NANOFILTRATION OF A HIGH SALINITY

GROUNDWATER ON THE

HOPI RESERVATION

Wilbert Odem
Northern Arizona University
Flagstaff, AZ

Contract No. 1425-3-CR-81-19540

Water Treatment Technology Program Report No. 3

May 1995

U. S. DEPARTMENT OF THE INTERIOR
Bureau of Reclamation
Denver Office
Technical Services Center
Environmental Resources Team
Water Treatment Engineering and Research Group

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY (Leave blank)

2. REPORT DATE
May 1995

3. REPORT TYPE AND DATES COVERED
Final

4. TITLE AND SUBTITLE
Nanofiltration of High Salinity Groundwater on the Hopi Reservation

5. FUNDING NUMBERS
Contract No.
1425-3-CR-81-19540

6. AUTHOR(S)
Wilbert Odem

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
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8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Bureau of Reclamation
Denver Federal Center
P.O. Box 25007
Denver, CO 80225-0007

10. SPONSORING/MONITORING AGENCY REPORT NUMBER
Water Treatment Technology Program Report No. 3

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Available from the National Technical Information Service, Operations Division, 5285 Port Royal Road, Springfield, Virginia 22161

12b. DISTRIBUTION CODE

13. ABSTRACT (*Maximum 200* words)

Commercial nanofiltration membranes were evaluated using a pilot scale testing apparatus for treatment of a high salinity groundwater used as a drinking water source at the Hopi Junior/Senior High School. Based on short term testing results (pressure requirements and permeate quality) two of the membranes were selected for longer term testing in the laboratory and on-site. Both of these membranes provide satisfactory treatment results which indicate that in a full scale system either membrane would produce drinking water that meets Federal and State requirements for total dissolved solids.

14. SUBJECT TERMS
Nanofiltration/drinking water/salinity/"N" Aquifer/Hopi Tribe water resources

15. NUMBER OF PAGES
46

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UL	UL	UL	UL

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. Z39-18
298-102

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Bureau of Reclamation
Mission Statement

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U.S. Department of the Interior
Mission Statement

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 sound use of our land and water resources; protecting our fish, wildlife, and biological diversity; 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 ensure that their development is in the best interests of all people by encouraging stewardship and citizen participation in their care. The Department also has a major responsibility for American Indian reservation communities and for people who live in island territories under U.S. Administration.

ACKNOWLEDGEMENTS

This project was funded under Contract No. 1425-3-CR-81-19540 through the Bureau of Reclamation's Water Treatment Technology Program. I would like to express my appreciation to Stan Hightower for his assistance throughout this project. In addition I would like to thank Tony Laban and the Facilities Management staff of the Hopi Junior and Senior High School for their cooperation and patience during the on-site testing. The Hopi Tribe's Natural Resources and Water Resources staff have also been very generous with their time and information.

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GLOSSARY

ACRONYMS/ABBREVIATIONS

an	centimeters
DBSA	Daniel B. Stephens and Associates
MCL.	maximum contaminant level
N	Newtons
NF	nanofiltration
ntu	nephelometric turbidity unit
O&M	operations and maintenance
psi	pounds per square inch
RO	reverse osmosis
SDI	silt density index
SR	salt rejection
TDS	total dissolved solids
TOC	total organic carbon
uv	ultraviolet

CHEMICAL FORMULAS

Al^{3+}	aluminum ion
Ba^{2+}	barium
Ca^{2+}	calcium ion
$CaCO_3$	calcium carbonate
Cl^-	chloride ion
Cl_2	chlorine
Cr	chromium
Fe^{2+}	ferrous ion
Fe*	ferric ion
H^+	hydrogen ion
HCO_3^-	bicarbonate ion
H_2O	water
H_2SO_4	sulfuric acid
K^+	potassium ion
Mg^{2+}	magnesium ion
Mn^{2+}	manganese ion
Na^+	sodium ion
Ni	nickel
NO_3^-	nitrate ion
SiO_2	silica
SO_4^{2-}	sulfate ion

SUMMARY

Commercial nanofiltration membranes were evaluated using a pilot scale testing apparatus for treatment of a high salinity groundwater used as a drinking water source at the Hopi Junior/Senior High School. Based on short term testing results (pressure requirements and permeate quality) two of the membranes were selected for longer term testing in the laboratory and on-site. Both of these membranes provided satisfactory treatment results which indicate that in a full scale system either membrane would produce a drinking water which meets Federal and State standards for TDS.

Hopi Tribal officials have expressed interest in the results of this testing. This information will be used to help determine their response to the water quality problems at the school. Officials of the Bureau of Indian Affairs, which is responsible for facilities at the high school, also have expressed interest in the results.

Preliminary estimates for a full scale system indicate that the system costs, installation costs, and first year checkout and monitoring will cost approximately $ 125,000, or about $2.50 per installed gallon per day, based on a 50,000 gallon per day need. Operation and maintenance costs are estimated at approximately $0.95 per 1000 gallons. Assuming a 20-year project life, the total costs are approximately $1.29 per 1000 gallons.

1 .O INTRODUCTION

Included in the Bureau of Reclamation's Water Treatment Technology Program's objectives is the development of effective and economic treatment of impaired quality water for rural America. According to the Program Plan the program will emphasize 'substantial participation by the non-Federal desalting and water treatment communities and by academia'. The Program Plan also emphasizes the importance of technology transfer to communities that can benefit from information developed through Program-sponsored research.

1.1 Background

Three water supply wells at the Hopi Junior and Senior High School serve the needs of the school and of the adjoining teachers: community. The school is located approximately 7 miles (11.3 km) east of the town of Polacca on the Hopi Reservation, or about 150 miles (241.4 km) northeast of Flagstaff, Arizona (Figure 1). Approximately 500-600 students attend the school and approximately 150 residents live in the teachers' community. Additionally, the water is used for landscaping and fields maintenance at the school. The three wells feed into an elevated storage tank located behind the school. The water from these wells is high in TDS (total dissolved solids), with high concentrations of sodium, chloride, and sulfate. The water quality does not represent a health threat, but has presented problems due to objectionable taste and corrosion of pipes and water heaters, and has caused problems with maintenance of the school football field

Dulaney (1989) stated that the Navajo, or "N", Aquifer has two chemically distinct types of water: 1) a calcimn bicarbonate type of water found in the north and west portions of the aquifer system, and 2) a sodium-chloride-sulfate. type of water near the east and southeast of the aquifer system (where the high school wells are located). Dulaney suggested that the high salinity associated with the sodium-chloride-sulfate waters may be due to mixing with either the overlying "D" Aquifer or the underlying "C" Aquifer. A report by the Council of Energy Resource Tribes (1989) on water quality issues on the Hopi reservation presented mean water quality data for water from the "N" Aquifer, the "D" Aquifer, 'the "C" Aquifer, and the alluvial aquifer. Data from the high school wells more closely resembles mean water quality from the "D" Aquifer, a lower quality source than the "N" Aquifer. However, ranges of data show that the high school water chemistry falls within maximum values presented for the "N" Aquifer (CERT. 1989). Daniel B. Stephens & Associates (DBSA) compiled the Report of Year Two Activities EPA 106 Water Quality Assessment Program for the Hopi Tribe. In this report DBSA addressed the problem of high salinity in the three high school wells and one in the nearby community of Polacca. A summary of water and analyses for the three high school wells was presented and is shown in Table 1. Figure 2 shows a map of the "N" Aquifer on the Hopi and Navajo Reservations.

DBSA suggests two reasons for the lower quality "N" Aquifer water observed in these wells: 1) a natural mixing of waters from the "N" Aquifer and the "D" Aquifer due to either faulting in the area, or more likely, to the correlation of the high salinity wells with the south-southeast boundary of the "N" Aquifer, or, 2) mixing of waters from the two aquifers due to poor construction of the high school wells. DBSA identified four possible mitigation options for addressing natural or manmade degradation of "N" Aquifer water quality at the Hopi High School:

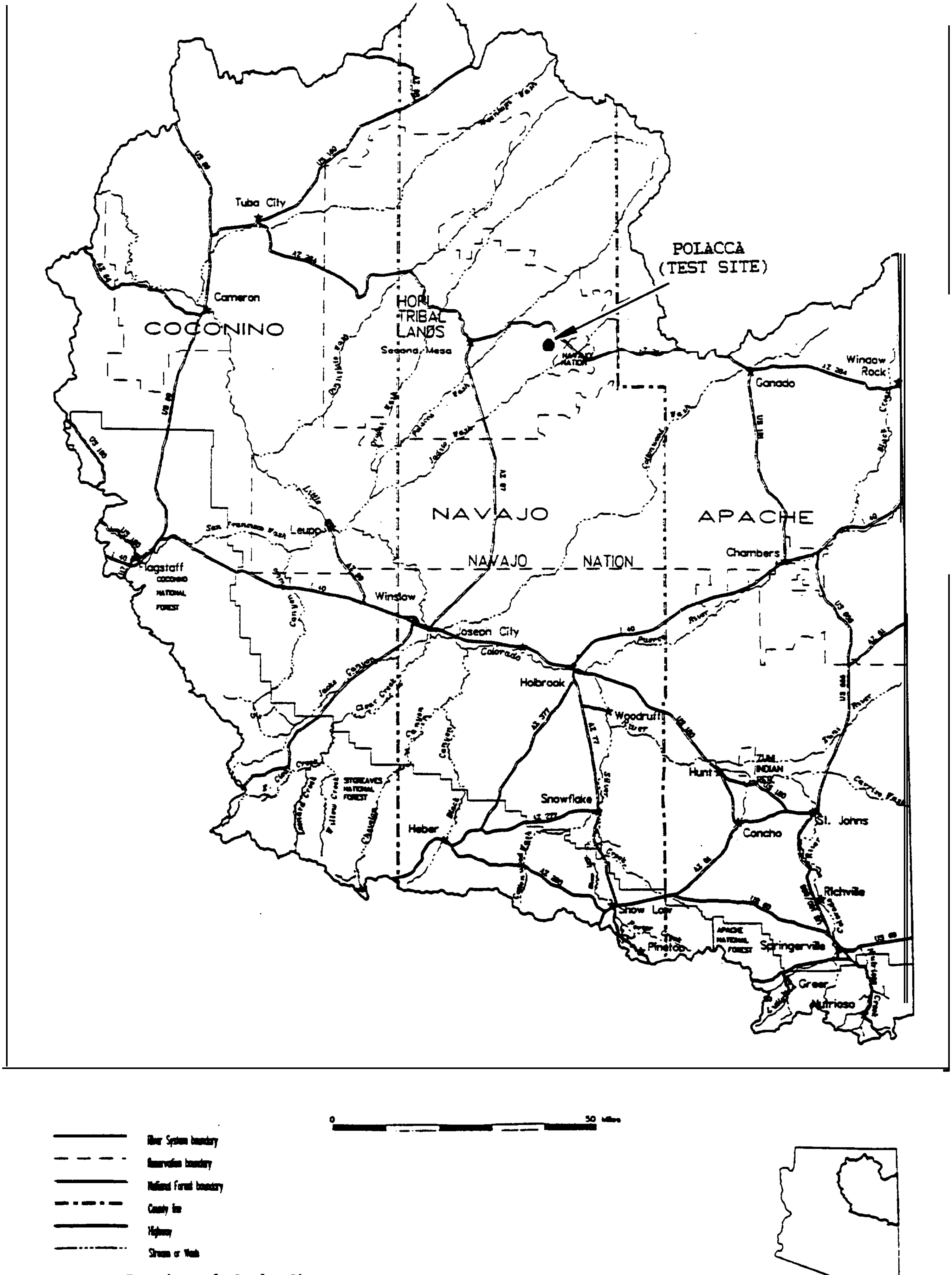


Figure 1. Location of Study Site.

TABLE 1. Water Quality of the Hopi High School Wells.

Parameter	Avg. Concentration (mg/l)	Concentration Range (mg/l)
Arsenic	< 0.02	
Barium	< 0.1	
cadmium	< 0.005	
Chromium	< 0.02	
Fluoride	2.58	
Lead	< 0.02	
Mercury	c 0.001	
Nitrate	0.14	
Selenium'	< 0.005	
Silver	< 0.02	
Alkalinity (as $CaCO_3$)	286.2	260 - 445
Calcium	4.88	1.4 - 8.0
Chloride	463.8	230 - 760
Copper	0.12	
Hardness	15.4	
Iron	0.2	
Magnesium	1.2	0.4 - 2.0
Manganese	< 0.05	
Potassium	1.62	0.8 - 2.8
PH	8.74	8.4 - 9.1
Silica (as SiO_2)	4.43	3.66 - 5.36
sodium	532.0	258 - 810
Sulfate	171.0	80 - 365
TDS	1420.8	1060 - 2180
Zinc	< 0.06	
E.C. (uS/cm)	2435	1550 - 3140

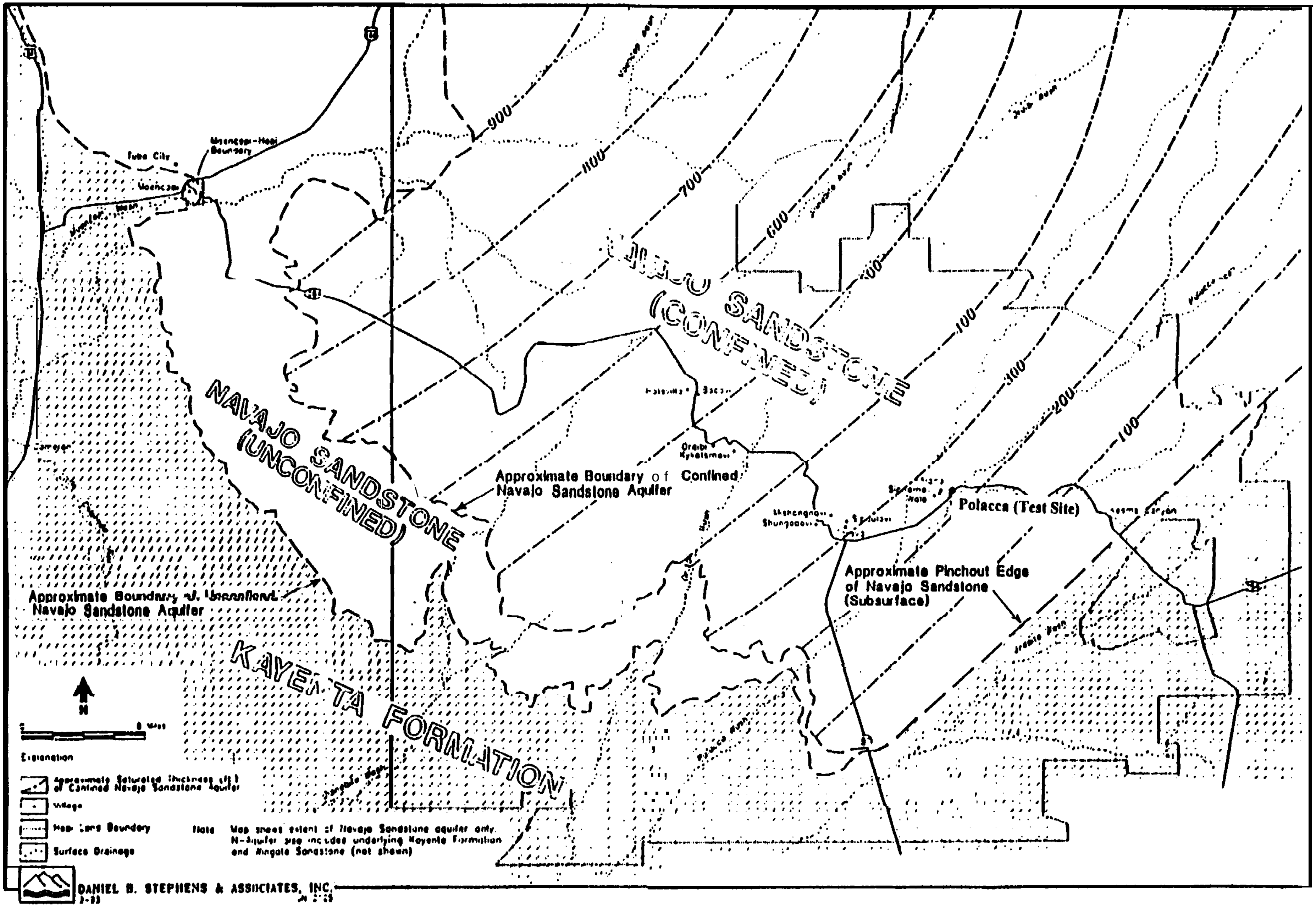


Figure 2. Extent of Navajo ("N") Aquifer On The Hopi & Navajo Reservation.

* Down-hole geophysical and water quality studies to attempt to identify the source of saline water,
* Rehabilitation of existing wells;
* Drilling of new wells;
* Installation of a water treatment (reverse osmosis type treatment system).

Down-hole testing has been completed for Well #3 with results inconclusive as to the amount of seepage that may be occurring from the "D" to the "N" Aquifer. At this time the Hopi Tribe is considering the three remaining options for mitigating the salinity problem.

1.2 Purpose of Study

The purpose of the present study is to investigate the technical feasibility of using nanofiltration to treat the water supplied by the three wells at the Hopi High School. This project was proposed in response to the Bureau of Reclamation's Request for Proposals for a preliminary research study of possible desalination demonstration projects under the Water Treatment Technology Program. A previous study by researchers at Northern Arizona University (Speidel, 1993) contained data that suggested that nanofiltration technology might provide a more cost effective approach to treatment than reverse osmosis. Nanofiltration is typically used to remove chemical compounds greater than a molecular weight of 500 Daltons. The advantage it offers over reverse osmosis is lower operating pressures, less strict pretreatment requirements, and a less concentrated reject brine which may alleviate disposal problems. Continued progress in membrane development has produced commercially available membranes that approach reverse osmosis rejection capabilities, but operate at lower pressures typical for nanofiltration. This study identified and tested commercially available nanofiltration membranes for heating the groundwater supplied by the wells at the Hopi High School.

2.0 METHODOLOGY

2.1 Preliminary Work

Prior to the actual testing of the membranes initial work had to be performed as described in the following tasks:

* determination of source water quality;
* identification and acquisition of candidate membranes:
* construction of pilot-testing apparatus.

The membranes selected for evaluation were as follows:

FilmTec NF90
FilmTec NF45
Desalination Systems Desal-5
Desalination Systems DK
Hydranautics PVD 1
Fluid Systems TFCS (two tested for replicability evaluation - identified as 5956 and 5957)
Purification Products Company NF 500

These membranes were chosen on the following bases: 1) commercial availability; 2) availability of the appropriate size membranes (diameter and length) to allow testing with our apparatus. Other membranes from other manufacuturers or distributors have been identified after the project testing period. It may be desirable to do preliminary testing of these membranes prior to final membrane selection.

2.2 Phase One

Short term testing of the nanofiltration membranes was carried out in Phase One evaluations. Each membrane was tested over a 24-hour period in which the feed water was made up in the laboratory **using the source** water **chemistry as** a **recipe. Table 1** contains water quality information for the Hopi High School wells obtained from the DBSA report. We used worst case water quality data for our laboratory recipes, knowing that though this doesn't reflect typical water quality at the high schools, it was prudent to put the system under the most rigorous conditions. Analyses are still needed for strontium, total and dissolved iron, and heterotrophic plate count. These will be obtained prior to full scale design Both reject and product streams were recycled back into the reservoir after passage through the membranes. Samples were obtained at 0.5, 1, 2, 4, 8, and 24 hours. The samples were analyzed for the following parameten:

1) Feed Water: Electrical conductivity, pH, flow, pressure, Cl^-, SO_4^{2-}, Ca^{2+}, Mg^{2+};

2) Permeate: Electrical conductivity, pH, flow, pressure, Cl^-, SO_4^{2-}, Ca^{2+}, Mg^{2+};

3) Reject: Flow, electrical conductivity.

Analyses of anions was conducted on a Wescan Ion Chromatograph or a Dionex Ion Chromatograph equipped with a conductivity detector. Cations were measured on a Perkin Elmer Atomic Absorption Spectrophotometer equipped with a flame furnace or a Hach DR 3000 Spectmphotometer. Temperature and pH were measured on a Coining Model 340 pH meter. Electrical conductivity was measured on an Orion Model 160 Conductivity Meter using an Orion Model 012210 Conductivity Probe.

Flow was maintained at approximately three gal/min (11.4 liters/min) per membrane at 10% recovery. The two best performing membranes were retested under Phase One conditions with additional specific ions analyses performed. Additionally, each membrane was tested to determine product recovery versus pressure variation.

Figures 3 and 4 show schematic diagrams of the membrane testing apparatus. The apparatus consisted of the feed reservoir, 5 µm cartridge pie-filters, the high pressure pump, four membrane pressure vessels, flow meters for the permeate and reject streams, pressure gauges associated with each pressure vessel, and associated valves and tubing. The influent water was introduced from the reservoir and delivered to the membranes by the high pressure pump. Pressure gauges upstream from each pressure vessel measured influent pressure to the membranes. Both the permeate and reject streams were recycled back to the reservoir.

2.3 Phase Two

The two best performing membranes (based on water quality of permeate and pressure requirements) from the Phase One testing underwent longer term testing to evaluate possible performance changes over time. The configuration of the testing apparatus and feed reservoir were the same as in Phase One testing (Figures 3 and 4). The reject and product streams were again recirculated back into the feed reservoir.

Phase Two testing was conducted over a ten-day time period. Flow was maintained at approximately three gal/min (11.4 liters/min) and the membranes operated at 10% recovery. Samples were taken at 0.5, 1, 2, 4, 8, and every 24 hours thereafter. The samples were analyzed for the following parameters:

1) Feed Water: Electrical conductivity, pH, pressure, temperature, flow, Ca^{2+}, Mg^{2+}, Na’, SO_4^{2-}, and Cl^-.

2) Permeate: Electrical conductivity, pH, pressure, temperature, flow. Ca^{2+}, Mg^{2+}, Na’, SO_4^{2-}, and Cl^-.

3) Reject: Electrical conductivity, pH, flow.

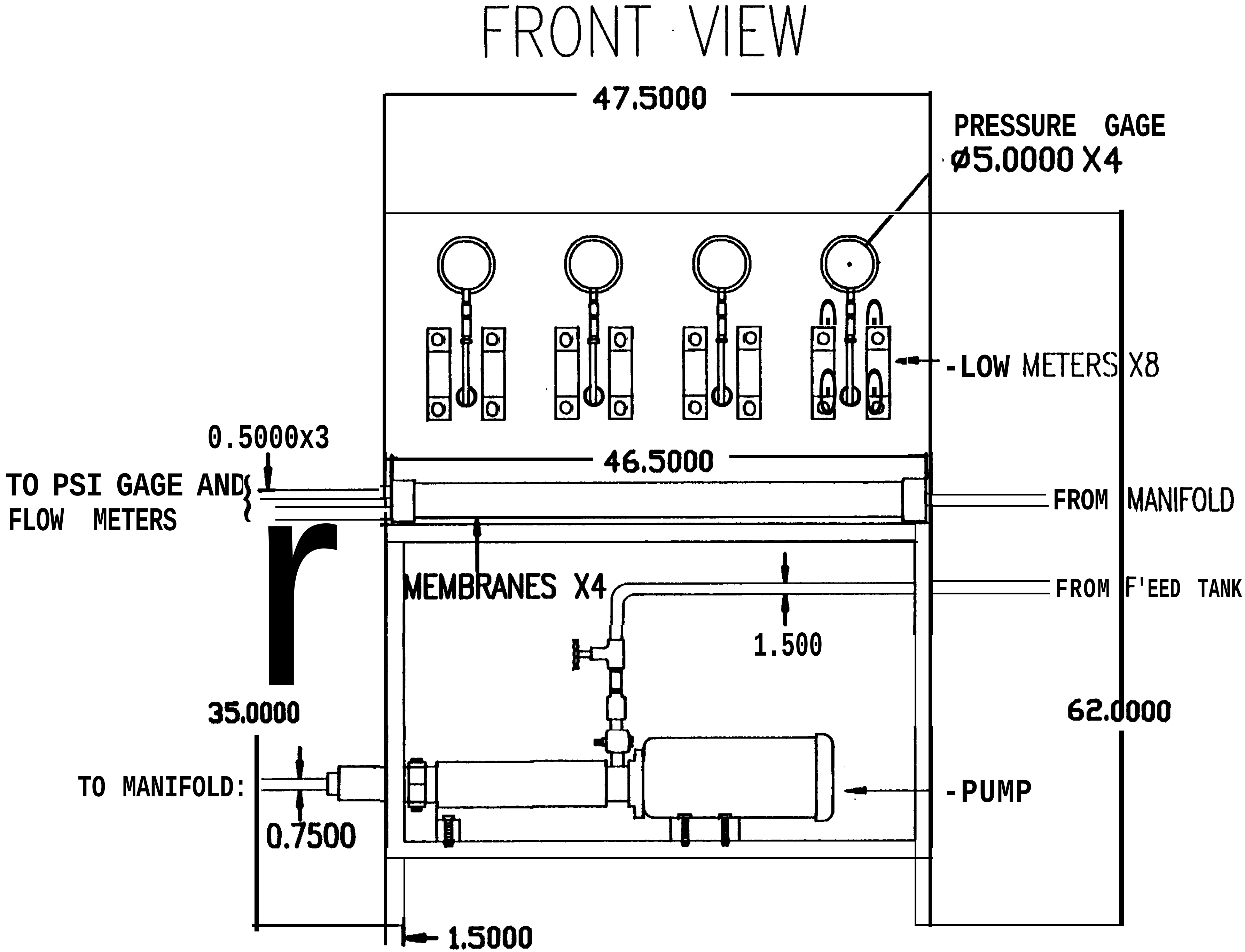


Figure3. Front View Schematic of the Membrane Testing Apparatus.

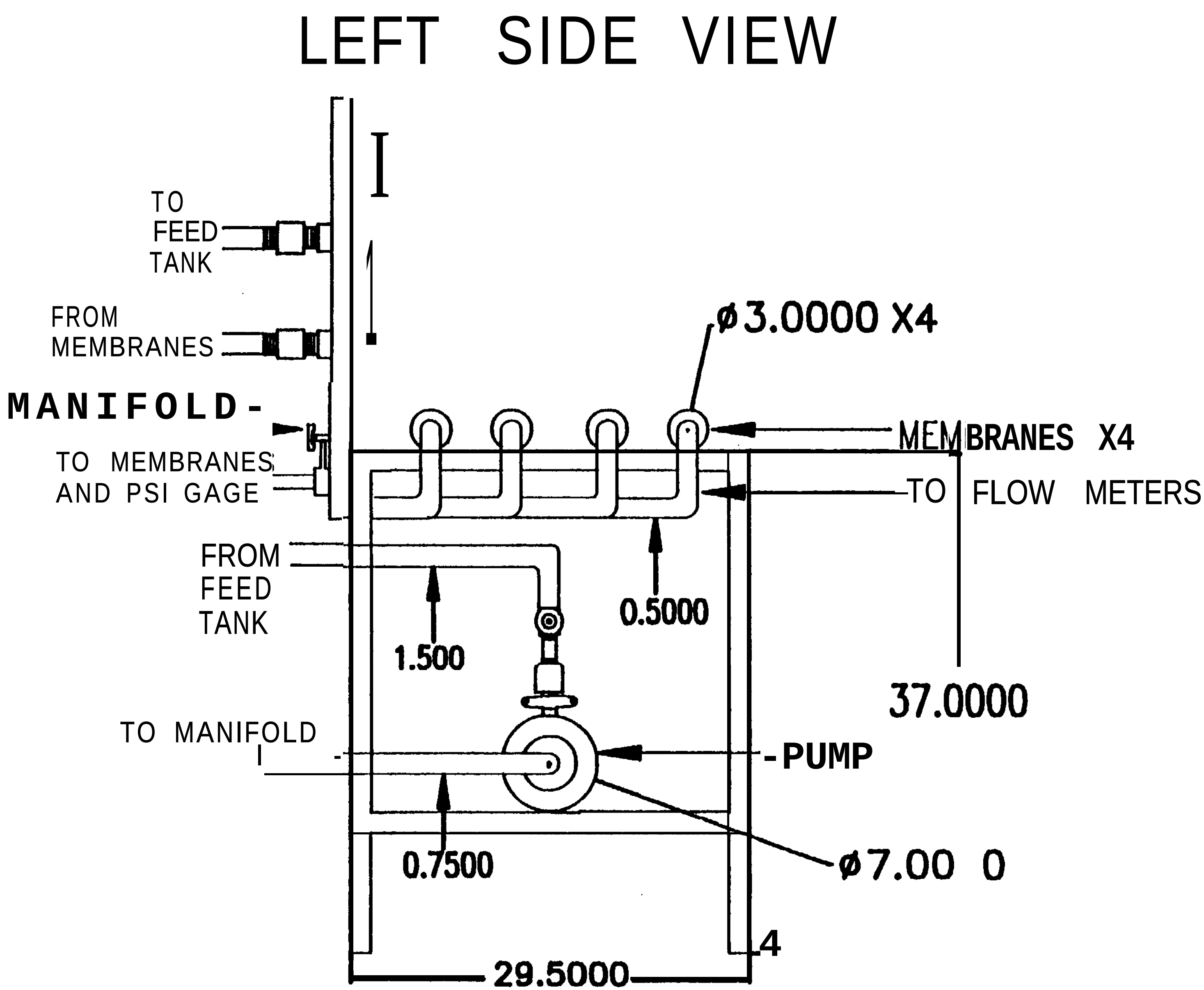


Figure4. Side View Schematic of the Membrane Testing Apparatus.

2.4 On-Site

The original proposal described testing only up through Phase Two evaluations. However, during the course of the project., communication was maintained with the Hopi Natural Resources and Water Resources agencies. Arnold Taylor, Director of Natural Resources, and Nat Nutongla, Head of Water Resources, were kept informed of the project's progress. We explored with them the possibility of testing the membranes on site at the high school and were put in touch with Tony Laban, Facilities Manager at the Hopi High School. Mr. Laban, who works for the Bureau of Indian Affairs, arranged for us to have access to the pump house at Well #1. We were able to install the testing apparatus with modifications to the facility's electrical and plumbing connections. Therefore, with much help from the tribal officials and facilities' management staff at the school, we were able to accomplish on-site testing, which was additional to the original project scope. it should be noted that this testing was done at no additional cost to the Bureau of Reclamation Approximately ten trips to the Hopi Reservation (ca. 300 miles, 482.8 km, round trip) were required for the setup and testing.

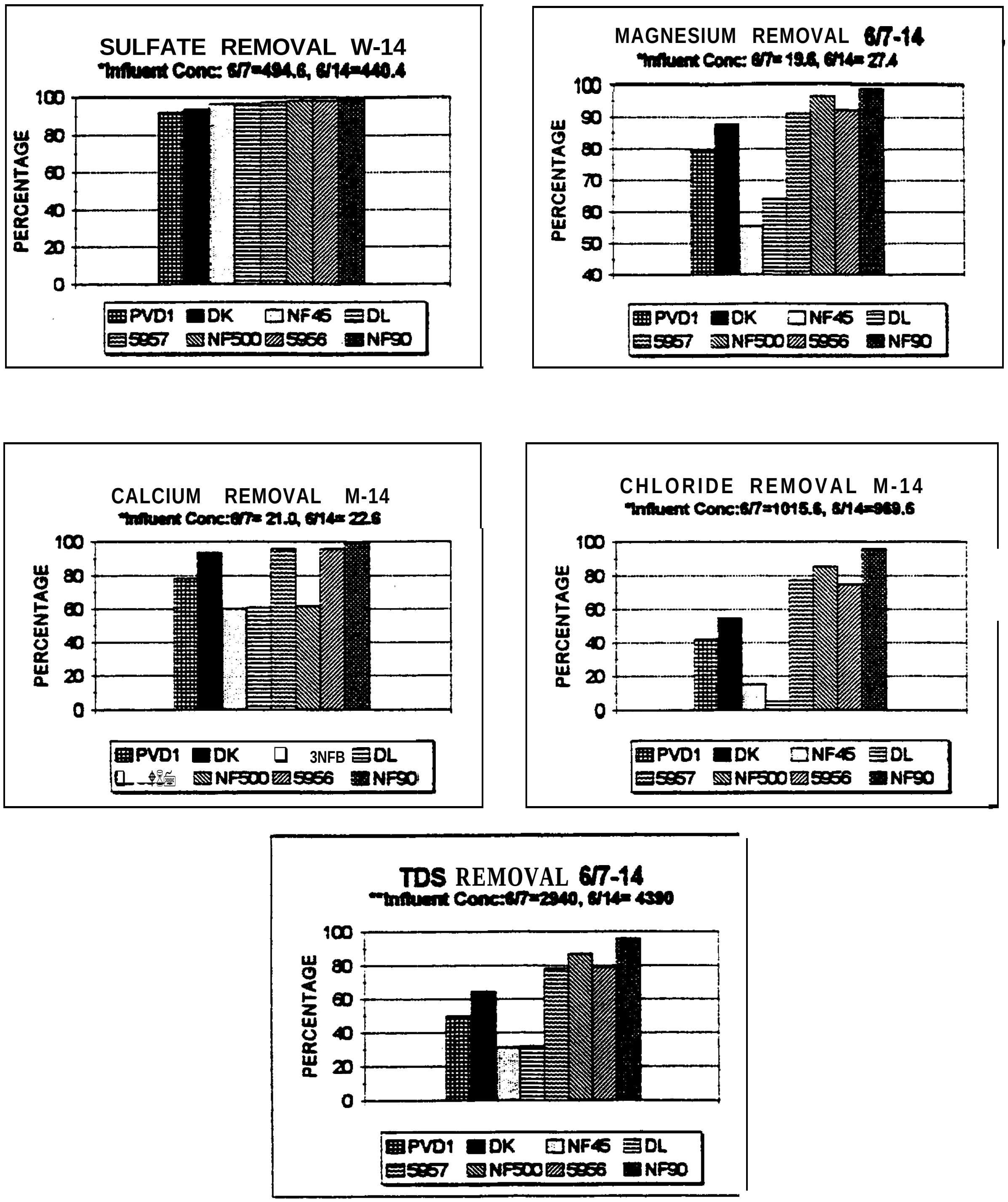
The two membranes tested in Phase Two were evaluated, along with one more membrane chosen from the original group of membranes. The tests were run for three days under conditions similar to Phase Two testing, i.e. approximately three gallons per minute, with 10% recovery. Additional testing was done on one of the membranes with the testing equipment reconfigured to run in series as opposed to in parallel. Three membranes of the same make were used to more closely simulate full scale operations. Samples were analyzed for the same parameters as in Phase Two testing.

3.0 RESULTS AND DISCUSSION

3.1 Phase One Testing

The Phase One testing occurred on 6/7, 6/14, and 6/28. As described in the methodology section this work consisted of membrane evaluation over a 24-hour period. Measured parameters included flow (influent, permeate, reject), system pressure, conductivity, SO_4^{2-}, Cl^-, Ca^{2+}, Mg^{2+}, permeate recovery, and salt rejection. The runs conducted on 6/7 and 6/14 included all eight membranes, while the 6/28 run was a replicate run for the two best performing membranes as determined by the two previous tests.

Results for the 6/7 and 6/14 runs are shown in Figure 5 and Appendix A. Also included are data sheets for all of the runs. The figures and the following synopsis of the data are based on the 24-hour sample taken for each membrane. All of the membranes exceeded 90% rejection of SO_4^{2-}. The FilmTec NF90 and the PPCM NF-500 rejected greater than 95% of the influent Mg^{2+}, while the Mg^{2+} rejection by the other membranes was as follows: Ruid Systems membranes (5956 and 5957) greater than 90%; the DeSal DK approximately 88%; the Hydranautics PVD1 80%; the DeSal DL less than 65%; and the FilmTec NF45 approximately 55%. Similar rejections were observed for Ca^{2+} rejection except for the PPCM NF-500 membrane which had about a 60%



* units = mg/l

** units = uS/cm

Figure 5. Results of Phase One Testing , 6/7/94 & 6/14/94

removal. Inspection of the calcium data from earlier PPCM samples, however, shows approximately 90-95% rejection, which is probably a more accurate estimation of the rejection.

Rejection of chloride showed the greatest disparity among the membranes. The FiiTec NF90 rejected 95% of the chloride, while the PPCM NF500 and the Fluid System membranes rejected 85% and 75%, respectively. The DeSal DK, the Hydranautics PVD1, the FilmTec NF45, and the DeSal DL membranes rejected approximately 55%, 42%. 15%, and 5% of the chloride respectively. Total dissolved solids removal, as measured by conductivity, showed similar patterns with removals as follows: FiiTec NF90 - 95%, PPCM NF-500 - 86%. Fluid Systems (5956 & 5957) - 79%, DeSal DK - 63%, Hydranautics PVD1 - 50%, FiiTec NF45 - 30%, and the DeSal DL - 30%.

The pressures required for the different membranes to achieve an approximate 10% recovery varied from membrane to membrane. The following initial pressures were recorded for the different membranes at the beginning of the runs (24-hr pressures were influenced by temperature effects and therefore are not used for comparison): FiiTec NF45 - 136 psi (93.8 N/cm'); FilmTec NF90 - 108 psi (74.5 N/cm*); PPCM NF-500 - 106 psi (73.1 N/cm^3); Desal DL - 105 psi (72.4 N/cm'); Hydranautics PVD1 - 80 psi (55.2 N/cm*); Desal DK - 102 psi (70.3 N/cm'); Fluid Systems TFCS (5956) - 139 psi (95.8 N/cm^2); Fluid Systems TFCS (5957) - 141 psi (97.2 N/cm^2). Initial startup temperatures were the same for every test. approximately 20° C ± 1° (-68" F).

Testing was also conducted to evaluate recovery and conductivity variation with changes in pressure. The influent startup temperature was the same for all of the membranes. All of the membranes showed an initial decrease in permeate conductivity as pressure increased. But at some point, typically between 120 - 140 psi (82.7 - 96.5 N/cm^2), the conductivity of the permeate began to increase. These data are included in Appendix A with the other Phase One information.

On 6/28 Phase One testing was again conducted on the FilmTec NF90 and the PPCM NP-500 membranes for replication purposes. Figure 6 and Appendix A show the results of this run. Both membranes rejected almost 100% of the influent SO_4^{2-}, Mg^{2+}, and Ca^{2+}. The FiiTec NF90 removed almost 100% of the influent Na' and greater than 95% of the Cl^-, while the PPCM NF500 rejected approximately 83% and 89% of these ions, respectively. Total dissolved solids rejection was almost 98% for the NF90 and approximately 92% for the NF-500. Both membranes again showed excellent rejection capabilities. Higher pressures were observed for both membranes. This was likely due to iron oxide fouling caused by inappropriate fittings supplied by a local distributor. The fittings were subsequently changed and membrane cleaning with an acid solution was performed

Based on permeate quality and on operating pressures, the FilmTec NF90 and the PPCM NF-500 are the best performing membranes as determined by this short term testing. Though the Hydranautics membrane operates at pressures 20% lower than these two membranes, the permeate quality is substantially lower. Therefore, these two membranes were chosen to undergo the Phase Two long term testing.

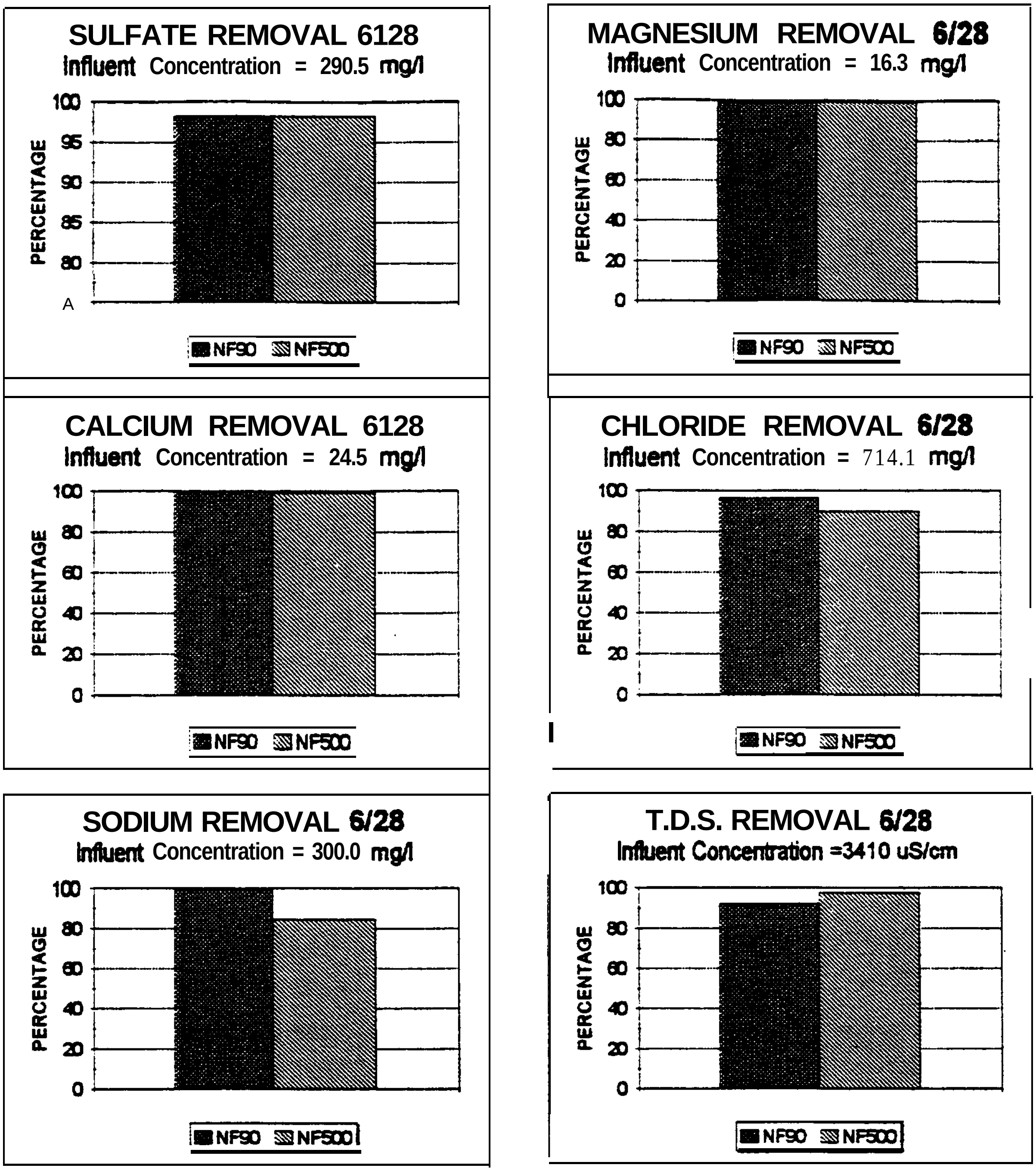


Figure 6. Results of Phase One Testing , 6/28/94

3.2 Phase Two Testing

The Phase Two testing was begun on 8/9/94 and lasted for ten days. Specific ion analyses were performed through the 24-hour sample. Thereafter only pH, conductivity, temperature, pressure, and flows were measured, except for the 10-day sample which received the full suite of analyses. Figure 7 and Appendix B show the results of this nm. A small increase in conductivity of the NF90 permeate (72 to 119 uS/cm) and no significant increase in the conductivity of the NP-500 was observed, suggesting little increase in the specific ion concentrations. During this longer term testing temperature again increased, stabilizing between 37" and 38" C (-99" F). This temperature increase was accompanied by a corresponding decrease in operating pressure, from 100 psi to 89 psi (68.9 to 61.4 N/cm^2) for the PPCM NF-500 and 128 psi to 99 psi (88.3 to 68.3 N/cm^2) for the FilmTec NF90. However, as noted above, the permeate quality did not deteriorate for the NF-500 membrane and only decreased slightly for the NF90 membrane.

At the ten-day sample a total dissolved solids rejection (as measured by conductivity) of 93% was measured for the PPCM NF-500 membrane and 97% for the FilmTec NF90. The last sample for which specific ions were measured, the 24-hour sample, showed rejections similar to the other Phase One tests. The NF90 membrane rejected slightly more of the Cl^-, Na'. and TDS, while both membranes rejected almost 100% of the Ca^{2+}, Mg^{2+}, and SO_4^{2-}.

Pressure measurements showed that the membrane cleaning performed after the 6/28 run had mixed results. The PPCM NF-500 membrane appears to have recovered completely, with an initial pressure reading of 100 psi (68.9 N/cm^2) for an approximately 10% recovery. This is comparable to the initial pressures observed in the first run on 6/7, approximately 106 psi (73.1 N/cm^2) for the same recovery. However, the FilmTec NF90 membrane cleaning doesn't appear to have been as successful, with an initial pressure reading of 128 psi (88.3 N/cm^2) for an approximate 10% recovery. This is a decrease from the 6/28 initial reading of 138 psi (95.1 N/cm^2), but still greater than the 108 psi (74.5 N/cm^2) recorded on the 6/7 run. Normally we would simply replace the slightly fouled membrane with a new one, but as the NF90 is still considered developmental, we were not able to obtain any more membranes until November 1994, which was too late to run the tests again. However, the results are still useful in interpreting the membrane capabilities, as the fouling did not appear to be excessive.

Both membranes performed as well in the longer term testing as they did in the short term tests. The FilmTec NF90 produces a higher quality permeate, while operating at a similar pressure.

3.3 On-Site Testing

On-site testing was conducted at the Hopi High School using three membranes: FilmTec NF90, PPCM NF-500, and Fluid Systems TFCS (5956). Ideally we would have been able to run the test for ten days. However, at the time we were conducting the tests hvo of the three wells were out of service for testing and repairs. Additionally, we had to dispose of the test water by simply draining it into an adjoining field., which may have caused some misperceptions about wasting water in this arid climate. Therefore, our extended run lasted slightly over two days. Figure 8 and Appendix C show the results of this run Samples were taken at 0.5, 1.0, 2.0, 4.0, and 52.0 hours and analyzed for the same parameters as in Phase One and Phase Two testing. In addition to using the actual

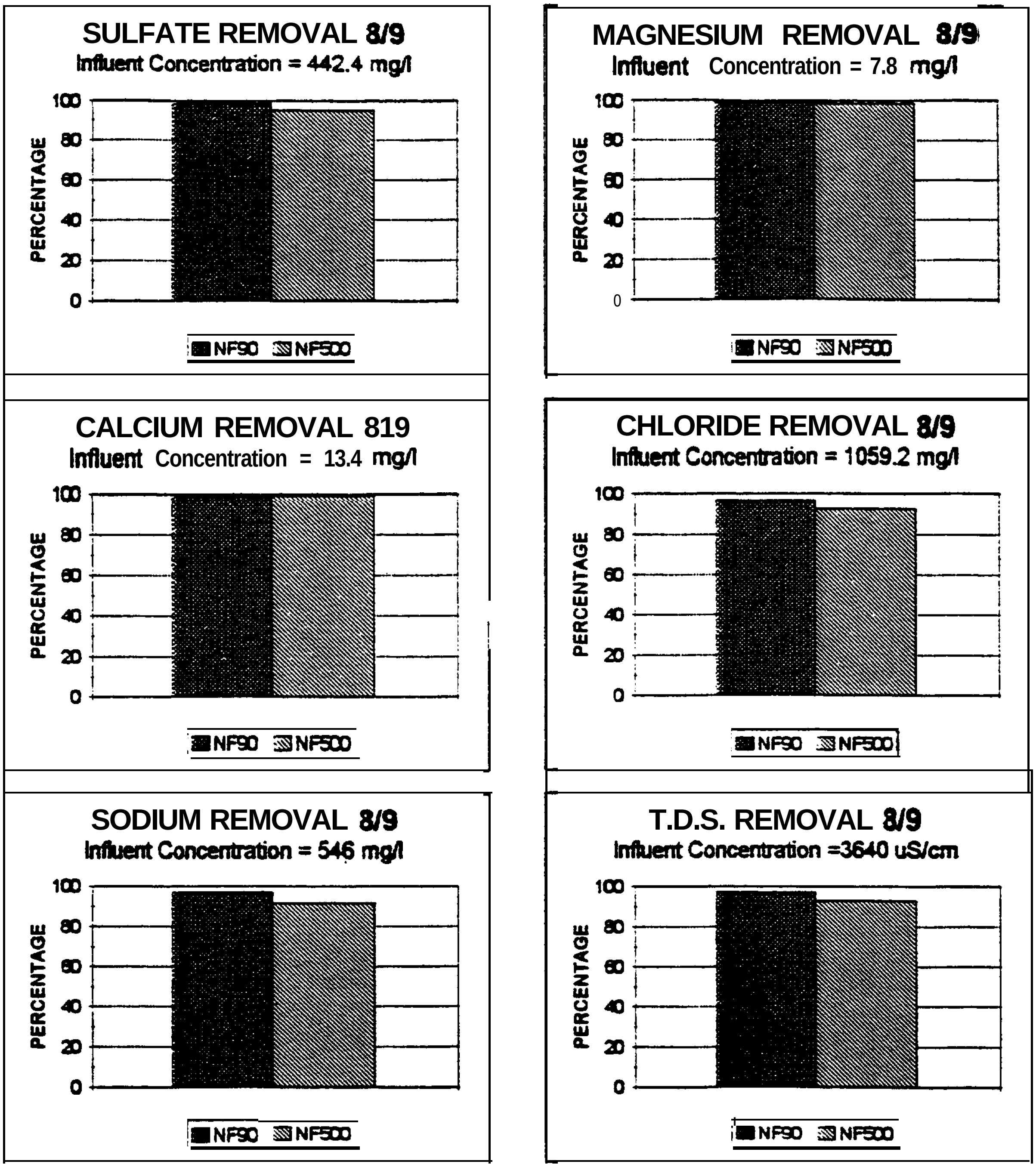


Figure 7. **Results** of Phase Two **Testing, 8/9/94**

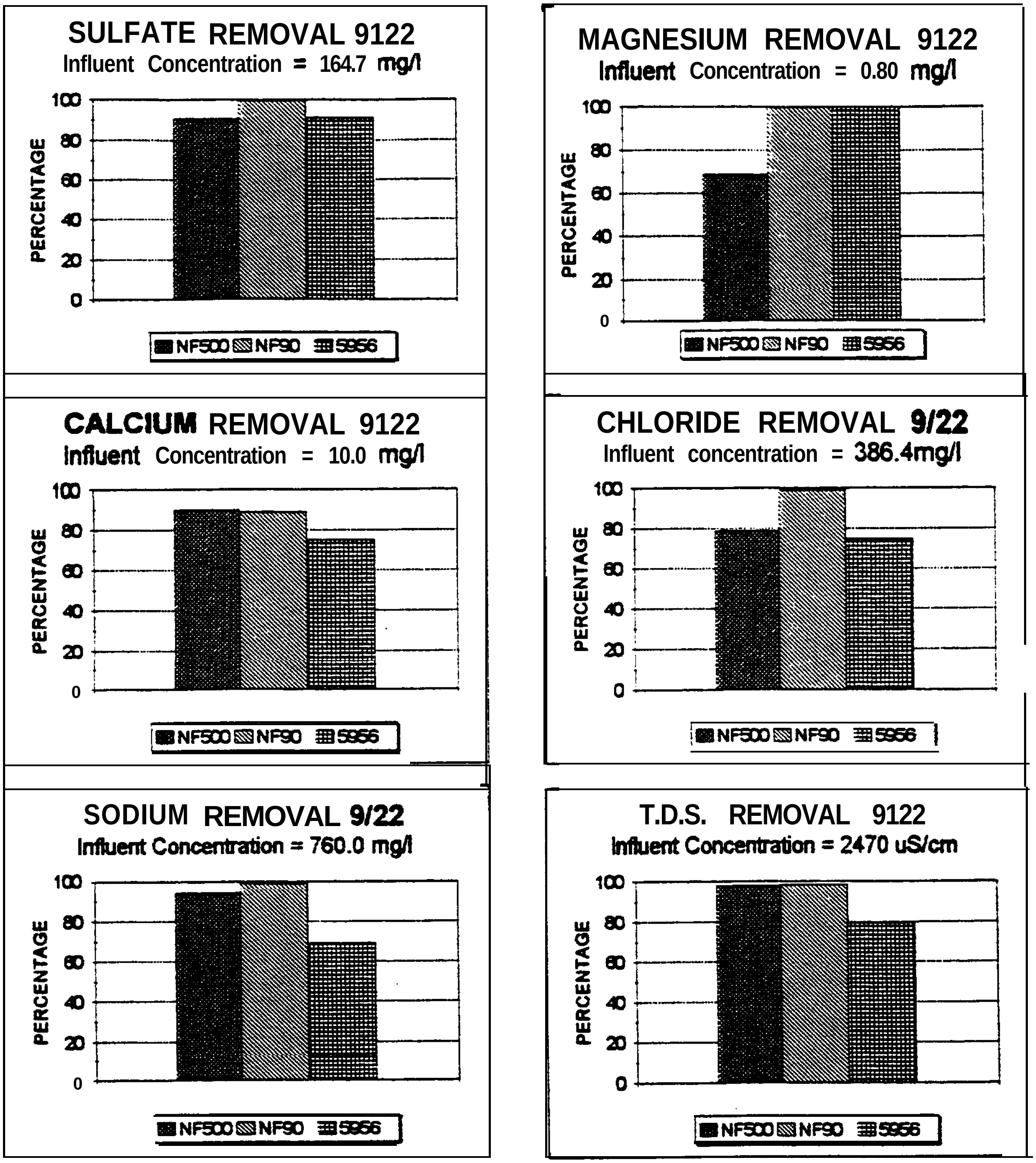


Figure 8. Results of On-Site Testing, 9/22/94.

groundwater we were able to avoid the temperature effects that affected the laboratory testing. The temperature remained at about 22°C (71.6" F) throughout the test.

The 52-hour samples were used to evaluate rejections for each of the membranes. The NF90 membrane achieved close to 100% rejections of Mg^{2+}, Na', SO_4^{2-}, and TDS. Rejection of Ca^{2+} was only 90%, however the influent Ca^{2+} concentration was low, so any measureable amount in the permeate (in this case 0.9 mg/l) will make the rejection appear somewhat low. This also occurred for Mg^{2+} and Ca^{2+} rejection by the PPCM NF-500 membrane (0.25 and 1.1 mg/l respectively), but which calculates as only a 68% and 90 % rejection The PPCM NF-500 rejected almost 100% of the SO_4^{2-} and Na', and approximately 98% of the Cl^- and TDS. The Fluid Systems TFCS membrane rejected almost 100% of the Mg^{2+}, 91% of the SO_4^{2-}, 75% of the Cl^- and Ca^{2+}, about 70% of the Na', and more than 80% of the TDS.

All of the membranes requited higher pressures to achieve a 10% recovery during the on-site tests than in the lab tests. The reason for this is not known at this time, but these pressures are still well below those used for reverse osmosis membranes. Further membrane testing on-site with new membranes would allow examination of this disparity in operating pressures. The on-site tests were very informative for a number of reasons. These tests provided confirmation of laboratory data, showing that the two best perfonning membranes also performed well in the field The tests also showed that laboratory simulation of the treatment process provides a reasonable estimation of on-site performance. It was also very informative to be able to interact with the people who are involved in this issue and to become aware of the various perspectives. These people included the Hopi Natural Resources and Water Resources staff, the Hopi High School facilities staff and BIA personnel, and the teachers, staff and students of Hopi High School.

In summary, it appears that the two membranes identified in the laboratory testing (FilmTec NF90 and PPCM NF-500) also performed well in the on-site evaluations. The FilmTec NF90 produces a higher quality product water, achieving a higher Cl^- and TDS removal than the PPCM NF-500. Both membranes operate at similar pressures, so there appears to be no economic basis with respect to energy consumption to choose one over the other. Therefore, looking purely at permeate quality it would appear that the FilmTec NF90 would be the preferred membrane.

4.0 PRELIMINARY DESIGN ESTIMATES

Preliminary design estimates were solicited from two firms based on the two best performing membranes. Summaries of these designs are presented below. Figure 9 shows a conceptual design for a full scale system. The designs were based on a product water flow of 50,000 gallons per day using a water analysis performed on a 10/06/87 sampling. The pilot scale testing used the high end of concentrations observed to look at worst case influent water quality. The preliminary designs are based on a more 'typical' water quality analysis. This water quality analysis is presented in Appendix D.

Assumptions:
50,000 **gal./day**
60 - 70% **Recovery**

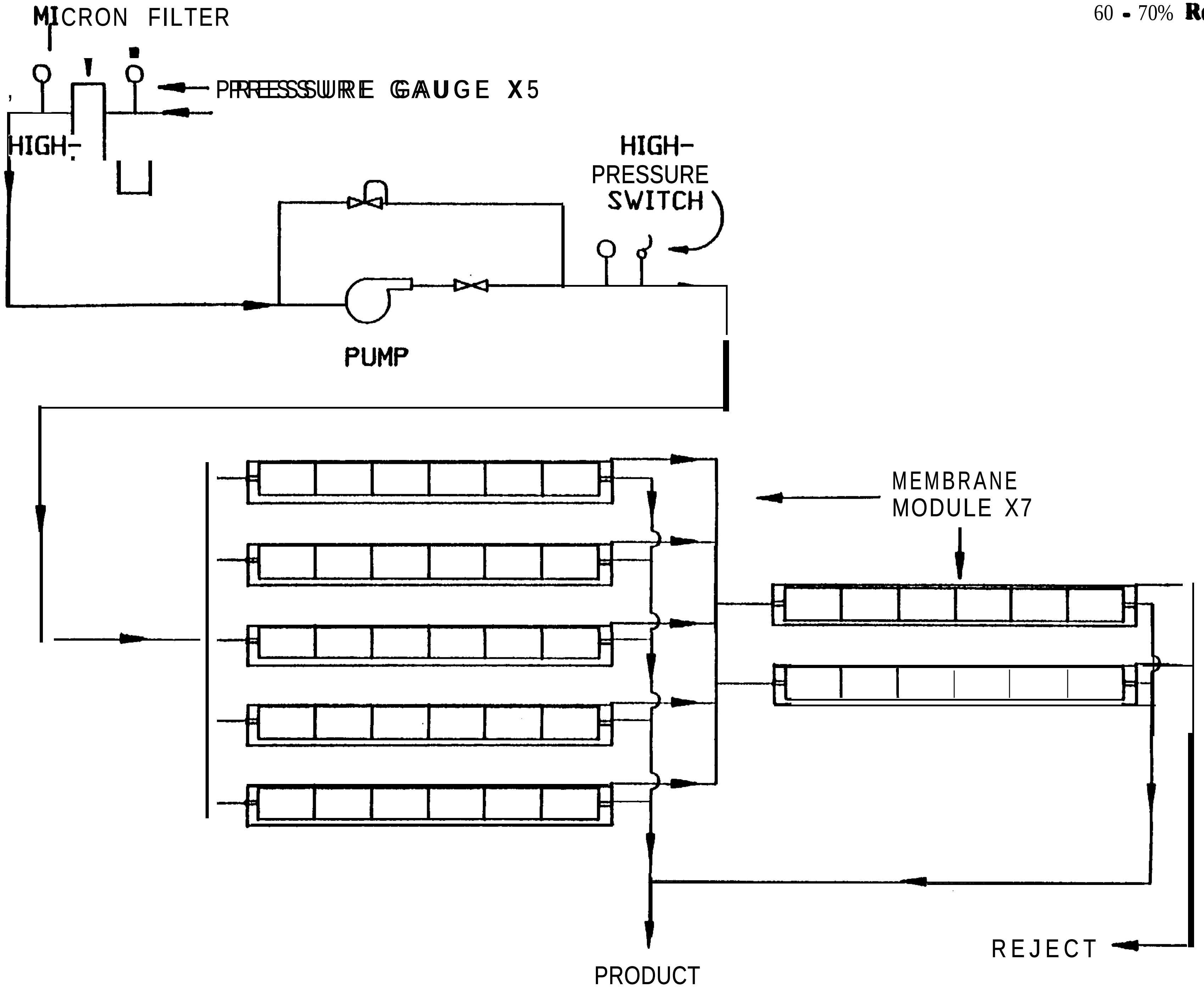


Figure 9. **Conceptual Design of a Full Scale Production System.**

4.1 Design One

A summary of the design components is as follows: twelve nanofiltration elements, three high pressure membrane vessels, one high pressure pump, 5 um pre-filtration cartridges, and associated piping, gauges, and valves. The estimated cost for this system is $62,750, excluding installation, start-up, operator training, and any applicable taxes. Membrane replacement is expected every three years at a cost of $13,500. No estimates were provided for product recovery or permeate or reject quality.

4.2 Design Two

A summary of the design components is as follows: two booster pumps, 5 um pre-filtration cartridge, high pressure pump, 35 membranes, five pressure vessels, electric control panel. and associated piping, valves, gauges, and flowmeters. Provision was also made for a water softener if needed. The estimated cost of this system is $83,220 and does not include installation and start-up costs. Addition of a water softener would add approximately $7,000 to the system costs. Full installation by the vendor is offered at a cost of $15,000. The estimated product water quality is 296 ppm $\pm$ 10 % and the reject stream would be approximately 13,000 ppm.

4.3 Brine Disposal

The requests for preliminary design estimates did not include the issue of brine disposal. This will be addressed prior to any full scale design implementation and will need to be discussed with the appropriate Hopi Tribe agencies in order to comply with tribal regulations. Some of the candidate approaches that may be investigated include discharge to sewage lagoons, spray irrigation, discharge to lined and unlined evaporation ponds, discharge to infiltration ponds, and discharge to wetlands with salt tolerant plants.

4.4 Pretreatment

Other than 5 µm cartridge filtration, pretreatment was not addressed in this report. Also, not all water quality parameters required for determining pretreatment were measured, i.e. Sr^{2+}, dissolved and total iron, HPC (heterotrophic plate count), turbidity, and SDI (silt density index). These need to be considered in any follow-on design of a demonstration pilot plant and/or full-scale system.

5.0 Discussions and Meetings

Meetings were held with users of the water and with appropriate tribal and agency representatives to discuss the water treatment testing. Results of these meetings and discussions are presented below.

5.1 Meeting with High School Teachers

The high school's teachers live in the community adjacent to the high school and are connected to the high school's water system. They have expressed concern about the water quality and many use bottled water and individual treatment systems. The project PI gave a presentation and demonstration for the teachers. A number of the teachers later filled water containers with product water from the pilot scale treatment system.. There was strong interest by the teachers in finding some resolution to the water quality problems they were experiencing.

5.2 Meeting with Officials

A meeting was held on-site attended by representatives of the Hopi Tribe, the Bureau of Indian Affairs, the Bureau of Reclamation. the high school's facilities management staff, and Northern Arizona University. Arnold Taylor, Manager of the Hopi Tribe's Department of Natural Resources, indicated that his Water Resources group was actively investigating solutions to the high school's water quality problems. Alternatives included redrilling of the production wells, establishment of a new well field in a different part of the N Aquifer, and on-site treatment. Stanley Hightower of the Bureau of Reclamation discussed funding for the project with Mr. Taylor and with the representative of the Bureau of Indian Affairs, who oversees facilities operations at the high school. The result of the meeting and discussions was that there appears to be sufficient interest by all parties to investigate possible funding for the full scale system if it is shown that it can successfully address the water quality problems at the high school.

6.0 CONCLUSIONS AND RECOMMENDATIONS

* Short and long term laboratory testing identified two nanofiltration membranes that significantly reduced the TDS. sodium, chloride, and sulfate levels of the feed water.

* Additional pilot-testing conducted on-site at the high school showed that the two membranes achieved significant reductions in the above parameters with the actual ground water from the high school wells. Projections based on the on-site testing indicate that at 80% recovery the final product water would have an electrical conductivity of 275-325 uS/cm (-250-300 mg/l TDS).

* Test data and information provided by the two design companies indicate the production system will require the nanofihration system and a pretreatment system similar to the conceptual design shown in Figure 9. The capital cost of this system. including installation and civil works is estimated to be $83,000 to $105,000.

* The 0 & M costs for this water, including membrane and cartridge replacement and electrical power is approximately $0.95/1000 gallons or $17,340 per year. This does not include the capital costs of approximately $105,000 and the costs for monitoring and checkout for the first year by Northern Arizona University of approximately $20,000. The capital costs and first year checkout costs amount to approximately $2.50 per installed gallon per day (based on 50,000 gpd production). Assuming these costs are covered by appropriate grants and/or matching funds and don't require amortization, over a 20-year project life this will raise the cost of the treated water to approximately $1.29 per 1000 gallons.

* Based on meetings with Tribal officials and the Bureau of Indian Affairs representative there appears to be sufficient interest to investigate funding for the full scale system.

* Design of a pilot demonstration facility or full-scale system should be preceded by additional analysis of pre-treatment needs, which would include at a minimum analysis of well water for Sr^{2+}, HPC, SDI, total and dissolved iron, and silica. Longer term on-site testing may also be beneficial for evaluation of pre-treatment needs. Additionally, brine disposal options would have to be investigated for both technical and regulatory viability.

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APPENDICES

Appendix A

Phase 1 Testing Results

Run **of 6/7/94**

MEMBRANE: MFG. **Filmtec** **MODEL#** **NF90**

FEEDWATER		**Cations (mg/l)**		**Anions (mg/l)**	
Temperature (deg c)	19.1	**Ca**	21.0	**SO4**	**494.60**
pH	9.03	**Mg**	19.6	Cl	1015.60
Conductivity (uS/cm)	**2940**	**Na**	**n/a**		

PERMEATE

HOUR	TEMP. (deg c)	pH	COND. (uS/cm)	PRESS. (psi)	FLOW (gpm) PERM.	FLOW (gpm) REJECT
0.5	21.3	9.22	87.8		0.28	n/a*
1.0	22.9	9.55	84.9	108.0107.0	0.27	nta
20	25.9	9.36	83.8	105.0	0.28	n/a
4.0	28.9	8.95	88.8	1020	0.29	n/a
8.0	33.3	9.53	111.2	85.0	0.28	230
24.0	36.8	8.94	116.5	84.0	0.26	2.40
REJECT24hr	36.8	8.72	3570	84.0	240	n/a

HOUR	ca	Mg	Na	SO4	cl
0.5	280	1.40	n/a	1.5	28.40
1.0	3.40	0.60	n/a	1.7	25.00
20	1.40	210	n/a	b/d	210.30
4.0	0.20	0.50	n/a	23.0	247.50
8.0	0.10	0.70	n/a	23.1	84.40
24.0	0.20	0.70	n/a	b/d	39.90
REJECT24hr	14.60	21.10	n/a	395.6	1128.40

ion values = mg/l

Run of 6/7/94

MEMBRANE: MFG. **Desal** **MODEL#** **DL**

FEEDWATER		**Cations (mg/l)**		Anions **(mg/l)**	
Temperature (de9 c)	19.1	ca	21.00	so4	494.60
pH	9.0	Mg	19.60	Cl	1015.60
Conductivity (uS/cm)	2940	**Na**	**n/a**		

PERMEATE

HOUR	TEMP. (deg c)	pH	COND. (uS/cm)	PRESS. (psi)	FLOW (gpm) PERM.	FLOW (gpm) REJECT
0.5	21.30	8.69	1615	105.0	0.33	n/a
1.0	23.20	8.81	1640	194.0	0.37	n/a
20	26.20	8.78	1693	101.0	0.38	n/a
4.0	28.90	8.58	1751	97.0	0.40	n/a
8.0	33.50	8.79	1922	75.0	0.33	2.80
24.0	36.80	8.63	2020	720	0.36	280
REJECT24hr	36.70	8.76	3340	720	280	n/a

HOUR	ca	Mg	Na	SO4	Cl
0.5	6.70	3.70	da	404.5	727.2
1.0	6.70	4.70	n/a	406.2	610.2
20	5.30	5.60	da	77.0	881.7
4.0	5.20	6.10	n/a	220.4	645.4
8.0	6.60	7.70	n/a	46.8	1130.0
24.0	8.30	7.00	nh	b/d	983.3
REJECT24hr	23.40	31.20	n/a	6115	1137.9

* b/d = below detection, n/a = not available

ion values = mg/l

Run of 6/7/94

MEMBRANE: MFG. Filmtec MODEL# NF45

FEEDWATER		Cations (mg/l)	Anions (mg/l)
Temperature (deg C)	19.1	Ca 21.06	so4 494.66
pH	9.0	Mg 19.66	cl 1015.60
conductivity (uS/cm)	2940.0	Na nia	

PERMEATE

HOUR	TEMP. (deg c)	pH	COND. (uS/cm)	PRESS. (psi)	FLOW (gpm) PERM.	REJECT
0.5	21.36	8.67	1799.0	105.00	0.33	n/a
1.0	23.30	8.80	1831.0	135.00	0.36	n/a
20	26.20	8.77	1869.0	132.06	0.38	n/a
4.0	29.00	8.59	1919.0	128.06	0.40	n/a
8.0	33.70	8.81	1901.0	85.00	0.29	2.20
24.0	36.80	8.71	1997.0	82.00	0.30	2.20
REJECT24hr	36.70	8.81	3370.0	82.00	2.20	n/a

HOUR	Ca	Mg	Na	SO4	Cl
0.5	8.30	5.40	n/a	321.3	884.1
1.0	9.10	5.00	n/a	181.7	765.1
20	9.10	7.00	n/a	175.0	849.5
4.0	10.20	7.40	nia	20.4	729.4
8.0	7.70	8.20	n/a	Wd	694.4
24.0	8.00	8.70	n/a	Wd	858.4
REJECT24hr	26.40	24.80	n/a	391.3	1055.7

ion values = mg/l

Run of 6/7/94

MEMBRANE: MFG. PPCM MODELS NF500

FEEDWATER		Cations (mg/l)	Anions (mg/l)
Temperature (deg C)	19.1	ca 21.00	so4 494.60
pH	9.0	Mg 19.60	Cl 1015.50
Conductivity (us/cm)	2940.0	Na n/a	

PERMEATE

HOUR	TEMP. (deg c)	pH	COND. (uS/cm)	PRESS. (psi)	PERM.	REJECT
0.5	21.30	9.05	215.0	106.0	0.30	n/a
1.0	23.30	9.13	216.0	105.0	0.31	n/a
20	26.30	9.00	225.0	102.0	0.33	n/a
4.0	29.30	8.79	248.0	98.0	0.35	n/a
8.0	33.50	8.97	343.0	75.0	0.26	320
24.0	36.90	8.75	381.0	72.0	0.26	3.20
REJECT24hr	36.70	8.79	3410.0	72.0	3.20	n/a

HOUR	Ca	Mg	Na	SO4	Cl
0.5	1.60	0.20	n/a	3.9	80.7
1.0	18.60	1.00	n/a	6.3	82.2
20	210	0.60	n/a	36.2	303.8
4.0	0.50	0.10	n/a	66.8	150.3
8.0	1.70	0.20	n/a	26.8	232.3
24.0	8.20	020	n/a	Wd	150.3
REJECT24hr	38.40	13.00	n/a	306.9	1154.6

● [illegible]

ion values = mg/l

Run of 6/14/94

MEMBRANE: MFG. Fluid Svs. **MODEL#** SE5957

FEEDWATER		Cations (mg/l)	Anions (mg/l)
Temperature (deg C)	19.60	Ca 22.60	SO4 440.40
pH	9.06	Mg 27.40	Cl 969.60
Conductivity (uS/cm)	4390	Na n/a	

PERMEATE

HOUR	TEMP. (deg c)	pH	COND. (uS/cm)	PRESS. (psi)	FLOW (gpm) PERM.	REJECT
0.5	21.90	9.19	880.0	141.0	0.30	1.50
1.0	23.80	9.27	848.0	149.0	0.32	1.49
2 0	25.00	9.18	842.0	139.0	0.32	1.49
4.0	29.60	9.16	881.0	137.0	0.35	1.48
8.0	33.70	9.02	922.0	129.0	0.35	1.60
24.0	36.90	8.00	929.0	128.0	0.34	1.60
REJECT24hr	37.29	8.96	4340	128.0	0.34	1.60

HOUR	ca	Mg	Na	SO4	Cl
0.5	240	290	n/a	47.10	270.00
1.0	2.20	210	n/a	32.10	197.70
2.0	1.30	2.70	n/a	55.70	418.30
4.0	0.30	250	n/a	n/a	n/a
8.0	0.40	3.40	n/a	32.00	279.00
24.0	0.90	2.40	n/a	27.60	220.00
REJECT24hr	9.80	32.20	n/a	395.8	911.70

ion values = mg/l

Run of 6/14/94

MEMBRANE: MFG. Fluid Svs. **MODEL#** SE5956

FEEDWATER		Cations (mg/l)	Anions (mg/l)
Pressure (psi)	30.0	Ca 22.60	so4 440.40
Temperature (de9 C)	19.6	Mg 27.40	Cl 969.60
Flow (gpm)	3.0	Na n/a	
pH	9.06		
conductivity (us/cm)	4390		

PERMEATE

HOUR	TEMP. (deg c)	pH	COND. (uS/cm)	PRESS. (psi)	FLOW (gpm) PERM.	REJECT
0.5	22.20	9.24	957.0	139.0	0.30	1.60
1.0	24.00	9.13	928.0	138.0	0.31	1.60
2.0	25.00	9.17	931.0	137.0	0.32	1.55
4.0	29.70	9.17	961.0	135.0	0.35	1.55
8.0	33.60	9.01	932.0	126.0	0.32	1.70
24.0	37.20	8.85	949.0	127.0	0.32	1.60
REJECT24hr	37.20	8.98	4310	127.0	0.32	1.60

HOUR	Ca	Mg	Na	SO4	Cl
0.5	2.40	3.20	n/a	49.70	313.50
1.0	290	250	n/a	38.10	241.00
20	2.50	4.50	n/a	58.40	620.20
4.0	3.90	1.60	n/a	n/a	n/a
8.0	0.40	3.10	n/a	27.30	212.70
24.0	1.40	210	nfa	34.10	243.20
REJECT24hr	14.80	20.80	n/a	380.8	676.80

* b/d = below detection, n/a = not available

ion values = mg/l

Run of 6/14/94

MEMBRANE: M F G Hydranautics **MODEL#** PVD1

FEEDWATER		Cations (mg/l)	Anions (mg/l)
Temperature (deg C)	19.6	Ca 22.60	804 440.40
pH	9.06	Mg 27.40	Cl 969.60
Conductivity (uS/cm)	4390	Na n/a	

PERMEATE

HOUR	TEMP. (deg c)	pH	COND. (uS/cm)	PRESS. (psi)	FLOW (gpm) PERM.	REJECT
0.5	22.20	9.20	2080	80.00	0.32	4.80
1.0	24.00	9.13	2090	79.00	0.34	4.80
2.0	25.10	9.14	2090	78.00	0.35	4.80
4.0	20.80	9.13	2150	77.00	0.37	4.60
8.0	33.50	9.16	2160	76.00	0.48	4.20
24.0	37.30	9.06	2190	76.00	0.48	4.20
REJECT24hr	37.30	8.98	3890	76.00	0.48	4.29

HOUR	ca	Mg	Na	SO4	cl
0.5	7.00	6.50	n/a	14.00	589.10
1.0	3.40	3.30	da	17.00	661.80
2.0	6.00	6.70	n/a	20.70	894.90
4.0	8.80	6.80	n/a	n/a	n/a
8.0	4.80	7.70	n/a	11.50	624.50
24.0	4.90	5.60	n/a	11.50	558.00
REJECT24hr	13.20	24.60	n/a	335.8	79260

ion values = mg/l

Run of 6/14/94

MEMBRANE: MFG. Desal **MODEL#** DK

FEEDWATER		Cations (mg/l)	Anions (mg/l)
Temperature (deg C)	19.6	Ca 22.60	so4 440.60
pH	9.06	Mg 27.40	Cl 969.60
Conductivity (uS/cm)	4390	Nan/a	

PERMEATE

HOUR	TEMP. (deg c)	pH	COND. (uS/cm)	PRESS. (psi)	FLOW (gpm) PERM.	REJECT
0.5	22.2	9.10	1420	1020	0.32	3.40
1.0	24.0	9.11	1451	101.0	0.34	3.30
2 0	25.0	9.00	1470	100.0	0.36	3.30
4.0	29.8	9.13	1549	08.0	0.38	3.30
8.0	33.6	9.14	1538	96.0	0.44	3.00
24.0	37.2	9.01	1560	96.0	0.44	2.80
REJECT24hr	37.3	8.97	4020	96.0	0.44	2 8 0

HOUR	ca	Mg	Na	SO4	cl
0.5	2 8 0	3.40	n/a	40.0	374.20
1.0	1.40	4.60	n/a	n/a	349.00
2 0	3.00	3.10	n/a	d a	872.80
4.0	3.10	3.80	n/a	n/a	d a
8.0	1.50	3.40	n/a	11.5	328.80
24.0	0.90	3.30	n/a	11.5	438.30
REJECT24hr	13.60	28.80	n/a	366.6	821.40

ion values = mg/l

Run of 6/28/94

MEMBRANE: MFG. PPCM MODELS NF500

FEEDWATER		Cations (mg/l)	Anions (mg/l)
Temperature (deg C)	20.6	Ca 24.50	so4 290.50
pH	9.01	Mg 18.30	Cl 714.10
Conductivity (uS/cm)	3410	Na 300	

PERMEATE

HOUR	TEMP. (deg c)	pH	COND. (uS/cm)	PRESS. (psi)	FLOW (gpm) PERM.	REJECT
0.5	2210	8.86	238.0	119.0	0.31	3.60
1.0	23.80	8.84	236.0	117.0	0.32	3.60
20	24.70	8.70	237.0	115.0	0.33	3.50
4.0	26.50	8.79	255.0	1120	0.34	3.50
8.0	28.60	a62	267.0	110.0	0.36	3.80
24.0	33.20	8.37	262.0	111.0	0.31	3.40
REJECT24hr	33.80	8.68	3770.0	111.0	0.31	3.40

HOUR	ca .	Mg	Na	SO4	Cl
0.5	0.14	0.12	47.90	15.50	46.30
1.0	0.13	0.10	46.10	8.75	43.10
20	0.19	0.14	40.00	31.00	60.00
4.0	0.21	0.16	41.30	43.80	67.30
8.0	0.25	0.18	37.10	31.50	72.00
24.0	0.15	0.10	46.10	5.25	72.00
REJECT24hr	15.60	18.30	440.00	390.0	760.00

ion values = mg/l

Run of 6/28/94

MEMBRANE: MFG. Filmtec MODEL# NF90

FEEDWATER		Cations (mg/l)	Anions (mg/l)
Temperature (deg C)	2 0 . 6	Ca 24.50	so4 290.50
pH	9.01	Mg 16.30	Cl 714.10
conductivity (uS/cm)	3410	Na 300.0	

PERMEATE

HOUR	TEMP. (deg c)	pH	COND. (uS/cm)	PRESS. (psi)	FLOW (gpm) PERM.	REJECT
0.5	2210	a95	85.50	138.0	0.32	210
1.0	23.80	9.31	78.10	135.0	0.34	200
20	24.70	9.23	80.00	133.0	0.35	1.90
4.0	26.50	9.21	83.20	131.0	0.37	1.90
8.0	28.60	9.24	86.40	130.0	0.39	1.80
24.0	34.20	8.61	81.20	134.0	0.37	1.80
REJECT24hr	33.80	8.64	3970.0	134.0	0.37	1.80

HOUR	ca	Mg	Na	SO4	cl
0.5	0.200	0.081	1.08	7.55	17.80
1.0	0.037	0.025	1.11	0.58	0.71
20	0.025	0.013	1.16	14.00	52.60
4.0	0.050	0.025	1.18	18.80	36.80
8.0	0.140	0.038	1.20	7.80	21.30
24.0	0.061	0.038	1.10	5.20	24.80
REJECT24hr	16.50	20.00	407.50	315.0	927.00

ion values = mg/l

Run of 6/7/94

Pressure variation results

FILMTEC NF90

PRESSURE	RECOVERY	CONDUCTIVITY
70	0.16	1062
80	0.19	109.8
90	024	103.1
100	029	98.3
110	0.34	87.7
120	0.39	63.8
130	0.42	83.5
140	0.48	82.7
150	0.52	87.5

DESAL - DL

'RESSURE	RECOVERY	CONDUCTIVITY
70	025	1905
80	0.32	1902
90	0.37	1824
100	0.42	1755
110	0.48	1702
120	0.53	1666
130	0.59	1642
140	0.65	1628
150	0.71	1644

PPCM NF500

PRESSURE	RECOVERY	CONDUCTIVITY
70	0.18	288
80	025	321
90	0.3	284
100	0.37	252
110	0.42	241
120	0.48	231
130	0.53	228
	0.59	225
140	0.63	237

FILMTEC NF45

PRESSURE	RECOVERY	CONDUCTIVITY
70	02	1958
80	025	1918
90	028	1878
100	0.33	1846
110	0.37	1843
120	0.39	1874
130	0.42	2010
140	0.42	2410
150	0.4	2480

Run of 6/14/94

Pressure variation results

FLUID SYS. SE5957

PRESSURE	RECOVERY	CONDUCTIVITY
70	0.16	860
80	0.18	1016
90	021	902
100	025	898
110	028	869
120	0.31	651
130	0.34	651
140	0.37	956
150	0.38	1010

FLUID SYS. SE5956

PRESSURE	RECOVERY	CONDUCTIVITY
70	0.16	981
80	0.19	1026
90	0.22	991
100	026	950
110	028	925
120	0.31	929
130	0.35	963
140	0.37	1226
150	0.38	1222

HYDRA. PVD1

PRESSURE	RECOVERY	CONDUCTIVITY
70	0.36	2160
80	0.41	2070
90	0.51	2010
100	0.59	1949
110	0.67	1888
120	0.75	1873
130	0.81	1873
140	0.89	1906
150	0.98	1961

DESAL DK

PRESSURE	RECOVERY	CONDUCTIVITY
70	025	1563
80	0.3	1683
90	0.36	1671
100	0.41	1579
110	0.48	1502
120	0.52	1443
130	0.58	1428
140	0.62	1460
150	0.68	1554

Run of 6128194

Pressure variation results

PPCM NF500			FILMTEC NF90		
PRESSURE	RECOVERY	CONDUCTIVITY	PRESSURE	RECOVERY	CONDUCTIVITY
70	a17	402	70	0.15	130.7
80	0.19	344	80	0.18	118.7
90	0.24	305	90	0.21	106.7
100	a29	285	loo	0.26	98.8
110	0.32	268	110	0.29	92.5
120	0.39	250	120	0.32	88.6
130	0.42	242	130	0.38	86
140	0.48	236	140	0.41	04.8
150	0.52	230	150	0.46	84.4

Run of **8/9/94**

Pressure variation results

PPCM NF500			FILMTEC NF90		
PRESSURE	RECOVERY	CON330TIVITY	PRESSURE	RECOVERY	CONDUCTIVITY
70	0.18	282	70	0.16	114.5
a0	0.24		80	0.19	134.3
90	a3	259	90	0.22	119.2
100	0.35	247	100	0.29	105.4
110	0.4	237	110	0.34	102.5
120	0.48	231	120	0.38	97.8
130	0.53	222	130	0.42	93.6
140	0.58	225	140	0.48	93.4
150	0.61	225	150	0.52	92.5

Appendix B

Phase 2 Testing Results

Run of 8/09/94

MEMBRANE: MFG. PPCM **MODEL#** NF500

FEEDWATER		Cations **(mg/l)**	Anions **(mg/l)**
Temperature (deg C)	20.2	Ca 13.40	so4 422.40
PH	8.6	**Mg** 7.80	Cl 1059.20
Conductivity **(uS/cm)**	3640	Na 546.0	

PERMEATE

HOUR	**TEMP. (deg c)**	**pH**	**COND. (uS/cm)**	PRESS. **(psi)**	FLOW **(gpm)** **PERM.**	FLOW **(gpm)** REJECT
0.5	21.60	8.90	354.0	100.0	0.30	3.10
1.0	21.90	8.98	224.0	100.0	0.30	3.70
2.0	**22.60**	8.90	221.0	100.0	0.29	3.00
4.0	**24.20**	8.98	214.0	96.00	0.28	3.00
8.0	27.30	8.80	243.0	92.00	0.29	2.90
24.0	31.00	8.44	250.0	89.00	0.28	2.90
REJECT 24 hr	32.60	8.63	3970	89.00	0.28	2.90
48.0	35.70	8.71	267.0	86.00	0.28	2.80
72.0	37.30	8.80	261.0	87.00	0.28	2.80
96.0	37.90	8.32	252.0	87.00	0.28	2.80
120.0	37.70	8.62	249.0	87.00	0.28	2.80
144.0	37.80	8.90	242.0	86.00	0.27	**2.80**
168.0	37.70	8.71	240.0	88.00	0.26	**2.70**
192.0	37.90	9.02	248.0	89.00	0.26	**2.80**
216.0	38.50	9.10	247.0	89.00	0.26	2.70
240.0	36.10	9.09	247.0	89.00	0.27	2.60
REJECT 240 hr			4120			

HOUR	Ca	**Mg**	Na	**SO4**	**Cl**
0.5	0.263	0.113	**45.80**	87.7	199.00
1.0	0.088	0.063	**45.40**	38.3	131.30
2 0	0.100	0.063	**39.50**	26.5	104.90
4.0	0,113	0.075	**38.50**	24.3	**108.00**
8.0	0.100	0.630	42.80	12.5	**64.50**
24.0	0.050	0.100	**44.80**	21.4	76.10
REJECT 24 **hr**	13.80	8.20	**600.0**	506.5	3267.50

ion values = mg/l

Run of 8/09/94

MEMBRANE: MFG. Filmtec **MODEL#** NF90

FEEDWATER		Cations (mg/l)		Anions (mg/l)	
Temperature (de9 C	20.0	Ca	13.40	SO4	420.50
pH	8.6	Mg	7.80	Cl	1059.20
Conductivity(uS/cm)	3640	Na	546.0		

PERMEATE

HOUR	TEMP. (deg c)	pH	COND. (uS/cm)	PRESS. (psi)	FLOW (gpm) PERM.	FLOW (gpm) REJECT
0.5	21.50	9.08	72.3	128.0	0.26	2.50
1.0	21.80	9.08	69.1	128.0	0.26	2.50
2.0	22.70	9.17	72.9	129.0	0.27	2.50
4.0	24.20	9.07	78.0	124.0	0.27	2.40
8.0	27.40	8.85	91.7	117.0	0.27	2.50
24.0	32.20	8.89	94.0	100.0	0.26	2.50
REJECT24hr	32.50	8.74	3990	100.0	0.26	2.50
48.0	35.50	8.83	108.9	97.0	0.27	2.40
72.0	37.30	8.74	111.9	97.0	0.27	2.50
96.0	38.00	8.58	114.3	97.0	0.27	2.50
120.0	38.00	8.76	173.5	97.0	0.27	2.50
144.0	37.60	8.79	108.2	98.0	0.26	2.40
168.0	37.50	8.82	110.1	98.0	0.25	2.50
192.0	37.80	9.00	119.2	99.0	0.25	2.50
216.0	38.50	9.04	121.1	99.0	0.25	2.50
240.0	36.70	9.29	119.1	99.0	0.25	2.50
REJECT240hr			4130			

HOUR	ca	Mg	Na	SO4	Cl
0.5	b/d	0.05	13.8	5.9	17.4
1.0	b/d	0.01	12.3	30.3	22.9
2.0	b/d	0.03	13.3	3.8	20.7
4.0	b/d	0.03	14.1	n/a	n/a
8.0	b/d	0.01	16.2	3.5	60.2
24.0	b/d	0.01	16.8	4.4	33.5
REJECT24hr	10.40	5.85	916.0	372.9	868.1

ion values = mg/l

Appendix C

On-Site Testing Resu lts

Run of 9/22/94

MEMBRANE: MFG. PPCM **MODEL#** NF500

FEEDWATER		Cations (mg/l)		Anions (mg/l)	
Temperature (deg C)	21.1	Ca	10.0	SO4	164.7
pH	8.6	Mg	0.8	Cl	386.4
Conductivity (us/cm)	2470	Na	760.0		

PERMEATE

HOUR	TEMP. (deg c)	pH	COND. (uS/cm)	PRESS. (psi)	FLOW (gpm) PERM.	REJECT
0.5	22.20	8.75	58.3	140.0	0.30	2.80
1.0	21.90	7.85	66.7	137.0	0.30	2.80
2.0	22.60	8.05	33.2	140.0	0.30	2.80
4.0	22.40	8.08	46.6	140.0	029	2.70
52.0	n/a	n/a	n/a	140.0	0.29	2.70

HOUR	Ca	Mg	Na	SO4	Cl
0.5	1.10	0.10	3.30	0.91	920
1.0	1.10	0.10	3.70	0.96	11.50
2.0	1.20	b/d	1.30	0.69	7.90
4.0	120	b/d	0.60	0.57	6.00
52.0	1.00	0.25	4.63	15.90	8.2

ion values = mg/l

Run of 9/22/94

MEMBRANE: MFG. Fluid Systems **MODEL#** 5956

FEEDWATER		Cations (mg/l)		Anions (mg/l)	
Temperature (deg C)	21.1	Ca	10.0	SO4	164.7
PH	8.63	Mg	0.8	Cl	386.4
Conductivity (uS/cm)	2470	Na	760.0		

PERMEATE

HOUR	TEMP. (deg c)	pH	COND. (uS/cm)	PRESS. (psi)	FLOW (gpm) PERM.	REJECT
0.5	22.20	8.45	563.0	181.0	026	2.30
1.0	2220	7.87	588.0	182.0	026	2.30
2.0	22.30	7.88	491.0	181.0	0.27	2.30
4.0	22.60	8.03	389.0	179.0	0.26	2.60
52.0	n/a	n/a	453.0	185.0	024	2.30

HOUR	Ca	Mg	Na	SO4	Cl
0.5	12.50	2.50	305.0	168.0	97.80
1.0	5.00	b/d	270.0	37.40	110.40
2.0	5.00	bid	267.5	2620	86.00
4.0	5.00	b/d	220.0	27.10	59.80
52.0	2.50	b/d	235.0	14.70	98.10

* b/d = below detection, n/a = not available

ion values = mg/l

Run of 9/22/94

MEMBRANE= MFG. FilmTec MODEL# NF90

FEEDWATER		Cations (mg/l)		Anions (mg/l)	
Temperature (deg C)	21.1	Ca	10.0	SO4	164.7
PH	8.63	Mg	0.8	Cl	386.4
conductivity (us/cm)	2470	Na	760.0		

PERMEATE

HOUR	TEMP. (deg c)	pH	COND. (uS/cm)	PRESS. (psi)	FLOW (gpm) PERM.	REJECT
0.5	22.20	0.07	37.2	158.0	0.29	2.80
1.0	21.90	8.03	38.4		0.29	2.60
2.0	22.60	0.20	35.3	160.0 150.0	0.28	2.80
4.0	22.50	8.35	33.2	150.0	0.27	2.70
52.0	n/a	n/a	25.9	n/a	n/a	n/a

HOUR	Ca	Mg	Na	SO4	Cl
0.5	0.90	b/d	0.50	0.64	4.50
1.0	1.10	Wd	0.60	0.55	4.50
2.0	1.00	Wd	2.60	0.43	3.50
4.0	1.10	Wd	3.80	0.36	2.60
52.0	1.10	Wd	4.30	0.49	3.50

ion values = mg/l

Run of 9/22/94

Pressure variation results

NF70

	(RECOVERY)	
PRESS	REJECT	PERM
70	4.70	0.09
80	4.50	0.10
90	4.36	0.13
100	4.10	0.15
110	3.96	0.18
120	3.70	0.19
130	3.46	0.21
140	3.10	0.25
150	280	0.28
160	260	0.30
170	230	0.32
180	1.90	0.34
190	1.60	0.38
200	1.10	0.39

NF500

	(RECOVERY)	
PRESS	REJECT	PERM
70	4.20	0.12
80	4.00	0.13
90	3.80	0.16
100	3.60	0.19
110	3.40	0.21
120	320	024
130	290	028
140	2.70	0.30
150	250	0:33
160	230	0.37
170	210	0.39
180	1.80	0.42
190	1.50	0.45
200	1.10	0.48

Appendix D

Water Quality Analysis for Preliminary Design Estimates

Inorganic Chemical Analysis

Lab Name and Address:
Western Technologies, Inc.
3737 Easst Broadway Road
P.O. Box 21387
Phoenix, AZ 85038

Hopi Jr./Sr. High School - Well No. 3 **10/06/87**

Contaminant Name	Analysis Results (mg/l)
Arsenic	4.02
Barium	co. 1
cadmium	co.005
alromium	CO.02
Fluoride	2.9
Lead	<0.02
Mercury	CO.001
Nitrates	<0.1
selenium	CO.005
Silver	<0.02
Alkalinity	260
Calcium	8
Chloride	760
Copper	<0.05
Hardness	28
Iron	0.3
Magnesium	7
Manganese	<0.05
PH	8.9
Sodium	810
Sulfate	320
TDS	2180
Zinc	<0.05