	295	9050	93.0	30.7	0.32	-	-

Tank Chemical Composition**

Tank	pH units	Conductivity µS/cm	Ca^{++} meq/ℓ	Mg^{++}* meq/ℓ	TH meq/ℓ
T-5	-	26 364	46.0	54.0	100
T-6	-	27 322	50.0	36.0	86.0
T-9	7.48	4 560	7.20	5.20	12.4
T-28	-	27 812	19.0	39.0	58.0
T-33	7.35	4 811	1.92	5.84	7.76

*Calculated from TH minus Ca^{++}
**Concentrations determined by operators' titrations

Major Cation Concentrations of Samples Analyzed by Atomic Absorption

Mode	Process stream	Throughput B/V	Ca^{++} meq/ℓ	Mg^{++} meq/ℓ	TH * meq/ℓ	Na^{+} meq/ℓ
Regen 1	Influent	1.23	43.4	47.9	91.3	261
Regen 1	Effluent	1.48	45.9	41.7	87.6	102
Regen 1/3	Effluent	2.47	61.4	77.4	139	171
Regen 3	Influent	2.87	13.7	38.4	52.1	330
Regen 3	Effluent	3.27	57.9	71.1	129	200
Regen 3	Effluent	4.07	58.9	72.9	132	226
Regen 3	Effluent	4.88	56.4	64.6	121	237
Regen 3	Effluent	5.68	56.9	56.8	114	256
Regen 3	Effluent	6.48	58.4	48.6	107	272
Regen 3	Effluent	7.28	54.4	43.0	97.4	284
Regen 3	Effluent	8.08	50.9	40.7	91.6	287
Regen 3	Effluent	8.89	46.9	39.1	86.0	294
Regen 3	Effluent	9.69	42.9	37.8	80.7	305
Regen 3	Effluent	10.49	39.9	36.2	76.1	307
Regen 3	Effluent	11.29	36.9	35.7	72.6	307
Regen 3	Effluent	12.10	34.9	34.6	69.5	312
Regen 3	Effluent	12.90	32.9	34.5	67.4	312
Regen 3	Effluent	13.70	30.9	34.7	65.6	310
Regen 3	Effluent	14.50	29.9	34.5	64.4	310
Regen 3	Effluent	15.30	28.9	34.6	63.5	311
Regen 3	Effluent	16.11	27.4	35.6	63.0	316
Regen 3	Effluent	16.91	26.4	35.0	61.4	311
Regen 3	Effluent	17.71	25.4	35.6	61.0	316
Regen 3	Effluent	18.51	24.6	36.0	60.6	318
Regen 3	Effluent	18.91	28.9	36.1	65.0	279
Rinse	Effluent	0.87	17.7	33.3	51.0	312
Service	Effluent	1.75	0.39	0.82	1.21	52.9
Service	Influent	3.33	7.19	4.71	11.9	38.0
Service	Effluent	3.33	0.32	0.68	1.00	49.6
Service	Effluent	8.06	0.31	0.67	0.98	49.6
Service	Effluent	12.79	0.31	0.67	0.98	49.0
Service	Effluent	17.52	0.31	0.66	0.97	48.8
Service	Effluent	22.25	0.31	0.71	1.02	48.6
Service	Effluent	26.98	0.33	0.81	1.14	48.8
Service	Effluent	31.71	0.36	1.11	1.47	48.3
Service	Effluent	36.44	0.43	1.64	2.07	47.8
Service	Effluent	41.17	0.52	2.60	3.12	47.0
Service	Influent	45.89	7.09	4.70	11.8	38.3
Service	Effluent	45.89	0.68	3.87	4.55	45.2
Service	Effluent	50.62	0.85	5.74	6.59	44.3
Service	Effluent	55.35	1.10	5.86	6.96	43.0
Service	Effluent	60.08	1.37	6.46	7.83	42.7
Service	Effluent	64.81	1.71	6.93	8.64	41.9
Service	Effluent	69.54	2.09	7.17	9.26	40.9
Service	Effluent	74.27	2.54	7.22	9.76	40.7
Service	Effluent	79.00	2.94	7.19	10.1	40.0
Service	Effluent	83.73	3.34	7.12	10.5	39.8
Service	Effluent	88.46	3.74	7.02	10.8	39.1
Service	Effluent	93.19	3.99	6.81	10.8	39.1
Service	Influent	94.76	7.29	4.12	12.0	38.7
Service	Effluent	94.76	4.19	6.77	11.0	39.4

*Calculated from Ca^{++} plus Mg^{++}

Chemical Analyses of Significant Components in Composite Samples

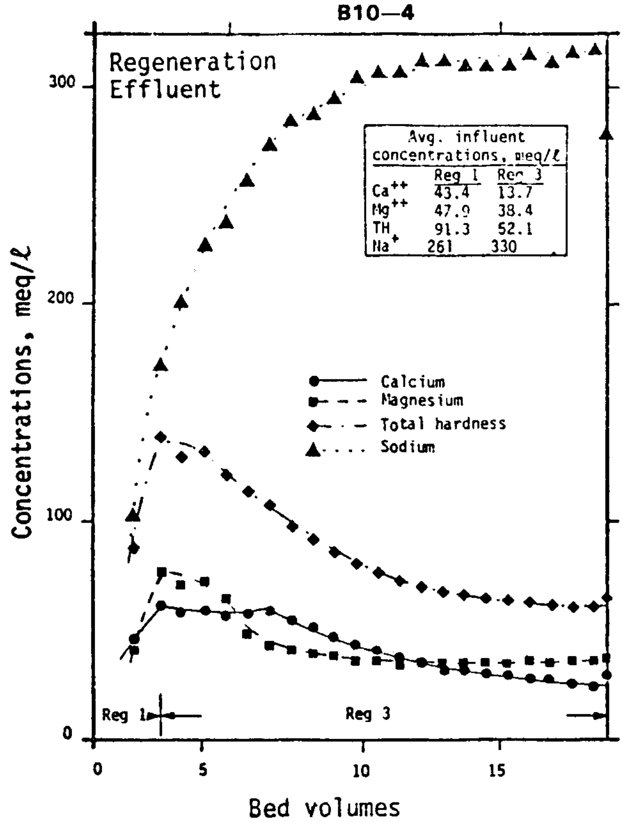
Sample		Cycle influent			Cycle effluent			
		Reg 1	Reg 3	Service	Reg 1	Reg 3	Service	Rinse
pH	units	7.10	6.96	7.32	7.26	7.50	7.37	7.45
TDS (calc)	mg/ℓ	22 241	24 864	3171	15 851	23 992	3223	14 398
Conductivity @ 25 °C	µS/cm	27 242	30 004	4829	18 726	27 448	4410	15 196
Silica	mg/ℓ	13	9	4	11	8	4	9
Calcium	mg/ℓ	870	274	145	1100	840	30.5	183
Magnesium	mg/ℓ	582	466	62.2	732	548	54.1	233
Sodium	mg/ℓ	6000	7600	874	3320	6820	1024	4490
Potassium	mg/ℓ	41.5	121	8.4	24.5	60.8	15.3	63
Iron, total	mg/ℓ	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03
Strontium	mg/ℓ	17.8	3.3	1.9	19.3	15.2	0.1	2.7
Bicarbonate	mg/ℓ	29.3	100	29.3	55.1	97.6	29.3	65.9
Sulfate	mg/ℓ	5700	7000	930	3900	6570	950	4100
Chloride	mg/ℓ	9000	9300	1120	6700	9040	1120	5260
T-alkalinity as $CaCO_3$	mg/ℓ	24	82	24	45	80	24	54
P-alkalinity as $CaCO_3$	mg/ℓ	ND	ND	ND	ND	ND	ND	ND

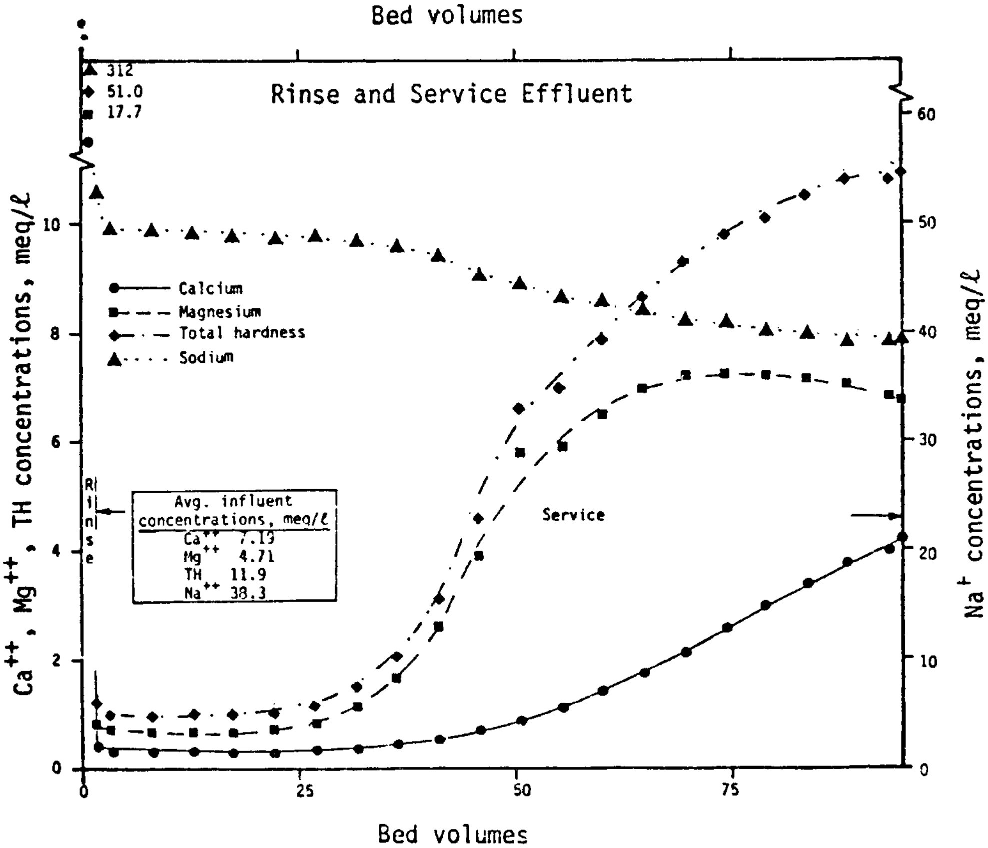
SERVICE PERFORMANCE SUMMARY

	Average concentrations, meq/ℓ			Removal	Resin capacity
	Influent	Effluent	Difference	%	eq/ℓ
Ca^{++}	7.19	1.37	5.82	81	0.541
Mg^{++}	4.71	4.05	0.66	14	0.061
TH*	11.90	5.42	6.48	54	0.603
Na^{+}	38.33	44.75	-6.42	-	-

*Calculated from Ca^{++} plus Mg^{++}

B10—4


Regeneration Effluent
Avg. influent concentrations, meq/ℓ
Reg 1 Reg 3
Ca++ 43.4 13.7
Mg++ 47.9 38.4
TH 91.3 52.1
Na+ 261 330
Calcium
Magnesium
Total hardness
Sodium
Reg 1
Reg 3
Concentrations, meq/ℓ
Bed volumes


Rinse and Service Effluent
312
51.0
17.7
Calcium
Magnesium
Total hardness
Sodium
Rinse
Service
Avg. influent concentrations, meq/ℓ
Ca++ 7.19
Mg++ 4.71
TH 11.9
Na++ 38.3
Ca++, Mg++, TH concentrations, meq/ℓ
Na+ concentrations, meq/ℓ
Bed volumes

APPENDIX C — DATA FROM PHASE 2

C1—1

Ion-Exchange - Run 3.02.00

Date: 2/14/79

Cycle: 3.02.08

Conditions: Feedwater - Wellton-Mohawk drainage pretreated (in Train IV) with high lime dosage for silica removal
Regenerants - recycled regenerant and fresh ED brine

Control Variables:

	Target	Actual
Fresh regeneration conc. (mg/L TDS)	20 000	19 990
Fresh regeneration flow rate (L/min)	3.0	3.0
Recycled regenerant flow rate (L/min)	16.0	14.8
Recycled regenerant volume (L)	800	800
Service termination point (meq/L Ca^{++})	4.5	4.1

Standard resin bed: Height = 1066 mm
Volume = 97.3 L

Chemical Compositions of Tank Waters Prior to Cycle 3.02.08

Tank	pH units	Conductivity µS/cm	Ca^{++} meq/L	Mg^{++} meq/L	TH meq/L
Recycle regenerant (T-5)	-	26 700	57.0	37.0	94.0
Spent regenerant (T-6)	-	26 480	58.0	38.0	96.0
Lime-softened feed (T-9)	7.4	5 136	8.00	6.80	14.8
Fresh ED brine (T-28)	6.6	27 260	5.40	30.6	36.0
IX product/ED feed (T-33)	7.1	5 750	1.60	4.60	6.20

Cycle 3.02.08 Operating Conditions

MODE	INPUT	OUTPUT	DURATION MIN	THROUGHPUT L	VOLUME BV	AVG FLOW RATE L/MIN	AVG FLOW RATE BV/MIN	BED EXPANSION %	TEMPERATURE C
REGEN 1	RE REGEN	WASTE	10	240	2.47	24.0	.25	53	17.8
REGEN 2	RE REGEN	SP REGEN	54	800	8.22	14.8	.15	30	
REGEN 3	FP REGEN	SP REGEN	310	933	9.59	3.0	.03	0.5	19.5
DRAIN 1	(VENT)	WASTE	3	62	.64	20.7	.21	0	
RINSE	FEED	WASTE	10	160	1.64	16.0	.16	0	
SERVICE	FEED	PRODUCT	226	6860	70.5	30.4	.31	0	
DRAIN 2	(VENT)	WASTE	2	41	.42	20.7	.21	0	

Fresh Regenerant Volume Balance

Run 3.02.00 Cycle no.	Date	Fresh regenerant volume (V_3) ℓ	Estimated fresh regenerant TDS mg/ℓ	Service volume (V_S) ℓ	Estimated ED feed TDS mg/ℓ	R %	$V_3/(1-R)V_S$
01	2/9/79	1650	21 724	9070	3168	87	1.43
02	2/10/79	1650	21 724	8490	3168	87	1.53
03	2/11/79	930	21 724	7830	3168	87	0.94
04	2/11/79	930	21 724	7050	3168	87	1.04
05	2/12/79	930	21 373	6960	3275	87	1.00
06	2/13/79	930	21 039	7160	3372	86	0.92
07	2/13/79	930	21 039	6530	3372	86	1.01
08	2/14/79	933	21 109	6860	3565	85	1.10

Influent and Effluent Compositions during Cycle 3.02.08

		Regen 1,2 influent	Regen 1 effluent	Regen 2 effluent	Regen 3 Influent	Regen 3 Effluent	Rinse service influent	Rinse effluent	Service effluent
pH	units	-	-	-	6.6	-	7.4	7.1	7.3
TDS(Σ ions)	mg/L	19 600	13 541	19 261	19 993	19 337	3179	17 011	3209
Conductivity @ 25 °C	μS/cm	-	-	-	24 929	-	5049	22 490	5161
Silica	mg/L	1.0	9.6	10.0	8.3	8.8	7.2	8.1	7.3
Calcium	mg/L	1050	1120	1320	186	940	152	179	35.1
Magnesium	mg/L	436	484	540	303	334	60.0	209	52.9
Sodium	mg/L	5510	3110	4940	6560	5650	918	5580	1061
Potassium	mg/L	22.6	14.3	20.8	82	23.0	8.2	69	12.9
Strontium	mg/L	15.3	15.0	17.9	2.4	13.1	2.5	2.8	0.8
Bicarbonate	mg/L	107	98	122	39.5	137	24.4	41.0	22.0
Carbonate	mg/L	ND	ND	ND	ND	ND	ND	ND	ND
Hydroxide	mg/L	ND	ND	ND	ND	ND	ND	ND	ND
Sulfate	mg/L	5240	3580	5100	5720	5140	908	4720	914
Chloride	mg/L	7220	5120	7200	7100	7100	1106	6210	1110
T-alkalinity as $CaCO_3$	mg/L	88	80	100	32.4	112	20.0	33.6	18.0
P-alkalinity as CaCO	mg/L	ND	ND	ND	ND	ND	ND	ND	ND

Major Cation Concentrations of Samples Analyzed by Atomic Absorption

CYCLE 3.02.08

MODE	PROCESS STREAM	THROUGHPUT BV	CA MEQ/L	MG MEQ/L	TH MEQ/L	NA MEQ/L
REGEN 1	EFFLUENT	0.00	16.82	11.85	28.67	63.98
REGEN 1	EFFLUENT	1.23	72.85	53.00	125.86	154.85
REGEN 2	EFFLUENT	2.47	77.84	53.58	131.42	193.13
REGEN 2	INFLUENT	3.08	52.40	35.88	88.28	239.67
REGEN 2	EFFLUENT	6.27	62.87	42.63	105.51	222.71
REGEN 3	EFFLUENT	10.69	55.89	38.27	94.16	233.58
REGEN 3	INFLUENT	12.55	9.28	24.94	34.22	285.34
REGEN 3	EFFLUENT	13.10	52.40	32.59	84.99	242.28
REGEN 3	EFFLUENT	15.52	46.41	23.13	69.53	247.06
REGEN 3	EFFLUENT	17.93	38.92	19.26	58.18	263.16
REGEN 3	EFFLUENT	20.28	38.92	25.02	63.94	257.50
RINSE	EFFLUENT	0.00	11.13	23.54	34.67	284.91
RINSE	EFFLUENT	.82	6.24	11.03	17.27	205.31
SERVICE	EFFLUENT	1.64	.32	.67	.99	54.59
SERVICE	INFLUENT	4.45	7.73	5.00	12.74	39.80
SERVICE	EFFLUENT	25.98	.30	.75	1.05	50.54
SERVICE	INFLUENT	38.14	7.63	4.91	12.55	39.10
SERVICE	EFFLUENT	50.31	1.53	5.79	7.32	44.45
SERVICE	EFFLUENT	62.48	2.79	7.37	10.16	42.45
SERVICE	INFLUENT	72.15	7.63	4.95	12.59	39.50
SERVICE	EFFLUENT	72.15	4.09	7.14	11.24	40.71

Service Performance Summary

CYCLE 3.02.08

	AVERAGE CONCENTRATIONS, MEQ/L INFLUENT	EFFLUENT	DIFFERENCE	REMOVAL %	RESIN CAPACITY EQ/L
CA	7.67	1.27	6.40	83	.451
MG	4.96	3.50	1.45	29	.102
TH	12.63	4.77	7.85	62	.554
NA	39.47	47.74	-8.27		

FIGURE A- a
MAJOR CATION CONCENTRATIONS
OF IX REGENERATION EFFLUENT
CYCLE 3.02.08

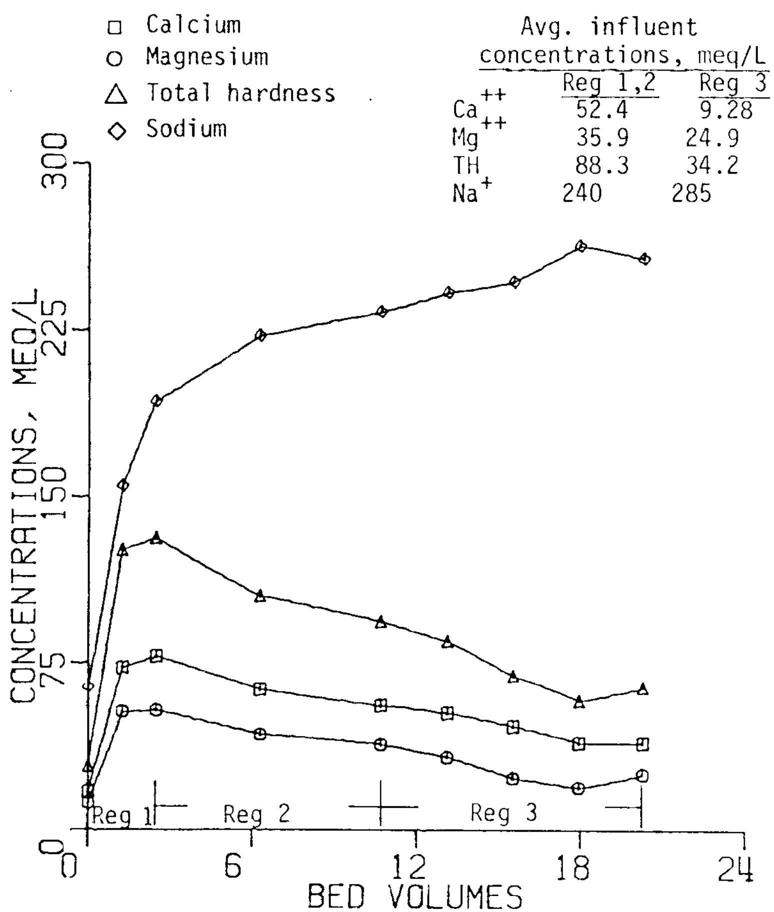
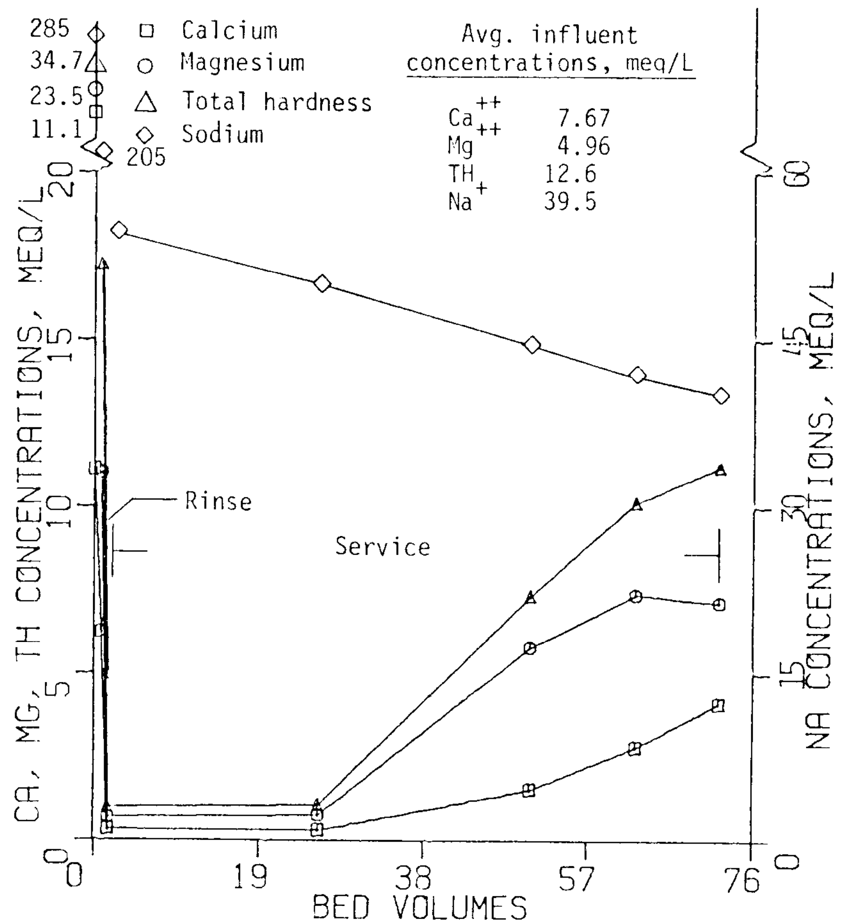


FIGURE A- b
MAJOR CATION CONCENTRATIONS OF
IX RINSE AND SERVICE EFFLUENTS
CYCLE 3.02.08



Ion-Exchange - Run 3.01.00C

Date: 1/27/79

Cycle: 3.01.32C

Conditions: Feedwater - Wellton-Mohawk drainage pretreated (in Train IV) with high lime dosage for silica removal
Regenerants - recycled regenerant and fresh ED brine

Control Variables:

	Target	Actual
Fresh regeneration conc. (mg/ℓ TDS)	20 000	22 230
Fresh regeneration flow rate (ℓ/min)	8.0	8.0
Recycled regenerant flow rate (ℓ/min)	16.0	14.6
Recycled regenerant volume (ℓ)	800	800
Service termination point (meq/ℓ Ca^{++})	1.5	1.3

Standard resin bed: Height = 1066 mm
Volume = 97.3 ℓ

Chemical Compositions of Tank Waters Prior to Cycle 3.01.32C

Tank	pH units	Conductivity µS/cm	Ca^{++} meq/ℓ	Mg^{++} meq/ℓ	TH meq/ℓ
Recycle regenerant (T-5)	-	27 600	42.0	48.0	90.0
Spent regenerant (T-6)	-	27 300	56.0	44.0	100
Lime-softened feed (T-9)	7.5	4 794	7.20	6.0	13.2
Fresh ED brine (T-28)	6.6	29 350	4.00	22.0	26.0
IX product/ED feed (T-33)	7.1	5 283	0.56	2.24	2.80

Cycle 3.01.32C Operating Conditions

MODE	INPUT	OUTPUT	DURATION MIN	THROUGHPUT L	VOLUME BV	AVG FLOW RATE L/MIN	AVG FLOW RATE BV/MIN	BED EXPANSION %	TEMPERATURE C
REGEN 1	RE REGEN	WASTE	10	240	2.47	24.00	.25	59	13.0
REGEN 2	RE REGEN	SP REGEN	55	800	8.22	14.55	.15	33	
REGEN 3	FR REGEN	SP REGEN	94	752	7.73	8.00	.08	10	12.5
DRAIN 1	(VENT)	WASTE	3	62	.64	20.70	.21		
RINSE	FEED	WASTE	10	160	1.64	16.00	.16		
SERVICE	FEED	PRODUCT	176	5270	54.16	29.94	.31		
DRAIN 2	(VENT)	WASTE	2	41	.42	20.70	.21		

Fresh Regenerant Volume Balance

Run 3.01.00C cycle no.	Date	Fresh regenerant volume (V_3) ℓ	Estimated fresh regenerant TDS mg/ℓ	Service volume (V_s) ℓ	Estimated ED feed TDS mg/ℓ	R %	$V_3/(1-R)V_s$
01	1/14	1800	-	7650	-	87	1.76
02	1/14	800	-	5940	-	87	1.01
03	1/15	800	21 300	5500	3190	87	1.09
04	1/14	800	21 300	5780	3190	87	1.03
05	1/16	800	21 300	4670	3550	85	1.16
06	1/16	600	21 300	5680	3550	85	0.71
07	1/16	600	21 300	5450	3550	85	0.74
19	1/22	700	19 000	5660	2890	87	0.95
20	1/22	700	19 000	5580	2890	87	0.97
21	1/23	700	18 000	5230	2830	87	1.00
22	1/23	700	18 000	4850	2830	87	1.08
23	1/23	900	18 000	6560	2830	87	1.02
24	1/23	900	18 000	6450	2830	87	1.05
25	1/24	750	22 800	6050	3220	88	1.01
26	1/25	750	22 500	5850	3330	87	0.99
27	1/25	750	22 500	5580	3330	87	1.03
28	1/25	760	22 500	5700	3330	87	1.01
29	1/26	750	20 200	5230	3120	87	1.07
30	1/26	750	20 200	5770	3120	87	0.97
31	1/26	750	20 200	5520	3120	87	1.01
32	1/27	750	21 300	5270	3275	86	1.06

Influent and Effluent Compositions during Cycle 3.01.32C

		Regen 1,2 influent	Regen 1 effluent	Regen 2 effluent	Regen 3 Influent	Regen 3 Effluent	Rinse & service influent	Rinse effluent	Service effluent
pH	Units	-	-	-	7.6	-	-	-	-
TDS (Σ ions)	mg/ℓ	20 450	13 596	30 039	22 280	21 150	3082	12 424	3149
Conductivity @ 25 °C	μS/cm	-	-	-	31 600	-	-	-	-
Silica	mg/ℓ	<1	<1	<1	8	<1	7	8	7
Calcium	mg/ℓ	870	910	1060	63	790	130	191	13.8
Magnesium	mg/ℓ	524	471	594	99.2	357	55.0	75.3	23.1
Sodium	mg/ℓ	5760	3460	5370	7960	6520	898	4180	1084
Potassium	mg/ℓ	27.7	29.0	41.0	64.0	49.0	8.1	30.7	11.0
Strontium	mg/ℓ	15.7	13.0	16.0	0.7	12.0	2.0	3.5	<0.1
Bicarbonate	mg/ℓ	93	73	98	63.4	102	24.4	43.9	22.9
Carbonate	mg/ℓ	ND	ND	ND	ND	ND	ND	ND	ND
Hydroxide	mg/ℓ	ND	ND	ND	ND	ND	ND	ND	ND
Sulfate	mg/ℓ	5460	3440	5260	6370	5740	934	3600	964
Chloride	mg/ℓ	7700	5200	7600	7660	7580	1030	4300	1030
T-alkalinity as $CaCO_3$	mg/ℓ	76	60	80	52.0	84	20.0	36.0	18.8
P-alkalinity as CaCO	mg/ℓ	ND	ND	ND	ND	ND	ND	ND	ND

Major Cation Concentrations of Samples Analyzed by Atomic Absorption

CYCLE 3.01.32C

MODE	PROCESS STREAM	THROUGHPUT BV	CA MEQ/L	MG MEQ/L	TH MEQ/L	NA MEQ/L
REGEN 1	EFFLUENT	0.00	14.27	10.37	24.64	61.55
REGEN 1	EFFLUENT	1.23	58.88	51.28	110.16	164.85
REGEN 2	EFFLUENT	4.08	63.87	54.57	118.44	218.36
REGEN 2	INFLUENT	4.86	43.41	43.13	86.54	250.54
REGEN 2	EFFLUENT	7.85	50.90	47.16	98.06	236.19
REGEN 3	EFFLUENT	10.69	51.40	45.76	97.16	243.58
REGEN 3	INFLUENT	11.27	3.14	8.16	11.31	346.24
REGEN 3	EFFLUENT	12.58	50.90	35.31	86.21	277.95
REGEN 3	EFFLUENT	14.47	39.92	24.44	64.36	292.74
REGEN 3	EFFLUENT	16.36	32.93	17.61	50.55	305.35
REGEN 3	EFFLUENT	18.42	34.43	23.46	57.89	285.34
RINSE	EFFLUENT	0.00	19.01	12.18	31.19	313.18
RINSE	EFFLUENT	.82	.51	.35	.87	58.37
SERVICE	EFFLUENT	1.64	.35	.24	.59	50.20
SERVICE	INFLUENT	3.49	6.59	4.64	11.23	39.19
SERVICE	EFFLUENT	20.72	.36	.26	.62	49.63
SERVICE	INFLUENT	30.26	6.64	4.58	11.21	38.71
SERVICE	EFFLUENT	37.96	.51	1.14	1.66	48.98
SERVICE	EFFLUENT	49.34	.93	3.28	4.22	46.28
SERVICE	EFFLUENT	55.81	1.32	4.48	5.80	44.63

Service Performance Summary

CYCLE 3.01.32C

	AVERAGE CONCENTRATIONS, MEQ/L			REMOVAL	RESIN CAPACITY
	INFLUENT	EFFLUENT	DIFFERENCE	%	EQ/L
CA	6.61	.55	6.06	92	.328
MG	4.61	1.24	3.37	73	.183
TH	11.22	1.79	9.43	84	.511
NA	38.95	48.71	-9.76		

FIGURE A- a
MAJOR CATION CONCENTRATIONS
OF IX REGENERATION EFFLUENT
CYCLE 3.01.32C

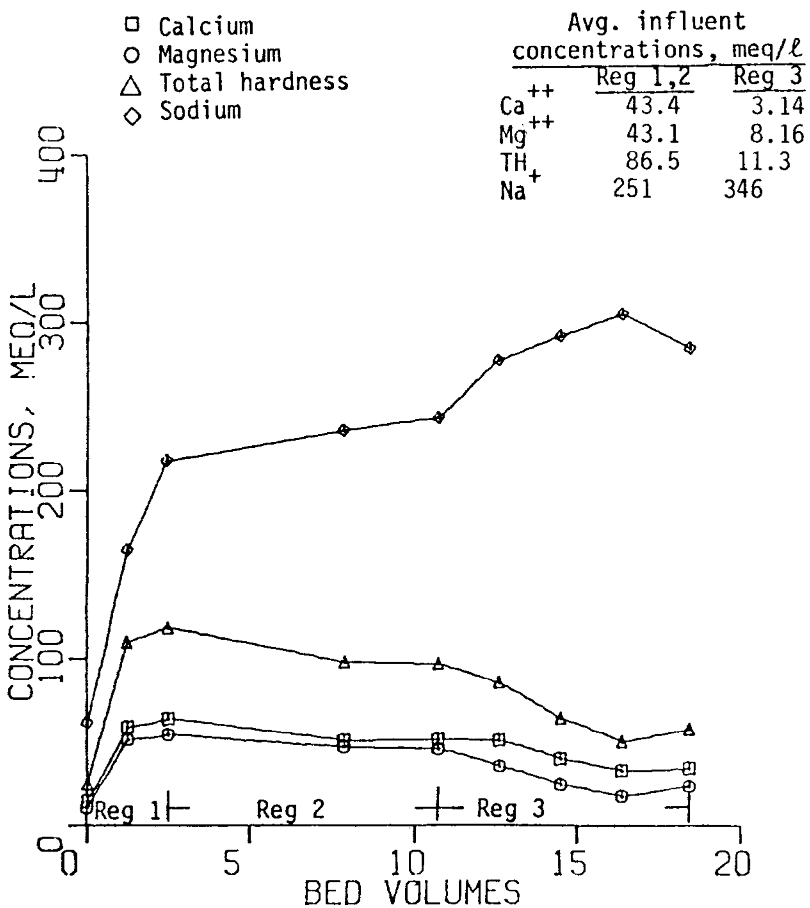
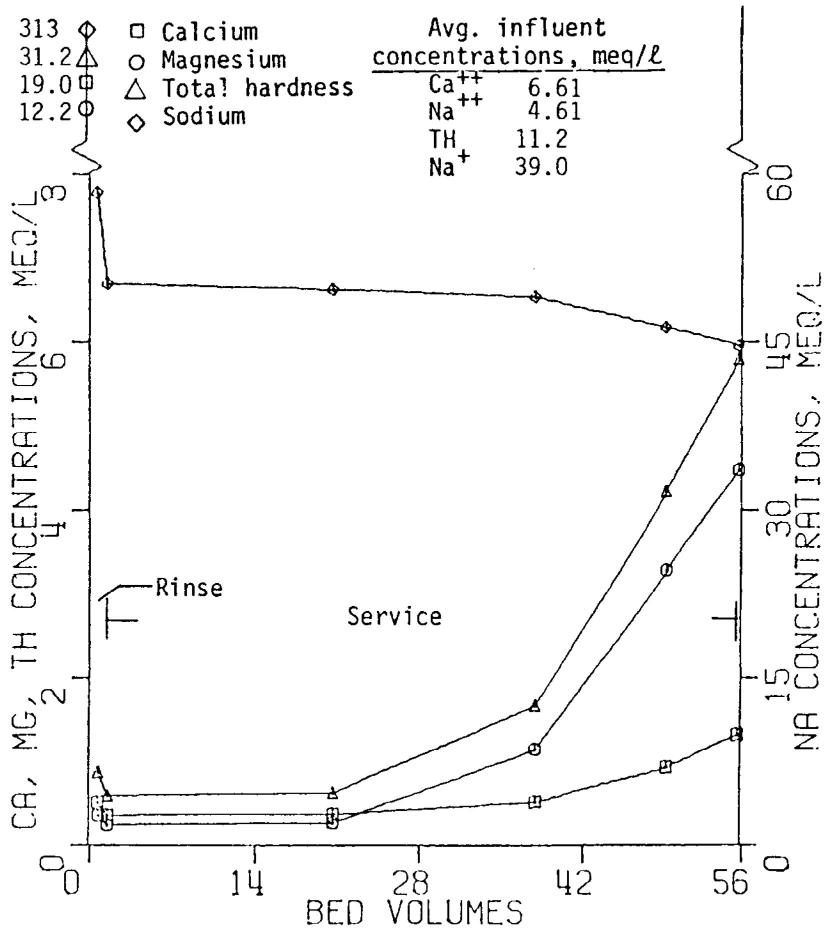


FIGURE A- b
MAJOR CATION CONCENTRATIONS OF
IX RINSE AND SERVICE EFFLUENTS
CYCLE 3.01.32C



Ion-Exchange - Run 3.02.00C

Date: 2/1/79

Cycle: 3.02.12C

Conditions: Feedwater - Wellton-Mohawk drainage pretreated (in Train IV) with high lime dosage for silica removal
Regenerants - recycled regenerant and fresh ED brine

Control Variables:

	Target	Actual
Fresh regeneration conc. (mg/L TDS)	20 000	20 400
Fresh regeneration flow rate (L/min)	3.0	3.2
Recycled regenerant flow rate (L/min)	16.0	14.6
Recycled regenerant volume (L)	800	800
Service termination point (meq/L Ca^{++})	1.5	1.2

Standard resin bed: Height = 1066 mm
Volume = 97.3 L

Chemical Compositions of Tank Waters Prior to Cycle 3.02.12C

Tank	pH units	Conductivity μS/cm	Ca^{++} meq/L	Mg^{++} meq/L	TH meq/L
Recycle regenerant (T-5)	-	27 250	40.0	28.0	68.0
Spent regenerant (T-6)	-	27 150	41.0	29.0	70.0
Lime-softened feed (T-9)	7.5	4 938	6.80	5.20	12.0
Fresh ED brine (T-28)	7.2	27 300	6.40	6.80	13.2
IX product/ED feed (T-33)	7.4	5 301	0.56	2.04	2.60

Cycle 3.02.12C Operating Conditions

MODE	INPUT	OUTPUT	DURATION MIN	THROUGHPUT L	VOLUME BV	AVG FLOW RATE L/MIN	AVG FLOW RATE BV/MIN	BED EXPANSION %	TEMPERATURE C
REGEN 1	RE REGEN	WASTE	10	240	2.47	24.0	.25	61	14.6
REGEN 2	RE REGEN	SP REGEN	55	800	8.22	14.5	.15	32	
REGEN 3	FR REGEN	SP REGEN	280	883	9.08	3.15	.03	2	15.2
DRAIN 1	(VENT)	WASTE	3	62	.64	20.7	.21	0	
RINSE	FEED	WASTE	10	140	1.44	14.0	.14	0	
SERVICE	FEED	PRODUCT	203	5910	60.7	29.1	.30	0	
DRAIN 2	(VENT)	WASTE	2	41	.42	20.7	.21	0	

Fresh Regenerant Volume Balance

Run 3.02.00C cycle no.	Date	Fresh regenerant volume (V_3) ℓ	Estimated fresh regenerant TDS mg/ℓ	Service volume (V_S) ℓ	Estimated ED feed TDS mg/ℓ	R %	$V_3/(1-R)V_S$
01	1/27	900	3275	6230	5283	86	1.07
02	1/28	900	3275	6320	5283	86	1.06
03	1/28	900	3275	5930	5283	86	1.12
04	1/29	5700	3294	7510	5313	85	4.96
05	1/29	840	3294	6610	5313	85	0.83
08	1/30	840	3206	6030	5171	85	0.94
09	1/31	840	3317	6000	5350	86	0.98
10	1/31	840	3317	6420	5350	86	0.92
11	1/31	840	3317	6180	5350	86	0.05
12	2/1	840	3287	5910	5301	85	0.97

Influent and Effluent Compositions during Cycle 3.02.12C

		Regen 1,2 influent	Regen 1 effluent	Regen 2 effluent	Regen 3		Rinse service influent	Rinse effluent	Service effluent
					Influent	Effluent			
pH	units	-	-	-	6.7	-	7.5	7.3	7.6
TDS (Σ ions)	mg/L	19 861	13 458	19 376	20 361	19 789	3052	4917	3137
Conductivity @ 25 °C	μS/cm	-	-	-	28 576	-	4994	7907	5275
Silica	mg/L	<1.0	<1.0	<1.0	10	<1.0	7	8	9
Calcium	mg/L	890	950	1110	24.4	820	141	7.8	8.8
Magresium	mg/L	408	486	536	117	295	58.7	7.2	22.9
Sodium	mg/L	5680	3280	5150	7060	5840	879	1752	1097
Potassium	mg/L	32.8	16.5	27.0	73	31.3	8.0	17.9	12.5
Strontium	mg/L	12.2	12.5	14.9	1.1	11.0	2.4	0.4	0.5
Bicarbonate	mg/L	97.6	73	98	65.9	112	26.8	31.7	12.9
Carbonate	mg/L	ND	ND	ND	ND	ND	ND	ND	ND
Hydroxide	mg/L	ND	ND	ND	ND	ND	ND	ND	ND
Sulfate	mg/L	5580	3700	5420	5900	5640	936	1550	980
Chloride	mg/L	7160	4940	7020	7120	7040	1000	1550	1002
T-alkalinity as $CaCO_3$	mg/L	80	60	80	54.0	92	22.0	26.0	10.6
P-alkalinity as CaCO	mg/L	ND	ND	ND	ND	ND	ND	ND	ND

Major Cation Concentrations of Samples Analyzed by Atomic Absorption

CYCLE 3.02.12C

MODE	PROCESS STREAM	THROUGHPUT BV	CA MEQ/L	MG MEQ/L	TH MEQ/L	NA MEQ/L
REGEN 1	EFFLUENT	0.00	12.57	9.88	22.45	55.42
REGEN 1	EFFLUENT	1.23	65.37	54.90	120.27	161.81
REGEN 2	EFFLUENT	2.47	66.87	54.40	121.27	200.09
REGEN 2	INFLUENT	3.06	44.41	33.58	77.99	247.06
REGEN 2	EFFLUENT	6.50	52.40	41.15	93.55	228.36
REGEN 3	EFFLUENT	10.69	48.40	37.70	86.10	260.55
REGEN 3	INFLUENT	10.85	1.22	9.63	10.85	307.09
REGEN 3	EFFLUENT	12.99	45.41	33.09	78.50	254.89
REGEN 3	EFFLUENT	15.23	40.42	20.16	60.58	259.68
REGEN 3	EFFLUENT	17.50	35.43	12.10	47.53	275.34
REGEN 3	EFFLUENT	19.78	36.43	18.85	55.27	260.55
RINSE	EFFLUENT	0.00	.61	.99	1.60	103.09
RINSE	EFFLUENT	.72	.14	.21	.35	51.11
SERVICE	EFFLUENT	1.44	.13	.19	.32	49.33
SERVICE	INFLUENT	3.23	7.24	4.85	12.08	38.49
SERVICE	EFFLUENT	21.49	.13	.20	.33	48.63
SERVICE	INFLUENT	31.36	7.19	4.88	12.07	38.41
SERVICE	EFFLUENT	41.53	.22	1.02	1.24	48.11
SERVICE	EFFLUENT	51.41	.49	2.89	3.38	46.15
SERVICE	INFLUENT	62.18	7.19	4.81	12.00	38.06
SERVICE	EFFLUENT	62.18	1.19	4.94	6.13	43.58

Service Performance Summary

CYCLE 3.02.12C

	AVERAGE CONCENTRATIONS, MEQ/L			REMOVAL	RESIN CAPACITY
	INFLUENT	EFFLUENT	DIFFERENCE	%	EQ/L
CA	7.20	.31	6.90	96	.419
MG	4.85	1.28	3.57	74	.217
TH	12.05	1.58	10.47	87	.636
NA	38.32	47.75	-9.43		

FIGURE A- a
MAJOR CATION CONCENTRATIONS
OF IX REGENERATION EFFLUENT
CYCLE 3.02.12C

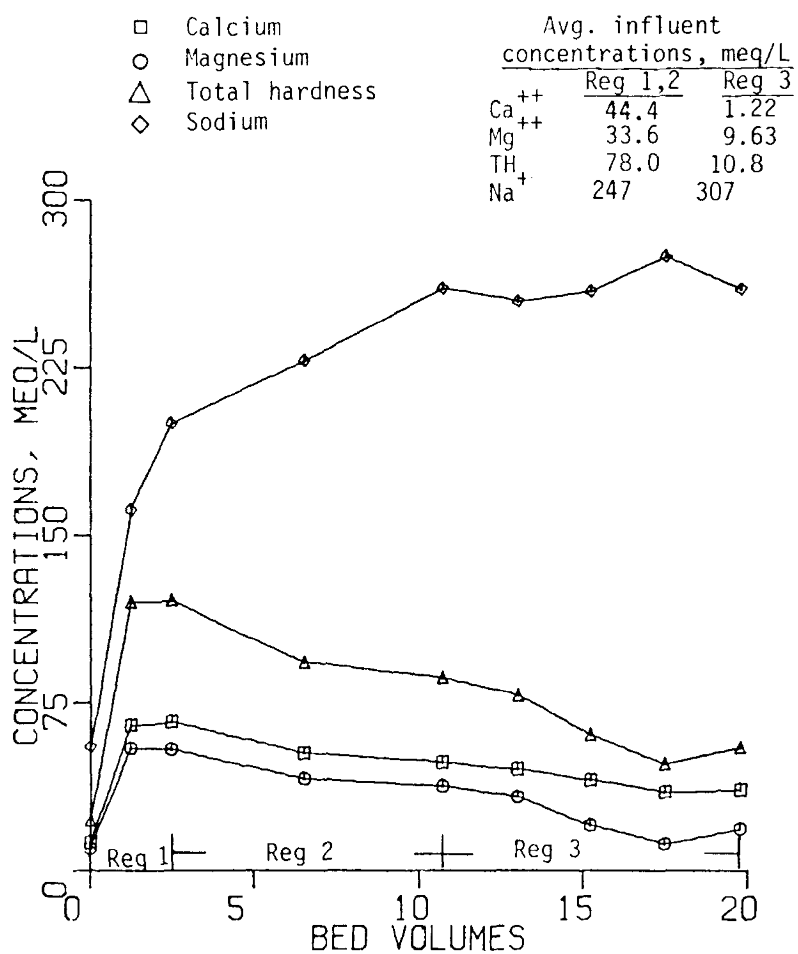
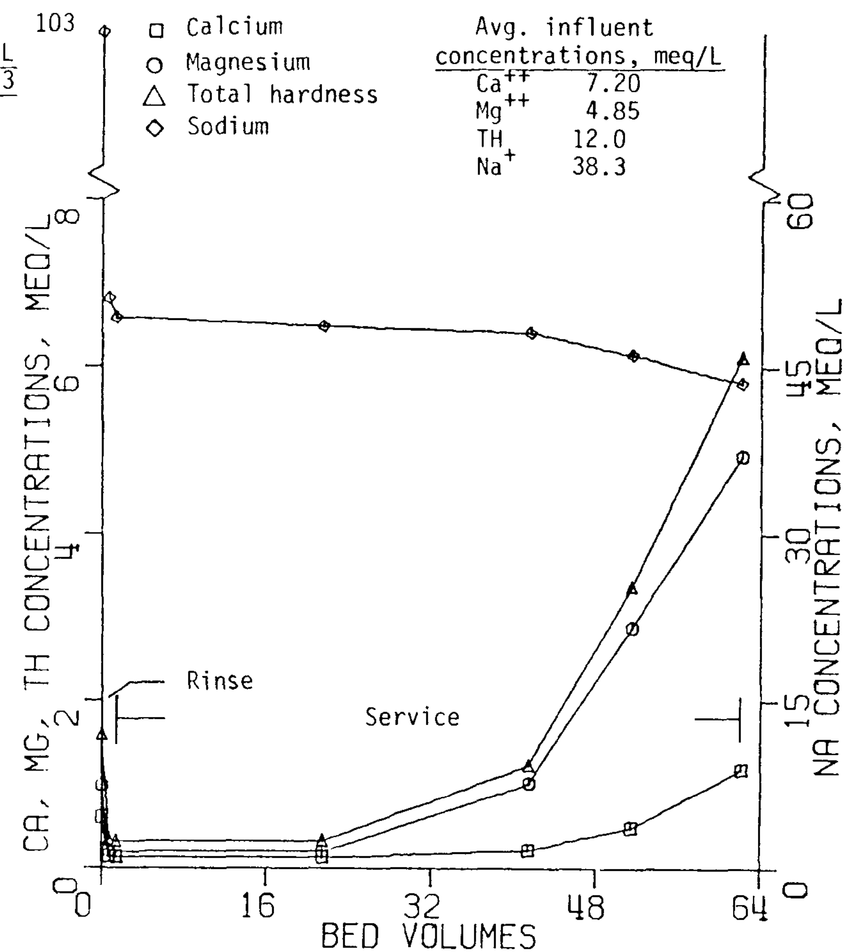


FIGURE A- b
MAJOR CATION CONCENTRATIONS OF
IX RINSE AND SERVICE EFFLUENTS
CYCLE 3.02.12C



C4—1

Ion-Exchange - Run 3.01.00

Date: 2/8/79

Cycle: 3.01.15

Conditions: Feedwater - Wellton-Mowhawk drainage pretreated (in Train IV) with high lime dosage for silica removal
Regenerants - recycled regenerant and fresh ED brine

Control Variables:

	Target	Actual
Fresh regeneration conc. (mg/L TDS)	20 000	20 610
Fresh regeneration flow rate (L/min)	8.0	7.2
Recycled regenerant flow rate (L/min)	16.0	14.6
Recycled regenerant volume (L)	800	800
Service termination point (meq/L Ca^{++})	4.5	4.6

Standard resin bed: Height = 1066 mm
Volume = 97.3

Chemical Compositions of Tank Waters Prior to Cycle 3.01.15

Tank	pH units	Conductivity µS/cm	Ca^{++} meq/L	Mg^{++} meq/L	TH meq/L
Recycle regenerant (T-5)	-	29 710	45.0	37.0	82.0
Spent regenerant (T-6)	-	29 960	47.0	35.0	82.0
Lime-softened feed (T-9)	7.7	4 705	7.20	5.20	12.4
Fresh ED brine (T-28)	6.8	27 850	10.0	25.2	35.2
IX product/ED feed (T-33)	7.2	5 161	1.76	4.84	6.60

Cycle 3.01.15 Operating Conditions

MODE	INPUT	OUTPUT	DURATION MIN	THROUGHPUT L	VOLUME BV	AVG FLOW RATE L/MIN	AVG FLOW RATE BV/MIN	BED EXPANSION %	TEMPERATURE C
REGEN 1	RE REGEN	WASTE	10	240	2.47	24.0	.25	58	16.9
REGEN 2	RE REGEN	SP REGEN	55	800	8.22	14.5	.15	33	
REGEN 3	FR REGEN	SP REGEN	175	1257	12.9	7.18	.07	10	15.7
DRAIN 1	(VENT)	WASTE	3	62	.64	20.7	.21	0	
RINSE	FEED	WASTE	10	160	1.64	16.0	.16	0	
SERVICE	FEED	PRODUCT	322	9640	99.1	29.9	.31	0	
DRAIN 2	(VENT)	WASTE	2	41	.42	20.7	.21	0	

Fresh Regenerant Volume Balance

Run 3.01.00 Cycle no.	Date	Fresh regenerant volume (V_3) ℓ	Fresh regenerant TDS mg/ℓ	Service volume (V_S) ℓ	Estimated ED feed TDS mg/ℓ	R %	$V_3/(1-R)V_S$
10	2/5/79	960	21 800	9850	3317	87	0.73
11	2/5/79	960	21 800	9860	3317	87	0.73
12	2/6/79	~1260	21 500	9860	3317	86	0.94
13	2/7/79	~1260	21 200	10460	3497	85	0.83
14	2/7/79	~1260	21 200	9920	3497	85	0.87
15	2/8/79	1257	21 700	9640	3200	87	1.01

Influent and Effluent Compositions during Cycle 3.01.15

		Regen 1,2 influent	Regen 1 effluent	Regen 2 effluent	Regen 3 Influent	Regen 3 Effluent	Rinse service influent	Rinse effluent	Service effluent
pH	units	-	-	-	6.7	-	7.1	7.0	7.0
TDS (Σ ions)	mg/L	22 204	14 705	21 652	20 608	21 083	3019	20 804	3010
Conductivity @ 25 °C	µS/cm	-	-	-	28 000	-	4742	27 527	4902
Silica	mg/L	<1.0	8	8	13	10	8	11	8
Calcium	mg/L	980	1260	1400	181	810	140	260	40.9
Magnesium	mg/L	312	452	445	292	270	58.5	298	53.0
Sodium	mg/L	6620	3540	5780	6760	6360	870	6900	967
Potassium	mg/L	26.5	16.1	23.2	59.7	27.2	8.0	59.3	10.5
Strontium	mg/L	12.0	15.3	17.3	2.0	9.8	2.3	3.5	0.8
Bicarbonate	mg/L	142	122	146	73.2	146	24.4	73.2	23.4
Carbonate	mg/L	ND	ND	ND	ND	ND	ND	ND	ND
Hydroxide	mg/L	ND	ND	ND	ND	ND	ND	ND	ND
Sulfate	mg/L	5900	3600	5700	6050	5800	876	5940	874
Chloride	mg/L	8340	5700	8140	7190	7660	1040	7270	1040
T-alkalinity as $CaCO_3$	mg/L	116	100	120	60.0	120	20.0	60.0	19.2
P-alkalinity as CaCO	mg/L	ND	ND	ND	ND	ND	ND	ND	ND

Major Cation Concentrations of Samples Analyzed by Atomic Absorption

CYCLE 3.01.15

MODE	PROCESS STREAM	THROUGHPUT RV	CA MEQ/L	MG MEQ/L	TH MEQ/L	NA MEQ/L
REGEN 1	EFFLUENT	0.00	17.37	12.51	29.88	62.46
REGEN 1	EFFLUENT	1.23	82.83	53.33	136.17	176.60
REGEN 2	EFFLUENT	2.47	86.83	52.52	138.35	221.84
REGEN 2	INFLUENT	3.06	48.90	25.68	74.58	287.95
REGEN 2	EFFLUENT	6.50	67.37	35.31	102.67	287.95
REGEN 3	EFFLUENT	10.69	54.89	27.65	82.54	280.56
REGEN 3	INFLUENT	11.65	9.03	24.03	33.06	294.04
REGEN 3	EFFLUENT	13.87	44.41	22.96	67.37	267.94
REGEN 3	EFFLUENT	17.11	35.43	21.48	56.91	304.05
REGEN 3	EFFLUENT	20.36	31.94	22.22	54.16	303.61
REGEN 3	EFFLUENT	20.61	35.93	22.88	58.81	317.09
RINSE	EFFLUENT	0.00	12.67	23.62	36.30	302.74
RINSE	EFFLUENT	.82	13.47	22.22	35.70	287.08
SERVICE	EFFLUENT	1.64	.31	.56	.87	48.85
SERVICE	INFLUENT	4.41	7.04	4.35	11.39	35.54
SERVICE	EFFLUENT	35.80	.30	.77	1.08	45.24
SERVICE	INFLUENT	52.72	7.04	4.44	11.48	35.80
SERVICE	EFFLUENT	69.95	1.94	6.14	8.08	37.89
SERVICE	EFFLUENT	86.87	3.64	6.44	10.08	36.84
SERVICE	INFLUENT	100.72	7.04	4.45	11.49	35.36
SERVICE	EFFLUENT	100.72	4.59	6.25	10.84	36.36

Service Performance Summary

CYCLE 3.01.15

	AVERAGE CONCENTRATIONS, MEQ/L INFLUENT	EFFLUENT	DIFFERENCE	REMOVAL %	RESIN CAPACITY EQ/L
CA	7.04	1.54	5.49	78	.544
MG	4.42	3.38	1.04	23	.103
TH	11.45	4.93	6.53	57	.647
NA	35.57	42.04	-6.47		

FIGURE A- a
MAJOR CATION CONCENTRATIONS
OF IX REGENERATION EFFLUENT
CYCLE 3.01.15

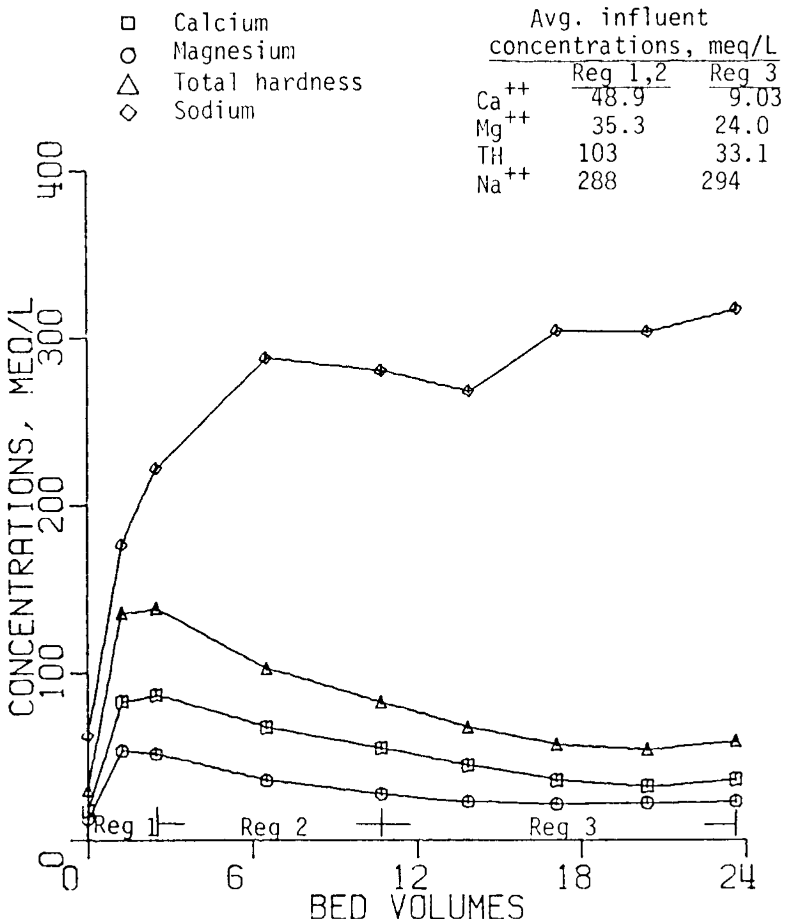
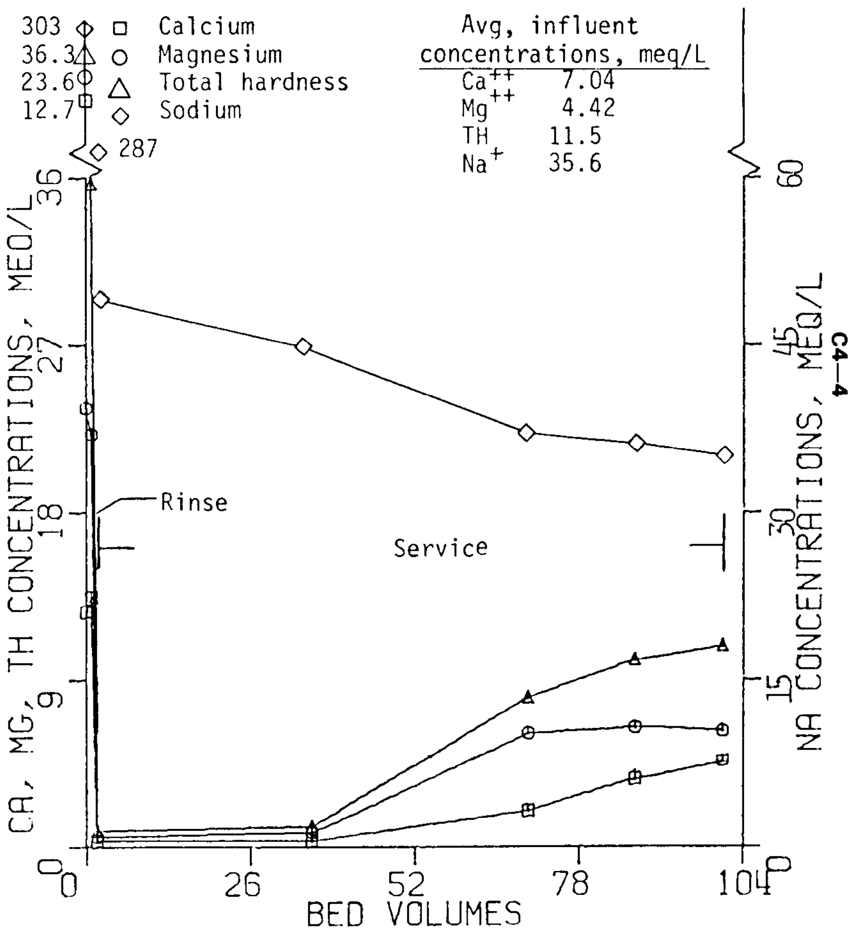


FIGURE A- b
MAJOR CATION CONCENTRATIONS OF
IX RINSE AND SERVICE EFFLUENTS
CYCLE 3.01.15



Ion-Exchange - Run 3.03.00

Date: 3/3/79

Cycle: 3.03.28

Conditions: Feedwater - Wellton-Mowhawk drainage pretreated (in Train IV) with high lime dosage for silica removal
Regenerants - recycled regenerant and fresh ED brine

Control variables:

	Target	Actual
Fresh regeneration conc. (mg/L TDS)	35 000	33 870
Fresh regeneration flow rate (L/min)	5.5	5.8
Recycled regenerant flow rate (L/min)	8.0	8.0
Recycled regenerant volume (L)	1600	1600
Service termination point (meq/L Ca^{++})	3.0	2.2

Standard resin bed: Height = 1066 mm
Volume = 97.3 L

Chemical Compositions of Tank Waters Prior to Cycle 3.03.28

Tank	pH units	Conductivity μS/cm	Ca^{++} meq/L	Mg^{++} meq/L	TH meq/L
Recycle regenerant (T-5)	-	41 855	48.0	54.0	102.0
Spent regenerant (T-6)	-	41 256	47.0	57.0	104.0
Lime-softened feed (T-9)	7.4	5 560	8.80	5.60	14.4
Fresh ED brine (T-28)	6.1	45 246	7.20	27.2	34.4
IX product/ED feed (T-33)	7.0	5 845	0.80	3.80	4.60

Cycle 3.03.28 Operating Conditions

Mode	Input	Output	Duration Min	Throughput L	Volume BV	Avg. Flow Rate L/Min	Avg. Flow Rate BV/Min	Bed Expansion %	Temperature C
Regen 1	Re Regen	Waste	10	240	2.47	24.0	.247	59	16.2
Regen 2	Re Regen	SP Regen	201	1600	16.4	7.96	.082	12	
Regen 3	Fr Regen	SP Regen	120	702	7.21	5.85	.060	6.8	16.7
Drain 1	(Vent)	Waste	3	62	.64	20.7	.210	0	
Rinse	Re	Waste	10	160	1.64	16.0	.164	0	
Service	Feed	Product	238	7030	72.2	29.5	.304	0	
Drain 2	(Vent)	Waste	2	41	.42	20.7	.210	0	

Fresh Regenerant Volume Balance

Run 3.03.00 Cycle no.	Date	Fresh regenerant volume (V_3) L	Estimated fresh regenerant TDS mg/L	Service volume (V_S) L	Estimated ED feed TDS mg/L	R %	$V_3/(1-R)V_S$
17	2/23/79	385	37 030	7520	3740	91	0.58
18	2/24/79	385	37 030	6690	3740	91	0.65
19	2/24/79	385	37 030	6750	3740	91	0.64
20	2/25/79	385	37 030	6130	3740	91	0.71
21	2/25/79	660	37 030	2830	3740	91	2.59
23	2/28/79	660	35 150	7780	3460	91	0.99
24	3/1/79	660	34 820	7630	3520	91	0.97
25	3/1/79	660	34 820	7330	3520	91	1.01
26	3/2/79	660	34 790	8170	3520	91	0.91
27	3/2/79	660	34 790	7520	3520	91	0.99
28	3/3/79	702	34 920	7030	3620	91	1.12

Influent and Effluent Compositions during Cycle 3.03.28

		Regen 1,2 influent	Regen 1 effluent	Regen 2 effluent	Regen 3 Influent	Regen 3 Effluent	Rinse service influent	Rinse effluent	Service effluent
pH	units	-	-	-	4.8	-	7.5	5.3	7.4
TDS(Σ ions)	mg/L	31 372	21 368	30 998	33 873	32 536	3370	29 053	3467
Conductivity @ 25 °C	µS/cm	-	-	-	44 854	-	5481	39 608	5822
Silica	mg/L	8.4	8.4	7.8	8.0	7.8	10.9	7.9	11.6
Calcium	mg/L	880	1440	1310	128	910	167	221	14.9
Magnesium	mg/L	652	765	763	337	459	68.5	255	44.6
Sodium	mg/L	9610	4980	8820	11 780	10 430	942	10 020	1168
Potassium	mg/L	60	24.1	40.7	98	47.2	10.0	91	13.7
Strontium	mg/L	17.2	21.0	21.0	1.1	16.5	2.2	4.2	<0.1
Bicarbonate	mg/L	73.2	78.1	83.0	10.7	73.2	34.2	12.2	31.7
Carbonate	mg/L	ND	ND	ND	ND	ND	ND	ND	ND
Hydroxide	mg/L	ND	ND	ND	ND	ND	ND	ND	ND
Sulfate	mg/L	7300	5320	7140	9040	7940	950	7520	974
Chloride	mg/L	12 780	8740	12 820	12 480	12 660	1196	10 930	1220
T-alkalinity as $CaCO_3$	mg/L	60	64	68	8.8	60	28.0	10.0	26.0
P-alkalinity as CaCO	mg/L	ND	ND	ND	ND	ND	ND	ND	ND

Major Cation Concentrations of Samples Analyzed by Atomic Absorption

CYCLE 3.03.28

MODE	PROCESS STREAM	THROUGHPUT BV	CA MEQ/L	MG MEQ/L	TH MEQ/L	NA MEQ/L
REGEN 1	EFFLUENT	0.00	19.96	14.65	34.61	90.47
REGEN 1	EFFLUENT	1.23	101.30	93.09	194.38	251.41
REGEN 2	EFFLUENT	2.47	96.81	82.39	179.19	331.45
REGEN 2	INFLUENT	3.12	43.91	53.66	97.57	418.01
REGEN 2	EFFLUENT	10.64	53.89	52.43	106.32	407.57
REGEN 3	EFFLUENT	18.89	46.91	51.28	98.16	414.96
REGEN 3	INFLUENT	19.67	6.39	27.74	34.12	512.40
REGEN 3	EFFLUENT	20.69	53.39	49.22	102.61	454.55
REGEN 3	EFFLUENT	22.50	47.41	33.33	80.74	467.59
REGEN 3	EFFLUENT	24.30	39.42	27.57	66.99	472.38
REGEN 3	EFFLUENT	26.10	37.43	26.42	63.84	492.39
RINSE	EFFLUENT	0.00	13.12	50.78	63.91	505.00
RINSE	EFFLUENT	.82	9.13	14.90	24.03	380.17
SERVICE	EFFLUENT	1.64	.16	.33	.49	60.16
SERVICE	INFLUENT	4.38	8.13	5.70	13.84	40.10
SERVICE	EFFLUENT	28.36	.11	.24	.35	53.81
SERVICE	INFLUENT	38.38	8.13	5.67	13.80	40.41
SERVICE	EFFLUENT	50.22	.29	2.87	3.17	51.24
SERVICE	EFFLUENT	61.75	.96	6.93	7.89	47.76
SERVICE	INFLUENT	73.90	8.43	5.70	14.13	40.50
SERVICE	EFFLUENT	73.90	2.20	8.48	10.67	44.45

Service Performance Summary

CYCLE 3.03.28

	AVERAGE CONCENTRATIONS, MEQ/L INFLUENT	EFFLUENT	DIFFERENCE	REMOVAL %	RESIN CAPACITY EQ/L
CA	8.23	.48	7.76	94	.560
MG	5.69	2.65	3.04	53	.219
TH	13.92	3.13	10.79	78	.780
NA	40.34	52.61	-12.27		

FIGURE A- a
MAJOR CATION CONCENTRATIONS
OF IX REGENERATION EFFLUENT
CYCLE 3.03.28

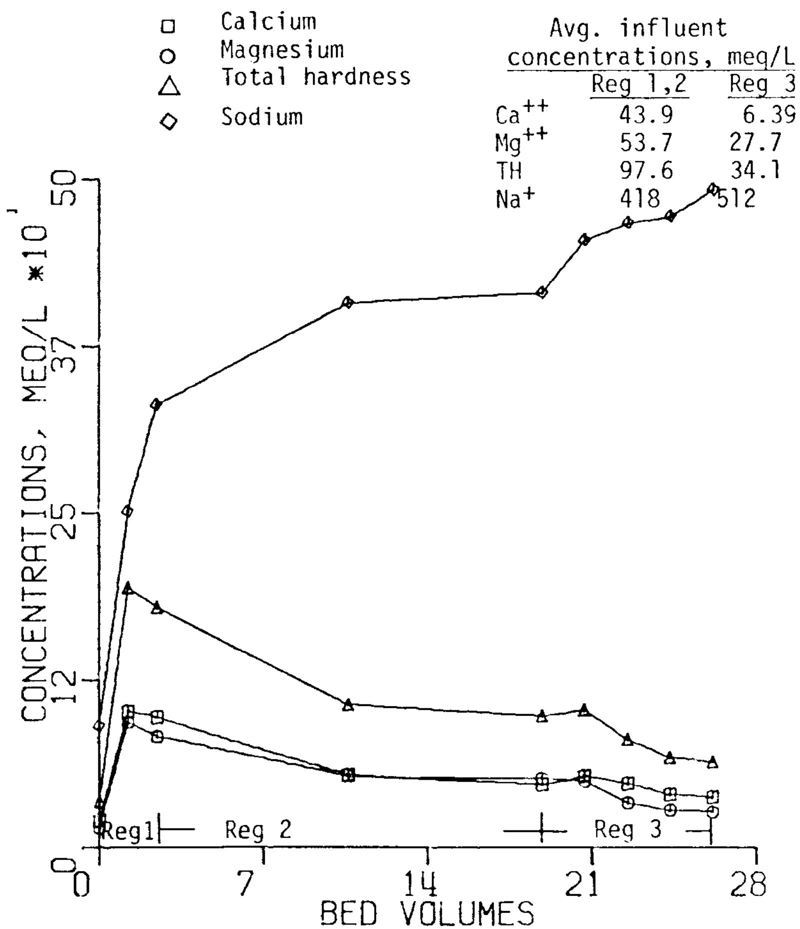
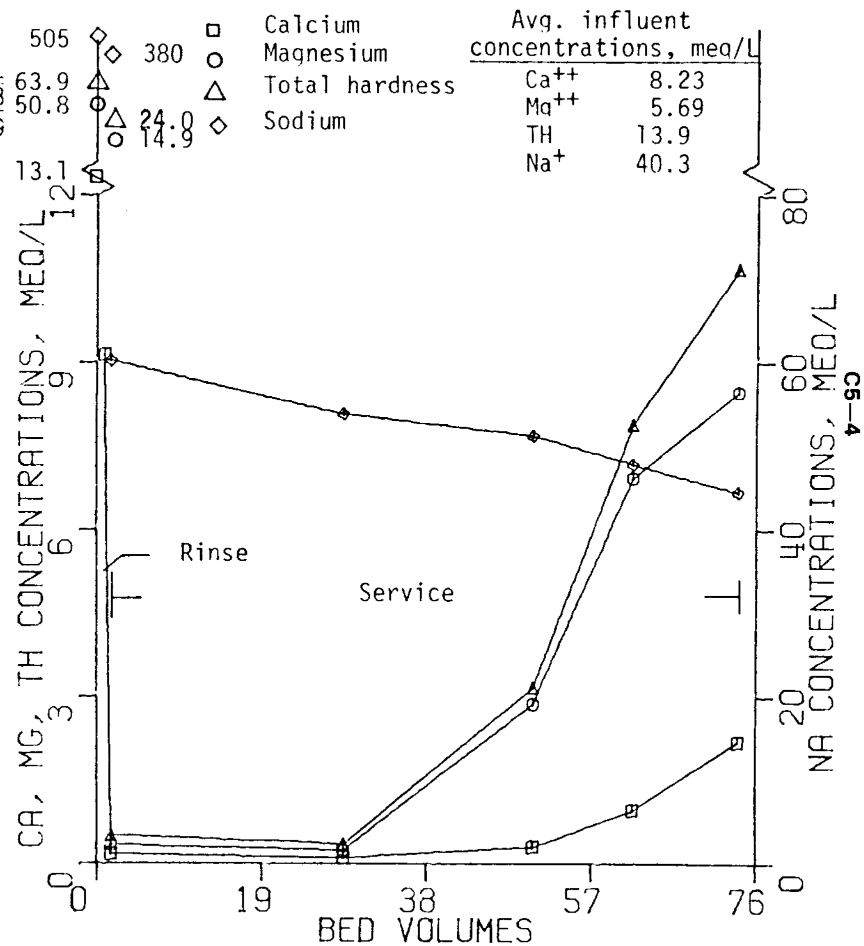


FIGURE A- b
MAJOR CATION CONCENTRATIONS OF
IX RINSE AND SERVICE EFFLUENTS
CYCLE 3.03.28



Ion-Exchange - Run 3.04.00

Date: 3/12/79

Cycle: 3.04.23

Conditions: Feedwater - Wellton-Mowhawk drainage pretreated (in Train IV) with high lime dosage for silica removal
Regenerants - recycled regenerant and fresh ED brine

Control variables:

	Target	Actual
Fresh regeneration conc. (mg/L TDS)	35 000	33 490
Fresh regeneration flow rate (L/min)	5.5	5.4
Recycled regenerant flow rate (L/min)	None	None
Recycled regenerant volume (L)	None	None
Service termination point (meq/L Ca^{++})	3.0	2.4

Standard resin bed: Height = 1066 mm
Volume = 97.3 L

Chemical Compositions of Tank Waters Prior to Cycle 3.04.23

Tank	pH units	Conductivity µS/cm	Ca^{++} meq/L	Mg^{++} meq/L	TH meq/L
Recycle regenerant (T-5)	-	40 631	53.0	71.0	124.0
Spent regenerant (T-6)	-	40 530	53.0	69.0	122.0
Lime-softened feed (T-9)	7.6	5 330	9.20	5.20	14.4
Lime softened feed (T-10)	7.5	5 394	10.0	4.40	14.4
Fresh ED brine (T-28)	6.1	44 044	7.60	30.4	38.0
IX product/ED feed (T-33)	7.0	5 651	1.04	2.16	3.20

Cycle 3.04.23 Operating Conditions

MODE	INPUT	OUTPUT	DURATION MIN	THROUGHPUT L	VOLUME BV	AVG FLOW RATE L/MIN	AVG FLOW RATE BV/MIN	BED EXPANSION %	TEMPERATURE C
REGEN 1	RE REGEN	WASTE	10	240	2.47	24.0	.247	56	19.8
REGEN 3	FR REGEN	SP REGEN	96	522	5.36	5.44	.056	-3.2	20.1
DRAIN 1	(VENT)	WASTE	3	62	.64	20.7	.210	0	
RINSE	FEED	WASTE	10	150	1.54	15.0	.154	0	
SERVICE	FEED	PRODUCT	182	5470	56.2	30.1	.309	0	
DRAIN 2	(VENT)	WASTE	2	41	.42	20.7	.210	0	

Fresh Regenerant Volume Balance

Run 3.04.00 Cycle no.	Date	Fresh regenerant volume (V_3) L	Estimated fresh regenerant TDS mg/L	Service volume (V_S) L	Estimated ED feed TDS mg/L	R %	$V_3/(1-R)V_S$
1	3/4/79	500	34 920	6290	3690	91	0.87
2	3/4/79	500	34 920	5940	3620	91	0.95
3	3/4/79	500	34 920	5420	3620	91	1.01
18	3/10/79	500	34 700	6460	3560	91	0.86
19	3/11/79	500	34 700	5990	3560	91	0.93
20	3/11/79	500	34 700	5810	3560	91	0.96
21	3/11/79	500	34 700	5580	3560	91	1.00
22	3/11/79	500	34 700	5730	3560	91	0.97
23	3/12/79	522	34 580	5470	3500	91	1.07

Influent and Effluent Compositions during Cycle 3.04.23

		Regen 1 influent	Regen 1 effluent	Regen 3 Influent	Regen 3 Effluent	Rinse & service influent	Rinse effluent	Service effluent
pH	units	-	-	6.2	-	7.1	6.5	7.3
TDS(Σ ions)	mg/L	21 851	21 254	33 487	30 217	3289	24 508	3447
Conductivity @ 25 °C	μS/cm	-	-	44 970	-	5372	33 502	5576
Silica	mg/L	4.2	10.2	8.4	12.0	4.7	9.0	4.8
Calcium	mg/L	2040	1620	144	1670	182	243	20.7
Magnesium	mg/L	955	809	373	721	56.3	246	41.6
Sodium	mg/L	4150	4710	11 400	8160	903	8220	1142
Potassium	mg/L	38	38	96	57	9.8	69	13.2
Strontium	mg/L	35	70	1.9	31	2.8	8.0	0.8
Bicarbonate	mg/L	93	98	31.7	98	23.4	31.7	24.4
Carbonate	mg/L	ND	ND	ND	ND	ND	ND	ND
Hydroxide	mg/L	ND	ND	ND	ND	ND	ND	ND
Sulfate	mg/L	5040	4860	9120	7540	924	6770	1004
Chloride	mg/L	9500	9040	12 320	11 940	1188	8920	1200
T-alkalinity as $CaCO_3$	mg/L	76	80	26.0	80	19.2	26.0	20.0
P-alkalinity as $CaCO_3$	mg/L	ND	ND	ND	ND	ND	ND	ND

Major Cation Concentrations of Samples Analyzed by Atomic Absorption

CYCLE 3.04.23

MODE	PROCESS STREAM	THROUGHPUT BV	CA MEQ/L	MG MEQ/L	TH MEQ/L	NA MEQ/L
REGEN 1	EFFLUENT	0.00	29.44	21.65	51.09	76.56
REGEN 1	INFLUENT	.74	101.80	78.60	180.40	180.51
REGEN 1	EFFLUENT	1.23	109.78	90.29	200.07	238.36
REGEN 3	EFFLUENT	2.47	102.30	86.56	186.88	297.52
REGEN 3	INFLUENT	3.19	7.19	30.70	37.89	495.87
REGEN 3	EFFLUENT	3.86	104.79	79.59	184.38	367.12
REGEN 3	EFFLUENT	5.26	87.82	54.49	142.31	390.60
REGEN 3	EFFLUENT	6.55	67.37	36.30	103.66	419.75
REGEN 3	EFFLUENT	7.84	56.89	41.40	98.29	349.72
RINSE	EFFLUENT	0.00	18.96	31.52	50.48	491.95
RINSE	EFFLUENT	.77	5.59	7.00	12.58	230.54
SERVICE	EFFLUENT	1.54	.23	.36	.59	56.59
SERVICE	INFLUENT	4.32	9.18	4.62	13.80	38.84
SERVICE	EFFLUENT	22.55	.16	.31	.48	52.41
SERVICE	INFLUENT	33.36	9.33	4.67	14.01	38.93
SERVICE	EFFLUENT	43.55	.52	3.09	3.62	48.72
SERVICE	EFFLUENT	54.05	1.77	6.09	7.86	44.80
SERVICE	INFLUENT	57.76	9.23	4.63	13.87	39.58
SERVICE	EFFLUENT	57.76	2.39	6.63	9.01	43.80

Service Performance Summary

CYCLE 3.04.23

	AVERAGE CONCENTRATIONS, MEQ/L INFLUENT	EFFLUENT	DIFFERENCE	REMOVAL %	RESIN CAPACITY EQ/L
CA	9.25	.55	8.69	94	.489
MG	4.64	2.04	2.60	56	.146
TH	13.89	2.59	11.30	81	.635
NA	39.12	50.91	-11.79		

FIGURE A- a
MAJOR CATION CONCENTRATIONS
OF IX REGENERATION EFFLUENT
CYCLE 3.04.23

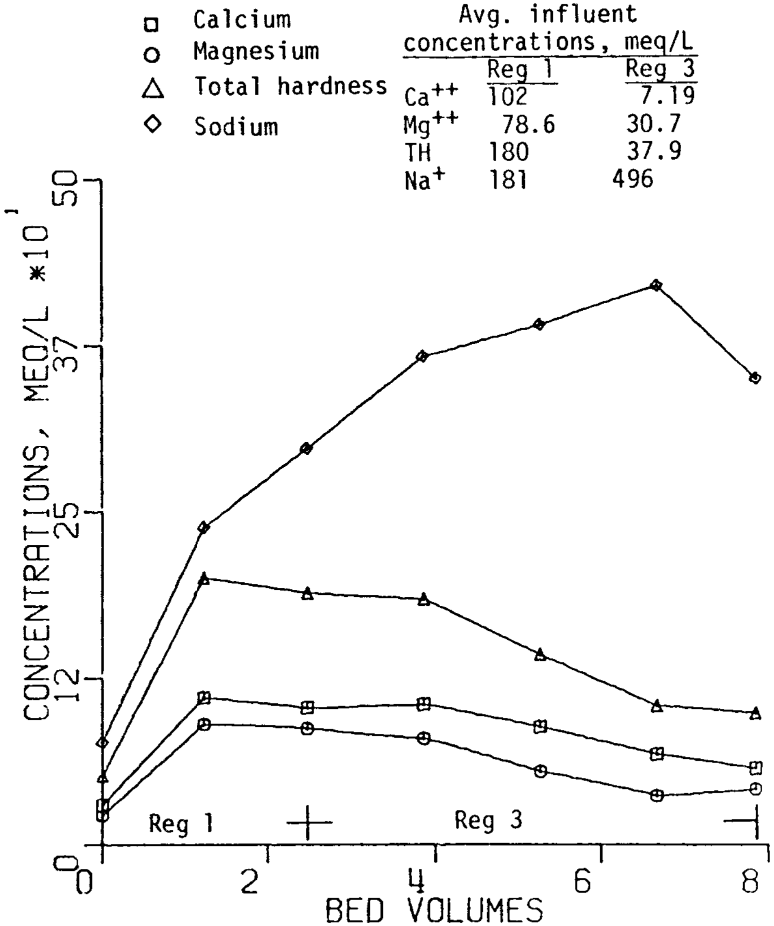
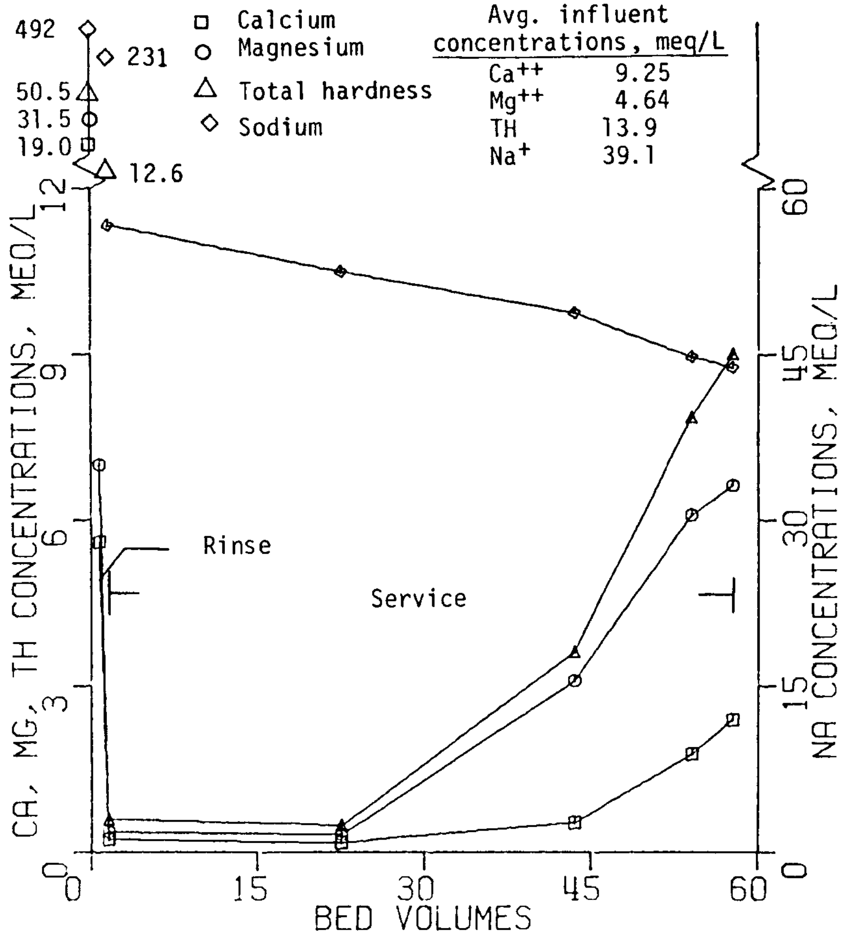


FIGURE A- b
MAJOR CATION CONCENTRATIONS OF
IX RINSE AND SERVICE EFFLUENTS
CYCLE 3.04.23



Ion-Exchange - Run 3.05.00

Date: 3/17/79

Cycle: 3.05.15

Conditions: Feedwater - Wellton-Mowhawk drainage pretreated (in Train IV) with high lime dosage for silica removal
Regenerants - recycled regenerant and fresh ED brine

Control variables:	Target	Actual
Fresh regeneration conc. (mg/L TDS)	35 000	32 840
Fresh regeneration flow rate (L/min)	5.5	5.5
Recycled regenerant flow rate (L/min)	16.0	15.6
Recycled regenerant volume (L)	800	800
Service termination point (meq/L Ca^{++})	3.0	2.8

Standard resin bed: Height = 1066 mm
Volume = 97.3 L

Chemical Compositions of Tank Waters Prior to Cycle 3.05.15

Tank	pH units	Conductivity µS/cm	Ca^{++} meq/L	Mg^{++} meq/L	TH meq/L
Recycle regenerant (T-5)	-	38 936	53.0	71.0	124.0
Spent regenerant (T-6)	-	38 832	53.0	67.0	120.0
Lime-softened feed (T-9)	7.3	5 493	8.00	6.40	14.4
Lime-softening feed (T-10)	7.5	5 503	8.00	6.00	14.0
Fresh ED brine (T-28)	5.5	44 036	6.80	26.0	32.8
IX product/ED feed (T-33)	7.0	5 703	0.80	2.80	3.60

Cycle 3.05.15 Operating Conditions

MODE	INPUT	OUTPUT	DURATION MIN	THROUGHPUT L	VOLUME BV	AVG FLOW RATE L/MIN	AVG FLOW RATE BV/MIN	BED EXPANSION %	TEMPERATURE C
REGEN 1	RE REGEN	WASTE	10	240	2.47	24.0	.247	54	18.2
REGEN 2	RE REGEN	SP REGEN	51	800	8.22	15.6	.161	34	
REGEN 3	FR REGEN	SP REGEN	87	479	4.92	5.5	.057	6.9	19.0
DRAIN 1	(VENT)	WASTE	3	62	.64	20.7	.210	0	
RINSE	FEED	WASTE	10	160	1.64	16.0	.164	0	
SERVICE	FEED	PRODUCT	204	6130	63.0	30.0	.309	0	
DRAIN 2	(VENT)	WASTE	2	41	.42	20.7	.210	0	

Fresh Regenerant Volume Balance

Run 3.05.00 Cycle no.	Date	Fresh regenerant volume (V_3) L	Estimated fresh regenerant TDS mg/L	Service volume (V_S) L	Estimated ED feed TDS mg/L	R %	$V_3/(1-R)V_S$
1	3/12/79	533	34 480	6040	3500	91	0.99
2	3/12/79	520	34 580	6470	3500	91	0.90
3	3/12/79	528	34 580	1310	3500	91	4.29
5	3/14/79	517	34 210	6540	3510	91	0.89
6	3/14/79	517	34 210	6280	3510	91	0.92
7	3/14/79	520	34 210	6700	3510	91	0.87
8	3/15/79	519	34 400	6450	3420	91	0.93
9	3/15/79	508	34 400	6830	3420	91	0.86
10	3/15/79	520	34 400	6790	3420	91	0.88
11	3/16/79	519	34 200	5610	3750	90	0.95
12	3/16/79	480	34 200	6170	3750	90	0.80
13	3/16/79	480	34 200	6000	3750	90	0.82
14	3/17/79	480	33 800	6050	3540	91	0.86
15	3/17/79	479	33 800	6130	3540	91	0.85

Influent and Effluent Compositions during Cycle 3.05.15

		Regen 1,2 influent	Regen 1 effluent	Regen 2 effluent	Regen 3 Influent	Regen 3 Effluent	Rinse service influent	Rinse effluent	Service effluent
pH	units	-	-	-	5.6	-	7.3	6.2	7.3
TDS	mg/L	28 115	19 719	28 616	32 835	31 274	3303	27 351	3435
Conductivity @ 25 °C	μS/cm	-	-	-	43 830	-	5284	37 034	5588
Silica	mg/L	8.4	8.2	7.6	6.2	6.6	8.6	6.5	8.7
Calcium	mg/L	1010	1400	1410	134	1230	157	288	19.4
Magnesium	mg/L	835	782	923	328	666	69.5	261	43.8
Sodium	mg/L	8120	4580	7520	11 300	9360	956	9510	1182
Potassium	mg/L	57	38	57	122	63	9.3	94	13.6
Strontium	mg/L	30	31	34	2.4	32	3.2	6.9	1.1
Bicarbonate	mg/L	83.0	87.8	73.2	18.5	83.0	24.4	21.0	23.4
Carbonate	mg/L	ND	ND	ND	ND	ND	ND	ND	ND
Hydroxide	mg/L	ND	ND	ND	ND	ND	ND	ND	ND
Sulfate	mg/L	5740	4240	5740	8920	7740	894	7070	954
Chloride	mg/L	12 240	8560	12 200	12 010	12 100	1190	10 100	1198
T-alkalinity as $CaCO_3$	mg/L	68	72	60	15.2	68	20.0	17.2	19.2
P-alkalinity as $CaCO_3$	mg/L	ND	ND	ND	ND	ND	ND	ND	ND

Major Cation Concentrations of Samples Analyzed by Atomic Absorption

CYCLE 3.05.15

Mode	Process Stream	Throughput BV	Ca Meq/L	Mg Meq/L	Th Meq/L	Na Meq/L
Regen 1	Effluent	0.00	27.45	19.67	47.12	75.34
Regen 1	Effluent	1.21	91.32	81.89	173.21	226.19
Regen 2	Effluent	2.42	93.81	85.76	179.57	286.65
Regen 2	Influent	4.67	50.40	68.72	119.12	353.20
Regen 2	Effluent	6.91	65.87	71.77	137.64	335.36
Regen 3	Effluent	10.60	58.38	68.23	126.61	347.98
Regen 3	Influent	10.77	6.69	27.00	33.68	491.52
Regen 3	Effluent	11.28	68.86	77.37	146.23	381.47
Regen 3	Effluent	12.52	65.87	50.45	116.32	427.58
Regen 3	Effluent	13.77	57.88	36.63	94.51	442.37
Regen 3	Effluent	15.52	57.88	43.05	100.93	432.36
Rinse	Effluent	0.00	17.47	28.81	46.27	487.60
Rinse	Effluent	.82	11.28	14.16	25.43	343.19
Service	Effluent	1.64	.29	.41	.71	60.03
Service	Influent	4.42	7.96	5.84	13.82	41.45
Service	Effluent	19.87	.22	.31	.54	54.15
Service	Effluent	29.13	7.88	5.72	13.60	41.32
Service	Effluent	38.09	.34	1.82	2.16	52.37
Service	Effluent	47.04	.77	4.63	5.39	48.98
Service	Effluent	56.31	1.60	6.78	8.38	46.41
Service	Influent	64.65	7.98	5.80	13.79	40.89
Service	Effluent	64.65	2.84	7.56	10.40	44.58

Service Performance Summary

CYCLE 3.05.15

	Average Concentrations, Meq/L			Removal	Resin Capacity
	Influent	Effluent	Difference	%	Eq/L
Ca	7.95	.70	7.25	91	.457
Mg	5.79	2.66	3.13	54	.197
Th	13.74	3.36	10.37	76	.654
Na	41.22	52.16	-10.93		

FIGURE A- a
MAJOR CATION CONCENTRATIONS
OF IX REGENERATION EFFLUENT
CYCLE 3.05.15

	Avg. influent concentrations, meq/L	
	Reg 1,2	Reg 3
Ca^{++}	50.4	6.7
Mg^{++}	68.7	27.0
TH	119	33.7
Na^{+}	353	492

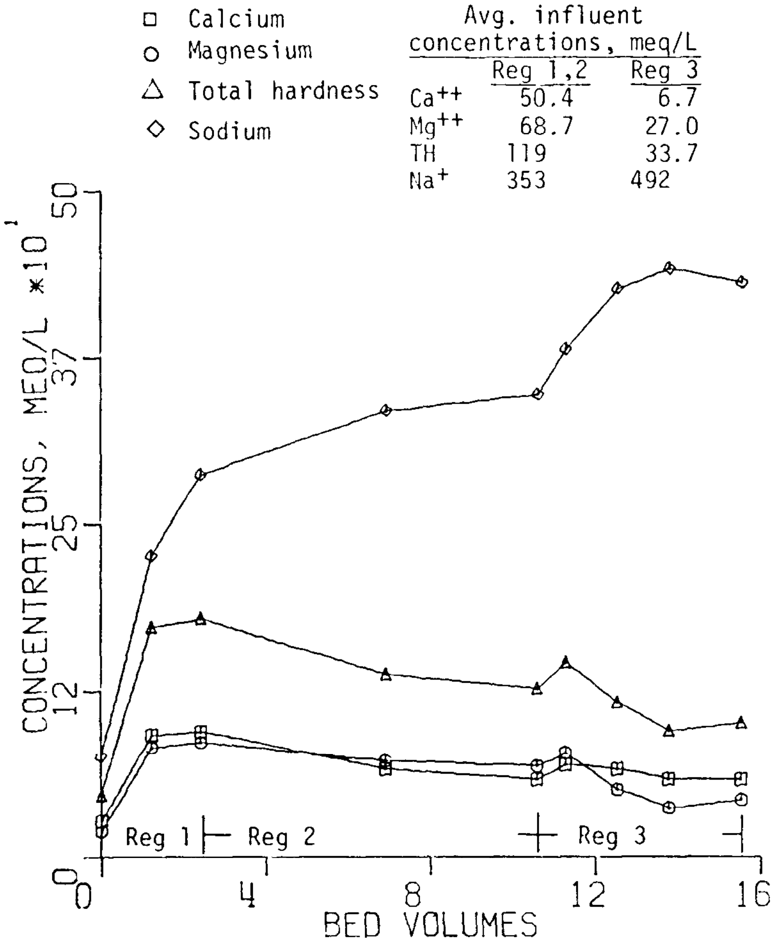
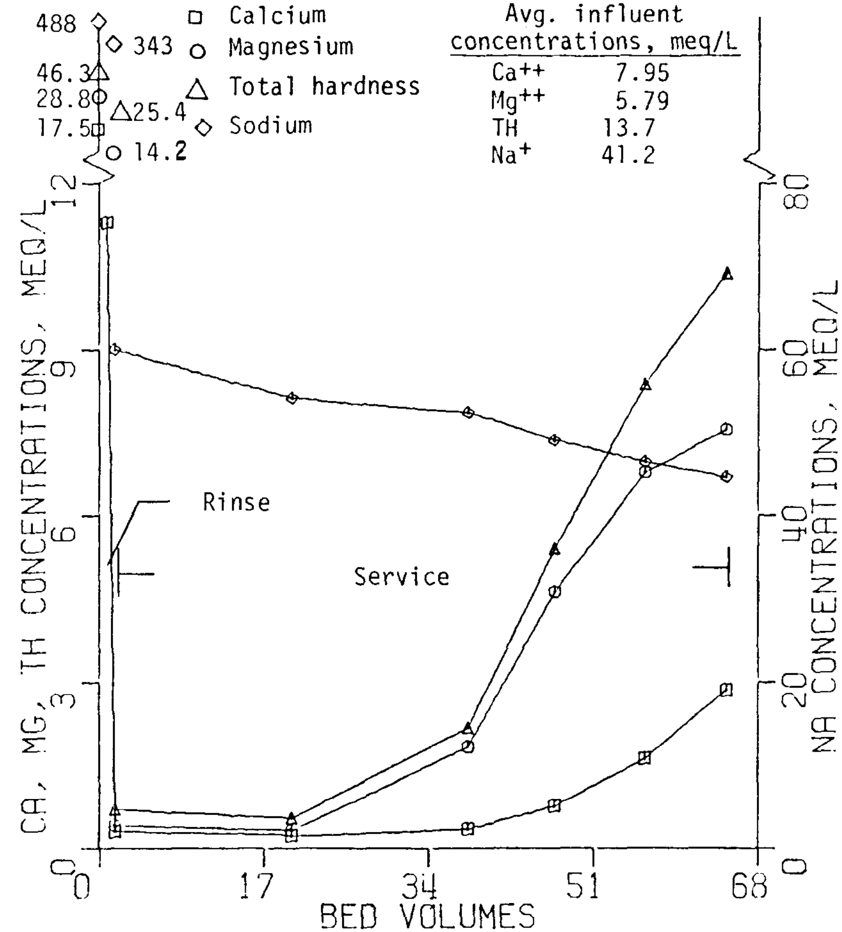


FIGURE A- b
MAJOR CATION CONCENTRATIONS OF
IX RINSE AND SERVICE EFFLUENTS
CYCLE 3.05.15

	Avg. influent concentrations, meq/L
Ca^{++}	7.95
Mg^{++}	5.79
TH	13.7
Na^{+}	41.2



SODIUM (NA), CALCIUM (CA), AND MAGNESIUM (MG) CONCENTRATIONS ARE MEASURED BY ATOMIC ABSORPTION.
TOTAL HARDNESS (TH) IS CALCULATED BY SUMMING THE CALCIUM AND MAGNESIUM CONCENTRATIONS.

Ion-Exchange - Run 3.06.13

Date:	3/21/79
Cycle:	3.06.13
Conditions:	Feedwater - Wellton-Mowhawk drainage pretreated (in Train IV) with high lime dosage for silica removal Regenerants - recycled regenerant and fresh ED brine

		Target	Actual
Control variables:	Fresh regeneration conc. (mg/L TDS)	35 000	33 250
	Fresh regeneration flow rate (L/min)	5.5	5.5
	Recycled regenerant flow rate (L/min)	24.0	23.3
	Recycled regenerant volume (L)	1600	1600
	Service termination point (meq/L Ca^{++})	3.0	3.4

Standard resin bed: Height = 1066 mm
Volume = 97.3 L

Chemical Compositions of Tank Waters Prior to Cycle 3.06.13

Tank	pH units	Conductivity µS/cm	Ca^{++} meq/L	Mg^{++} meq/L	TH meq/L
Recycle regenerant (T-5)	-	37 322	50.0	58.0	108.0
Spent regenerant (T-6)	-	38 878	53.0	69.0	122.0
Lime-softened feed (T-9)	7.2	5 357	8.40	5.60	14.0
Lime softened feed (T-10)	7.2	5 399	9.20	4.80	14.0
Fresh ED brine (T-28)	4.1	44 362	8.40	28.0	36.4
IX product/ED feed (T-33)	6.8	5 608	0.72	2.28	3.00

Cycle 3.06.13 Operating Conditions

MODE	INPUT	OUTPUT	DURATION MIN	THROUGHPUT L	VOLUME BV	AVG FLOW RATE L/MIN	AVG FLOW RATE BV/MIN	BED EXPANSION %	TEMPERATURE C
REGEN 1	RE REGEN	WASTE	10	240	2.47	24.0	.247	57	18.2
REGEN 2	RE REGEN	SP REGEN	68	1600	16.4	23.7	.242	59	
REGEN 3	FR REGEN	SP REGEN	109	601	6.18	5.52	.057	8.2	18.8
DRAIN 1	(VENT)	WASTE	3	62	.64	20.7	.210	0	
RINSE	FEED	WASTE	10	160	1.64	16.0	.164	0	
SERVICE	FEED	PRODUCT	246	7310	75.1	29.7	.305	0	
DRAIN 2	(VENT)	WASTE	2	41	.42	20.7	.210	0	

Fresh Regenerant Volume Balance

Run 3.06.00 Cycle no.	Date	Fresh regenerant volume (V_3) L	Estimated fresh regenerant TDS mg/L	Service volume (V_S) L	Estimated ED feed TDS mg/L	R %	$V_3/(1-R)V_S$
1	3/17/79	480	33 800	6280	3540	91	0.83
2	3/17/79	480	33 800	6110	3540	91	0.85
3	3/18/79	480	33 800	6290	3540	91	0.83
8	3/18/79	600	33 300	6950	3520	91	0.93
9	3/19/79	600	33 300	6830	3520	91	0.94
10	3/20/79	600	33 850	7050	3500	91	0.93
11	3/20/79	600	33 850	7410	3500	91	0.89
12	3/21/79	600	32 950	6670	3480	91	0.98
13	3/21/79	601	32 950	7310	3480	91	0.89

Influent and Effluent Compositions during Cycle 3.06.13

		Regen 1,2 influent	Regen 1 effluent	Regen 2 effluent	Regen 3 Influent	Regen 3 Effluent	Rinse service influent	Rinse effluent	Service effluent
pH	units	-	-	-	4.1	-	7.1	4.2	6.9
TDS (Σ ions)	mg/L	28 264	20 485	28 482	33 251	31 777	3272	27 782	3394
Conductivity @ 25 °C	μS/cm	-	-	-	44 299	-	5388	37 986	5626
Silica	mg/L	8.8	7.6	7.8	7.3	7.2	7.3	7.1	7.5
Calcium	mg/L	1030	1590	1450	170	1230	172	265	23.9
Magnesium	mg/L	849	785	919	377	652	72.0	279	53.0
Sodium	mg/L	8110	4790	7680	11 800	9540	921	9790	1152
Potassium	mg/L	51	32	47	107	55	8.5	87	12.9
Strontium	mg/L	26	27	28	2.7	27	2.6	6.2	0.5
Bicarbonate	mg/L	97.6	61.0	78.1	3.9	73.2	22.0	4.9	22.0
Carbonate	mg/L	ND	ND	ND	ND	ND	ND	ND	ND
Hydroxide	mg/L	ND	ND	ND	ND	ND	ND	ND	ND
Sulfate	mg/L	5700	4200	5960	8590	7700	860	6900	920
Chloride	mg/L	12 400	9000	12 320	12 200	12 500	1214	10 450	1210
T-alkalinity as $CaCO_3$	mg/L	80.0	50.0	64.0	3.2	60.0	18.0	4.0	18.0
P-alkalinity as $CaCO_3$	mg/L	ND	ND	ND	ND	ND	ND	ND	ND

Major Cation Concentrations of Samples Analyzed by Atomic Absorption

CYCLE 3.06.13

Mode	Process Stream	Throughput BV	Ca Meq/L	Mg Meq/L	Th Meq/L	Na Meq/L
Regen 1	Effluent	0.00	38.42	26.50	64.93	105.26
Regen 1	Effluent	1.26	95.81	80.25	176.06	227.49
Regen 2	Effluent	2.53	94.31	83.05	177.36	302.31
Regen 2	Influent	5.92	51.40	69.88	121.27	352.76
Regen 2	Effluent	10.29	60.38	71.11	131.49	348.41
Regen 3	Effluent	19.02	53.89	69.88	123.77	350.59
Regen 3	Influent	19.76	8.48	31.03	39.51	513.27
Regen 3	Effluent	20.55	69.36	72.10	141.46	401.04
Regen 3	Effluent	22.09	63.87	46.67	110.54	434.54
Regen 3	Effluent	23.62	55.89	35.31	91.20	466.72
Regen 3	Effluent	25.21	53.39	40.41	93.80	429.75
Rinse	Effluent	0.00	16.17	30.78	46.95	501.96
Rinse	Effluent	.82	9.83	13.33	23.16	349.72
Service	Effluent	1.64	.23	.37	.60	58.55
Service	Influent	4.39	8.28	5.86	14.14	41.06
Service	Effluent	23.33	.16	2.86	3.02	52.59
Service	Effluent	34.32	8.33	5.88	14.21	40.15
Service	Effluent	45.01	.37	2.67	3.04	50.59
Service	Effluent	56.01	.96	5.96	6.92	46.85
Service	Effluent	66.69	2.07	7.70	9.76	43.28
Service	Influent	74.64	8.58	5.89	14.48	39.89
Service	Effluent	76.77	3.44	8.21	11.65	42.32

Service Performance Summary

CYCLE 3.06.13

	Average Concentrations, Meq/L			Removal	Resin Capacity
	Influent	Effluent	Difference	%	Eq/L
Ca	8.40	.82	7.58	90	.570
Mg	5.88	3.93	1.94	33	.146
Th	14.28	4.75	9.53	67	.716
Na	40.37	50.21	-9.84		

FIGURE **A- a**
MAJOR CATION CONCENTRATIONS
OF IX REGENERATION EFFLUENT
CYCLE 3.06.13

	Avg. influent concentrations, meq/L	
	Reg 1,2	Reg 3
Ca^{++}	51.4	8.48
Mg^{++}	69.9	31.0
TH	121	39.5
Na^{+}	353	513

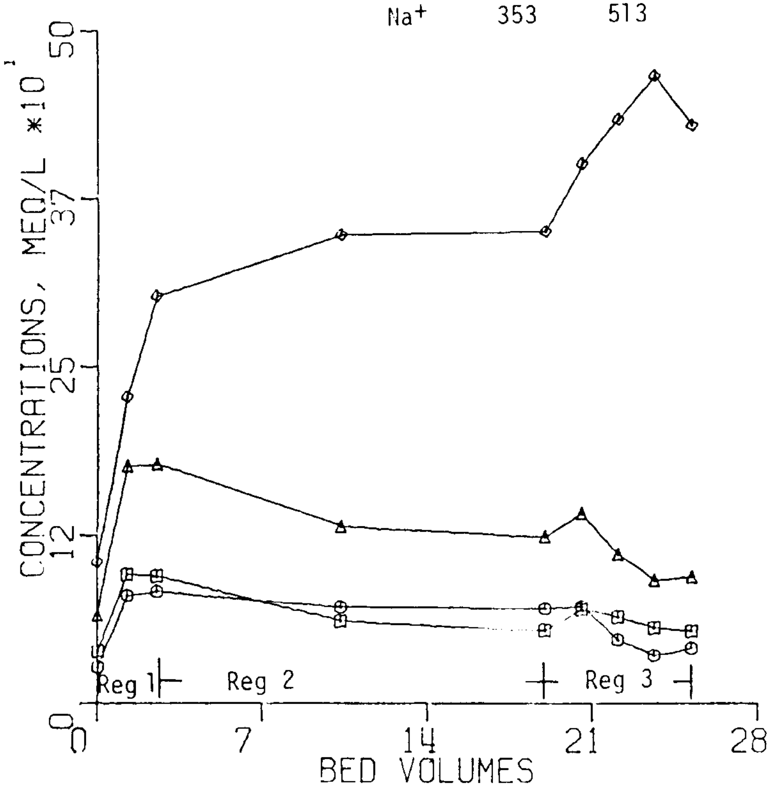
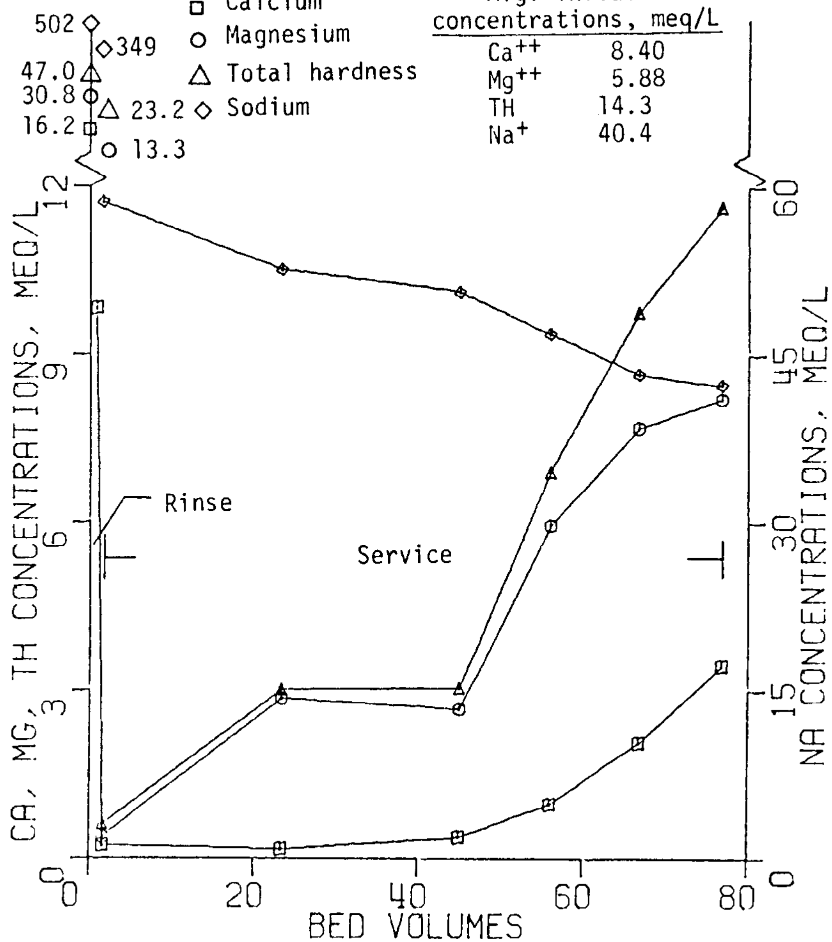


FIGURE **A- b**
MAJOR CATION CONCENTRATIONS OF
IX RINSE AND SERVICE EFFLUENTS
CYCLE 3.06.13

	Avg. influent concentrations, meq/L
Ca^{++}	8.40
Mg^{++}	5.88
TH	14.3
Na^{+}	40.4



SODIUM (NA), CALCIUM (CA), AND MAGNESIUM (MG) CONCENTRATIONS ARE MEASURED BY ATOMIC ABSORPTION.
TOTAL HARDNESS (TH) IS CALCULATED BY SUMMING THE CALCIUM AND MAGNESIUM CONCENTRATIONS.

Ion-Exchange - Run 3.07.00

Date: 3/22/79

Cycle: 3.07.04

Conditions: · Feedwater - Wellton-Mowhawk drainage pretreated (in Train IV) with high lime dosage for silica removal
Regenerants - recycled regenerant and fresh ED brine

Control variables:

	Target	Actual
Fresh regeneration conc. (mg/L TDS)	~~35 000~~	~~32 910~~
Fresh regeneration flow rate (L/min)	5.5	5.4
Recycled regenerant flow rate (L/min)	None	None
Recycled regenerant volume (L)	None	None
Service termination point (meq/L Ca^{++})	3.0	3.1

Standard resin bed: Height = 1066 mm
Volume = 97.3 L

Chemical Compositions of Tank Waters Prior to Cycle 3.07.04

Tank	pH units	Conductivity µS/cm	Ca^{++} meq/L	Mg^{++} meq/L	TH meq/L
Recycle regenerant (T-5)	-	38 550	51.0	71.0	122.0
Spent regenerant (T-6)	-	38 170	92.0	108.0	200.0
Lime-softened feed (T-9)	7.2	5 408	8.40	6.00	14.4
Lime-softened feed (T-10)	7.3	5 449	8.40	5.80	14.2
Fresh ED brine (T-28)	4.2	43 847	8.00	28.0	36.0
IX product/ED feed (T-33)	6.8	5 676	0.88	3.02	3.90

Cycle 3.07.04 Operating Conditions

Mode	Input	Output	Duration Min	Throughput L	Volume BV	Avg. Flow Rate L/Min	Avg. Flow Rate BV/Min	Bed Expansion %	Temperature C
Regen 1	Re Regen	Waste	10	240	2.47	24.0	.247	55	17.5
Regen 3	FR Regen	SP Regen	93	502	5.16	5.42	.056	6.9	18.9
Drain L	(Vent)	Waste	3	62	.64	20.7	.210	0	
Rinse	Feed	Waste	10	150	1.54	15.0	.154	0	
Service	Feed	Product	189	5700	58.58	30.2	.310	0	
Drain 2	(Vent)	Waste	2	41	.42	20.7	.210	0	

Fresh Regenerant Volume Balance

Run 3.07.00 Cycle no.	Date	Fresh regenerant volume (V_3) L	Estimated fresh regenerant TDS mg/L	Service volume (V_S) L	Estimated ED feed TDS mg/L	R %	$V_3/(1-R)V_S$
1	3/21/79	500	32 950	5740	3480	91	0.95
2	3/21/79	503	32 950	5660	3480	91	0.97
3	3/22/79	501	33 770	5450	3520	91	1.01
4	3/22/79	502	33 770	5700	3520	91	0.97

Influent and Effluent Compositions during Cycle 3.07.04

		Regen 1 influent	Regen 1 effluent	Regen 3 Influent	Regen 3 Effluent	Rinse & service influent	Rinse effluent	Service effluent
pH	units	-	-	4.2	-	-	4.5	7.3
TDS (Σ ions)	mg/L	28 469	20 745	32 906	29 646	-	28 235	3492
Conductivity @ 25 °C	μS/cm	-	-	43 869	-	-	37 586	5715
Silica	mg/L	8.2	10.4	6.6	8.2	-	7.3	7.8
Calcium	mg/L	1130	1530	171	1750	197	356	27.3
Magnesium	mg/L	870	849	385	781	74.2	333	54.3
Sodium	mg/L	8120	4590	11 570	8170	940	9790	1167
Potassium	mg/L	50	36	119	54	-	81	13.9
Strontium	mg/L	28	27	3.3	33	-	7.6	0.6
Bicarbonate	mg/L	10.7	73.2	7.3	97.6	-	7.3	24.4
Carbonate	mg/L	ND	ND	ND	ND	-	ND	ND
Hydroxide	mg/L	ND	ND	ND	ND	-	ND	ND
Sulfate	mg/L	5900	4680	8600	6700	-	7510	950
Chloride	mg/L	12 360	8960	12 050	11 300	-	10 050	1254
T-alkalinity as $CaCO_3$	mg/L	8.8	60.0	6.0	80.0	-	6.0	20.0
P-alkalinity as $CaCO_3$	mg/L	ND	ND	ND	ND	-	ND	ND

Major Cation Concentrations of Samples Analyzed by Atomic Absorption

CYCLE 3.07.04

Mode	Process Stream	Throughput BV	Ca Meq/L	Mg Meq/L	Th Meq/L	Na Meq/L
Regen 1	Effluent	0.00	36.93	28.89	65.82	103.09
Regen 1	Influent	.73	56.39	71.60	127.99	353.20
Regen 1	Effluent	1.22	98.80	88.97	187.77	235.75
Regen 3	Effluent	2.44	102.30	89.88	192.17	280.12
Regen 3	Influent	3.16	8.53	31.69	40.22	503.26
Regen 3	Effluent	3.83	117.76	92.67	210.44	338.84
Regen 3	Effluent	5.22	92.81	55.31	148.12	411.92
Regen 3	Effluent	6.61	73.85	38.77	112.62	434.10
Regen 3	Effluent	7.62	65.87	45.68	111.55	365.38
Rinse	Effluent	0.00	19.61	33.00	52.61	491.95
Rinse	Effluent	.77	16.92	21.73	38.64	378.86
Service	Effluent	1.54	.32	.44	.76	60.37
Service	Influent	4.33	9.08	6.12	15.21	41.24
Service	Effluent	22.62	.27	.44	.71	55.72
Service	Effluent	34.40	.91	5.07	5.98	49.67
Service	Effluent	54.23	2.17	7.62	9.79	45.50
Service	Influent	60.12	8.63	6.08	14.72	40.58
Service	Effluent	60.12	3.14	8.11	11.25	43.80

Service Performance Summary

CYCLE 3.07.04

	Average Concentrations Meq/L			Removal	Resin Capacity
	Influent	Effluent	Difference	%	Eq/L
Ca	8.86	1.02	7.84	88	.459
Mg	6.10	3.65	2.45	40	.144
Th	14.96	4.67	10.29	69	.603
Na	40.91	52.08	-11.17		

FIGURE A- a
MAJOR CATION CONCENTRATIONS
OF IX REGENERATION EFFLUENT
CYCLE 3.07.04

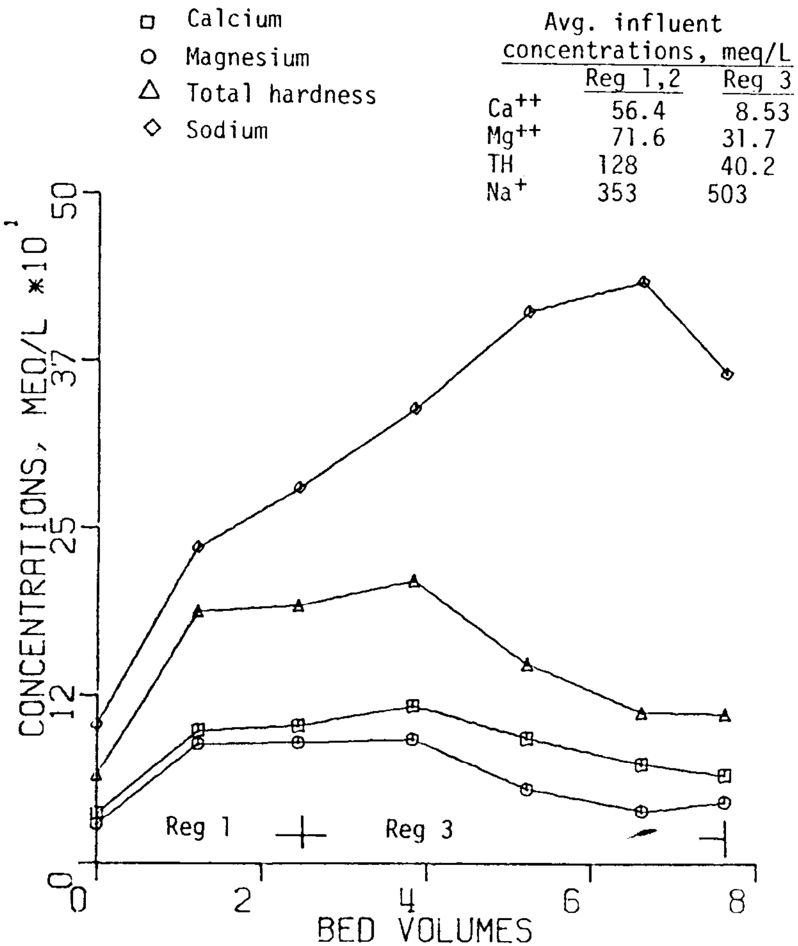
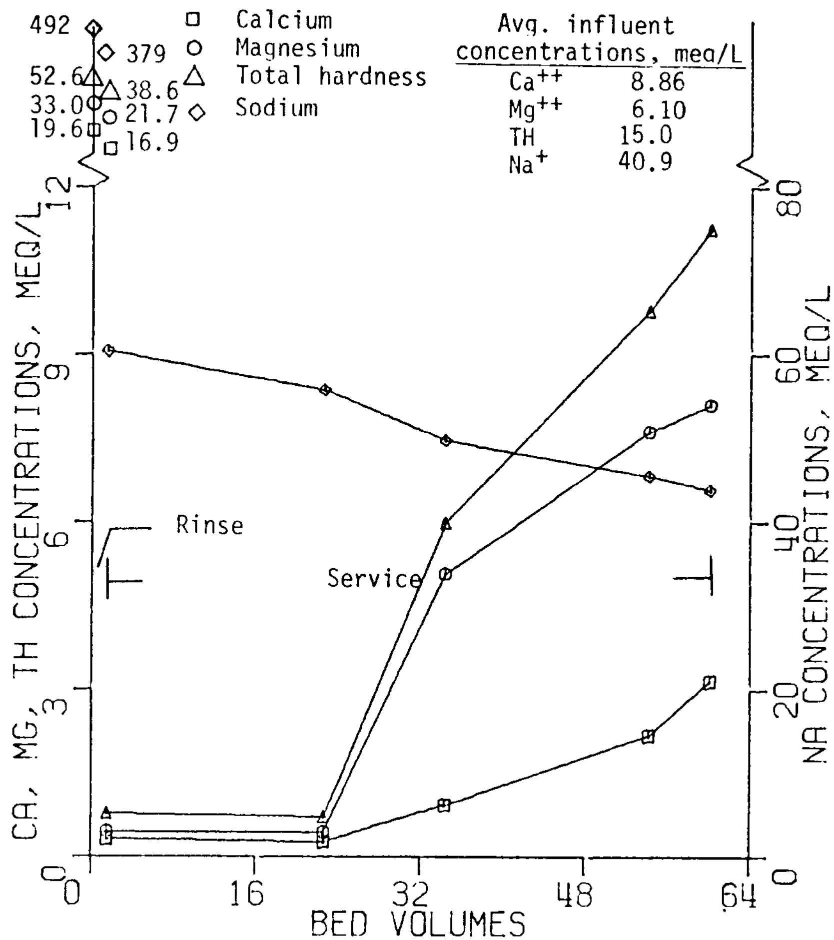


FIGURE A- b
MAJOR CATION CONCENTRATIONS OF
IX RINSE AND SERVICE EFFLUENTS
CYCLE 3.07.04



SODIUM (NA), CALCIUM (CA), AND MAGNESIUM (MG) CONCENTRATIONS ARE MEASURED BY ATOMIC ABSORPTION.
TOTAL HARDNESS (TH) IS CALCULATED BY SUMMING THE CALCIUM AND MAGNESIUM CONCENTRATIONS.

Ion-Exchange - Run 3.07.04B

Date: 3/23/79

Cycle: 3.07.04B

Conditions: Feedwater - Wellton-Mowhawk drainage pretreated (in Train IV) with high lime dosage for silica removal
Regenerant - Fresh ED brine
Backwash - Feedwater

Control variables:

	Target	Actual
Fresh regeneration conc. (mg/L TDS)	35 000	34 330
Fresh regeneration flow rate (L/min)	5.5	5.5
Recycled regenerant flow rate (L/min)	None	None
Recycled regenerant volume (L)	None	None
Service termination point (meq/L Ca^{++})	3.0	3.7

Standard resin bed: Height = 1066 mm
Volume = 97.3 L

Chemical Compositions of Tank Waters Prior to Cycle 3.07.04B

Tank	pH units	Conductivity µS/cm	Ca^{++} meq/L	Mg^{++} meq/L	TH meq/L
Lime-softened feed (T-9)	7.3	5 577	9.00	5.40	14.4
Lime-softened feed (T-10)	7.4	5 610	8.80	5.60	14.4
Fresh ED brine (T-28)	4.6	44 286	7.60	27.2	34.8
IX product/ED feed (T-33)	7.2	5 782	0.88	3.32	4.20

Cycle 3.07.04B Operating Conditions

MODE	INPUT	OUTPUT	DURATION MIN	THROUGHPUT L	VOLUME BV	AVG FLOW RATE L/MIN	AVG FLOW RATE BV/MIN	BED EXPANSION %	TEMPERATURE C
BW	FEED	WASTE	10	240	2.47	24.0	.247	44	23.0
DRAIN 1	(VENT)	WASTE	3	62	.64	20.7	.210	0	
REGEN	FR REGEN	WASTE	91	501	5.15	5.49	.056	4.5	21.5
DRAIN 1	(VENT)	WASTE	3	62	.64	20.7	.210	0	
RINSE	FEED	WASTE	10	170	1.75	17.0	.175	0	
SERVICE	FEED	PRODUCT	180	5440	55.9	30.2	.311	0	
DRAIN 2	(VENT)	WASTE	2	41	.42	20.7	.210	0	

Fresh Regenerant Volume Balance

Run 3.07.00B Cycle no.	Date	Fresh regenerant volume (V_3) L	Estimated fresh regenerant TDS mg/L	Service volume (V_S) L	Estimated ED feed TDS mg/L	R %	$V_3/(1-R)V_S$
1	3/22/79	499	33 770	5490	3520	91	1.00
2	3/23/79	499	34 150	5360	3580	91	1.01
3	3/23/79	495	34 150	5310	3580	91	1.01
4	3/23/79	501	34 150	5440	3580	91	1.00

Influent and Effluent Compositions during Cycle 3.07.04B

		Backwash effluent	Regeneration		Backwash, rinse, & service influent	Rinse effluent	Service effluent
			Influent	Effluent			
pH	units	-	4.7	-	7.3	5.2	7.4
TDS (Σ ions)	mg/L	3764	34 329	27 338	3378	28 588	3464
Conductivity @ 25 $^{\circ}$C	µS/cm	-	44 886	-	5347	38 881	5525
Silica	mg/L	6.8	7.2	6.8	6.1	7.2	6.3
Calcium	mg/L	177	172	1880	190	344	28.4
Magnesium	mg/L	82.2	378	641	68.0	328	54.1
Sodium	mg/L	1018	12 140	7240	950	10 000	1182
Potassium	mg/L	9	121	47	8.9	96	14.6
Strontium	mg/L	5.0	2.9	32	2.9	6.5	0.8
Bicarbonate	mg/L	73.2	14.6	97.6	24.4	13.2	24.4
Carbonate	mg/L	ND	ND	ND	ND	ND	ND
Hydroxide	mg/L	ND	ND	ND	ND	ND	ND
Sulfate	mg/L	900	8500	6900	904	6950	924
Chloride	mg/L	1500	13 000	10 500	1230	10 850	1236
T-alkalinity as $CaCO_3$	mg/L	60.0	12.0	80.0	20.0	10.8	20.0
P-alkalinity as $CaCO_3$	mg/L	ND	ND	ND	ND	ND	ND

Major Cation Concentrations of Samples Analyzed by Atomic Absorption

CYCLE 3.07.04B

MODE	PROCESS STREAM	THROUGHPUT BV	CA MEQ/L	MG MEQ/L	TH MEQ/L	NA MEQ/L
BW	EFFLUENT	0.00	10.23	7.03	17.26	46.63
BW	EFFLUENT	1.23	8.53	6.36	14.90	44.32
REGEN	EFFLUENT	2.47	8.08	6.04	14.12	43.15
REGEN	INFLUENT	3.20	8.58	31.11	39.69	528.06
REGEN	EFFLUENT	3.93	172.65	114.49	287.14	295.35
REGEN	EFFLUENT	5.29	121.76	56.95	178.71	388.43
REGEN	EFFLUENT	6.64	90.32	38.44	128.76	440.19
REGEN	EFFLUENT	7.60	76.85	38.85	115.69	421.49
RINSE	EFFLUENT	0.00	19.86	34.40	54.26	519.79
RINSE	EFFLUENT	.67	15.02	19.42	34.44	370.60
SERVICE	EFFLUENT	1.75	.31	.42	.73	59.55
SERVICE	INFLUENT	4.85	9.68	5.70	15.38	42.28
SERVICE	EFFLUENT	20.38	.25	.35	.60	54.41
SERVICE	INFLUENT	29.70	9.68	5.60	15.28	41.32
SERVICE	EFFLUENT	39.02	.53	2.93	3.46	52.02
SERVICE	EFFLUENT	49.27	1.53	6.30	7.84	49.15
SERVICE	INFLUENT	57.66	9.58	5.60	15.19	42.28
SERVICE	EFFLUENT	57.66	3.74	7.69	11.43	45.67

Service Performance Summary

CYCLE 3.07.04B

	AVERAGE CONCENTRATIONS, MEQ/L INFLUENT	EFFLUENT	DIFFERENCE	REMOVAL %	RESIN CAPACITY EQ/L
CA	9.65	.81	8.84	92	.494
MG	5.64	2.57	3.06	54	.171
TH	15.28	3.38	11.90	78	.665
NA	41.96	53.12	-11.16		

FIGURE A- a
MAJOR CATION CONCENTRATIONS
OF IX REGENERATION EFFLUENT
CYCLE 3.07.04B

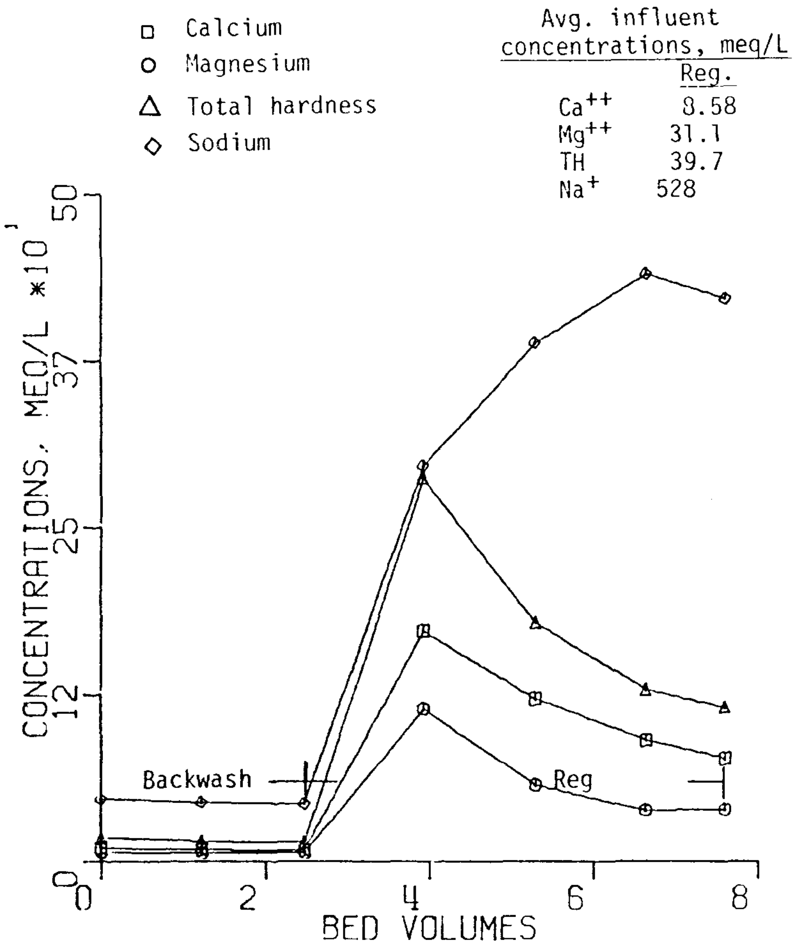
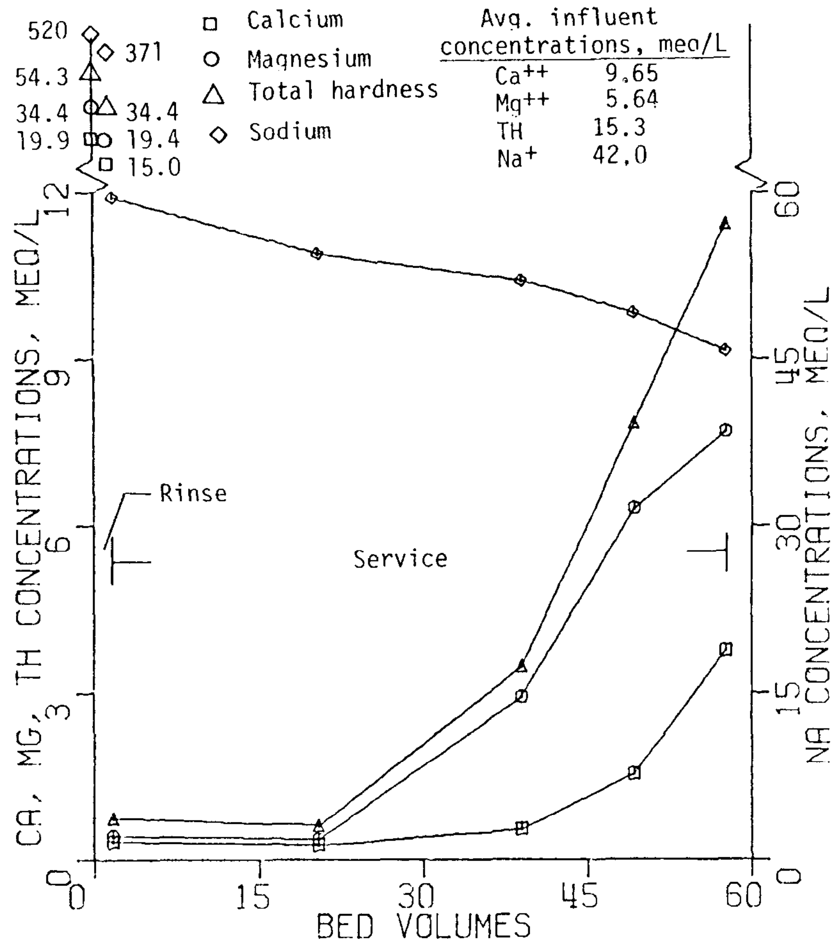


FIGURE A- b
MAJOR CATION CONCENTRATIONS OF
IX RINSE AND SERVICE EFFLUENTS
CYCLE 3.07.04B



SODIUM (NA), CALCIUM (CA), AND MAGNESIUM (MG) CONCENTRATIONS ARE MEASURED BY ATOMIC ABSORPTION.
TOTAL HARDNESS (TH) IS CALCULATED BY SUMMING THE CALCIUM AND MAGNESIUM CONCENTRATIONS.

Ion-Exchange - Run 3.08.00

Date: 5/2/79

Cycle: 3.08.77

Conditions: Feedwater - Wellton-Mowhawk drainage pretreated (in Train IV) with high lime dosage for silica removal
Regenerants - recycled regenerant and fresh ED brine

Control Variables:

	Target	Actual
Fresh regeneration conc. (mg/L TDS)	50 000	51 340
Fresh regeneration flow rate (L/min)	3.0	3.2
Recycled regenerant flow rate (L/min)	16.0	16.2
Recycled regenerant volume (L)	800	800
Service termination point (meq/L Ca^{++})	1.5	1.2

Standard resin bed: Height = 1081 mm
Volume = 98.7

Chemical Compositions of Tank Waters Prior to Cycle 3.08.77

Tank	pH units	Conductivity µS/cm	Ca^{++} meq/L	Mg^{++} meq/L	TH meq/L
Recycle regenerant (T-5)	-	50 367	74.0	126.0	200.0
Spent regenerant (T-6)	-	50 201	107.0	149.0	256.0
Lime-softened feed (T-9)	7.3	5 218	8.40	5.60	14.0
Lime-softened feed (T-10)	7.3	5 281	8.80	5.20	14.0
Fresh ED brine (T-28)	4.1	62 040	6.40	37.6	44.0
IX product/ED feed (T-33)	7.0	5 978	0.40	2.00	2.40

Cycle 3.08.77 Operating Conditions

MODE	INPUT	OUTPUT	DURATION MIN	THROUGHPUT L	VOLUME BV	AVG FLOW RATE L/MIN	AVG FLOW RATE BV/MIN	BED EXPANSION %	TEMPERATURE C
REGEN 1	RE REGEN	WASTE	10	240	2.43	24.0	.243	59.	20.5
REGEN 2	RE REGEN	SP REGEN	49	800	8.11	16.2	.164	36.	
REGEN 3	FR REGEN	SP REGEN	86	270	2.74	3.16	.032	6.8	22.0
DRAIN 1	(VENT)	WASTE	3	62	.63	20.7	.209	0.0	
RINSE	FEED	WASTE	10	160	1.62	16.0	.162	0.0	
SERVICE	FEED	PRODUCT	158	4710	47.7	29.8	.302	0.0	
DRAIN 2	(VENT)	WASTE	2	41	.42	20.5	.208	0.0	

Fresh Regenerant Volume Balance

Run 3.08.00 Cycle no.	Date	Fresh regenerant volume (V_3) L	Estimated fresh regenerant TDS mg/L	Service volume (V_S) L	Estimated ED feed TDS mg/L	R %	$V_3/(1-R)V_S$
32	4/8/79	581	52 400	9480	3340	94	1.12
33	4/8/79	271	52 400	8280	3340	94	0.60
34	4/8/79	273	52 400	7620	3340	94	0.65
35	4/9/79	271	52 600	8130	3770	94	0.53
36	4/9/79	273	52 600	7840	3770	94	0.63
37	4/13/79	273	52 290	6380	3430	94	0.68
38	4/16/79	273	52 290	7450	3430	94	0.64
39	4/17/79	272	51 900	460	3450	94	10.38
52	4/20/79	1440	51 650	10 020	3440	94	2.48
53	4/21/79	272	51 650	7780	3440	94	0.60
54	4/21/79	386	51 650	7720	3440	94	0.86
55	4/21/79	271	51 650	7520	3440	94	0.62
56	4/22/79	270	51 650	7080	3440	94	0.66
57	4/23/79	271	51 450	7010	3590	94	0.67
58	4/23/79	270	51 450	7130	3590	94	0.62
59	4/25/79	273	51 420	6410	3340	94	0.76
60	4/25/79	272	51 420	5980	3340	94	0.81
61	4/26/79	271	51 500	6010	3690	94	0.72
62	4/26/79	271	51 500	6070	3690	94	0.71
63	4/27/79	270	51 760	5790	3640	94	0.75
64	4/28/79	270	51 760	5610	3640	94	0.78
65	4/28/79	270	51 760	5770	3640	94	0.75
66	4/28/79	270	51 760	5510	3640	94	0.79
67	4/29/79	270	51 760	5730	3640	94	0.76
68	4/29/79	270	51 760	5500	3640	94	0.79
69	4/29/79	270	51 760	5330	3640	94	0.82
70	4/29/79	270	51 760	5280	3640	94	0.83
71	4/30/79	269	50 850	5350	3590	94	0.81
72	4/30/79	270	50 850	5260	3590	94	0.83
73	4/30/79	270	50 850	5220	3590	94	0.83
74	5/1/79	271	51 250	5170	3560	94	0.86
75	5/1/79	270	51 250	5180	3560	94	0.85
76	5/1/79	270	51 250	5040	3560	94	0.88
77	5/2/79	270	52 050	4710	3710	94	0.91

Influent and Effluent Compositions during Cycle 3.08.77

		Regen 1,2 influent	Regen 1 effluent	Regen 2 effluent	Regen 3 Influent	Regen 3 Effluent	Rinse service influent	Rinse effluent	Service effluent
pH	units	-	-	-	4.2	-	7.2	4.5	7.0
TDS (Σ ions)	mg/L	35 822	25 846	35 575	51 338	40 469	3329	41 603	4713
Conductivity @ 25 °C	μS/cm	-	-	-	61 732	-	5272	51 916	7064
Silica	mg/L	7.0	15.4	14.6	4.5	9.4	3.1	3.6	5.6
Calcium	mg/L	1370	1850	1790	114	1600	166	477	26.5
Magnesium	mg/L	1498	1289	1577	332	1450	64.9	364	34.2
Sodium	mg/L	9740	5890	9230	18 060	11 100	939	14 140	1595
Potassium	mg/L	68	43	64	149	74	8.9	111	14.4
Strontium	mg/L	43	41.0	46.0	2.5	47.0	3.0	14.9	1.2
Bicarbonate	mg/L	83.0	73.0	88.0	ND	98.0	19.5	15.6	19.5
Carbonate	mg/L	ND	ND	ND	ND	ND	ND	ND	ND
Hydroxide	mg/L	ND	ND	ND	ND	ND	ND	ND	ND
Sulfate	mg/L	4500	3700	4400	15 000	8460	930	11 500	1824
Chloride	mg/L	18 520	14 580	18 380	17 680	17 640	1198	14 980	1198
T-alkalinity as $CaCO_3$	mg/L	68.0	6.0	7.2	ND	8.0	16.0	12.8	16.0
P-alkalinity as $CaCO_3$	mg/L	ND	ND	ND	ND	ND	ND	ND	ND

Major Cation Concentrations of Samples Analyzed by Atomic Absorption

CYCLE 3.08.77

MODE	PROCESS STREAM	THROUGHPUT BV	CA MEQ/L	MG MEQ/L	TH MEQ/L	NA MEQ/L
REGEN 1	EFFLUENT	0.00	39.92	32.35	72.27	109.61
REGEN 1	EFFLUENT	1.21	124.75	150.95	275.70	303.18
REGEN 2	EFFLUENT	2.41	109.78	143.95	253.73	363.64
REGEN 2	INFLUENT	4.71	68.36	123.29	191.66	423.66
REGEN 2	EFFLUENT	6.51	81.84	127.08	208.91	414.09
REGEN 3	EFFLUENT	10.45	74.35	123.21	197.56	421.92
REGEN 3	INFLUENT	10.74	5.69	27.33	33.01	785.56
REGEN 3	EFFLUENT	11.06	96.81	152.59	249.40	488.04
REGEN 3	EFFLUENT	11.70	83.83	119.92	203.75	552.41
REGEN 3	EFFLUENT	13.20	62.38	79.09	141.47	507.61
RINSE	EFFLUENT	0.00	24.90	30.45	55.35	692.04
RINSE	EFFLUENT	.81	22.75	30.04	52.80	519.36
SERVICE	EFFLUENT	1.62	5.34	3.00	8.34	155.72
SERVICE	INFLUENT	4.34	8.18	5.36	13.54	40.06
SERVICE	EFFLUENT	14.31	.17	.20	.37	52.33
SERVICE	INFLUENT	24.27	8.13	5.32	13.45	39.15
SERVICE	EFFLUENT	26.99	.18	.40	.58	51.94
SERVICE	EFFLUENT	39.68	.45	2.58	3.03	48.76
SERVICE	EFFLUENT	46.32	.88	4.83	5.71	46.45
SERVICE	EFFLUENT	49.34	1.19	5.68	6.87	45.54

Service Performance Summary

CYCLE 3.08.77

	AVERAGE CONCENTRATIONS, MEQ/L INFLUENT	EFFLUENT	DIFFERENCE	REMOVAL %	RESIN CAPACITY EQ/L
CA	8.16	1.02	7.14	87	.341
MG	5.34	1.75	3.59	67	.171
TH	13.50	2.77	10.73	79	.512
NA	39.60	64.43	-24.83		

FIGURE A- a
MAJOR CATION CONCENTRATIONS
OF IX REGENERATION EFFLUENT
CYCLE 3.08.77

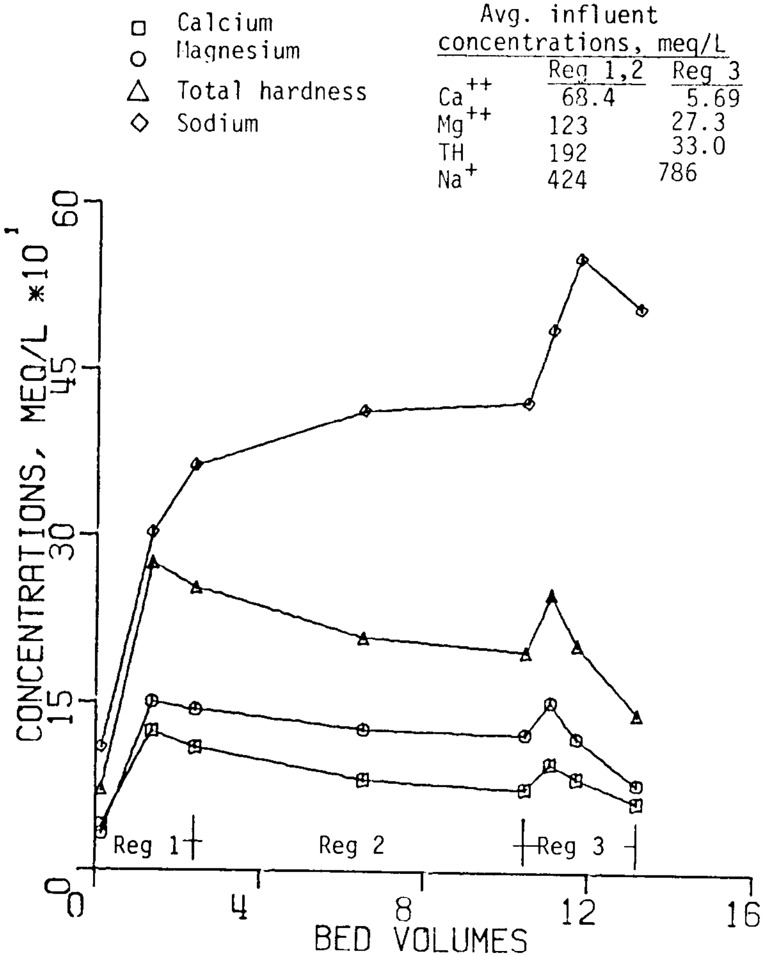
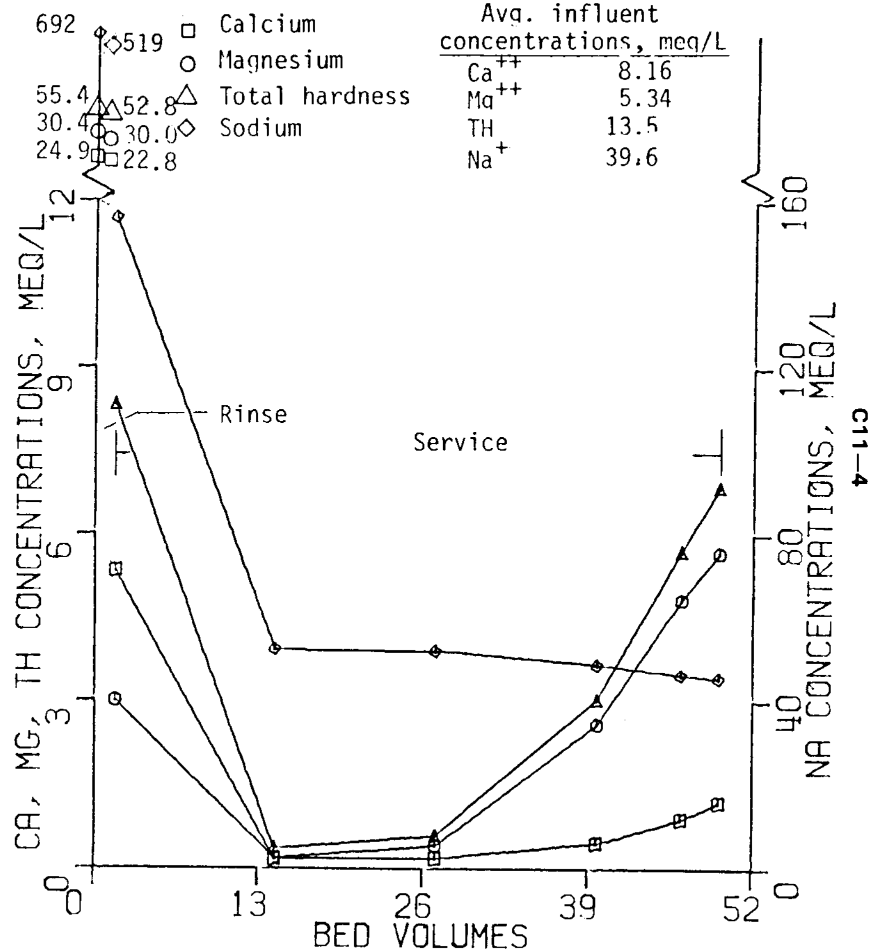


FIGURE A- b
MAJOR CATION CONCENTRATIONS OF
IX RINSE AND SERVICE EFFLUENTS
CYCLE 3.08.77



SODIUM (NA), CALCIUM (CA), AND MAGNESIUM (MG) CONCENTRATIONS ARE MEASURED BY ATOMIC ABSORPTION. TOTAL HARDNESS (TH) IS CALCULATED BY SUMMING THE CALCIUM AND MAGNESIUM CONCENTRATIONS.

Ion-Exchange - Run 3.09.00

Date: 5/4/79

Cycle: 3.09.10

Conditions: Feedwater - Wellton-Mowhawk drainage pretreated (in Train IV) with high lime dosage for silica removal
Regenerants - recycled regenerant and fresh ED brine

Control Variables:

	Target	Actual
Fresh regeneration conc. (mg/L TDS)	50 000	51 960
Fresh regeneration flow rate (L/min)	8.0	8.0
Recycled regenerant flow rate (L/min)	16.0	16.5
Recycled regenerant volume (L)	800	800
Service termination point (meq/L Ca^{++})	1.5	1.7

Chemical Compositions of Tank Waters Prior to Cycle 3.09.10

Tank	pH units	Conductivity µS/cm	Ca^{++} meq/L	Mg^{++} meq/L	TH meq/L
Recycle regenerant (T-5)	-	49 935	78.0	116.0	194.0
Spent regenerant (T-6)	-	49 504	110.0	98.0	208.0
Lime-softened feed (T-9)	7.3	5 180	9.20	6.40	15.6
Lime softened feed (T-10)	7.3	5 179	9.20	6.40	15.6
Fresh ED brine (T-28)	4.4	62 327	6.80	39.2	46.0
IX product/ED feed (T-33)	7.1	5 460	0.48	1.84	2.32

Cycle 3.09.10 Operating Conditions

MODE	INPUT	OUTPUT	DURATION MIN	THROUGHPUT L	VOLUME BV	AVG FLOW RATE L/MIN	AVG FLOW RATE BV/MIN	BED EXPANSION %	TEMPERATURE C
REGEN 1	RE REGEN	WASTE	10	240	2.43	24.0	.243	50.	26.0
REGEN 2	RE REGEN	SP REGEN	49	800	8.11	16.5	.167	32.	
REGEN 3	FR REGEN	SP REGEN	34	272	2.75	8.02	.081	16.	27.0
DRAIN 1	(VENT)	WASTE	3	62	.63	20.7	.209	0.0	
RINSE	FEED	WASTE	10	150	1.52	15.0	.152	0.0	
SERVICE	FEED	PRODUCT	171	5140	52.1	30.1	.305	0.0	
DRAIN 2	(VENT)	WASTE	2	41	.42	20.5	.208	0.0	

Fresh Regenerant Volume Balance

Run 3.09.00 Cycle no.	Date	Fresh regenerant volume (V_3) L	Estimated fresh regenerant TDS mg/L	Service volume (V_S) L	Estimated ED feed TDS mg/L	R %	$V_3/(1-R)V_S$
5	5/3/79	268	52 450	5260	3450	94	0.89
6	5/3/79	269	52 450	5130	3450	94	0.92
7	5/4/79	270	52 560	5220	3380	94	0.92
8	5/4/79	270	52 560	5120	3380	94	0.94
9	5/4/79	271	52 560	5030	3380	94	0.96
10	5/4/79	272	52 560	5140	3380	94	0.94

Influent and Effluent Compositions during Cycle 3.09.10

		Regen 1,2 influent	Regen 1 effluent	Regen 2 effluent	Regen 3 Influent	Regen 3 Effluent	Rinse service influent	Rinse effluent	Service effluent
pH	units	-	-	-	4.4	-	7.2	5.2	7.1
TDS (Σ ions)	mg/L	35 596	25 071	34 632	51 958	41 951	3199	40 759	3555
Conductivity @ 25 °C	μS/cm	-	-	-	61 596	-	5223	51 178	5746
Silica	mg/L	4.8	4.6	4.8	4.0	4.6	3.9	4.0	4.0
Calcium	mg/L	1510	2050	1960	133	1850	189	600	13.4
Magnesium	mg/L	1563	1161	1570	370	1456	53.0	435	27.5
Sodium	mg/L	9490	5530	8700	18 120	11 340	877	13 180	1211
Potassium	mg/L	74	48	70	149	85	9.3	110	12.6
Strontium	mg/L	36	34	39	2.1	42	2.5	14.0	0.2
Bicarbonate	mg/L	83.0	87.8	73.2	4.9	78.1	22.0	19.5	20.5
Carbonate	mg/L	ND	ND	ND	ND	ND	ND	ND	ND
Hydroxide	mg/L	ND	ND	ND	ND	ND	ND	ND	ND
Sulfate	mg/L	4300	3240	4120	15 000	9000	920	11 900	1120
Chloride	mg/L	18 540	12 920	18 100	18 160	18 100	1126	14 500	1150
T-alkalinity as $CaCO_3$	mg/L	68.0	72.0	60.0	4.0	64.0	18.0	16.0	16.8
P-alkalinity as $CaCO_3$	mg/L	ND	ND	ND	ND	ND	ND	ND	ND

Major Cation Concentrations of Samples Analyzed by Atomic Absorption

CYCLE 3.09.10

MODE	PROCESS STREAM	THROUGHPUT BV	CA MEQ/L	MG MEQ/L	TH MEQ/L	NA MEQ/L
REGEN 1	EFFLUENT	0.00	43.91	30.78	74.69	103.52
REGEN 1	EFFLUENT	1.22	137.23	128.81	266.03	302.31
REGEN 2	EFFLUENT	2.43	128.24	133.83	262.07	359.29
REGEN 2	INFLUENT	5.11	75.35	128.64	203.99	412.79
REGEN 2	EFFLUENT	6.94	89.82	128.23	218.05	403.65
REGEN 3	EFFLUENT	10.62	81.34	127.08	208.42	404.09
REGEN 3	INFLUENT	10.86	6.64	30.45	37.09	788.17
REGEN 3	EFFLUENT	11.11	104.79	157.20	261.99	436.28
REGEN 3	EFFLUENT	11.59	102.30	131.28	233.57	537.19
REGEN 3	EFFLUENT	12.89	86.33	107.90	194.23	555.02
REGEN 3	EFFLUENT	13.38	88.32	72.35	160.67	563.29
RINSE	EFFLUENT	0.00	32.44	43.05	75.48	678.99
RINSE	EFFLUENT	.76	23.90	29.30	53.20	485.86
SERVICE	EFFLUENT	1.52	.48	.62	1.10	72.60
SERVICE	INFLUENT	4.26	9.93	4.31	14.24	37.84
SERVICE	EFFLUENT	14.31	.18	.22	.40	49.59
SERVICE	INFLUENT	25.58	9.18	4.22	13.40	37.10
SERVICE	EFFLUENT	27.10	.19	.29	.48	50.02
SERVICE	EFFLUENT	39.89	.38	1.76	2.15	47.50
SERVICE	EFFLUENT	46.29	.78	3.94	4.73	45.72
SERVICE	INFLUENT	53.60	9.13	4.26	13.40	37.10
SERVICE	EFFLUENT	53.60	1.65	5.88	7.53	43.24

Service Performance Summary

CYCLE 3.09.10

	AVERAGE CONCENTRATIONS, MEQ/L INFLUENT	EFFLUENT	DIFFERENCE	REMOVAL %	RESIN CAPACITY EQ/L
CA	9.41	.44	8.97	95	.467
MG	4.27	1.46	2.81	66	.146
TH	13.68	1.90	11.78	86	.614
NA	37.35	51.18	-13.83		

FIGURE A- a
MAJOR CATION CONCENTRATIONS
OF IX REGENERATION EFFLUENT
CYCLE 3.09.10

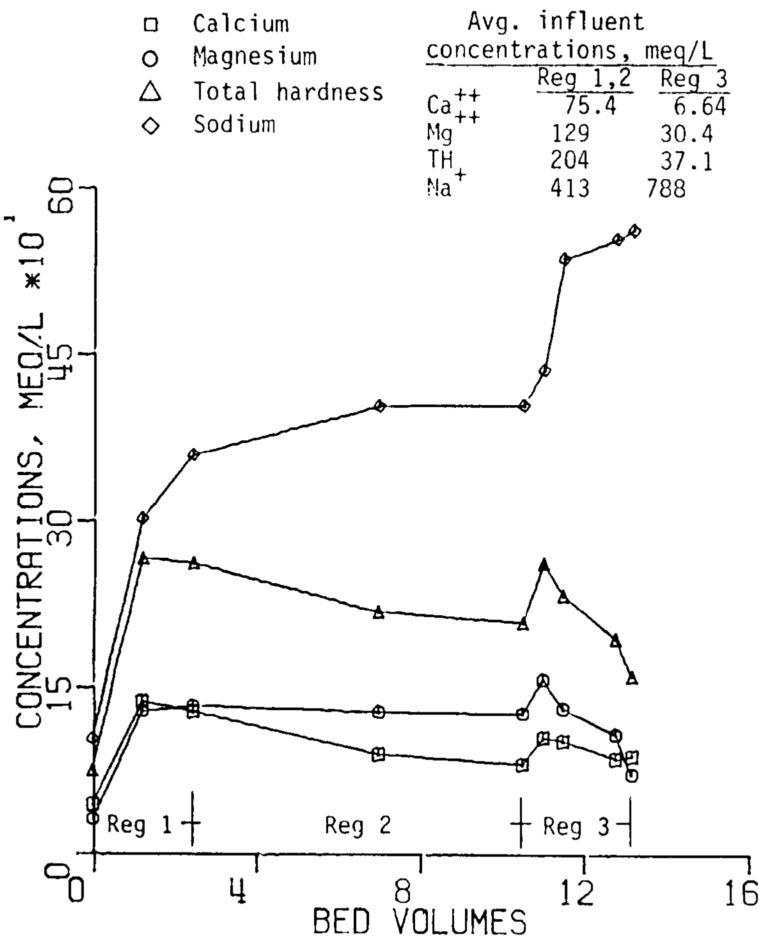
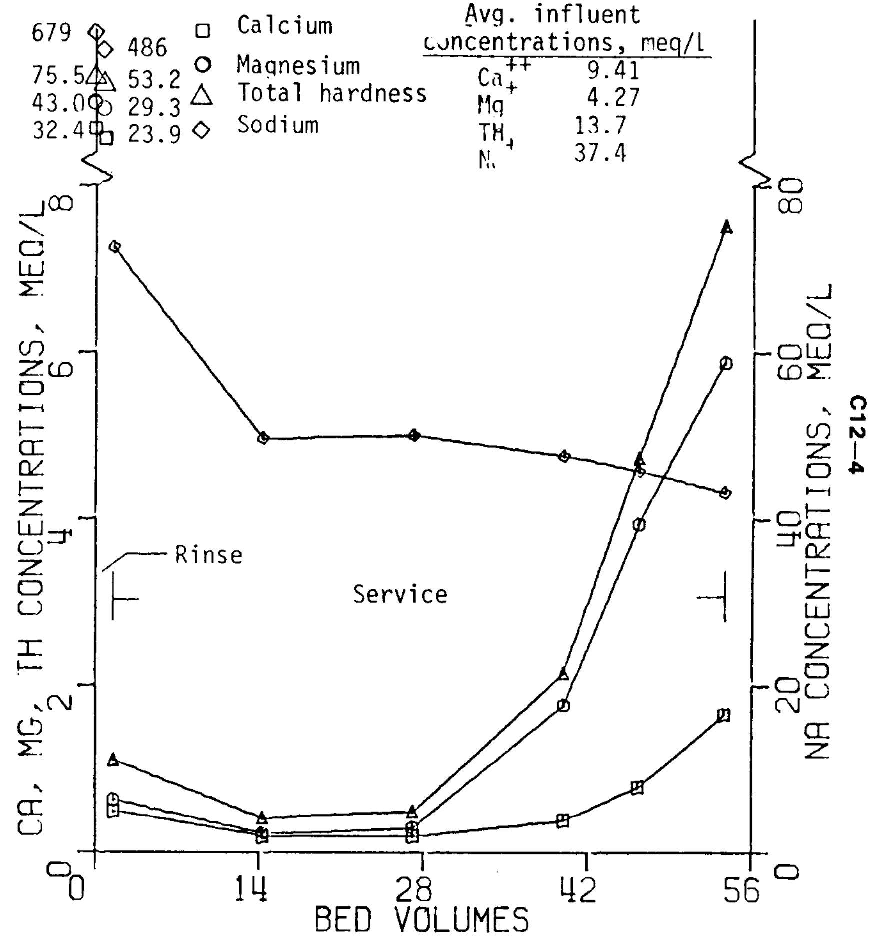


FIGURE A- b
MAJOR CATION CONCENTRATIONS OF
IX RINSE AND SERVICE EFFLUENTS
CYCLE 3.09.10



SODIUM (NA), CALCIUM (CA), AND MAGNESIUM (MG) CONCENTRATIONS ARE MEASURED BY ATOMIC ABSORPTION.
TOTAL HARDNESS (TH) IS CALCULATED BY SUMMING THE CALCIUM AND MAGNESIUM CONCENTRATIONS.

Ion-Exchange - Run 3.10.00

Date: 5/9/79

Cycle: 3.10.15

Conditions: Feedwater - Wellton-Mowhawk drainage pretreated (in Train IV) with high lime dosage for silica removal
Regenerants - recycled regenerant and fresh ED brine

Control variables:

	Target	Actual
Fresh regeneration conc. (mg/L TDS)	50 000	50 320
Fresh regeneration flow rate (L/min)	5.5	5.6
Recycled regenerant flow rate (L/min)	16.0	16.6
Recycled regenerant volume (L)	1600	1600
Service termination point (meq/L Ca^{++})	1.5	1.5

Standard resin bed: Height = 1081 mm
Volume = 98.7 L

Chemical Compositions of Tank Waters Prior to Cycle 3.10.15

Tank	pH units	Conductivity µS/cm	Ca^{++} meq/L	Mg^{++} meq/L	TH meq/L
Recycle regenerant (T-5)	-	49 339	61.0	111.0	172.0
Spent regenerant (T-6)	-	49 182	95.0	107.0	202.0
Lime-softened feed (T-9)	7.4	5 082	8.8	4.8	13.6
Lime softened feed (T-10)	7.5	5 133	9.2	5.2	14.4
Fresh ED brine (T-28)	5.1	59 220	5.8	25.7	31.5
IX product/ED feed (T-33)	7.2	5 178	0.36	1.96	2.32

Cycle 3.10.15 Operating Conditions

MODE	INPUT	OUTPUT	DURATION MIN	THROUGHPUT L	VOLUME BV	AVG FLOW RATE L/MIN	AVG FLOW RATE BV/MIN	BED EXPANSION %	TEMPERATURE C
REGEN 1	RE REGEN	WASTE	10	240	2.43	24.0	.243	55.	20.5
REGEN 2	RE REGEN	SP REGEN	96	1600	16.2	16.6	.168	35.0	
REGEN 3	FR REGEN	SP REGEN	68	382	3.87	5.59	.057	11.	22.3
DRAIN 1	(VENT)	WASTE	3	62	.63	20.7	.209	0.0	
RINSE	FEED	WASTE	10	160	1.62	16.0	.162	0.0	
SERVICE	FEED	PRODUCT	208	6260	63.4	30.1	.305	0.0	
DRAIN 2	(VENT)	WASTE	2	41	.42	20.7	.209	0.0	

Fresh Regenerant Volume Balance

Run 3.10.00 Cycle no.	Date	Fresh regenerant volume (V_3) L	Estimated fresh regenerant TDS mg/L	Service volume (V_S) L	Estimated ED feed TDS mg/L	R %	$V_3/(1-R)V_S$
03	5/5/79	795	52 560	8770	3380	94	1.62
04	5/6/79	301	52 560	5960	3380	94	0.91
05	5/6/79	302	52 560	5990	3380	94	0.90
06	5/6/79	301	52 560	6000	3380	94	0.90
07	5/7/79	301	50 730	6040	3370	94	0.86
08	5/7/79	301	50 730	6070	3370	94	0.86
09	5/7/79	302	50 730	5920	3370	94	0.88
10	5/7/79	302	50 730	6070	3370	94	0.86
11	5/8/79	302	50 210	5920	3300	94	0.90
12	5/8/79	381	50 210	6290	3300	94	1.06
13	5/8/79	381	50 210	6200	3300	94	1.08
14	5/9/79	382	50 770	6230	3210	95	1.14
15	5/9/79	382	50 770	6260	3210	95	1.13

Influent and Effluent Compositions during Cycle 3.10.15

	Units	Regen 1, 2 influent	Regen 1 effluent	Regen 2 effluent	Regen 3 Influent	Regen 3 Effluent	Rinse, service influent	Rinse effluent	Service effluent
pH	units	-	-	-	5.1	-	7.3	5.9	7.2
TDS (Σ ions)	mg/L	36 885	27 100	35 665	50 324	43 283	3253	40 960	3375
Conductivity @ 25 °C	μS/cm	-	-	-	60 400	-	5297	49 674	5579
E. F. (TDS/cond.)	-	-	-	-	0.83	-	0.61	0.82	0.60
Silica	mg/L	6.6	4.6	4.6	3.7	4.2	4.6	4.3	4.7
Calcium	mg/L	1280	1960	1580	114	1320	166	388	10.8
Magnesium	mg/L	1512	1295	1528	340	1097	64.9	309	36.1
Sodium	mg/L	10 520	6150	9520	17 350	12 990	887	13 760	1145
Potassium	mg/L	76	50	72	157	91	9.6	123	13
Strontium	mg/L	33	37	37	2.1	38	2.5	12	0.4
Bicarbonate	mg/L	97.6	63.4	83.0	17.1	83.0	24.4	24.4	24.9
Carbonate	mg/L	ND	ND	ND	ND	ND	ND	ND	ND
Hydroxide	mg/L	ND	ND	ND	ND	ND	ND	ND	ND
Sulfate	mg/L	4900	4240	4900	14 740	10 160	940	13 200	990
Chloride	mg/L	18 460	13 300	17 940	17 600	17 500	1154	13 140	1150
T-alkalinity as $CaCO_3$	mg/L	80.0	52.0	68.0	14.0	68.0	20.0	20.0	20.0
P-alkalinity as $CaCO_3$	mg/L	ND	ND	ND	ND	ND	ND	ND	ND
ΣAnions	meq/L	624.4	464.5	609.5	803.8	706.7	52.53	646.0	53.47
ΣCations	meq/L	648.5	473.9	621.3	792.4	724.4	52.51	646.7	53.66
Control value	meq/L	-2.46	-1.28	-1.24	+0.9	-1.60	+0.02	-0.07	-0.20

Major Cation Concentrations of Samples Analyzed by Atomic Absorption

CYCLE 3.10.15

MODE	PROCESS STREAM	THROUGHPUT BV	CA MEQ/L	MG MEQ/L	TH MEQ/L	NA MEQ/L
REGEN 1	EFFLUENT	0.00	64.37	50.70	115.07	143.11
REGEN 1	EFFLUENT	1.22	119.76	127.16	246.92	297.09
REGEN 2	EFFLUENT	2.43	121.76	136.63	258.38	382.78
REGEN 2	INFLUENT	4.79	63.87	124.44	188.32	457.59
REGEN 2	EFFLUENT	10.68	68.36	124.12	192.48	447.59
REGEN 3	EFFLUENT	18.59	64.37	124.86	189.23	452.37
REGEN 3	INFLUENT	19.05	5.69	27.98	33.67	754.68
REGEN 3	EFFLUENT	20.35	82.34	105.51	187.85	598.96
REGEN 3	EFFLUENT	20.63	73.85	90.29	164.14	617.66
REGEN 3	EFFLUENT	21.66	64.87	76.71	141.58	633.32
REGEN 3	EFFLUENT	22.45	59.38	61.65	121.03	578.95
RINSE	EFFLUENT	0.00	22.41	33.25	55.66	711.18
RINSE	EFFLUENT	.81	15.97	17.94	33.91	477.16
SERVICE	EFFLUENT	1.62	.13	.24	.37	58.90
SERVICE	INFLUENT	4.37	8.48	5.41	13.89	38.97
SERVICE	EFFLUENT	16.87	.07	.16	.23	52.33
SERVICE	INFLUENT	30.28	8.58	5.51	14.09	39.58
SERVICE	EFFLUENT	32.11	.08	.22	.30	52.46
SERVICE	EFFLUENT	47.36	.21	2.11	2.32	50.98
SERVICE	EFFLUENT	54.98	.53	4.55	5.09	48.50
SERVICE	EFFLUENT	62.61	1.26	6.62	7.87	45.67
SERVICE	INFLUENT	65.05	8.48	5.50	13.98	39.41
SERVICE	EFFLUENT	65.05	1.53	7.00	8.53	45.02

Service Performance Summary

CYCLE 3.10.15

	AVERAGE CONCENTRATIONS, MEQ/L INFLUENT	EFFLUENT	DIFFERENCE	REMOVAL %	RESIN CAPACITY EQ/L
CA	8.52	.28	8.23	97	.522
MG	5.47	1.71	3.76	69	.239
TH	13.99	1.99	12.00	86	.761
NA	39.32	51.78	-12.45		

FIGURE A- a
MAJOR CATION CONCENTRATIONS
OF IX REGENERATION EFFLUENT
CYCLE 3.10.15

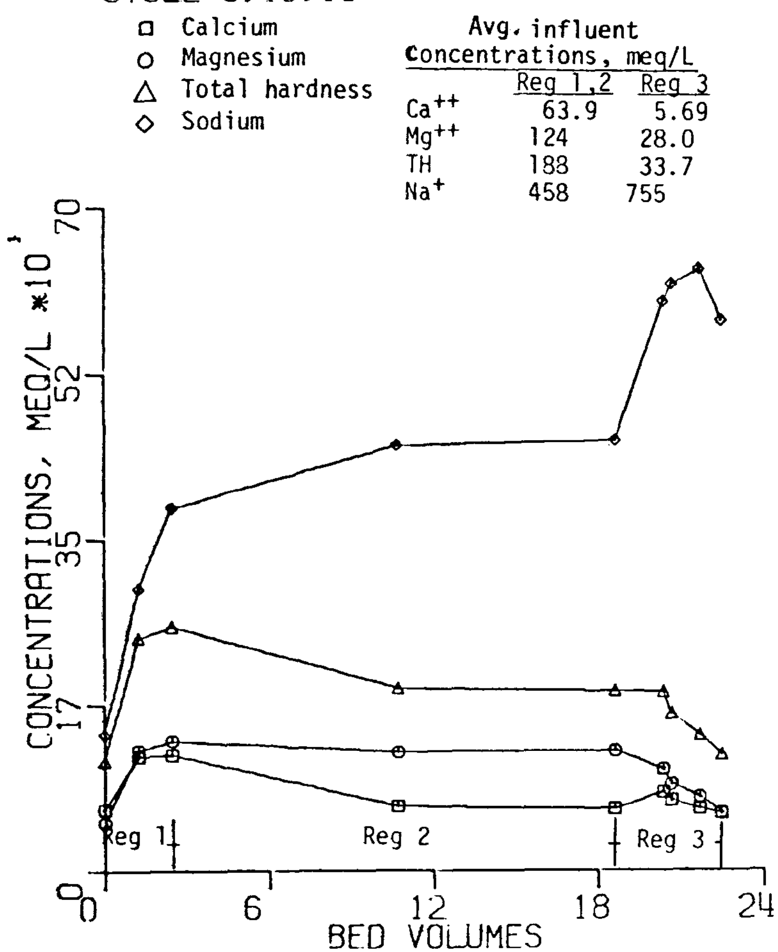
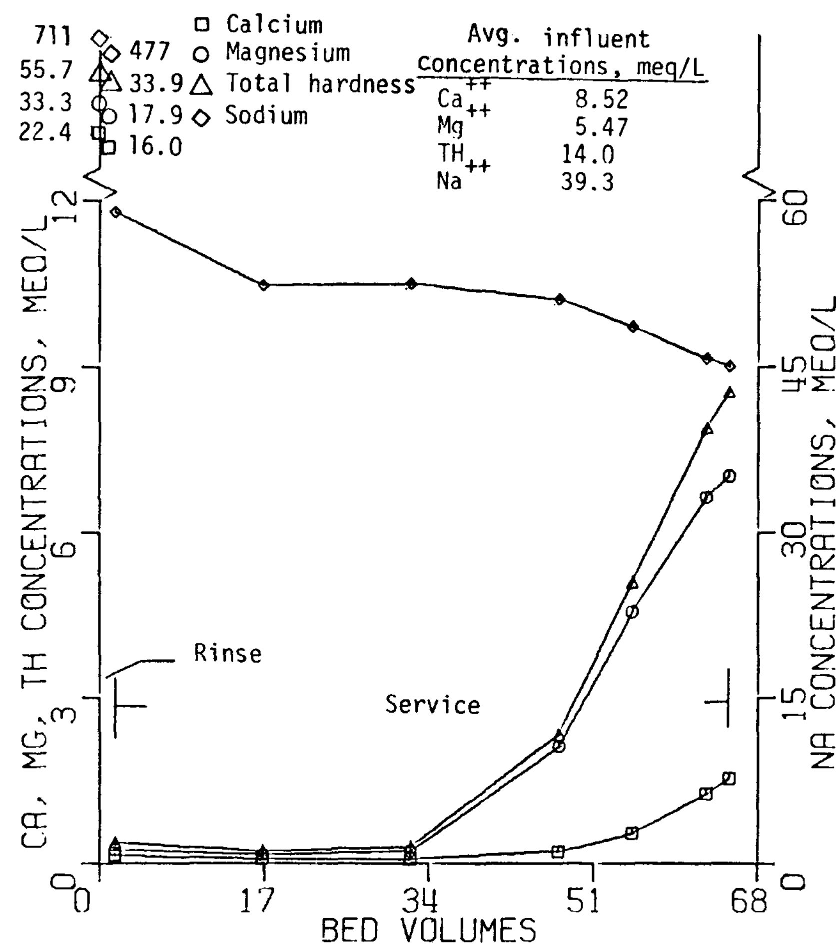


FIGURE A- b
MAJOR CATION CONCENTRATIONS OF
IX RINSE AND SERVICE EFFLUENTS
CYCLE 3.10.15



SODIUM (NA), CALCIUM (CA), AND MAGNESIUM (MG) CONCENTRATIONS ARE MEASURED BY ATOMIC ABSORPTION.
TOTAL HARDNESS (TH) IS CALCULATED BY SUMMING THE CALCIUM AND MAGNESIUM CONCENTRATIONS.

Ion-Exchange - Run 3.11.00

Date: 5/12/79

Cycle: 3.11.12

Conditions: Feedwater - Wellton-Mowhawk drainage pretreated (in Train IV) with high lime dosage for silica removal
Regenerants - recycled regenerant and fresh ED brine

Control variables:

	Target	Actual
Fresh regeneration conc. (mg/L TDS)	50 000	51 810
Fresh regeneration flow rate (L/min)	5.5	5.5
Recycled regenerant flow rate (L/min)	None	None
Recycled regenerant volume (L)	None	None
Service termination point (meq/L Ca^{++})	1.5	1.3

Standard resin bed: Height = 1081 mm
Volume = 98.7 L

Chemical Compositions of Tank Waters Prior to Cycle 3.11.12

Tank	pH units	Conductivity µS/cm	Ca^{++} meq/L	Mg^{++} meq/L	TH meq/L
Recycle regenerant (T-5)	-	50 698	66.0	116.0	182.0
Spent regenerant (T-6)	-	50 394	66.0	110.0	176.0
Lime-softened feed (T-9)	7.3	5 188	9.20	3.00	12.2
Lime softened feed (T-10)	7.5	5 177	8.0	-	5.20
Fresh ED brine (T-28)	5.9	62 098	6.0	29.0	35.0
IX product/ED feed (T-33)	7.3	5 471	0.48	1.20	1.69

Cycle 3.11.12 Operating Conditions

MODE	INPUT	OUTPUT	DURATION MIN	THROUGHPUT L	VOLUME BV	AVG FLOW RATE L/MIN	AVG FLOW RATE BV/MIN	BED EXPANSION %	TEMPERATURE C
REGEN 1	RE REGEN	WASTE	10	231	2.34	23.1	.234	51.	22.0
REGEN 3	FR REGEN	SP REGEN	51	281	2.85	5.49	.056	9.6	24.2
DRAIN 1	(VENT)	WASTE	3	62	.63	20.7	.209	0.0	
RINSE	FEED	WASTE	10	150	1.52	15.0	.152	0.0	
SERVICE	FEED	PRODUCT	152	4580	46.4	30.1	.305	0.0	
DRAIN 2	(VENT)	WASTE	2	41	.42	20.7	.209	0.0	

Fresh Regenerant Volume Balance

Run 3.11.00 Cycle no.	Date	Fresh regenerant volume (V_3) L	Estimated fresh regenerant TDS mg/L	Service volume (V_S) L	Estimated ED feed TDS mg/L	R %	$V_3/(1-R)V_S$
03	5/10/79	282	50 770	5330	3370	94	0.93
04	5/10/79	281	50 770	4580	3370	94	1.09
05	5/11/79	281	52 150	4610	3510	94	1.03
06	5/11/79	282	52 150	4900	3510	94	0.98
07	5/11/79	280	52 150	4870	3510	94	0.98
08	5/11/79	280	52 150	4840	3510	94	0.98
09	5/11/79	281	52 150	4600	3510	94	1.04
10	5/11/79	281	52 150	4490	3510	94	1.06
11	5/12/79	281	52 600	4510	3390	94	1.11
12	5/12/79	281	52 600	4580	3390	94	1.10

Influent and Effluent Compositions during Cycle 3.11.12

	Units	Regen 1 influent	Regen 1 effluent	Regen 3 influent	Regen 3 effluent	Rinse, service influent	Rinse effluent	Service effluent
pH	units	-	-	6.0	-	7.3	6.3	7.2
TDS (Σ ions)	mg/L	37 616	27 892	51 814	42 832	3279	40 219	4783
Conductivity @ 25 °C	μS/cm	-	-	63 479	-	5321	50 800	7309
E. F. (TDS/cond.)	-	-	-	0.82	-	0.61	0.79	0.65
Silica	mg/L	4.6	4.0	4.1	4.2	6.8	4.2	6.9
Calcium	mg/L	1250	2230	124	2360	156	510	20.2
Magnesium	mg/L	1542	1208	363	1402	75.2	370	39.8
Sodium	mg/L	10 470	6180	18 240	11 050	909	13 470	1592
Potassium	mg/L	76	47	166	78	8.9	123	16.3
Strontium	mg/L	40	40	2.7	50	2.9	11.2	0.9
Bicarbonate	mg/L	73.2	83.0	34.2	87.8	19.5	31.2	22.0
Carbonate	mg/L	ND	ND	ND	ND	ND	ND	ND
Hydroxide	mg/L	ND	ND	ND	ND	ND	ND	ND
Sulfate	mg/L	5560	4400	15 280	9100	940	10 960	1925
Chloride	mg/L	18 600	13 700	17 600	18 700	1160	14 740	1160
T-alkalinity as $CaCO_3$	mg/L	60.0	68.0	28.0	72.0	16.0	25.6	18.0
P-alkalinity as $CaCO_3$	mg/L	ND	ND	ND	ND	ND	ND	ND
ΣAnions	meq/L	641.7	479.5	815.3	718.5	52.62	644.6	73.18
ΣCations	meq/L	647.5	481.6	833.8	716.9	53.91	645.2	73.96
Control value	meq/L	-0.57	-0.28	-1.45	+0.14	-1.29	-0.06	-0.64

Major Cation Concentrations of Samples Analyzed by Atomic Absorption

CYCLE 3.11.12

MODE	PROCESS STREAM	THROUGHPUT BV	CA MEQ/L	MG MEQ/L	TH MEQ/L	NA MEQ/L
REGEN 1	EFFLUENT	0.00	52.89	33.09	85.98	117.88
REGEN 1	INFLUENT	.70	62.38	126.91	189.29	455.42
REGEN 1	EFFLUENT	1.17	145.71	131.52	277.23	324.49
REGEN 3	EFFLUENT	2.34	132.24	130.86	263.10	382.34
REGEN 3	INFLUENT	2.51	6.19	29.88	36.06	793.39
REGEN 3	EFFLUENT	2.95	153.19	150.37	303.56	464.55
REGEN 3	EFFLUENT	3.45	124.25	121.73	245.98	510.66
REGEN 3	EFFLUENT	3.90	106.29	105.93	212.21	526.75
REGEN 3	EFFLUENT	5.18	71.86	64.03	135.89	535.45
RINSE	EFFLUENT	0.00	30.44	35.72	66.16	702.91
RINSE	EFFLUENT	.76	20.91	24.53	45.43	486.30
SERVICE	EFFLUENT	1.52	1.49	3.40	4.89	171.38
SERVICE	INFLUENT	4.27	7.83	6.02	13.86	39.23
SERVICE	EFFLUENT	14.04	.14	.21	.36	52.11
SERVICE	INFLUENT	25.64	7.68	6.06	13.74	39.45
SERVICE	EFFLUENT	26.55	.16	.39	.55	51.15
SERVICE	EFFLUENT	39.07	.49	3.17	3.66	48.46
SERVICE	EFFLUENT	45.48	1.04	5.43	6.47	46.28
SERVICE	INFLUENT	47.92	7.63	6.01	13.64	39.58
SERVICE	EFFLUENT	47.92	1.33	6.12	7.44	45.15

Service Performance Summary

CYCLE 3.11.12

	AVERAGE CONCENTRATIONS, MEQ/L			REMOVAL	RESIN CAPACITY
	INFLUENT	EFFLUENT	DIFFERENCE	%	EQ/L
CA	7.72	.52	7.20	93	.334
MG	6.03	1.95	4.08	68	.190
TH	13.75	2.46	11.29	82	.524
NA	39.42	66.45	-27.03		

FIGURE A - a
MAJOR CATION CONCENTRATIONS
OF IX REGENERATION EFFLUENT
CYCLE 3.11.12

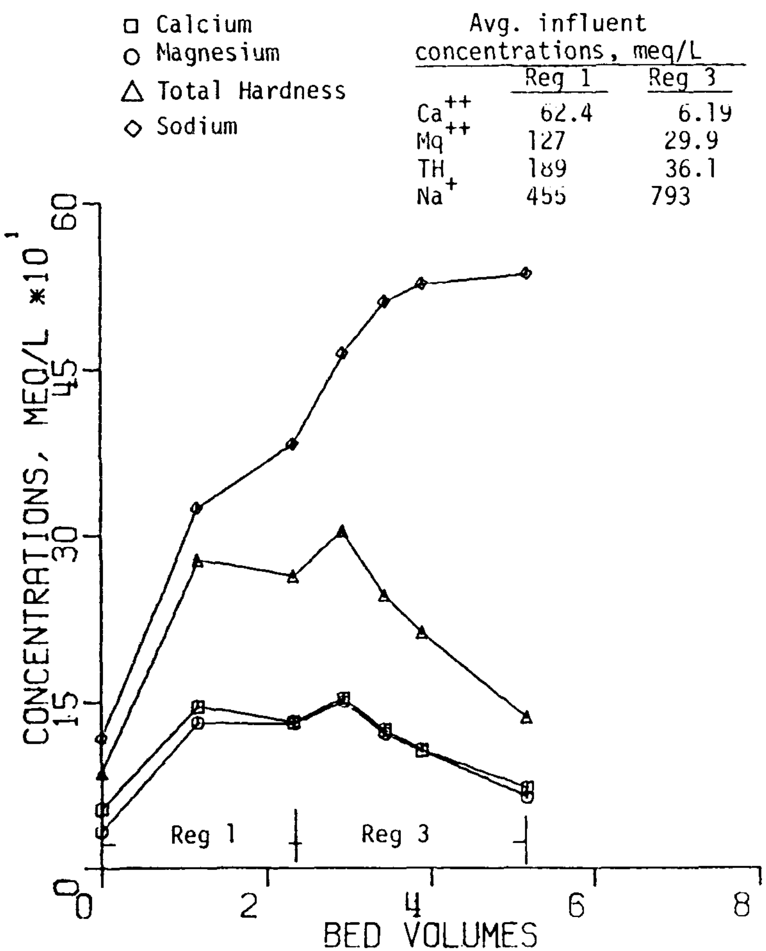
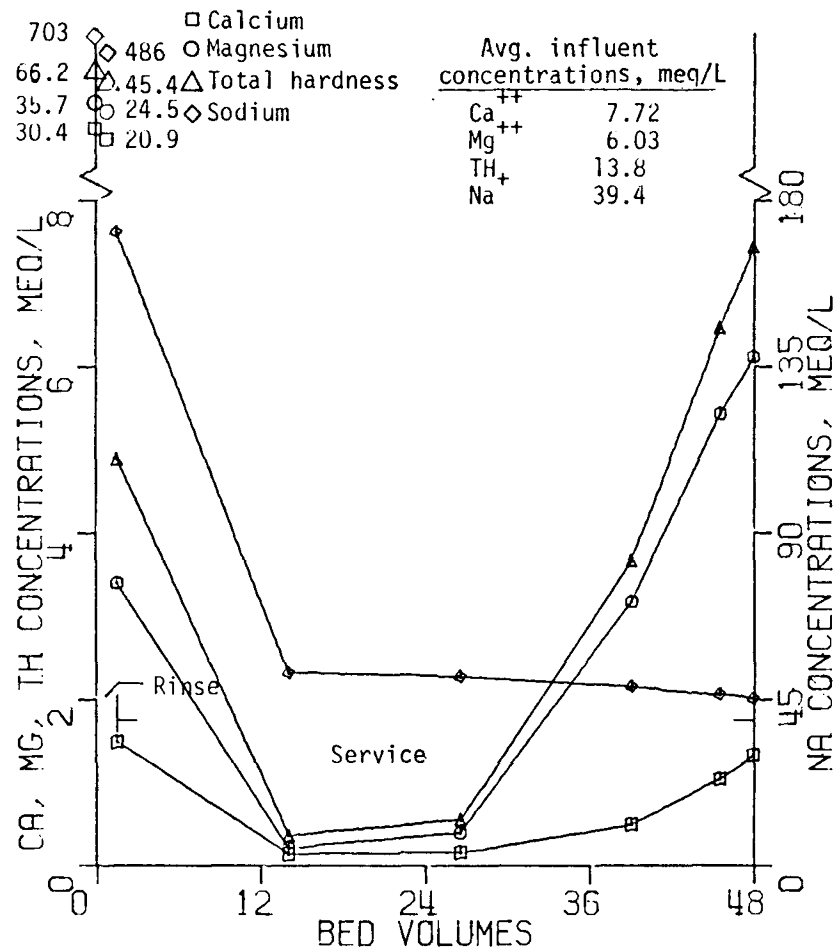


FIGURE A - b
MAJOR CATION CONCENTRATIONS OF
IX RINSE AND SERVICE EFFLUENTS
CYCLE 3.11.12



SODIUM (NA), CALCIUM (CA), AND MAGNESIUM (MG) CONCENTRATIONS ARE MEASURED BY ATOMIC ABSORPTION.
TOTAL HARDNESS (TH) IS CALCULATED BY SUMMING THE CALCIUM AND MAGNESIUM CONCENTRATIONS.

Ion-Exchange - Run 3.26.00D

Date: 5/26/79

Cycle: 3.26.12D

Conditions: Feedwater - Wellton-Mowhawk drainage pretreated (in Train IV) with high lime dosage for silica removal
Regenerants - recycled regenerant and fresh ED brine

Control variables:		Target	Actual
	Fresh regeneration conc. (mg/L TDS)	50 000	52 120
	Fresh regeneration flow rate (L/min)	5.5	5.5
	Recycled regenerant flow rate (L/min)	8.0	7.8
	Recycled regenerant volume (L)	800	800
	Service termination point (meq/L Ca^{++})	1.5	·1.6

Standard resin bed: Height = 1081 mm
Volume = 97.7 L

Chemical Compositions of Tank Waters Prior to Cycle 3.26.12D

Tank	pH units	Conductivity µS/cm	Ca^{++} meq/L	Mg^{++} meq/L	TH meq/L
Recycle regenerant (T-5)	-	50 671	73.5	118.0	192.0
Spent regenerant (T-6)	-	50 666	76.0	116.0	192.0
Lime-softened feed (T-9)	7.2	5 242	9.6	3.8	13.4
Lime softened feed (T-10)	7.4	5 224	9.6	3.8	13.4
Fresh ED brine (T-28)	4.0	61 491	6.8	23.7	30.5
IX product/ED feed (T-33)	7.2	5 480	0.36	1.0	1.4

Cycle 3.26.12D Operating Conditions

MODE	INPUT	OUTPUT	DURATION MIN	THROUGHPUT L	VOLUME BV	AVG FLOW RATE L/MIN	AVG FLOW RATE BV/MIN	BED EXPANSION %	TEMPERATURE C
REGEN 1	RE REGEN	WASTE	10	240	2.43	24.0	.243	47.	26.8
REGEN 2	RE REGEN	SP REGEN	102	800	8.11	7.82	.079	11.	
REGEN 3	FR REGEN	SP REGEN	55	299	3.03	5.48	.056	9.6	28.0
DRAIN 1	(VENT)	WASTE	3	62	.63	20.7	.209	0.0	
RINSE	FEED	WASTE	10	160	1.62	16.0	.162	0.0	
SERVICE	FEED	PRODUCT	185	5540	56.1	29.9	.303	0.0	
DRAIN 2	(VENT)	WASTE	2	41	.42	20.7	.209	0.0	

Fresh Regenerant Volume Balance

Run 3.26.00D Cycle no.	Date	Fresh regenerant volume (V_3) L	Estimated fresh regenerant TDS mg/L	Service volume (V_S) L	Estimated ED feed TDS mg/L	R %	$V_3/(1-R)V_S$
03	5/23/79	304	52 680	6530	3490	94	0.80
04	5/23/79	304	52 680	6610	3490	94	0.79
05	5/24/79	300	52 770	6020	3270	95	0.94
06	5/24/79	299	52 770	6050	3270	95	0.93
07	5/24/79	299	52 770	5890	3270	95	0.96
08	5/25/79	298	52 740	5770	3200	95	0.99
09	5/25/79	299	52 740	5700	3200	95	1.01
10	5/25/79	299	52 740	5730	3200	95	1.00
11	5/26/79	299	52 930	5670	3400	94	0.94
12	5/26/79	299	52 930	5540	3400	94	0.96

Influent and Effluent Compositions during Cycle 3.26.12D

	Units	Regen 1, 2 influent	Regen 1 effluent	Regen 2 effluent	Regen 3 Influent	Regen 3 Effluent	Rinse, service influent	Rinse effluent	Service effluent
pH	units	-	-	-	4.0	-	7.3	4.3	7.2
TDS (Σ ions)	mg/L	37 020	-	-	52 122	-	3290	42 902	4655
Conductivity @ 25 °C	μS/cm	-	-	-	61 950	-	4529	53 550	6713
E. F. (TDS/cond.)	-	-	-	-	0.84	-	0.73	0.80	0.69
Silica	mg/L	5.6	5.8	6.4	5.4	6.0	3.9	5.3	3.8
Calcium	mg/L	1430	2150	1950	118	1470	175	440	17.9
Magnesium	mg/L	1563	1061	1493	303	1376	47.2	343	31.3
Sodium	mg/L	10 220	5610	9350	18 450	11 470	927	14 610	1588
Potassium	mg/L	7.2	46	74	109	82	8.9	86	14.3
Strontium	mg/L	36	36	38	1.3	36	2.4	12.9	0.5
Bicarbonate	mg/L	58.6	73.2	73.2	35.6	73.2	17.6	24.4	19.5
Carbonate	mg/L	ND	ND	ND	ND	ND	ND	ND	ND
Hydroxide	mg/L	ND	ND	ND	ND	ND	ND	ND	ND
Sulfate	mg/L	4600	3340	4340	15 000	8480	928	12 080	1798
Chloride	mg/L	19 100	13 200	18 900	18 100	18 200	1180	15 300	1180
T-alkalinity as $CaCO_3$	mg/L	48.0	60.0	60.0	29.2	60.0	14.4	20.0	16.0
P-alkalinity as $CaCO_3$	mg/L	ND	ND	ND	ND	ND	ND	ND	ND
ΣAnions	meq/L	635.6	443.1	624.8	823.6	691.3	52.91	683.6	71.06
ΣCations	meq/L	645.5	440.6	629.6	836.2	688.4	53.22	688.2	72.87
Control value	meq/L	-1.00	+0.37	-0.49	-0.98	+0.26	-0.34	-0.43	-1.50

Major Cation Concentrations of Samples Analyzed by Atomic Absorption

CYCLE 3.26.12D

MODE	PROCESS STREAM	THROUGHPUT BV	CA MEQ/L	MG MEQ/L	TH MEQ/L	NA MEQ/L
REGEN 1	EFFLUENT	0.00	23.70	10.86	34.57	63.90
REGEN 1	EFFLUENT	1.22	168.16	126.01	294.17	294.04
REGEN 2	EFFLUENT	2.43	133.73	128.48	262.21	373.21
REGEN 2	INFLUENT	4.41	71.36	128.64	200.00	444.54
REGEN 2	EFFLUENT	6.39	87.33	124.53	211.85	429.32
REGEN 3	EFFLUENT	10.51	72.85	126.50	199.36	439.76
REGEN 3	INFLUENT	10.85	5.89	24.94	30.83	802.52
REGEN 3	EFFLUENT	11.13	93.81	158.44	252.25	478.47
REGEN 3	EFFLUENT	11.74	77.84	125.19	203.03	535.02
REGEN 3	EFFLUENT	12.35	68.86	106.17	175.04	562.42
REGEN 3	EFFLUENT	13.58	58.88	63.46	122.34	555.02
RINSE	EFFLUENT	0.00	23.65	30.12	53.78	730.32
RINSE	EFFLUENT	.81	21.51	27.90	49.41	576.34
SERVICE	EFFLUENT	1.62	.96	3.23	4.19	168.77
SERVICE	INFLUENT	4.35	9.08	3.91	12.99	39.97
SERVICE	EFFLUENT	16.49	.12	1.72	1.84	52.63
SERVICE	INFLUENT	23.77	8.98	3.91	12.89	39.84
SERVICE	EFFLUENT	31.05	.13	2.27	2.40	52.63
SERVICE	EFFLUENT	45.92	.38	2.13	2.52	50.72
SERVICE	EFFLUENT	53.50	1.04	4.42	5.46	47.50
SERVICE	INFLUENT	57.75	8.88	3.92	12.80	39.45
SERVICE	EFFLUENT	57.75	1.61	5.39	7.00	46.24

Service Performance Summary

CYCLE 3.26.12D

	AVERAGE CONCENTRATIONS, MEQ/L			REMOVAL	RESIN CAPACITY
	INFLUENT	EFFLUENT	DIFFERENCE	%	EQ/L
CA	8.98	.44	8.54	95	.479
MG	3.91	2.57	1.34	34	.075
TH	12.89	3.01	9.88	77	.555
NA	39.76	66.85	-27.09		

FIGURE A- a
MAJOR CATION CONCENTRATIONS
OF IX REGENERATION EFFLUENT
CYCLE 3.26.12D

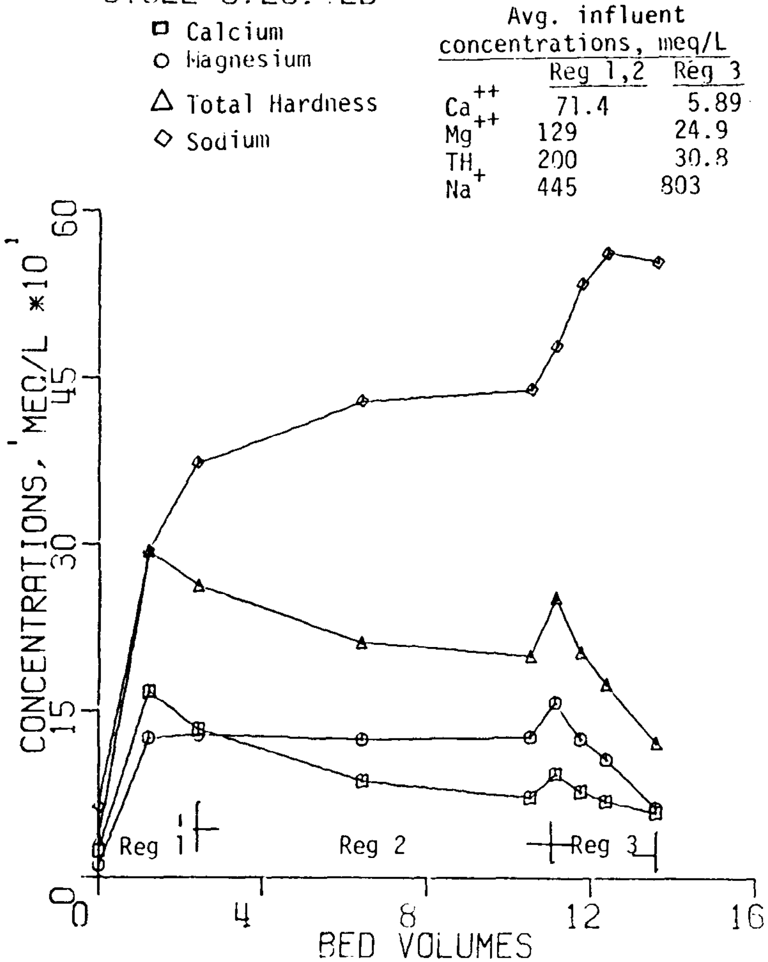
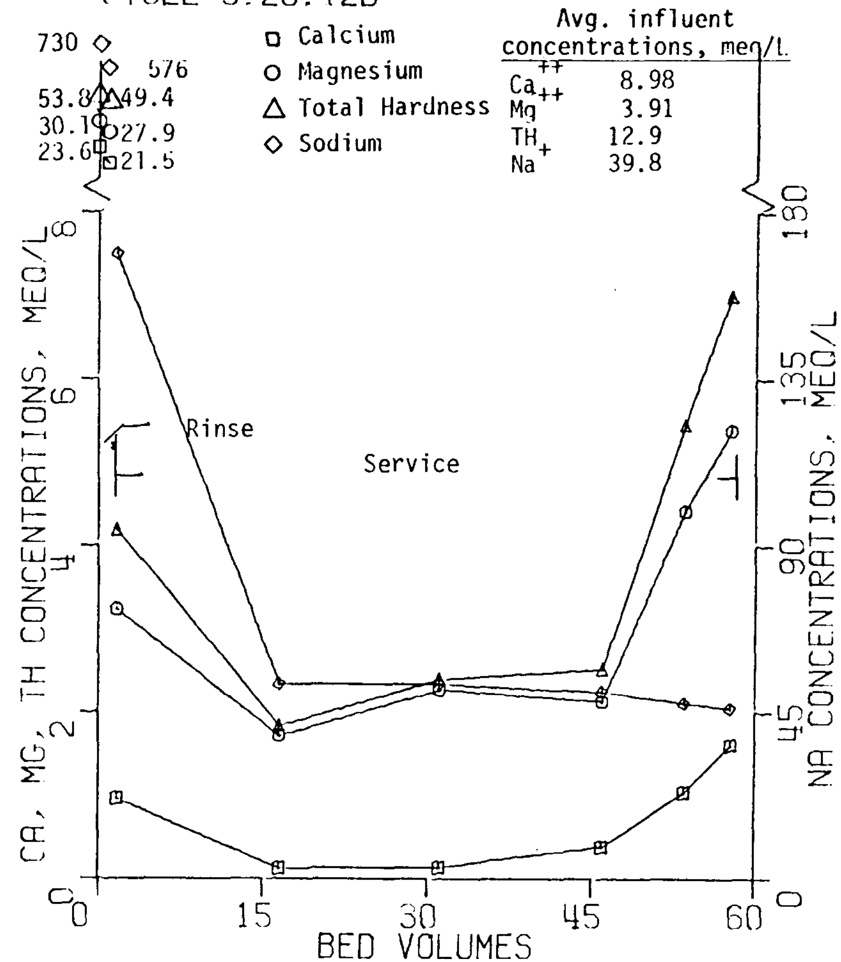


FIGURE A- b
MAJOR CATION CONCENTRATIONS OF
IX RINSE AND SERVICE EFFLUENTS
CYCLE 3.26.12D



SODIUM (NA), CALCIUM (CA), AND MAGNESIUM (MG) CONCENTRATIONS ARE MEASURED BY ATOMIC ABSORPTION.
TOTAL HARDNESS (TH) IS CALCULATED BY SUMMING THE CALCIUM AND MAGNESIUM CONCENTRATIONS.

Ion-Exchange - Run 3.27.25D

Date: 6/2/79

Cycle: 3.27.25D

Conditions: Feedwater - Wellton-Mowhawk drainage pretreated (in Train IV) with high lime dosage for silica removal
Regenerants - recycled regenerant and fresh ED brine

Control variables:

	Target	Actual
Fresh regeneration conc. (mg/L TDS)	50 000	53 400
Fresh regeneration flow rate (L/min)	5.5	5.4
Recycled regenerant flow rate (L/min)	24.0	24.2
Recycled regenerant volume (L)	800	800
Service termination point (meq/L Ca^{++})	1.5	1.6

Standard resin bed: Height = 1081 mm
Volume = 98.7 L

Chemical Compositions of Tank Waters Prior to Cycle 3.27.25D

Tank	pH units	Conductivity μS/cm	Ca^{++} meq/L	Mg^{++} meq/L	TH meq/L
Recycle regenerant (T-5)	-	49 197	80.0	128.0	208.0
Spent regenerant (T-6)	-	48 998	96.0	126.0	222.0
Lime-softened feed (T-9)	7.3	5 343	9.6	4.4	14.0
Lime softened feed (T-10)	7.2	5 336	10.0	4.0	14.0
Fresh ED brine (T-28)	3.9	62 028	8.0	23.0	31.0
IX product/ED feed (T-33)	7.2	5 788	0.64	1.0	1.6

Cycle 3.27.25D Operating Conditions

MODE	INPUT	OUTPUT	DURATION MIN	THROUGHPUT L	VOLUME BV	AVG FLOW RATE L/MIN	BV/MIN	BED EXPANSION %	TEMPERATURE C
REGEN 1	RE REGEN	WASTE	10	240	2.43	24.0	.243	49.	26.0
REGEN 2	RE REGEN	SP REGEN	33	800	8.11	24.2	.246	49.	
REGEN 3	FR REGEN	SP REGEN	50	271	2.75	5.42	.055	9.6	28.0
DRAIN 1	(VENT)	WASTE	3	62	.63	20.7	.209	0	
RINSE	FEED	WASTE	10	140	1.42	14.0	.142	0	
SERVICE	FEED	PRODUCT	162	4780	48.4	29.5	.299	0	
DRAIN 2	(VENT)	WASTE	2	41	.42	20.7	.209	0	

C16—2

Fresh Regenerant Volume Balance

Run 3.27.00D Cycle no.	Date	Fresh regenerant volume (V_3) L	Fresh regenerant TDS mg/L	Service volume (V_S) L	Estimated ED feed TDS mg/L	R %	$V_3/(1-R)V_S$
03	5/27/79	299	52 930	5580	3400	94	0.96
04	5/27/79	299	52 930	5330	3400	94	1.00
05	5/27/79	300	52 930	5190	3400	94	1.03
06	5/28/79	299	52 930	5260	3400	94	1.01
07	5/28/79	298	52 930	5480	3400	94	0.97
08	5/28/79	299	52 930	4980	3400	94	1.07
09	5/28/79	273	52 930	4920	3400	94	0.99
10	5/29/79	271	53 400	4730	3480	94	1.00
11	5/29/79	272	53 400	4950	3480	94	0.96
12	5/29/79	273	53 400	4630	3480	94	1.03
13	5/29/79	271	53 400	4700	3480	94	1.01
14	5/30/79	272	53 640	4760	3860	94	0.89
15	5/30/79	-	53 640	-	3860	94	-
18	5/31/79	694	53 400	5990	3580	94	1.97
19	6/1/79	271	53 510	4810	3610	94	0.95
20	6/1/79	272	53 510	5010	3610	94	0.92
21	6/1/79	272	53 510	4780	3610	94	0.96
22	6/1/79	274	53 510	4640	3610	94	1.00
23	6/1/79	272	53 510	4740	3610	94	0.97
24	6/2/79	270	53 760	4660	3590	94	1.01
25	6/2/79	271	53 760	4780	3590	94	0.98

Influent and Effluent Compositions during Cycle 3.27.25D

	Units	Regen 1, 2 influent	Regen 1 effluent	Regen 2 effluent	Regen 3 Influent	Regen 3 Effluent	Rinse, service influent	Rinse effluent	Service effluent
pH	units	-	-	-	3.9	-	7.3	4.2	6.7
TDS (Σ ions)	mg/L	35 600	-	-	53 402	-	3549	43 624	5562
Conductivity @ 25 °C	µS/cm	-	-	-	62 515	-	5463	53 328	7890
E. F. (TDS/cond.)	-	-	-	-	0.85	-	0.65	0.82	0.70
Silica	mg/L	5.8	5.6	6.2	4.9	5.4	4.5	4.9	4.7
Calcium	mg/L	1520	1920	1890	125	1560	177	463	26.9
Magnesium	mg/L	1419	1108	1478	276	1286	60.1	342	37.9
Sodium	mg/L	9820	6190	9230	18 540	11 850	1017	14 980	1862
Potassium	mg/L	67	46	65	134	77	8.4	103	15.5
Strontium	mg/L	35	34	38	2.1	37	2.9	11.5	0.8
Bicarbonate	mg/L	73.2	97.6	73.2	ND	97.6	19.5	ND	19.5
Carbonate	mg/L	ND	ND	ND	ND	ND	ND	ND,	ND
Hydroxide	mg/L	ND	ND	ND	ND	ND	ND	ND	ND
Sulfate	mg/L	4060	3560	4400	16 000	8500	990	11 500	2375
Chloride	mg/L	18 600	13 500	18 500	18 320	18 100	1270	16 220	1220
T-alkalinity as $CaCO_3$	mg/L	60.0	80.0	60.0	ND	80.0	16.0	ND	16.0
T-acidity as $CaCO_3$	mg/L	-	-	-	12.0	-	-	10.0	-
ΣAnions	meq/L	610.5	456.6	614.7	850.1	689.3	56.77	697.1	84.20
ΣCations	meq/L	621.5	458.2	619.9	838.9	701.9	58.30	705.8	85.87
Control value	meq/L	-1.15	-0.22	-0.54	+0.84	-1.17	-1.55	-0.79	-1.17

Major Cation Concentrations of Samples Analyzed by Atomic Absorption

CYCLE 3.27.25D

MODE	PROCESS STREAM	THROUGHPUT BV	CA MEQ/L	MG MEQ/L	TH MEQ/L	NA MEQ/L
REGEN 1	EFFLUENT	0.00	44.41	28.48	72.89	117.44
REGEN 1	EFFLUENT	1.22	124.25	117.53	241.78	308.83
REGEN 2	EFFLUENT	2.43	116.27	124.28	240.55	369.73
REGEN 2	INFLUENT	4.64	75.85	116.79	192.64	427.14
REGEN 2	EFFLUENT	6.61	87.82	117.94	205.77	417.14
REGEN 3	EFFLUENT	10.54	80.84	119.51	200.34	423.23
REGEN 3	INFLUENT	10.81	6.24	22.72	28.95	806.44
REGEN 3	EFFLUENT	11.08	98.80	145.19	243.99	487.17
REGEN 3	EFFLUENT	11.69	82.83	118.85	201.68	523.27
REGEN 3	EFFLUENT	12.29	66.87	90.53	157.40	577.21
REGEN 3	EFFLUENT	13.27	60.38	61.32	121.70	622.01
RINSE	EFFLUENT	0.00	24.40	27.65	52.06	713.79
RINSE	EFFLUENT	.71	22.26	27.98	50.24	585.04
SERVICE	EFFLUENT	1.42	1.44	5.37	6.80	223.58
SERVICE	INFLUENT	4.11	8.68	4.81	13.50	41.71
SERVICE	EFFLUENT	14.27	.20	.21	.41	55.07
SERVICE	INFLUENT	20.85	8.68	4.74	13.42	41.45
SERVICE	EFFLUENT	27.13	.21	.32	.54	55.55
SERVICE	EFFLUENT	39.98	.47	2.18	2.66	52.46
SERVICE	EFFLUENT	46.56	1.06	4.59	5.66	49.46
SERVICE	INFLUENT	49.85	8.63	4.77	13.41	41.71
SERVICE	EFFLUENT	49.85	1.55	5.75	7.30	48.11

Service Performance Summary

CYCLE 3.27.25D

	AVERAGE CONCENTRATIONS, MEQ/L INFLUENT	EFFLUENT	DIFFERENCE	REMOVAL %	RESIN CAPACITY EQ/L
CA	8.67	.56	8.11	94	.393
MG	4.78	1.95	2.82	59	.137
TH	13.44	2.51	10.93	81	.529
NA	41.63	76.23	-34.60		

FIGURE A- a
MAJOR CATION CONCENTRATIONS
OF IX REGENERATION EFFLUENT
CYCLE 3.27.25D

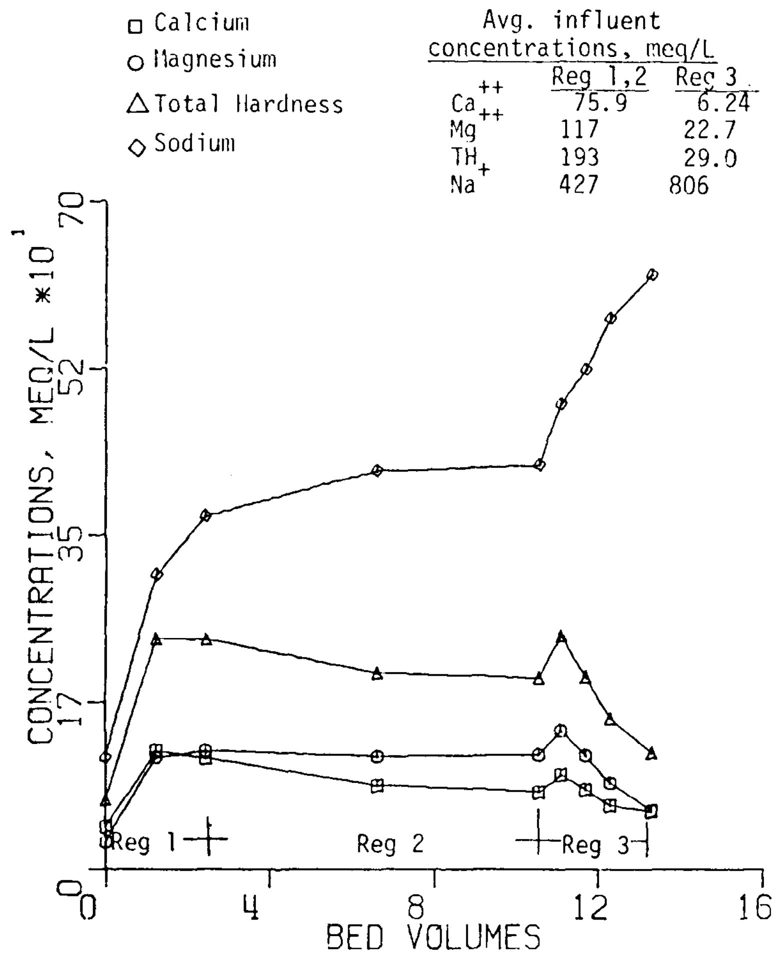
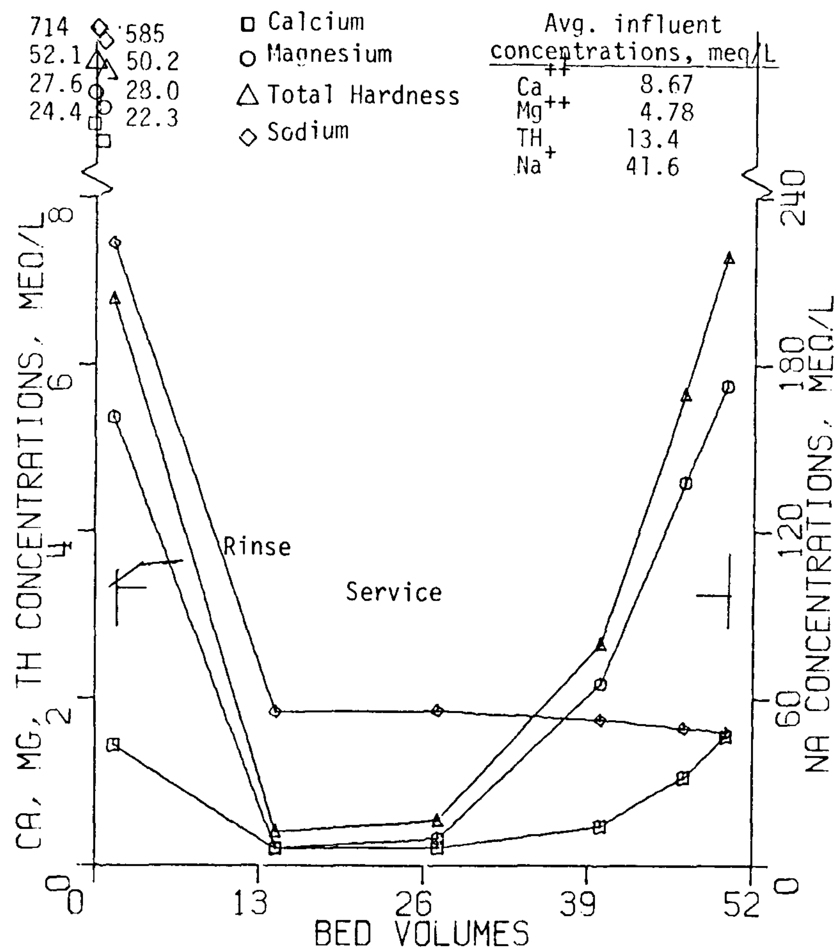


FIGURE A- b
MAJOR CATION CONCENTRATIONS OF
IX RINSE AND SERVICE EFFLUENTS
CYCLE 3.27.25D



SODIUM (NA), CALCIUM (CA), AND MAGNESIUM (MG) CONCENTRATIONS ARE MEASURED BY ATOMIC ABSORPTION.
TOTAL HARDNESS (TH) IS CALCULATED BY SUMMING THE CALCIUM AND MAGNESIUM CONCENTRATIONS.

Ion-Exchange - Run 3.12.00

Date: 6/6/79

Cycle: 3.12.09

Conditions: Feedwater - Wellton-Mowhawk drainage pretreated (in Train IV) with high lime dosage for silica removal
Regenerants - recycled regenerant and fresh ED brine

Control variables:

	Target	Actual
Fresh regeneration conc. (mg/L TDS)	35 000	35 660
Fresh regeneration flow rate (L/min)	3.0	3.1
Recycled regenerant flow rate (L/min)	8.0	8.1
Recycled regenerant volume (L)	800	800
Service termination point (meq/L Ca^{++})	3.0	2.8

Standard resin bed: Height = 1081 mm
Volume = 98.7 L

Chemical Compositions of Tank Waters Prior to Cycle 3.12.09

Tank	pH units	Conductivity µS/cm	Ca^{++} meq/L	Mg^{++} meq/L	TH meq/L
Recycle regenerant (T-5)	-	37 099	63.5	78.5	142.0
Spent regenerant (T-6)	-	36 910	71.5	68.5	140.0
Lime-softened feed (T-9)	7.4	5 355	9.4	4.2	13.6
Lime softened feed (T-10)	7.4	5 345	9.8	4.2	14.0
Fresh ED brine (T-28)	4.3	44 870	6.6	17.4	24.0
IX product/ED feed (T-33)	6.8	5 836	0.68	1.7	2.4

Cycle 3.12.09 Operating Conditions

MODE	INPUT	OUTPUT	DURATION MIN	THROUGHPUT L	VOLUME BV	AVG FLOW RATE L/MIN	AVG FLOW RATE BV/MIN	BED EXPANSION %	TEMPERATURE C
REGEN 1	RE REGEN	WASTE	10	240	2.43	24.0	.243	44.	27.1
REGEN 2	RE REGEN	SP REGEN	99	800	8.11	8.06	.082	8.9	
REGEN 3	FR REGEN	SP REGEN	146	452	4.58	3.09	.031	1.8	28.7
DRAIN 1	(VENT)	WASTE	3	62	.63	20.7	.209	0.0	
RINSE	FEED	WASTE	10	140	1.42	14.0	.142	0.0	
SERVICE	FEED	PRODUCT	175	5250	53.2	30.0	.304	0.0	
DRAIN 2	(VENT)	WASTE	2	41	.42	20.7	.209	0.0	

Fresh Regenerant Volume Balance

Run 3.12.00 Cycle no.	Date	Fresh regenerant volume (V_3) L	Fresh regenerant TDS mg/L	Service volume (V_S) L	Estimated ED feed TDS mg/L	R %	$V_3/(1-R)V_S$
02	6/3/79	450	36 440	6030	3540	91	0.88
03	6/4/79	452	36 440	5470	3540	91	0.97
04	6/4/79	451	36 440	5260	3540	91	1.01
05	6/4/79	452	36 440	5200	3540	91	1.02
06	6/5/79	452	36 330	5170	3590	91	1.00
07	6/5/79	454	36 330	5250	3590	91	0.99
08	6/5/79	453	36 330	5130	3590	91	1.02
09	6/6/79	452	35 580	5250	3620	91	0.96

Influent and Effluent Compositions during Cycle 3.12.09

	Units	Regen 1, 2 influent	Regen 1 effluent	Regen 2 effluent	Regen 3 Influent	Regen 3 Effluent	Rinse, service influent	Rinse effluent	Service effluent
pH	units	-	-	-	4.3	-	7.3	4.4	6.9
TDS (Σ ions)	mg/L	26 584	18 169	26 261	35 655	31 363	3411	34 061	4833
Conductivity @ 25 °C	μS/cm	-	-	-	44 651	-	5345	42 360	7522
E. F. (TDS/cond.)	-	-	-	-	0.80	-	0.64	0.80	0.64
Silica	mg/L	4.8	4.6	4.8	4.5	4.6	3.7	4.4	3.7
Calcium	mg/L	1230	1480	1620	139	1220	172	300	26.9
Magnesium	mg/L	960	687	950	197	731	55.6	187	34.3
Sodium	mg/L	7240	4140	6700	12 520	9000	968	11 700	1721
Potassium	mg/L	49	30	45	72	51	7.9	83	14.5
Strontium	mg/L	27	28	28	2.4	23	2.6	6.5	0.5
Bicarbonate	mg/L	73.2	58.6.	73.2	ND	73.2	19.5	ND	22.0
Carbonate	mg/L	ND	ND	ND	ND	ND	ND	ND	ND
Hydroxide	mg/L	ND	ND	ND	ND	ND	ND	ND	ND
Sulfate	mg/L	4000	3240	4000	10 600	7200	970	9900	2150
Chloride	mg/L	13 000	8500	12 840	12 120	13 060	1212	11 880	1200
T-alkalinity as $CaCO_3$	mg/L	60.0	48.0	60.0	ND	60.0	16.0	ND	18.0
T-acidity as $CaCO_3$	mg/L	-	-	-	16.0	-	-	14.0	-
ΣAnions	meq/L	451.2	308.2	446.7	562.7	519.6	54.71	541.4	78.64
ΣCations	meq/L	457.2	311.9	452.2	569.7	514.3	55.52	541.6	79.41
Control value	meq/L	-0.83	-0.74	-0.78	-0.79	+0.64	-0.84	-0.03	-0.58

Major Cation Concentrations of Samples Analyzed by Atomic Absorption

CYCLE 3.12.09

MODE	PROCESS STREAM	THROUGHPUT BV	CA MEQ/L	MG MEQ/L	TH MEQ/L	NA MEQ/L
REGEN 1	EFFLUENT	0.00	38.42	21.65	60.07	90.91
REGEN 1	EFFLUENT	1.46	99.30	79.09	178.40	223.14
REGEN 2	EFFLUENT	2.43	94.81	84.53	179.34	265.33
REGEN 2	INFLUENT	2.92	61.38	79.01	140.39	314.92
REGEN 2	EFFLUENT	6.27	78.84	75.64	154.48	291.43
REGEN 3	EFFLUENT	10.51	66.87	76.21	143.08	430.19
REGEN 3	INFLUENT	10.80	6.94	16.21	23.15	299.57
REGEN 3	EFFLUENT	11.64	69.86	86.01	155.87	331.88
REGEN 3	EFFLUENT	12.77	64.87	72.59	137.46	377.12
REGEN 3	EFFLUENT	13.90	46.91	36.87	83.78	448.46
REGEN 3	EFFLUENT	15.10	58.38	29.38	87.77	485.86
RINSE	EFFLUENT	0.00	12.67	15.47	28.15	534.58
RINSE	EFFLUENT	.71	17.12	15.47	32.59	487.17
SERVICE	EFFLUENT	1.42	1.17	3.64	4.81	203.57
SERVICE	INFLUENT	4.15	8.63	4.68	13.32	42.06
SERVICE	EFFLUENT	14.79	.18	.17	.36	54.94
SERVICE	INFLUENT	26.95	8.48	4.67	13.16	41.24
SERVICE	EFFLUENT	28.17	.20	.25	.45	53.72
SERVICE	EFFLUENT	41.54	.54	2.23	2.77	51.50
SERVICE	EFFLUENT	48.23	1.38	4.88	6.26	48.11
SERVICE	INFLUENT	54.61	8.58	4.69	13.27	41.45
SERVICE	EFFLUENT	54.61	2.84	6.39	9.23	45.24

Service Performance Summary

CYCLE 3.12.09

	AVERAGE CONCENTRATIONS, MEQ/L			REMOVAL	RESIN CAPACITY
	INFLUENT	EFFLUENT	DIFFERENCE	%	EQ/L
CA	8.57	.69	7.88	92	.419
MG	4.68	1.97	2.72	58	.145
TH	13.25	2.65	10.60	80	.564
NA	41.58	71.25	-29.66		

FIGURE A- a
MAJOR CATION CONCENTRATIONS
OF IX REGENERATION EFFLUENT
CYCLE 3.12.09

□ Calcium
○ Magnesium
△ Total Hardness
◇ Sodium

Avg. influent concentrations meq/L

	Reg 1,2	Reg 3
Ca^{++}	61.4	6.94
Mg^{++}	79.0	16.2
TH	140	23.2
Na^{+}	315	300

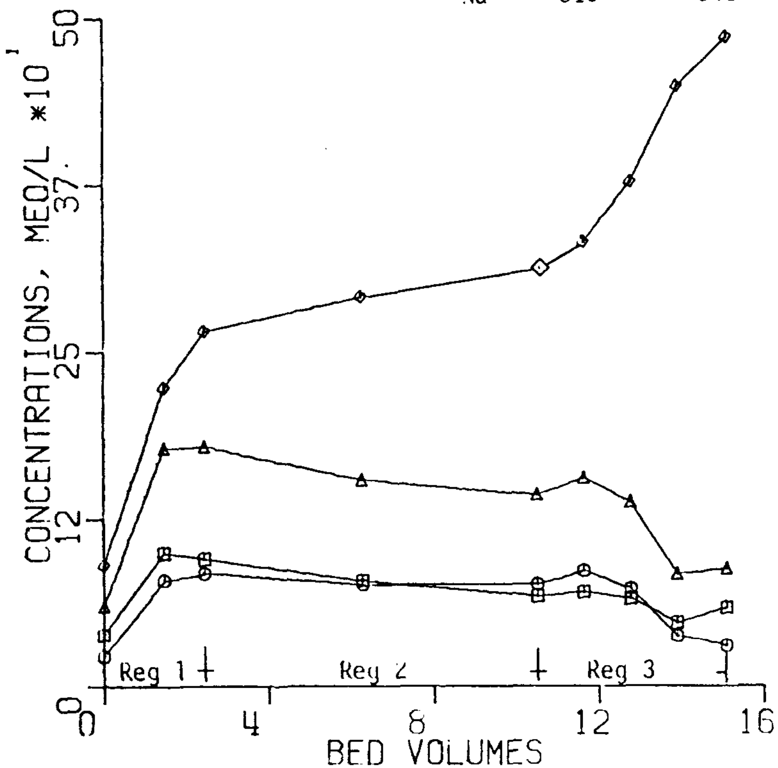
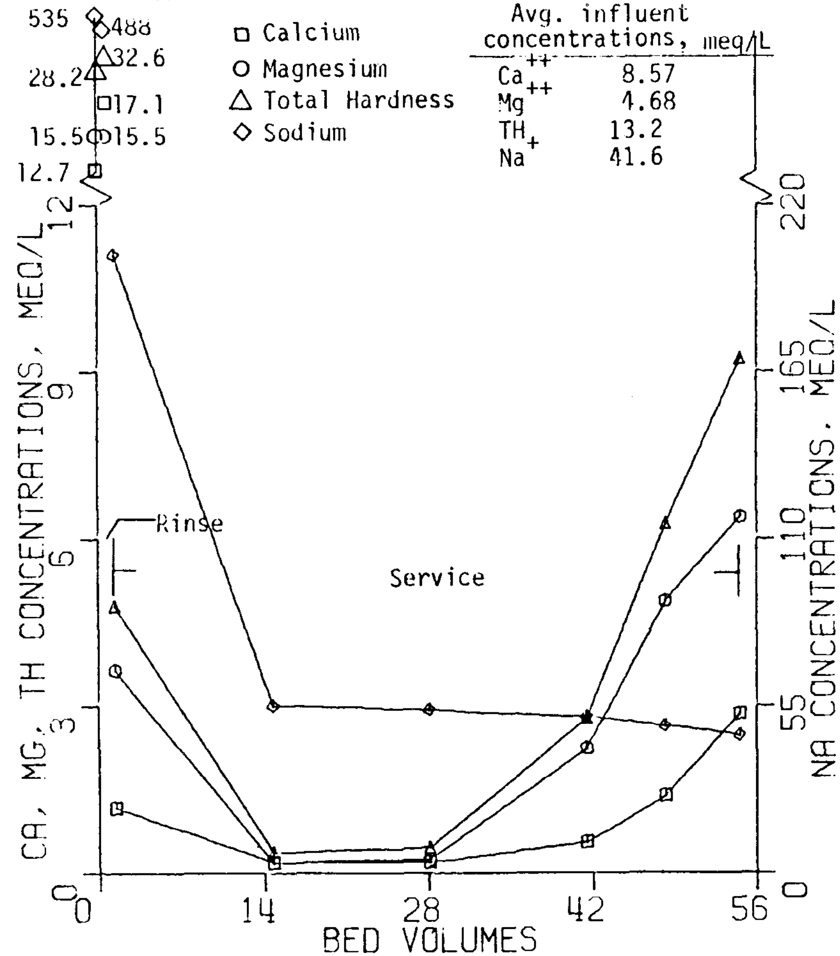


FIGURE A- b
MAJOR CATION CONCENTRATIONS OF
IX RINSE AND SERVICE EFFLUENTS
CYCLE 3.12.09

□ Calcium
○ Magnesium
△ Total Hardness
◇ Sodium

Avg. influent concentrations, meq/L

Ca^{++}	8.57
Mg^{++}	4.68
TH_{+}	13.2
Na	41.6



SODIUM (NA), CALCIUM (CA), AND MAGNESIUM (MG) CONCENTRATIONS ARE MEASURED BY ATOMIC ABSORPTION.
TOTAL HARDNESS (TH) IS CALCULATED BY SUMMING THE CALCIUM AND MAGNESIUM CONCENTRATIONS.

Ion-Exchange - Run 3.13.00

Date: 6/8/79

Cycle: 3.13.08

Conditions: Feedwater - Wellton-Mowhawk drainage pretreated (in Train IV) with high lime dosage for silica removal
Regenerants - recycled regenerant and fresh ED brine

Control variables:

	Target	Actual
Fresh regeneration conc. (mg/L TDS)	35 000	33 930
Fresh regeneration flow rate (L/min)	3.0	3.0
Recycled regenerant flow rate (L/min)	24.0	24.6
Recycled regenerant volume (L)	800	800
Service termination point (meq/L Ca^{++})	3.0	3.2

Standard resin bed: Height = 1081 mm
Volume = 98.7 L

Chemical Compositions of Tank Waters Prior to Cycle 3.13.08

Tank	pH units	Conductivity uS/cm	Ca^{++} meq/L	Mg^{++} meq/L	TH meq/L
Recycle regenerant (T-5)	-	37 192	70.0	71.0	141.0
Spent regenerant (T-6)	-	37 109	68.5	69.5	138.0
Lime-softened feed (T-9)	7.4	5 284	8.6	4.8	13.4
Lime softened feed (T-10)	7.5	5 139	9.0	4.6	13.6
Fresh ED brine (T-28)	4.8	42 970	6.0	16.8	22.8
IX product/ED feed (T-33)	7.1	5 675	0.48	1.4	1.9

Cycle 3.13.08 Operating Conditions

MODE	INPUT	OUTPUT	DURATION MIN	THROUGHPUT L	VOLUME BV	AVG FLOW RATE L/MIN	AVG FLOW RATE BV/MIN	BED EXPANSION %	TEMPERATURE C
REGEN 1	RE REGEN	WASTE	10	240	2.43	24.0	.243	42.	28.3
REGEN 2	RE REGEN	SP REGEN	33	800	8.11	24.6	.249	42.	
REGEN 3	FR REGEN	SP REGEN	153	452	4.58	2.96	.030	5.5	31.5
DRAIN 1	(VENT)	WASTE	3	62	.63	20.7	.209	0.0	
RINSE	FEED	WASTE	10	150	1.52	15.0	.152	0.0	
SERVICE	FEED	PRODUCT	183	5410	54.8	29.6	.300	0.0	
DRAIN 2	(VENT)	WASTE	2	41	.42	20.7	.209	0.0	

C18—2

Fresh Regenerant Volume Balance

Run 3.13.00 Cycle no.	Date	Fresh regenerant volume (V_3) L	Fresh regenerant TDS mg/L	Service volume (V_S) L	Estimated ED feed TDS mg/L	R %	$V_3/(1-R)V_S$
03	6/7/79	451	34 510	5460	3520	91	0.93
04	6/7/79	451	34 510	5600	3520	91	0.91
05	6/7/79	451	34 510	5510	3520	91	0.92
06	6/8/79	453	34 040	5170	3520	91	0.96
07	6/8/79	452	34 040	5550	3520	91	0.90
08	6/8/79	452	34 040	5410	3520	91	0.92

Influent and Effluent Compositions during Cycle 3.13.08

	Units	Regen 1, 2 influent	Regen 1 effluent	Regen 2 effluent	Regen 3 Influent	Regen 3 Effluent	Rinse, service influent	Rinse effluent	Service effluent
pH	units	-	-	-	4.8	-	7.3	5.1	7.2
TDS (Σ ions)	mg/L	26 999	19 932	26 397	33 927	30 788	3346	32 107	4524
Conductivity @ 25 °C	µS/cm	-	-	-	42 735	-	5193	40 356	6694
E. F. (TDS/cond.)	-	-	-	-	0.79	-	0.64	0.80	0.68
Silica	mg/L	5.2	4.4	5.0	4.2	4.8	4.1	4.3	4.2
Calcium	mg/L	1260	1620	1650	119	1300	171	261	28.4
Magnesium	mg/L	947	736	945	223	735	59.6	208	39.7
Sodium	mg/L	7290	4470	6760	11 890	8840	941	11 090	1509
Potassium	mg/L	46	34	48	92	57	8.4	88	15.1
Strontium	mg/L	18	19	20	1.2	18	1.9	3.5	0.5
Bicarbonate	mg/L	73.2	48.8	48.8	97.6	73.2	19.5	12.2	19.5
Carbonate	mg/L	ND	ND	ND	ND	ND	ND	ND	ND
Hydroxide	mg/L	ND	ND	ND	ND	ND	ND	ND	ND
Sulfate	mg/L	4300	3400	4200	9600	6860	960	9040	1740
Chloride	mg/L	13 060	9600	12 720	11 900	12 900	1180	11 400	1168
T-alkalinity as $CaCO_3$	mg/L	60.0	40.0	40.0	80.0	60.0	16.0	10.0	16.0
T-acidity as $CaCO_3$	mg/L	-	-	-	-	-	-	-	-
ΣAnions	meq/L	459.2	342.4	447.1	537.3	508.0	53.60	410.1	69.51
ΣCations	meq/L	459.4	337.1	455.8	543.9	411.7	54.62	514.9	70.72
Control value	meq/L	-0.04	+0.98	-1.23	-0.78	-0.46	-1.09	-0.60	-1.02

Major Cation Concentrations of Samples Analyzed by Atomic Absorption

CYCLE 3.13.08

MODE	PROCESS STREAM	THROUGHPUT BV	CA MEQ/L	MG MEQ/L	TH MEQ/L	NA MEQ/L
REGEN 1	EFFLUENT	0.00	38.42	22.22	60.65	94.39
REGEN 1	EFFLUENT	1.22	107.78	79.18	186.96	228.80
REGEN 2	EFFLUENT	2.43	100.80	81.48	182.28	267.51
REGEN 2	INFLUENT	3.93	62.87	77.94	140.82	317.09
REGEN 2	EFFLUENT	6.67	77.84	77.12	154.96	305.79
REGEN 3	EFFLUENT	10.66	70.36	76.30	146.66	311.44
REGEN 3	INFLUENT	10.90	5.94	18.35	24.29	517.18
REGEN 3	EFFLUENT	11.73	71.36	83.46	154.81	336.23
REGEN 3	EFFLUENT	12.82	65.37	70.29	135.66	349.28
REGEN 3	EFFLUENT	13.91	49.90	37.37	87.27	428.01
REGEN 3	EFFLUENT	15.31	64.87	34.07	98.94	454.55
RINSE	EFFLUENT	0.00	10.13	17.70	27.83	511.96
RINSE	EFFLUENT	.76	16.32	16.05	32.37	461.07
SERVICE	EFFLUENT	1.52	3.79	2.93	6.72	171.81
SERVICE	INFLUENT	4.22	8.53	4.86	13.40	40.58
SERVICE	EFFLUENT	14.10	.16	.19	.35	52.59
SERVICE	INFLUENT	16.20	8.63	4.86	13.49	39.76
SERVICE	EFFLUENT	29.67	.18	.31	.49	52.33
SERVICE	EFFLUENT	42.25	.61	2.86	3.48	49.72
SERVICE	EFFLUENT	45.55	.95	3.98	4.93	48.50
SERVICE	EFFLUENT	51.54	2.10	5.93	8.03	45.06
SERVICE	INFLUENT	56.33	8.63	4.91	13.54	40.32
SERVICE	EFFLUENT	56.33	3.24	6.72	9.97	43.80

Service Performance Summary

CYCLE 3.13.08

	AVERAGE CONCENTRATIONS, MEQ/L INFLUENT	EFFLUENT	DIFFERENCE	REMOVAL %	RESIN CAPACITY EQ/L
CA	8.60	1.04	7.56	88	.414
MG	4.88	2.09	2.78	57	.152
TH	13.47	3.14	10.34	77	.567
NA	40.22	64.32	-24.10		

FIGURE A- a
MAJOR CATION CONCENTRATIONS
OF IX REGENERATION EFFLUENT
CYCLE 5.13.05

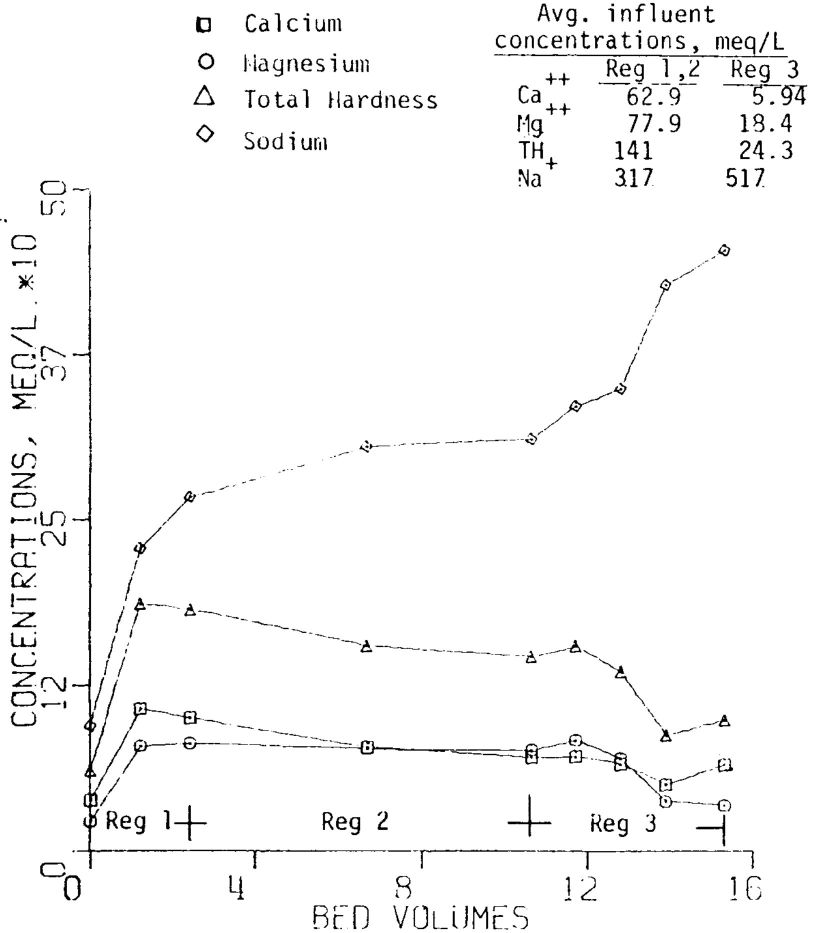
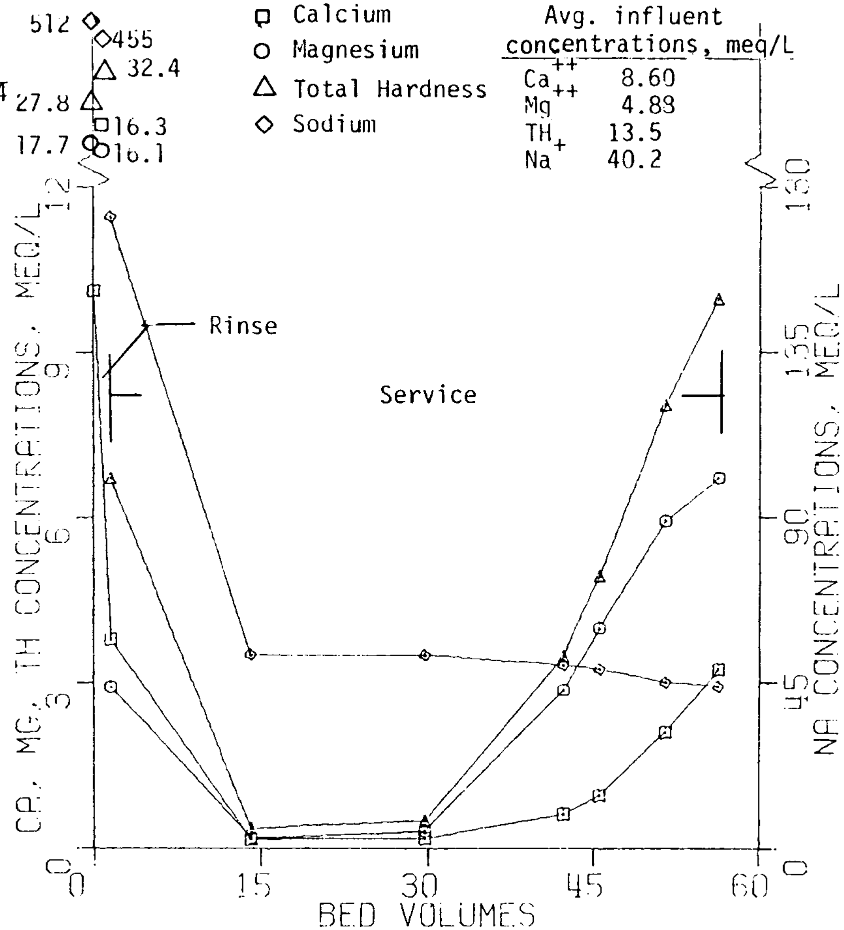


FIGURE A- b
MAJOR CATION CONCENTRATIONS OF
IX RINSE AND SERVICE EFFLUENTS
CYCLE 5.13.06



SODIUM (NA), CALCIUM (CA), AND MAGNESIUM (MG) CONCENTRATIONS ARE MEASURED BY ATOMIC ABSORPTION.
TOTAL HARDNESS (TH) IS CALCULATED BY SUMMING THE CALCIUM AND MAGNESIUM CONCENTRATIONS.

Ion-Exchange - Run 3.14.00

Date: 6/11/79

Cycle: 3.14.10

Conditions: Feedwater - Wellton-Mowhawk drainage pretreated (in Train IV) with high lime dosage for silica removal
Regenerants - recycled regenerant and fresh ED brine

Control variables:

	Target	Actual
Fresh regeneration conc. (mg/L TDS)	35 000	32 950
Fresh regeneration flow rate (L/min)	5.5	5.5
Recycled regenerant flow rate (L/min)	16.0	16.5
Recycled regenerant volume (L)	800	800
Service termination point (meq/L Ca^{++})	3.0	3.0

Standard resin bed: Height = 1081 mm
Volume = 98.7 L

Chemical Compositions of Tank Waters Prior to Cycle 3.14.10

Tank	pH units	Conductivity µS/cm	Ca^{++} meq/L	Mg^{++} meq/L	TH meq/L
Recycle regenerant (T-5)	-	36 287	60.0	70.0	130.0
Spent regenerant (T-6)	-	36 467	56.0	72.0	128.0
Lime-softened feed (T-9)	7.5	5 610	9.4	4.6	14.0
Lime softened feed (T-10)	7.4	5 319	8.8	4.8	13.6
Fresh ED brine (T-28)	6.2	43 140	6.4	19.2	25.6
IX product/ED feed (T-33)	7.3	5 636	0.52	1.6	2.1

Cycle 3.14.10 Operating Conditions

MODE	INPUT	OUTPUT	DURATION MIN	THROUGHPUT L	VOLUME BV	AVG FLOW RATE L/MIN	AVG FLOW RATE BV/MIN	BED EXPANSION %	TEMPERATURE C
REGEN 1	RE REGEN	WASTE	10	248	2.51	24.8	.251	45.	28.0
REGEN 2	RE REGEN	SP REGEN	49	792	8.02	16.3	.165	24.	
REGEN 3	FR REGEN	SP REGEN	82	450	4.56	5.47	.055	8.2	31.9
DRAIN 1	(VENT)	WASTE	3	62	.63	20.7	.209	0.0	
RINSE	FEED	WASTE	10	140	1.42	14.0	.142	0.0	
SERVICE	FEED	PRODUCT	190	5710	57.9	30.1	.304	0.0	
DRAIN 2	(VENT)	WASTE	2	41	.42	20.7	.209	0.0	

Fresh Regenerant Volume Balance

Run 3.14.00 Cycle no.	Date	Fresh regenerant volume (V_3) L	Fresh regenerant TDS mg/L	Service volume (V_S) L	Estimated ED feed TDS mg/L	R %	$V_3/(1-R)V_S$
03	6/9/79	451	34 040	6070	3520	91	0.82
04	6/9/79	451	34 040	5250	3520	91	0.94
05	6/10/79	451	34 040	5300	3520	91	0.94
06	6/10/79	452	34 040	5530	3520	91	0.90
07	6/10/79	452	34 040	5680	3520	91	0.87
08	6/10/79	451	34 040	5640	3520	91	0.88
09	6/11/79	451	34 560	5530	3490	91	0.92
10	6/11/79	450	34 560	5710	3490	91	0.89

Influent and Effluent Compositions during Cycle 3.14.10

	Units	Regen 1, 2 influent	Regen 1 effluent	Regen 2 effluent	Regen 3 Influent	Regen 3 Effluent	Rinse, service influent	Rinse effluent	Service effluent
pH	units	-	-	-	6.2	-	7.3	6.4	7.2
TDS (Σ ions)	mg/L	26 346	19 160	25 706	32 950	29 788	3331	29 978	3979
Conductivity @ 25 °C	μS/cm	-	-	-	43 388	-	4879	39 328	6385
C. F. (TDS/cond.)	-	-	-	-	0.76	-	0.68	0.76	0.62
Silica	mg/L	4.6	5.0	4.4	4.5	4.6	3.7	4.3	3.9
Calcium	mg/L	1150	1610	1580	120	1300	175	270	23.0
Magnesium	mg/L	765	654	806	198	591	52.1	182	37.6
Sodium	mg/L	7280	4460	6710	11 680	8740	930	10 300	1309
Potassium	mg/L	46	31	42	94	51	8.3	84	13.7
Strontium	mg/L	27	27	30	1.8	28	2.8	6.0	0.8
Bicarbonate	mg/L	73.2	73.2	73.2	51.2	73.2	19.5	31.7	21.0
Carbonate	mg/L	ND	ND	ND	ND	ND	ND	ND	ND
Hydroxide	mg/L	ND	ND	ND	ND	ND	ND	ND	ND
Sulfate	mg/L	4200	3200	4200	8400	6200	960	8200	1388
Chloride	mg/L	12 800	9100	12 260	12 400	12 800	1180	10 900	1182
T-alkalinity as $CaCO_3$	mg/L	60.0	60.0	60.0	42.0	60.0	16.0	26.0	17.2
P-alkalinity as $CaCO_3$	mg/L	ND	ND	ND	ND	ND	ND	ND	ND
Σ Anions	meq/L	449.8	324.6	434.5	525.6	491.4	53.60	478.8	62.60
Σ Cations	meq/L	438.8	329.6	438.8	532.8	495.6	53.75	478.8	61.55
Control value	meq/L	+1.55	-0.97	-0.62	-0.87	-0.54	-0.15	0.0	+0.97

Major Cation Concentrations of Samples Analyzed by Atomic Absorption

CYCLE 3.14.10

MODE	PROCESS STREAM	THROUGHPUT BV	CA MEQ/L	MG MEQ/L	TH MEQ/L	NA MEQ/L
REGEN 1	EFFLUENT	0.00	40.42	20.16	60.58	98.30
REGEN 1	EFFLUENT	1.26	99.80	68.40	168.20	221.84
REGEN 2	EFFLUENT	2.51	96.81	70.70	167.51	265.77
REGEN 2	INFLUENT	4.00	57.39	62.96	120.35	316.66
REGEN 2	EFFLUENT	6.48	73.35	62.96	136.32	303.61
REGEN 3	EFFLUENT	10.60	63.87	62.88	126.75	316.22
REGEN 3	INFLUENT	11.05	5.99	16.30	22.28	508.05
REGEN 3	EFFLUENT	11.77	72.36	69.14	141.49	362.33
REGEN 3	EFFLUENT	12.93	54.89	52.35	107.24	401.91
REGEN 3	EFFLUENT	14.04	48.40	28.48	76.88	433.23
REGEN 3	EFFLUENT	15.15	73.35	30.29	103.64	452.81
RINSE	EFFLUENT	0.00	12.92	16.13	29.06	493.69
RINSE	EFFLUENT	.71	13.72	13.50	27.22	414.96
SERVICE	EFFLUENT	1.42	.63	1.09	1.73	112.66
SERVICE	INFLUENT	4.16	8.78	3.87	12.65	39.28
SERVICE	EFFLUENT	15.42	.15	.17	.33	52.15
SERVICE	INFLUENT	27.00	8.73	3.95	12.68	40.19
SERVICE	EFFLUENT	29.43	.16	.21	.37	52.59
SERVICE	EFFLUENT	43.44	.39	1.89	2.28	49.46
SERVICE	EFFLUENT	50.44	1.14	4.38	5.52	46.50
SERVICE	EFFLUENT	57.44	2.69	6.01	8.70	43.54
SERVICE	INFLUENT	59.27	8.78	3.97	12.75	40.15
SERVICE	EFFLUENT	59.27	2.99	6.16	9.15	42.98

Service Performance Summary

CYCLE 3.14.10

	AVERAGE CONCENTRATIONS, MEQ/L INFLUENT	EFFLUENT	DIFFERENCE	REMOVAL %	RESIN CAPACITY EQ/L
CA	8.77	.61	8.15	93	.472
MG	3.93	1.66	2.27	58	.131
TH	12.69	2.27	10.42	82	.603
NA	39.87	57.61	-17.73		

FIGURE A- a
MAJOR CATION CONCENTRATIONS
OF IX REGENERATION EFFLUENT
CYCLE 3.14.10

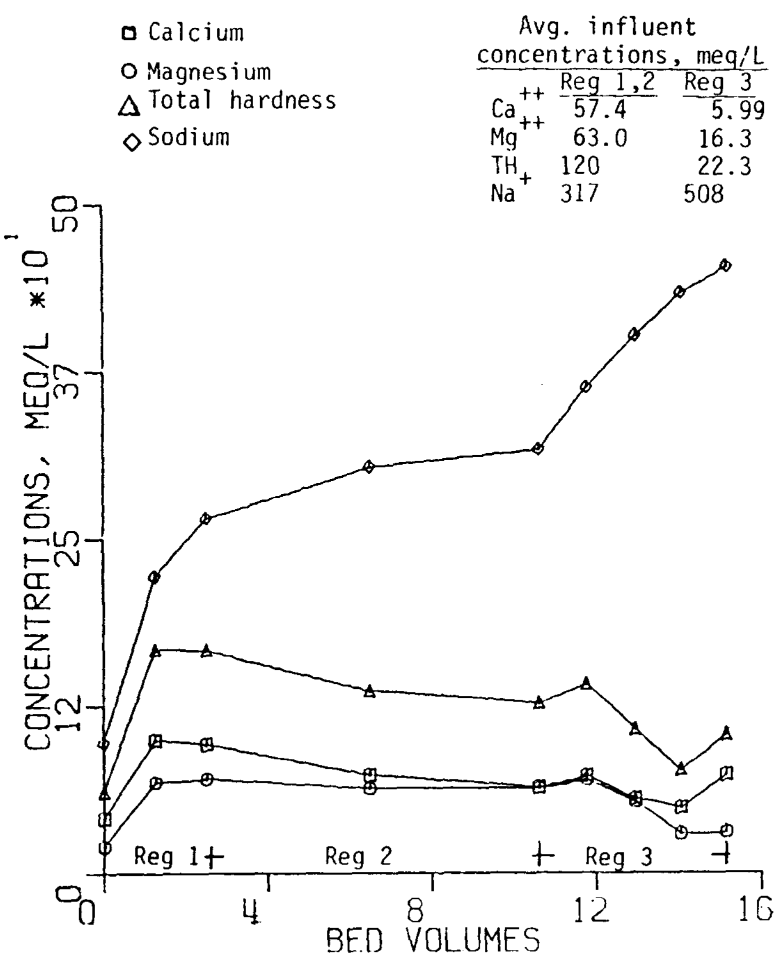
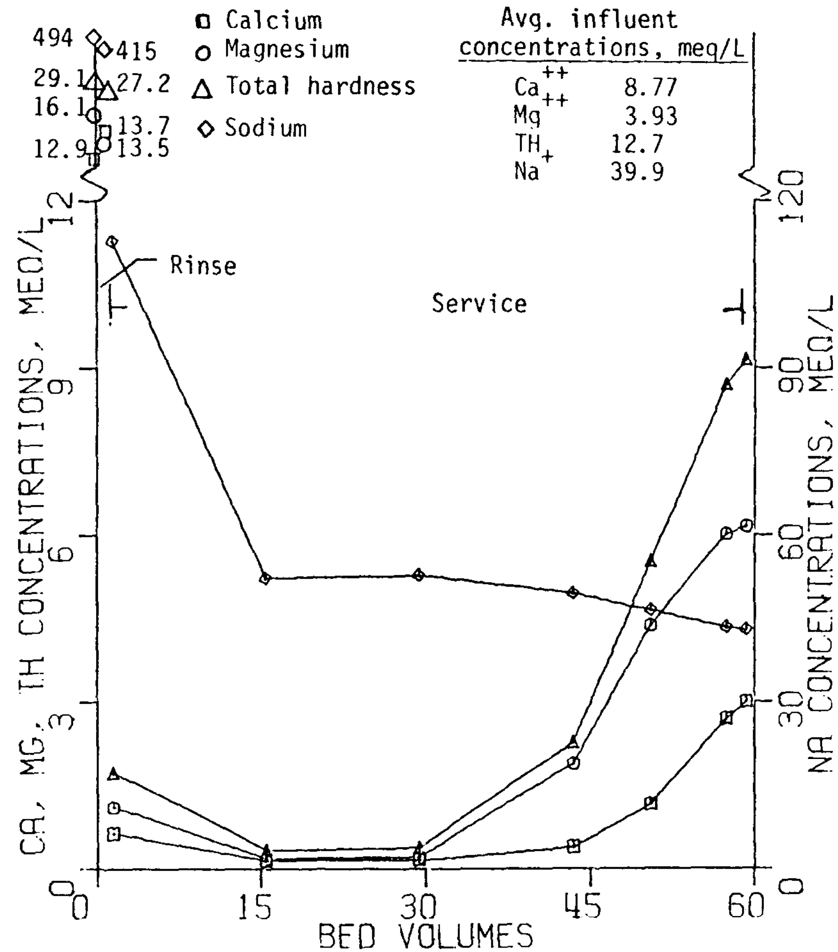


FIGURE A- b
MAJOR CATION CONCENTRATIONS OF
IX RINSE AND SERVICE EFFLUENTS
CYCLE 3.14.10



SODIUM (NA), CALCIUM (CA), AND MAGNESIUM (MG) CONCENTRATIONS ARE MEASURED BY ATOMIC ABSORPTION.
TOTAL HARDNESS (TH) IS CALCULATED BY SUMMING THE CALCIUM AND MAGNESIUM CONCENTRATIONS.

C19-4

Ion-Exchange - Run 3.15.00

Date: 6/13/79

Cycle: 3.15.08

Conditions: Feedwater - Wellton-Mowhawk drainage pretreated (in Train IV) with high lime dosage for silica removal
Regenerants - recycled regenerant and fresh ED brine

Control variables:

	Target	Actual
Fresh regeneration conc. (mg/L TDS)	35 000	33 670
Fresh regeneration flow rate (L/min)	8.0	7.9
Recycled regenerant flow rate (L/min)	8.0	8.1
Recycled regenerant volume (L)	800	800
Service termination point (meq/L Ca^{++})	3.0	3.2

Standard resin bed: Height = 1081 mm
Volume = 98.7 L

Chemical Compositions of Tank Waters Prior to Cycle 3.15.08

Tank	pH units	Conductivity µS/cm	Ca^{++} meq/L	Mg^{++} meq/L	TH meq/L
Recycle regenerant (T-5)	-	36 181	59.0	67.0	126.0
Spent regenerant (T-6)	-	36 606	60.0	64.0	124.0
Lime-softened feed (T-9)	7.3	5 342	9.6	4.0	13.6
Lime softened feed (T-10)	7.7	5 225	9.6	3.6	13.2
Fresh ED brine (T-28)	6.2	44 274	6.4	18.8	25.2
IX product/ED feed (T-33)	7.2	5 616	0.64	1.6	2.2

Cycle 3.15.08 Operating Conditions

MODE	INPUT	OUTPUT	DURATION MIN	THROUGHPUT L	VOLUME BV	AVG FLOW RATE L/MIN	BV/MIN	BED EXPANSION %	TEMPERATURE C
REGEN 1	RE REGEN	WASTE	10	248	2.51	24.8	.251	42.	32.0
REGEN 2	RE REGEN	SP REGEN	98	792	8.02	8.06	.082	9.0	
REGEN 3	FR REGEN	SP REGEN	57	451	4.57	7.93	.080	11.	35.8
DRAIN 1	(VENT)	WASTE	3	62	.63	20.7	.209	0.0	
RINSE	FEED	WASTE	10	150	1.52	15.0	.152	0.0	
SERVICE	FEED	PRODUCT	193	5910	59.9	30.6	.310	0.0	
DRAIN 2	(VENT)	WASTE	2	41	.42	20.7	.209	0.0	

Fresh Regenerant Volume Balance

Run 3.15.00 Cycle no.	Date	Fresh regenerant volume (V_3) L	Fresh regenerant TDS mg/L	Service volume (V_S) L	Estimated ED feed TDS mg/L	R %	$V_3/(1-R)V_S$
03	6/12/79	452	35 710	5930	3270	92	0.97
04	6/12/79	452	35 710	5880	3270	92	0.97
05	6/12/79	451	35 710	5710	3270	92	1.00
06	6/12/79	452	35 710	5910	3270	92	0.97
07	6/13/79	451	35 820	5830	3480	91	0.91
08	6/13/79	451	35 820	5910	3480	91	0.90

Influent and Effluent Compositions during Cycle 3.15.08

	Units	Regen 1, 2 influent	Regen 1 effluent	Regen 2 effluent	Regen 3 Influent	Regen 3 Effluent	Rinse, service influent	Rinse effluent	Service effluent
pH	units	-	-	-	6.3	-	7.2	6.4	7.1
TDS (Σ ions)	mg/L	26 329	18 861	26 067	33 670	31 481	3238	31 286	3428
Conductivity @ 25 °C	µS/cm	-	-	-	44 373	-	5338	40 416	5692
E. F. (TDS/cond.)	-	-	-	-	0.76	-	0.61	0.77	0.60
Silica	mg/L	5.0	5.0	4.6	4.6	4.8	3.3	4.3	3.3
Calcium	mg/L	1100	1720	1580	122	1250	188	312	24.2
Magnesium	mg/L	758	557	745	213	600	43.0	212	32.3
Sodium	mg/L	7480	4330	6970	11 760	9400	904	10 690	1171
Potassium	mg/L	46	30	49	99	59	8.6	91	12.1
Strontium	mg/L	27	30	30	2.0	29	2.9	7.4	0.7
Bicarbonate	mg/L	73.2	48.8	48.8	29.3	58.6	14.6	29.3	14.6
Carbonate	mg/L	ND	ND	ND	ND	ND	ND	ND	ND
Hydroxide	mg/L	ND	ND	ND	ND	ND	ND	ND	ND
Sulfate	mg/L	4100	3200	4300	9100	6700	920	9100	1000
Chloride	mg/L	12 740	8940	12 340	12 340	13 380	1154	10 840	1170
T-alkalinity as $CaCO_3$	mg/L	60.0	40.0	40.0	24.0	48.0	12.0	24.0	12.0
P-alkalinity as $CaCO_3$	mg/L	ND	ND	ND	ND	ND	ND	ND	ND
Σ Anions	meq/L	446.0	319.7	438.5	538.1	518.0	51.95	495.8	54.08
Σ Cations	meq/L	444.4	321.4	445.3	537.7	522.8	52.53	500.5	55.13
Control value	meq/L	+0.22	-0.36	-0.98	+0.05	-0.59	-0.63	-0.60	-1.11

Major Cation Concentrations of Samples Analyzed by Atomic Absorption

CYCLE 3.15.08

MODE	PROCESS STREAM	THROUGHPUT BV	CA MEQ/L	MG MEQ/L	TH MEQ/L	NA MEQ/L
REGEN 1	EFFLUENT	0.00	26.95	10.12	37.07	71.77
REGEN 1	EFFLUENT	1.26	126.25	64.77	191.02	224.88
REGEN 2	EFFLUENT	2.51	103.79	63.21	167.00	275.34
REGEN 2	INFLUENT	3.17	54.89	62.39	117.28	325.36
REGEN 2	EFFLUENT	6.59	72.36	59.75	132.11	314.92
REGEN 3	EFFLUENT	10.51	59.88	59.34	119.22	321.44
REGEN 3	INFLUENT	11.16	6.09	17.53	23.62	511.53
REGEN 3	EFFLUENT	11.64	61.38	73.91	135.29	414.09
REGEN 3	EFFLUENT	12.76	68.86	69.88	138.74	385.82
REGEN 3	EFFLUENT	13.89	47.41	32.59	80.00	450.63
REGEN 3	EFFLUENT	15.09	80.84	33.33	114.17	452.81
RINSE	EFFLUENT	0.00	15.47	18.77	34.23	506.74
RINSE	EFFLUENT	.76	16.42	16.05	32.47	426.71
SERVICE	EFFLUENT	1.52	.43	.54	.98	80.47
SERVICE	INFLUENT	4.31	8.98	3.43	12.41	39.19
SERVICE	EFFLUENT	16.10	.17	.20	.37	51.89
SERVICE	INFLUENT	29.13	9.08	3.42	12.51	39.19
SERVICE	EFFLUENT	30.68	.18	.26	.43	51.07
SERVICE	EFFLUENT	45.27	.50	2.16	2.66	49.59
SERVICE	EFFLUENT	52.40	1.29	4.32	5.61	47.19
SERVICE	EFFLUENT	59.85	2.79	5.57	8.37	43.85
SERVICE	INFLUENT	61.40	9.23	3.44	12.67	39.71
SERVICE	EFFLUENT	61.40	3.24	5.76	9.00	43.50

Service Performance Summary

CYCLE 3.15.08

	AVERAGE CONCENTRATIONS, MEQ/L			REMOVAL	RESIN CAPACITY
	INFLUENT	EFFLUENT	DIFFERENCE	%	EQ/L
CA	9.10	.64	8.46	93	.507
MG	3.43	1.59	1.85	54	.110
TH	12.53	2.22	10.31	82	.617
NA	39.36	53.47	-14.10		

FIGURE A- a
MAJOR CATION CONCENTRATIONS
OF IX REGENERATION EFFLUENT
CYCLE 3.15.08

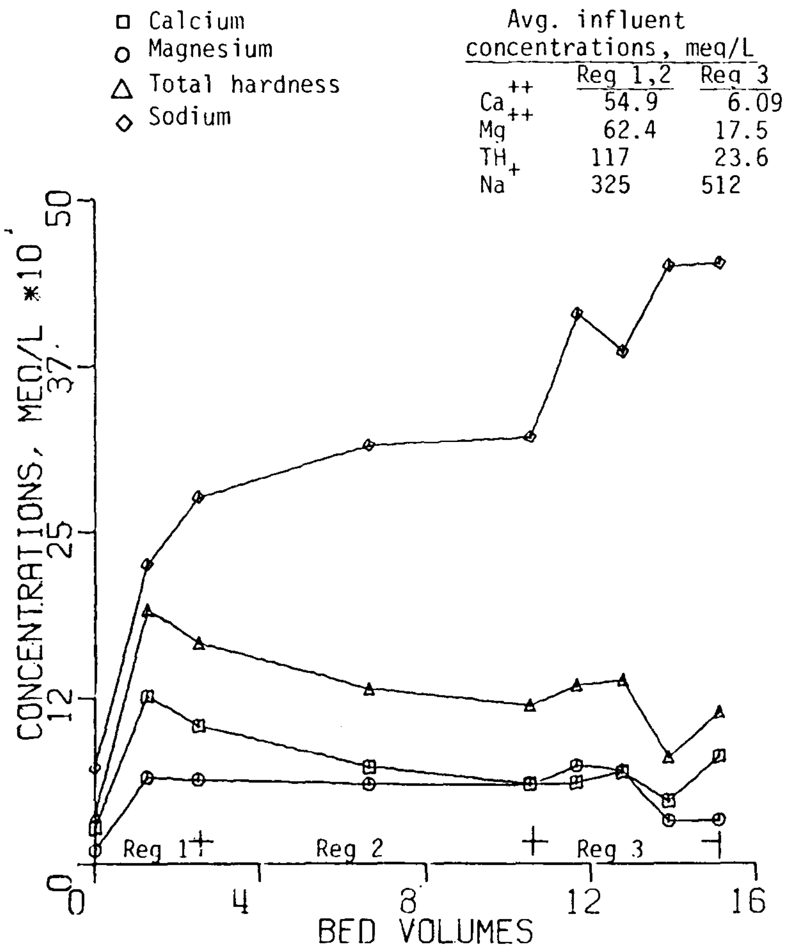
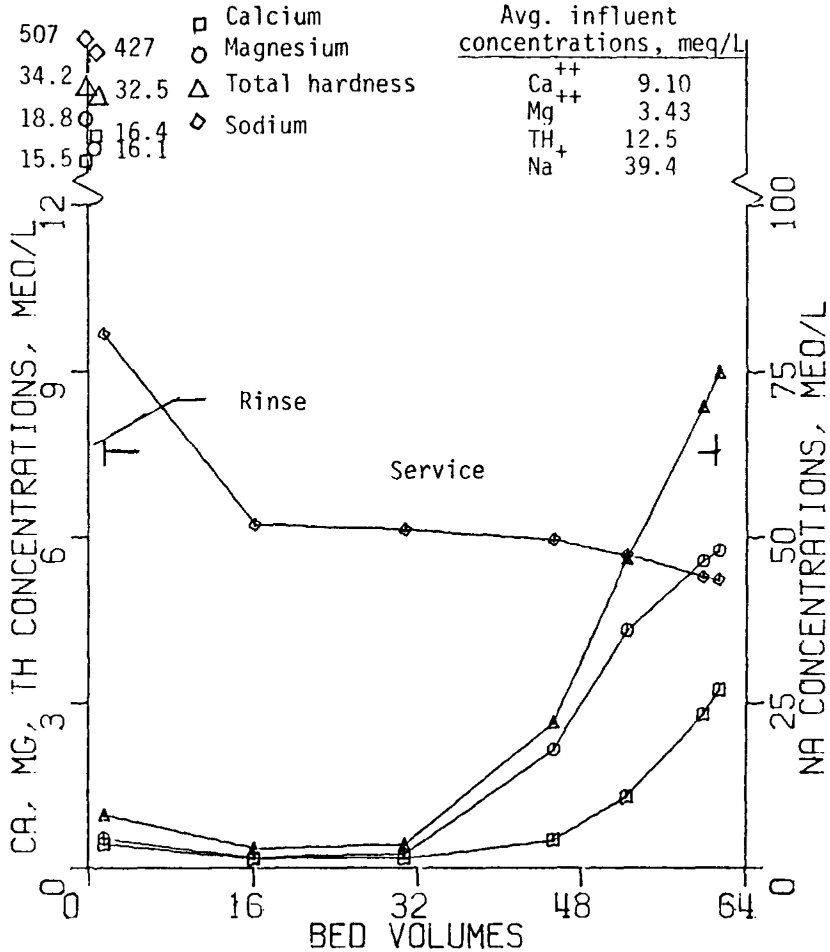


FIGURE A- b
MAJOR CATION CONCENTRATIONS OF
IX RINSE AND SERVICE EFFLUENTS
CYCLE 3.15.08



SODIUM (NA), CALCIUM (CA), AND MAGNESIUM (MG) CONCENTRATIONS ARE MEASURED BY ATOMIC ABSORPTION.
TOTAL HARDNESS (TH) IS CALCULATED BY SUMMING THE CALCIUM AND MAGNESIUM CONCENTRATIONS.

Ion-Exchange - Run 3.16.00

Date: 6/15/79

Cycle: 3.16.06

Conditions: Feedwater - Wellton-Mowhawk drainage pretreated (in Train IV) with high lime dosage for silica removal
Regenerants - recycled regenerant and fresh ED brine

Control variables:

	Target	Actual
Fresh regeneration conc. (mg/L TDS)	35 000	36 070
Fresh regeneration flow rate (L/min)	8.0	8.0
Recycled regenerant flow rate (L/min)	24.0	24.6
Recycled regenerant volume (L)	800	800
Service termination point (meq/L Ca^{++})	3.0	·3.1

Standard resin bed: Height = 1081 mm
Volume = 98.7 L

Chemical Compositions of Tank Waters Prior to Cycle 3.16.06

Tank	pH units	Conductivity µS/cm	Ca^{++} meq/L	Mg^{++} meq/L	TH meq/L
Recycle regenerant (T-5)	-	32 246	50.0	54.0	104.0
Spent regenerant (T-6)	-	35 814	57.0	65.0	122.0
Lime-softened feed (T-9)	7.3	5 220	9.6	4.4	14.0
Lime softened feed (T-10)	7.4	5 186	9.6	4.8	14.4
Fresh ED brine (T-28)	4.9	43 837	6.4	18.4	24.8
IX product/ED feed (T-33)	7.2	5 620	0.64	2.0	2.6

Cycle 3.16.06 Operating Conditions

MODE	INPUT	OUTPUT	DURATION MIN	THROUGHPUT L	VOLUME BV	AVG FLOW RATE L/MIN	AVG FLOW RATE BV/MIN	BED EXPANSION %	TEMPERATURE C
REGEN 1	RE REGEN	WASTE	10	249	2.52	24.9	.252	42.	30.8
REGEN 2	RE REGEN	SP REGEN	33	791	8.01	24.3	.247	36.	
REGEN 3	FR REGEN	SP REGEN	56	451	4.57	8.01	.081	11.	33.5
DRAIN 1	(VENT)	WASTE	3	62	.63	20.7	.209	0.0	
RINSE	FEED	WASTE	10	150	1.52	15.0	.152	0.0	
SERVICE	FEED	PRODUCT	193	5830	59.1	30.2	.306	0.0	
DRAIN 2	(VENT)	WASTE	2	41	.42	20.7	.209	0.0	

Fresh Regenerant Volume Balance

Run 3.16.00 Cycle no.	Date	Fresh regenerant volume (V_3) L	Fresh regenerant TDS mg/L	Service volume (V_S) L	Estimated ED feed TDS mg/L	R %	$V_3/(1-R)V_S$
03	6/14/79	450	35 700	6270	3440	92	0.85
04	6/14/79	451	35 700	5860	3440	92	0.92
05	6/14/79	451	35 700	5770	3440	92	0.93
06	6/15/79	451	35 510	5830	3480	91	0.90

Influent and Effluent Compositions during Cycle 3.16.06

	Units	Regen 1, 2 influent	Regen 1 effluent	Regen 2 effluent	Regen 3 Influent	Regen 3 Effluent	Rinse, service influent	Rinse effluent	Service effluent
pH	units	-	-	-	5.6	-	7.1	5.9	7.0
TDS (Σ ions)	mg/L	25 322	18 076	24 632	36 067	31 760	3211	31 273	3786
Conductivity @ 25 °C	µS/cm	-	-	-	45 262	-	5214	40 416	5968
E. F. (TDS/cond.)	-	-	-	-	0.80	-	0.62	0.77	0.63
Silica	mg/L	5.4	5.6	5.2	4.1	4.4	3.6	4.3	3.6
Calcium	mg/L	1060	1570	1540	39.9	1580	184	328	24.6
Magnesium	mg/L	663	541	679	213	631	42.6	200	31.3
Sodium	mg/L	7190	4190	6550	12 670	9030	896	10 770	1269
Potassium	mg/L	46	29	42	103	55	8.2	87	13.3
Strontium	mg/L	19	22	23	1.7	26	2.3	6.1	0.1
Bicarbonate	mg/L	58.6	58.6	73.2	15.6	73.2	18.5	17.1	18.5
Carbonate	mg/L	ND	ND	ND	ND	ND	ND	ND	ND
Hydroxide	mg/L	ND	ND	ND	ND	ND	ND	ND	ND
Sulfate	mg/L	4520	3400	4200	10 100	6600	940	8800	1260
Chloride	mg/L	11 760	8260	11 520	12 920	13 760	1116	11 060	1166
T-alkalinity as $CaCO_3$	mg/L	48.0	48.0	60.0	12.8	60.0	15.2	14.0	15.2
P-alkalinity as $CaCO_3$	mg/L	ND	ND	ND	ND	ND	ND	ND	ND
Σ Anions	meq/L	426.9	304.8	413.7	575.1	526.8	51.37	495.6	59.44
Σ Cations	meq/L	421.8	306.3	419.2	572.0	525.6	51.92	503.7	59.35
Control value	meq/L	+0.75	-0.32	-0.85	+0.34	+0.12	-0.62	-1.04	+0.09

Major Cation Concentrations of Samples Analyzed by Atomic Absorption

CYCLE 3.16.06

MODE	PROCESS STREAM	THROUGHPUT BV	CA MEQ/L	MG MEQ/L	TH MEQ/L	NA MEQ/L
REGEN 1	EFFLUENT	0.00	23.65	11.60	35.26	77.86
REGEN 1	EFFLUENT	1.26	108.28	59.42	167.71	206.61
REGEN 2	EFFLUENT	2.52	95.61	59.18	154.99	260.11
REGEN 2	INFLUENT	4.00	52.89	54.57	107.46	312.74
REGEN 2	EFFLUENT	6.22	69.86	54.57	124.43	283.60
REGEN 3	EFFLUENT	10.66	60.88	53.50	114.38	288.82
REGEN 3	INFLUENT	11.07	1.99	17.53	19.52	551.11
REGEN 3	EFFLUENT	11.47	80.34	74.81	155.15	387.12
REGEN 3	EFFLUENT	12.36	74.85	55.06	129.91	404.52
REGEN 3	EFFLUENT	13.26	66.37	43.79	110.15	429.75
REGEN 3	EFFLUENT	15.20	105.79	36.38	142.17	493.26
RINSE	EFFLUENT	0.00	16.97	18.27	35.24	521.10
RINSE	EFFLUENT	.76	16.12	14.16	30.27	427.58
SERVICE	EFFLUENT	1.52	.83	1.07	1.90	119.18
SERVICE	INFLUENT	4.27	9.48	3.51	12.99	39.63
SERVICE	EFFLUENT	16.21	.19	.19	.38	52.50
SERVICE	INFLUENT	23.25	9.48	3.57	13.05	40.28
SERVICE	EFFLUENT	30.59	.21	.23	.44	53.28
SERVICE	EFFLUENT	45.29	.47	1.81	2.26	50.76
SERVICE	EFFLUENT	52.32	1.18	4.35	5.54	47.93
SERVICE	EFFLUENT	59.67	2.89	5.47	8.36	45.37
SERVICE	INFLUENT	60.59	9.58	3.58	13.16	40.58
SERVICE	EFFLUENT	60.59	3.09	5.52	8.62	44.98

Service Perofrmance Summary

CYCLE 3.16.06

	AVERAGE CONCENTRATIONS, MEQ/L			REMOVAL	RESIN CAPACITY
	INFLUENT	EFFLUENT	DIFFERENCE	%	EQ/L
CA	9.51	.66	8.86	93	.523
MG	3.55	1.52	2.03	57	.120
TH	13.07	2.18	10.88	83	.643
NA	40.16	59.55	-19.39		

FIGURE A- a
MAJOR CATION CONCENTRATIONS
OF IX REGENERATION EFFLUENT
CYCLE 3.16.06

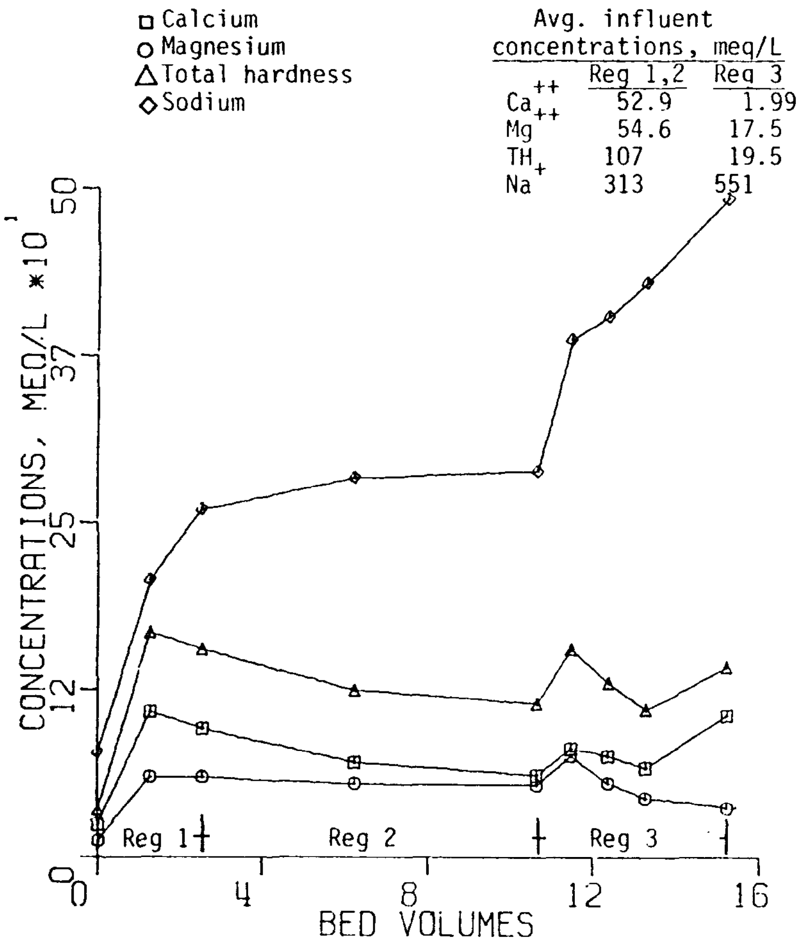
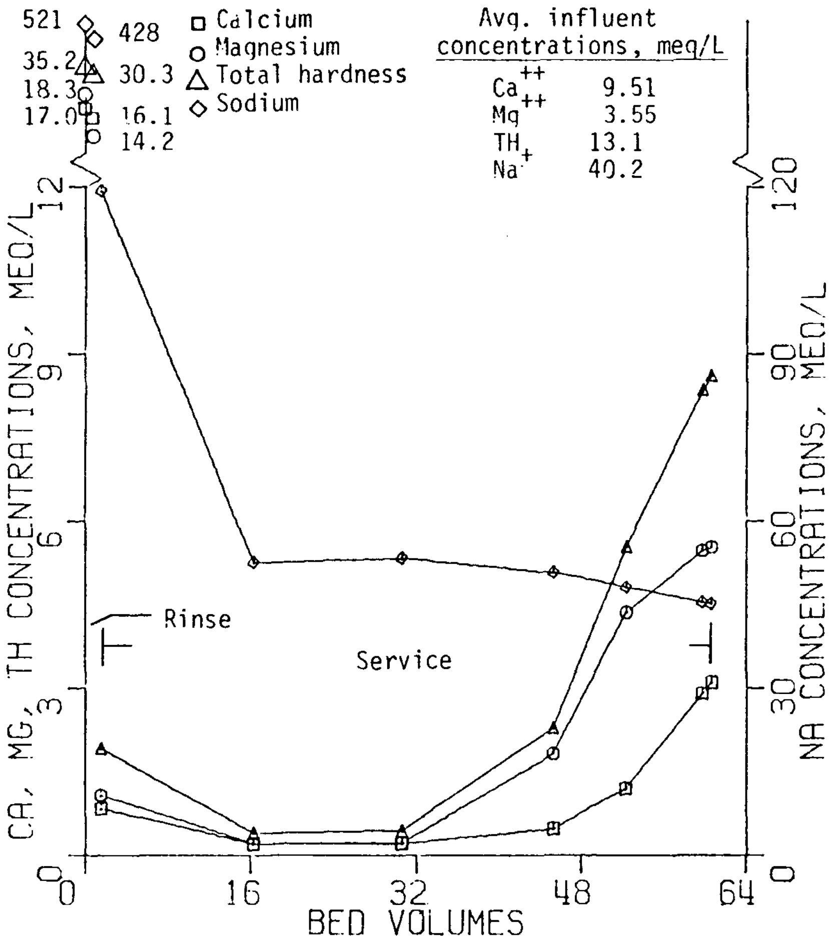


FIGURE A- b
MAJOR CATION CONCENTRATIONS OF
IX RINSE AND SERVICE EFFLUENTS
CYCLE 3.16.06



SODIUM (NA), CALCIUM (CA), AND MAGNESIUM (MG) CONCENTRATIONS ARE MEASURED BY ATOMIC ABSORPTION.
TOTAL HARDNESS (TH) IS CALCULATED BY SUMMING THE CALCIUM AND MAGNESIUM CONCENTRATIONS.

Ion-Exchange - Run 3.17.00

Date: 6/18/79

Cycle: 3.17.08

Conditions: Feedwater - Wellton-Mowhawk drainage pretreated (in Train IV) with high lime dosage for silica removal
Regenerants - recycled regenerant and fresh ED brine

Control variables:

	Target	Actual
Fresh regeneration conc. (mg/L TDS)	20 000	20 160
Fresh regeneration flow rate (L/min)	5.5	5.5
Recycled regenerant flow rate (L/min)	16.0	17.2
Recycled regenerant volume (L)	1600	1600
Service termination point (meq/L Ca^{++})	4.5	4.4

Standard resin bed: Height = 1081 mm
Volume = 98.7 L

Chemical Compositions of Tank Waters Prior to Cycle 3.17.08

Tank	pH units	Conductivity µS/cm	Ca^{++} meq/L	Mg^{++} meq/L	TH meq/L
Recycle regenerant (T-5)	-	26 448	44.0	30.0	74.0
Spent regenerant (T-6)	-	25 950	44.0	30.0	74.0
Lime-softened feed (T-9)	7.2	5 234	8.8	4.0	12.8
Lime softened feed (T-10)	7.5	5 191	8.8	4.4	13.2
Fresh ED brine (T-28)	6.2	26 919	6.4	11.6	18.0
IX product/ED feed (T-33)	7.2	5 675	0.8	2.0	2.8

Cycle 3.17.08 Operating Conditions

MODE	INPUT	OUTPUT	DURATION MIN	THROUGHPUT L	VOLUME BV	AVG FLOW RATE L/MIN	AVG FLOW RATE BV/MIN	BED EXPANSION %	TEMPERATURE C
REGEN 1	RE REGEN	WASTE	10	245	2.48	24.5	.248	46.	25.8
REGEN 2	RE REGEN	SP REGEN	92	1595	16.2	17.3	.175	25.0	
REGEN 3	FR REGEN	SP REGEN	182	1000	10.13	5.49	.056	5.6	28.4
DRAIN 1	(VENT)	WASTE	3	62	.63	20.7	.209	0.0	
RINSE	FEED	WASTE	10	150	1.52	15.0	.152	0.0	
SERVICE	FEED	PRODUCT	231	6920	70.1	30.0	.304	0.0	
DRAIN 2	(VENT)	WASTE	2	41	.42	20.7	.209	0.0	

Fresh Regenerant Volume Balance

Run 3.17.00 Cycle no.	Date	Fresh regenerant volume (V_3) L	Fresh regenerant TDS mg/L	Service volume (V_S) L	Estimated ED feed TDS mg/L	R %	$V_3/(1-R)V_S$
03	6/16/79	1000	19 520	7130	3300	85	0.95
04	6/16/79	1000	19 520	6310	3300	85	1.07
05	6/17/79	1000	19 520	6330	3300	85	1.07
06	6/17/79	1000	19 520	6320	3300	85	1.07
07	6/18/79	1000	19 520	6830	3300	85	0.99
08	6/18/79	1000	19 520	6920	3300	85	0.98

Influent and Effluent Compositions during Cycle 3.17.08

	Units	Regen 1, 2 influent	Regen 1 effluent	Regen 2 effluent	Regen 3 Influent	Regen 3 Effluent	Rinse, service influent	Rinse effluent	Service effluent
pH	units	-	-	-	6.2	-	7.2	6.3	7.2
TDS (Σ ions)	mg/L	19 187	15 239	19 698	20 159	20 593	3302	18 259	3408
Conductivity @ 25 °C	μS/cm	-	-	-	26 133	-	5190	24 600	5408
E. F. (TDS/cond.)	-	-	-	-	0.77	-	0.64	0.74	0.63
Silica	mg/L	4.4	4.8	4.4	4.1	4.6	3.9	4.0	3.5
Calcium	mg/L	850	1210	1140	115	850	165	129	25.8
Magnesium	mg/L	365	421	420	130	237	50.3	102	32.7
Sodium	mg/L	5600	3570	5410	7000	6340	952	6400	1151
Potassium	mg/L	36.0	24	34	59.0	36	8.2	52.3	11.6
Strontium	mg/L	13	16	16	1.3	12	2.3	2.0	0.2
Bicarbonate	mg/L	78.1	73.2	73.2	19.5	73.2	20.5	19.5	19.5
Carbonate	mg/L	ND	ND	ND	ND	ND	ND	ND	ND
Hydroxide	mg/L	ND	ND	ND	ND	ND	ND	ND	ND
Sulfate	mg/L	4300	4000	4600	5680	5100	960	5050	1010
Chloride	mg/L	7940	5920	8000	7150	7940	1140	6500	1154
T-alkalinity as $CaCO_3$	mg/L	64.0	60.0	60.0	16.0	60.0	16.8	16.0	16.0
P-alkalinity as $CaCO_3$	mg/L	ND	ND	ND	ND	ND	ND	ND	ND
Σ Anions	meq/L	314.8	251.5	322.7	320.3	331.4	52.49	288.9	53.91
Σ Cations	meq/L	317.3	251.5	328.0	322.5	338.9	54.05	294.6	54.35
Control value	meq/L	-0.49	0.0	-1.03	-0.42	-1.42	-1.68	-1.25	-0.46

Major Cation Concentrations of Samples Analyzed by Atomic Absorption

CYCLE 3.17.08

MODE	PROCESS STREAM	THROUGHPUT BV	CA MEQ/L	MG MEQ/L	TH MEQ/L	NA MEQ/L
REGEN 1	EFFLUENT	0.00	27.94	15.14	43.09	75.69
REGEN 1	EFFLUENT	1.24	78.34	46.01	124.35	153.98
REGEN 2	EFFLUENT	2.48	78.84	44.03	122.88	191.39
REGEN 2	INFLUENT	4.94	42.42	30.04	72.46	243.58
REGEN 2	EFFLUENT	11.07	46.91	31.19	78.10	236.19
REGEN 3	EFFLUENT	18.61	43.41	30.29	73.70	240.54
REGEN 3	INFLUENT	20.56	5.74	10.70	16.44	304.48
REGEN 3	EFFLUENT	21.11	42.42	26.67	69.08	247.93
REGEN 3	EFFLUENT	23.62	36.93	16.46	53.39	258.81
REGEN 3	EFFLUENT	26.12	31.94	11.36	43.29	270.99
REGEN 3	EFFLUENT	28.74	51.90	16.95	68.85	302.31
RINSE	EFFLUENT	0.00	7.39	10.45	17.84	305.79
RINSE	EFFLUENT	.76	5.19	6.30	11.49	242.71
SERVICE	EFFLUENT	1.52	.25	.35	.61	74.38
SERVICE	INFLUENT	4.25	8.23	4.22	12.46	40.02
SERVICE	EFFLUENT	17.30	.23	.30	.53	52.33
SERVICE	INFLUENT	31.57	8.18	4.26	12.44	40.28
SERVICE	EFFLUENT	33.09	.26	.46	.72	53.28
SERVICE	EFFLUENT	48.87	.90	3.56	4.45	49.93
SERVICE	EFFLUENT	56.76	1.93	5.46	7.38	46.93
SERVICE	INFLUENT	71.63	8.33	4.25	12.58	42.06
SERVICE	EFFLUENT	71.63	4.44	6.30	10.74	43.63

Service Performance Summary

CYCLE 3.17.08

	AVERAGE CONCENTRATIONS, MEQ/L			REMOVAL	RESIN CAPACITY
	INFLUENT	EFFLUENT	DIFFERENCE	%	EQ/L
CA	8.25	1.07	7.18	87	.503
MG	4.24	2.36	1.88	44	.132
TH	12.49	3.44	9.05	72	.635
NA	40.79	52.82	-12.04		

FIGURE A- a
MAJOR CATION CONCENTRATIONS
OF IX REGENERATION EFFLUENT
CYCLE 3.17.08

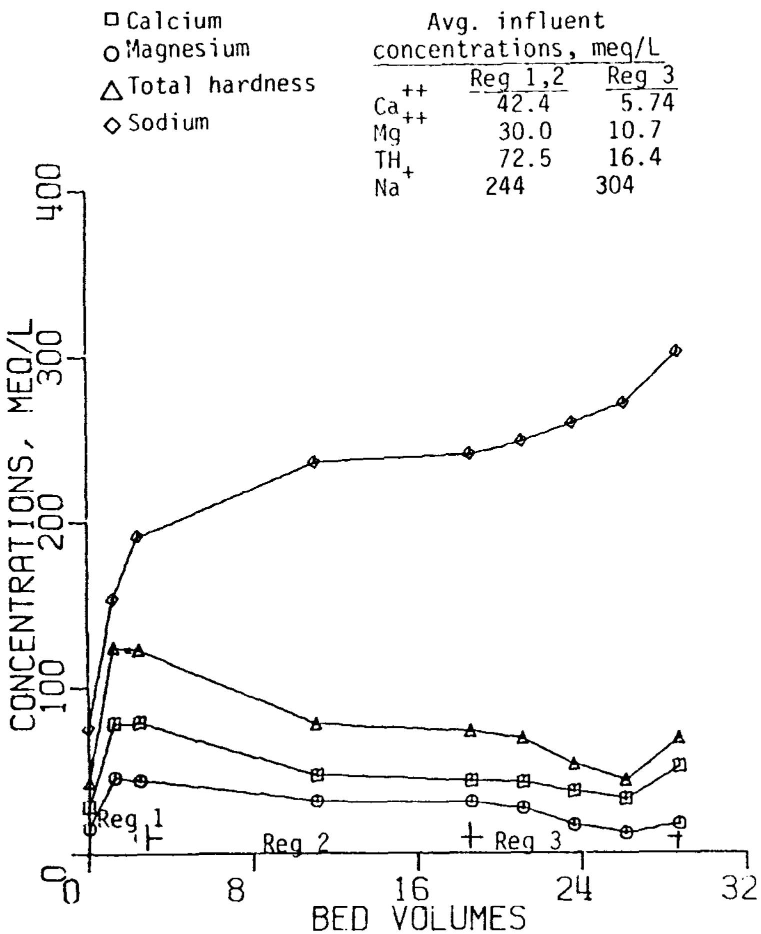
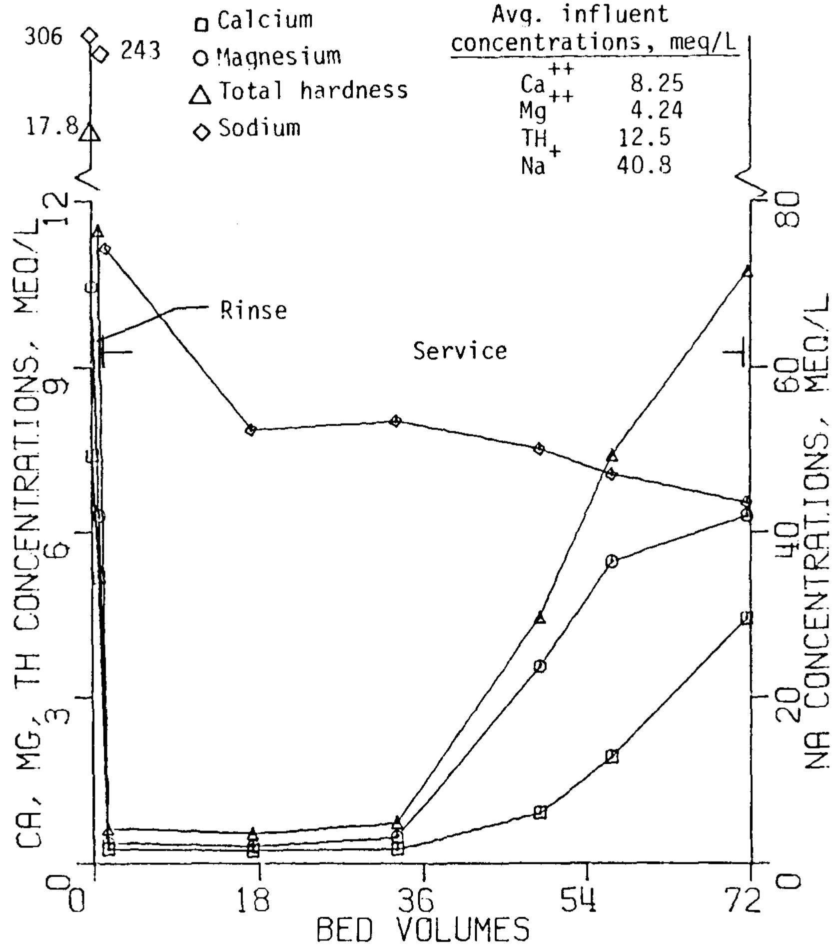


FIGURE A- b
MAJOR CATION CONCENTRATIONS OF
IX RINSE AND SERVICE EFFLUENTS
CYCLE 3.17.08



SODIUM (NA), CALCIUM (CA), AND MAGNESIUM (MG) CONCENTRATIONS ARE MEASURED BY ATOMIC ABSORPTION.
TOTAL HARDNESS (TH) IS CALCULATED BY SUMMING THE CALCIUM AND MAGNESIUM CONCENTRATIONS.

Ion-Exchange - Run 3.18.00

Date: 6/21/79

Cycle: 3.18.09

Conditions: Feedwater - Wellton-Mowhawk drainage pretreated (in Train IV) with high lime dosage for silica removal
Regenerants - recycled regenerant and fresh ED brine

Control variables:

	Target	Actual
Fresh regeneration conc. (mg/L TDS)	20 000	19 980
Fresh regeneration flow rate (L/min)	5.5	5.4
Recycled regenerant flow rate (L/min)	None	None
Recycled regenerant volume (L)	None	None
Service termination point (meq/L Ca^{++})	4.5	4.2

Standard resin bed: Height = 1081 mm
Volume = 98.7 L

Chemical Compositions of Tank Waters Prior to Cycle 3.18.09

Tank	pH units	Conductivity µS/cm	Ca^{++} meq/L	Mg^{++} meq/L	TH meq/L
Recycle regenerant (T-5)	-	22 481	35.0	27.0	62.0
Spent regenerant (T-6)	-	25 367	44.0	26.0	70.0
Lime-softened feed (T-9)	7.1	5 335	8.0	4.4	12.4
Lime softened feed (T-10)	7.5	5 253	9.6	2.8	12.4
Fresh ED brine (T-28)	6.5	26 716	6.8	15.6	22.4
IX product/ED feed (T-33)	7.0	5 760	-	-	-

Cycle 3.18.09 Operating Conditions

MODE	INPUT	OUTPUT	DURATION MIN	THROUGHPUT L	VOLUME BV	AVG FLOW RATE L/MIN	AVG FLOW RATE BV/MIN	BED EXPANSION %	TEMPERATURE C
REGEN 1	RE REGEN	WASTE	10	248	2.51	24.8	.251	44.	26.4
REGEN 3	FR REGEN	SP REGEN	182	979	9.92	5.38	.054	6.4	27.8
DRAIN 1	(VENT)	WASTE	3	62	.63	20.7	.209	0.0	
RINSE	FEED	WASTE	10	160	1.62	16.0	.162	0.0	
SERVICE	FEED	PRODUCT	213	6410	64.9	30.1	.305	0.0	
DRAIN 2	(VENT)	WASTE	2	41	.42	20.7	.209	0.0	

Fresh Regenerant Volume Balance

Run 3.18.00 Cycle no.	Date	Fresh regenerant volume (V_3) L	Fresh regenerant TDS mg/L	Service volume (V_S) L	Estimated ED feed TDS mg/L	R %	$V_3/(1-R)V_S$
03	6/19/79	852	19 860	6780	3300	85	0.86
04	6/19/79	852	19 860	6780	3300	85	0.86
05	6/19/79	852	19 860	6650	3300	85	0.88
06	6/20/79	1000	19 570	7010	3300	85	0.96
07	6/20/79	1021	19 570	7350	3300	85	0.94
08	6/20/79	1000	19 570	6360	3300	85	1.06
09	6/21/79	979		6410	3300		

Influent and Effluent Compositions during Cycle 3.18.09

	Units	Regen 1 Influent	Regen 1 Effluent	Regen 3 Influent	Regen 3 Effluent	Rinse, service influent	Rinse effluent	Service effluent
pH	units	-	-	6.4	-	7.4	6.6	7.3
TDS (Σ ions)	mg/L	16 705	12 307	19 981	20 201	3421	18 154	3533
Conductivity @ 25 °C	µS/cm	-	-	27 436	-	5431	25 037	5603
E. F. (TDS/cond.)	-	-	-	0.73	-	0.63	0.73	0.63
Silica	mg/L	3.6	5.0	4.1	5.0	4.2	4.5	4.3
Calcium	mg/L	690	1020	128	1190	166	136	39.1
Magnesium	mg/L	316	314	199	319	53.3	149	45.2
Sodium	mg/L	4800	2870	6850	5660	983	6220	1179
Potassium	mg/L	30	21	63	32	8.5	59	12.7
Strontium	mg/L	17	18	1.8	22	2.7	2.3	0.7
Bicarbonate	mg/L	48.8	58.6	35.1	73.2	19.5	33.2	22.0
Carbonate	mg/L	ND	ND	ND	ND	ND	ND	ND
Hydroxide	mg/L	ND	ND	ND	ND	ND	ND	ND
Sulfate	mg/L	4200	3000	5500	5000	990	5100	1030
Chloride	mg/L	6600	5000	7200	7900	1194	6450	1200
T-alkalinity as $CaCO_3$	mg/L	40.0	48.0	28.8	60.0	16.0	27.2	18.0
P-alkalinity as $CaCO_3$	mg/L	ND	ND	ND	ND	ND	ND	ND
Σ Anions	meq/L	274.5	204.5	318.3	328.2	54.62	288.7	55.67
Σ Cations	meq/L	270.4	202.5	322.4	331.2	55.70	291.2	57.28
Control value	meq/L	+0.94	+0.60	-0.82	-0.95	-1.14	-0.54	-1.68

Major Cation Concentrations of Samples Analyzed by Atomic Absorption

CYCLE 3.18.09

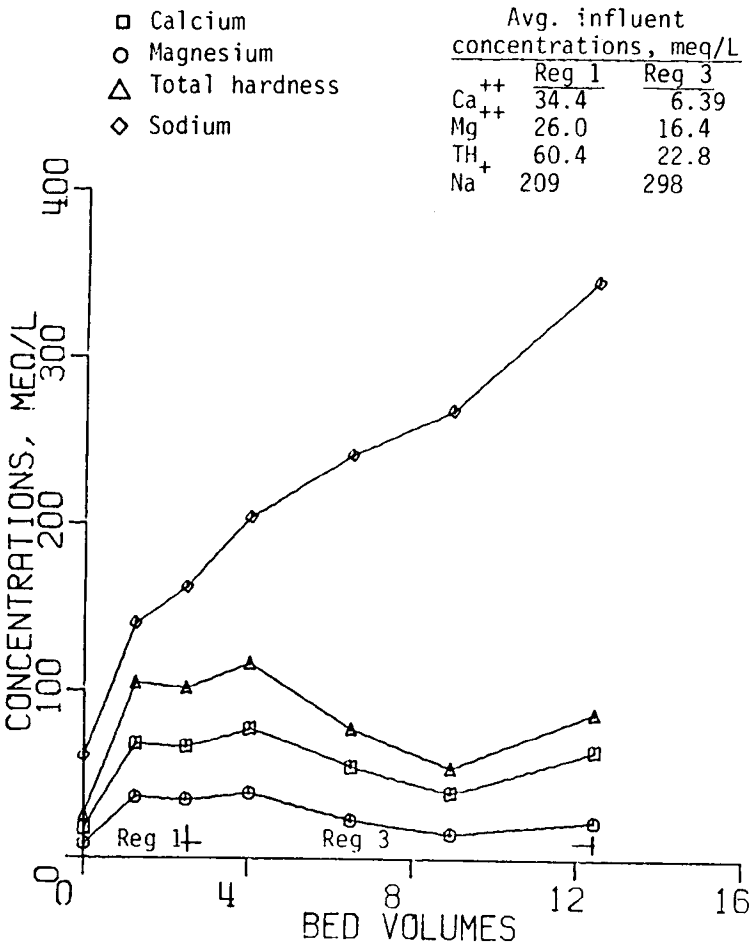
MODE	PROCESS STREAM	THROUGHPUT BV	CA MEQ/L	MG MEQ/L	TH MEQ/L	NA MEQ/L
REGEN 1	EFFLUENT	0.00	17.27	8.31	25.58	60.90
REGEN 1	INFLUENT	.75	34.43	26.01	60.44	208.79
REGEN 1	EFFLUENT	1.26	68.36	36.46	104.82	140.50
REGEN 3	EFFLUENT	2.51	66.87	34.90	101.76	162.68
REGEN 3	INFLUENT	3.33	6.39	16.38	22.77	297.96
REGEN 3	EFFLUENT	4.04	77.84	39.01	116.86	204.44
REGEN 3	EFFLUENT	6.49	54.89	22.96	77.85	241.84
REGEN 3	EFFLUENT	8.94	39.42	14.98	54.40	269.25
REGEN 3	EFFLUENT	12.43	64.87	22.47	87.34	347.11
RINSE	EFFLUENT	0.00	8.28	15.64	23.92	297.96
RINSE	EFFLUENT	.81	5.84	9.47	15.30	238.36
SERVICE	EFFLUENT	1.62	.29	.55	.84	63.51
SERVICE	INFLUENT	4.37	8.53	4.12	12.65	41.93
SERVICE	EFFLUENT	19.31	.25	.44	.70	53.98
SERVICE	INFLUENT	34.86	8.08	4.42	12.50	41.15
SERVICE	EFFLUENT	36.99	.48	1.93	2.41	52.50
SERVICE	EFFLUENT	54.67	2.44	6.09	8.53	46.11
SERVICE	EFFLUENT	62.91	3.79	6.55	10.34	44.85
SERVICE	INFLUENT	66.57	8.13	4.44	12.58	41.93
SERVICE	EFFLUENT	66.57	4.24	6.54	10.78	43.89

Service Performance Summary

CYCLE 3.18.09

	AVERAGE CONCENTRATIONS, MEQ/L INFLUENT	EFFLUENT	DIFFERENCE	REMOVAL %	RESIN CAPACITY EQ/L
CA	8.25	1.19	7.06	86	.458
MG	4.33	2.72	1.60	37	.104
TH	12.58	3.91	8.66	69	.563
NA	41.67	52.18	-10.51		

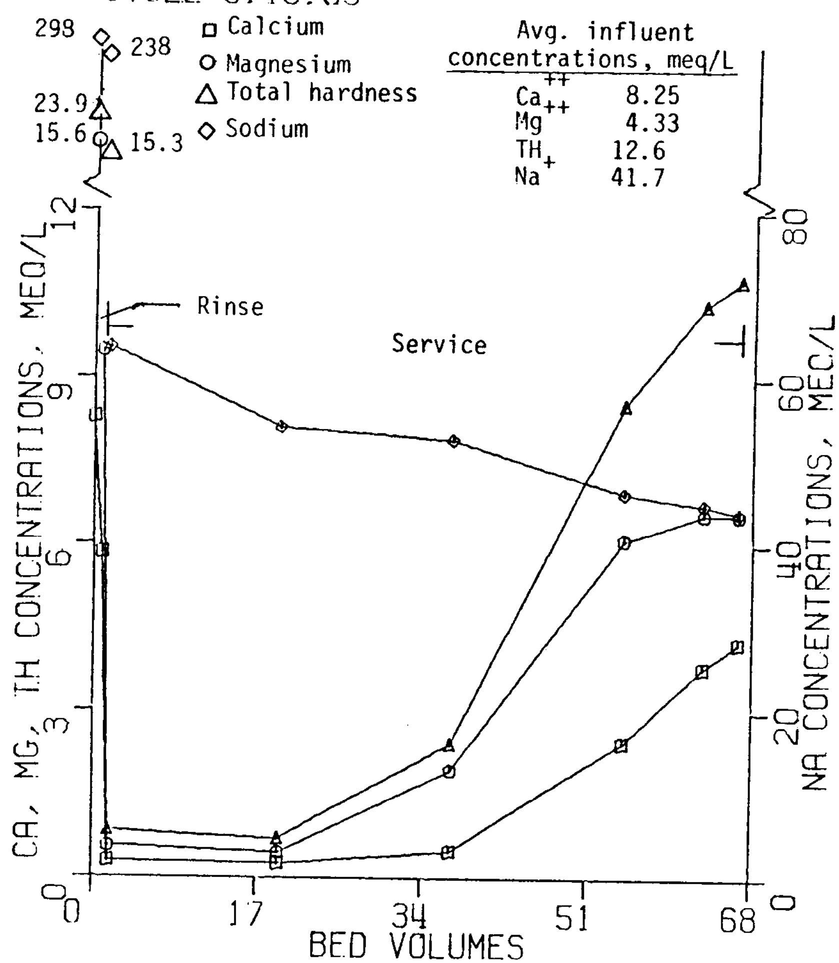
FIGURE A- a
MAJOR CATION CONCENTRATIONS
OF IX REGENERATION EFFLUENT
CYCLE 3.18.09



Avg. influent concentrations, meq/L

	Reg 1	Reg 3
Ca^{++}	34.4	6.39
Mg^{++}	26.0	16.4
TH	60.4	22.8
Na^{+}	209	298

FIGURE A- b
MAJOR CATION CONCENTRATIONS OF
IX RINSE AND SERVICE EFFLUENTS
CYCLE 3.18.09



Avg. influent concentrations, meq/L

Ca^{++}	8.25
Mg^{++}	4.33
TH	12.6
Na^{+}	41.7

SODIUM (NA), CALCIUM (CA), AND MAGNESIUM (MG) CONCENTRATIONS ARE MEASURED BY ATOMIC ABSORPTION. TOTAL HARDNESS (TH) IS CALCULATED BY SUMMING THE CALCIUM AND MAGNESIUM CONCENTRATIONS.

Ion-Exchange - Run 3.18.00B

Date: 6/25/79

Cycle: 3.18.13B

Conditions: Feedwater - Wellton-Mowhawk drainage pretreated (in Train IV) with high lime dosage for silica removal
Regenerant - fresh ED brine
Backwash - feedwater

Control variables:

	Target	Actual
Fresh regeneration conc. (mg/L TDS)	20 000	20 620
Fresh regeneration flow rate (L/min)	5.5	5.5
Recycled regenerant flow rate (L/min)	None	None
Recycled regenerant volume (L)	None	None
Service termination point (meq/L Ca^{++})	4.5	4.6

Standard resin bed: Height = 1081 mm
Volume = 98.7 L

Chemical Compositions of Tank Waters Prior to Cycle 3.18.13B

Tank	pH units	Conductivity µS/cm	Ca^{++} meq/L	Mg^{++} meq/L	TH meq/L
Recycle regenerant (T-5)	-	24 151	41.0	27.0	68.0
Spent regenerant (T-6)	-	24 919	43.0	23.0	66.0
Lime-softened feed (T-9)	7.1	5 381	9.6	4.0	13.6
Lime softened feed (T-10)	7.3	5 150	9.2	4.0	13.2
Fresh ED brine (T-28)	6.4	27 224	6.8	14.8	21.6
IX product/ED feed (T-33)	7.1	5 719	1.04	2.4	3.4

Cycle 3.18.13B Operating Conditions

MODE	INPUT	OUTPUT	DURATION MIN	THROUGHPUT L	VOLUME BV	AVG FLOW RATE L/MIN	AVG FLOW RATE BV/MIN	BED EXPANSION %	TEMPERATURE C
BACKWASH	FEED	WASTE	10	240	2.43	24.0	.243	43.	27.2
DRAIN 1	(VENT)	WASTE	3	62	.63	20.7	.209	0.0	
REGEN	FR REGEN	WASTE	137	751	7.61	5.47	.055	5.2	30.2
DRAIN 2	(VENT)	WASTE	3	62	.63	20.7	.209	0.0	
RINSE	FEED	WASTE	10	150	1.52	15.0	.152	0.0	
SERVICE	FEED	PRODUCT	176	5270	53.4	29.9	.303	0.0	
DRAIN 3	(VENT)	WASTE	2	41	.42	20.7	.209	0.0	

Fresh Regenerant Volume Balance

Run 3.18.00B Cycle no.	Date	Fresh regenerant volume (V_3) L	Fresh regenerant TDS mg/L	Service volume (V_S) L	Estimated ED feed TDS mg/L	R %	$V_3/(1-R)V_S$
04	6/22/79	852	-	6190	3300	-	-
05	6/23/79	852	-	5610	3300	-	-
06	6/23/79	748	-	5160	3300	-	-
07	6/23/79	740	-	5430	3300	-	-
08	6/24/79	750	-	4770	3300	-	-
09	6/24/79	750	-	5020	3300	-	-
10	6/24/79	752	-	4980	3300	-	-
11	6/24/79	758	-	5000	3300	-	-
12	6/25/79	750	-	4950	3300	-	-
13	6/25/79	751	-	5270	3300	-	-

Influent and Effluent Compositions during Cycle 3.18.13B

	Units	Backwash Influent	Backwash Effluent	Regeneration Influent	Regeneration Effluent	Rinse, service influent	Rinse effluent	Service effluent
pH	units	-	-	6.3	-	7.3	6.4	7.1
TDS (Σ ions)	mg/L	3581	4055	20 615	17 248	3372	17 606	3460
Conductivity @ 25 °C	μS/cm	-	-	27 216	-	5144	23 503	5437
E. F. (TDS/cond.)	-	-	-	0.76	-	0.65	0.75	0.64
Silica	mg/L	4.0	4.0	4.2	4.4	4.0	4.2	3.8
Calcium	mg/L	186	185	33.2	1050	180	148	31.2
Magnesium	mg/L	47.5	56.9	186	269	46.0	136	33.1
Sodium	mg/L	1010	1170	7070	4680	959	6030	1162
Potassium	mg/L	9.0	10	61	29	8.3	52	12.1
Strontium	mg/L	6.0	6.0	1.5	18	2.8	2.1	0.7
Bicarbonate	mg/L	48.8	73.2	29.3	97.6	19.5	33.2	17.1
Carbonate	mg/L	ND	ND	ND	ND	ND	ND	ND
Hydroxide	mg/L	ND	ND	ND	ND	ND	ND	ND
Sulfate	mg/L	1050	1150	5780	4580	966	4850	990
Chloride	mg/L	1220	1400	7450	6520	1186	6350	1210
T-alkalinity as $CaCO_3$	mg/L	40.0	60.0	24.0	80.0	16.0	27.2	14.0
P-alkalinity as $CaCO_3$	mg/L	ND	ND	ND	ND	ND	ND	ND
Σ Anions	meq/L	57.09	64.65	331.0	280.9	53.90	280.7	55.04
Σ Cations	meq/L	57.49	65.20	326.1	279.3	54.76	282.3	55.15
Control value	meq/L	-0.41	-0.50	+0.94	+0.38	-0.91	-0.35	-0.11

Major Cation Concentrations of Samples Analyzed by Atomic Absorption

CYCLE 3.18.13B

MODE	PROCESS STREAM	THROUGHPUT BV	CA MEQ/L	MG MEQ/L	TH MEQ/L	NA MEQ/L
BACKWASH	EFFLUENT	0.00	10.53	5.31	15.84	52.20
BACKWASH	INFLUENT	.73	9.28	3.91	13.19	43.93
BACKWASH	EFFLUENT	1.22	8.98	4.54	13.53	49.15
REGEN	EFFLUENT	2.43	8.53	4.35	12.88	46.98
REGEN	INFLUENT	3.43	1.66	15.31	16.97	307.53
REGEN	EFFLUENT	4.32	90.32	50.12	140.44	187.47
REGEN	EFFLUENT	6.20	66.37	27.16	93.53	236.19
REGEN	EFFLUENT	8.08	50.40	16.05	66.45	265.77
REGEN	EFFLUENT	10.02	47.90	14.16	62.06	287.08
RINSE	EFFLUENT	0.00	9.08	13.83	22.91	302.74
RINSE	EFFLUENT	.76	5.34	7.19	12.53	217.05
SERVICE	EFFLUENT	1.52	.29	.47	.76	60.90
SERVICE	INFLUENT	4.25	8.73	3.72	12.45	40.58
SERVICE	EFFLUENT	14.26	.27	.40	.68	53.63
SERVICE	INFLUENT	25.49	9.03	3.75	12.79	41.02
SERVICE	EFFLUENT	27.00	.31	.60	.92	54.11
SERVICE	EFFLUENT	39.75	1.18	3.63	4.81	50.41
SERVICE	EFFLUENT	46.12	2.99	5.47	8.46	46.50
SERVICE	INFLUENT	54.91	9.18	3.88	13.07	41.76
SERVICE	EFFLUENT	54.91	4.59	5.98	10.57	44.19

Service Performance Summary

CYCLE 3.18.13B

	AVERAGE CONCENTRATIONS, MEQ/L INFLUENT	EFFLUENT	DIFFERENCE	REMOVAL %	RESIN CAPACITY EQ/L
CA	8.98	1.19	7.79	87	.416
MG	3.79	2.21	1.57	42	.084
TH	12.77	3.40	9.36	73	.500
NA	41.12	52.25	-11.13		

FIGURE A- a
MAJOR CATION CONCENTRATIONS
OF IX REGENERATION EFFLUENT
CYCLE 3.18.13B

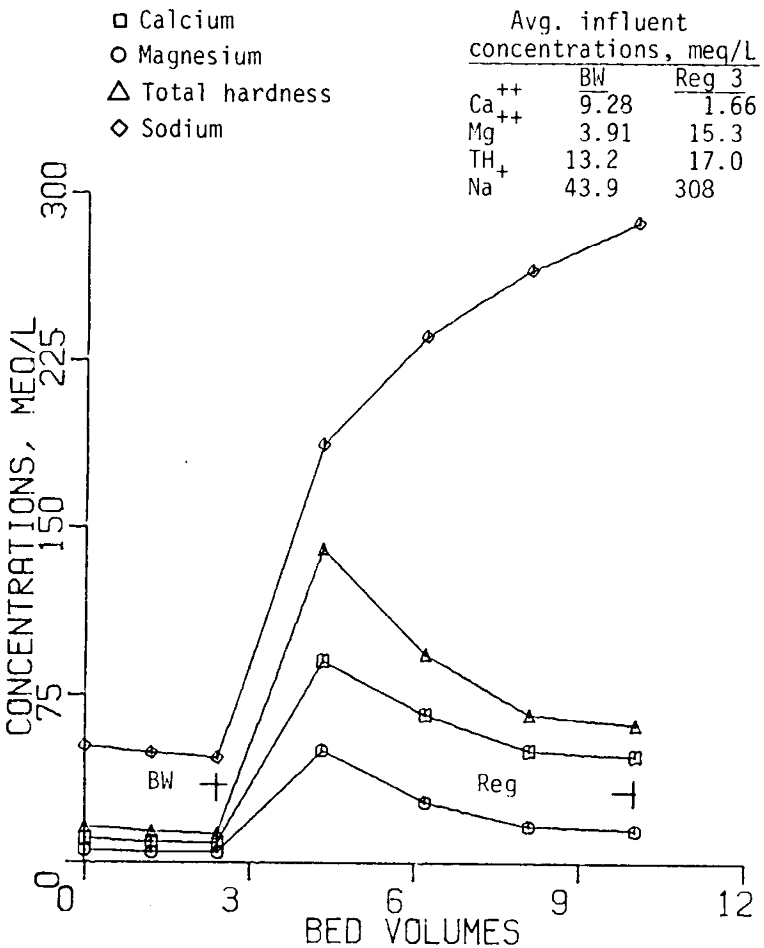
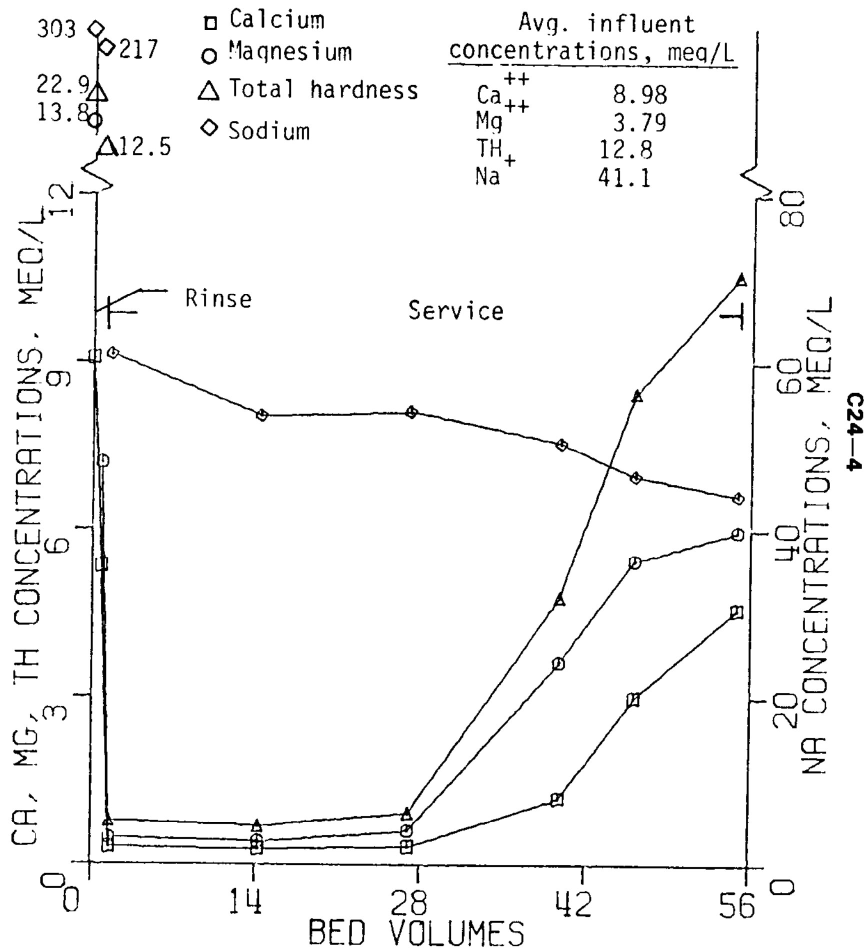


FIGURE A- b
MAJOR CATION CONCENTRATIONS OF
IX RINSE AND SERVICE EFFLUENTS
CYCLE 3.18.13B



SODIUM (NA), CALCIUM (CA), AND MAGNESIUM (MG) CONCENTRATIONS ARE MEASURED BY ATOMIC ABSORPTION.
TOTAL HARDNESS (TH) IS CALCULATED BY SUMMING THE CALCIUM AND MAGNESIUM CONCENTRATIONS.

Ion-Exchange - Run 3.19.00

Date: 6/28/79

Cycle: 3.19.09

Conditions: Feedwater - Welton-Mowhawk drainage pretreated (in train IV) with high lime dosage for silica removal
Regenerants - recycled regenerant and fresh ED brine

Control variables:

	Target	Actual
Fresh regeneration conc. (mg/L TDS)	20 000	19 410
Fresh regeneration flow rate (L/min)	5.5	5.4
Recycled regenerant flow rate (L/min)	8.0	8.8
Recycled regenerant volume (L)	800	800
Service termination point (meq/L Ca^{++})	4.5	4.7

Standard resin bed: Height = 1081 mm
Volume = 98.7 L

Chemical Compositions of Tank Waters Prior to Cvcle 3.19.09

Tank	pH units	Conductivity µS/cm	Ca^{++} meq/L	Mg^{++} meq/L	TH meq/L
Recycled regenerant (T-5)	-	24 732	40.0	22.0	62.0
Spent regenerant (T-6)	-	24 341	41.0	27.0	68.0
Lime-softened feed (T-9)	7.1	5 382	10.0	3.6	13.6
Lime-softened feed (T-10)	7.3	5 362	10.0	3.2	13.2
Fresh ED brine (T-28)	6.3	25 756	6.4	15.2	21.6
IX product/ED feed (T-33)	7.2	5 759	1.2	2.2	3.4

Cycle 3.19.09 Operating Conditions

MODE	INPUT	OUTPUT	DURATION MIN	THROUGHPUT L	VOLUME BV	AVG FLOW RATE L/MIN	AVG FLOW RATE BV/MIN	BED EXPANSION %	TEMPERATURE C
REGEN 1	RE REGEN	WASTE	10	240	2.43	24.0	.243	41.	31.0
REGEN 2	RE REGEN	SP REGEN	91	800	8.11	8.77	.089	8.7	
REGEN 3	FR REGEN	SP REGEN	144	781	7.91	5.42	.055	3.3	35.0
DRAIN 1	(VENT)	WASTE	3	62	.63	20.7	.209	0.0	
RINSE	FEED	WASTE	10	150	1.52	15.0	.152	0.0	
SERVICE	FEED	PRODUCT	180	5420	54.9	30.1	.305	0.0	
DRAIN 2	(VENT)	WASTE	2	41	.42	20.7	.209	0.0	

Fresh Regenerant Volume Balance

Run 3.19.00 Cycle no.	Date	Fresh regenerant volume (V_3) L	Fresh regenerant TDS mg/L	Service volume (V_S) L	Estimated ED feed TDS mg/L	R %	$V_3/(1-R)V_S$
3.19.03	6/26/79	918	20 240	6040	3300	86	1.07
3.19.04	6/26/79	918	20 240	5610	3300	86	1.14
3.19.05	6/27/79	918	19 550	5780	3300	85	1.07
3.19.06	6/27/79	785	19 550	5660	3300	85	0.94
3.19.07	6/27/79	776	19 550	5220	3300	85	1.00
3.19.08	6/28/79	780	19 490	5330	3300	85	0.98
3.19.09	6/28/79	781	19 490	5420	3300	85	0.97

Influent and Effluent Compositions during Cycle 3.19.09

	Units	Regen 1, 2 influent	Regen 1 effluent	Regen 2 effluent	Regen 3 Influent	Regen 3 Effluent	Rinse effluent	Service effluent
pH	units	-	-	-	6.4	-	6.6	7.2
TDS (Σ ions)	mg/L	18 209	13 520	17 884	19 411	18 695	18 145	3 529
Conductivity @ 25 °C	μS/cm	-	-	-	26 208	-	25 075	5 553
E. F. (TDS/cond.)	-	-	-	-	0.74	-	0.72	0.64
Silica	mg/L	5.2	4.6	4.6	4.3	5.2	3.8	2.1
Calcium	mg/L	910	1 240	1 190	138	890	169	38.6
Magnesium	mg/L	359	348	379	193	246	141	38.0
Sodium	mg/L	5 210	3 070	4 630	6 620	5 500	6 070	1 167
Potassium	mg/L	37	30	38	72	45	64	13.0
Strontium	mg/L	19	19	19	1.8	16	2.9	0.7
Bicarbonate	mg/L	48.8	48.8	63.4	22.0	73.2	23.9	17.1
Carbonate	mg/L	ND	ND	ND	ND	ND	ND	ND
Hydroxide	mg/L	ND	ND	ND	ND	ND	ND	ND
Sulfate	mg/L	4 400	3 440	4 160	5 100	4 100	5 000	1 050
Chloride	mg/L	7 220	5 320	7 400	7 260	7 820	6 670	1 202
T-alkalinity as $CaCO_3$	mg/L	40.0	40.0	52.0	22.0	60.0	19.6	14.0
P-alkalinity as $CaCO_3$	mg/L	ND	ND	ND	ND	ND	ND	ND
Σ Anions	meq/L	296.1	222.5	296.4	311.4	307.2	292.7	55.78
Σ Cations	meq/L	302.9	225.2	293.4	312.6	305.4	285.8	56.16
Control value	meq/L	-1.45	-0.76	+0.64	-0.24	+0.37	+1.49	-0.39

Major Cation Concentrations of Samples Analyzed by Atomic Absorption

CYCLE 3.19.09

MODE	PROCESS STREAM	THROUGHPUT BV	CA MEQ/L	MG MEQ/L	TH MEQ/L	NA MEQ/L
REGEN 1	EFFLUENT	0.00	21.96	9.47	31.42	60.46
REGEN 1	EFFLUENT	1.22	82.34	41.07	123.41	148.76
REGEN 2	EFFLUENT	2.43	77.35	38.68	116.03	181.82
REGEN 2	INFLUENT	5.72	45.41	29.55	74.96	226.62
REGEN 2	EFFLUENT	6.61	54.39	30.95	85.34	210.53
REGEN 3	EFFLUENT	10.52	48.40	28.89	77.29	215.31
REGEN 3	INFLUENT	11.45	6.89	15.88	22.77	287.95
REGEN 3	EFFLUENT	12.44	50.90	28.89	79.79	237.93
REGEN 3	EFFLUENT	14.37	45.91	20.91	66.81	247.93
REGEN 3	EFFLUENT	16.40	39.42	15.14	54.57	257.94
REGEN 3	EFFLUENT	18.43	39.92	13.91	53.83	255.76
RINSE	EFFLUENT	0.00	8.78	14.24	23.02	284.47
RINSE	EFFLUENT	.76	7.98	10.78	18.77	251.41
SERVICE	EFFLUENT	1.52	.37	.63	.99	61.77
SERVICE	INFLUENT	4.27	9.58	4.23	13.81	41.24
SERVICE	EFFLUENT	8.23	.32	.46	.78	53.68
SERVICE	EFFLUENT	14.94	.31	.46	.77	53.46
SERVICE	EFFLUENT	21.65	.32	.48	.80	52.81
SERVICE	EFFLUENT	28.37	.37	.74	1.11	52.20
SERVICE	EFFLUENT	41.79	1.42	4.38	5.80	47.06
SERVICE	EFFLUENT	48.50	3.24	6.37	9.61	46.67
SERVICE	EFFLUENT	55.82	4.69	6.45	11.14	42.32
SERVICE	INFLUENT	56.43	9.53	4.16	13.70	40.41
SERVICE	EFFLUENT	56.43	4.74	6.40	11.14	41.84

Service Performance Summary

CYCLE 3.19.09

	AVERAGE CONCENTRATIONS, MEQ/L INFLUENT	EFFLUENT	DIFFERENCE	REMOVAL %	RESIN CAPACITY EQ/L
CA	9.56	1.25	8.31	87	.456
MG	4.20	2.46	1.73	41	.095
TH	13.75	3.71	10.04	73	.552
NA	40.82	50.77	-9.95		

FIGURE A- a
MAJOR CATION CONCENTRATIONS
OF IX REGENERATION EFFLUENT
CYCLE 3.19.09

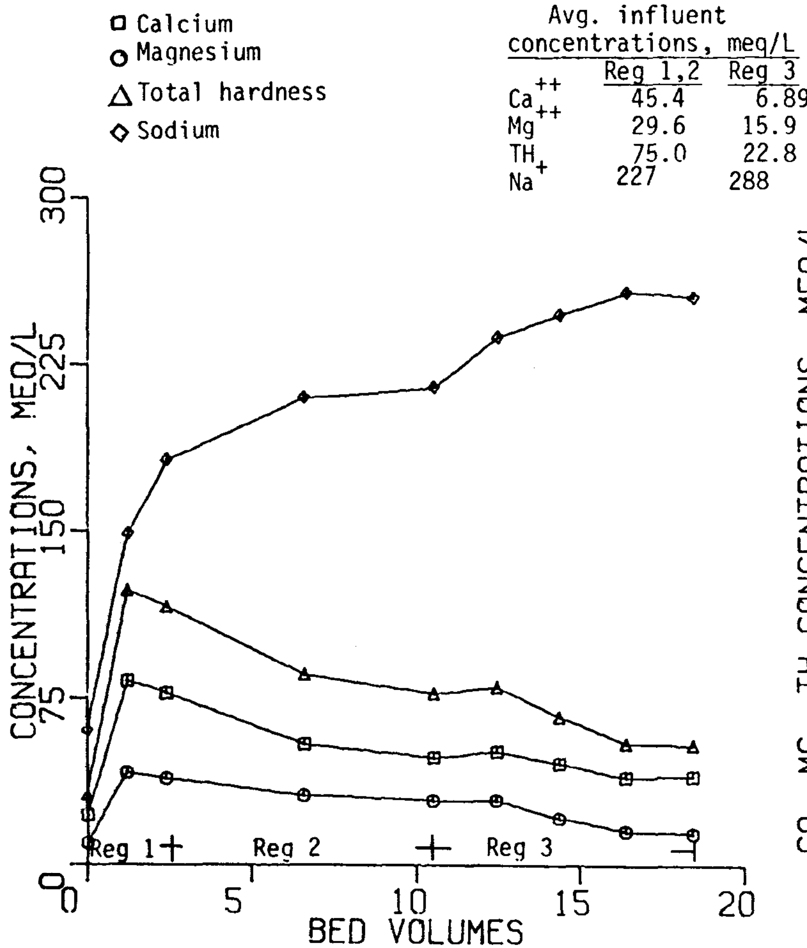
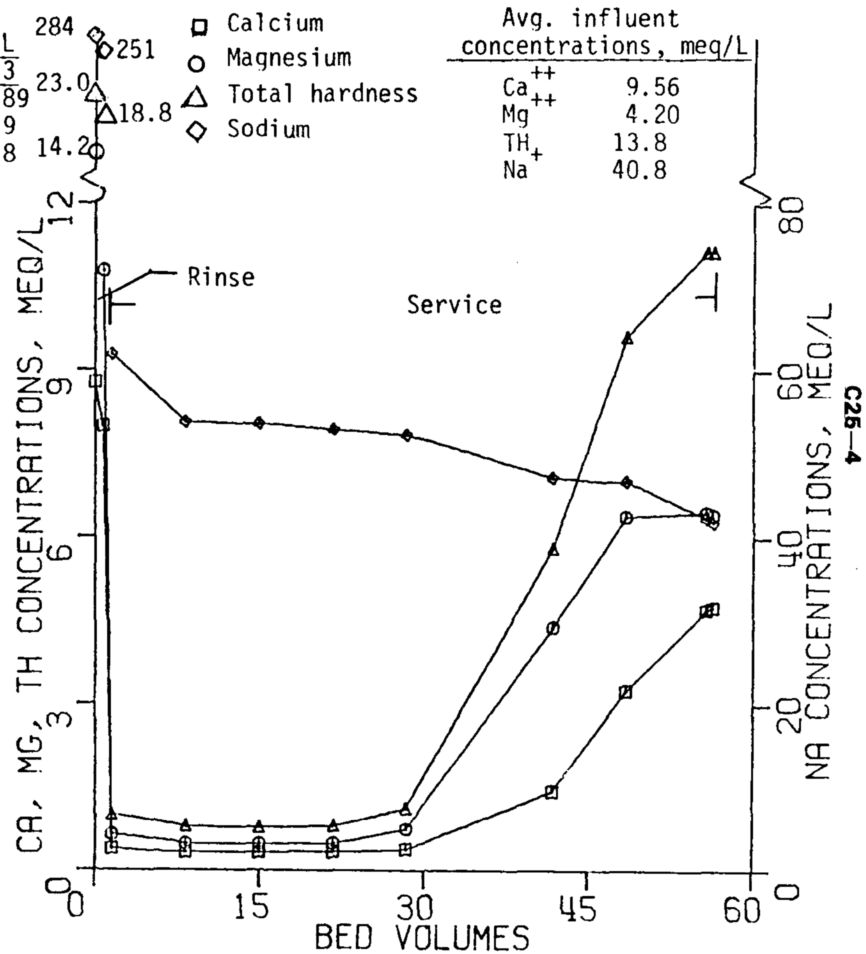


FIGURE A- b
MAJOR CATION CONCENTRATIONS OF
IX RINSE AND SERVICE EFFLUENTS
CYCLE 3.19.09



SODIUM (NA), CALCIUM (CA), AND MAGNESIUM (MG) CONCENTRATIONS ARE MEASURED BY ATOMIC ABSORPTION.
TOTAL HARDNESS (TH) IS CALCULATED BY SUMMING THE CALCIUM AND MAGNESIUM CONCENTRATIONS.

Ion-Exchange - Run 3.20.10

Date:	7/2/79
Cycle:	3.20.10
Conditions:	Feedwater - Wellton-Mowhawk drainage pretreated (in train IV) with high lime dosage for silica removal Regenerants - recycled regenerant and fresh ED brine

Control variables:

	Target	Actual
Fresh regeneration conc. (mg/L TDS)	20 000	19 600
Fresh regeneration flow rate (L/min)	5.5	5.6
Recycled regenerant flow rate (L/min)	24.0	23.1
Recycled regenerant volume (L)	800	805
Service termination point (meq/L Ca^{++})	4.5	4.6

Standard resin bed: Height = 1081 mm
Volume = 98.7 L

Chemical Compositions of Tank Waters Prior to Cycle 3.20.10

Tank	pH units	Conductivity µS/cm	Ca^{++} meq/L	Mg^{++} meq/L	TH meq/L
Recycled regenerant (T-5)	-	24 552	47.0	25.0	72.0
Spent regenerant (T-6)	-	24 397	90.0	20.0	110.0
Lime-softened feed (T-9)	7.2	5 299	9.2	4.4	13.6
Lime-softened feed (T-10)	7.3	5 242	9.2	4.4	13.6
Fresh ED brine (T-28)	6.2	26 201	6.4	13.6	20.0
IX product/ED feed (T-33)	7.2	5 642	1.2	2.4	3.6

Cycle 3.20.10 Operating Conditions

MODE	INPUT	OUTPUT	DURATION MIN	THROUGHPUT L	VOLUME BV	AVG FLOW RATE L/MIN	AVG FLOW RATE BV/MIN	BED EXPANSION %	TEMPERATURE C
REGEN 1	RE REGEN	WASTE	10	235	2.38	23.5	.238	41.	29.8
REGEN 2	RE REGEN	SP REGEN	35	805	8.16	23.1	.234	41.	29.9
REGEN 3	FR REGEN	SP REGEN	173	97	9.78	5.58	.057	3.6	32.0
DRAIN 1	(VENT)	WASTE	3	62	.63	20.7	.209	0.0	
RINSE	FEED	WASTE	10	150	1.52	15.0	.152	0.0	
SERVICE	FEED	PRODUCT	200	5960	60.4	29.8	.302	0.0	
DRAIN 2	(VENT)	WASTE	2	41	.42	20.7	.209	0.0	

Fresh Regenerant Volume Balance

Run 3.20.00 Cycle no.	Date	Fresh regenerant volume (V_3) L	Fresh regenerant TDS mg/L	Service volume (V_S) L	Estimated ED feed TDS mg/L	R %	$V_3/(1-R)V_S$
03	6/30/79	952	19 280	5850	3300	85	1.08
04	6/30/79	952	19 280	6080	3300	85	1.04
05	6/30/79	952	19 280	5820	3300	85	1.09
06	7/1/79	952	19 280	5850	3300	85	1.08
07	7/1/79	952	19 280	5940	3300	85	1.07
08	7/1/79	943	19 280	5630	3300	85	1.12
09	7/2/79	952	19 777	5680	3300	85	1.11
10	7/2/79	965	19 777	5960	3300	85	1.11

Influent and Effluent Compositions during Cycle 3.20.10

	Units	Regen 1, 2 influent	Regen 1 effluent	Regen 2 effluent	Regen 3 Influent	Regen 3 Effluent	Rinse, service influent	Rinse effluent	Service effluent
pH	units	-	-	-	6.2	-	7.1	6.3	7.1
TDS (Σ ions)	mg/L	18 235	13 593	17 870	19 604	19 312	3 393	18 236	3 480
Conductivity @ 25 °C	μS/cm	-	-	-	26 110	-	5 135	24 592	5 459
E. F. (TDS/cond.)	-	-	-	-	0.75	-	0.66	0.74	0.64
Silica	mg/L	3.8	3.2	3.8	3.9	3.6	3.4	3.6	3.4
Calcium	mg/L	930	1 180	1 240	137	930	182	149	36.5
Magnesium	mg/L	298	342	372	171	224	53.0	146	44.3
Sodium	mg/L	5 200	3 190	4 710	6 700	5 710	935	6 290	1 140
Potassium	mg/L	32	26	30	68	35	8.6	63	13.6
Strontium	mg/L	18	19	21	2.0	16	2.8	2.5	0.7
Bicarbonate	mg/L	73.2	73.2	73.2	22.0	73.2	13.7	22.0	17.1
Carbonate	mg/L	ND	ND	ND	ND	ND	ND	ND	ND
Hydroxide	mg/L	ND	ND	ND	ND	ND	ND	ND	ND
Sulfate	mg/L	4 260	3 260	4 060	5 090	5 020	1 014	4 880	1 008
Chloride	mg/L	7 420	5 500	7 360	7 410	7 300	1 180	6 680	1 216
T-alkalinity as $CaCO_3$	mg/L	60.0	60.0	60.0	18.0	60.0	11.2	18.0	14.0
P-alkalinity as $CaCO_3$	mg/L	ND	ND	ND	ND	ND	ND	ND	ND
Σ Anions	meq/L	299.3	224.3	293.4	315.4	311.6	54.63	290.5	55.58
Σ Cations	meq/L	298.3	226.9	298.6	314.1	314.5	54.40	294.7	55.42
Control value	meq/L	+0.20	-0.74	-1.12	+0.26	-0.59	+0.25	-0.93	+0.17

Major Cation Concentrations of Samples Analyzed by Atomic Absorption

CYCLE 3.20.10

MODE	PROCESS STREAM	THROUGHPUT BV	CA MEQ/L	MG MEQ/L	TH MEQ/L	NA MEQ/L
REGEN 1	EFFLUENT	0.00	31.44	13.33	44.77	79.16
REGEN 1	EFFLUENT	1.19	67.86	33.25	101.12	151.81
REGEN 2	EFFLUENT	2.38	72.36	36.79	109.15	177.90
REGEN 2	INFLUENT	4.26	46.41	24.53	70.93	226.19
REGEN 2	EFFLUENT	6.13	57.88	29.47	87.35	213.14
REGEN 3	EFFLUENT	10.58	50.90	27.24	78.14	220.10
REGEN 3	INFLUENT	12.34	6.84	14.07	20.91	291.43
REGEN 3	EFFLUENT	13.01	53.89	26.58	80.48	245.76
REGEN 3	EFFLUENT	15.45	47.41	16.63	64.03	255.76
REGEN 3	EFFLUENT	17.88	39.42	11.85	51.27	264.46
REGEN 3	EFFLUENT	20.36	38.42	11.77	50.19	267.07
RINSE	EFFLUENT	0.00	8.08	13.17	21.25	289.69
RINSE	EFFLUENT	.76	6.99	9.88	16.86	256.63
SERVICE	EFFLUENT	1.52	.31	.50	.82	60.46
SERVICE	INFLUENT	4.24	9.03	4.39	13.42	40.80
SERVICE	EFFLUENT	16.01	.28	.41	.69	53.85
SERVICE	INFLUENT	23.26	8.98	4.49	13.47	41.28
SERVICE	EFFLUENT	30.50	.31	.60	.92	52.81
SERVICE	EFFLUENT	45.00	1.14	4.63	5.77	48.24
SERVICE	EFFLUENT	52.24	2.40	6.37	8.77	45.24
SERVICE	EFFLUENT	59.49	4.09	6.76	10.85	42.89
SERVICE	INFLUENT	61.90	8.98	4.39	13.37	40.58
SERVICE	EFFLUENT	61.90	4.59	6.80	11.39	42.71

Service Performance Summary

CYCLE 3.20.10

	AVERAGE CONCENTRATIONS, MEQ/L INFLUENT	EFFLUENT	DIFFERENCE	REMOVAL %	RESIN CAPACITY EQ/L
CA	9.00	1.09	7.91	88	.477
MG	4.42	2.58	1.84	42	.111
TH	13.42	3.67	9.75	73	.589
NA	40.89	51.25	-10.36		

FIGURE A- a
MAJOR CATION CONCENTRATIONS
OF IX REGENERATION EFFLUENT
CYCLE 3.20.10

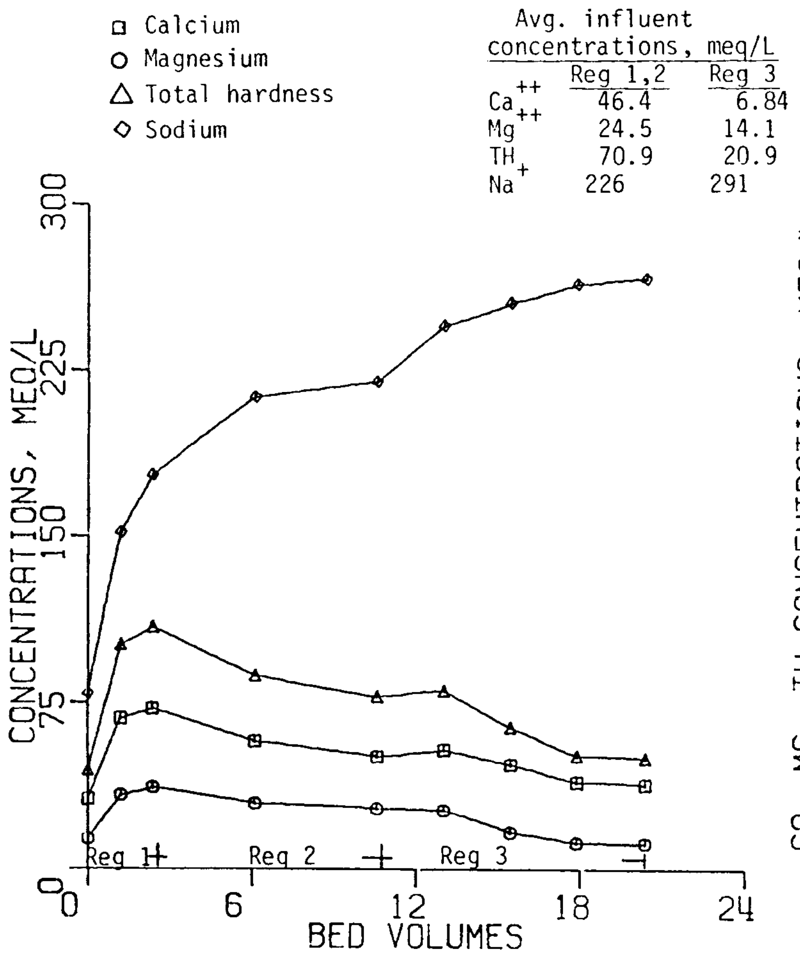
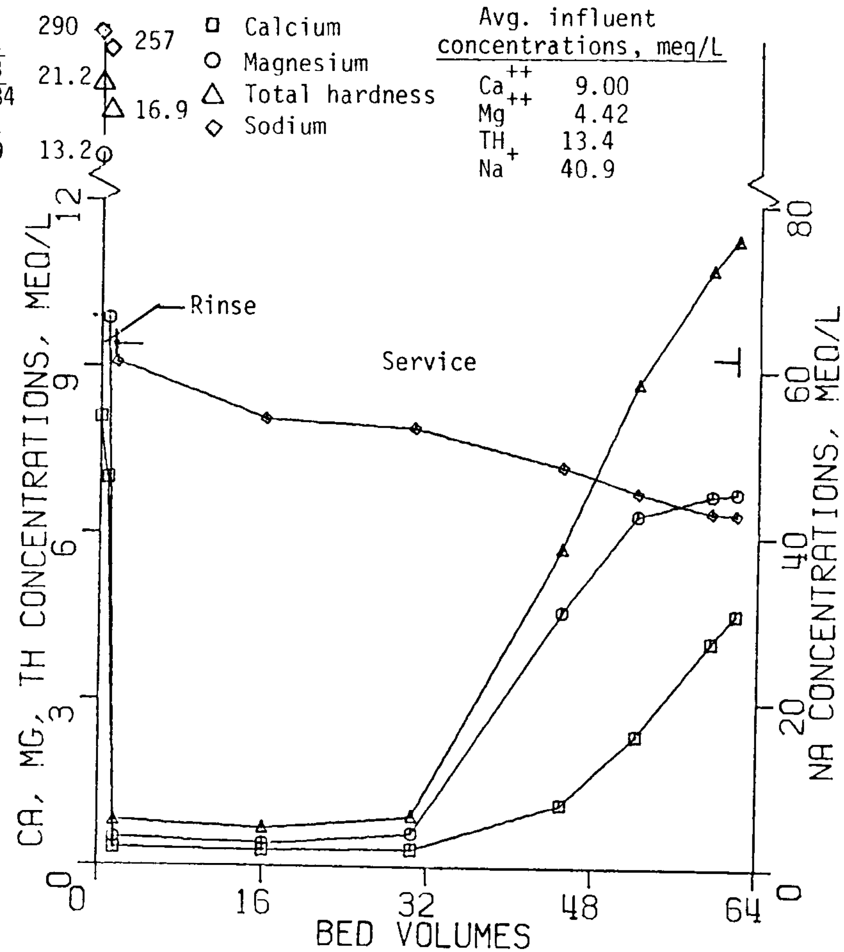


FIGURE A- b
MAJOR CATION CONCENTRATIONS OF
IX RINSE AND SERVICE EFFLUENTS
CYCLE 3.20.10



SODIUM (NA), CALCIUM (CA), AND MAGNESIUM (MG) CONCENTRATIONS ARE MEASURED BY ATOMIC ABSORPTION.
TOTAL HARDNESS (TH) IS CALCULATED BY SUMMING THE CALCIUM AND MAGNESIUM CONCENTRATIONS.

Ion-Exchange - Run 3.18.00E

Date:	7/9/79
Cycle:	3.18.21E
Conditions:	Feedwater - Wellton-Mowhawk drainage pretreated (in train IV) with high lime dosage for silica removal Regenerant - fresh ED brine plus 100 mg/L SHMP Source of backwash - IX feedwater

Control variables:		Target	Actual
	Fresh regeneration conc. (mg/L TDS)	20 000	21 820
	Fresh regeneration flow rate (L/min)	5.5	5.4
	Recycled regenerant flow rate (L/min)	None	None
	Recycled regenerant volume (L)	None	None
	Service termination point (meq/L Ca^{++})	4.5	4.1

Standard resin bed: Height = 1081 mm
Volume = 98.7 L

Chemical Compositions of Tank Waters Prior to Cycle 3.18.21E

Tank	pH units	Conductivity uS/cm	Ca^{++} meq/L	Mg^{++} meq/L	TH meq/L
Lime-softened feed (T-9)	7.2	5 146	9.6	4.4	14.0
Lime softened feed (T-10)	7.3	5 151	9.4	4.2	13.6
Fresh ED brine (T-28)	6.3	28 792	6.0	16.0	22.0
IX product/ED feed (T-33)	7.1	5 557	0.88	2.1	3.0

Cycle 3.18.21E Operating Conditions

MODE	INPUT	OUTPUT	DURATION MIN	THROUGHPUT L	VOLUME BV	AVG FLOW RATE L/MIN	AVG FLOW RATE BV/MIN	BED EXPANSION %	TEMPERATURE C
BACKWASH	FEED	WASTE	10	240	2.43	24.0	.243	30.	27.5
DRAIN 1	(VENT)	WASTE	3	62	.63	20.7	.209	0.0	
REGEN 3	FR REGEN	WASTE	136	735	7.45	5.40	.055	1.1	30.3
DRAIN	(VENT)	WASTE	3	62	.63	20.7	.209	0.0	
RINSE	FEED	WASTE	10	150	1.52	15.0	.152	0.0	
SERVICE	FEED	PRODUCT	189	5680	57.5	30.1	.304	0.0	
DRAIN	(VENT)	WASTE	2	41	.42	20.7	.209	0.0	

Fresh Regenerant Volume Balance

Run 3.18.00E Cycle no.	Date	Fresh regenerant volume (V_3) L	Fresh regenerant TDS mg/L	Service volume (V_S) L	Estimated ED feed TDS mg/L	R %	$V_3/(1-R)V_S$
16E	7/7/79	748	22 050	12 590	3300	87	0.45
17E	7/8/79	748	22 050	6 040	3300	87	0.95
18E	7/8/79	748	22 050	5 270	3300	87	1.08
19E	7/8/79	748	22 050	5 240	3300	87	1.09
20E	7/9/79	748	22 150	5 590	3300	87	1.03
21E	7/9/79	735	22 150	5 680	3300	87	1.00

Influent and Effluent Compositions during Cycle 3.18.21E

	Units	Backwash effluent	Regeneration Influent	Regeneration Effluent	BW, rinse service effluent	Rinse effluent	Service effluent
pH	units	-	6.1	-	7.3	6.5	7.2
TDS (Σ ions)	mg/L	3 626	21 822	18 086	3 259	18 028	3 368
Conductivity @ 25 °C	µS/cm	-	28 846	-	5 263	24 795	5 469
E. F. (TDS/cond.)	-	-	0.76	-	0.62	0.73	0.62
Silica	mg/L	4.6	4.2	4.8	3.5	4.3	3.9
Calcium	mg/L	163	120	1 150	167	123	29.8
Magnesium	mg/L	61.4	185	251	52.8	122	39.1
Sodium	mg/L	997	7 540	4 870	926	6 230	1 114
Potassium	mg/L	12	62	29	8.5	51	11.9
Strontium	mg/L	5.0	1.5	18.0	2.9	2.0	0.7
Bicarbonate	mg/L	63.4	29.3	73.2	20.0	25.9	19.0
Carbonate	mg/L	ND	ND	ND	ND	ND	ND
Hydroxide	mg/L	ND	ND	ND	ND	ND	ND
Sulfate	mg/L	1 035	5 780	5 150	910	4 850	980
Chloride	mg/L	1 285	8 100	6 540	1 168	6 620	1 170
T-alkalinity as $CaCO_3$	mg/L	52.0	24.0	60.0	16.4	21.2	15.6
P-alkalinity as $CaCO_3$	mg/L	ND	ND	ND	ND	ND	ND
Σ Anions	meq/L	58.85	349.4	292.9	52.23	288.2	53.73
Σ Cations	meq/L	56.97	350.8	291.0	53.24	288.5	53.48
Control value	meq/L	+1.84	-0.25	+0.42	-1.10	-0.07	+0.26

Major Cation Concentrations of Samples Analyzed by Atomic Absorption

CYCLE 3.18.21E

MODE	PROCESS STREAM	THROUGHPUT BV	CA MEQ/L	MG MEQ/L	TH MEQ/L	NA MEQ/L
BACKWASH	EFFLUENT	0.00	9.48	5.42	14.90	46.59
BACKWASH	EFFLUENT	1.22	7.88	4.94	12.82	43.06
REGEN 3	EFFLUENT	2.43	7.68	4.79	12.47	42.11
REGEN 3	INFLUENT	3.36	5.99	15.23	21.21	327.97
REGEN 3	EFFLUENT	4.29	99.30	48.81	148.11	200.96
REGEN 3	EFFLUENT	6.15	70.86	23.05	93.90	249.24
REGEN 3	EFFLUENT	8.02	54.39	13.74	68.14	279.25
REGEN 3	EFFLUENT	9.88	47.90	12.18	60.09	295.35
RINSE	EFFLUENT	0.00	8.18	14.32	22.50	322.31
RINSE	EFFLUENT	.76	4.14	5.96	10.10	214.44
SERVICE	EFFLUENT	1.52	.23	.40	.62	56.24
SERVICE	INFLUENT	4.26	8.23	4.31	12.55	40.15
SERVICE	EFFLUENT	14.92	.22	.35	.57	53.46
SERVICE	INFLUENT	21.62	8.28	4.31	12.60	39.80
SERVICE	EFFLUENT	28.31	.24	.43	.67	53.24
SERVICE	EFFLUENT	41.71	.75	3.09	3.83	49.24
SERVICE	EFFLUENT	48.41	1.79	5.44	7.23	45.63
SERVICE	EFFLUENT	55.11	3.39	6.50	9.90	43.15
SERVICE	INFLUENT	59.07	8.38	4.32	12.70	39.80
SERVICE	EFFLUENT	59.07	4.09	6.60	10.69	41.93

Service Performance Summary

CYCLE 3.18.21E

	AVERAGE CONCENTRATIONS, MEQ/L INFLUENT	EFFLUENT	DIFFERENCE	REMOVAL %	RESIN CAPACITY EQ/L
CA	8.30	.93	7.37	89	.424
MG	4.32	2.23	2.09	48	.120
TH	12.62	3.16	9.46	75	.544
NA	39.92	50.73	-10.82		

FIGURE A- a
MAJOR CATION CONCENTRATIONS
OF IX REGENERATION EFFLUENT
CYCLE 3.18.21E

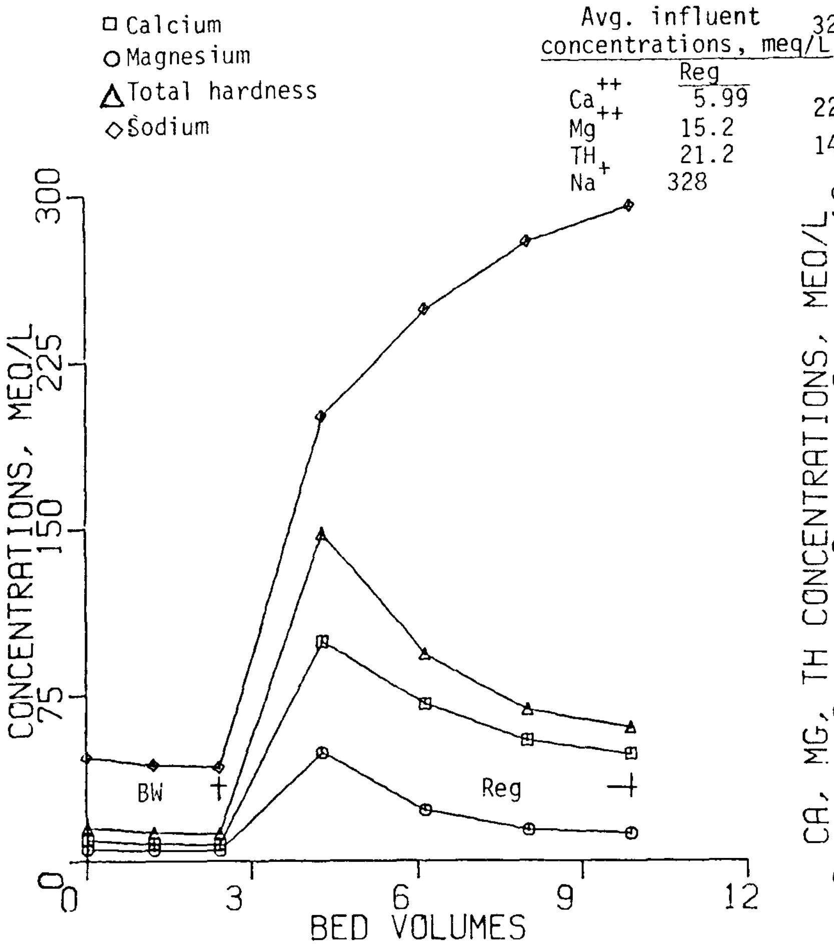
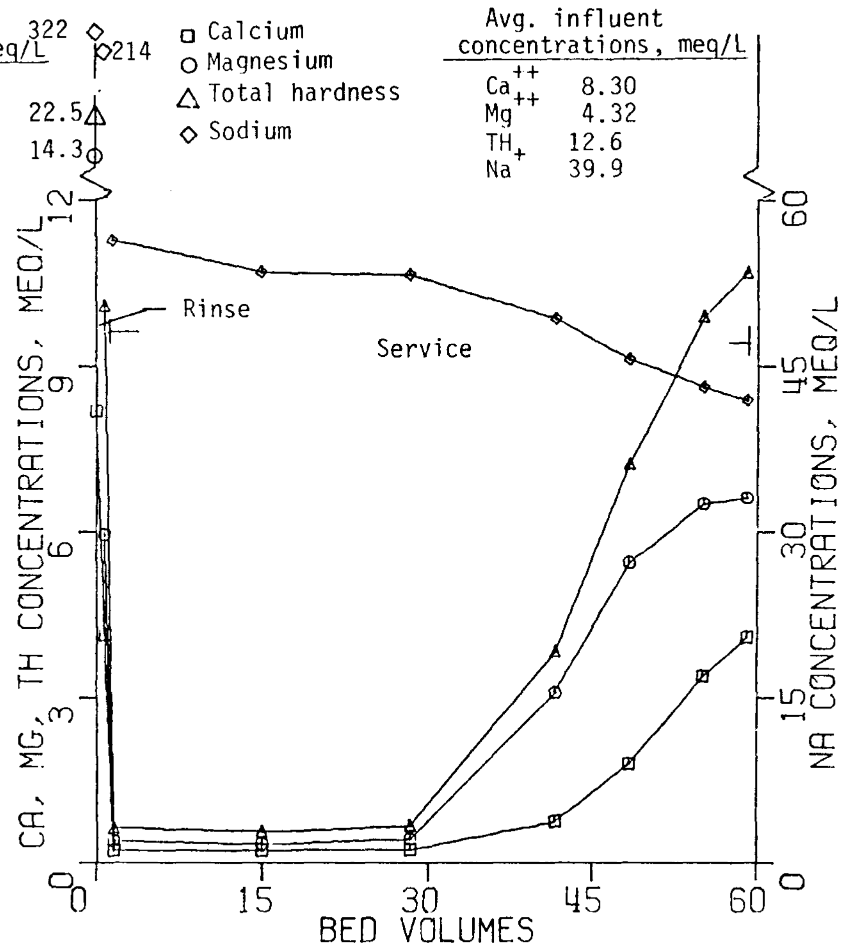


FIGURE A- b
MAJOR CATION CONCENTRATIONS OF
IX RINSE AND SERVICE EFFLUENTS
CYCLE 3.18.21E



SODIUM (NA), CALCIUM (CA), AND MAGNESIUM (MG) CONCENTRATIONS ARE MEASURED BY ATOMIC ABSORPTION.
TOTAL HARDNESS (TH) IS CALCULATED BY SUMMING THE CALCIUM AND MAGNESIUM CONCENTRATIONS.

Ion-Exchange - Run 3.21.00

Date: 8/2/79

Cycle: 3.21.56

Conditions: Feedwater - Wellton-Mowhawk drainage pretreated (in train IV) with high lime dosage for silica removal
Regenerants - recycled regenerant and fresh ED brine

Control variables:

	Target	Actual
Fresh regeneration conc. (mg/L TDS)	35 000	33 880
Fresh regeneration flow rate (L/min)	3.0	3.0
Recycled regenerant flow rate (L/min)	16.0	16.1
Recycled regenerant volume (L)	1 600	1 588
Service termination point (meq/L Ca^{++})	3.0	3.0

Standard resin bed: Height = 1081 mm
Volume = 98.7 L

Chemical Compositions of Tank Waters Prior to Cycle 3.21.56

Tank	pH units	Conductivity µS/cm	Ca^{++} meq/L	Mg^{++} meq/L	TH meq/L
Recycled regenerant (T-5)	-	37 701	45.0	34.0	79.0
Spent regenerant (T-6)	-	37 964	46.0	49.0	95.0
Lime-softened feed (T-9)	7.2	5 252	9.8	3.2	13.0
Lime-softened feed (T-10)	7.2	5 196	9.6	3.0	12.6
Fresh ED brine (T-28)	6.4	42 416	5.0	16.6	21.6
IX product/ED feed (T-33)	6.9	5 682	0.40	1.08	1.48

Cycle 3.21.56 Operating Conditions

MODE	INPUT	OUTPUT	DURATION MIN	THROUGHPUT L	VOLUME BV	AVG FLOW RATE L/MIN	AVG FLOW RATE BV/MIN	BED EXPANSION %	TEMPERATURE C
REGEN 1	RE REGEN	WASTE	10	252	2.55	25.2	.255	33.	32.3
REGEN 2	RE REGEN	SP REGEN	99	1588	16.1	16.1	.163	17.0	33.5
REGEN 3	FR REGEN	SP REGEN	202	605	6.13	3.00	.030	3.0	36.5
DRAIN 1	(VENT)	WASTE	3	62	.63	20.7	.209	0.0	
RINSE	FEED	WASTE	10	150	1.52	15.0	.152	0.0	
SERVICE	FEED	PRODUCT	245	7370	74.7	30.1	.305	0.0	
DRAIN 2	(VENT)	WASTE	2	41	.42	20.7	.209	0.0	

Fresh Regenerant Volume Balance

Run 3.21.00 Cycle no.	Date	Fresh regenerant volume (V_3) L	Fresh regenerant TDS mg/L	Service volume (V_S) L	Estimated ED feed TDS mg/L	R %	$V_3/(1-R)V_S$
23	7/17/79	450	39 950	8 100	3 300	93	0.77
24	7/18/79	450	33 730	7 320	3 300	92	0.72
25	7/19/79	454	34 020	6 830	3 300	92	0.79
26	7/19/79	454	34 020	6 690	3 300	92	0.81
27	7/20/79	452	33 940	2 720	3 300	92	-
43	7/27/79	445	32 720	8 050	3 300	91	0.63
44	7/27/79	448	32 720	6 720	3 300	91	0.76
45	7/28/79	455	32 720	6 600	3 300	91	0.78
46	7/28/79	495	32 720	7 060	3 300	91	0.80
47	7/28/79	458	32 720	6 540	3 300	91	0.80
48	7/29/79	452	32 720	6 830	3 300	91	0.75
49	7/29/79	453	32 720	6 870	3 300	91	0.75
50	7/30/79	700	33 770	8 030	3 300	92	1.02
51	7/30/79	699	33 770	7 770	3 300	92	1.06
52	7/31/79	700	33 710	7 580	3 300	92	1.09
53	7/31/79	701	33 710	7 450	3 300	92	1.11
54	8/1/79	600	33 630	7 260	3 300	92	0.97
55	8/1/79	604	33 630	7 650	3 300	92	1.08
56	8/2/79	605	33 350	7 370	3 300	91	0.95

Influent and Effluent Compositions during Cycle 3.21.56

	Units	Regen 1, 2 influent	Regen 1 effluent	Regen 2 effluent	Regen 3 influent	Rinse & service influent	Rinse effluent	Service effluent
pH	units	-	-	-	6.5	7.2	6.8	7.0
TDS (Σ ions)	mg/L	29 311	20 581	28 156	33 881	3 360	22 463	3 612
Conductivity @ 25 °C	µS/cm	-	-	-	42 725	5 234	29 390	5 735
E. F. (TDS/cond.)	-	-	-	-	0.79	0.64	0.76	0.63
Silica	mg/L	2.6	2.4	2.2	2.3	1.7	1.9	1.8
Calcium	mg/L	880	1 530	1 330	97	189	109	12.8
Magnesium	mg/L	474	475	512	198	36.9	110	20.1
Sodium	mg/L	9 140	5 080	8 140	11 860	946	7 830	1 259
Potassium	mg/L	49	31	45	105	8.3	70	13.0
Strontium	mg/L	21	25	24	1.2	2.6	2.4	0.3
Bicarbonate	mg/L	24.4	97.6	102.5	36.6	17.6	29.8	17.1
Carbonate	mg/L	ND	ND	ND	ND	ND	ND	ND
Hydroxide	mg/L	ND	ND	ND	ND	ND	ND	ND
Sulfate	mg/L	6 400	4 740	6 100	9 500	1 010	6 950	1 110
Chloride	mg/L	12 320	8 600	11 900	12 080	1 148	7 360	1 178
T-alkalinity as $CaCO_3$	mg/L	20.0	80.0	84.0	30.0	14.4	24.4	14.0
P-alkalinity as $CaCO_3$	mg/L	ND	ND	ND	ND	ND	ND	ND
Σ Anions	meq/L	481.26	342.94	464.44	539.26	53.71	352.88	56.63
Σ Cations	meq/L	482.22	337.76	464.27	539.79	53.89	356.91	57.40
Control value	meq/L	-0.13	+0.95	+0.02	-0.06	-0.19	-0.72	-0.78

Major Cation Concentrations of Samples Analyzed by Atomic Abosorption

CYCLE 3.21.56

MODE	PROCESS STREAM	THROUGHPUT BV	CA MEQ/L	MG MEQ/L	TH MEQ/L	NA MEQ/L
REGEN 1	EFFLUENT	0.00	34.43	16.71	51.14	94.82
REGEN 1	EFFLUENT	1.28	99.30	49.96	149.26	259.68
REGEN 2	EFFLUENT	2.55	98.30	50.70	149.00	308.39
REGEN 2	INFLUENT	6.46	43.91	39.01	62.92	397.56
REGEN 2	EFFLUENT	10.69	53.89	37.86	91.75	377.12
REGEN 3	EFFLUENT	18.66	45.91	36.95	82.86	376.69
REGEN 3	INFLUENT	19.45	4.84	16.30	21.14	515.88
REGEN 3	EFFLUENT	20.20	52.89	42.63	95.53	434.54
REGEN 3	INFLUENT	21.75	4.79	18.02	22.82	513.70
REGEN 3	EFFLUENT	23.29	39.92	18.27	56.19	447.59
REGEN 3	EFFLUENT	24.78	39.92	17.20	57.12	464.55
RINSE	EFFLUENT	0.00	7.44	15.72	23.16	507.18
RINSE	EFFLUENT	.76	8.48	11.77	20.25	428.01
RINSE	EFFLUENT	1.52	.23	.40	.63	82.95
SERVICE	EFFLUENT	1.52	.22	.40	.63	83.51
SERVICE	INFLUENT	4.26	9.48	3.14	12.62	39.36
SERVICE	EFFLUENT	10.66	.10	.16	.26	52.28
SERVICE	EFFLUENT	19.61	.09	.16	.25	52.46
SERVICE	INFLUENT	36.26	9.38	3.20	12.56	40.19
SERVICE	EFFLUENT	38.09	.11	.17	.28	52.07
SERVICE	EFFLUENT	56.38	.18	1.03	1.21	51.24
SERVICE	EFFLUENT	65.52	.79	4.02	4.81	47.98
SERVICE	INFLUENT	76.19	9.43	3.25	12.68	40.28
SERVICE	EFFLUENT	76.19	2.99	6.01	9.00	43.45

Service Performance Summary

CYCLE 3.21.56

	AVERAGE CONCENTRATIONS, MEQ/L INFLUENT	EFFLUENT	DIFFERENCE	REMOVAL %	RESIN CAPACITY EQ/L
CA	9.43	.42	9.01	96	.673
MG	3.20	1.27	1.93	60	.144
TH	12.63	1.69	10.94	87	.817
NA	39.94	52.78	-12.84		

FIGURE A- a
MAJOR CATION CONCENTRATIONS
OF IX REGENERATION EFFLUENT
CYCLE 3.21.56

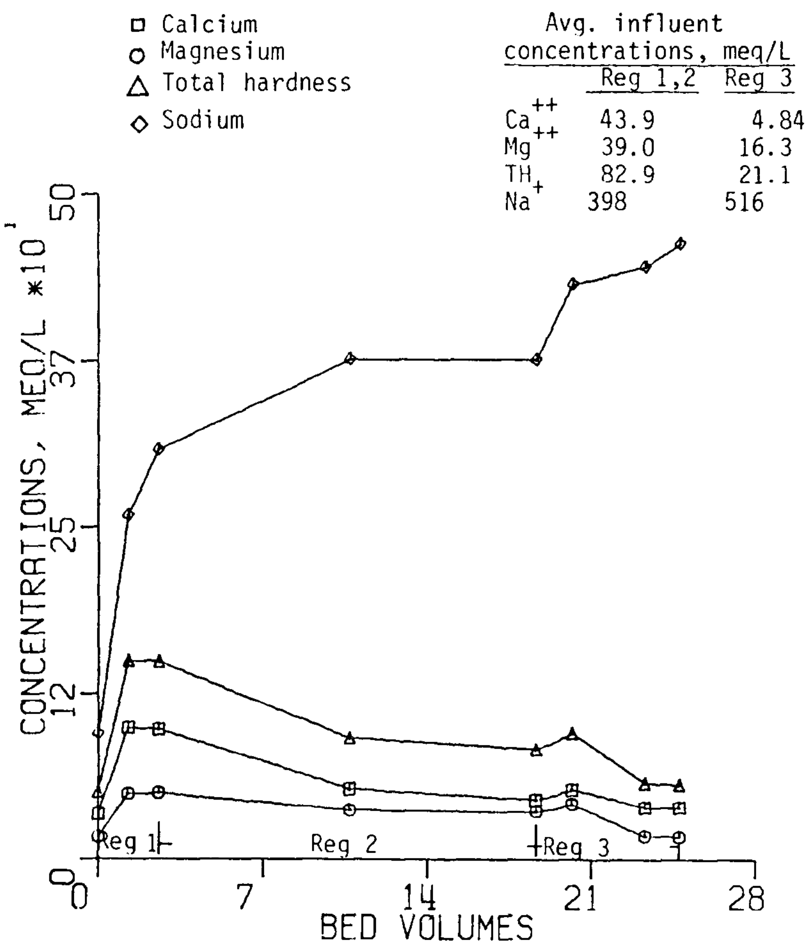
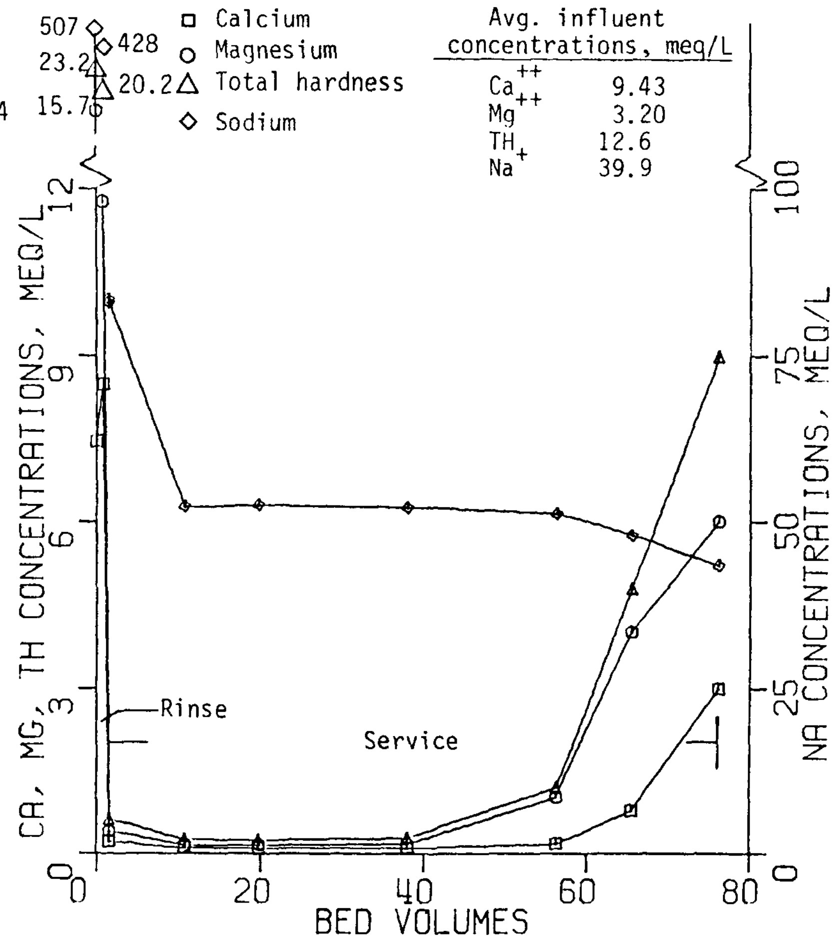


FIGURE A- b
MAJOR CATION CONCENTRATIONS OF
IX RINSE AND SERVICE EFFLUENTS
CYCLE 3.21.56



SODIUM (NA), CALCIUM (CA), AND MAGNESIUM (MG) CONCENTRATIONS ARE MEASURED BY ATOMIC ABSORPTION.
TOTAL HARDNESS (TH) IS CALCULATED BY SUMMING THE CALCIUM AND MAGNESIUM CONCENTRATIONS.

C28-4

Ion-Exchange - Run 3.22.00

Date: 8/6/79

Cycle: 3.22.12

Conditions: Feedwater - Wellton-Mowhawk drainage pretreated (in train IV) with high lime dosage for silica removal
Regenerants - recycled regenerant and fresh ED brine

Control variables:

	Target	Actual
Fresh regeneration conc. (mg/L TDS)	35 000	33 780
Fresh regeneration flow rate (L/min)	8.0	7.7
Recycled regenerant flow rate (L/min)	None	None
Recycled regenerant volume (L)	None	None
Service termination point (meq/L Ca^{++})	3.0	2.9

Chemical Compositions of Tank Waters Prior to Cycle 3.22.12

Tank	pH units	Conductivity µS/cm	Ca^{++} meq/L	Mg^{++} meq/L	TH meq/L
Recycled regenerant (T-5)	-	36 828	54.0	40.0	94.0
Spent regenerant (T-6)	-	36 502	53.0	47.0	100.0
Lime-softened feed (T-9)	7.5	5 156	9.4	3.6	13.0
Lime-softened feed (T-10)	7.6	5 165	9.2	4.2	13.4
Fresh ED brine (T-28)	6.3	41 664	7.0	17.0	24.0
IX product/ED feed (T-33)	7.3	5 776	0.64	1.04	1.68

Cycle 3.22.12 Operating Conditions

MODE	INPUT	OUTPUT	DURATION MIN	THROUGHPUT L	VOLUME BV	AVG FLOW RATE L/MIN	AVG FLOW RATE BV/MIN	BED EXPANSION %	TEMPERATURE C
REGEN 1	RE REGEN	WASTE	10	247	2.46	24.7	.246	32.	29.3
REGEN 3	FR REGEN	SP REGEN	68	520	5.17	7.66	.076	5.7	33.2
DRAIN 1	(VENT)	WASTE	3	62	.62	20.7	.205	0.0	
RINSE	FEED	WASTE	10	132	1.31	13.2	.131	0.0	
SERVICE	FEED	PRODUCT	186	4926	49.0	26.5	.263	0.0	
DRAIN 2	(VENT)	WASTE	2	41	.42	20.7	.209	0.0	

Fresh Regenerant Volume Balance

Run 3.22.00 Cycle no.	Date	Fresh regenerant volume (V_3) L	Fresh regenerant TDS mg/L	Service volume (V_S) L	Estimated ED feed TDS mg/L	R %	$V_3/(1-R)V_S$
04	8/3/79	518	32 910	6 120	3 300	91	0.97
05	8/4/79	518	32 910	5 660	3 300	91	1.05
06	8/4/79	519	32 910	5 640	3 300	91	1.06
07	8/4/79	520	32 910	5 390	3 300	91	1.11
08	8/5/79	520	32 910	5 770	3 300	91	1.04
09	8/5/79	521	32 910	5 820	3 300	91	1.03
10	8/5/79	521	32 910	5 530	3 300	91	1.08
11	8/6/79	520	33 430	5 800	3 300	91	1.04
12	8/6/79	520	33 430	5 580	3 300	91	1.08

Influent and Effluent Compositions during Cycle 3.22.12

		Regen 1		Regen 3		Rinse & service	Rinse	Service
	Units	Influent	Effluent	Influent	Effluent	influent	effluent	effluent
pH	units	-	-	6.2	-	7.3	6.6	7.3
TDS (Σ ions)	mg/L	27 577	21 424	33 775	29 736	3 311	22 328	4 244
Conductivity @ 25 °C	uS/cm	-	-	43 921	-	5 302	29 582	6 688
E. F. (TDS/cond.)	-	-	-	0.77	-	0.62	0.75	0.63
Silica	mg/L	2.4	2.4	2.3	2.4	2.1	2.3	2.6
Calcium	mg/L	1 000	1 690	107	1 620	180	185	18.9
Magnesium	mg/L	486	525	163	421	41.7	90.7	22.2
Sodium	mg/L	8 410	5 180	11 830	8 410	923	7 610	1 437
Potassium	mg/L	59	46	107	56	8.5	72	14.5
Strontium	mg/L	26	28	1.5	29	2.9	3.2	0.5
Bicarbonate	mg/L	73.2	92.7	24.4	97.6	20.5	24.9	22.0
Carbonate	mg/L	ND	ND	ND	ND	ND	ND	ND
Hydroxide	mg/L	ND	ND	ND	ND	ND	ND	ND
Sulfate	mg/L	5 180	4 260	9 480	7 180	958	7 590	1 566
Chloride	mg/L	12 340	9 600	12 060	11 920	1 174	6 750	1 160
T-alkalinity as $CaCO_3$	mg/L	60.0	76.0	20.0	80.0	16.8	20.4	18.0
P-alkalinity as $CaCO_3$	mg/L	ND	ND	ND	ND	ND	ND	ND
Σ Anions	meq/L	457.21	361.07	538.08	487.42	53.41	348.92	65.70
Σ Cations	meq/L	457.82	354.66	536.12	483.40	52.85	349.64	65.66
Control value	meq/L	-0.08	+1.12	+0.23	+0.52	+0.60	-0.13	+0.04

Major Cation Concentrations of Samples Analyzed by Atomic Absorption

CYCLE 3.22.12

MODE	PROCESS STREAM	THROUGHPUT BV	CA MEQ/L	MG MEQ/L	TH MEQ/L	NA MEQ/L
REGEN 1	EFFLUENT	0.00	57.39	29.71	87.10	157.89
REGEN 1	INFLUENT	.74	49.90	40.00	89.90	365.81
REGEN 1	EFFLUENT	1.23	94.81	49.79	144.60	240.54
REGEN 3	EFFLUENT	2.46	106.29	53.09	159.37	285.34
REGEN 3	INFLUENT	3.14	5.34	13.42	18.75	514.57
REGEN 3	EFFLUENT	3.68	111.78	51.36	163.13	344.06
REGEN 3	EFFLUENT	4.90	77.84	33.17	111.01	375.38
REGEN 3	EFFLUENT	6.12	59.38	22.80	82.18	415.83
REGEN 3	EFFLUENT	7.65	50.90	18.11	69.01	435.84
RINSE	EFFLUENT	0.00	14.22	12.92	27.14	482.38
RINSE	EFFLUENT	.66	11.53	8.20	19.72	371.90
SERVICE	EFFLUENT	1.31	.64	1.61	2.25	143.98
SERVICE	INFLUENT	3.68	9.23	3.46	12.69	40.37
SERVICE	EFFLUENT	7.63	.16	.15	.31	53.02
SERVICE	EFFLUENT	13.95	.12	.14	.26	52.81
SERVICE	INFLUENT	24.74	9.23	3.38	12.61	39.93
SERVICE	EFFLUENT	26.59	.14	.18	.32	52.50
SERVICE	EFFLUENT	39.22	.45	1.53	1.98	50.07
SERVICE	EFFLUENT	45.54	1.41	3.72	5.13	47.02
SERVICE	INFLUENT	50.28	9.13	3.42	12.56	40.15
SERVICE	EFFLUENT	50.28	2.89	4.90	7.79	45.06

Service Performance Summary

CYCLE 3.22.12

	AVERAGE CONCENTRATIONS, MEQ/L INFLUENT	EFFLUENT	DIFFERENCE	REMOVAL %	RESIN CAPACITY EQ/L
CA	9.20	.51	8.69	94	.426
MG	3.42	1.15	2.27	66	.111
TH	12.62	1.66	10.96	87	.537
NA	40.15	57.08	-16.93		

FIGURE A- a
MAJOR CATION CONCENTRATIONS
OF IX REGENERATION EFFLUENT
CYCLE 3.22.12

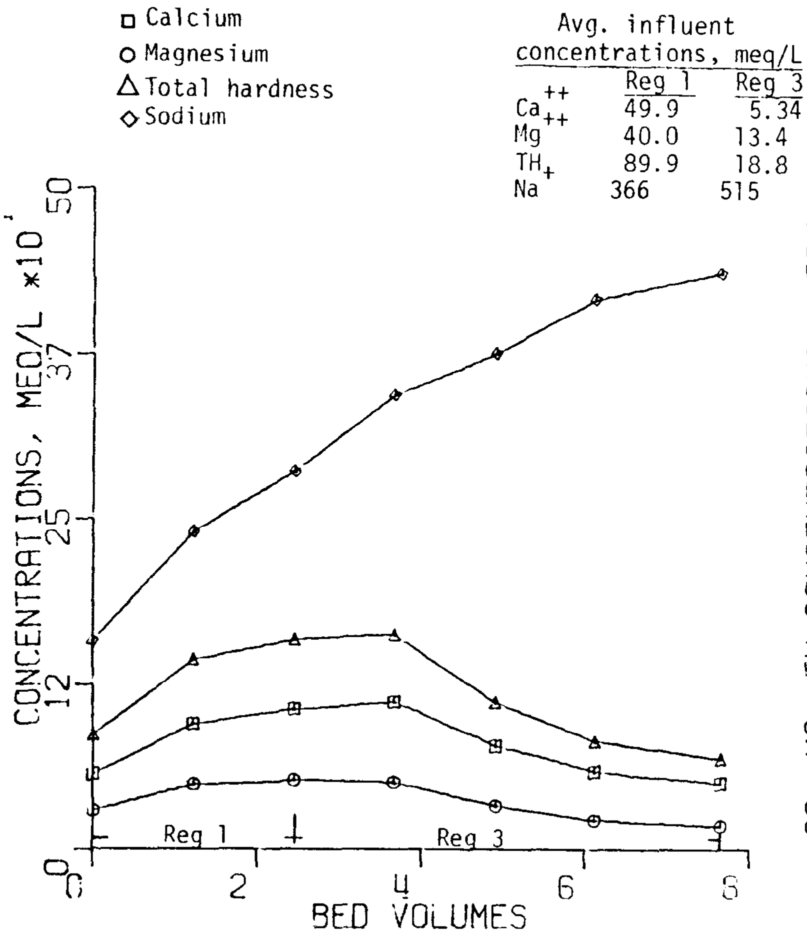
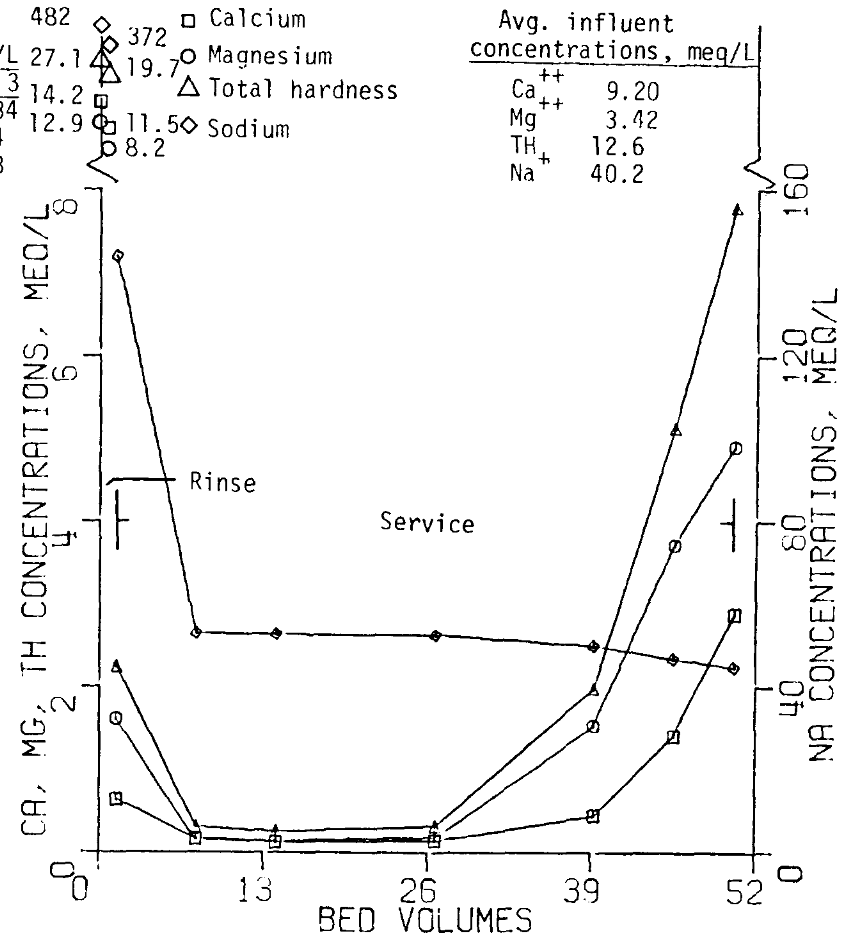


FIGURE A- b
MAJOR CATION CONCENTRATIONS OF
IX RINSE AND SERVICE EFFLUENTS
CYCLE 3.22.12



SODIUM (NA), CALCIUM (CA), AND MAGNESIUM (MG) CONCENTRATIONS ARE MEASURED BY ATOMIC ABSORPTION.
TOTAL HARDNESS (TH) IS CALCULATED BY SUMMING THE CALCIUM AND MAGNESIUM CONCENTRATIONS.

C29-4

Ion-Exchange - Run 3.23.00

Date: 8/22/79

Cycle: 3.23.33

Conditions: Feedwater - Wellton-Mowhawk drainage pretreated (in Train IV) with high lime dosage for silica removal
Regenerants - recycled regenerant and fresh ED brine

Control variables:

	Target	Actual
Fresh regeneration conc. (mg/L TDS)	35 000	34 600
Fresh regeneration flow rate (L/min)	5.5	5.5
Recycled regenerant flow rate (L/min)	16.0	16.2
Recycled regenerant volume (L)	800	794
Service termination point (meq/L Ca^{++})	3.0	2.5

Standard resin bed: Height = 1102 mm
Volume = 100.6L

Chemical Compositions of Tank Waters Prior to Cycle 3.23.33

Tank	pH units	Conductivity uS/cm	Ca^{++} meq/L	Mg^{++} meq/L	TH meq/L
Recycle regenerant (T-5)	-	39 794	38.0	38 0	76.0
Spent regenerant (T-6)	-	39 541	43.0	37.0	80.0
Lime-softened feed (T-9)	7.4	5 090	9.0	4.0	13.0
Lime softened feed (T-10)	7.5	4 980	8.4	4.4	12.8
Fresh ED brine (T-28)	6.9	43 665	6.8	21.2	28.0
IX product/ED feed (T-33)	7.4	5 381	0.40	1.60	2.00

Cycle 3.23.33 Operating Conditions

MODE	INPUT	OUTPUT	DURATION MIN	THROUGHPUT L	VOLUME BV	AVG FLOW RATE L/MIN	AVG FLOW RATE BV/MIN	BED EXPANSION %	TEMPERATURE C
REGEN 1	RE REGEN	WASTE	10	246	2.45	24.6	.245	33.	27.5
REGEN 2	RE REGEN	SP REGEN	49	794	7.89	16.2	.161	19.	27.5
REGEN 3	FR REGEN	SP REGEN	136	750	7.46	5.51	.055	4.2	29.5
DRAIN 1	(VENT)	WASTE	3	62	.62	20.7	.205	0.0	
RINSE	FEED	WASTE	10	128	1.27	12.8	.127	0.0	
SERVICE	FEED	PRODUCT	336	8650	86.0	25.7	.256	0.0	
DRAIN 2	(VENT)	WASTE	2	41	.42	20.7	.209	0.0	

Fresh Regenerant Volume Balance

Run 3.23.00 Cycle no.	Date	Fresh regenerant volume (V_3) L	Fresh regenerant TDS mg/L	Service volume (V_S) L	Estimated ED feed TDS mg/L	R %	$V_3/(1-R)V_S$
07	8/9/79	451	33 560	6 676	3 300	91	0.80
08	8/9/79	451	33 560	6 501	3 300	91	0.82
09	8/10/79	450	33 890	6 070	3 300	92	0.87
10	8/10/79	451	33 890	5 756	3 300	92	0.92
11	8/10/79	451	33 890	6 688	3 300	92	0.79
12	8/11/79	452	33 890	6 088	3 300	92	0.87
13	8/11/79	650	33 890	6 777	3 300	92	1.13
14	8/11/79	649	33 890	6 635	3 300	92	1.15
15	8/12/79	650	33 890	6 937	3 300	92	1.10
16	8/12/79	650	33 890	7 228	3 300	92	1.06
17	8/12/79	650	33 890	7 374	3 300	92	1.04
28	8/20/79	751	33 690	9 275	3 300	92	0.95
29	8/20/79	751	33 690	9 094	3 300	92	0.97
30	8/21/79	751	33 820	8 231	3 300	92	1.07
31	8/21/79	751	33 820	8 693	3 300	92	1.02
32	8/21/79	750	33 820	7 945	3 300	92	1.11
33	8/22/79	750	34 340	8 650	3 300	92	1.04

Influent and Effluent Compositions during Cycle 3.23.33

	Units	Regen 1,2 influent	Regen 1 effluent	Regen 2 effluent	Regen 3 influent	Regen 3 effluent	Rinse & service influent	Rinse effluent	Service effluent
pH	units	-	-	-	6.9	-	7.2	7.0	7.1
TDS (Σ ions)	mg/L	31 190	22 572	31 487	34 600	32 574	3 306	24 294	3 502
Conductivity @ 25.°C	μS/cm	-	-	-	4 318.0	-	514.0	3 281.4	579.2
E. F. (TDS/cond.)	-	-	-	-	7.9	-	6.4	7.4	6.0
Silica	mg/L	6.2	5.8	5.6	7.2	6.2	3.9	5.0	3.9
Calcium	mg/L	930	1 680	1 800	122	1 070	173	134	13.4
Magnesium	mg/L	459	597	566	263	368	48.2	178	33.9
Sodium	mg/L	9 630	5 390	8 490	12 100	9 800	920	8 350	1 200
Potassium	mg/L	57	50	36	103	66	7.9	54	12.3
Strontium	mg/L	21	27	27	1.6	22	2.7	2.6	0.9
Bicarbonate	mg/L	146.4	122.0	122.0	72.7	141.5	22.0	60.5	22.0
Carbonate	mg/L	ND	ND	ND	ND	ND	ND	ND	ND
Hydroxide	mg/L	ND	ND	ND	ND	ND	ND	ND	ND
Sulfate	mg/L	7 600	5 660	8 200	9 700	8 600	1 012	6 800	1 020
Chloride	mg/L	12 340	9 040	12 240	12 240	12 500	1 116	8 710	1 196
T-alkalinity as $CaCO_3$	mg/L	120.0	100.0	100.0	59.6	116.0	18.0	49.6	18.0
P-alkalinity as $CaCO_3$	mg/L	ND	ND	ND	ND	ND	ND	ND	ND
Σ Anions	meq/L	508.82	374.92	518.10	548.53	534.08	52.92	388.34	55.35
Σ Cations	meq/L	505.01	369.30	507.23	556.24	512.15	52.88	385.99	55.99
Control value	meq/L	+0.48	+0.95	+1.34	-0.90	+2.62	+0.04	+0.38	-0.67

Major Cation concentrations of Samples Analyzed by Atomic Absorption

CYCLE 3.23.33

MODE	PROCESS STREAM	THROUGHPUT BV	CA MEQ/L	MG MEQ/L	TH MEQ/L	NA MEQ/L
REGEN 1	EFFLUENT	0.00	40.42	25.68	66.10	105.26
REGEN 1	EFFLUENT	1.22	115.77	64.61	180.38	260.55
REGEN 2	EFFLUENT	2.45	112.28	59.75	172.03	318.83
REGEN 2	INFLUENT	4.38	46.41	37.78	84.18	418.88
REGEN 2	EFFLUENT	6.47	74.85	42.47	117.32	387.56
REGEN 3	EFFLUENT	10.34	60.88	36.87	97.75	397.56
REGEN 3	INFLUENT	11.27	5.59	21.65	27.23	526.32
REGEN 3	EFFLUENT	12.20	64.37	41.48	105.85	374.08
REGEN 3	EFFLUENT	14.07	55.39	27.16	82.55	378.43
REGEN 3	EFFLUENT	15.93	48.90	21.23	70.14	421.92
REGEN 3	EFFLUENT	17.79	53.39	22.80	76.19	413.22
RINSE	EFFLUENT	0.00	8.38	21.98	30.36	488.04
RINSE	EFFLUENT	.64	10.98	20.91	31.88	481.08
RINSE	EFFLUENT	1.27	.25	.63	.88	76.12
SERVICE	EFFLUENT	1.27	.40	1.24	1.65	76.99
SERVICE	INFLUENT	3.58	8.13	4.11	12.24	37.76
SERVICE	EFFLUENT	12.02	.05	.19	.24	43.93
SERVICE	EFFLUENT	22.51	.07	.20	.27	43.93
SERVICE	INFLUENT	41.96	8.13	3.94	12.08	37.67
SERVICE	EFFLUENT	43.50	.06	.21	.27	42.19
SERVICE	EFFLUENT	64.74	.32	3.33	3.66	37.84
SERVICE	EFFLUENT	75.23	1.15	6.43	7.58	33.93
SERVICE	INFLUENT	87.26	7.93	4.02	11.95	36.49
SERVICE	EFFLUENT	87.26	2.54	7.35	9.89	32.62

Service Performance Summary

CYCLE 3.23.33

	AVERAGE CONCENTRATIONS, MEQ/L INFLUENT	EFFLUENT	DIFFERENCE	REMOVAL %	RESIN CAPACITY EQ/L
CA	8.07	.45	7.62	94	.655
MG	4.02	2.16	1.86	46	.160
TH	12.09	2.61	9.48	78	.815
NA	37.31	42.35	-5.04		

FIGURE A- a
MAJOR CATION CONCENTRATIONS
OF IX REGENERATION EFFLUENT
CYCLE 3.23.33

□ Calcium
○ Magnesium
△ Total hardness
◇ Sodium

Avg. influent concentrations, meq/L

	Reg 1,2	Reg 3
Ca^{++}	46.4	5.59
Mg^{++}	37.8	21.6
TH	84.2	27.2
Na^{+}	419	526

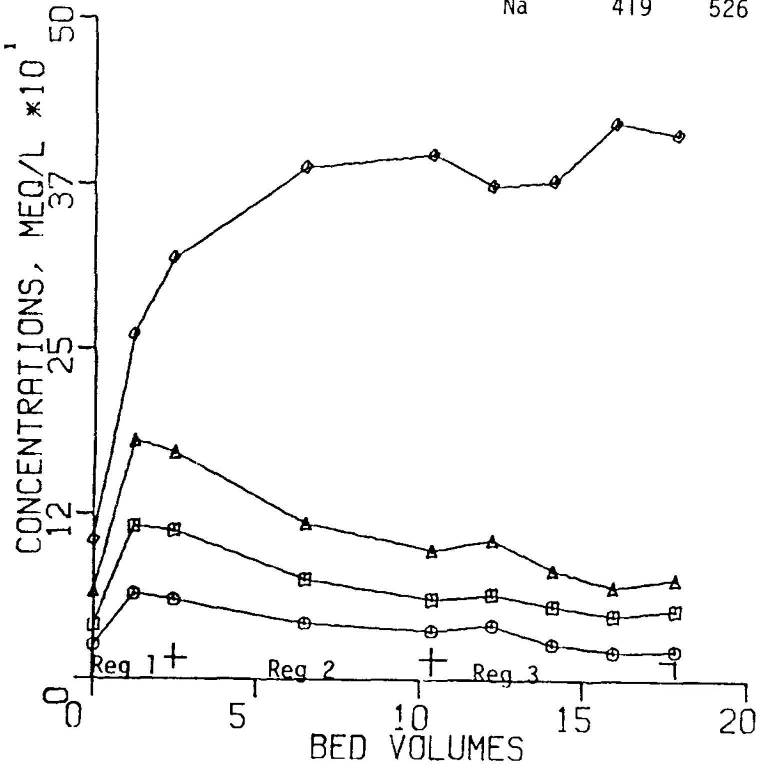
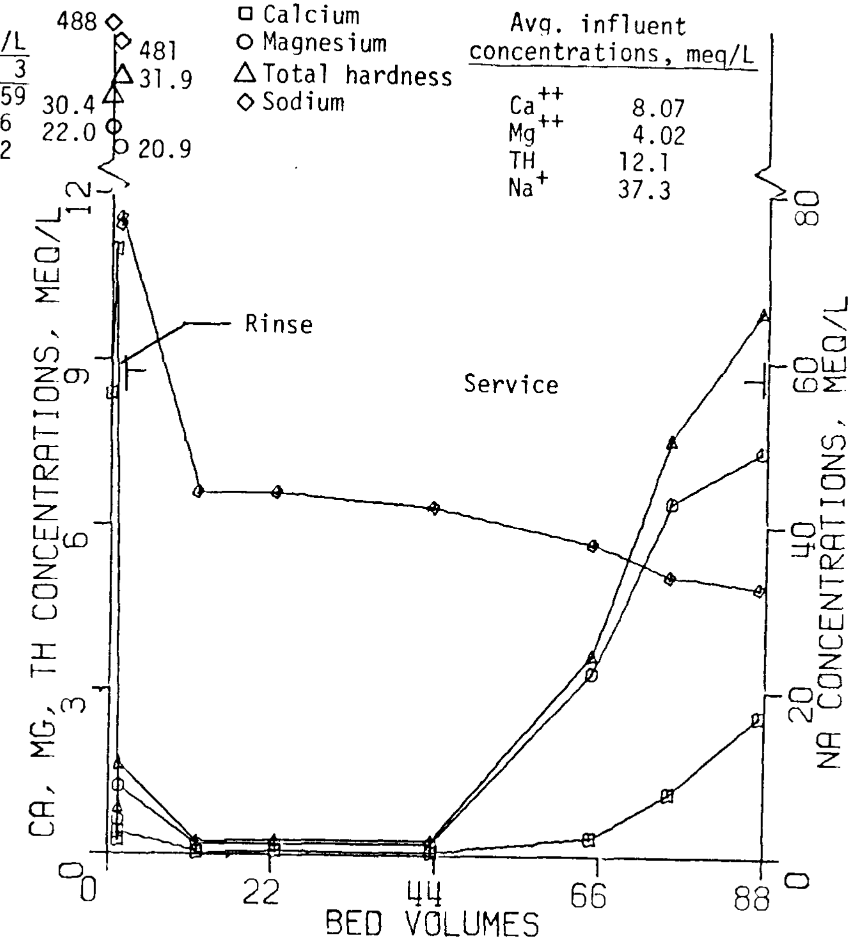


FIGURE A- b
MAJOR CATION CONCENTRATIONS OF
IX RINSE AND SERVICE EFFLUENTS
CYCLE 3.23.33

□ Calcium
○ Magnesium
△ Total hardness
◇ Sodium

Avg. influent concentrations, meq/L

Ca^{++}	8.07
Mg^{++}	4.02
TH	12.1
Na^{+}	37.3



SODIUM (NA), CALCIUM (CA), AND MAGNESIUM (MG) CONCENTRATIONS ARE MEASURED BY ATOMIC ABSORPTION.
TOTAL HARDNESS (TH) IS CALCULATED BY SUMMING THE CALCIUM AND MAGNESIUM CONCENTRATIONS.

C30-4

Ion-Exchange - Run 3.24.00

Date: 8/25/79

Cycle: 3.24.11

Conditions: Feedwater - Wellton-Mowhawk drainage pretreated (in Train IV) with high lime dosage for silica removal
Regenerants - recycled regenerant and fresh ED brine

Control variables:

	Target	Actual
Fresh regeneration conc. (mg/L TDS)	35 000	34 360
Fresh regeneration flow rate (L/min)	8.0	8.0
Recycled regenerant flow rate (L/min)	16.0	15.5
Recycled regenerant volume (L)	1 600	1 573
Service termination point (meq/L Ca^{++})	3.0	3.1

Standard resin bed: Height = 1102 mm
Volume = 100.6 L

Chemical Compositions of Tank Waters Prior to Cycle 3.24.11

Tank	pH units	Conductivity µS/cm	Ca^{++} meq/L	Mg^{++} meq/L	TH meq/L
Recycle regenerant (T-5)	-	39 506	46.0	41.0	87.0
Spent regenerant (T-6)	-	39 472	46.0	41.0	87.0
Lime-softened feed (T-9)	7.4	5 069	7.6	108.4	116.0
Lime softened feed (T-10)	7.4	5 059	7.6	106.4	114.0
Fresh ED brine (T-28)	6.9	43 195	6.4	21.2	27.6
IX product/ED feed (T-33)	7.2	5 182	0.40	1.92	2.32

Cycle 3.24.11 Operating Conditions

MODE	INPUT	OUTPUT	DURATION MIN	THROUGHPUT L	VOLUME BV	AVG FLOW RATE L/MIN	AVG FLOW RATE BV/MIN	BED EXPANSION %	TEMPERATURE C
REGEN 1	RE REGEN	WASTE	10	267	2.65	26.7	.265	33.	30.0
REGEN 2	RE REGEN	SP REGEN	101	1573	15.6	15.5	.154	17.0	29.9
REGEN 3	FR REGEN	SP REGEN	89	703	6.99	7.92	.079	4.4	30.8
DRAIN 1	(VENT)	WASTE	3	62	.62	20.7	.205	0.0	
RINSE	FEED	WASTE	10	126	1.25	12.6	.125	0.0	
SERVICE	FEED	PRODUCT	346	8750	87.0	25.3	.251	0.0	
DRAIN 2	(VENT)	WASTE	2	41	.42	20.7	.209	0.0	

C31—2

Fresh Regenerant Volume Balance

Run 3.24.00 Cycle no.	Date	Fresh regenerant volume (V_3) L	Fresh regenerant TDS mg/L	Service volume (V_S) L	Estimated ED feed TDS mg/L	R %	$V_3/(1-R)V_S$
04	8/23/79	451	32 880	7 860	3 300	91	0.66
05	8/23/79	451	32 880	7 012	3 300	91	0.74
06	8/24/79	450	34 320	7 634	3 300	92	0.70
07	8/24/79	703	34 320	8 599	3 300	92	0.97
08	8/24/79	702	34 320	7 916	3 300	92	1.06
09	8/25/79	702	34 320	8 171	3 300	92	1.02
10	8/25/79	705	34 320	8 066	3 300	92	1.04
11	8/26/79	703	34 110	8 750	3 300	92	0.96

Influent and Effluent Compositions during Cycle 3.24.11

	Units	Regen 1,2 influent	Regen 1 effluent	Regen 2 effluent	Regen 3 influent	Regen 3 effluent	Rinse & service influent	Rinse effluent	Service effluent
pH	units	-	-	-	7.0	-	7.4	7.2	7.4
TDS (Σ ions)	mg/L	32 181	21 905	29 773	34 360	33 413	3 215	23 929	3 398
Conductivity @ 25.°C	µS/cm	-	-	-	4 325.1	-	503.7	3 193.0	537.7
E. F. (TDS/cond.)	-	-	-	-	7.9	-	6.4	7.5	6.3
Silica	mg/L	5.2	4.0	4.0	4.7	4.4	4.4	4.4	4.7
Calcium	mg/L	1 020	1 730	1 360	118	1 070	156	240	17.0
Magnesium	mg/L	565	612	578	286	457	55.0	203	39.1
Sodium	mg/L	9 540	5 190	8 610	12 050	10 350	916	8 040	1 150
Potassium	mg/L	52	33	49	105	63	8.5	68	11.6
Strontium	mg/L	16	24	20	1.1	17	1.8	3.9	0.1
Bicarbonate	mg/L	102.5	112.2	131.8	75.2	131.8	20.0	60.0	23.4
Carbonate	mg/L	ND	ND	ND	ND	ND	ND	ND	ND
Hydroxide	mg/L	ND	ND	ND	ND	ND	ND	ND	ND
Sulfate	mg/L	8 580	4 900	6 840	9 700	8 700	958	6 750	1 028
Chloride	mg/L	12 300	9 300	12 180	12 020	12 620	1 094	8 560	1 124
T-alkalinity as $CaCO_3$	mg/L	84.0	92.0	108.0	61.6	108.0	16.4	49.2	19.2
P-alkalinity as $CaCO_3$	mg/L	ND	ND	ND	ND	ND	ND	ND	ND
Σ Anions	meq/L	527:38	366.26	488.24	542.37	539.39	51.14	383.06	53.50
Σ Cations	meq/L	514.06	363.83	491.65	556.30	543.21	52.41	380.24	54.39
Control value	meq/L	+1.61	+0.42	-0.44	-1.64	-0.45	-1.41	+0.47	-0.94

Major Cation Concentrations of Samples Analyzed by Atomic Absorption

CYCLE 3.24.11

MODE	PROCESS STREAM	THROUGHPUT BV	CA MEQ/L	MG MEQ/L	TH MEQ/L	NA MEQ/L
REGEN 1	EFFLUENT	0.00	45.91	26.09	72.00	105.70
REGEN 1	EFFLUENT	1.33	113.77	72.02	185.79	274.03
REGEN 2	EFFLUENT	2.65	100.80	63.21	164.01	331.01
REGEN 2	INFLUENT	6.51	50.90	46.50	97.40	414.96
REGEN 2	EFFLUENT	10.36	56.39	47.57	103.96	394.52
REGEN 3	EFFLUENT	18.23	44.91	42.88	87.79	423.23
REGEN 3	INFLUENT	19.09	5.89	23.54	29.43	524.14
REGEN 3	EFFLUENT	19.96	59.38	44.03	103.41	452.37
REGEN 3	EFFLUENT	21.69	54.39	29.88	84.27	464.98
REGEN 3	EFFLUENT	23.42	43.91	22.88	66.79	487.60
REGEN 3	EFFLUENT	25.24	60.88	28.48	89.36	479.77
RINSE	EFFLUENT	0.00	13.47	21.81	35.28	511.53
RINSE	EFFLUENT	.63	16.37	20.74	37.11	480.21
RINSE	EFFLUENT	1.25	.39	.62	1.01	65.68
SERVICE	EFFLUENT	1.25	.31	.49	.80	76.60
SERVICE	INFLUENT	3.51	8.33	4.20	12.53	40.76
SERVICE	EFFLUENT	9.55	.19	.19	.38	52.68
SERVICE	EFFLUENT	18.10	.19	.18	.38	52.20
SERVICE	INFLUENT	33.68	9.53	4.13	13.66	39.67
SERVICE	EFFLUENT	34.94	.18	.17	.35	51.81
SERVICE	EFFLUENT	51.78	.18	.38	.56	51.63
SERVICE	EFFLUENT	60.33	.28	1.81	2.10	50.28
SERVICE	EFFLUENT	77.17	1.59	7.60	9.19	43.28
SERVICE	EFFLUENT	85.72	2.50	7.37	9.86	41.02
SERVICE	INFLUENT	88.23	7.73	4.09	11.83	38.89
SERVICE	EFFLUENT	88.23	3.14	7.50	10.64	40.37

Service Performance Summary

CYCLE 3.24.11

	AVERAGE CONCENTRATIONS, MEQ/L INFLUENT	EFFLUENT	DIFFERENCE	REMOVAL %	RESIN CAPACITY EQ/L
CA	8.53	.60	7.93	93	.690
MG	4.14	2.11	2.03	49	.177
TH	12.67	2.71	9.96	79	.867
NA	39.77	50.79	-11.01		

FIGURE A- a
MAJOR CATION CONCENTRATIONS OF IX REGENERATION EFFLUENT CYCLE 3.24.11

Avg. influent concentrations, meq/L

	Reg 1,2	Reg 3
Ca^{++}	50.9	5.89
Mg^{++}	46.5	23.5
TH	97.4	29.4
Na^{+}	415	524

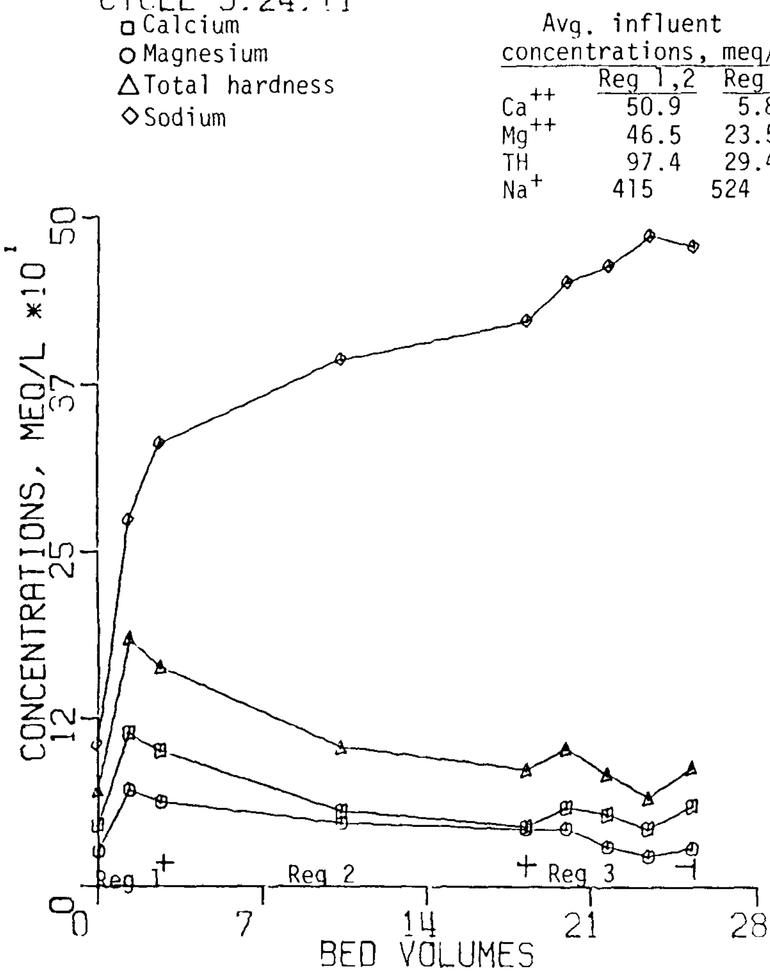
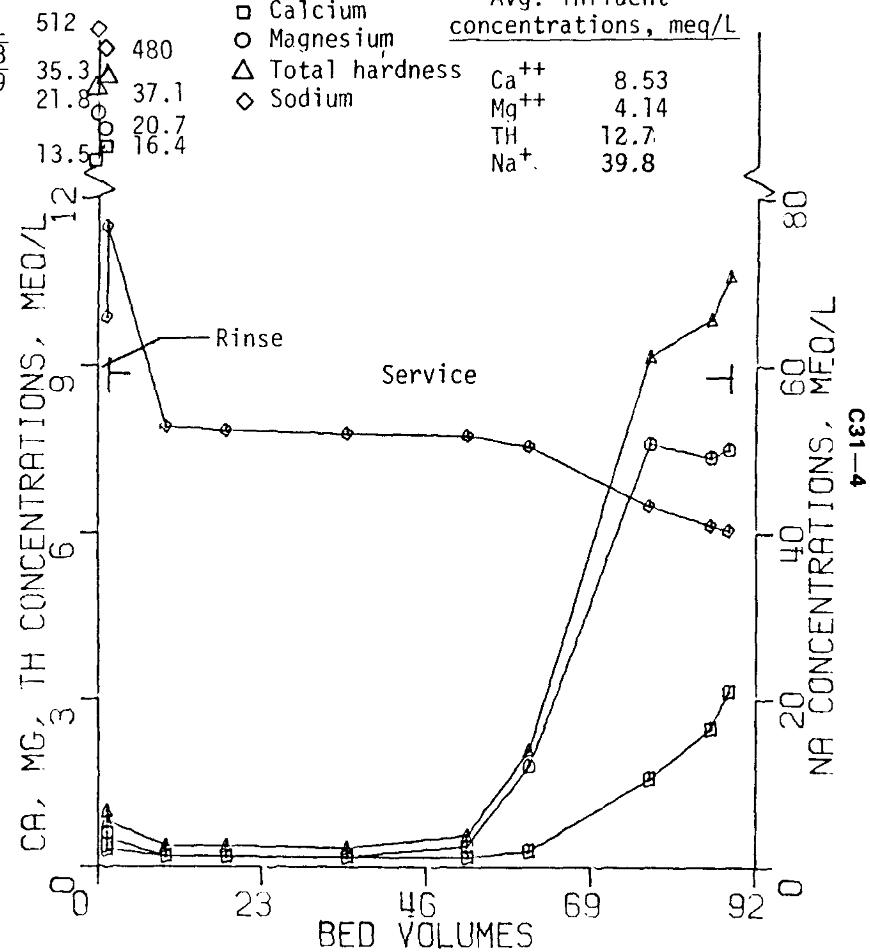


FIGURE A- b
MAJOR CATION CONCENTRATIONS OF IX RINSE AND SERVICE EFFLUENTS CYCLE 3.24.11

Avg. influent concentrations, meq/L

Ca^{++}	8.53
Mg^{++}	4.14
TH	12.7
Na^{+}	39.8



SODIUM (NA), CALCIUM (CA), AND MAGNESIUM (MG) CONCENTRATIONS ARE MEASURED BY ATOMIC ABSORPTION.
TOTAL HARDNESS (TH) IS CALCULATED BY SUMMING THE CALCIUM AND MAGNESIUM CONCENTRATIONS.

Ion-Exchange - Run 3.25.00

Date: 8/29/79

Cycle: 3.25.10

Conditions: Feedwater - Wellton-Mowhawk drainage pretreated (in Train IV) with high lime dosage for silica removal
Regenerants - recycled regenerant and fresh ED brine

Control variables:		Target	Actual
	Fresh regeneration conc. (mg/L TDS)	35 000	33 300
	Fresh regeneration flow rate (L/min)	3.0	3.0
	Recycled regenerant flow rate (L/min)	None	None
	Recycled regenerant volume (L)	None	None
	Service termination point (meq/L Ca^{++})	3.0	3.1

Standard resin bed: Height = 1102 mm
Volume = 100.6L

Chemical Compositions of Tank Waters Prior to Cycle 3.25.10

Tank	pH units	Conductivity µS/cm	Ca^{++} meq/L	Mg^{++} meq/L	TH meq/L
Recycle regenerant (T-5)	-	37 389	50.0	79.0	129.0
Spent regenerant (T-6)	-	37 084	58.0	68.0	126.0
Lime-softened feed (T-9)	7.4	5 050	7.8	3.9	11.7
Lime softened feed (T-10)	7.5	4 970	8.0	3.5	11.5
Fresh ED brine (T-28)	7.1	42 638	6.4	22.8	29.2
IX product/ED feed (T-33)	7.4	5 515	0.6	1.48	2.08

Cycle 3.25.10 Operating Conditions

MODE	INPUT	OUTPUT	DURATION MIN	THROUGHPUT L	VOLUME BV	AVG FLOW RATE L/MIN	AVG FLOW RATE BV/MIN	BED EXPANSION %	TEMPERATURE C
REGEN 1	RE REGEN	WASTE	10	232	2.31	23.2	.231	29.	27.3
REGEN 3	FR REGEN	SP REGEN	148	451	4.48	3.04	.030	4.4	29.5
DRAIN 1	(VENT)	WASTE	3	62	.62	20.7	.205	0.0	
RINSE	FEED	WASTE	10	126	1.25	12.6	.125	0.0	
SERVICE	FEED	PRODUCT	211	5317	52.9	25.2	.250	0.0	
DRAIN 2	(VENT)	WASTE	2	41	.42	20.7	.209	0.0	

C32—2

Fresh Regenerant Volume Balance

Run 3.25.00 Cycle no.	Date	Fresh regenerant volume (V_3) L	Fresh regenerant TDS mg/L	Service volume (V_S) L	Estimated ED feed TDS mg/L	R %	$V_3/(1-R)V_S$
03	8/27/79	449	34 310	5 946	3 300	92	0.90
04	8/27/79	451	34 310	5 908	3 300	92	0.91
05	8/27/79	448	34 310	5 563	3 300	92	0.96
06	8/28/79	449	33 590	5 464	3 300	92	0.97
07	8/28/79	450	33 590	5 562	3 300	92	0.95
08	8/28/79	450	33 590	5 421	3 300	92	0.98
09	8/29/79	451	33 840	5 340	3 300	92	0.99
10	8/29/79	451	33 840	5 317	3 300	92	1.00

Influent and Effluent Compositions during Cycle 3.25.10

	Units	Regen 1 Influent	Regen 1 Effluent	Regen 3 Influent	Regen 3 Effluent	Rinse & service influent	Rinse effluent	Service effluent
pH	Units	-	-	7.1	-	7.4	7.3	7.3
TDS (Σ ions)	mg/L	27 999	19 610	33 307	28 138	3 175	26 431	4 516
Conductivity @ 25.°C	μS/cm	-	-	4 292.1	-	505.6	3 430.9	687.2
C. F. (TDS/cond.)	-	-	-	7.8	-	6.3	7.7	6.6
Silica	mg/L	6.4	5.6	3.7	5.2	5.8	6.7	5.3
Calcium	mg/L	1 280	1 740	118	1 540	145	258	33
Magnesium	mg/L	648	652	265	613	52.0	179	33.3
Sodium	mg/L	7 840	4 330	11 500	7 630	884	8 770	1 470
Potassium	mg/L	53	33	108	46	8.0	59	15.4
Strontium	mg/L	23	27	4.4	22	2.0	5.0	0.4
Bicarbonate	mg/L	268.4	102.5	87.8	122.0	22.0	63.4	24.4
Carbonate	mg/L	ND	ND	ND	ND	ND	ND	ND
Hydroxide	mg/L	ND	ND	ND	ND	ND	ND	ND
Sulfate	mg/L	5 560	4 400	9 300	6 080	946	8 430	1 820
Chloride	mg/L	12 320	8 320	11 920	12 080	1 110	8 660	1 114
T-alkalinity as $CaCO_3$	mg/L	220.0	84.0	72.0	100.0	18.0	52.0	20.0
P-alkalinity as $CaCO_3$	mg/L	ND	ND	ND	ND	ND	ND	ND
Σ Anions	meq/L	467.83	328.11	531.42	469.49	51.45	421.01	69.81
Σ Cations	meq/L	460.10	330.27	530.80	460.85	50.22	410.72	68.73
Control value	meq/L	+1.05	-0.42	+0.07	+1.17	+1.36	+1.55	+0.90

Major Cation Concentrations of Samples Analyzed by Atomic Absorption

CYCLE 3.25.10

MODE	PROCESS STREAM	THROUGHPUT BV	CA MEQ/L	MG MEQ/L	TH MEQ/L	NA MEQ/L
REGEN 1	EFFLUENT	0.00	38.42	19.67	58.09	91.78
REGEN 1	INFLUENT	.69	63.87	53.33	117.21	341.02
REGEN 1	EFFLUENT	1.15	107.78	67.16	174.94	215.31
REGEN 3	EFFLUENT	2.31	117.76	66.42	184.18	264.90
REGEN 3	INFLUENT	2.85	5.89	21.81	27.70	500.22
REGEN 3	EFFLUENT	3.42	100.80	69.14	169.93	299.26
REGEN 3	EFFLUENT	4.57	79.84	52.92	132.76	343.63
REGEN 3	EFFLUENT	5.69	50.90	28.23	79.13	405.83
REGEN 3	EFFLUENT	6.78	45.41	23.62	69.03	356.68
RINSE	EFFLUENT	0.00	12.67	20.08	32.76	452.37
RINSE	EFFLUENT	.63	16.87	18.19	35.06	426.27
RINSE	EFFLUENT	1.25	5.04	5.35	10.39	207.92
SERVICE	EFFLUENT	1.25	5.44	5.31	10.75	206.61
SERVICE	INFLUENT	3.51	7.49	4.30	11.79	36.54
SERVICE	EFFLUENT	7.01	.11	.18	.29	46.98
SERVICE	EFFLUENT	12.52	.12	.18	.30	46.11
SERVICE	INFLUENT	22.54	6.84	4.21	11.04	35.67
SERVICE	EFFLUENT	23.80	.11	.24	.35	46.11
SERVICE	EFFLUENT	35.07	.31	1.01	1.33	44.37
SERVICE	EFFLUENT	40.83	.71	2.50	3.21	42.19
SERVICE	EFFLUENT	46.34	1.48	4.19	5.67	39.58
SERVICE	EFFLUENT	51.85	2.45	5.46	7.90	36.54
SERVICE	INFLUENT	54.11	7.39	4.33	11.71	35.89
SERVICE	EFFLUENT	54.11	3.09	5.71	8.81	36.54

Service Performance Summary

CYCLE 3.25.10

	AVERAGE CONCENTRATIONS, MEQ/L			REMOVAL	RESIN CAPACITY
	INFLUENT	EFFLUENT	DIFFERENCE	%	EQ/L
CA	7.24	.88	6.36	88	.336
MG	4.28	1.78	2.50	58	.132
TH	11.52	2.66	8.86	77	.468
NA	36.03	52.66	-16.63		

FIGURE A- a
MAJOR CATION CONCENTRATIONS
OF IX REGENERATION EFFLUENT
CYCLE 3.25.10

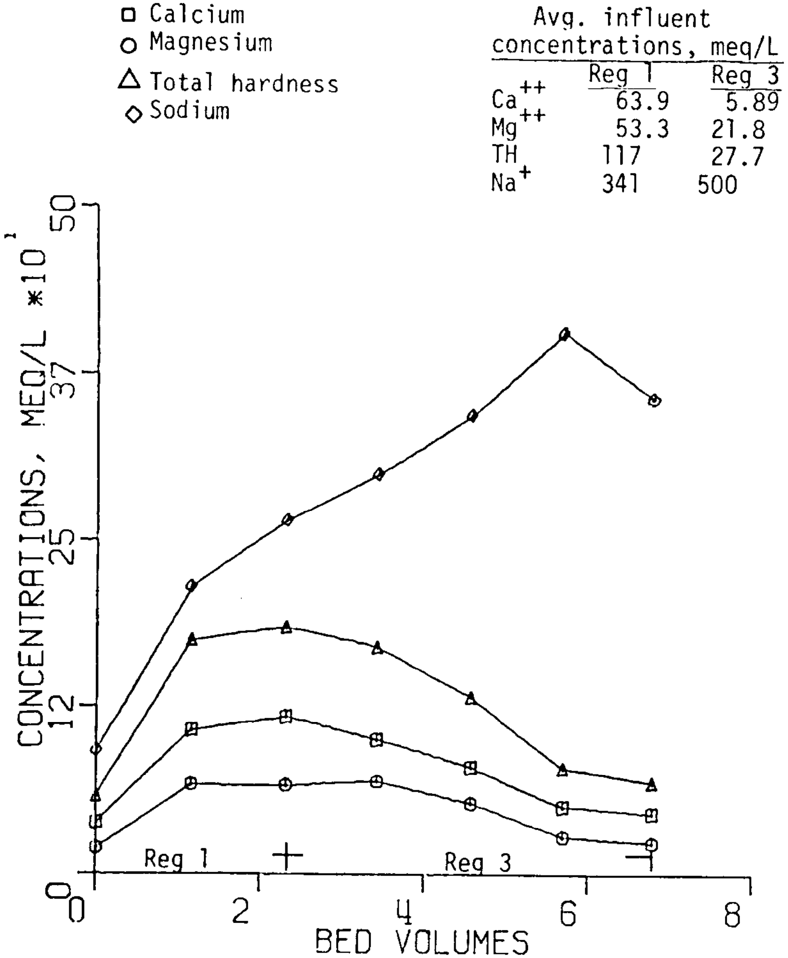
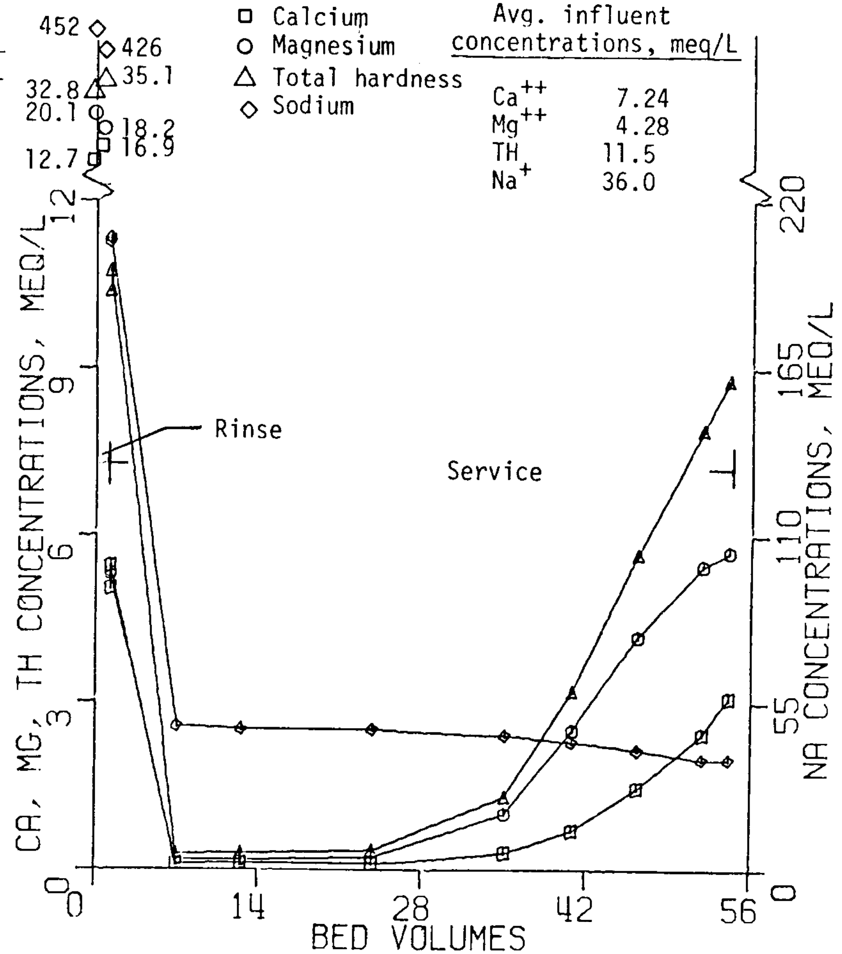


FIGURE A- b
MAJOR CATION CONCENTRATIONS OF
IX RINSE AND SERVICE EFFLUENTS
CYCLE 3.25.10



SODIUM (NA), CALCIUM (CA), AND MAGNESIUM (MG) CONCENTRATIONS ARE MEASURED BY ATOMIC ABSORPTION.
TOTAL HARDNESS (TH) IS CALCULATED BY SUMMING THE CALCIUM AND MAGNESIUM CONCENTRATIONS.

APPENDIX D — DATA FROM PHASE 3

D1—1

Ion-Exchange - Run 4.01.00

Date:	9/9/79
Cycle:	4.01.39
Conditions:	Feedwater - Wellton-Mowhawk drainage pretreated (in Train IV) with high lime dosage for silica removal Regenerant - fresh ED brine. Source of backwash - IX feedwater

Control variables:	Target	Actual
Fresh regeneration conc. (mg/L TDS)	35 000	33 418
Fresh regeneration flow rate (L/min)	10.0	10.2
Recycled regenerant flow rate (L/min)	None	None
Recycled regenerant volume (L)	None	None
Service termination point (meq/L Ca^{++})	3.0	2.4

Standard resin bed: Height = 1102 mm
Volume = 100.6 L

Chemical Compositions of Tank Waters Prior to Cycle 4.01.39

Tank	pH units	Conductivity uS/cm	Ca^{++} meq/L	Mg^{++} meq/L	TH meq/L
Recycle regenerant (T-5)	-	-	-	-	-
Spent regenerant (T-6)	-	-	-	-	-
Lime-softened feed (T-9)	7.4	5 659	9.1	3.6	12.7
Lime softened feed (T-10)	7.5	5 069	9.2	3.6	12.8
Fresh ED brine (T-28)	7.0	43 469	9.6	16.4	26.0
IX product/ED feed (T-33)	7.5	5 344	1.08	1.04	2.12

Cycle 4.01.39 Operating Conditions

MODE	INPUT	OUTPUT	DURATION MIN	THROUGHPUT L	VOLUME BV	AVG FLOW RATE L/MIN	AVG FLOW RATE BV/MIN	BED EXPANSION %	TEMPERATURE C
BACKWASH	FEED	WASTE	10	240	2.39	24.0	.239	27.	28.6
DRAIN 1	(VENT)	WASTE	3	62	.62	20.7	.205	0.0	
REGEN 3	FR REGEN	WASTE	35	359	3.57	10.2	.101	8.4	29.5
DRAIN 1	(VENT)	WASTE	3	62	.62	20.7	.205	0.0	
RINSE	FEED	WASTE	10	118	1.17	11.8	.117	0.0	
SERVICE	FEED	PRODUCT	131	3772	37.5	28.8	.286	0.0	
DRAIN 2	(VENT)	WASTE	2	41	.42	20.7	.209	0.0	

Fresh Regenerant Volume Balance

Run 4.01.00 Cycle no.	Date	Fresh regenerant volume (V_3) L	Fresh regenerant TDS mg/L	Service volume (V_S) L	Estimated ED feed TDS mg/L	R %	$V_3/(1-R)V_S$
05	8/31/79	451	34 000	5 861	3 300	92	0.92
06	8/31/79	451	34 000	5 509	3 300	92	0.97
07	8/31/79	451	34 000	5 376	3 300	92	1.00
08	9/1/79	451	34 000	4 070	3 300	92	1.32
09	9/1/79	451	34 000	4 935	3 300	92	1.09
10	9/1/79	451	34 000	5 106	3 300	92	1.05
11	9/1/79	451	34 000	4 709	3 300	92	1.14
12	9/1/79	451	34 000	4 665	3 300	92	1.15
13	9/2/79	451	34 000	4 778	3 300	92	1.12
14	9/2/79	451	34 000	4 072	3 300	92	1.32
15	9/2/79	401	34 000	4 449	3 300	92	1.07
16	9/2/79	401	34 000	4 379	3 300	92	1.09
17	9/2/79	400	34 000	4 329	3 300	92	1.10
18	9/3/79	400	34 000	4 402	3 300	92	1.08
19	9/3/79	401	34 000	4 473	3 300	92	1.07
20	9/3/79	400	34 000	4 294	3 300	92	1.11
21	9/3/79	320	34 000	3 551	3 300	92	1.18
22	9/3/79	322	34 000	3 223	3 300	92	1.18
23	9/4/79	322	34 640	3 168	3 300	92	1.21
24	9/4/79	280	34 640	3 148	3 300	92	1.07
25	9/4/79	280	34 640	3 193	3 300	92	1.06
26	9/6/79	358	34 260	4 264	3 300	92	1.00
27	9/6/79	358	34 260	3 927	3 300	92	1.08
28	9/7/79	358	34 200	3 639	3 300	92	1.17
29	9/7/79	358	34 200	3 870	3 300	92	1.10
30	9/7/79	358	34 200	3 996	3 300	92	1.07
31	9/7/79	359	34 200	4 021	3 300	92	1.06
32	9/7/79	358	34 200	4 469	3 300	92	0.95
33	9/7/79	359	34 200	4 263	3 300	92	1.00
34	9/8/79	358	34 200	4 426	3 300	92	0.96
35	9/8/79	358	34 200	3 868	3 300	92	1.10
36	9/8/79	358	34 200	3 753	3 300	92	1.14
37	9/8/79	359	34 200	4 173	3 300	92	1.02
38	9/9/79	358	33 780	3 900	3 300	92	1.08
39	9/9/79	359	33 780	3 772	3 300	92	1.12

Influent and Effluent Compositions during Cycle 4.01.39

	Units	Backwash effluent	Regeneration Influent	Regeneration Effluent	Rinse & service influent	Rinse effluent	Service effluent
pH	units	-	7.1	-	7.5	7.4	7.3
TDS (Σ ions)	mg/L	3 822	33 418	23 795	3 148	22 280	3 442
Conductivity @ 25.°C	μS/cm	-	4 278.0	-	518.2	2 813.9	558.8
E. F. (TDS/cond.)	-	-	7.8	-	6.1	7.9	6.2
Silica	mg/L	4.0	4.0	4.2	3.3	3.9	3.4
Calcium	mg/L	203	179	1 800	180	800	31.5
Magnesium	mg/L	62.4	185	449	42.5	202	18.0
Sodium	mg/L	1 060	11 700	6 010	858	6 960	1 160
Potassium	mg/L	14	95	47	8.1	57	7.8
Strontium	mg/L	<0.1	1.0	7.0	0.2	5.2	0.1
Bicarbonate	mg/L	73.2	74.2	97.6	22.0	61.5	23.4
Carbonate	mg/L	ND	ND	ND	ND	ND	ND
Hydroxide	mg/L	ND	ND	ND	ND	ND	ND
Sulfate	mg/L	995	8 880	6 180	928	5 840	1 008
Chloride	mg/L	1 410	12 300	9 200	1 106	8 350	1 190
T-alkalinity as $CaCO_3$	mg/L	60.0	60.8	80.0	18.0	50.4	19.2
P-alkalinity as $CaCO_3$	mg/L	ND	ND	ND	ND	ND	ND
Σ Anions	meq/L	61.77	533.24	389.93	50.96	358.28	55.02
Σ Cations	meq/L	61.73	535.55	389.55	50.01	360.67	53.71
Control value	meq/L	+0.03	-0.28	+0.06	+1.06	-0.42	+1.37

Major Cation Concentrations of Samples Analyzed by Atomic Absorption

CYCLE 4.01.39

MODE	PROCESS STREAM	THROUGHPUT BV	CA MEQ/L	MG MEQ/L	TH MEQ/L	NA MEQ/L
BACKWASH	EFFLUENT	0.00	14.02	6.26	20.29	50.02
BACKWASH	EFFLUENT	1.19	9.28	4.26	13.54	41.45
REGEN 3	EFFLUENT	2.39	8.38	3.85	12.24	46.98
REGEN 3	INFLUENT	2.89	8.93	15.23	24.16	508.92
REGEN 3	EFFLUENT	3.30	149.20	67.00	216.20	225.75
REGEN 3	EFFLUENT	4.21	131.24	61.56	192.80	345.37
REGEN 3	EFFLUENT	5.12	104.79	46.67	151.46	363.64
REGEN 3	EFFLUENT	5.92	76.35	23.79	100.13	307.53
RINSE	EFFLUENT	0.00	64.87	23.46	88.33	482.82
RINSE	EFFLUENT	.59	53.89	25.43	79.32	412.79
RINSE	EFFLUENT	1.17	3.32	1.22	4.54	77.42
SERVICE	EFFLUENT	1.17	1.43	.76	2.18	67.42
SERVICE	INFLUENT	3.75	8.88	3.58	12.46	37.36
SERVICE	EFFLUENT	5.75	.62	.26	.88	48.72
SERVICE	EFFLUENT	10.33	.61	.31	.92	50.02
SERVICE	INFLUENT	18.06	8.58	3.36	11.94	37.36
SERVICE	EFFLUENT	19.49	.59	.36	.96	54.37
SERVICE	EFFLUENT	28.65	.83	1.02	1.85	49.15
SERVICE	EFFLUENT	33.23	1.42	2.01	3.43	43.37
SERVICE	EFFLUENT	37.81	2.10	3.58	5.68	41.45
SERVICE	INFLUENT	38.67	8.53	3.19	11.73	37.28
SERVICE	EFFLUENT	38.67	2.40	3.52	5.92	40.84

Service Performance Summary

CYCLE 4.01.39

	AVERAGE CONCENTRATIONS, MEQ/L			REMOVAL	RESIN CAPACITY
	INFLUENT	EFFLUENT	DIFFERENCE	%	EQ/L
CA	8.67	.92	7.74	89	.290
MG	3.38	.96	2.42	72	.091
TH	12.04	1.88	10.16	84	.381
NA	37.34	50.29	-12.95		

FIGURE A- a
MAJOR CATION CONCENTRATIONS
OF IX REGENERATION EFFLUENT
CYCLE 4.01.39

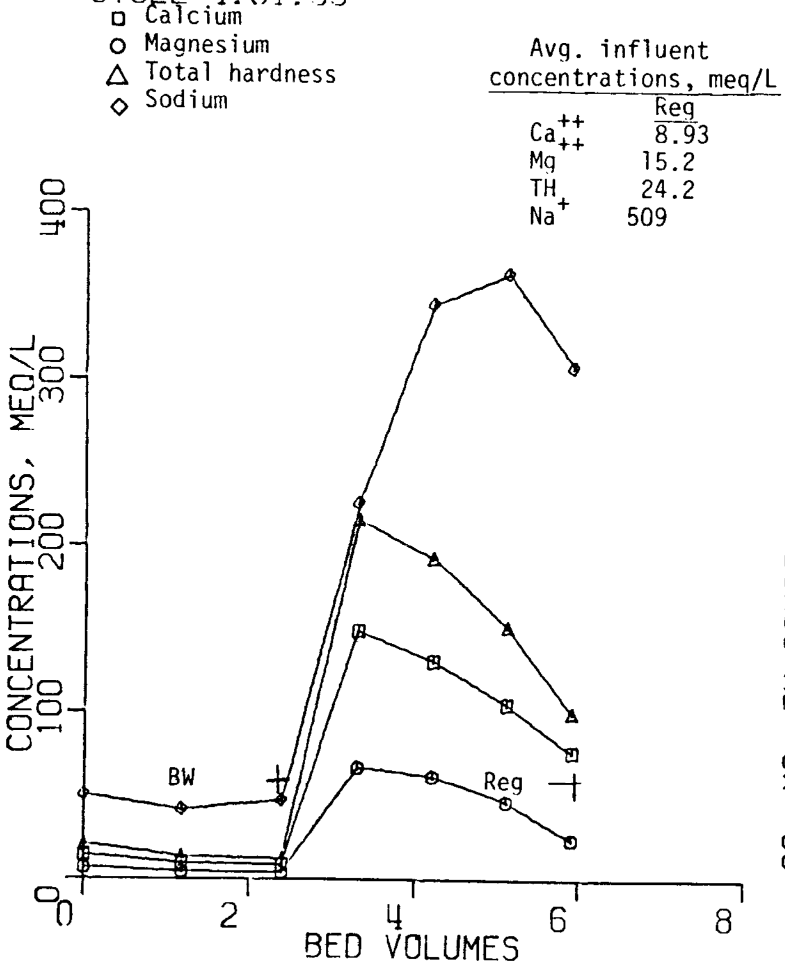
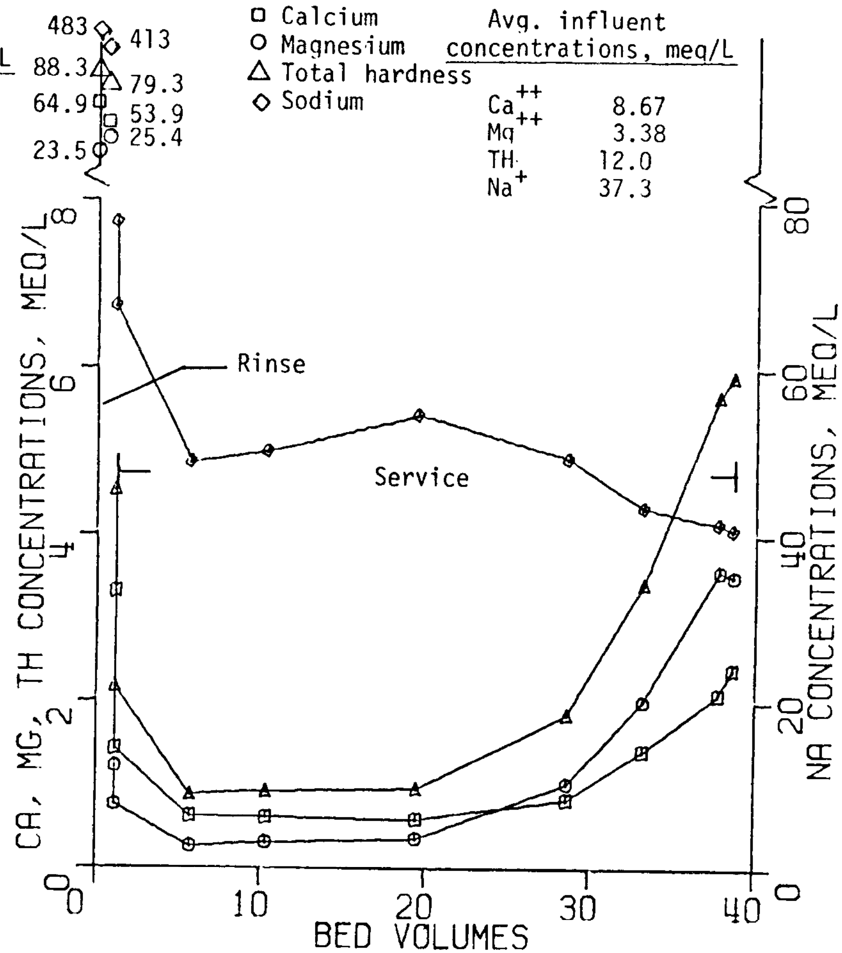


FIGURE A- b
MAJOR CATION CONCENTRATIONS OF
IX RINSE AND SERVICE EFFLUENTS
CYCLE 4.01.39



SODIUM (NA), CALCIUM (CA), AND MAGNESIUM (MG) CONCENTRATIONS ARE MEASURED BY ATOMIC ABSORPTION.
TOTAL HARDNESS (TH) IS CALCULATED BY SUMMING THE CALCIUM AND MAGNESIUM CONCENTRATIONS.

Ion-Exchange - Run 4.01.00

Date: 9/11/79

Cycle: 4.01.51

Conditions: Feedwater - Wellton-Mowhawk drainage pretreated (in Train IV) with high lime dosage for silica removal
Regenerant - fresh ED brine.
Source of backwash - IX feedwater.

Control variables:

	Target	Actual
Fresh regeneration conc. (mg/L TDS)	35 000	33 730
Fresh regeneration flow rate (L/min)	8.0	8.2
Recycled regenerant flow rate (L/min)	None	None
Recycled regenerant volume (L)	None	None
Service termination point (meq/L Ca^{++})	3.0	2.6

Standard resin bed: Height = 1102 mm
Volume = 100.6L

Chemical Compositions of Tank Waters Prior to Cycle 4.01.51

Tank	pH units	Conductivity uS/cm	Ca^{++} meq/L	Mg^{++} meq/L	TH meq/L
Recycle regenerant (T-5)	-	-	-	-	-
Spent regenerant (T-6)	-	-	-	-	-
Lime-softened feed (T-9)	7.4	4 145	9.4	3.4	12.8
Lime softened feed (T-10)	7.3	5 055	9.4	3.4	12.8
Fresh ED brine (T-28)	6.8	4 154	10.4	13.2	23.6
IX product/ED feed (T-33)	7.3	5 530	0.72	0.56	1.28

Cycle 4.01.51 Operating Conditions

MODE	INPUT	OUTPUT	DURATION MIN	THROUGHPUT L	VOLUME BV	AVG FLOW RATE L/MIN	BV/MIN	BED EXPANSION %	TEMPERATURE C
BACKWASH	FEED	WASTE	10	249	2.48	24.9	.248	27.	29.5
DRAIN 1	(VENT)	WASTE	3	62	.62	20.7	.205	0.0	
REGEN 3	FR REGEN	WASTE	46	375	3.73	8.24	.082	4.5	24.0
DRAIN 1	(VENT)	WASTE	3	62	.62	20.7	.205	0.0	
RINSE	FEED	WASTE	10	130	1.29	13.0	.129	0.0	
SERVICE	FEED	PRODUCT	134	4056	40.3	30.3	.301	0.0	
DRAIN 2	(VENT)	WASTE	2	41	.42	20.7	.209	0.0	

D2—2

Fresh Regenerant Volume Balance

Run 4.01.00 Cycle no.	Date	Fresh regenerant volume (V_3) L	Fresh regenerant TDS mg/L	Service volume (V_S) L	Estimated ED feed TDS mg/L	R %	$V_3/(1-R)V_S$
05	8/31/79	451	34 000	5 861	3 300	92	0.92
06	8/31/79	451	34 000	5 509	3 300	92	0.97
07	8/31/79	451	34 000	5 376	3 300	92	1.00
08	9/1/79	451	34 000	4 070	3 300	92	1.32
09	9/1/79	451	34 000	4 935	3 300	92	1.09
10	9/1/79	451	34 000	5 106	3 300	92	1.05
11	9/1/79	451	34 000	4 709	3 300	92	1.14
12	9/1/79	451	34 000	4 665	3 300	92	1.15
13	9/2/79	451	34 000	4 778	3 300	92	1.12
14	9/2/79	451	34 000	4 072	3 300	92	1.32
15	9/2/79	401	34 000	4 449	3 300	92	1.07
16	9/2/79	401	34 000	4 379	3 300	92	1.09
17	9/2/79	400	34 000	4 329	3 300	92	1.10
18	9/3/79	400	34 000	4 402	3 300	92	1.08
19	9/3/79	401	34 000	4 473	3 300	92	1.07
20	9/3/79	400	34 000	4 294	3 300	92	1.11
21	9/3/79	320	34 000	3 551	3 300	92	1.18
22	9/3/79	322	34 000	3 223	3 300	92	1.18
23	9/4/79	322	34 640	3 168	3 300	92	1.21
24	9/4/79	280	34 640	3 148	3 300	92	1.07
25	9/4/79	280	34 640	3 193	3 300	92	1.06
26	9/6/79	358	34 260	4 264	3 300	92	1.00
27	9/6/79	358	34 260	3 927	3 300	92	1.08
28	9/7/79	358	34 200	3 639	3 300	92	1.17
29	9/7/79	358	34 200	3 870	3 300	92	1.10
30	9/7/79	358	34 200	3 996	3 300	92	1.07
31	9/7/79	359	34 200	4 021	3 300	92	1.06
32	9/7/79	358	34 200	4 469	3 300	92	0.95
33	9/7/79	359	34 200	4 263	3 300	92	1.00
34	9/8/79	358	34 200	4 426	3 300	92	0.96
35	9/8/79	358	34 200	3 868	3 300	92	1.10
36	9/8/79	358	34 200	3 753	3 300	92	1.14
37	9/8/79	359	34 200	4 173	3 300	92	1.02
38	9/9/79	358	33 780	3 900	3 300	92	1.08
39	9/9/79	359	33 780	3 772	3 300	92	1.12
40	9/9/79	372	33 780	4 096	3 300	92	1.07
41	9/9/79	371	33 780	3 760	3 300	92	1.16
42	9/9/79	376	33 780	3 875	3 300	92	1.14
43	9/9/79	377	33 780	3 837	3 300	92	1.16
44	9/10/79	377	33 420	3 948	3 300	91	1.11
45	9/10/79	378	33 420	3 743	3 300	91	1.17
46	9/10/79	378	33 420	3 707	3 300	91	1.18
47	9/10/79	382	33 420	4 119	3 300	91	1.08
48	9/10/79	376	33 420	3 822	3 300	91	1.14
49	9/10/79	377	33 420	3 618	3 300	91	1.21
50	9/11/79	378	33 000	4 128	3 300	91	1.05
51	9/11/79	375	33 000	4 056	3 300	91	1.06

Influent and Effluent Compositions during Cycle 4.01.51

	Units	Backwash effluent	Regeneration Influent	Regeneration Effluent	Rinse & service influent	Rinse effluent	Service effluent
pH	units	-	7.0	-	7.4	7.4	7.2
TDS (Σ ions)	mg/L	3 891	33 730	25 577	3 144	20 092	3 338
Conductivity @ 25.°C	µS/cm	-	4 314.7	-	517.8	2 825.9	562.9
E. F. (TDS/cond.)	-	-	7.8	-	6.1	7.1	5.9
Silica	mg/L	4.0	3.9	4.4	3.8	4.1	3.6
Calcium	mg/L	209	196	1 880	175	480	20.3
Magnesium	mg/L	60.0	152	372	48.6	124	16.3
Sodium	mg/L	1 040	11 970	6 600	847	6 680	1 150
Potassium	mg/L	10	95	50	7.9	57	11.5
Strontium	mg/L	<0.1	5.0	9.0	0.6	5.0	0.3
Bicarbonate	mg/L	87.8	68.3	122.0	27.3	52.2	25.9
Carbonate	mg/L	ND	ND	ND	ND	ND	ND
Hydroxide	mg/L	ND	ND	ND	ND	ND	ND
Sulfate	mg/L	1 180	9 200	7 040	934	5 650	950
Chloride	mg/L	1 300	12 040	9 500	1 100	7 040	1 160
T-alkalinity as $CaCO_3$	mg/L	72.0	56.0	100.0	22.4	42.8	21.2
P-alkalinity as $CaCO_3$	mg/L	ND	ND	ND	ND	ND	ND
Σ Anions	meq/L	62.76	532.48	416.71	51.01	317.21	53.01
Σ Cations	meq/L	60.86	545.52	413.00	49.79	326.30	52.68
Control value	meq/L	+1.76	-1.55	+0.57	+1.36	-1.81	+0.36

Major Cation Concentrations of Samples Analyzed by Atomic Absorption

CYCLE 4.01.51

MODE	PROCESS STREAM	THROUGHPUT BV	CA MEQ/L	MG MEQ/L	TH MEQ/L	NA MEQ/L
BACKWASH	EFFLUENT	0.00	12.52	5.95	18.48	50.02
BACKWASH	EFFLUENT	1.24	9.08	4.45	13.53	44.80
REGEN 3	EFFLUENT	2.48	8.48	4.17	12.66	41.32
REGEN 3	INFLUENT	3.13	9.78	12.51	22.29	520.66
REGEN 3	EFFLUENT	3.87	154.19	56.95	211.15	297.96
REGEN 3	EFFLUENT	4.52	115.77	43.70	159.47	336.23
REGEN 3	EFFLUENT	5.26	88.82	33.00	121.83	364.94
REGEN 3	EFFLUENT	6.24	81.84	28.31	110.15	373.21
RINSE	EFFLUENT	0.00	31.94	17.86	49.80	487.17
RINSE	EFFLUENT	.65	27.94	13.00	40.95	338.84
RINSE	EFFLUENT	1.29	1.05	.71	1.76	77.86
SERVICE	EFFLUENT	1.29	1.02	.69	1.71	75.25
SERVICE	INFLUENT	5.81	8.93	4.15	13.08	36.41
SERVICE	EFFLUENT	8.81	.35	.21	.56	48.72
SERVICE	EFFLUENT	10.32	.37	.20	.57	45.67
SERVICE	INFLUENT	18.44	8.33	4.01	12.34	35.89
SERVICE	EFFLUENT	19.35	.38	.24	.62	51.76
SERVICE	EFFLUENT	28.37	.59	.69	1.29	52.20
SERVICE	EFFLUENT	32.88	.87	1.59	2.46	50.89
SERVICE	EFFLUENT	37.40	1.89	3.26	5.15	44.80
SERVICE	INFLUENT	41.61	8.68	3.93	12.62	36.84
SERVICE	EFFLUENT	41.61	2.64	4.56	7.20	42.19

Service Performance Summary

CYCLE 4.01.51

	AVERAGE CONCENTRATIONS, MEQ/L			REMOVAL	RESIN CAPACITY
	INFLUENT	EFFLUENT	DIFFERENCE	%	EQ/L
CA	8.65	.81	7.84	91	.316
MG	4.03	1.05	2.98	74	.120
TH	12.68	1.86	10.82	85	.436
NA	36.38	51.54	-15.16		

FIGURE A- a
MAJOR CATION CONCENTRATIONS
OF IX REGENERATION EFFLUENT
CYCLE 4.01.51

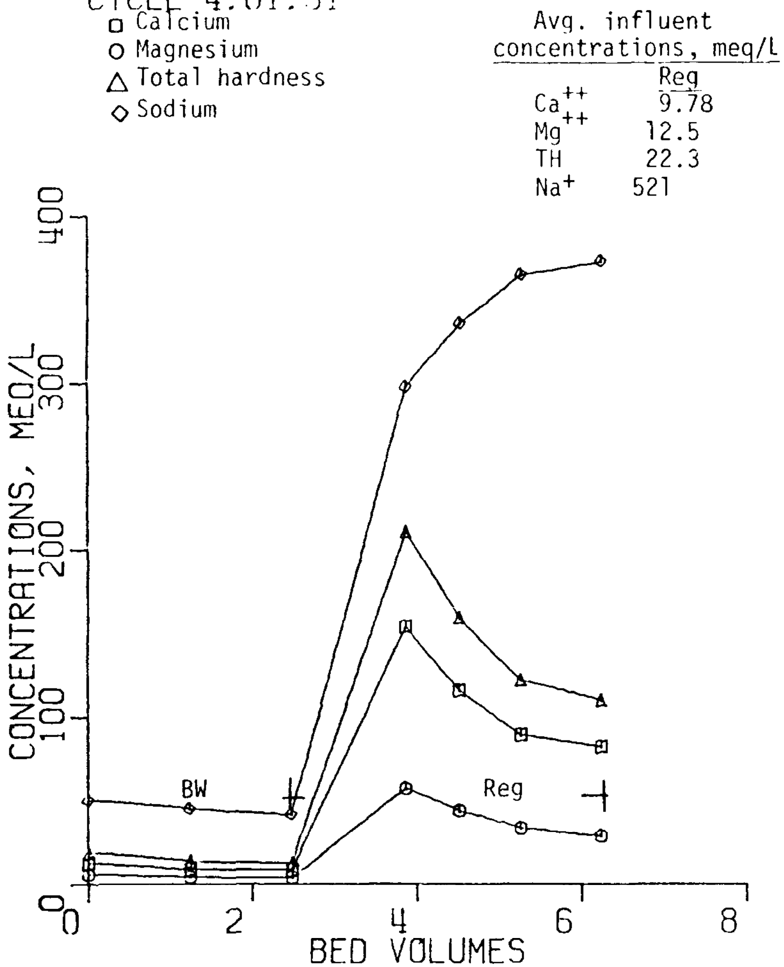
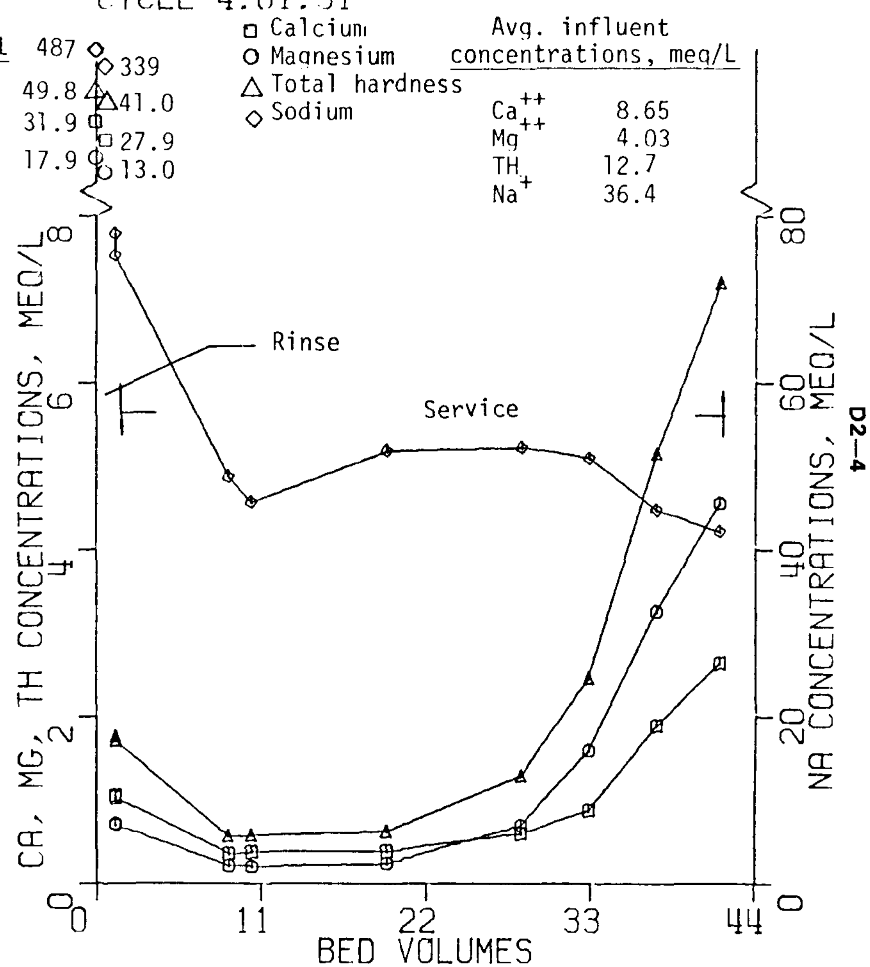


FIGURE A- b
MAJOR CATION CONCENTRATIONS OF
IX RINSE AND SERVICE EFFLUENTS
CYCLE 4.01.51



SODIUM (NA), CALCIUM (CA), AND MAGNESIUM (MG) CONCENTRATIONS ARE MEASURED BY ATOMIC ABSORPTION.
TOTAL HARDNESS (TH) IS CALCULATED BY SUMMING THE CALCIUM AND MAGNESIUM CONCENTRATIONS.

Ion-Exchange - Run 4.02.00

Date: 9/16/79

Cycle: 4.02.27

Conditions: Feedwater - Wellton-Mowhawk drainage pretreated (in Train IV) with high lime dosage for silica removal
Regenerants - recycled regenerant and fresh ED brine

Control variables:

	Target	Actual
Fresh regeneration conc. (mg/L TDS)	35 000	32 330
Fresh regeneration flow rate (L/min)	24.0	24.3
Recycled regenerant flow rate (L/min)	24.0	23.6
Recycled regenerant volume (L)	1 600	1 589
Service termination point (meq/L Ca^{++})	3.0	2.3

Standard resin bed: Height = 1102 mm
Volume = 100.6 L

Chemical Compositions of Tank Waters Prior to Cycle 4.02.27

Tank	pH units	Conductivity µS/cm	Ca^{++} meq/L	Mg^{++} meq/L	TH meq/L
Recycle regenerant (T-5)	-	-	59.0	45.0	104.0
Spent regenerant (T-6)	-	-	61.0	46.0	107.0
Lime-softened feed (T-9)	-	-	9.4	3.4	12.8
Lime softened feed (T-10)	-	-	9.4	3.4	12.8
Fresh ED brine (T-28)	-	-	7.6	16.0	23.6
IX product/ED feed (T-33)	-	-	0.64	1.36	2.00

Cycle 4.02.27 Operating Conditions

MODE	INPUT	OUTPUT	DURATION MIN	THROUGHPUT L	VOLUME BV	AVG FLOW RATE L/MIN	AVG FLOW RATE BV/MIN	BED EXPANSION %	TEMPERATURE C
REGEN 1	RE REGEN	WASTE	10	251	2.49	25.1	.249	29.	28.2
REGEN 2	RE REGEN	SP REGEN	67	1589	15.8	23.7	.235	31.0	28.9
REGEN 3	FR REGEN	SP REGEN	22	540	5.37	24.3	.242	30.	30.9
DRAIN 1	(VENT)	WASTE	3	62	.62	20.7	.205	0.0	
RINSE	FEED	WASTE	10	132	1.31	13.2	.131	0.0	
SERVICE	FEED	PRODUCT	217	6508	64.7	30.0	.298	0.0	
DRAIN 2	(VENT)	WASTE	2	41	.42	20.7	.209	0.0	

Fresh Regenerant Volume Balance

Run 4.02.00 Cycle no.	Date	Fresh regenerant volume (V_3) L	Fresh regenerant TDS mg/L	Service volume (V_S) L	Estimated ED feed TDS mg/L	R %	$V_3/(1-R)V_S$
18	9/13/79	387	33 090	6 334	3 300	91	0.71
19	9/14/79	400	33 090	6 134	3 300	91	0.75
20	9/14/79	402	33 090	6 064	3 300	91	0.76
21	9/14/79	399	33 090	6 017	3 300	91	0.76
22	9/14/79	401	33 090	5 782	3 300	91	0.80
23	9/15/79	400	33 090	5 472	3 300	91	0.84
24	9/15/79	401	33 090	5 821	3 300	91	0.79
25	9/15/79	522	33 090	5 483	3 300	91	1.09
26	9/16/79	540	33 420	6 191	3 300	91	1.02
27	9/16/79	540	33 420	6 508	3 300	91	0.96

Influent and Effluent Compositions during Cycle 4.02.27

	Units	Regen 1,2 influent	Regen 1 effluent	Regen 2 effluent	Regen 3 influent	Regen 3 effluent	Rinse & service influent	Rinse effluent	Service effluent
pH	units	-	-	-	7.2	-	7.5	7.3	7.4
TDS (Σ ions)	mg/L	28 091	20 626	27 772	32 328	31 407	3 125	20 349	3 294
Conductivity @ 25.°C	µS/cm	-	-	-	4 189.7	-	504.6	2 821.7	533.2
E. F. (TDS/cond.)	-	-	-	-	7.7	-	6.2	7.2	6.2
Silica	mg/L	2.6	3.2	3.4	3.3	3.6	3.0	3.2	3.0
Calcium	mg/L	1 110	1 560	1 310	138	1 080	151	288	19.2
Magnesium	mg/L	593	614	655	196	415	50.1	139	29.1
Sodium	mg/L	8 300	4 940	7 660	11 100	9 460	868	6 610	1 100
Potassium	mg/L	58	45	57	93	65	8.4	58	11.0
Strontium	mg/L	26	22	25	4.4	21	2.0	5.9	0.1
Bicarbonate	mg/L	141.5	122.0	122.0	73.2	122.0	22.4	55.1	23.4
Carbonate	mg/L	ND	ND	ND	ND	ND	ND	ND	ND
Hydroxide	mg/L	ND	ND	ND	ND	ND	ND	ND	ND
Sulfate	mg/L	5 460	4 220	5 540	8 640	7 840	924	5 580	986
Chloride	mg/L	12 400	9 100	12 400	12 080	12 400	1 096	7 610	1 122
T-alkalinity as $CaCO_3$	mg/L	116.0	100.0	100.0	60.0	100.0	18.4	45.2	19.2
P-alkalinity as $CaCO_3$	mg/L	ND	ND	ND	ND	ND	ND	ND	ND
Σ Anions	meq/L	465.93	346.68	467.27	522.02	515.18	50.60	331.88	52.64
Σ Cations	meq/L	467.30	344.89	454.49	508.34	501.68	49.67	314.96	51.49
Control value	meq/L	-0.19	+0.33	+1.74	+1.67	+1.67	+1.04	+3.22	+1.26

Major Cation Concentrations of Samples Analyzed by Atomic Absorption

CYCLE 4.02.27

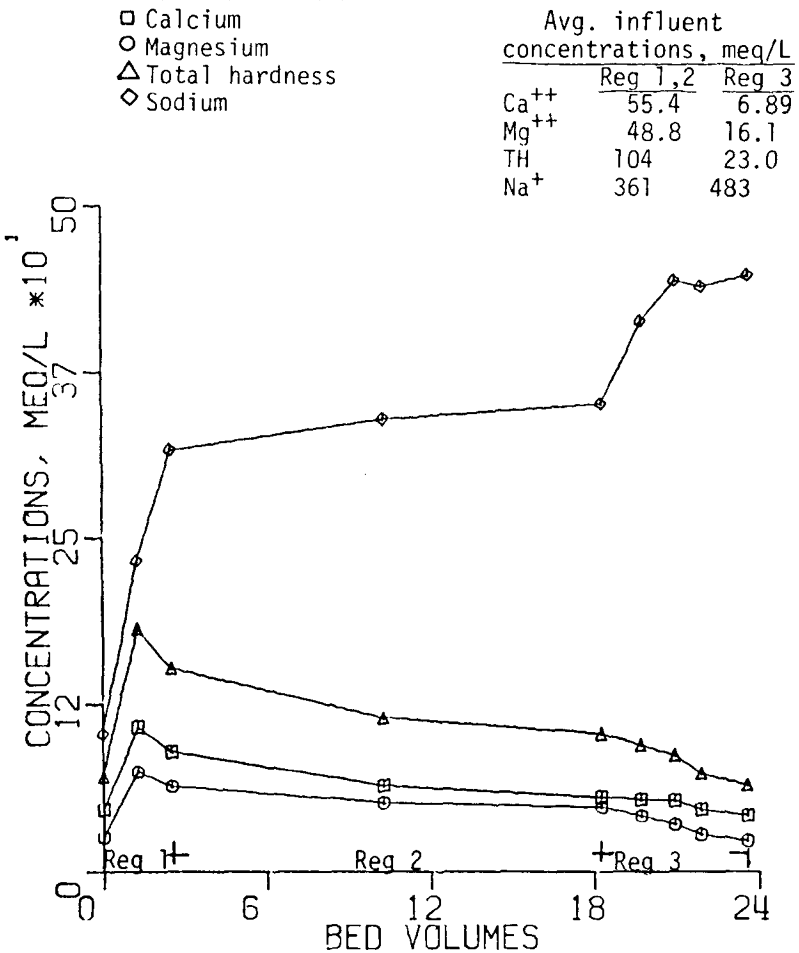
MODE	PROCESS STREAM	THROUGHPUT BV	CA MEQ/L	MG MEQ/L	TH MEQ/L	NA MEQ/L
REGEN 1	EFFLUENT	0.00	45.91	25.02	70.93	102.22
REGEN 1	EFFLUENT	1.25	107.29	74.32	181.61	233.14
REGEN 2	EFFLUENT	2.49	89.32	63.37	152.70	317.09
REGEN 2	INFLUENT	5.08	55.39	48.81	104.20	361.03
REGEN 2	EFFLUENT	10.25	63.87	50.70	114.57	339.28
REGEN 3	EFFLUENT	18.24	54.89	47.74	102.63	350.59
REGEN 3	INFLUENT	19.21	6.89	16.13	23.02	482.82
REGEN 3	EFFLUENT	19.69	53.39	40.74	94.13	413.22
REGEN 3	EFFLUENT	20.90	52.40	34.40	86.80	443.67
REGEN 3	EFFLUENT	21.87	45.91	27.16	73.07	439.32
REGEN 3	EFFLUENT	23.56	41.42	22.72	64.13	448.02
RINSE	EFFLUENT	0.00	25.95	20.33	46.28	469.77
RINSE	EFFLUENT	.66	17.61	13.58	31.20	361.03
RINSE	EFFLUENT	1.31	.29	.39	.68	59.59
SERVICE	EFFLUENT	1.31	.31	.36	.67	58.29
SERVICE	INFLUENT	4.00	6.39	4.24	10.63	35.54
SERVICE	EFFLUENT	9.06	.26	.23	.49	48.72
SERVICE	EFFLUENT	16.81	.31	.23	.54	49.59
SERVICE	INFLUENT	31.72	8.48	4.13	12.61	36.02
SERVICE	EFFLUENT	32.61	.33	.29	.62	49.15
SERVICE	EFFLUENT	48.12	.65	2.13	2.79	47.85
SERVICE	EFFLUENT	55.87	1.23	4.56	5.79	44.80
SERVICE	EFFLUENT	63.62	3.04	6.17	9.22	44.80
SERVICE	INFLUENT	66.00	8.03	4.09	12.12	36.76
SERVICE	EFFLUENT	66.00	2.35	6.35	8.69	39.06

Service Performance Summary

CYCLE 4.02.27

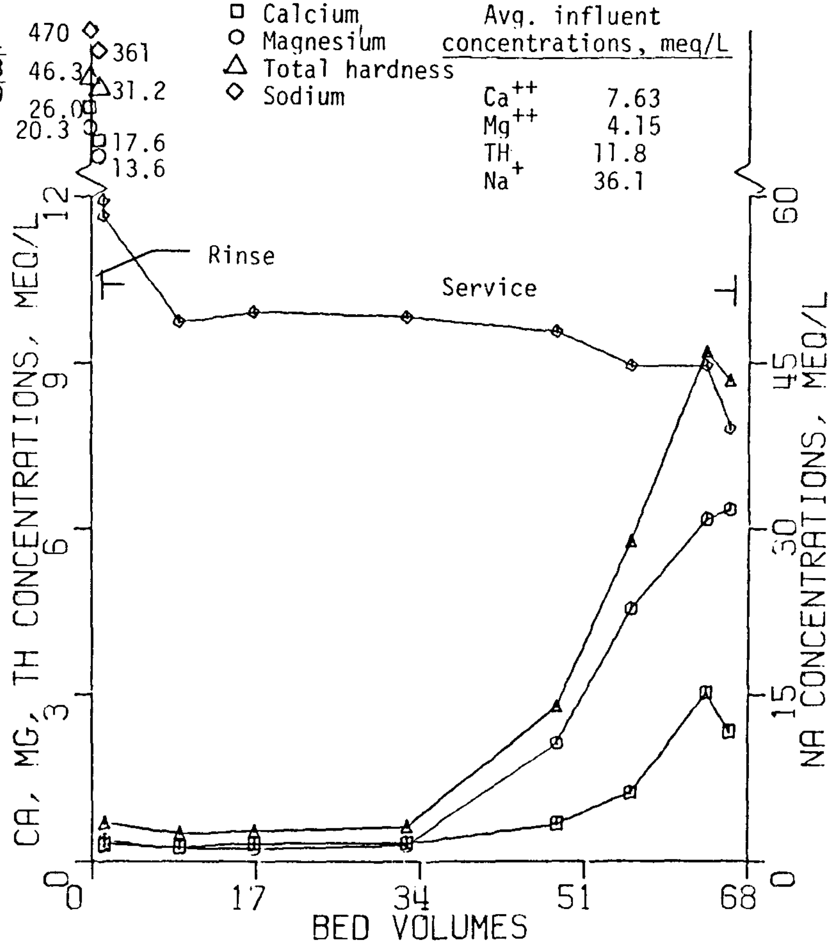
	AVERAGE CONCENTRATIONS, MEQ/L INFLUENT	EFFLUENT	DIFFERENCE	REMOVAL %	RESIN CAPACITY EQ/L
CA	7.63	.73	6.90	90	.446
MG	4.15	1.69	2.46	59	.159
TH	11.79	2.42	9.36	79	.606
NA	36.10	48.44	-12.34		

FIGURE A- a
MAJOR CATION CONCENTRATIONS
OF IX REGENERATION EFFLUENT
CYCLE 4.02.27



	Reg 1,2	Reg 3
Ca^{++}	55.4	6.89
Mg^{++}	48.8	16.1
TH	104	23.0
Na^{+}	361	483

FIGURE A- b
MAJOR CATION CONCENTRATIONS OF
IX RINSE AND SERVICE EFFLUENTS
CYCLE 4.02.27



Ca^{++}	7.63
Mg^{++}	4.15
TH	11.8
Na^{+}	36.1

SODIUM (NA), CALCIUM (CA), AND MAGNESIUM (MG) CONCENTRATIONS ARE MEASURED BY ATOMIC ABSORPTION.
TOTAL HARDNESS (TH) IS CALCULATED BY SUMMING THE CALCIUM AND MAGNESIUM CONCENTRATIONS.

Ion-Exchange - Run 4.02.00

Date: 9/18/79

Cycle: 4.02.34

Conditions: Feedwater - Wellton-Mowhawk drainage pretreated (in Train IV) with high lime dosage for silica removal
Regenerants - recycled regenerant and fresh ED brine

Control variables:	Target	Actual
Fresh regeneration conc. (mg/L TDS)	35 000	34 370
Fresh regeneration flow rate (L/min)	12.0	12.8
Recycled regenerant flow rate (L/min)	24.0	23.2
Recycled regenerant volume (L)	1 600	1 586
Service termination point (meq/L Ca^{++})	3.0	2.8

Standard resin bed: Height = 1102 mm
Volume = 100.6 L

Chemical Compositions of Tank Waters Prior to Cycle 4.02.34

Tank	pH units	Conductivity µS/cm	Ca^{++} meq/L	Mg^{++} meq/L	TH meq/L
Recycle regenerant (T-5)	-	36 327	47.0	45.0	92.0
Spent regenerant (T-6)	-	36 940	47.0	56.0	103.0
Lime-softened feed (T-9)	7.36	4 940	9.0	3.8	12.8
Lime softened feed (T-10)	7.65	4 950	8.8	4.4	13.2
Fresh ED brine (T-28)	7.01	42 445	8.0	17.6	25.6
IX product/ED feed (T-33)	7.41	4 749	0.64	1.52	2.16

Cycle 4.02.34 Operating Conditions

MODE	INPUT	OUTPUT	DURATION MIN	THROUGHPUT L	VOLUME BV	AVG FLOW RATE L/MIN	AVG FLOW RATE BV/MIN	BED EXPANSION %	TEMPERATURE C
REGEN 1	RE REGEN	WASTE	10	254	2.52	25.4	.252	30.	27.3
REGEN 2	RE REGEN	SP REGEN	68	1586	15.8	23.2	.231	31.0	27.0
REGEN 3	FR REGEN	SP REGEN	42	540	5.37	12.8	.127	11.	28.0
DRAIN 1	(VENT)	WASTE	3	62	.62	20.7	.205	0.0	
RINSE	FEED	WASTE	10	132	1.31	13.2	.131	0.0	
SERVICE	FEED	PRODUCT	225	6791	67.5	30.2	.300	0.0	
DRAIN 2	(VENT)	WASTE	2	41	.42	20.7	.209	0.0	

D4—2

Fresh Regenerant Volume Balance

Run 4.02.00 Cycle no.	Date	Fresh regenerant volume (V_3) L	Fresh regenerant TDS mg/L	Service volume (V_S) L	Estimated ED feed TDS mg/L	R %	$V_3/(1-R)V_S$
18	9/13/79	387	33 090	6 334	3 300	91	0.71
19	9/14/79	400	33 090	6 134	3 300	91	0.75
20	9/14/79	402	33 090	6 064	3 300	91	0.76
21	9/14/79	399	33 090	6 017	3 300	91	0.76
22	9/14/79	401	33 090	5 782	3 300	91	0.80
23	9/15/79	400	33 090	5 472	3 300	91	0.84
24	9/15/79	401	33 090	5 821	3 300	91	0.79
25	9/15/79	522	33 090	5 483	3 300	91	1.09
26	9/16/79	540	33 420	6 191	3 300	91	1.02
27	9/16/79	540	33 420	6 508	3 300	91	0.96
28	9/16/79	600	33 420	6 848	3 300	91	1.02
29	9/16/79	600	33 420	6 581	3 300	91	1.06
30	9/17/79	602	33 030	6 748	3 300	92	1.03
31	9/17/79	602	33 030	6 776	3 300	92	0.92
32	9/17/79	541	33 030	6 553	3 300	92	0.95
33	9/18/79	541	33 690	6 852	3 300	92	0.93
34	9/18/79	540	33 690	6 791	3 300	92	0.94

Influent and Effluent Compositions during Cycle 4.02.34

	Units	Regen 1,2 influent	Regen 1 effluent	Regen 2 effluent	Regen 3 influent	Regen 3 effluent	Rinse & service influent	Rinse effluent	Service effluent
pH	units	-	-	-	7.2	-	7.4	7.2	7.5
TDS (Σ ions)	mg/L	27 767	19 623	27 939	34 370	31 020	3 239	21 705	3 433
Conductivity @ 25.°C	µS/cm	-	-	-	4 157.2	-	503.9	2 907.2	530.4
E. F. (TDS/cond.)	-	-	-	-	8.3	-	6.4	7.5	6.5
Silica	mg/L	2.6	2.8	2.6	3.3	3.4	2.9	2.9	2.8
Calcium	mg/L	1 020	1 510	1 450	143	1 030	172	302	20.2
Magnesium	mg/L	604	612	701	231	444	48.6	134	29.0
Sodium	mg/L	8 120	4 600	7 680	12 100	9 400	890	7 360	1 170
Potassium	mg/L	49	29	49	105	61	7.7	54	10.7
Strontium	mg/L	22	22	25	2.9	20	2.2	5.1	0.2
Bicarbonate	mg/L	248.9	107.4	131.8	84.9	122.0	25.4	26.8	29.8
Carbonate	mg/L	ND	ND	ND	ND	ND	ND	ND	ND
Hydroxide	mg/L	ND	ND	ND	ND	ND	ND	ND	ND
Sulfate	mg/L	5 200	4 100	5 200	9 400	7 880	960	5 850	1 040
Chloride	mg/L	12 500	8 640	12 700	12 300	12 060	1 130	7 970	1 130
T-alkalinity as $CaCO_3$	mg/L	204.0	88.0	108.0	69.6	100.0	20.8	22.0	24.4
P-alkalinity as $CaCO_3$	mg/L	ND	ND	ND	ND	ND	ND	ND	ND
Σ Anions	meq/L	465.09	330.97	468.81	544.25	506.42	52.36	347.20	54.10
Σ Cations	meq/L	455.56	327.04	465.92	555.24	498.84	51.54	347.75	54.57
Control value	meq/L	+1.30	+0.75	+0.39	-1.29	+0.95	+0.89	-0.10	-0.49

Major Cation Concentrations of Samples Analyzed by Atomic Absorption

CYCLE 4.02.34

MODE	PROCESS STREAM	THROUGHPUT BV	CA MEQ/L	MG MEQ/L	TH MEQ/L	NA MEQ/L
REGEN 1	EFFLUENT	0.00	24.95	12.59	37.54	68.73
REGEN 1	EFFLUENT	1.26	103.29	66.50	169.80	221.40
REGEN 2	EFFLUENT	2.52	97.31	66.26	163.56	276.64
REGEN 2	INFLUENT	6.22	50.90	49.71	100.61	353.20
REGEN 2	EFFLUENT	10.14	59.38	51.19	110.57	339.28
REGEN 3	EFFLUENT	18.22	52.40	46.58	98.98	352.33
REGEN 3	INFLUENT	18.98	7.14	19.01	26.15	526.32
REGEN 3	EFFLUENT	19.62	56.39	41.40	97.79	404.52
REGEN 3	EFFLUENT	21.01	46.41	28.48	74.88	423.23
REGEN 3	EFFLUENT	22.41	40.42	24.12	64.53	421.92
REGEN 3	EFFLUENT	23.55	43.41	28.81	72.22	389.73
RINSE	EFFLUENT	0.00	25.95	19.92	45.87	508.92
RINSE	EFFLUENT	.66	19.46	15.47	34.93	393.21
RINSE	EFFLUENT	1.31	.39	.35	.73	61.77
SERVICE	EFFLUENT	1.31	.37	.30	.67	60.03
SERVICE	INFLUENT	4.01	8.73	3.54	12.27	36.76
SERVICE	EFFLUENT	10.01	.22	.19	.41	50.02
SERVICE	EFFLUENT	18.41	.22	.16	.38	49.15
SERVICE	INFLUENT	34.91	8.23	4.26	12.49	37.28
SERVICE	EFFLUENT	35.51	.19	.30	.49	47.85
SERVICE	EFFLUENT	52.62	.72	3.37	4.08	46.98
SERVICE	EFFLUENT	61.32	1.85	6.07	7.91	44.37
SERVICE	INFLUENT	68.82	8.98	4.16	13.14	36.06
SERVICE	EFFLUENT	68.82	2.84	7.23	10.07	39.36

Service Performance Summary

CYCLE 4.02.34

	AVERAGE CONCENTRATIONS, MEQ/L			REMOVAL	RESIN CAPACITY
	INFLUENT	EFFLUENT	DIFFERENCE	%	EQ/L
CA	8.65	.66	7.99	92	.539
MG	3.98	1.92	2.06	52	.139
TH	12.63	2.58	10.05	80	.679
NA	36.70	48.10	-11.40		

FIGURE A- a
MAJOR CATION CONCENTRATIONS
OF IX REGENERATION EFFLUENT
CYCLE 4.02.34

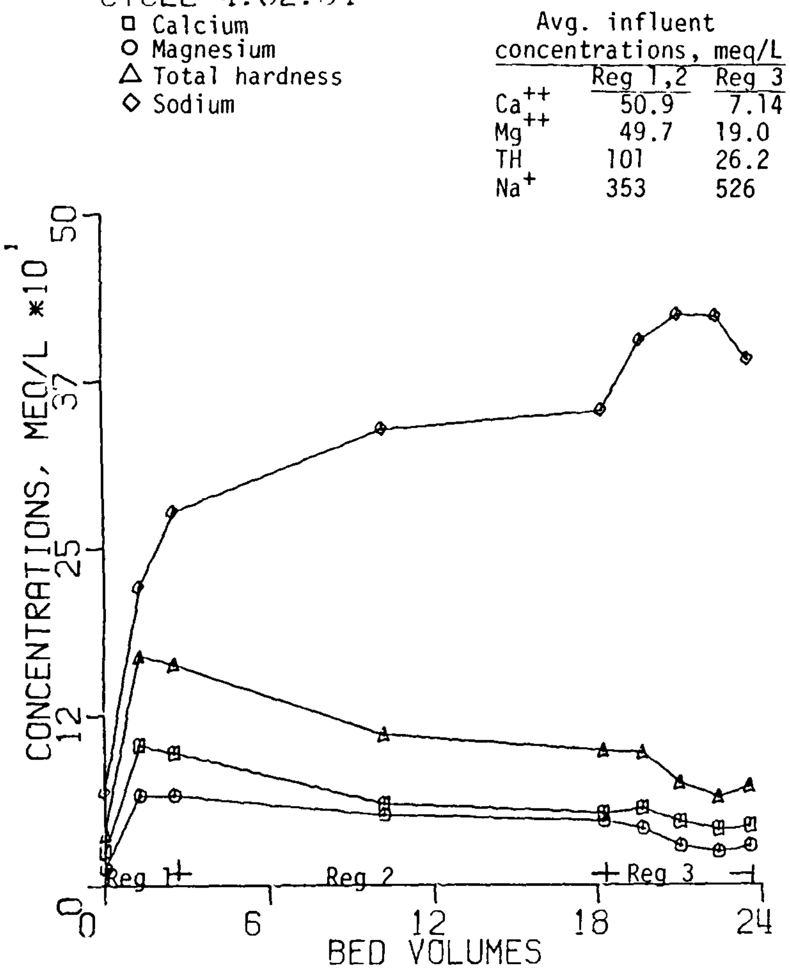
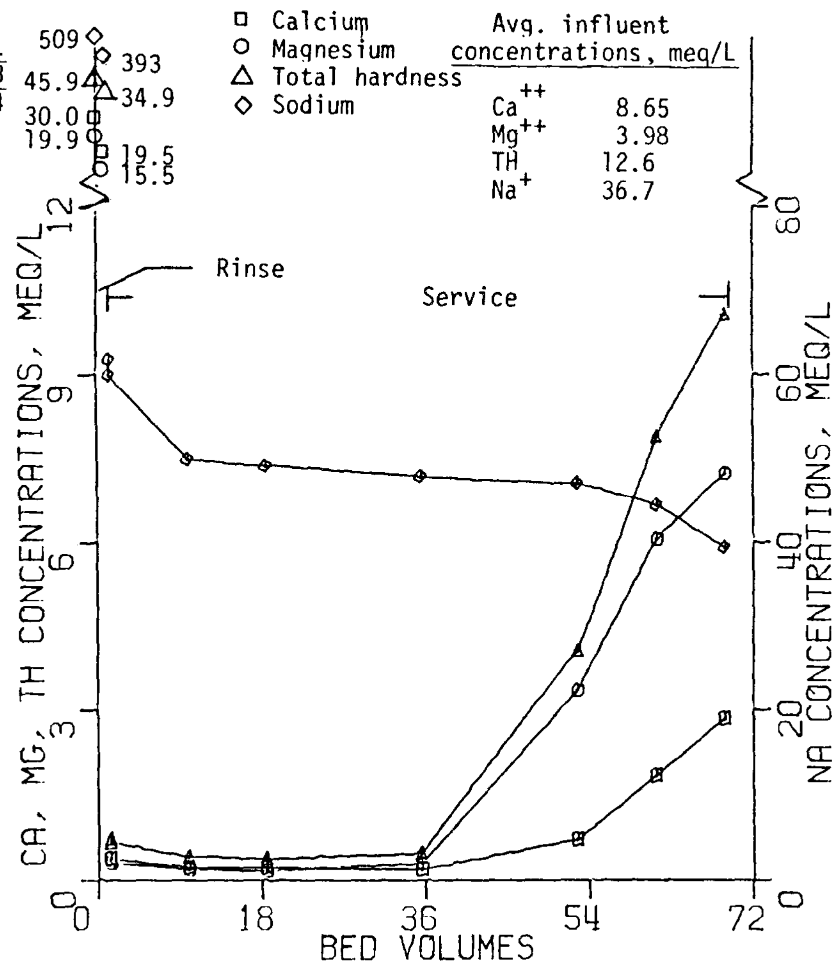


FIGURE A- b
MAJOR CATION CONCENTRATIONS OF
IX RINSE AND SERVICE EFFLUENTS
CYCLE 4.02.34



SODIUM (NA), CALCIUM (CA), AND MAGNESIUM (MG) CONCENTRATIONS ARE MEASURED BY ATOMIC ABSORPTION.
TOTAL HARDNESS (TH) IS CALCULATED BY SUMMING THE CALCIUM AND MAGNESIUM CONCENTRATIONS.

Ion-Exchange - Run 4.02.00

Date: 9/20/79

Cycle: 4.02.42

Conditions: Feedwater - Wellton-Mowhawk drainage pretreated (in Train IV) with high lime dosage for silica removal
Regenerants - recycled regenerant and fresh ED brine

Control variables:

	Target	Actual
Fresh regeneration conc. (mg/L TDS)	35 000	33 630
Fresh regeneration flow rate (L/min)	24.0	24.0
Recycled regenerant flow rate (L/min)	24.0	23.8
Recycled regenerant volume (L)	1 600	1 600
Service termination point (meq/L Ca^{++})	3.0	2.7

Standard resin bed: Height = 1102 mm
Volume = 100.6 L

Chemical Compositions of Tank Waters Prior to Cycle 4.02.42

Tank	pH units	Conductivity uS/cm	Ca^{++} meq/L	Mg^{++} meq/L	TH meq/L
Recycle regenerant (T-5)	-	37 236	52.0	49.0	101.0
Spent regenerant (T-6)	-	37 179	54.0	49.0	103.0
Lime-softened feed (T-9)	7.5	4 916	8.8	4.0	12.8
Lime softened feed (T-10)	7.6	4 863	8.8	4.0	12.8
Fresh ED brine (T-28)	7.2	41 728	9.6	20.8	30.4
IX product/ED feed (T-33)	7.4	4 962	0.6	1.16	1.76

Cycle 4.02.42 Operating Conditions

MODE	INPUT	OUTPUT	DURATION MIN	THROUGHPUT L	VOLUME BV	AVG FLOW RATE L/MIN	AVG FLOW RATE BV/MIN	BED EXPANSION %	TEMPERATURE C
REGEN 1	RE REGEN	WASTE	10	251	2.50	25.1	.250	31.	28.7
REGEN 2	RE REGEN	SP REGEN	67	1589	15.8	23.6	.235	31.0	28.5
REGEN 3	FR REGEN	SP REGEN	23	541	5.38	24.0	.239	31.	28.7
DRAIN 1	(VENT)	WASTE	3	62	.62	20.7	.205	0.0	
RINSE	FEED	WASTE	10	129	1.28	12.9	.128	0.0	
SERVICE	FEED	PRODUCT	231	6889	68.5	29.8	.296	0.0	
DRAIN 2	(VENT)	WASTE	2	41	.42	20.7	.209	0.0	

D5—2

Fresh Regenerant Volume Balance

Run 4.02.00 Cycle no.	Date	Fresh regenerant volume (V_3) L	Fresh regenerant TDS mg/L	Service volume (V_S) L	Estimated ED feed TDS mg/L	R %	$V_3/(1-R)V_S$
18	9/13/79	387	33 090	6 334	3 300	91	0.71
19	9/14/79	400	33 090	6 134	3 300	91	0.75
20	9/14/79	402	33 090	6 064	3 300	91	0.76
21	9/14/79	399	33 090	6 017	3 300	91	0.76
22	9/14/79	401	33 090	5 782	3 300	91	0.80
23	9/15/79	400	33 090	5 472	3 300	91	0.84
24	9/15/79	401	33 090	5 821	3 300	91	0.79
25	9/15/79	522	33 090	5 483	3 300	91	1.09
26	9/16/79	540	33 420	6 191	3 300	91	1.02
27	9/16/79	540	33 420	6 508	3 300	91	0.96
28	9/16/79	600	33 420	6 848	3 300	91	1.02
29	9/16/79	600	33 420	6 581	3 300	91	1.06
30	9/17/79	602	33 030	6 748	3 300	92	1.03
31	9/17/79	602	33 030	6 776	3 300	92	0.92
32	9/17/79	541	33 030	6 553	3 300	92	0.95
33	9/18/79	541	33 690	6 852	3 300	92	0.93
34	9/18/79	540	33 690	6 791	3 300	92	0.94
36	9/18/79	541	33 690	6 347	3 300	92	1.00
37	9/19/79	541	33 710	6 426	3 300	92	0.99
39	9/19/79	542	33 710	6 432	3 300	92	0.99
40	9/19/79	542	33 710	6 417	3 300	92	0.99
41	9/19/79	541	33 710	6 658	3 300	92	0.96
42	9/20/79	541	33 960	6 889	3 300	92	0.93

Influent and Effluent Compositions during Cycle 4.02.42

	Units	Regen 1,2 influent	Regen 1 effluent	Regen 2 effluent	Regen 3 influent	Regen 3 effluent	Rinse & service influent	Rinse effluent	Service effluent
pH	Units	-	-	-	7.5	-	7.5	7.5	7.5
TDS (Σ ions)	mg/L	27 984	19 742	28 827	33 631	31 508	3 079	21 507	3 254
Conductivity @ 25 °C	µS/cm	-	-	-	4 222.8	-	495.1	2 920.1	518.9
E. F. (TDS/cond.)	-	-	-	-	8.0	-	6.2	7.4	6.3
Silica	mg/L	2.4	2.4	2.6	3.4	2.8	3.5	3.0	3.5
Calcium	mg/L	1 030	1 590	1 490	167	1 000	168	332	21.8
Magnesium	mg/L	602	600	738	254	484	46.4	194	31.0
Sodium	mg/L	8 230	4 660	7 730	11 500	9 530	841	7 070	1 100
Potassium	mg/L	57	36	53	83	60	7.4	44	11.8
Strontium	mg/L	25	25	31	3.6	25	2.1	5.0	0.4
Bicarbonate	mg/L	97.6	68.3	122.0	119.6	146.4	26.8	89.3	29.8
Carbonate	mg/L	ND	ND	ND	ND	ND	ND	ND	ND
Hydroxide	mg/L	ND	ND	ND	ND	ND	ND	ND	ND
Sulfate	mg/L	5 500	4 120	6 080	9 420	8 220	930	5 800	950
Chloride	mg/L	12 440	8 640	12 580	12 080	12 040	1 054	7 970	1 106
T-alkalinity as $CaCO_3$	mg/L	80.0	56.0	100.0	98.0	120.0	22.0	73.2	24.4
P-alkalinity as $CaCO_{33}$	mg/L	ND	ND	ND	ND	ND	ND	ND	ND
Σ Anions	meq/L	467.17	330.74	483.60	539.03	513.34	49.62	347.18	51.55
Σ Cations	meq/L	460.95	332.90	473.38	531.68	506.37	49.02	341.31	51.80
Control value	meq/L	+0.85	-0.41	+1.34	+0.87	+0.86	+0.68	+1.07	-0.28

Major Cation Concentrations of Samples Analyzed by Atomic Absorption

CYCLE 4.02.42

MODE	PROCESS STREAM	THROUGHPUT BV	CA MEQ/L	MG MEQ/L	TH MEQ/L	NA MEQ/L
REGEN 1	EFFLUENT	0.00	18.46	9.96	28.42	60.46
REGEN 1	EFFLUENT	1.25	110.28	64.12	174.39	224.88
REGEN 2	EFFLUENT	2.50	101.30	67.65	168.95	294.48
REGEN 2	INFLUENT	6.26	51.40	49.55	100.94	357.98
REGEN 2	EFFLUENT	10.25	58.88	49.38	108.26	334.49
REGEN 3	EFFLUENT	18.24	53.89	50.29	104.18	351.46
REGEN 3	INFLUENT	19.44	8.33	20.91	29.24	500.22
REGEN 3	EFFLUENT	19.44	56.39	42.55	98.94	388.86
REGEN 3	EFFLUENT	20.63	51.40	34.16	85.55	412.35
REGEN 3	EFFLUENT	21.83	46.41	28.48	74.88	434.97
REGEN 3	EFFLUENT	23.74	40.42	25.84	66.26	487.17
RINSE	EFFLUENT	0.00	24.45	25.76	50.21	456.72
RINSE	EFFLUENT	.64	23.45	19.51	42.96	388.43
RINSE	EFFLUENT	1.28	.52	.49	1.01	62.20
SERVICE	EFFLUENT	1.28	.47	.51	.98	61.33
SERVICE	INFLUENT	3.95	7.98	3.56	11.55	35.71
SERVICE	EFFLUENT	9.29	.26	.26	.52	47.85
SERVICE	EFFLUENT	17.29	.25	.28	.53	50.02
SERVICE	INFLUENT	31.52	8.33	3.93	12.26	36.36
SERVICE	EFFLUENT	33.00	.25	.33	.58	50.02
SERVICE	EFFLUENT	49.01	.60	2.13	2.73	46.98
SERVICE	EFFLUENT	57.01	1.30	4.63	5.93	40.45
SERVICE	EFFLUENT	65.02	2.15	5.76	7.91	38.67
SERVICE	INFLUENT	69.76	7.83	3.43	11.27	34.67
SERVICE	EFFLUENT	69.76	2.69	6.24	8.93	39.19

Service Performance Summary

CYCLE 4.02.42

	AVERAGE CONCENTRATIONS, MEQ/L INFLUENT	EFFLUENT	DIFFERENCE	REMOVAL %	RESIN CAPACITY EQ/L
CA	8.05	.71	7.34	91	.503
MG	3.64	1.85	1.79	49	.122
TH	11.69	2.56	9.13	78	.625
NA	35.58	47.34	-11.76		

FIGURE A- a
MAJOR CATION CONCENTRATIONS
OF IX REGENERATION EFFLUENT
CYCLE 4.02.42

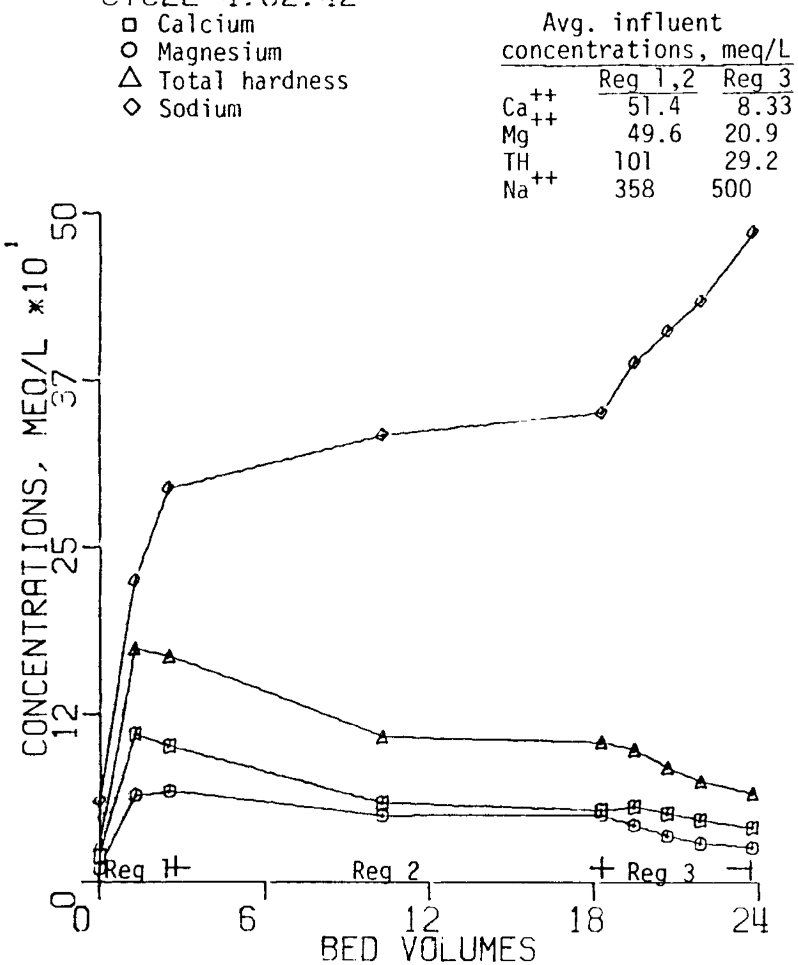
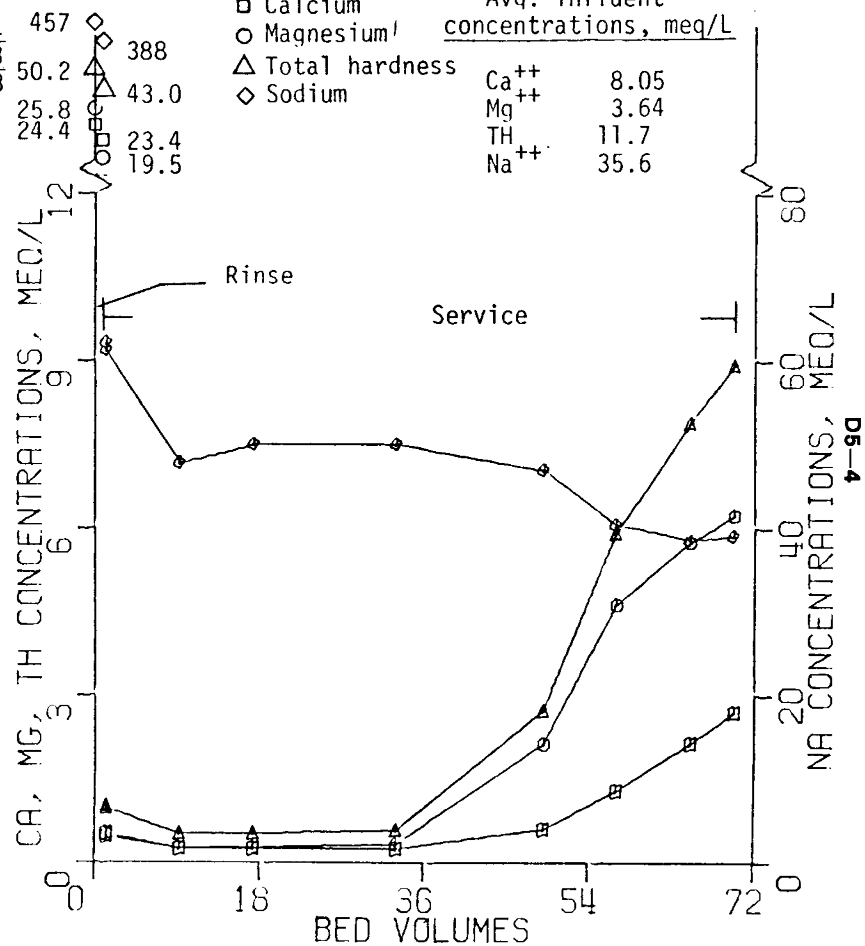


FIGURE A- b
MAJOR CATION CONCENTRATIONS OF
IX RINSE AND SERVICE EFFLUENTS
CYCLE 4.02.42



SODIUM (NA), CALCIUM (CA), AND MAGNESIUM (MG) CONCENTRATIONS ARE MEASURED BY ATOMIC ABSORPTION.
TOTAL HARDNESS (TH) IS CALCULATED BY SUMMING THE CALCIUM AND MAGNESIUM CONCENTRATIONS.

Ion-Exchange - Run 4.03.00B

Date: 9/22/79

Cycle: 4.03.13B

Conditions: Feedwater - Wellton-Mowhawk drainage pretreated (in Train IV) with high lime dosage for silica removal
Regenerant - fresh ED brine.
Source of backwash - IX feedwater.

Control variables:

	Target	Actual
Fresh regeneration conc. (mg/L TDS)	35 000	32 744
Fresh regeneration flow rate (L/min)	5.5	4.1
Recycled regenerant flow rate (L/min)	None	None
Recycled regenerant volume (L)	None	None
Service termination point (meq/L Ca^{++})	3.0	3.0

Standard resin bed: Height = 1102 mm
Volume = 100.6 L

Chemical Compositions of Tank Waters Prior to Cycle 4.03.13B

Tank	pH units	Conductivity uS/cm	Ca^{++} meq/L	Mg^{++} meq/L	TH meq/L
Recycle regenerant (T-5)	-	-	-	-	-
Spent regenerant (T-6)	-	-	-	-	-
Lime-softened feed (T-9)	7.5	4 973	8.6	3.6	12.2
Lime softened feed (T-10)	7.4	4 969	8.8	3.7	12.5
Fresh ED brine (T-28)	7.2	42 182	7.2	17.6	24.8
IX product/ED feed (T-33)	7.5	5 396	0.96	1.52	2.48

Cycle 4.03.13B Operating Conditions

MODE	INPUT	OUTPUT	DURATION MIN	THROUGHPUT L	VOLUME BV	AVG FLOW RATE L/MIN	AVG FLOW RATE BV/MIN	BED EXPANSION %	TEMPERATURE C
BACKWASH	FEED	WASTE	10	240	2.39	24.0	.239	27.	26.0
DRAIN 1	(VENT)	WASTE	3	62	.62	20.7	.205	0.0	
REGEN 3	FR REGEN	WASTE	59	318	3.16	5.39	.054	3.1	30.4
DRAIN 1	(VENT)	WASTE	3	62	.62	20.7	.205	0.0	
RINSE	FEED	WASTE	10	131	1.30	13.1	.130	0.0	
SERVICE	FEED	PRODUCT	110	3343	33.2	30.4	.302	0.0	
DRAIN 2	(VENT)	WASTE	2	41	.42	20.7	.209	0.0	

Fresh Regenerant Volume Balance

Run 4.03.00B Cycle no.	Date	Fresh regenerant volume (V_3) L	Fresh regenerant TDS mg/L	Service volume (V_s) L	Estimated ED feed TDS mg/L	R %	$V_3/(1-R)V_s$
01	9/20/79	463	33 960	5 874	3 300	92	0.94
02	9/20/79	453	33 960	5 158	3 300	92	1.05
03	9/20/79	450	33 960	4 531	3 300	92	1.18
04	9/21/79	449	32 570	4 414	3 300	91	1.16
09	9/22/79	-	33 480	4 079	3 300	91	-
10	9/22/79	-	33 480	3 752	3 300	91	-
11	9/22/79	319	33 480	3 345	3 300	91	1.11
12	9/22/79	319	33 480	3 35[illegible]	3 300	91	1.11
13	9/22/79	318	33 480	3 343	3 300	91	1.11

Influent and Effluent Compositions during Cycle 4.03.13B

	Units	Backwash effluent	Regeneration Influent	Regeneration Effluent	Rinse effluent	Service effluent
pH	units	-	7.3	-	7.7	7.3
TDS(Σ ions)	mg/L	3 735	32 744	22 350	20 993	3 468
Conductivity @ 25.°C	µS/cm	-	4 112.0	-	2844.2	548.3
E. F. (TDS/cond.)	-	-	8.0	-	7.4	6.3
Silica	mg/L	4.6	3.2	5.2	2.9	2.3
Calcium	mg/L	182	126	2 040	305	10.3
Magnesium	mg/L	55.8	209	616	145	17.2
Sodium	mg/L	1 080	11 300	4 790	6 990	1 210
Potassium	mg/L	12	84	39	50	5.8
Strontium	mg/L	2.0	5.0	39	4.3	0.4
Bicarbonate	mg/L	58.6	136.6	161.0	95.6	22.0
Carbonate	mg/L	ND	ND	ND	ND	ND
Hydroxide	mg/L	ND	ND	ND	ND	ND
Sulfate	mg/L	1 100	8 700	5 580	5 460	1 110
Chloride	mg/L	1 240	12 180	9 080	7 940	1 090
T-alkalinity as $CaCO_3$	mg/L	48.0	112.0	132.0	78.4	18.0
P-alkalinity as $CaCO_3$	mg/L	ND	ND	ND	ND	ND
Σ Anions	meq/L	58.93	527.13	375.09	339.36	54.30
Σ Cations	meq/L	61.00	517.29	362.72	332.59	54.72
Control value	meq/L	-2.04	+1.19	+2.09	+1.26	-0.44

Major Cation Concentrations of Samples Analyzed By Atomic Absorption

CYCLE 4.03.13B

MODE	PROCESS STREAM	THROUGHPUT BV	CA MEQ/L	MG MEQ/L	TH MEQ/L	NA MEQ/L
BACKWASH	EFFLUENT	0.00	10.68	5.23	15.91	51.33
BACKWASH	EFFLUENT	1.19	8.53	4.21	12.74	45.24
REGEN 3	EFFLUENT	2.39	7.63	4.11	11.74	40.89
REGEN 3	INFLUENT	2.39	6.29	17.20	23.49	491.52
REGEN 3	EFFLUENT	3.03	138.22	72.59	210.82	134.84
REGEN 3	EFFLUENT	3.67	161.18	75.80	236.98	242.71
REGEN 3	EFFLUENT	4.31	119.76	53.33	173.09	271.86
REGEN 3	EFFLUENT	5.55	95.81	45.10	140.91	309.26
RINSE	EFFLUENT	0.00	21.46	17.04	38.49	423.23
RINSE	EFFLUENT	.65	22.46	14.24	36.69	339.71
RINSE	EFFLUENT	1.30	4.09	2.84	6.93	134.41
SERVICE	EFFLUENT	1.30	1.29	2.30	3.59	128.32
SERVICE	INFLUENT	2.81	9.03	4.04	13.07	36.10
SERVICE	EFFLUENT	2.81	.51	.48	.99	61.77
SERVICE	EFFLUENT	4.32	.30	.29	.59	53.94
SERVICE	EFFLUENT	4.02	.28	.26	.54	55.24
SERVICE	EFFLUENT	7.34	.26	.24	.50	50.89
SERVICE	EFFLUENT	8.85	.30	.26	.55	50.46
SERVICE	EFFLUENT	10.37	.29	.26	.55	49.59
SERVICE	EFFLUENT	11.88	.31	.26	.58	48.72
SERVICE	EFFLUENT	13.39	.29	.29	.58	49.15
SERVICE	EFFLUENT	16.41	.33	.37	.70	48.72
SERVICE	INFLUENT	16.41	8.38	3.84	12.22	35.97
SERVICE	EFFLUENT	19.43	.37	.57	.94	48.72
SERVICE	EFFLUENT	22.45	.53	.86	1.39	46.98
SERVICE	EFFLUENT	25.47	.84	1.48	2.32	46.54
SERVICE	EFFLUENT	28.49	1.37	2.54	3.91	43.93
SERVICE	EFFLUENT	31.51	2.50	3.42	5.92	48.72
SERVICE	EFFLUENT	33.02	2.79	3.98	6.78	46.98
SERVICE	EFFLUENT	34.53	2.79	4.20	6.99	41.76

Service Performance Summary

CYCLE 4.03.13B

	AVERAGE CONCENTRATIONS, MEQ/L INFLUENT	EFFLUENT	DIFFERENCE	REMOVAL %	RESIN CAPACITY EQ/L
CA	8.71	.83	7.88	91	.262
MG	3.94	1.20	2.74	69	.091
TH	12.65	2.03	10.62	84	.353
NA	36.04	50.79	-14.75		

FIGURE A - a

MAJOR CATION CONCENTRATIONS OF IX REGENERATION EFFLUENT CYCLE 4.03.13B

□ Calcium
○ Magnesium
△ Total hardness
◇ Sodium

	Avg. influent concentrations, meq/L
	Reg.
Ca^{++}	6.29
Mg^{++}	17.2
TH	23.5
Na^{+}	492

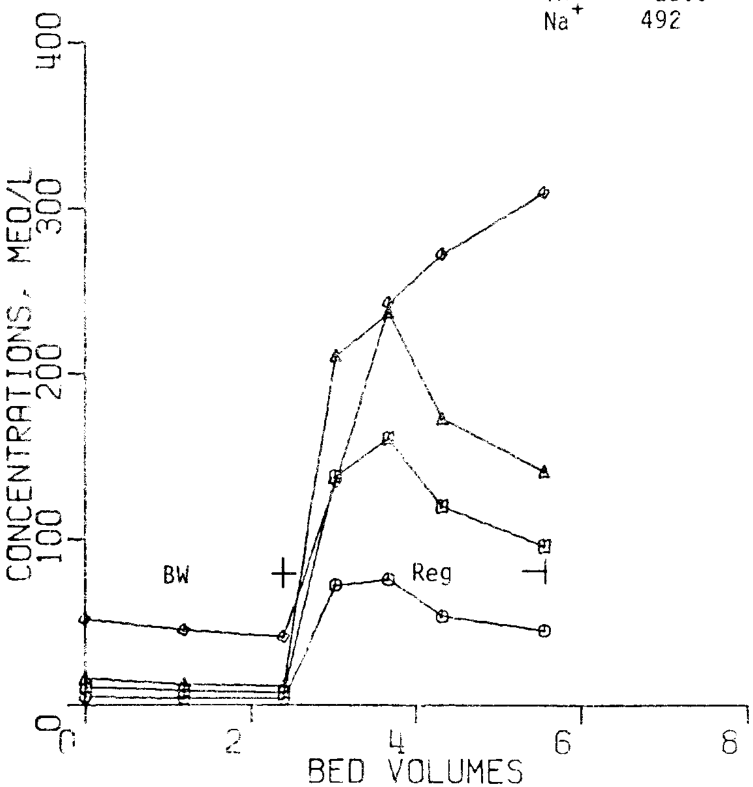
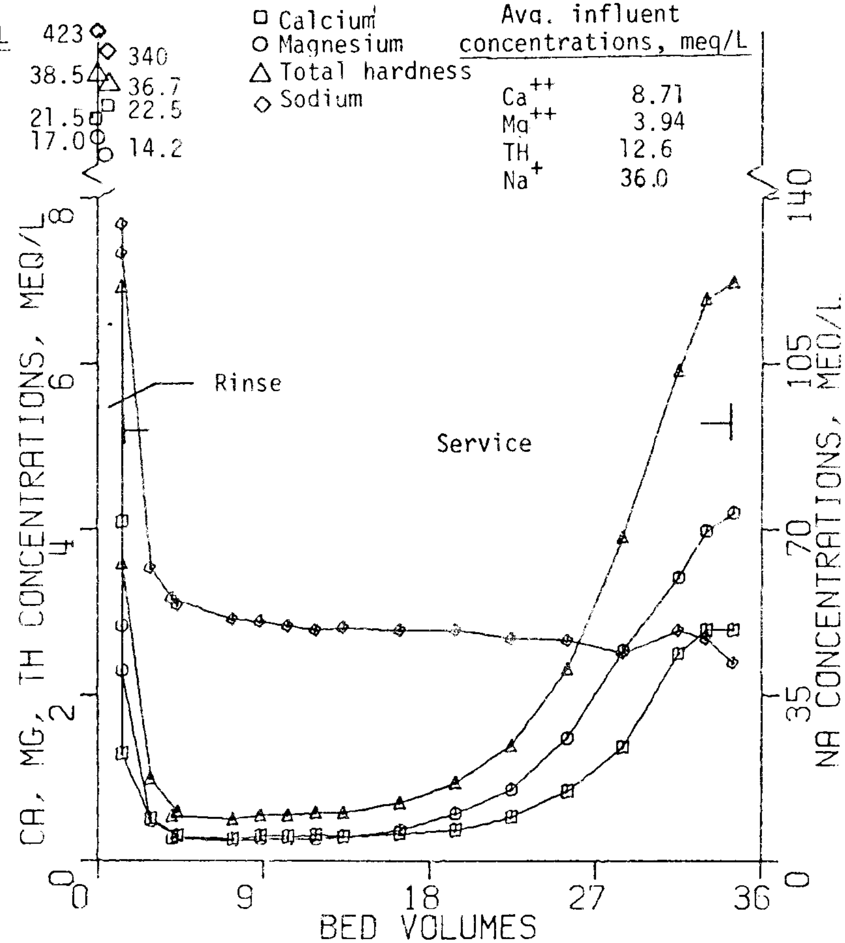


FIGURE A - b

MAJOR CATION CONCENTRATIONS OF IX RINSE AND SERVICE EFFLUENTS CYCLE 4.03.13B

□ Calcium
○ Magnesium
△ Total hardness
◇ Sodium

	Avg. influent concentrations, meq/L
Ca^{++}	8.71
Mg^{++}	3.94
TH	12.6
Na^{+}	36.0



SODIUM (NA), CALCIUM (CA), AND MAGNESIUM (MG) CONCENTRATIONS ARE MEASURED BY ATOMIC ABSORPTION. TOTAL HARDNESS (TH) IS CALCULATED BY SUMMING THE CALCIUM AND MAGNESIUM CONCENTRATIONS.

D6-4

Ion-Exchange - Run 4.04.00E

Date: 9/24/79

Cycle: 4.04.07E

Conditions: Feedwater - Wellton-Mowhawk drainage pretreated (in Train IV) with high lime dosage for silica removal
Regenerant - fresh ED brine plus 100 mg/L SHMP
Source of backwash - IX feedwater.

Control variables:

	Target	Actual
Fresh regeneration conc. (mg/L TDS)	35 000	32 816
Fresh regeneration flow rate (L/min)	5.5	5.6
Recycled regenerant flow rate (L/min)	None	None
Recycled regenerant volume (L)	None	None
Service termination point (meq/L Ca^{++})	3.0	2.5

Standard resin bed: Height =1102 mm
Volume =100.6 L

Chemical Compositions of Tank Waters Prior to Cycle 4.04.07E

Tank	pH units	Conductivity uS/cm	Ca^{++} meq/L	Mg^{++} meq/L	TH meq/L
Recycle regenerant (T-5)	-	-	-	-	-
Spent regenerant (T-6)	-	-	-	-	-
Lime-softened feed (T-9)	7.3	4 933	9.2	3.6	12.8
Lime softened feed (T-10)	7.4	4 939	8.4	4.2	12.6
Fresh ED brine (T-28)	7.0	41 763	7.6	17.6	25.2
IX product/ED feed (T-33)	7.5	5 313	0.72	1.44	2.16

Cycle 4.04.07E Operating Conditions

MODE	INPUT	OUTPUT	DURATION MIN	THROUGHPUT L	VOLUME BV	AVG FLOW RATE L/MIN	AVG FLOW RATE BV/MIN	BED EXPANSION %	TEMPERATURE C
BACKWASH	FEED	WASTE	10	240	2.39	24.0	.239	26.	26.5
DRAIN 1	(VENT)	WASTE	3	62	.62	20.7	.205	0.0	
REGEN 3	FR REGEN	WASTE	57	317	3.15	5.55	.055	1.5	29.2
DRAIN 1	(VENT)	WASTE	3	62	.62	20.7	.205	0.0	
RINSE	FEED	WASTE	10	130	1.29	13.0	.129	0.0	
SERVICE	FEED	PRODUCT	130	3876	38.5	29.8	.296	0.0	
DRAIN 2	(VENT)	WASTE	2	41	.42	20.7	.209	0.0	

Fresh Regenerant Volume Balance

Run 4.04.00E Cycle no.	Date	Fresh regenerant volume (V_3) L	Fresh regenerant TDS mg/L	Service volume (V_S) L	Estimated ED feed TDS mg/L	R %	$V_3/(1-R)V_S$
03	9/23/79	319	33 480	4 352	3 300	91	0.85
04	9/23/79	319	33 480	4 103	3 300	91	0.90
05	9/23/79	319	33 480	3 936	3 300	91	0.94
06	9/24/79	319	33 480	4 102	3 300	91	0.90
07	9/24/79	317	33 480	3 876	3 300	91	0.95

Influent and Effluent Compositions during Cycle 4.04.07E

	Units	Backwash effluent	Regeneration Influent	Regeneration Effluent	Rinse & service influent	Rinse effluent	Service effluent
pH	units	-	6.9	-	7.4	7.2	7.2
TDS(Σ ions)	mg/L	3 627	32 816	25 386	3 081	20 339	3 216
Conductivity @ 25 °C	µS/cm	-	4 120.0	-	489.3	2 820.2	531.8
E. F. (TDS/cond.)	-	-	8.0	-	6.3	7.2	6.1
Silica	mg/L	4.2	3.0	4.2	1.9	2.4	1.9
Calcium	mg/L	156	141	2 440	174	330	14.5
Magnesium	mg/L	53.2	159	675	39.0	135	13.0
Sodium	mg/L	1 030	11 400	5 460	838	6 535	1 120
Potassium	mg/L	5.0	87	34	8.1	47	10.0
Strontium	mg/L	<0.1	2.8	31	2.3	3.9	0.1
Bicarbonate	mg/L	58.6	103.4	122.0	19.5	75.6	21.0
Carbonate	mg/L	ND	ND	ND	ND	ND	ND
Hydroxide	mg/L	ND	ND	ND	ND	ND	ND
Sulfate	mg/L	1 100	9 100	6 720	910	5 610	960
Chloride	mg/L	1 220	11 820	9 900	1 088	7 600	1 076
T-alkalinity as $CaCO_3$	mg/L	48.0	84.8	100.0	16.0	62.0	17.2
P-alkalinity as $CaCO_3$	mg/L	ND	ND	ND	ND	ND	ND
Σ Anions	meq/L	57.32	524.69	421.3	49.96	332.5	50.69
Σ Cations	meq/L	57.09	518.30	416.4	48.60	313.1	50.77
Control value	meq/L	+0.23	+0.78	+0.74	+1.54	+3.68	-0.08

Major Cation Concentrations of Samples Analyzed by Atomic Absorption

CYCLE 4.04.07E

MODE	PROCESS STREAM	THROUGHPUT BV	CA MEQ/L	MG MEQ/L	TH MEQ/L	NA MEQ/L
BACKWASH	EFFLUENT	0.00	9.28	5.09	14.38	48.06
BACKWASH	EFFLUENT	1.19	7.73	3.99	11.73	40.41
REGEN 3	EFFLUENT	2.39	7.29	4.12	11.41	39.93
REGEN 3	INFLUENT	2.72	7.04	13.09	20.12	495.87
REGEN 3	EFFLUENT	3.10	174.65	102.88	277.53	186.39
REGEN 3	EFFLUENT	3.82	159.68	64.53	224.21	285.99
REGEN 3	EFFLUENT	4.54	134.23	44.77	179.01	312.74
REGEN 3	EFFLUENT	5.53	146.21	47.98	194.19	350.59
RINSE	EFFLUENT	0.00	24.45	17.12	41.57	434.97
RINSE	EFFLUENT	.65	27.45	18.19	45.63	361.03
RINSE	EFFLUENT	1.29	.55	.54	1.10	61.55
SERVICE	EFFLUENT	1.29	.57	.47	1.04	61.77
SERVICE	EFFLUENT	2.77	.29	.26	.56	48.93
SERVICE	INFLUENT	3.96	9.38	3.14	12.52	35.32
SERVICE	EFFLUENT	4.26	.27	.24	.51	50.46
SERVICE	EFFLUENT	5.74	.24	.26	.50	52.20
SERVICE	EFFLUENT	7.22	.25	.25	.50	53.50
SERVICE	EFFLUENT	8.70	.25	.25	.50	53.50
SERVICE	EFFLUENT	10.18	.25	.23	.48	53.72
SERVICE	EFFLUENT	11.67	.25	.23	.48	50.24
SERVICE	EFFLUENT	13.15	.25	.23	.48	49.80
SERVICE	EFFLUENT	16.11	.26	.27	.53	51.11
SERVICE	INFLUENT	16.11	8.93	3.13	12.06	35.89
SERVICE	EFFLUENT	19.07	.28	.35	.63	50.46
SERVICE	EFFLUENT	22.04	.30	.44	.74	49.59
SERVICE	EFFLUENT	25.00	.40	.58	.98	48.50
SERVICE	EFFLUENT	27.97	.56	.99	1.55	49.15
SERVICE	EFFLUENT	30.93	.85	1.73	2.58	48.06
SERVICE	EFFLUENT	33.89	1.44	2.85	4.29	45.67
SERVICE	EFFLUENT	36.86	1.70	3.60	5.29	43.50
SERVICE	EFFLUENT	38.34	2.45	3.95	6.40	43.06
SERVICE	INFLUENT	39.82	8.68	2.64	11.32	35.71
SERVICE	EFFLUENT	39.82	2.54	4.28	6.82	45.45

Service Performance Summary

CYCLE 4.04.07E

	AVERAGE CONCENTRATIONS, MEQ/L			REMOVAL	RESIN CAPACITY
	INFLUENT	EFFLUENT	DIFFERENCE	%	EQ/L
CA	9.00	.65	8.35	93	.322
MG	2.97	1.08	1.88	63	.073
TH	11.97	1.74	10.23	85	.394
NA	35.64	49.39	-13.76		

FIGURE A-a
MAJOR CATION CONCENTRATIONS
OF IX REGENERATION EFFLUENT
CYCLE 4.04.07E

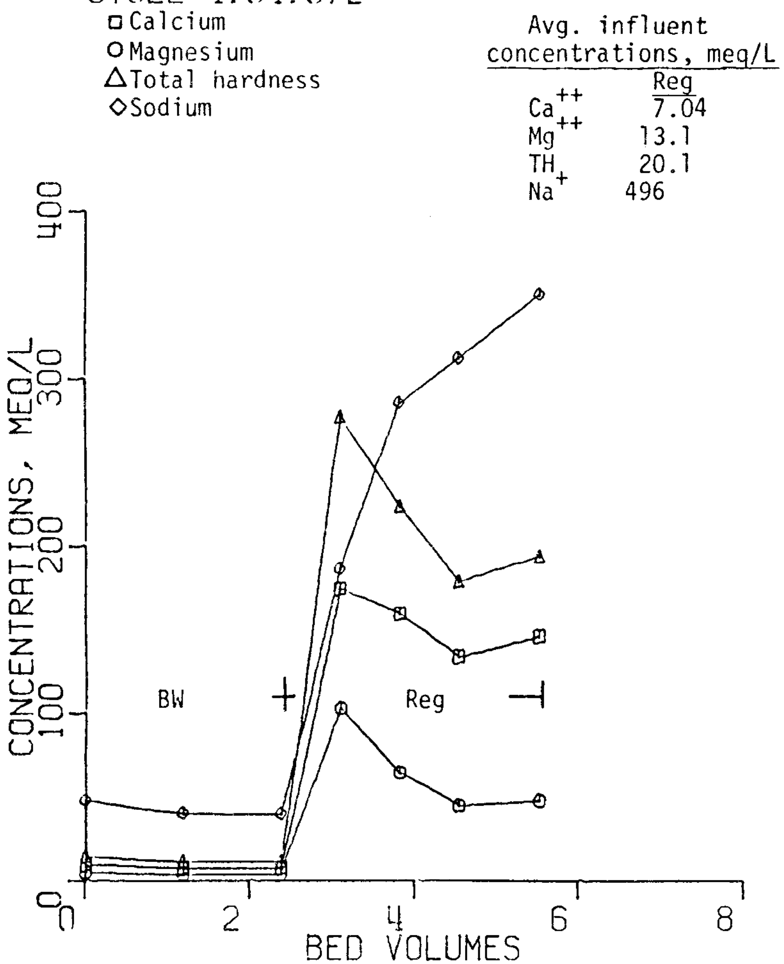
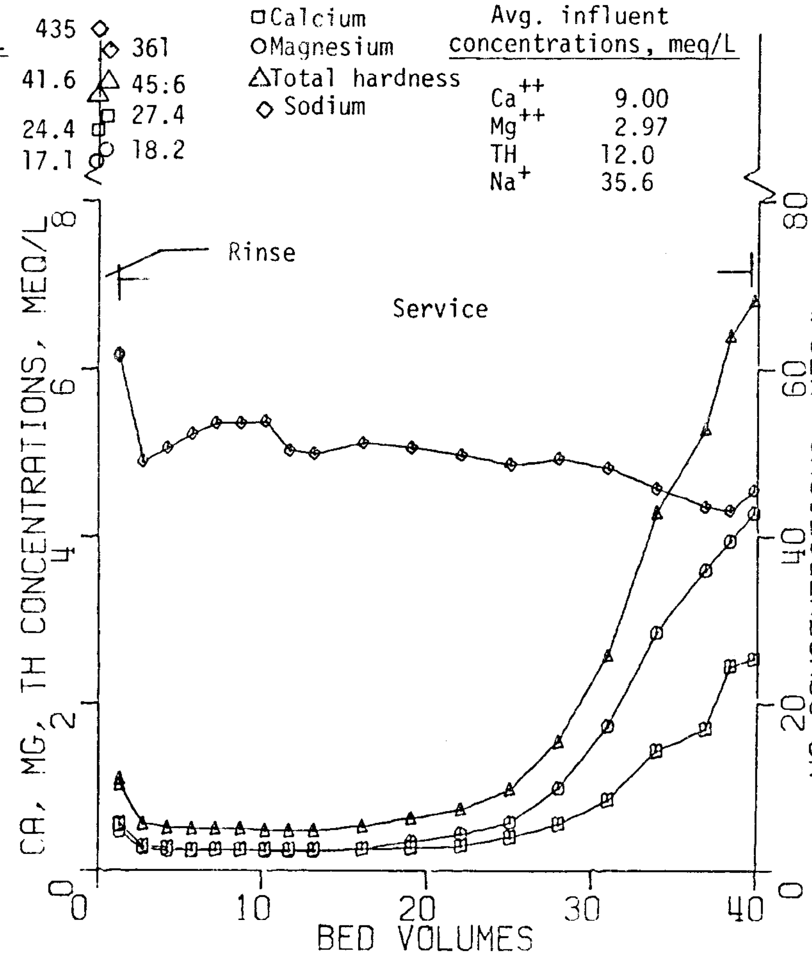


FIGURE A-b
MAJOR CATION CONCENTRATIONS OF
IX RINSE AND SERVICE EFFLUENTS
CYCLE 4.04.07E



SODIUM (NA), CALCIUM (CA), AND MAGNESIUM (MG) CONCENTRATIONS ARE MEASURED BY ATOMIC ABSORPTION.
TOTAL HARDNESS (TH) IS CALCULATED BY SUMMING THE CALCIUM AND MAGNESIUM CONCENTRATIONS.

Ion-Exchange - Run 4.05.00B

Date: 9/25/79

Cycle: 4.05.09B

Conditions: Feedwater - Wellton-Mowhawk drainage pretreated (in Train IV) with high lime dosage for silica removal
Regenerant - fresh ED brine.
Source of backwash - IX feedwater.
Air mix during backwash

Control variables:

	Target	Actual
Fresh regeneration conc. (mg/L TDS)	35 000	32 104
Fresh regeneration flow rate (L/min)	5.5	5.7
Recycled regenerant flow rate (L/min)	None	None
Recycled regenerant volume (L)	None	None
Service termination point (meq/L Ca^{++})	3.0	3.3

Standard resin bed: Height = 1102 mm
Volume = 100.6 L

Chemical Compositions of Tank Waters Prior to Cycle 4.05.09B

Tank	pH units	Conductivity uS/cm	Ca^{++} meq/L	Mg^{++} meq/L	TH meq/L
Recycle regenerant (T-5)	-	36 772	46.0	47.0	93.0
Spent regenerant (T-6)	-	37 808	48.0	52.0	100.0
Lime-softened feed (T-9)	7.4	4 981	9.8	2.8	12.6
Lime softened feed (T-10)	7.5	4 933	9.4	3.2	12.6
Fresh ED brine (T-28)	7.0	42 049	8.4	17.2	25.6
IX product/ED feed (T-33)	7.4	5 300	0.72	0.88	1 6

Cycle 4.05.09B Operating Conditions

MODE	INPUT	OUTPUT	DURATION MIN	THROUGHPUT L	VOLUME BV	AVG FLOW RATE L/MIN	AVG FLOW RATE BV/MIN	BED EXPANSION %	TEMPERATURE C
BACKWASH	FEED	WASTE	10	240	2.39	24.0	.239	65.	28.5
DRAIN 1	(VENT)	WASTE	3	62	.62	20.7	.205	0.0	
REGEN 3	FR REGEN	WASTE	42	240	2.39	5.66	.056	0.0	33.3
DRAIN 1	(VENT)	WASTE	3	62	.62	20.7	.205	0.0	
RINSE	FEED	WASTE	10	134	1.33	13.4	.133	0.0	
SERVICE	FEED	PRODUCT	82	2521	25.1	30.7	.306	0.0	
DRAIN 2	(VENT)	WASTE	2	41	.42	20.7	.209	0.0	

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Fresh Regenerant Volume Balance

Run 4.05.00B Cycle no.	Date	Fresh regenerant volume (V_3) L	Fresh regenerant TDS mg/L	Service volume (V_S) L	Estimated ED feed TDS mg/L	R %	$V_3/(1-R)V_S$
01	9/24/79	318	33 200	3 792	3 300	91	0.97
02	9/24/79	318	33 200	3 579	3 300	91	1.03
03	9/24/79	320	33 200	3 301	3 300	91	1.13
04	9/25/79	320	33 940	3 122	3 300	92	1.22
05	9/25/79	320	33 940	3 234	3 300	92	1.18
06	9/25/79	243	33 940	2 429	3 300	92	1.19
07	9/25/79	238	33 940	2 431	3 300	92	1.17
08	9/25/79	240	33 940	2 368	3 300	92	1.21
09	9/25/79	240	33 940	2 521	3 300	92	1.13

Influent and Effluent Compositions during Cycle 4.05.09B

	Units	Backwash effluent	Regeneration Influent	Regeneration Effluent	Rinse & service influent	Rinse effluent	Service effluent
pH	Units	-	7.0	-	7.3	7.2	7.3
TDS (Σ ions)	mg/L	3 506	32 104	21 015	2 986	20 309	3 400
Conductivity @ 25.°C	µS/cm	-	4 160.3	-	481.6	2 839.2	530.2
E. F. (TDS/cond.)	-	-	7.7	-	6.2	7.2	6.4
Silica	mg/L	3.0	2.6	3.2	2.1	2.3	1.9
Calcium	mg/L	160	163	2 260	169	420	26.8
Magnesium	mg/L	45.3	202	514	42.8	145	16.6
Sodium	mg/L	1 000	11 200	4 330	825	6 700	1 170
Potassium	mg/L	4.0	93	41	8.4	57	10.6
Strontium	mg/L	<0.1	3.2	30	2.2	4.5	0.5
Bicarbonate	mg/L	48.8	80.5	117.1	19.5	60.0	19.5
Carbonate	mg/L	ND	ND	ND	ND	ND	ND
Hydroxide	mg/L	ND	ND	ND	ND	ND	ND
Sulfate	mg/L	1 060	8 600	5 300	902	5 100	1 070
Chloride	mg/L	1 185	11 760	8 420	1 015	7 820	1 084
T-alkalinity as $CaCO_3$	mg/L	40.0	66.0	96.0	16.0	49.2	16.0
P-alkalinity as $CaCO_3$	mg/L	ND	ND	ND	ND	ND	ND
Σ Anions	meq/L	56.38	512.21	349.42	47.81	327.89	53.26
Σ Cations	meq/L	55.31	514.40	345.14	48.11	325.92	53.88
Control value	meq/L	+1.09	-0.27	+0.77	-0.35	+0.38	-0.67

Major Cation Concentrations of Samples Analyzed by Atomic Absorption

CYCLE 4.05.09B

MODE	PROCESS STREAM	THROUGHPUT BV	CA MEQ/L	MG MEQ/L	TH MEQ/L	NA MEQ/L
BACKWASH	EFFLUENT	0.00	8.58	3.75	12.34	51.76
BACKWASH	EFFLUENT	1.19	7.68	3.60	11.28	43.06
REGEN 3	EFFLUENT	2.39	7.63	3.56	11.19	43.50
REGEN 3	INFLUENT	2.67	8.13	16.63	24.76	487.17
REGEN 3	EFFLUENT	2.84	93.31	44.28	137.59	130.49
REGEN 3	EFFLUENT	3.35	159.68	63.62	223.30	238.80
REGEN 3	EFFLUENT	3.80	159.68	54.24	213.92	263.16
REGEN 3	EFFLUENT	4.77	143.21	47.08	190.29	264.46
RINSE	EFFLUENT	0.00	26.95	16.87	43.82	420.18
RINSE	EFFLUENT	.67	32.93	20.99	53.92	343.63
RINSE	EFFLUENT	1.33	3.44	2.09	5.53	111.79
SERVICE	EFFLUENT	1.33	3.34	1.94	5.29	114.83
SERVICE	EFFLUENT	2.86	.71	.50	1.21	56.98
SERVICE	INFLUENT	4.08	8.88	3.43	12.31	35.84
SERVICE	EFFLUENT	4.39	.53	.36	.89	53.07
SERVICE	EFFLUENT	5.92	.47	.36	.83	50.89
SERVICE	EFFLUENT	7.44	.48	.36	.84	49.59
SERVICE	EFFLUENT	8.97	.47	.40	.88	50.46
SERVICE	EFFLUENT	10.50	.50	.43	.93	48.72
SERVICE	EFFLUENT	12.03	.54	.49	1.03	46.54
SERVICE	INFLUENT	12.03	8.18	3.51	11.70	39.80
SERVICE	EFFLUENT	13.56	.61	.61	1.22	52.63
SERVICE	EFFLUENT	15.08	.71	.74	1.45	53.50
SERVICE	EFFLUENT	16.61	.83	.95	1.77	52.63
SERVICE	EFFLUENT	18.14	1.01	1.25	2.26	50.89
SERVICE	EFFLUENT	19.67	1.32	1.70	3.02	50.89
SERVICE	EFFLUENT	21.20	1.65	2.11	3.75	51.33
SERVICE	EFFLUENT	22.72	2.05	2.64	4.69	50.02
SERVICE	EFFLUENT	24.25	2.50	3.08	5.57	43.93
SERVICE	EFFLUENT	25.78	3.14	3.43	6.58	46.54
SERVICE	INFLUENT	26.39	8.73	3.60	12.33	35.23
SERVICE	EFFLUENT	26.39	3.34	3.62	6.96	39.80

Service Performance Summary

CYCLE 4.05.09B

	AVERAGE CONCENTRATIONS, MEQ/L INFLUENT	EFFLUENT	DIFFERENCE	REMOVAL %	RESIN CAPACITY EQ/L
CA	8.60	1.15	7.45	87	.187
MG	3.51	1.22	2.29	65	.057
TH	12.11	2.38	9.74	80	.244
NA	36.96	52.44	-15.48		

FIGURE A- a
MAJCR CATION CONCENTRATIONS
OF IX REGENERATION EFFLUENT
CYCLE 4.05.09B

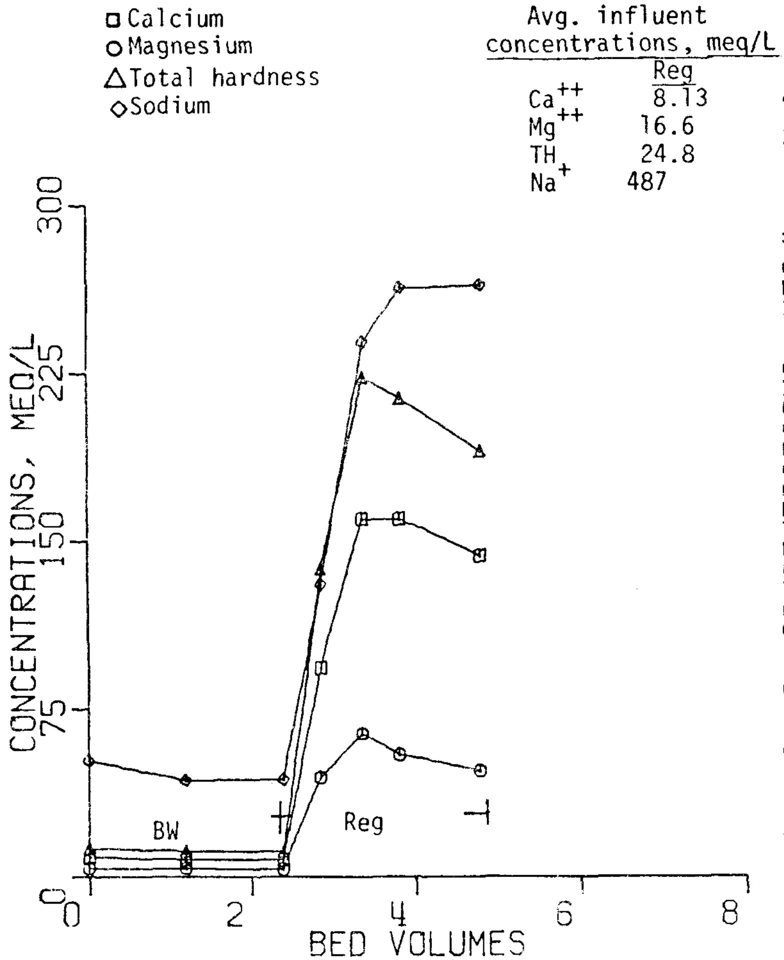
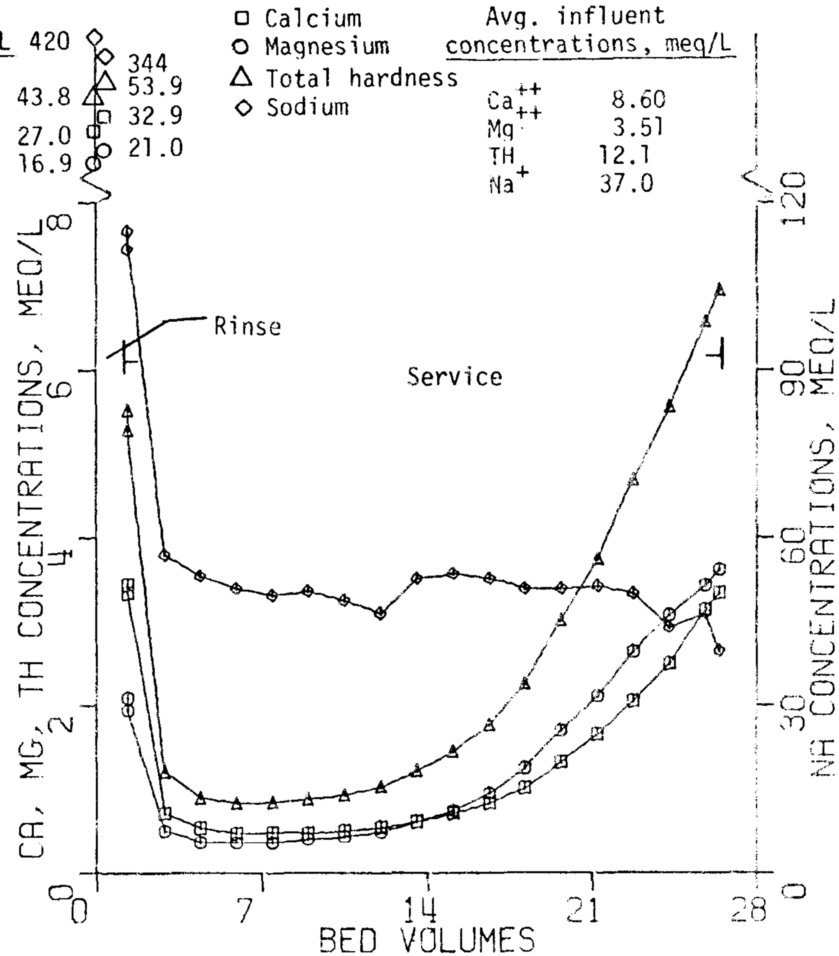


FIGURE A- b
MAJOR CATION CONCENTRATIONS OF
IX RINSE AND SERVICE EFFLUENTS
CYCLE 4.05.09B



SODIUM (NA), CALCIUM (CA), AND MAGNESIUM (MG) CONCENTRATIONS ARE MEASURED BY ATOMIC ABSORPTION.
TOTAL HARDNESS (TH) IS CALCULATED BY SUMMING THE CALCIUM AND MAGNESIUM CONCENTRATIONS.

Ion-Exchange - Run 4.06.00F

Date: 9/27/79

Cycle: 4.06.07F

Conditions: · Feedwater - Wellton-Mowhawk drainage pretreated (in Train IV) with high lime dosage for silica removal
Regenerants - recycled regenerant and fresh ED brine
100 mg/L of SHMP added to fresh regenerant passing into recycled regenerant

Control variables:

	Target	Actual
Fresh regeneration conc. (mg/L TDS)	35 000	29 730
Fresh regeneration flow rate (L/min)	5.5	5.6
Recycled regenerant flow rate (L/min)	16.0	15.6
Recycled regenerant volume (L)	800	804
Service termination point (meq/L Ca^{++})	3.0	2.8

Standard resin bed: Height =1102 mm
Volume =100.6 L

Chemical Compositions of Tank Waters Prior to Cycle 4.06.07F

Tank	pH units	Conductivity uS/cm	Ca^{++} meq/L	Mg^{++} meq/L	TH meq/L
Recycle regenerant (T-5)	-	37 847	84.0	45.0	129.0
Spent regenerant (T-6)	-	37 710	95.0	36.0	131.0
Lime-softened feed (T-9)	7.4	4 801	9.1	3.6	12.7
Lime softened feed (T-10)	7.4	4 864	9.1	3.5	12.6
Fresh ED brine (T-28)	6.8	41 911	7.6	14.4	22.0
IX product/ED feed (T-33)	7.2	5 010	0.52	1.40	1.92

Cycle 4.06.07F Operating Conditions

MODE	INPUT	OUTPUT	DURATION MIN	THROUGHPUT L	VOLUME BV	AVG FLOW RATE L/MIN	AVG FLOW RATE BV/MIN	BED EXPANSION %	TEMPERATURE C
REGEN 1	RE REGEN	WASTE	10	236	2.35	23.6	.235	30.	28.2
REGEN 2	RE REGEN	SP REGEN	51	804	7.99	15.9	.158	15.	29.0
REGEN 3	FR REGEN	SP REGEN	93	519	5.16	5.60	.056	1.6	30.0
DRAIN 1	(VENT)	WASTE	3	62	.62	20.7	.205	0.0	
RINSE	FEED	WASTE	10	131	1.30	13.1	.130	0.0	
SERVICE	FEED	PRODUCT	210	6386	63.5	30.4	.302	0.0	
DRAIN 2	(VENT)	WASTE	2	41	.42	20.7	.209	0.0	

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Fresh Regenerant Volume Balance

Run 4.06.00F Cycle no.	Date	Fresh regenerant volume (V_3) L	Fresh regenerant TDS mg/L	Service volume (V_S) L	Estimated ED feed TDS mg/L	R %	$V_3/(1-R)V_S$
01	9/25/79	741	33 940	7 268	3 300	92	1.21
02	9/26/79	738	33 620	7 321	3 300	92	1.19
04	9/26/79	519	33 620	6 341	3 300	92	0.96
05	9/26/79	520	33 620	6 261	3 300	92	0.98
06	9/27/79	519	33 500	6 356	3 300	91	0.95
07	9/27/79	519	33 500	6 386	3 300	91	0.95

Influent and Effluent Compositions during Cycle 4.06.07F

	Units	Regen 1,2 influent	Regen 1 effluent	Regen 2 effluent	Regen 3 Influent	Regen 3 Effluent	Rinse & service influent	Rinse effluent	Service effluent
pH	units	-	-	-	6.6	-	7.2	6.7	7.0
TDS(Σ ions)	mg/L	29 730	20 908	29 838	33 133	31 525	3 106	21 427	3 182
Conductivity @ 25 °C	μS/cm	-	-	-	4 299.4	-	497.9	2 998.4	517.4
E. F. (TDS/cond.)	-	-	-	-	7.7	-	6.2	7.1	6.1
Silica	mg/L	2.4	2.2	1.8	2.6	2.6	1.7	2.3	1.6
Calcium	mg/L	1 660	1 980	2 120	145	1 770	167	224	10.6
Magnesium	mg/L	631	565	664	180	387	40.3	97.6	13.0
Sodium	mg/L	7 970	4 590	7 530	11 500	8 850	852	7 400	1 100
Potassium	mg/L	49	31	46	96	44	7.0	56	9.2
Strontium	mg/L	29	28	34	3.5	29	2.3	3.6	0.4
Bicarbonate	mg/L	248.9	112.2	122.0	65.9	122.0	18.0	53.7	19.5
Carbonate	mg/L	ND	ND	ND	ND	ND	ND	ND	ND
Hydroxide	mg/L	ND	ND	ND	ND	ND	ND	ND	ND
Sulfate	mg/L	7 160	5 100	7 100	9 100	8 220	920	5 700	940
Chloride	mg/L	11 980	8 500	12 220	12 040	12 100	1 098	7 890	1 088
T-alkalinity as $CaCO_3$	mg/L	204.0	92.0	100.0	54.0	100.0	14.8	44.0	16.0
P-alkalinity as $CaCO_3$	mg/L	ND	ND	ND	ND	ND	ND	ND	ND
Σ Anions	meq/L	491.25	347.93	494.69	530.35	514.63	50.50	342.26	50.66
Σ Cations	meq/L	483.37	346.38	489.92	524.83	506.92	48.94	342.62	49.69
Control value	meq/L	+1.02	+0.28	+0.61	+0.66	+0.95	+1.76	-0.07	+1.09

Major Cation Concentrations of Samples Analyzed by Atomic Absorption

CYCLE 4.06.07F

MODE	PROCESS STREAM	THROUGHPUT BV	CA MEQ/L	MG MEQ/L	TH MEQ/L	NA MEQ/L
REGEN 1	EFFLUENT	0.00	32.93	15.64	48.57	88.30
REGEN 1	EFFLUENT	1.17	124.75	61.23	185.99	227.93
REGEN 2	EFFLUENT	2.35	129.24	58.35	187.60	280.99
REGEN 2	INFLUENT	4.40	82.83	51.93	134.77	346.67
REGEN 2	EFFLUENT	6.29	101.30	54.07	155.37	347.54
REGEN 3	EFFLUENT	10.39	86.33	49.79	136.12	347.54
REGEN 3	INFLUENT	10.94	7.24	14.81	22.05	500.22
REGEN 3	EFFLUENT	11.72	96.81	43.79	140.59	371.90
REGEN 3	EFFLUENT	12.61	90.82	31.36	122.18	383.21
REGEN 3	EFFLUENT	13.73	74.35	21.32	95.67	407.57
REGEN 3	EFFLUENT	15.56	68.86	18.02	86.89	417.57
RINSE	EFFLUENT	0.00	16.52	12.02	28.53	504.57
RINSE	EFFLUENT	.65	17.02	12.10	29.11	434.97
RINSE	EFFLUENT	1.30	.30	.30	.60	63.51
SERVICE	EFFLUENT	1.30	.29	.28	.57	62.64
SERVICE	EFFLUENT	2.81	.14	.13	.28	50.02
SERVICE	INFLUENT	4.02	8.73	3.60	12.34	36.19
SERVICE	EFFLUENT	4.33	.13	.12	.25	49.59
SERVICE	EFFLUENT	5.84	.10	.12	.22	50.02
SERVICE	EFFLUENT	7.35	.11	.12	.23	50.02
SERVICE	EFFLUENT	8.86	.14	.12	.25	48.72
SERVICE	EFFLUENT	10.37	.11	.12	.23	47.85
SERVICE	EFFLUENT	17.02	.11	.12	.23	50.02
SERVICE	INFLUENT	31.23	8.63	3.60	12.24	36.41
SERVICE	EFFLUENT	32.74	.12	.17	.29	49.59
SERVICE	EFFLUENT	48.46	.41	1.50	1.91	45.24
SERVICE	EFFLUENT	56.32	1.30	3.61	4.92	43.06
SERVICE	EFFLUENT	64.18	2.59	4.83	7.43	40.89
SERVICE	INFLUENT	64.78	8.43	2.87	11.31	35.97
SERVICE	EFFLUENT	64.78	2.79	4.35	7.14	40.89

Service Performance Summary

CYCLE 4.06.07F

	AVERAGE CONCENTRATIONS, MEQ/L			REMOVAL	RESIN CAPACITY
	INFLUENT	EFFLUENT	DIFFERENCE	%	EQ/L
CA	8.60	.50	8.10	94	.514
MG	3.36	1.16	2.20	66	.140
TH	11.96	1.66	10.31	86	.654
NA	36.19	47.48	-11.29		

FIGURE A- a
MAJOR CATION CONCENTRATIONS
OF IX REGENERATION EFFLUENT
CYCLE 4.06.07F

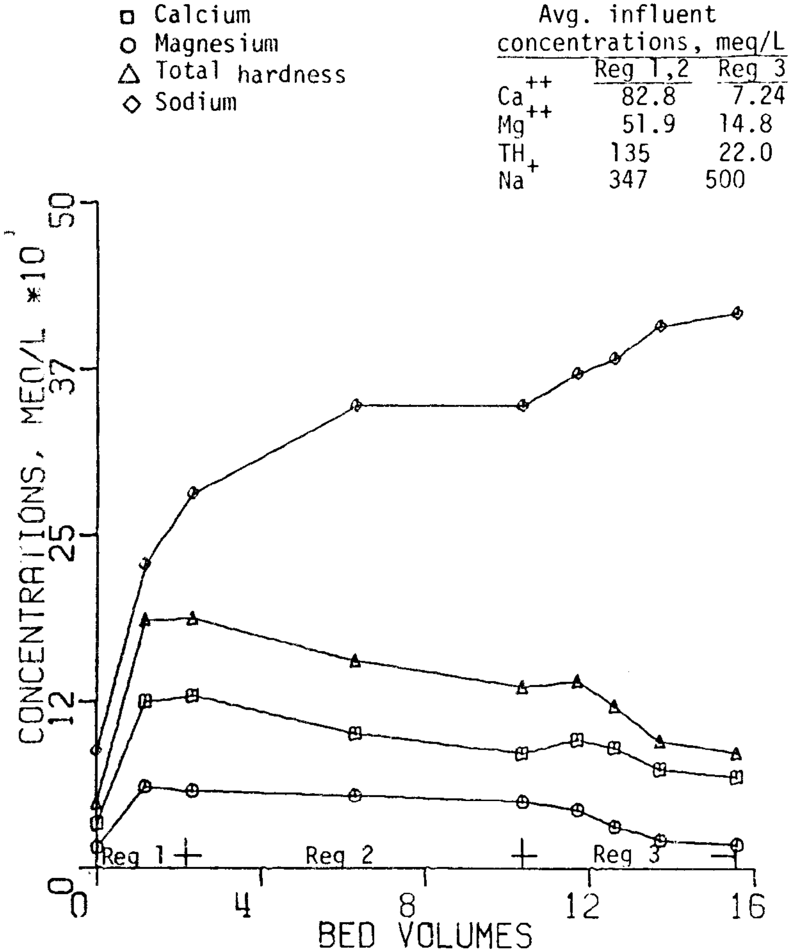
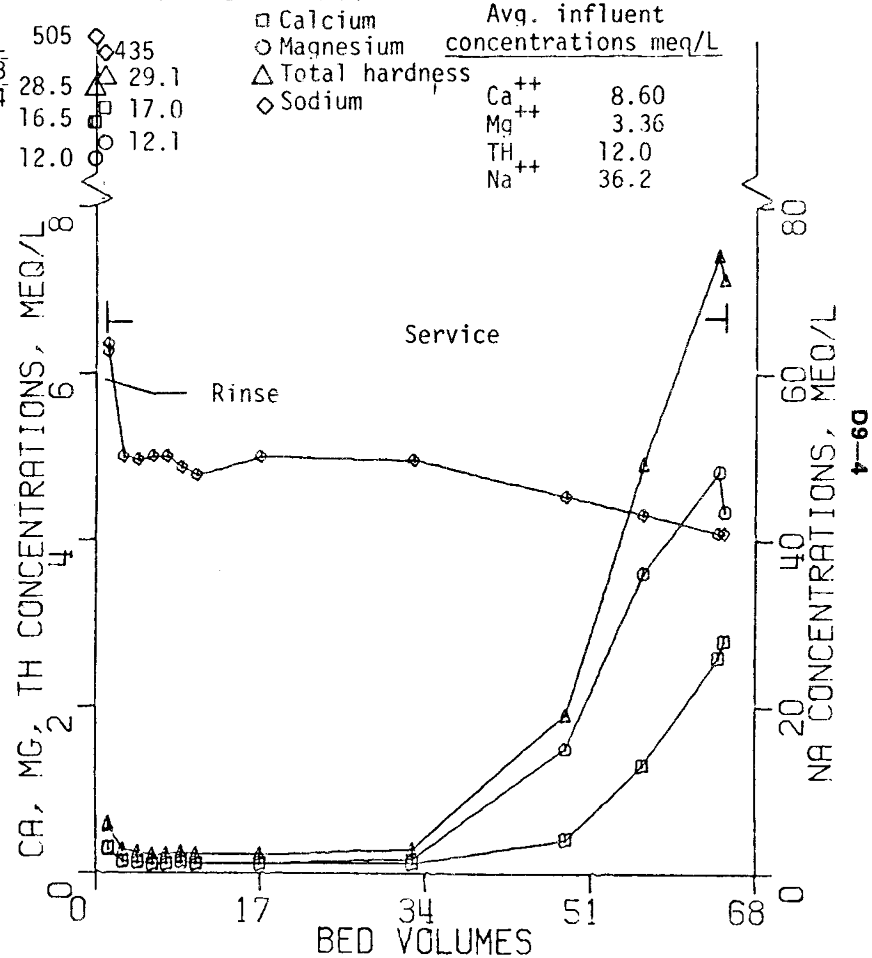


FIGURE A- b
MAJOR CATION CONCENTRATIONS OF
IX RINSE AND SERVICE EFFLUENTS
CYCLE 4.06.07F



SODIUM (NA), CALCIUM (CA), AND MAGNESIUM (MG) CONCENTRATIONS ARE MEASURED BY ATOMIC ABSORPTION.
TOTAL HARDNESS (TH) IS CALCULATED BY SUMMING THE CALCIUM AND MAGNESIUM CONCENTRATIONS.

Table E-1. — *Ionics Aquamite V electrodialysis unit performance — 1979*

	March			April		May			June				July		August		September		
	12	19	26	23	30	7	14	29	4	11	18	25	3	6	13	20	4	17	24
Operating time, hour	7357.1	7444.4	7550.3	7786.9	7825.0	7902.8	7996.6	8169.8	8219.3	8289.7	8376.8	8456.1	8526.0	8842.7	8912.0	8961.0	9141.3	9316.5	9416.0
Brine concentration, g/m³	33 945	32 583	ND	52 438	52 760	51 680	50 503	56 777	33 361	36 465	19 406	20 470	22 263	31 208	34 033	32 322	33 110	33 098	33 491
Feed temperature, °C	21.5	21.0	22.0	26.0	26.0	25.0	27.0	28.0	29.5	31.0	27.0	31.0	30.0	31.0	29.0	28.0	30.2	28.2	29.5
Dilute flow rate, L/min	34	34	34	34	34	34	34	34	34	34	34	34	34	34	34	34	34	34	34
Brine makeup flow rate, L/min	1.3	1.2	0	0	0	0	0.35	0.15	1.35	1.0	4.4	4.5	3.5	1.2	1.0	0.98	1.1	1.2	1.1
Product flow rate, L/min	32.4	32.19	31.83	32.4	32.6	32.7	33.0	32.9	33.0	32.7	32.0	32.8	32.6	31.7	32.5	32.2	33.0	32.6	32.4
Brine flow rate, L/min	2.83	2.87	1.16	1.44	1.64	1.65	1.40	1.80	3.2	2.36	5.88	7.40	5.0	2.7	2.8	2.5	2.6	2.6	2.8
Brine pH, units	5.77	4.3	3.8	3.88	4.27	4.54	4.36	4.01	5.24	5.95	6.45	5.85	5.85	6.11	6.17	6.80	6.88	6.72	6.67
Electrical stage 1																			
Current, amperes	22.0	20.8	23.4	24.1	24.1	23.6	24.8	26.5	24.0	24.1	21.6	21.8	22.7	24.1	21.3	20.4	21.6	21.0	20.7
Voltage, volts	155	153	153	157	154	153	156	156	154	154	155	153	155	155	152	153	154	154	155
Specific cell pair resistance, Ω-cm²	80.7	83.4	75.7	82.0	80.4	79.9	81.0	77.5	87.5	90.3	92.4	99.2	94.2	90.9	96.1	98.7	98.9	97.0	102.1
Electrical stage 2																			
Current, amperes	8.6	8.2	9.7	9.6	9.6	9.6	10.6	10.5	8.6	8.6	7.4	7.3	7.7	9.7	8.2	7.8	8.4	8.2	8.2
Voltage, volts	123	122	122	125	122	122	124	124	123	123	124	122	124	124	123	122	124	124	124
Specific cell pair resistance, Ω-cm²	163.3	168.2	145.1	163.4	159.4	156.0	150.1	155.0	194.4	201.5	215.0	235.5	221.5	180.2	201.5	205.2	204.0	199.4	205.5
Feed cationic concentration, meq/L	53.4	55.0	ND	50.3	55.0	51.2	52.9	52.1	55.3	54.9	55.1	55.6	56.2	54.5	52.4	47.37	50.9	52.0	51.83
Product cationic concentration, meq/L	6.68	7.55	ND	7.89	7.54	7.10	6.72	8.65	6.06	6.89	6.25	6.80	5.81	5.92	8.19	6.29	7.08	7.40	7.19
Current efficiency, %	66.8	71.6	--	54.5	72.9	61.3	57.1	51.4	66.1	64.2	73.7	73.4	72.5	62.9	65.6	63.7	63.9	66.8	67.6

Table E-2. *Chemical analysis — Ionics Aquamite V electrodialysis — 1979*

Sample stream	March 12			March 19			March 26		
	Feed	Product	Brine	Feed	Product	Brine	Feed	Product	Brine
pH units	7.0	6.4	5.8	6.9	6.0	5.8	7.3	5.2	3.8
TDS, g/m^3	3418	502	33 945	3483	517	32 583			
Conductivity at 25 °C, $\mu S/cm$	5802	810	45 644	5824	866	43 505	5938	921	63 583
E. F.	0.59	0.62	0.74	0.60	0.60	0.75			
Silica, g/m^3	12.2	5.8	5.5	10.7	10.4	10.0	7.0	7.1	8.0
Calcium, g/m^3	12.7	1.3	154	6.1	1.6	86	3.2	1.7	75
Magnesium, g/m^3	30.6	2.8	350	20.5	2.3	203	7.0	1.6	257
Sodium, g/m^3	1148	146	11 430	1215	167	11 580			
Potassium, g/m^3	12.1	1.2	135	6.8	0.8	59			
Total iron, g/m^3	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10			
Total manganese, g/m^3	<0.30	<0.30	<0.30	<0.30	<0.30	<0.30			
Strontium, g/m^3	0.3	0.2	2.1	0.8	0.7	1.9			
Bicarbonate, g/m^3	24.4	7.3	43.9	25.4	8.3	32.7	17.1	6.3	N/D
Carbonate, g/m^3	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D
Sulfate, g/m^3	994	214	9420	1004	227	8370			
Chloride, g/m^3	1196	129	12 410	1204	109	12 250			
T-alkalinity as $CaCO_3$, g/m^3	20.0	6.0	36.0	20.8	6.8	26.8	14.0	5.2	N/D
T-acidity as $CaCO_3$, g/m^3	—	—	—	—	—	—	—	—	—
T-phosphorus as PO_4, g/m^3	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01			
Hydroxide, g/m^3	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D
Σ anions, meq/L	54.8	8.22	547.0	55.3	7.94	520.5	—	—	—
Σ cations, meq/L	53.4	6.68	537.2	55.0	7.57	526.3	—	—	—
Control value, meq/L	+1.50	+6.56	+1.14	+0.27	+1.61	-0.71	—	—	—

Table E-2. *Chemical analysis — Ionics Aquamite V electrodialysis — 1979* — Continued

Sample stream	April 23			April 30			May 7		
	Feed	Product	Brine	Feed	Product	Brine	Feed	Product	Brine
pH, units	6.6	5.1	3.8	7.0	5.4	4.8	6.8	5.6	4.4
TDS, g/m^3	3162	509	52 438	3498	520	52 760	3251	494	51 680
Conductivity at 25 °C, μS/cm	5122	746	62 670	5829	876	63 622	5413	814	62 830
E. F.	0.62	0.68	0.84	0.60	0.59	0.83	0.60	0.61	0.82
Silica, g/m^3	4.6	4.6	4.0	4.5	4.5	3.0	3.5	3.6	3.5
Calcium, g/m^3	5.8	0.6	107	6.5	0.9	128	7.1	1.2	117
Magnesium, g/m^3	21.2	2.3	395	16.9	1.4	354	19.7	1.6	35.4
Sodium, g/m^3	1103	175	18 090	1218	169	18 760	1126	158	18 140
Potassium, g/m^3	11.0	2.2	184	10.6	1.2	148	11.2	1.6	188
Total iron, g/m^3	<0.10	<0.10	0.28	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10
Total manganese, g/m^3	<0.30	<0.30	<0.30	N/D	N/D	N/D	<0.30	<0.30	<0.30
Strontium, g/m^3	0.5	0.5	1.9	0.7	0.6	3.2	0.7	0.6	2.3
Bicarbonate, g/m^3	10.2	4.9	N/D	17.1	7.3	26.8	14.6	2.4	17.1
Carbonate, g/m^3	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D
Sulfate, g/m^3	910	195	15 360	1010	218	15 140	970	215	15 100
Chloride, g/m^3	1100	128	18 300	1218	122	18 200	1114	114	18 080
T-alkalinity as $CaCO_3$, g/m^3	8.4	4.0	N/D	14.0	6.0	22.0	12.0	2.0	14.0
T-acidity as $CaCO_3$, g/m^3	—	—	—	—	—	—	—	—	—
T-phosphorus as PO_4, g/m^3	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Hydroxide, g/m^3	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D
Σ anions, meq/L	50.15	7.75	836.19	55.68	8.10	829.23	51.53	7.21	824.85
Σ cations, meq/L	50.31	7.90	829.50	54.98	7.55	855.42	51.26	7.73	802.70
Control value, meq/L	-0.18	-0.66	0.51	+0.72	+2.37	-2.02	+0.30	-0.74	-1.72

Table E-2. *Chemical analysis — Ionics Aquamite V electrodialysis — 1979* — Continued

Sample stream	May 14			May 29			June 4		
	Feed	Product	Brine	Feed	Product	Brine	Feed	Product	Brine
pH, units	7.0	5.4	4.5	6.5	5.1	3.5	6.9	5.0	4.8
TDS, g/m^3	3353	476	50 503	3368	708	56 777	3443	435	33 361
Conductivity at 25 °C, μS/cm	5443	767	60 782	5423	985	65 645	5797	736	43 176
E. F.	0.62	0.62	0.83	0.62	0.72	0.86	0.60	0.59	0.77
Silica, g/m^3	4.9	5.0	5.0	3.7	1.6	18.5	4.0	4.2	6.5
Calcium, g/m^3	5.3	0.5	79	8.3	0.7	174	9.6	0.7	109
Magnesium, g/m^3	22.4	1.7	360	14.0	1.6	289	15.6	1.1	190
Sodium, g/m^3	1164	150.0	17 620	1157	194	19 800	1224	136	11 500
Potassium, g/m^3	7.4	1.0	110	9.8	1.8	171	10.0	0.7	101
Total iron, g/m^3	<0.10	<0.10	0.12	<0.10	<0.10	<0.32	<0.10	<0.10	<0.10
Total manganese, g/m^3	<0.30	<0.30	<0.30	<0.30	<0.30	<0.30	<0.30	<0.30	<0.30
Strontium, g/m^3	0.1	<0.10	0.6	0.9	0.8	3.1	0.7	0.6	1.8
Bicarbonate, g/m^3	19.5	4.9	13.7	9.8	2.4	N/D	19.5	5.9	12.2
Carbonate, g/m^3	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D
Sulfate, g/m^3	984	220	14 620	1038	359	17 740	960	205	9340
Chloride, g/m^3	1150	98	17 700	1130	146	18 600	1200	81.2	12 100
T-alkalinity as $CaCO_3$, g/m^3	16.0	4.0	11.2	8.0	2.0	N/D	16.0	4.8	10.0
T-acidity as $CaCO_3$, g/m^3	—	—	—	—	—	70.0	—	—	—
T-phosphorus as PO_4, g/m^3	0.49	0.10	1.25	<0.01	<0.01	<0.01	0.01	0.02	0.01
Hydroxide, g/m^3	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D
Σ anions, meq/L	53.26	7.42	804.1	53.66	8.96	894.23	54.17	6.66	536.1
Σ cations, meq/L	52.93	6.71	802.9	52.17	8.67	898.20	55.28	6.07	523.9
Control value, meq/L	+0.35	+3.21	+0.10	+1.49	+1.13	−0.28	−1.17	+2.79	+1.44

Table E-2. *Chemical analysis — Ionics Aquamite V electrodialysis — 1979* — Continued

Sample stream	June 11 Feed	Product	Brine	June 18 Feed	Product	Brine	June 25 Feed	Product	Brine
pH, units	7.1	5.4	6.2	7.2	4.8	6.4	6.9	5.0	6.0
TDS, g/m^3	3436	481	36 465	3487	431	19 406	3510	461	20 470
Conductivity at 25 °C, $\mu S/cm$	5482	756	44 625	5718	696	27 008	5624	687	27 853
E. F.	0.63	0.64	0.82	0.61	0.62	0.72	0.62	0.67	0.73
Silica, g/m^3	5.3	4.4	5.5	4.6	1.8	6.5	4.0	4.0	3.5
Calcium, g/m^3	10.0	0.9	137	18.5	1.7	128	22.4	2.3	159
Magnesium, g/m^3	22.0	1.90	280	30.5	2.7	210	31.1	2.2	206
Sodium, g/m^3	1203	153	12 560	1180	136	6570	1203	148	6900
Potassium, g/m^3	11.3	1.4	129	12.4	1.2	68	11.6	0.6	73
Total iron, g/m^3	0.18	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10
Total manganese, g/m^3	<0.30	<0.30	<0.30	<0.30	<0.30	<0.30	0.03	<0.01	0.04
Strontium, g/m^3	0.8	0.7	2.6	0.3	0.1	1.5	0.4	0.1	1.6
Bicarbonate, g/m^3	23.4	4.9	51.2	20.5	3.9	41.5	17.1	2.9	26.8
Carbonate, g/m^3	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D
Sulfate, g/m^3	1000	230	10 100	1020	213	5050	990	235	5750
Chloride, g/m^3	1160	84	13 200	1200	71	7330	1230	66	7350
T-alkalinity as $CaCO_3$, g/m^3	19.2	4.0	42.0	16.8	3.2	34.0	14.0	2.4	22.0
T-acidity as $CaCO_3$, g/m^3	—	—	—	—	—	—	—	—	—
T-phosphorus as PO_4, g/m^3	0.02	0.01	0.30	0.02	0.02	0.03	0.01	<0.01	<0.01
Hydroxide, g/m^3	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D
Σ anions, meq/L	53.94	7.24	583.6	55.43	6.50	312.6	55.60	6.80	327.6
Σ cations, meq/L	54.95	6.91	579.6	55.09	6.26	311.2	56.31	6.75	326.9
Control value, meq/L	−1.07	+1.52	+0.44	+0.36	+1.19	+0.29	−0.74	+0.25	+0.13

Table E-2. *Chemical analysis — Ionics Aquamite V electrodialysis — 1979* — Continued

Sample stream	July 3			August 6			August 13		
	Feed	Product	Brine	Feed	Product	Brine	Feed	Product	Brine
pH, units	6.8	4.9	5.9	7.1	4.8	6.3	7.1	5.1	6.3
TDS, g/m^3	3575	410	22 263	3434	407	31 208	3279	516	34 033
Conductivity at 25 °C, μS/cm	5674	660	35 137	5569	692	41 958	5253	754	43 139
E. F.	0.63	0.62	0.63	0.62	0.59	0.74	0.62	0.68	0.79
Silica, g/m^3	3.9	3.4	4.0	3.0	2.2	27.5	2.7	2.5	3.0
Calcium, g/m^3	20.1	1.9	176	9.3	1.0	28.0	10.8	0.9	29.2
Magnesium, g/m^3	28.3	1.8	228	11.0	0.79	147	19.3	1.5	216
Sodium, g/m^3	1208	128	7470	1216	133	10 900	1149	184	12 000
Potassium, g/m^3	13.2	1.0	93	9.0	0.7	102	11.0	0.7	122
Total iron, g/m^3	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10
Total manganese, g/m^3	<0.30	<0.30	<0.30	<0.30	<0.30	<0.30	<0.30	<0.30	<0.30
Strontium, g/m^3	0.1	<0.01	1.7	0.4	0.3	1.6	0.17	0.05	2.0
Bicarbonate, g/m^3	17.1	3.4	20.5	17.1	2.4	41.5	18.0	4.9	41.0
Carbonate, g/m^3	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D
Sulfate, g/m^3	1068	207	6050	1030	205	8600	990	244	9580
Chloride, g/m^3	1216	63	8220	1138	62	11 360	1078	78.0	12 040
T-alkalinity as $CaCO_3$, g/m^3	14.0	2.8	16.8	14.0	2.0	34.0	14.8	4.0	33.6
T-acidity as $CaCO_3$, g/m^3	—	—	—	—	—	—	—	—	—
T-phosphorus as PO_4, g/m^3	<0.01	<0.01	<0.01	0.05	0.03	0.07	0.04	0.02	0.06
Hydroxide, g/m^3	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D
Σ anions, meq/L	56.83	6.15	358.2	53.84	6.05	500.28	51.33	7.36	539.87
Σ cations, meq/L	56.21	5.81	354.9	54.50	5.92	490.28	52.39	8.19	544.39
Control value, meq/L	+0.63	+1.52	+0.60	-0.71	+0.61	+1.27	-1.18	-3.76	-0.53

Table E-2. *Chemical analysis — Ionics Aquamite V electrodialysis — 1979* — Continued

Sample stream	August 20			September 4			September 17		
	Feed	Product	Brine	Feed	Product	Brine	Feed	Product	Brine
pH, units	7.0	5.0	6.6	7.1	5.2	6.6	7.2	5.7	6.7
TDS, g/m^3	3072	446	32 322	3223	489	33 110	3290	556	33 098
Conductivity at 25 °C, $\mu S/cm$	5038	718	42 247	5171	787	43 272	5236	955	41819
E. F.	0.61	0.62	0.76	0.62	0.62	0.76	0.63	0.58	0.79
Silica, g/m^3	6.3	6.0	6.5	3.9	3.7	4.5	3.2	3.1	3.5
Calcium, g/m^3	8.1	0.2	19.6	23.6	2.3	281	8.7	1.1	137
Magnesium, g/m^3	31.1	2.4	358	14.5	1.3	190	13.7	1.6	200
Sodium, g/m^3	1015	139	10 710	1111	157	11 290	1155	165	11 600
Potassium, g/m^3	9.6	0.9	119	10.0	1.1	112	9.6	1.3	106
Total iron, g/m^3	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10
Total manganese, g/m^3	<0.30	<0.30	<0.30	<0.30	<0.30	<0.30	<0.30	<0.30	<0.30
Strontium, g/m^3	0.4	0.4	1.1	0.4	0.1	3.6	0.1	<0.1	3.2
Bicarbonate, g/m^3	19.5	2.4	68.3	23.4	4.9	88.8	22.0	4.9	87.8
Carbonate, g/m^3	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D
Sulfate, g/m^3	914	222	9040	944	242	8940	966	273	8860
Chloride, g/m^3	1068	73.2	12 000	1092	76.8	12 200	1112	106	12 100
T-alkalinity as $CaCO_3$, g/m^3	16.0	2.0	56.0	19.2	4.0	72.8	18.0	4.0	72.0
T-acidity as $CaCO_3$, g/m^3	—	—	—	—	—	—	—	—	—
T-phosphorus as PO_4, g/m^3	0.04	0.06	0.08	0.09	0.05	0.24	0.02	0.01	0.02
Hydroxide, g/m^3	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D
Σ anions, meq/L	49.49	6.73	527.94	50.85	7.29	531.84	51.85	8.76	527.33
Σ cations, meq/L	47.37	6.29	499.38	50.96	7.08	523.71	52.05	7.40	530.67
Control value, meq/L	+2.42	+2.10	+3.44	-0.12	+0.94	+0.97	-0.22	+5.61	-0.40

Table E-2. *Chemical analysis — Ionics Aquamite V electrodialysis — 1979* — Continued

Sample stream	September 24		
	Feed	Product	Brine
pH, units	7.1	5.1	6.6
TDS, g/m^3	3262	513	33 491
Conductivity at 25 °C, $\mu S/cm$	5205	907	43860
E. F.	0.63	0.56	0.76
Silica, g/m^3	2.2	2.0	3.5
Calcium, g/m^3	13.1	0.6	179
Magnesium, g/m^3	15.1	1.5	216
Sodium, g/m^3	1142	161	11 690
Potassium, g/m^3	9.8	1.3	104
Total iron, g/m^3	<0.10	<0.10	<0.10
Total manganese, g/m^3	<0.30	<0.30	<0.30
Strontium, g/m^3	0.3	0.1	3.2
Bicarbonate, g/m^3	19.5	2.4	75.6
Carbonate, g/m^3	N/D	N/D	N/D
Sulfate, g/m^3	960	248	8900
Chloride, g/m^3	1100	96	12 320
T-alkalinity as $CaCO_3$, g/m^3	16.0	2.0	62.0
T-acidity as $CaCO_3$, g/m^3	N/D	N/D	N/D
T-phosphorus as PO_4, g/m^3	0.46	0.32	1.80
Hydroxide, g/m^3	N/D	N/D	N/D
Σ anions, meq/L	51.35	7.91	534.17
Σ cations, meq/L	51.83	7.19	537.95
Control value, meq/L	-0.54	+3.15	-0.45

APPENDIX F — PILOT PLANT EQUIPMENT PROBLEMS

Summary

The Yuma Desalting Test Facility was designed and constructed at the E&R Center by the Bureau of Reclamation. During initial operation of the IX pilot plant at YDTF, it became apparent that a number of serious equipment problems needed resolution before reliable operation would be possible. In November 1977, during truck transport from Denver to Yuma, the lower sections of both acrylic IX columns were destroyed. This occurred because the columns were left in upright operational position in the IX trailer rather than packed and cushioned for the trip. A rough highway and vibrations caused the acrylic columns to fail. Associated piping to the columns was broken. All were repaired within 3 weeks by using materials on hand. Fortunately, spare 14-inch acrylic pipe, which was a special order item, was on hand at the E&R Center.

The most serious IX equipment problems arose in early 1978 from the 1- and 1.5-inch Plastomatic-brand PVC solenoid valves in the IX pilot plant. The valve solenoids generated so much heat when energized continuously (in the open position) that the plastic would soften, allowing parts of the valves to separate. This problem was accentuated by warm Yuma, Arizona, ambient temperatures. In addition, the valves closed so quickly that they caused severe, repeated water hammer that resulted in the continual appearance of water leaks in the threaded PVC piping system. Saline water flowing from leaks caused an electrical shock hazard as the water contacted the hot, poorly electrically insulated solenoids and undergrounded solenoid wiring.

This situation required that the testing be suspended, and most of the piping and solenoid valves in the IX pilot plant were removed and discarded. New electric motor-operated PVC ball valves were procured from Asahi Valve Company, after an order to Cellanese Corporation was cancelled because of a labor strike. The entire IX piping system was redesigned around the new valves by the Yuma Projects Office. They were installed with glued PVC fittings on specially fabricated pipe support frames. This resulted in an excellent piping system, which caused minimal downtime during the remainder of the test program. The total delay in testing caused by the valve problem was about 3 months.

Numerous problems also were encountered with the microprocessor used in the IX control system. The original electrical interface between the microprocessor and the electric valves and pumps did not provide adequate electrical isolation. Electrical spikes from the operating electrical equipment frequently caused the microprocessor to operate some valves or pumps erroneously that were not specified in the microprocessor program. Several months of intermittent work on more refined interfacing of the electrical hardware were required until a reasonably reliable system was developed. The final interface included direct-current-powered relays between the microprocessor triacs and the motorized valves and pumps. However, even the final system was subject to occasional errors due to electrical spikes in the power system. Microprocessor control technology has advanced considerably since the subject IX microprocessor was purchased, and we believe that present equipment would not be subject to the problems encountered.

Also, there were considerable problems with the Signet-brand flow indicators. Because of poor selection, the flowmeters had a range too high for the flow to be measured, resulting in excessive error—especially at low flow rates. These meters had analog, current-powered readouts rather than pulse-sensing digital readouts. Little trouble was experienced with the pulse-sensing converters for sending a milliampere signal to the recorder. The flow meter hardware included flimsy, poorly insulated electrical connectors which gave intermittent signals when the parts became wet or dirty — which is inevitable in such a pilot plant. The more substantial connectors of the Signet flow totalizer gave no such problem and Signet's more recent flow meters use such connectors. Factory calibrations had grave error and recalibrations were necessary. Volume and stopwatch measurements ultimately provided the only reliable flow rates for the IX. The flow meters were useful only as flow indicators. The Leeds and Northrup speed max. 250 Series multipoint recorder used to record flow rates was unreliable also and was finally eliminated after repeated repair work failed to keep the device operating reliably. Instead, a digital voltmeter was used to monitor the flow readings.

Some Specific Ion Exchange Equipment Failures From Operating Logs

September 25, 1978. —A failure occurred in one of the microprocessor circuit boards which contains the microprocessor output triacs (solid state relays). The faulty board was replaced with a spare. The defective board was sent to the E&R Center for repair.

November 26, 1978. — The recycle regenerant pump P-4 started leaking at the shaft seal. Inspection revealed that the seal failure was caused by scale buildup at the ceramic seal (predominantly gypsum). The seal assembly was replaced, the scale buildup of the pump parts was removed, and the pump returned to service. A flushing procedure was developed to minimize scale buildup in the pump and appurtenant equipment.

January 10, 1979. — The chemical injection pump, used for addition of acid or caustic to trim the pH of filter 10 effluent during transfer to the IX feed tank (T-9), failed.

January 29, 1979. — During a fresh regeneration of the IX resin at a specified flow rate of 3 L/min, an electric valve actuator failed to close a parallel flow valve. This resulted in the flow rate increasing to approximately 32 L/min, which resulted in a loss of about 5700 L of fresh regenerant from the ED brine storage tank. For repair, a faulty relay in the valve control circuit was located and replaced. In addition, operators began a new procedure of checking the status of the microprocessor actuated valves by observing the valve flags and pumps at the start of each microprocessor mode.

March 10, 1979. — Two equipment failures occurred during fresh regenerant production cycles. The level control system of metering tank 2 failed to stop the fresh regenerant pump 1 when the tank level reached the pump cutout point. This failure was detected when it happened, and equipment damage or lost time did not occur. Inspection of the low-level sensor revealed that process water had entered and damaged the electrical component of the sensor. The failed sensor was replaced when power could be interrupted in the microprocessor control system without losing time. The alternate metering tank T-1 was used in the interim. The other failure occurred during both regeneration and exhaustion modes. Motor-operated valve 21, one of the three column 1 regeneration flow control valves, opened without being selected at about 3 to 4 minutes into these two modes. Upset did not result from either occurrence because an isolation valve was closed manually immediately after the first incident occurred. The intermittent nature of this type of failure makes isolation of the cause(s) difficult.

March 27, 1979. — Faulty low-level sensors in volume metering tanks T-1 and T-2 were replaced.

April 5, 1979. — A rupture occurred in the lower section of column 1 during the exhaustion mode of cycle 3.08.25A. A large fragment of the 360-mm acrylic cylinder broke away, spilling the majority of the resin from the column. The rupture occurred under approximately 60-kPa shell pressure along paths of dense internal crazing which were visible prior to the rupture. Inspection of other crazed areas of the broken cyclinder section revealed that the crazing was internal to the 6-mm-thick cylinder wall; that is, the inner and outer wall surfaces were smooth. Gradual crazing is a property of acrylic in contact with water and limits the useful life of acrylic for aqueous applications.

April 9, 1979. — The 4-mm (No. 5 sieve) fabric screen which was glued to the distribution plate above IX column 2 became partially unglued. The screen was replaced with a larger circle of screen retained by flange gaskets.

April 18, 1979. — A replacement IX column fabricated at the Bureau of Reclamation, E&R Center, was received at YDTF and installed. The column replaced original column 1 which failed on April 5. A spare replacement column was shipped from the E&R Center later. The need for the spare was evident from the extensive crazing in the acrylic cylinders of column 2. Similar crazing was the only forewarning of the failure of column 1. Use of the same material (acrylic) for fabrication of the replacement columns rather than clear PVC resulted primarily from the time constraint. The replacement column 1 was tested hydraulically and loaded with resin.

A problem of poor flow distribution in the IX column 1 was investigated. Upon testing, it was found that the flow distribution across the plate was uneven. The diameters of the distribution plate orifices, which were all originally 1.6 mm, were found to vary significantly even after cleaning. Generally, proximal orifice erosion and distal orifice fouling were evident in the 356-mm-diameter distribution plate from the single, central, 24-mm-diameter flow source. The orifices in the central portion of the plate was blocked off with an acrylic cover which was redrilled to provide a balanced flow distribution.

July 19, 1979. — Owing to frequent microprocessor malfunctions, the IX operation was switched to manual control and the microprocessor was removed for maintenance.

July 24, 1979. — The agitator drive-motor bearings became noticeably noisy in operation. The motor was removed for disassembly and inspection. The bearings were found to be in need of replacement. Following reassembly and testing, the motor was installed, and the agitator was returned to service. Maintenance was completed during a period when operation of the agitator was not required. This failure occurred because the agitator had not been lubricated according to manufacturer's recommendations.

August 8, 1979. — Prior to cycle 3.23.05A, the microprocessor, which had been removed on July 19, was reinstalled and operation was returned to microprocessor control. Several relays had become marginally operable and had to be replaced. The long downtime was due to delivery delays for the relays and some capacitors. The capacitors were required to eliminate microprocessor errors, which resulted from electrical spikes, from various electrical sources.

August 20, 1979. — The start of cycle 3.23.29 was delayed 1.3 hours due to a microprocessor relay malfunction. The faulty relay was replaced and normal operation was resumed.

September 8, 1979. — The beginning of cycle 4.01.34 was delayed 9.0 hours due to a malfunction of the low-level sensing device of tanks T-9 and T-10.

Ionics Aquamite V Electrodialysis Equipment Failures From Operating Logs

October 28, 1978. — The motor-operated product diversion valve failed and caused the 110-V control circuit fuse to fail. Since the unit was not able to attain 95 percent recovery and the reason was not apparent at the time, the ED unit was left secured over the weekend.

October 30, 1978. — The motor capacitor and motor were found to be defective on the product diversion valve. These components were replaced and the valve was tested and returned to service. A relay in the valve control circuit was found to have burned contacts and this relay was replaced also at the time. The ED unit was brought on-line and adjusted to 95-percent recovery. However, recovery repeatedly dropped below 95 percent and the desired brine conductivity of 6.2 S/m could not be attained.

November 1, 1978. — The product diversion valve failed again. The valve was returned to service but, within a few hours, the controller housing became abnormally warm. The entire valve and controller assembly was replaced. This solved the problem and the removed valve was repaired.

November 11, 1978. — The membrane stack was disassembled and inspected following the development of an excessive voltage drop across a group of cell pairs in the first hydraulic stage. Incomplete cell pairs were found at two locations in the area where the excessive voltage drop had been detected. The membranes that were out of sequence were relocated to their correct positions during reassembly. (The stack had been assembled in this disorder by the manufacturer's representative.) Other problems were not found. A voltage probe of the stack following reassembly indicated a normal voltage drop pattern throughout the stack.

November 12, 1978. — Tests conducted revealed that the high-pressure relief valve located at the brine pump discharge had failed and was relieving back to the suction side of the pump. This failure was severely limiting the quantity of brine recycle and, thus, that of the recovery and reject concentration. The valve was replaced and the unit was returned to service. The defective valve was shipped to Ionics, Inc. for replacement under warranty.

November 20, 1978. — A replacement brine pump was received and installed on the ED unit. The bronze Aurora-brand (a unit of General Signal Corporation) turbine pump gradually lost output pressure because corrosion of the close tolerance impeller. This type of corrosion is accelerated at high brine concentrations and low pH.

November 1978. — Installation of instrumentation for automatic startup and shutdown of the ED unit was completed. The equipment monitored the level in the ED feed tank and operated the unit on the basis of feed water availability.

Electrical and plumbing preparations were begun to allow relocation of the ED unit prior to Phase 2 of the high recovery program. A 2- by 10-m enclosed trailer located south of the IX trailer was outfitted to contain the ED unit. Relocation of the ED unit was done to allow preparation for PTU (proof test unit) installations on RO pad 2 where the ED was located originally. The move was accomplished on December 26, 1978.

The high-level sensor float in the brine storage tank T-28 failed to indicate a high-level condition on December 18, 1978. The situation was discovered before any loss of brine occurred. The float was found wedged between the low-level sensor conduit and the tank wall. The high-level sensor was relocated during the week to prevent a recurrence.

Partial drain down of the ED stack and piping had occurred during shutdown periods since December. On December 21, 1978, the main ED feed valve was inspected and found to be out of adjustment. The cam-operated microswitches in the actuator were adjusted to provide a watertight seal when the valve was closed.

During past operation of the ED unit, numerous failures have occurred in the product and brine diversion valves. These two valves were operated in parallel on the ED used for high recovery, by diverting the product and brine back to the feed tank when the brine was off specifications, or to storage when the brine met specifications—as measured by a brine inline conductivity instrument. Continuous cycling of the valves when the brine stream was at, or passing through, the specifications level was contributing to the valve failures described earlier. A time delay relay was installed to delay the diversion of the product and brine streams to storage. This modification reduced the number of times these valves cycled as the criterion level was passed.

Because of the relocation of the ED unit to a more remote and elevated location with respect to the ED feed tank T-33, the need of a transfer pump in the feed system was required for providing adequate flow. The control of the transfer pump was integrated with the ED control circuit to provide completely automatic operation with provision for manual shutoff override at the pump for maintenance and safety.

November 20, 1978. — A decline in the ED unit brine pump capacity was noted. The brine pump was replaced due to loss of pumping capacity after about 360 hours of unit operation at varied brine concentrations. As a result the brine pH was added to the list of unit conditions being monitored and recorded. A criterion was established that, if the brine pH was detected to drop to 5.2 pH units or less, the rectifier was to be turned off and the brine stream flushed with feed water until the brine stream pH reached 6.4 units.

* * * * *

February 1, 1979. — To improve the accuracy of the TDS through determinations from electrical conductivity measurements in the YDTF Chemical Laboratory, the Beckman Instruments, Inc. model RC-18A conductivity bridge was sent to the Yuma MCAS (Marine Corps Air Station). On February 5, MCAS returned the bridge after checking the values of bridge resistances and replacing corroded wires. At YDTF, calibration of the epoxy dip conductivity cell with a standard cell yielded a correction factor of 1.02. These corrections reduced the instrument error from approximately 7 percent down to within 2 percent of documented solution conductivities in the range of 2 to 5 S/m.

March 23, 1979. — The bronze ED concentrate pump was replaced again, this time after about 940 hours of operation at varied brine concentrations. Inspection of the pump revealed the obvious cause of the performance decline to be erosion at both radial edges of the turbine buckets. This wear appeared to be accelerated by corrosion. A crack was detected in the pump's outer casting. Replacement parts were ordered. Upon arrival of parts, the damaged pump was rebuilt (as a spare). Isolation and bypass valves were installed around the ED feed-forwarding pump to allow flushing of the membrane stack using clearwell forwarding pump 3. A faulty local cutout switch in the ED feed-forwarding pump control circuit was replaced.

March 27, 1979. — The ED unit was secured due to burning of components in the membrane stack. The burning was detected when an operator removed the stack enclosure panels to investigate an odor of burning plastic. Fusing of the outer edge of several electrode and intermembrane spacers was evident near each of the four electrodes. The membrane stack was disassembled and selected components were inspected. The most significant and obvious damage was sustained by the electrode plates themselves. Generally, damage to the electrodes appeared to result from failure of the very thin plastic insulation tape used to prevent short circuiting of current between intended dead areas of oppositely charged electrodes. The location of damage to the electrode plates indicated that short circuiting occurred: (1) through the intraelectrical-stage brine channels, and (2) across the outer surface of the membrane stack. The visible minor damage to other elctrode compartment components and adjacent components was limited to noneffective areas of those compartments. All of the needed replacement components were on hand.

April 2, 1979. — Reassembly of the ED membrane stack was completed. The components of all four electrode compartments (electrodes, electrode spacers, and electrode heavy cation membranes) were replaced. In addition, 14 cation membranes, 10 anion membranes, and 17 intermembrane spacers were replaced. The ED unit was returned to service following 158 hours of downtime.

April 9, 1979. —A high, 26-V drop was measured across the second "Y" stream spacer of the third hydraulic stage of the ED unit. The unit was secured immediately. On April 10, the membrane stack was disassembled and inspected. Observations were:

1. The electrical insulation tape on all four electrodes had deteriorated by current short circuiting between intended dead areas of the electrodes above and below both the "X" and "Y" channels (the dilute and concentrate streams, which interchange with polarity reversal) and along all four outer edges of the four electrodes.

2. In the second hydraulic stage, the outlet ports of the last two "Y" stream spacers were obstructed with a salt which was insoluble in a 10 percent HCl solution — indicating that the salt was probably gypsum.

3. The first eight cell pairs of the third hydraulic stage had a heavy salt encrustation partially obstructing the "Y" outlet channel.

4. The inlet port of the last "Y" stream spacer in the third hydraulic stage was obstructed with salt.

5. A heavy residue of salt was precipitated on the widest wall of the trapezoidal "X" stream inlet channel through the last three cell pairs of the fourth hydraulic stage. The "X" stream spacer inlet ports are opposite the widest wall and were unobstructed.

Component replacements included:

1. All four electrodes,

2. E-1 electrode compartment spacer, and

3. Components of the first two cell pairs below E-3 (two cation membranes, two anion membranes, and four intermembrane spacers).

Component repairs were:

1. All electrical insulating tape was removed from replaced electrodes and fresh tape was applied.

2. Electrode compartment spacer channel inserts were mended with RTV (silicone base sealant).

3. Brine pump channel rings and impeller were replaced with spares.

April 14, 1979. — The ED unit brine pump failed again. The pump had operated only 15 hours after being rebuilt on April 13 with the best used components on hand. The ED unit remained off line until April 16 when the brine pump capacity was restored following assembly with a set of re-machined channel rings. Failure downtime of the brine pump was 56 hours.

April 19, 1979. — A new bronze turbine pump was received from Ionics, Inc. The new pump was installed in place of the pump that was re-assembled on April 16 since it was already failing.

May 3, 1979. —The bronze ED concentrate pump was replaced with a Flotec, Inc. model C10 pump received onsite May 2. The Flotec pump was constructed of PVC and had a Hastelloy TM type shaft. There was no downtime due to the brine recirculation pump after the pump substitution was completed.

May 14, 1979. — The ED membrane stack had been flushed with a 5-percent solution of HCl due to a higher than normal voltage drop (26 V) occurring during negative polarity above the lower electrode of the first electrical stage. On May 21, the ED stack was disassembled because of recurring higher than normal voltage drop (20 V) in the same vicinity under the same conditions.

Observations were:

1. First hydraulic stage

    a. The first six cell pairs were fused together by melted spacer plastic at the outlet port corner.

2. Second hydraulic stage

   a. The cell pair 49 lower spacer was obstructed with white salt (soluble in 10-percent HCl) through the last three passes and at the rectangular inlet port.

   b. The electrode compartment and components of the cell pair directly above cell pair 49 were fused at the outlet port corner and inlet port corner.

   c. The heavy cation membrane and electrode compartment spacer areas near the electrode compartment spacer inserted channels were partially separated from the remainder of those components and were burned at the edges of these areas.

Replacements were:

1. First hydraulic stage

   a. Cell pair 75, anion membrane and spacer above and below, were replaced because of shear damage — probably resulting from spacers misalignment.

2. Second hydraulic stage

   a. For cell pairs 40, 44, 45, 46, and 48, the same components were replaced for the same reason as 1a. above.

   b. For cell pairs 49 and 50, all components were replaced because of scaling.

May 29, 1979. —The ED unit was shut down on May 29 because of leakage from the brine diversion valve. A failed O-ring seal was replaced and the unit was returned to service after 1.3 hours. There was not any IX experiment downtime because continuous operation of the ED unit was not required.

June 11 through 13, 1979. — Several intermittent failures of the starter unit (230 V) for the ED feed transfer pump motor were experienced. On one occasion, the transfer pump failed to start, and was electrically "tripped" off line on three occasions. The problem was eliminated by replacement of one of the two-phase overload relay heater elements (eutectic alloy and ratchet type). The failures resulted in 2 hours of lost time for the test program.

July 10, 1979. —The ED stack was disassembled for inspection and installation of the improved electrode compartment spacers, which were received on July 9. The new spacers were sent by Ionics, Inc. to provide better electrical insulation. Observations were:

1. Electrical Stage 1

   a. Rectangular grommet of electrode E-1 was torn.

   b. There was slight scaling around E-1 port openings.

   c. There was fusing of the inserts in the closed off ports of the E-1 spacer to the electrode compartment cation membrane.

   d. There was slight fusing on the corner of the first five cell pairs near the outlet ports.

   e. There was minimal damage to the taped areas of electrode E-2.

2. Electrical Stage 2

   a. The encapsulation of the electrode rinse ports of electrode E-3 was crinkled and separating.

   b. The electrode terminal side of the stack showed a severe brown discoloration caused by rust from the center electrode connector.

   c. A minor flaw from manufacturing was discovered in the cation membrane of cell pair 112.

   d. There was white precipitate on the edges of the "Y" inlet ports of cell pairs 119 through 125. The sample was soluble in 10-percent HCl and effervesced profusely and was thus assumed to be calcium carbonate.

   e. Minimal fusing occurred in cell pair 123 on edge near "Y" inlet ports.

   f. Anion membrane of cell pair 124 was slightly warped and fused to the spacer near "Y" inlet ports.

g. A slight separation of closed off ports of the electrode compartment spacer was noted (E-4 compartment).

h. There was a white deposit around "X" inlet port of electrode E-4 and a slight deterioration of tape along one edge.

Repairs and replacements were:

1. Electrical Stage 1

   a. On electrode E-1, the edges were retaped and the grommets were replaced.

   b. Electrode E-1 spacer was replaced.

   c. All components of cell pairs 1 through 5 were replaced.

   d. Electrode E-2 compartment spacer was replaced.

2. Electrical Stage 2

   a. Electrode E-3 compartment spacer was replaced.

   b. The cation membrane of cell pair 112 was replaced.

   c. Anion membrane of cell pairs 124 and 125 was replaced.

   d. Heavy cation membrane was replaced.

   e. Electrode E-4 compartment spacer was replaced.

   f. E-4 electrode was replaced with a retaped spare electrode.

Most of these stack failures occurred because of a poor insulation design in the Ionics, Inc. ED stack, which became evident during high recovery operation. Later design modifications by Ionics, including encapsulation of insulated electrode areas, mitigated many of these problems.

APPENDIX G — MODIFIED GYPSUM SATURATION COMPUTER PROGRAM

Modified gypsum saturation computer program was based on one used at YDTF for estimating the percent recovery or concentration factor corresponding to calcium sulfate saturation [9].

The program is written in FORTRAN IV and used on a Control Data Corporation computer at the E&R Center. The YTDF program was modified to calculate the incremental molar concentration to saturation for the particular solution; that is, the moles/L of gypsum that needed to be added (–) to or removed (+) from the starting solution to reach saturation in gypsum. Thus, only the Ca^{+2}, SO_4^{-2}, and TDS were changed in the entered solution composition to reach saturation, unlike the "Marshall Program" [9] used at YDTF in which the concentration of all ion charges with the concentration factor.

The following program was used to calculate values shown in table 11.

```
PROGRAM LAVEGWA(INPUT,OUTPUT,TAPE5=INPUT,TAPE6=OUTPUT)
C
C  GYPSUM PRECIPITATION CALCULATIONS
C  PROGRAM IN FORTRAN - ALTERED FOR HIGH RECOVERY EXPERIMENTS
C  MODIFIED BY J. KAAKINEN
DIMENSION TITLE(4),CA(13),VAL(13),YYY(13),ATOMWT(13)
DATA ATOMWT/40.08,24.312,22.9898,39.102,55.847,
+ 54.938,87.62,1.0,61.001,1.0,96.04,35.453,94.9498/
DATA VAL/2.0,2.0,1.0,1.0,2.0,2.0,2.0,1.0,1.0,1.0,
+ 2.0,1.0,3.0/
C
C READ IN TITLE, TEMP, ARRAY CA FOR ION VALUES
C
22 PRINT *,#ENTER THE TITLE#
READ(5,3) TITLE
3 FORMAT(4A10)
PRINT *,#ENTER THE TEMPERATURE IN DEGREES CELSIUS#
READ *,TEMP
PRINT*.#ENTER THE MG/L OF THE IONS IN#
PRINT*,#ORDER USING ZEROS FOR NON-DETECTED OR NOT USED.#
PRINT*,#PUT COMMAS BETWEEN VALUES AND NEGLECT T-ALK,#
PRINT*,#P-ALK, AND NH-PO4#
READ*,CA
CACA=CA(1)
TA=TEMP+273.16
SOLPO=10.**(390.9619-152.6246*ALOG10(TA)
+-12545.6/TA+0.0818493*TA)
XKDISO=10.**(-158.540+62.160*ALOG10(TA)
++4810.6/TA-0.046298*TA)
C
C CALCULATE THE CURVE DATA DHS
C
IF(TA.LE.273.0 .OR. TA.GT.373.0) GO TO 21
DHS=0.00987*TA**0.6939
GO TO 30
21 IF(TA.LE.273.0 .OR. TA.GT.550.0) GO TO 31
DHS=0.00008049*TA**1.506
GO TO 30
31 PRINT*, #ERROR IN TEMPERATURE ABSOLUTE, TA = #,TA
GO TO 99
C
C CALCULATE A,B,C
C
30 A=1.60 -0.155 * EXP(-0.02054*TEMP)
B= 0.088 * EXP(-0.0605*TEMP)
C= 0.02 * EXP(-0.01336*TEMP)
C
C CALCULATE AI1, CAL1, R, TMG1
C
KK=0
DO 33 K=1,100
AI1=0.0
DO 35 I=1,13
YYY(I) = CA(I)/(1000.0 * ATOMWT(I))
AI1=AI1 + (YYY(I) / 2.0 * VAL(I)**2)
35 CONTINUE
CAL1=YYY(1)
R=YYY(11)/YYY(1)
TMG1=YYY(2)
SOLP1=R*CAL1**2
WF1=AI1*(0.05838-0.003260*AI1+0.00012489*AI1**2)
FMR1=AI1*(0.9970-0.01883*AI1)
```

```
ASSMG=0.0
CFML=1
DO 23 J=1,100
CAL=CAL1*CFML
TMG=TMG1*CFML
AI=AI1*CFML-4.*ASSMG
SOLP=SOLPO*10.**(8.*DHS*SQRT(AI)/(1.+A*SQRT(AI))
++B*AI-C*AI**2)
XKDIS=XKDISO*10.**(8.*DHS*SQRT(AI)/(1.+SQRT(AI)))
ASSMG=TMG*SOLP/(XKDIS*CAL+SOLP)
X=SQRT((SOLP+ASSMG*CAL)/SOLP1)
IF(ABS(X-CFML)/X-.001)24,24,23
23 CFML=X
24 IF(ABS(X-1.09)-0.005)34,34,25
25 SCR=(YYY(11)*X-ASSMG)/(YYY(1)*X)
IF(SCR-1.)27,26,26
26 CALN=YYY(1)*X
YYY(11)=YYY(11)-YYY(1)+CALN
YYY(1)=CALN
GO TO 29
27 SULN=YYY(11)*X
YYY(1)=YYY(1)-YYY(11)+SULN
YYY(11)=SULN
29 CA(1)=YYY(1)*1000.*ATOMWT(1)
33 CA(11)=YYY(11)*1000.*ATOMWT(11)
34 KK=KK+K
JJ=J
CASR=(CACA-CA(1))/ATOMWT(1)
AIF=CFML*AI1
CFWF=AIF*(0.05838-0.003260*AIF+0.00012489*
+AIF**2)/WF1
CFMR=AIF*(0.9970-0.01883*AIF)/FMR1
WRITE(6,4)TITLE
4 FORMAT(///1H ,4A10)
WRITE(6,5)AI1
5 FORMAT(27H IONIC STR OF SALINE WATER=E12.4)
WRITE(6,6)CAL1
6 FORMAT(26H INITIAL CONCN OF CALCIUM=E12.4)
WRITE(6,7)R
7 FORMAT(20H MOLAL RATIO SO4/CA=E12.4)
WRITE(6,8)TMG1
8 FORMAT(28H INITIAL CONCN OF MAGNESIUM=E12.4)
WRITE(6,9)
9 FORMAT(28H A PAR FOR KDISS(MGSO4)=1.0 //)
WRITE(6,91)CA(1)
91 FORMAT(31H CALCIUM CONCENTRATION (MG/L) =F10.2)
WRITE(6,92)CA(11)
92 FORMAT(31H SULFATE CONCENTRATION (MG/L) =F10.2)
WRITE(6,94)CASR
94 FORMAT(32H CASO4 PRECIPITATED (MMOLES/L) =F8.4)
WRITE(6,93)KK
93 FORMAT(7H ITJK =I6//)
WRITE(6,10)
10 FORMAT((60H CONCN FACTORS FOR CASO4 DIHYDRATE),CF=CONCN(SATD)/CONCN(INI
+4HTIAL))
WRITE(6,11)
11 FORMAT(61H TEMP(C) CF(MOLAL) CF(MOLAR) CF(WT FRACT) ION STR(MOLAL-SATD
+17H SOLY PD(ZERO) IT)
WRITE(6,12)TEMP,CFML,CFMR,CFWF,AIF,
+SOLPO,JJ
12 FORMAT(1H,F9.0,2F10.5,F13.5,F16.5,F17.8,I3//)
WRITE(6,13)
13  FORMAT(52HOPARTICULAR CONSTANTS USED IN THE ABOVE CALCULATIONS)
WRITE(6,14)
14 FORMAT(60H TEMP(C)    DH SLOPE    K(O)DISS(MGSO4)    A PARA    B(GYPS)
+9H  C(GYPS))
WRITE(6,15)(TEMP,DHS,XKDISO,A,B,C,I=1,NST)
15 FORMAT(F10.2,F10.4,3X,F14.8,F13.3,2F11.4 )
RECOV=100-100/(CFMR)
WRITE(6,16)RECOV
16 FORMAT(//18HOPERCENT RECOVERY=F10.2//)
99 PRINT*, #DO YOU WANT TO PROCESS ANOTHER#
PRINT*,#SET OF DATA\ - TYPE YES OR NO#
   READ(5,2) IANS
2 FORMAT(A3)
IF(IANS.EQ.3HYES) GO TO 22
STOP
END
```

APPENDIX H — SAMPLE OF ION EXCHANGE DATA REDUCTION

The following is a description of the methods used in the mathematical analysis of an ion exchange data cycle. Data from cycle run No. 2.01.76 are used in this sample calculation. Raw data sheets, tables H-1, H-2, and H-3, include the IX operating data sheet, which has the lines numbered here for easier reference, the operator's tritration data sheet, and the chemical laboratory analyses sheets, respectively. Chemical laboratory results, and not operator's titration results, are used in this sample. Results for this sample calculation are in table B-5 and figure B-3 in appendix B.

The volume of resin in column 1 was 97.3 L. This value was calculated from an average resin height of 1066 mm (measured after backwash, regeneration, and drain down to the top of the resin bed) and the column inside diameter of 341 mm, corresponding to 91 300-mm^2 of cross-sectional area. Thus, the resin volume was 97.3 L (1066 by 91 300-mm^2). This volume was used in the expression of IX throughput volume as numbers of resin BV (bed volumes) a dimensionless expression of water throughput volume, flow rates (BV/min), and for the calculation of specific resin capacities as equivalents of calcium removed per liter of resin (eq/L).

Throughput Volume Calculation for Each Mode

Throughput volumes are used in plotting column effluent concentration data and for calculating average leakage and resin capacity.

Regeneration 1 (or Backwash). — The mode duration from operating data sheet (table H-1) line 14 was 7.00 minutes. The flow rate from line 15 was 28 L/min, which corresponds to 0.287 BV/min in terms of bed volumes (28 L/min ÷ 97.3 L). Total throughput volume was 196 L (7.00 min × 28 L/min) or 2.01 BV (196 L ÷ 97.3 L). Percent bed expansion was calculated from the resin height measured at the end of the mode and from the standard resin height. Thus, [169.0 cm (*line 17*) - 106.6 cm] ÷ 106.6 cm = 0.59 or 59 percent. Samples were collected at the beginning of the mode and at the end, as shown in table H-2.

Regeneration 2. — The initial sampling point corresponded to the last point of Regeneration 1. Total volume was calculated from the duration in *line 17* and the flow rate in *line 19;* 34.0 min × 26 L/min = 884 L; 884 L ÷ 97.3 L = 9.09 BV. The incremental times between samplings were determined by calculating the difference between sampling times for the laboratory analysis or titration data sheets as shown in table B-3. The incremental bed volume (throughput between samplings) was the product of the time increment and the flow rate; for example, 7 min × 0.267 BV/min = 1.87 BV. The accumulated bed volumes were the sums of the corresponding and all previous volume increments of that mode. In the case of Regeneration 2, the accumulated volume was continued from Regeneration 1.

Regeneration 3. — The total volume was 400 L, listed as volume from tank 2 in *line 5:* 400 L ÷ 97.3 L = 4.11 BV. The duration was 135 minutes as given in *line 21.* The average flow rate was 2.96 L/min (400 L ÷ 135 min) or 0.030 BV/min (2.96 L/min ÷ 97.3 L).

Rinse. — Only a slow rinse was used. The volume throughput was recorded as a totalized volume of 150 L on *line 28.* Applying a calibration factor of 1.1 (unnecessary for cycles after 2.01.119A when the totalizer was recalibrated) gave a throughput of 165 L, or 1.70 BV. The duration was 10.0 minutes (*line 27*). The flow rate was 16.5 L/min (165 L ÷ 10 min) or 0.17 BV/min.

Service or exhaustion. — Leakage gradually rose to the termination point of 3.0 meq/L calcium at a time of day of 1310 (military time units), as shown on the titration data sheet. The elapsed exhaustion time was 164 minutes (*line 11*). The total volume throughput, 4450 L (*line 12*), was corrected by the 1.1 calibration factor to 4895 L or 50.3 BV. Average flow rate was 29.8 L/min (4895 L ÷ 164 min) or 0.307 BV/min. The time increment and volumes were calculated the same as for regeneration.

Discrete Column Effluent Concentrations

The concentrations, expressed in meq/L, were calculated from laboratory analyses for Ca, Mg, and Na. The equivalent weights of Ca^{+2}, Mg^{+2}, and Na^{+1}, are 20.04, 12.15, and 23.0, respectively. Caculations of the concentrations for sample No. AN 502 in table H-3 are illustrated as follows:

Ca: 630 mg/L ÷ 20.04 = 31.4 meq/L

Mg: 360 mg/L ÷ 12.15 = 29.6 meq/L

Total hardness: 31.4 meq/L + 29.6 meq/L = 61.0 meq/L (assumed Ca + Mg)

Na: 2290 mg/L ÷ 23.0 = 99.6 meq/L

In the case of the end of Regeneration 3, the last sample collected is from above the resin bed during drain down.

A plot of data from these calculations is shown in appendix figure B-3.

Average Column Exhaustion Effluent Concentrations. —These yielded the overall calcium and total harness balance of a run. They were obtained by numerical integration (using the trapezoidal method) of the data in calculations for calcium, as follows:

$$5.83\left(\frac{0.29+0.26}{2}\right)+4.605\left(\frac{0.26}{2}+0.26+0.27+0.33+0.45+0.76+1.24+1.85+\frac{2.59}{2}\right)+3.07\left(\frac{2.59+2.94}{2}\right)=41.6\left(\frac{\text{meq - BV}}{\text{L}}\right)$$

Dividing by the 50.3-BV throughput yields an average calcium leakage of 0.827 meq/L. Using the same procedure, average exhaustion effluent concentrations for Mg, total hardness, and Na were calculated as 2.14 meq/L, 2.96 meq/L, and 47.4 meq/L, respectively.

Average Exhaustion Influent Concentrations. — Average Ca in samples No. AN 520, AN 534, and AN 526 from chemical analysis sheets yielded 6.27 meq/L Ca. The calculations for the major cations was similar, yielding for Mg, Ca+Mg, and Na: 6.06 meq/L, 12.3 meq/L, and 38.1 meq/L, respectively.

Major Cation Balance

For Ca, Mg, Ca+Mg (total hardness), and Na in terms of equivalents exchanged, the influent minus the effluent should be close to zero.

Ca: (6.27 meq/L - 0.83 meq/L) 4895 L = 26 600 meq = 26.6 eq

Mg: (6.06 meq/L - 2.14 meq/L) 4895 L = 19 200 meq = 19.2 eq

Ca +
Mg: (12.3 meq/L - 2.96 meq/L) 4895 L = 45 800 meq = 45.8 eq

Na: (38.1 meq/L - 47.4 meq/L) 4895 L = -45 500 meq = -45.5 eq

The sum of Ca+Mg and Na is 300 meq or 0.3 eq. (This information is a check for arithmetic and other errors only and is not reported in the IX data packets contained in appendixes B, C, and D.)

Calculation of Resin Capacities

For Ca, Mg, Ca+Mg (approximate total hardness), the equivalents removed (calculated above) divided by the resin volume yield resin capacities for the particular operating conditions.

Ca: 26.6 eq ÷ 97.3 L = 0.273 eq/L

Similarly, resin capacities for Mg and Ca + Mg are 0.197 eq/L and 0.471 eq/L, respectively.

Calculation of TWRC

Values for **TWRC** for calcium were calculated from the specific resin capacity (0.273 eq/L) and total cycle duration (7+34+135+3+10+164=353 min). For cycle 2.01.76 the **TWRC** was 0.273 ÷ 353 = 0.773 meq/(L·min). *This value for **TWRC** was not the one in appendix B data because the definition of TWRC was recently changed to the one in the Glossary.*

Table H1. — Sample IX pilot plant operating data — Yuma Desalting Test Facility

No.	Mode	Item			Run 1		Run 2		Run 3		Run 4		Run 5	
1		RUN NO.			2.01.76		2.01.77		2.01.78		2.01.79		2.01.80	
2		DATE/TIME			27 OCT 78 0715		27 OCT 78 1330		10-28-78 0008		28 OCT 78 0520		28 OCT 78 1210	
3		INITIALS			RH	DJ	RH	DJ	BUL RH		RH	DJ	DJ	SLC
4		Tank 1 (5.22 ℓ/cm)	hti / hti	Δ vol (ℓ)	— / —	—	— / —	—	156.2 / 138.2	250.6	129.0 / 71.1	302.7	— / —	—
5		Tank 2 (5.22 ℓ/cm)	hti / hti	Δ vol (ℓ)	105.0 / 28.5	400	105.0 / 255	410	— / —	—	— / —	—	185.5 / 128	
6		Tank 5 (11.5 ℓ/cm) Recycle regenerant	hti / hti	Δ vol (ℓ)	209.0 / 213.5	51.75	213.5 / 246.6	380.6	~~252.4~~ / 249.2	48.3	249.2 / 252.5	37.45	252.5 / 245.0	
7		Tank 6 (17.8 ℓ/cm) Spent regenerant	hti / hti	Δ vol (ℓ)	191.0 / 198.0	54.6	192.0 / 211.4	772.5	241.4 / 239.0	84.0	239.0 / 233.5	115.7	233.5 / 234.5	
8		Tank 9 (35.0 ℓ/cm) Feed	hti / hti	Δ vol (ℓ)	376.0 / 234.8	4942	234.8 / ~~0~~	2348	376.0 / 262.8	3962	262.8 / 139.0	4333	376.0 /	3938
9		Tank 28 Level, %			90									
10		Tank 33 (72.58 ℓ/cm) Product	hti / hti	Δ vol (ℓ)	153.5 / 216.6	4520	215 / 233.9	1371.7	225.5 / 234.2	631.5	228.2 / 233.3	370.2	— /	3092
11	SERVICE	Duration (min)	Ti / Tf	ΔT	999 / 835	164	999 / 746	253	999 / 873	126	999 / 857	142	999 /	124
12	SERVICE	Totalizer volume (10 x ℓ)	Vi / Vf	Δ vol	3336 / 3721	4450	3746 / 4522	7260	4538 / 4879	3410	4894 / 5277	3830	— /	336
13	SERVICE	Flowrate (ℓ/min)			30.0		30.0		30.5		30.0			
14	REGEN 1	Duration (min)			007		007		015		015		015	
15	REGEN 1	Flowrate (ℓ/min)			28.0		28.0		27		26		27	
16	REGEN 1	Resin Height (cm) (at end of mode)			169.0		161.0		164.0		163.0		163.5	
17	REGEN 2	Duration (min)			034		034		034		034		034	
18	REGEN 2	Temperature (°C)			21°		22.5		22.8°		21.8°		21.5°	
19	REGEN 2	Flowrate (ℓ/min)			26.0		26.0		26.0		26.0		26.0	
20	REGEN 2	Resin Height (cm) (at end of mode)			163.0		163.5		162.5		162		163.0	
21	REGEN 3	Duration (min)			135		137		100		102		100	
22	REGEN 3	Temperature (°C)			23.0°		24.5		22.5°		22.2°		24°	
23	REGEN 3	Flowrate (ℓ/min)			2.96		~~2.50~~ 2.4		2.8 ~~3.09~~		2.96		3.13	
24	REGEN 3	Resin Height (cm) (at end of mode)			108.5		109.0		107		107.6		*106.0	
25	DRAIN	Duration (min)			003		003		003		003		003	
26	DRAIN	Resin Height (cm) (at end of mode)			106.0		105.8		105.5		105.6		105.7	
27	SLOW RINSE	Duration (min)			010		010		010		010		010	
28	SLOW RINSE	Totalizer volume (10 x ℓ) initial			3321	150	3751	150	4522	160	4879	150	5277	150
29	SLOW RINSE	Flowrate (ℓ/min)			15.5		15		16		15.5		15.5	
30	FAST RINSE	Duration (min)			—		—		-		—			
31	FAST RINSE	Totalizer volume (10 x ℓ) final	Vf	Δ vol	—	—	—	—	-	.	-	-		
32	FAST RINSE	Flowrate (ℓ/min)			—		—		.		—			

33	L, Lab samples; T, Titrations; C, Conditioning;	Run 1 L	Run 1 T	Run 1 C	Run 2 L	Run 2 T	Run 2 C	Run 3 L	Run 3 T	Run 3 C	Run 4 L	Run 4 T	Run 4 C	Run 5 L	Run 5 T	Run 5 C
		X	X				X			X			X			X

COMMENTS: * Run 2.01.77 During service mode The processor mal-
1505-7
functioning. Unless 37+38 came on line Then automatically secoring
Run ~~[illegible]~~ Reset ck processor out started working right Mode Time
859

1810 Starte Mode 1/2 continued with Run
1440 Took at wrong Time

Revised 10/24/78 PEL/ch

Table H2 — Sample IX pilot plant titration data — Yuma Desalting Test Facility

Operator's Titrations

YUMA DESALTING TEST FACILITY
IX PILOT PLANT TITRATION DATA

Run 2.01.76
Date 27Oct78
lab Samples Submitted

TIME OF DAY	MODE TIME	MODE INF/EFF.	INITIALS	TITRANT VOL. (mℓ)	CALCIUM (meq/ℓ)	TITRANT VOL. (mℓ)	TOTAL HARDNESS (meq/ℓ)
0718	004	R-1-E	RH	3.0	30.0	5.65	56.5
0722	000	" " "	"	4.6	46.0	9.0	90.0
0729	027	" 2 "	"	5.0	50.0	10.0	100.0
0736	020	" " "	"	5.1	51.0	10.6	106.0
0743	013	" " T	"	4.7	47.0	9.3	93.0
0743	013	" " E	"	5.15	51.5	5.0	100.0
0750	006	" " "	"	4.9	49.0	10.1	101.0
0756	140	" 3 "	"	4.85	48.5	9.7	97.0
0816	120	" " "	"	5.4	54.0	4.8	96.0
0836	100	" " "	"	6.5	65.0	6.5	130.0
0856	080	" " "	"	7.5	75.0	7.2	144.0
0856	080	" " T	"	1.5	6.0	5.2	20.8
0916	060	" " E	"	7.7	77.0	7.2	144.0
0936	040	" " "	"	8.8	88.0	7.5	150.0
0956	020	" " "	"	8.35	83.5	6.7	134.0
1013	003	" D-D	"	8.0	80.0	6.9	138.0
1016	010	R-S-E	"	2.15	21.5	3.85	38.5
1021	005	" " "	"	.65	2.6	1.2	4.8
1026	999	S - I	"	1.55	6.2	3.05	12.1
1026	999	" E	"	.1	.2	.35	.7
1045	980	" "	"	.1	.2	.25	.5
1100	965	" "	"	.1	.2	.45	.9
1115	950	" "	"	.15	.3	.4	.8
1130	935	" "	"	.1	.2	.5	1.0
1145	920	Service Inf	RH	1.6	6.4	3.0	12.0
1145	920	" Eff	"	.25	.50	.75	1.5
1200	905	" "	"	.3	.6	.95	1.9
1215	890	" "	"	.5	1.0	1.65	3.3
1230	875	" "	"	.75	1.5	2.6	5.2
1245	860	" "	"	.95	1.9	3.6	7.2
1300	845	" "	"	1.4	2.8	4.3	8.6
1310	835	" "	"	1.5	3.0	4.6	9.2
1310	835	" Inf	"	1.6	6.4	2.9	11.6

Table H3 — Sample chemical laboratory analyses — Yuma Desalting Test Facility

1 of 6

HI-REC

TEST RUN NO. (2.01.76) ANAL. DATE WEEK OF 10-23-78 CHECK

	AN	502	503	504	505	507	508	509	510
a	DATE	10-27							
b	TIME (HR)	0718	0722	0729	0736	0743	0750	0756	0816
c	SOURCE	R-1-EF	R-1-EF	R-2-EF	R-2-EF	R-2-EF	R-2-EF	R-3-EF	R-3-EF
	SPEECIE	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l
Units	pH								
Deg.	°C								
US	EC								
1.	NFR								
2.	VR								
3.	FR								
4.	Mg++	360.	577.	650.	663.	656.	649.	637.	635.
5.	HPO_4								
6.	Ca++	630.	950	1070.	1080.	1050.	1020.	1010.	1000.
7.	Sr++								
8.	Al+++								
9.	T-Fe++								
10.	Mn								
11.	SiO_2								
12.	Na	2290.	2920.	3150.	3400.	3480.	3590.	3640.	3630.
13.	T-Alk								
14.	P-Alk								
15.	Sol.Alk								
16.	TOC								

* All Alkalinities as $CaCO_3$

7/15/77 JS/bd

APPENDIX I — HOW DOES THIS CATION EXCHANGE SOFTENING PROCESS SUCCEED?

Softening saline water by IX for desalting pretreatment and then using the desalting reject as the sole regenerant may not seem logically possible to those unaquainted with some of the basic physiochemical relationships of IX. On the basis solely of mass balances between Na^+ and Ca^{++}, this IX-desalting process may seem reminiscent of a perpetual motion machine because there is no supplemental input of chemicals to sustain the process. Even some of the Na^+ is lost and unavailable for use as regenerant in the reject brine when membrane desalting is used because rejection of Na^+ by the membrane is not total. Successful cyclic operation is aided by — but not generally dependent upon — regenerant recycling. The following simplified basic IX expressions explain how the process works for the case when regenerant is not recycled. A later section in this appendix includes a mass balance of Na^+ in the process when regenerant is recycled.

Simplified mathematical expressions for the cation exchange softening process [30] clarify the basic chemical thermodynamic driving forces at equilibrium. More rigorous equations are available elsewhere [31, 33], but the following equations demonstrate the principle chemical mechanism of monovalent-divalent ion exchange.

Equilibrium Expressions

The process of cation exchange softening, removal of primarily Ca^{++} and Mg^{++} from water and their replacement by an equivalent amount of Na^+ is expressed by:

$$TH^{++} + 2\overline{Na}^{+} \gtrless \overline{TH}^{++} + 2Na^{+} \qquad \text{(I-1)}$$

The TH^{++} (total hardness) means Ca^{++} plus Mg^{++}. A bar above indicates an ion attached to the cation exchange resin or the resin phase and without a bar indicates the aqueous solution phase.

The mass-action expression for this exchange at equilibrium on a microscale can be written:

$$K_{TH/Na} = \frac{\overline{C}_{TH}\, C^2_{Na}}{\overline{C}^2_{Na}\, C_{TH}} \qquad \text{(I-2)}$$

where C_{Na} and C_{TH} are the molar concentrations of reactant and products in moles per liter and $K_{TH/Na}$ is an average equilibrium constant. The activity coefficients of the individual cations in solution and in the resin phase are assumed to equal 1.0 and have been left out of this approximate relationship for mathematical simplicity. Activity coefficients approach a value of 1.0 in dilute solutions but are nearly impossible to measure in the resin phase. Also, this equation does not account for mass transfer or kinetic rates, and does not consider a finite bed size wherein equilibrium concentrations vary with depth into the bed and the bed is not fully exhausted. Yet this simplified equation is useful for illustrating the general equilibrium behavior and driving forces for cation exchange softening.

Equation I-2 can be converted to an equivalent fraction form:

$$\frac{\overline{X}_{TH}}{(1-\overline{X}_{TH})^2} = K_{TH/Na}\,\frac{\overline{C}}{C}\cdot\frac{X_{TH}}{(1-X_{TH})^2} \qquad \text{(I-3)}$$

where:

X_{TH} = the fraction of total equivalents in solution which are Ca^{++} plus Mg^{++} The bar above again indicates the resin phase. The remaining cations are assumed to be Na^+ so that $X_{TH} + X_{Na} = 1$. Over 90 percent of the cations in many brackish waters consist of Na^+, Mg^{++}, and Ca^{++},

C = the total equivalent concentration of cations in equivalents per liter of solution (not individual molar concentrations as in equation I-2). Note that C is proportional to the TDS concentration, and

$\overline{C}$ = the total cation exchange capacity of the resin in equivalents per liter of resin.

The derivation of equation I-3 is not difficult and is contained in references 30, 31, and 33. Reference 31 contains a more exact approach for the ternary system of Ca^{+2}, Mg^{+2} and Na^{+1}.

Several aspects of this IX process can be illustrated using equation I-3. The values of $K_{TH/Na}$ and $\overline{C}$ are primarily a property of the resin and relatively constant in the present case of fully ionized cation exchange. During softening, the resin is exhausted with brackish feed water. The feed water at the YDTF had a C of about 0.05 meq/L. Equation I-3 indicates that a lower C favors greater absorption of $\overline{TH}^{++}$ onto the resin phase from the solution and simultaneous desorption of Na^{++} from the resin into the solution. During regeneration, the higher C of the regenerant (about 0.55 eq/L in 35 g/L fresh regenerant from 92-percent recovery desalting reject at the YDTF) accompanies greater exchange of the $\overline{TH}^{++}$ in the resin for Na^{+} from solution. In addition, since the desalting reject is concentrated, softened water, X_{TH} for the reject is considerably lower than that for the unsoftened feed. This also drives the regeneration of the resin to the Na form, achieving a low $\overline{X}_{TH}$.

The key point demonstrated using equation I-3 is that the higher total concentration C of the IX regenerant (desalting reject) as compared to the IX feed tends to favor absorption of the divalent cations during service or exhaustion, but tends to drive elution of the divalent cations from the resin during regeneration. This effect becomes more important with higher desalting recoveries because then there is a larger factor between values of C for the IX feed and regenerant.

In an earlier Bureau of Reclamation report [10], it was stated that it was unlikely that IX softening with reject brine regeneration could be carried out where the ratio of sodium to calcium equivalent concentrations in the IX feed was less than 1.8. Application of equation I-3 shows that such a 1.8 ratio limitation to all water compositions and desalting recoveries cannot be strictly adhered to. This is especially true when Na^{+} can be passed through the resin more than once through regenerant recycling.

Conservation of Na^{+} Due to Regenerant Recycling

A sodium to calcium ratio limitation almost completely disappears when regenerant is recycled. Sodium accumulates and cycles within the IX desalting process in the regenerant recycling system and between the IX and desalting unit. This can be illustrated using the data for cycle 4.02.42. A mass balance of Na^{+} per cycle for cycle 4.04.42 is shown on figure I-1. In terms of this Na^{+} mass balance, it is seen that the process requires that there be sufficient Na^{+} in the partially softened feed (on average) to offset outputs of Na^{+} from the system in a cycle. The loss of Na^{+} in the rinse effluent and drain could be eliminated by further recycling this stream as in the recommended IX cycle (table 14). Because the loss of Na^{+} in the desalting product and in the spent regenerant are approximately proportional to the Na^{+} concentrations in the system, these Na^{+} concentrations reach a level where the output of Na^{+} equals the input at steady state. (The concentration of Na^{+} in the desalted product is relatively high in this experimental example because of the primary purpose for which the ED was being operated, which was to produce reject brine for IX regeneration rather than to produce a low TDS product water.)

Thus, the rule of thumb suggested by Haugseth and Beetelshees [10] that the equivalency ratio of Na^{+} to Ca^{++} should be greater than 1.8 to avoid the requirement for supplemental NaCl is not valid — particularly when regenerant recycling is accomplished. Rather, the Na^{+} to Ca^{++} ratio is largely irrelevant, in this case, and other process variables and relationships dominate as just outlined. Hopefully, further modeling in the future will better define these relations and the limitations posed by a feed water composition and desalting recovery.

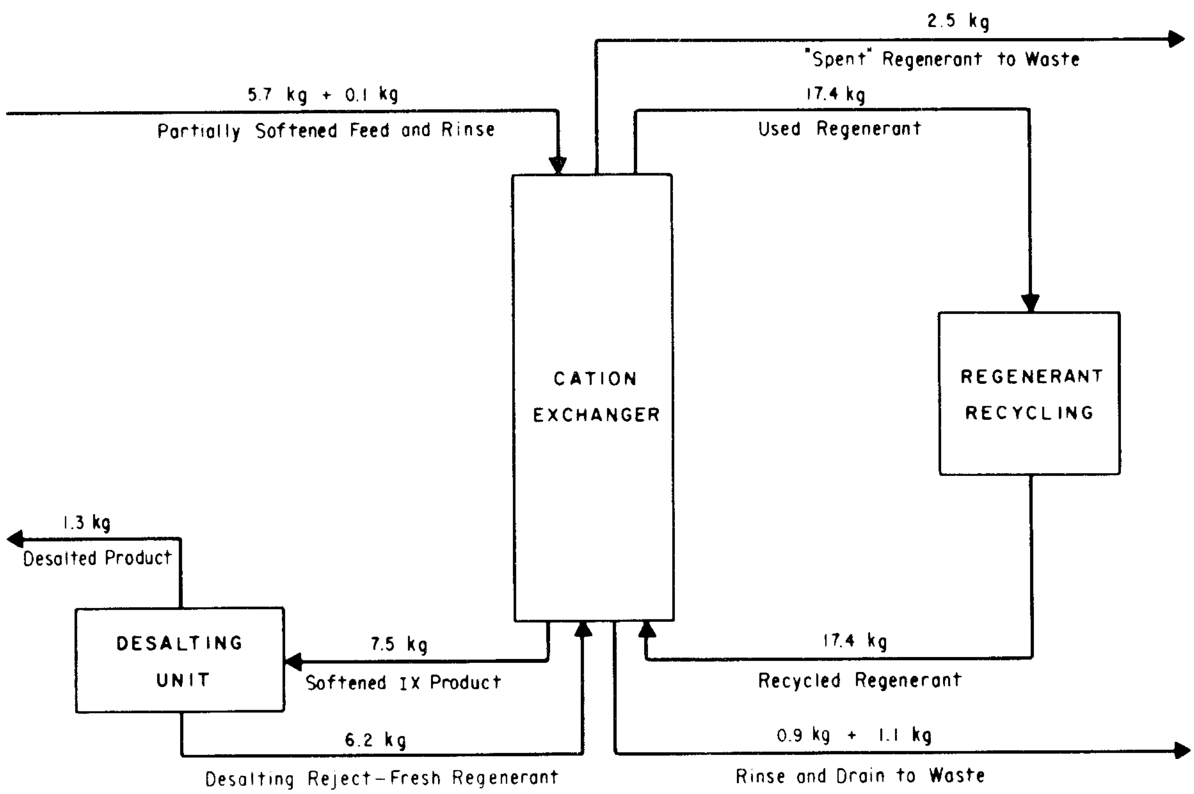


Figure I1. — Mass balance of Na^+ during cycle 4.02.42.

Mission of the Bureau of Reclamation

The Bureau of Reclamation of the U.S. Department of the Interior is responsible for the development and conservation of the Nation's water resources in the Western United States.

The Bureau's original purpose "to provide for the reclamation of arid and semiarid lands in the West" today covers a wide range of interrelated functions. These include providing municipal and industrial water supplies; hydroelectric power generation; irrigation water for agriculture; water quality improvement; flood control; river navigation; river regulation and control; fish and wildlife enhancement; outdoor recreation; and research on water-related design, construction, materials, atmospheric management, and wind and solar power.

Bureau programs most frequently are the result of close cooperation with the U.S. Congress, other Federal agencies, States, local governments, academic institutions, water-user organizations, and other concerned groups.