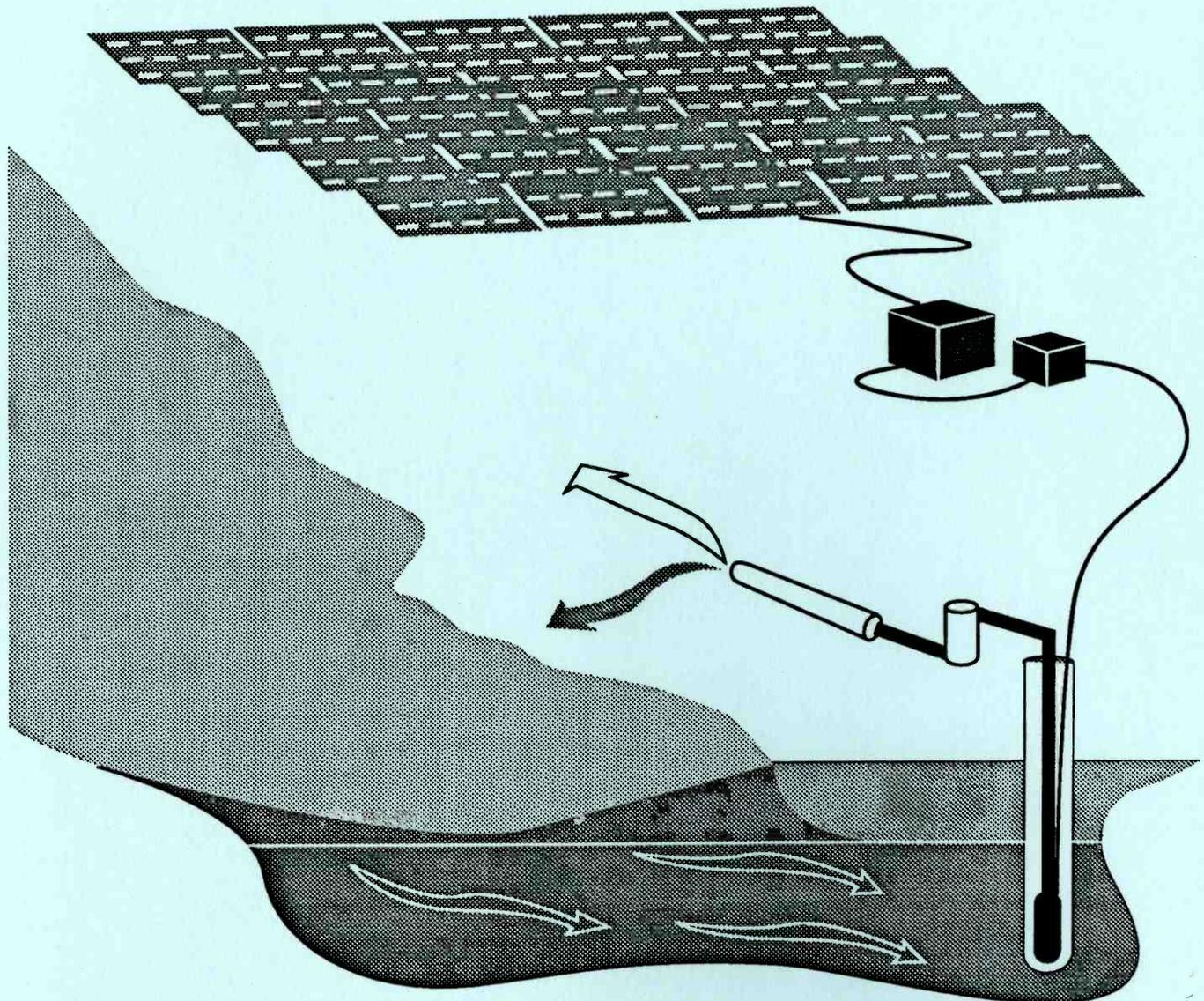


Project Report
**TEST OF NANOFILTER METHOD
OF
TREATING RECHARGED MUNICIPAL EFFLUENT**



A Joint Effort
by
The John F. Long Foundation and The University of Arizona
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PROJECT REPORT
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Recharged Municipal Effluent

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1. Introduction

The nanofilter is a relatively new water treatment option that has been commercially available since 1986. The name nanofilter is used here as a generic name rather than a specific product name. There are at least five companies that make filter elements that can be classified as nanofilters (City of Ft. Myers, 1987).

The nanofilter operates on a molecular scale and is related to reverse osmosis. Simply stated, this process treats water by forcing it through a porous membrane. The water molecules are able to pass through the membrane, as well as some of the smaller organic and inorganic molecules in the water. The larger organic and inorganic molecules are removed. The nanofilter will remove most of the dissolved solids (salinity) and hardness plus a large percentage of the dissolved organic matter including trihalomethanes (THM) precursors and essentially all of the bacteria and viruses. THM and TOX precursors are naturally occurring organics (humic and fluvic acids) that will produce THMs and organic halogens (TOX) (both are suspected carcinogens) when disinfectants such as chlorine or chloramines are added to the water. Nanofiltration has a built in safety feature in that the membrane compresses slightly as it ages which produces even better quality of water over time. In contrast activated charcoal has to be continuously monitored to make sure its absorption capacity has not been used up, the quality of water deteriorates over time.

Nanofiltration, sometimes called membrane softening, is designed to be used for water containing 300-1200 ppm salinity. Municipal effluent in Arizona generally has 600 to 1200 ppm salinity so this process should work well. It is particularly effective in removing dissolved organics, virus, bacteria and parasitic protozoans. The nanofilter is being used in several

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Florida locations. The City of Fort Myers in Florida is presently constructing the largest of these facilities, a 20 million gallon per day plant (City of Ft Myers, 1987).

2. Background

The prefix nano means one thousand millionth or 10^{-9} . One nanometer is equivalent to 10 angstroms. The NF-70 NANOFILTRATION membranes made by FilmTec, a subsidiary of Dow Chemical company, will completely reject all molecular species of 10 angstroms or greater in diameter, consistent with the 200 molecular weight cutoff. Rejection of molecular species below the 200 molecular weight is dependent on their size, ionic charge and membrane affinity (Watson & Hornburg, 1987). This molecular weight cutoff is ideal for eliminating organic precursors that are not removed in conventional treatment plants. The nanofilter will also remove most of the sulfates, calcium and magnesium and about 1/2 of the sodium and chloride.

One of the first papers on nanofilters was presented by Hickman et al (1985). Their paper was summarized in the title: "The economics of low pressure reverse osmosis: membrane processes more economical for potable water treatment than lime softening". Conlon (1985) wrote a paper describing pilot tests. Taylor (1985) was already doing pilot testing in Florida. The complete results of these pilot tests were published in an article by Taylor et al (1987). Peter Eriksson has released a recent paper on the nanofilter (Eriksson, 1988). The nanofilter was first commercially available in 1986. The first listed author of this paper learned about nanofiltration from Bruce Watson, of the DSS Engineers Inc. based in Orlando, Fla., while attending a water conference in Kuwait in October, 1987. A paper was presented there (Watson & Hornburg, 1987).

3. Cost of Nanofiltration

Nanofiltration has a higher molecular cutoff than reverse osmosis. The membrane is coarser. Because of this, substantially less energy is required to force the water through the membrane. The system operates at a pressure of 80 to 100 psi. The amount of energy required to operate the filter is about the same as pumping water from a well with a static water level 200 feet below the surface. The gallons per square foot passing through a unit area of filter can be double that of reverse osmosis (Taylor et al. 1987). This reduces capital costs. The combination of reduced capital costs and reduced energy costs makes the nanofilter method less expensive than reverse osmosis and brings the cost down to reasonable levels.

The Fort Myers, Florida projected nanofiltration cost, including operation and capital recovery, is approximately \$0.50/1000 gallons (City of Ft. Myers, 1987). Since these projections were made bids have been received on the nanofilter equipment which are 79 percent of the projected cost. See Appendix C. Additional testing has also shown that the operation costs will be lower than projected. In contrast the total unit cost of Tucson's proposed \$85 million dollar treatment plant for Central Arizona Project (CAP) water if operated at a 65 million gallons per day

(mgd) level, 365 days out of the year, will be \$0.47/1000 gallons (Carollo, 1987). The unit costs are the sum of the operation costs and the capital recovery costs. The operation costs of the 65 mgd plant using ozone is given in the final report from Carollo, Black & Veatch, November 1987 at \$0.11/1000 gallons. (Carollo, 1987). The capital recovery costs were estimated to be \$8.5 million per year or \$0.36/1000 gallons. The capital recovery costs would be lower per unit of water if the plant was operated at a higher level of output, but the problem remains that there is no place to sell the additional water for several years until the city grows. This is a further advantage in the nanofiltration system, it is relatively easy to expand the plant as the demand grows.

4. Use of Nanofiltration with Municipal Effluent

This study was set up to test the hypothesis that nanofiltration of recharged municipal effluent would provide a water that could be directly used for domestic water. The work by Dr. Herman Bouwers of the U.S Water Conservation Laboratory clearly showed the many advantages of using recharge as a tertiary treatment of secondary treated municipal effluent. The total organic content (TOC) of the water was dramatically reduced from TOC of 19.3 ppm to 3.1 ppm within 5 to 10 days in tests at the "Flushing Meadows" recharge site approximately 1.5 miles west of 91st Avenue in the streambed of the Salt River in Phoenix. The results of this research as well as later work at the 23rd Avenue recharge site showed that the recharged and repumped effluent could be used for contact recreation, and for unrestricted irrigation use but needed additional treatment before being used for drinking water. Dr. Bouwer's research showed how the 120 acre 23rd Avenue site, if modified, would recharge 36,000 acre feet of effluent per year (Bouwer, 1985).

This nanofiltration "bench test" was set up to use recharged municipal effluent and show how it could be converted to a quality suitable for drinking water from the aspects of salinity, hardness, parasitic protozoans, bacteria, virus, and organic precursors.

5. Procedure

Initially it was hoped that existing wells from the "flushing meadows recharge" site could be used to provide recharged municipal effluent. However initial analysis of the only well containing water showed it to be different in quality than the municipal effluent based on conductivity measurements. It was decided that a shallow well would be dug near 91st Avenue in the compound of Pioneer Sand Company. The water level at the selected location was only 4-foot below the surface.

The sponsor of this research, John F. Long Foundation, provided a backhoe and an eight foot deep hole was excavated, and an 8-inch PVC perforated vertical pipe was installed. The pipe was approximately 10 feet long with 2-foot exposed above ground leaving 8-foot below ground level. There was a 4-foot depth from the surface to the water table and approximately 4-feet of pipe below the water level. The hole containing the pipe was backfilled with 3/8 inch gravel, donated by the Pioneer Sand

Company. The well was developed for several days by pumping with a 1/4 hp 1.5 inch "Little Giant Pump" before the nanofilter was installed. In the development of the well it was pumped at a rate 10 to 15 times greater than it was pumped during the operation of the nanofilter.

A 1/3 h.p. 1-inch submersible pump was used to pressurize the nanofilter. A 24 panel photovoltaic array was used to provide power for the pump. The array tracked the sun so that it operated at a maximum production of 22 amps most of the time at an average of 26.5 volts. The array and test site is shown in a schematic in Figure 1 and the actual test site is shown in Figure 2A with a closeup of the well and nanofilter in Figure 2B. The efficiency of the Goulds 5ES03 a.c. submersible pump was only about 15%, much lower than expected, so that a generator was needed to augment the photovoltaic production for continuous operation. The efficiency would be better if a larger nanofilter was used with the pump. A Westec 24 volt inverter converted the PV dc power to ac power. This inverter drew approximately 25 amps at 26.5 volts. The generator initially was used directly to run the pump. Approximately 1/2 of the way into the project the generator was used to charge the batteries so that the system was continuously operated using the inverter. Under this system the generator was used only in the evening. After the 30 day test was completed a more efficient DC pump was installed so that the generator would not be needed.

A 2.5 inch diameter NF70 nanofilter element from Filmtec, a subsidiary of Dow Chemical, was used in the test. The test vessel was provided by Carl Hickman. The installation of the element within the vessel was accomplished and the test started on May 14, 1988.

6. Results from the Operation of the Nanofilter Test

In order to evaluate the performance of the nanofilter for treating the recharged municipal effluent, several operational parameters were monitored during the thirty day test period. These parameters included:

1. water temperature
2. system operating pressure
3. product water flow rate
4. reject water flow rate
5. maintenance requirements.

The basic operational results of the nanofilter test are given in Table 1. These results show the pressure, the flow rate in gpm, and the temperature which was measured periodically. The table shows a change in the 5-micron cotton fiber prefilter on 5/22 and 6/11. These changes were made when the reject water flow had dropped significantly.

The pressure was not always recorded. It stayed fairly constant and was periodically adjusted back to 100 psi after slight decreases. The readings before and after the adjustments are noted in Table 1. A graphical representation of the pressure data is given in Figure 3. The amount of product water produced by the filter was directly proportional to the pressure in the vicinity of 100 psi. The product water flow would start near 50 psi.

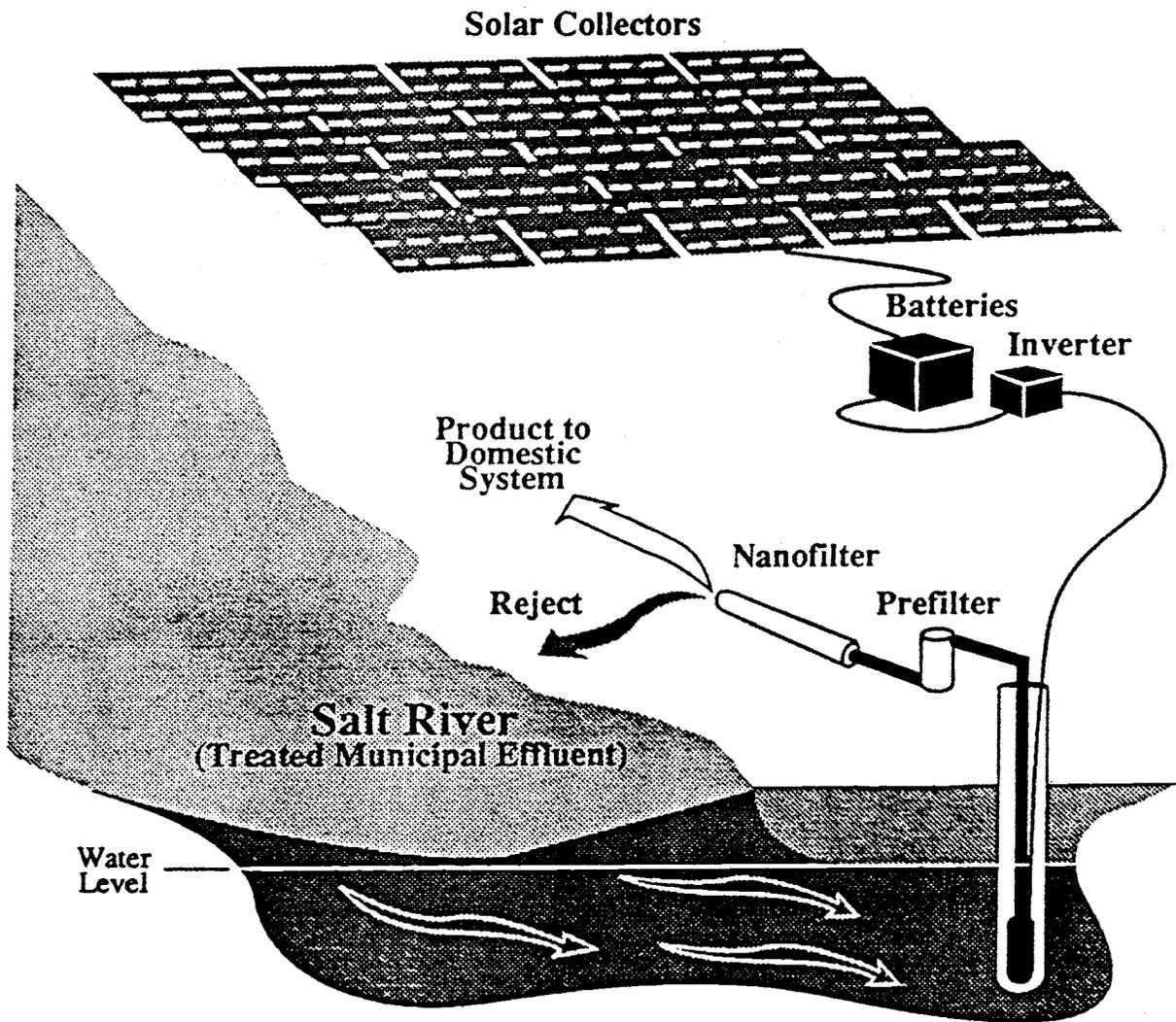


FIGURE 1. Schematic diagram of solar powered nanofilter test using recharged municipal effluent.

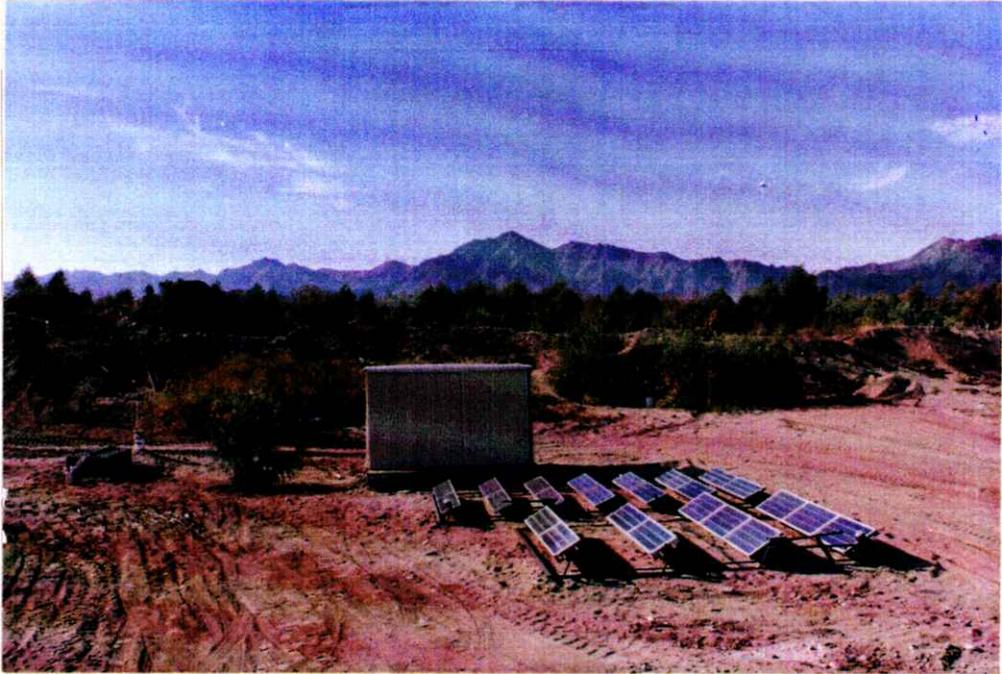


TABLE 1

OPERATION DATA
RECHARGED MUNICIPAL EFFLUENT
NANOFILTRATION TEST

| Date | Time | Pressure psi | Product gpd/sq ft | Reject percent | Comments |
|---------------------|--------|-----------------|----------------------|-------------------|---|
| 5/14 | 4:30P | 100 | | | Started test |
| 5/14 | 5:21P | 100 | 27.91 | 77.7 | |
| 5/16 | 5:44P | | 27.36 | 78.3 | |
| 5/17 | 4:09P | | 25.92 | 79.0 | |
| 5/18 | 6:40P | | 22.93 | 78.8 | |
| 5/19 | 6:44P | | 21.99 | 80.3 | |
| 5/20 | 6:37P | | 24.53 | 77.8 | |
| 5/21 | 6:23P | | 22.04 | 78.3 | Inlet pipe leaking |
| 5/21 | 11:36P | 82/100 | 22.37 | 69.0 | Inlet pipe leaking |
| 5/22 | 1:24A | 100 | 22.87 | - | fixed leak & changed pre-filter. |
| 5/22 | 7:06P | | 20.93 | 83.3 | |
| 5/23 | 6:55P | | 19.82 | 83.6 | |
| 5/24 | 9:30A | | 19.16 | 84.3 | |
| 5/24 | 5:22P | | 19.61 | 83.7 | |
| 5/25 | 6:10P | | 18.94 | 81.1 | |
| 5/27 | 12:18A | | 19.72 | 80.6 | |
| 5/29 | 12:05A | | 21.32 | 79.3 | |
| 5/30 | 6:38P | | 22.04 | 82.0 | |
| 5/31 | 6:32P | | 22.71 | 81.4 | |
| 6/1 | 7:26P | | 21.99 | 84.3 | |
| 6/2 | 2:11P | 87/100 | - | - | |
| 6/2 | 6:29P | | 21:05 | 75.5 | |
| 6/3 | - | | - | - | Generator off 24 hrs. |
| 6/4 | 6:37P | | 20.93 | 78.3 | |
| 6/5 | 6:06P | | 20.55 | 77.5 | |
| 6/6 | 6:36P | | 20.38 | 79.4 | |
| 6/7 | | | | | Generator off 24 hrs. |
| 6/8 | | | | | Pump ran approx 8 hrs. |
| 6/9 | | | | | Generator off 24 hrs. |
| 6/10 | | | | | Repaired generator. |
| 6/11 | 12:30A | 85/100 | 16.76 | 84.6 | |
| 6/12 | 6:24P | | 17.17 | 82.3 | |
| 6/13 | 6:44P | | 17.33 | 83.1 | |
| 6/14 | 11:14A | 100 | 18.17 | 83.1 | |
| 6/14 | 12:30P | 100 | 33.73 | 71.2 | Replaced the 5 micron prefilter & cleaned the nanofilter. |
| 6/14 | 6:02P | | 34.17 | 71.0 | |
| End of 30 day test. | | | | | |
| Averages | | 97 | 22.22 | 79.6 | |

The temperature was recorded several times over the 30 day period at 23 degrees centigrade. Since groundwater was being used the temperature was constant over the 30 day test period.

The amount of product water produced is given in gallons per day per square foot of membrane. The number of square feet in the membrane in the 2.5 inch by 40 inch element was given by Filmtec Inc as 26. The amount of flux through the filter decreased from 27.91 gpd/sq ft down to 18.17 gpd/sq ft before the nanofilter was cleaned with 3.5 pounds of PFIZER FLOCLEAN AES510 detergent provided by Carl Hickman. The cleaning was very effective in increasing the flow to 33.73 gpd/sq ft which is a 21.9 percent increase. At the time of the cleaning it was noted that dark organic laden water was removed from the nanofilter. This material was the cause of the membrane fouling. A ten gallon volume of product water containing the detergent was circulated through the nanofilter and out the reject hose for 45 minutes and then flushed out before the nanofilter was placed back into service.

From product and reject flow data the percentage rejected or the percentage of water recovered as product can be calculated. Table 1 gives the percentage rejected while Figure 4 gives the amount of water recovered. These recovery values are dependent both on the filtration effectiveness of both the 5 micron prefilter and nanofilter. They are also dependent on the amount of water that the pump would produce. The more water pumped, the higher would be the flow in the reject stream and the lower would be the recovery percentage. A leaking inlet pipe on days 7 & 8 caused a rise in the recovery percentage because the reject flow was reduced. When this leak was fixed and the prefilter changed there was a reduction in recovery percentage primarily because of the increase in the reject stream. The rise in recovery between 6/1 and 6/2 or day 19 and 20 can be explained only by a blockage or an unreported leak that was repaired by 6/11 or day 29 in Figure 4. The high rate of recovery on day 31 was due to the nanofilter being cleaned.

The most important information in the operational data is the product water flow through the nanofilter. It did gradually decrease over the 30 days but after cleaning the rate was greater than it was initially.

7. Effect on Salinity and Hardness

Samples were periodically taken and analyzed in the laboratory under the direction of Dr. Gordon Dutt. The results of this testing are given in Table 2.

This table shows a dramatic reduction in salinity of the recharged municipal effluent due to nanofiltration. The results show a reduction in salinity in the product water with a corresponding rise in salinity in the reject water.

The salinity of the influent which is the recharged municipal effluent showed a slight rise, 1484 ppm on May 14, 1988 to 1631 ppm on May 24, and then a steady reduction to 930 ppm on July 29, 1988. This improvement in quality could be due to the development of the well as water

TABLE 2
SALINITY DATA
RECHARGED MUNICIPAL EFFLUENT
NANOFILTER TEST May 14-July 29, 1988
Dissolved Solids in ppm for Date Indicated

| | May 14 | | | May 17 | | | May 24 | | |
|-------------|--------|-------|------|--------|-------|------|--------|-------|------|
| | Inf. | Prod. | Rej. | Inf. | Prod. | Rej. | Inf. | Prod. | Rej. |
| Sodium | 306 | 71 | 329 | 325 | 86 | 326 | 338 | 128 | 349 |
| Potassium | 8.9 | 1.5 | 8.3 | 10.0 | 2.0 | 8.0 | 7.4 | 2.9 | 8.2 |
| Calcium | 101 | 4.9 | 123 | 90 | 8.2 | 127 | 104 | 14.2 | 130 |
| Magnesium | 40 | 1.6 | 49 | 36 | 2.6 | 49 | 41 | 3.7 | 49 |
| Phosphates | <.8 | <.8 | <.8 | <.8 | <.8 | <.8 | <.8 | <.8 | <.8 |
| Chloride | 455 | 79 | 468 | 427 | 105 | 443 | 499 | 165 | 493 |
| Sulfates | 145 | 23 | 174 | 128 | 7.2 | 166 | 158 | 7.5 | 171 |
| Bicarbonate | 381 | 44 | 437 | 378 | 56 | 472 | 393 | 93 | 458 |
| Nitrates | 3.7 | 3.0 | 2.3 | 4.0 | 2.9 | 2.4 | 2.1 | 2.7 | 2.0 |
| Hardness* | 417 | 19 | 507 | 373 | 31 | 518 | 428 | 51 | 526 |
| EC (ds/m) | 2.12 | 0.34 | 2.34 | 2.17 | 0.49 | 2.35 | 2.33 | 0.75 | 2.64 |
| TDS (ppm) | 1484 | 238 | 1638 | 1519 | 343 | 1645 | 1631 | 525 | 1848 |

| | May 22 | | | May 29 | | June 6 | | |
|-------------|--------|-------|------|--------|-------|--------|-------|------|
| | Inf. | Prod. | Rej. | Inf. | Prod. | Inf. | Prod. | Rej. |
| Sodium | 325 | 110 | 299 | 315 | 40 | 205 | 91 | 277 |
| Potassium | 7.0 | 2.4 | 8.1 | 6.8 | 2.2 | 5.6 | 2.0 | 6.4 |
| Calcium | 111 | 13.2 | 157 | 104 | 12 | 76 | 12 | 97 |
| Magnesium | 42 | 2.6 | 59 | 42 | 4.0 | 33 | 2.7 | 42 |
| Phosphates | <.8 | <.8 | <.8 | <.8 | <.8 | <.8 | <.8 | <.8 |
| Chloride | 477 | 168 | 499 | 464 | 54 | 300 | 136 | 316 |
| Sulfates | 148 | 9.8 | 185 | 176 | 8.5 | 123 | 5.9 | 163 |
| Bicarbonate | 397 | 66 | 471 | 403 | 65 | 390 | 79 | 470 |
| Nitrates | 3.9 | 3.4 | 2.0 | 5.9 | 2.6 | 2.5 | 1.9 | 2.9 |
| Hardness* | 448 | 44 | 634 | 432 | 46 | 383 | 42 | 414 |
| EC (ds/m) | 2.3 | 0.66 | 2.69 | 2.32 | 0.29 | 1.69 | 52 | 2.00 |
| TDS (ppm) | 1610 | 462 | 1883 | 1624 | 203 | 1183 | 364 | 1400 |

| | June 14 | | | July 29** | | |
|-------------|---------|-------|------|-----------|-------|------|
| | Inf. | Prod. | Rej. | Inf. | Prod. | Rej. |
| Sodium | 226 | 73 | 248 | 243 | 57 | 303 |
| Potassium | 5.7 | 1.5 | 6.7 | - | - | - |
| Calcium | 78 | 7.7 | 101 | 69 | 3 | 94 |
| Magnesium | 33 | 2.6 | 44 | 34 | 2 | 47 |
| Phosphates | <.8 | <.8 | <.8 | - | - | - |
| Chloride | 317 | 100 | 338 | 320 | 82 | 400 |
| Sulfates | 116 | 4.9 | 163 | 110 | 3 | 150 |
| Bicarbonate | 366 | 67 | 482 | - | - | - |
| Nitrates | 4.6 | 3.1 | 4.0 | <.2 | <.2 | <.2 |
| Hardness* | 230 | 30 | 432 | 312 | 15 | 428 |
| EC (ds/m) | 1.63 | .44 | 2.05 | 1.60 | .31 | 2.0 |
| TDS (ppm) | 1141 | 308 | 1435 | 930 | 170 | 1200 |

*Hardness expressed as ppm as CaCO₃.

**This set of data was developed by the Arizona Testing Laboratories.

Additional data from samples tested in November and December, 1988 is in Appendix A.

was removed during the test. The water quality of the influent towards the end of the test are closer to what Bouwer (1985) reported for recharged effluent.

The salinity results help to verify the assumption that the water pumped from the shallow 4-foot deep well located next in the streambed of the Salt River between two channels carrying treated secondary effluent could in fact be called recharged municipal effluent. From time to time other types of water are in the channels including irrigation return flow, urban storm runoff as well as upstream releases or overflows from storage reservoirs. It has been several years since there was any sizable overflows or releases from the reservoirs. There does not appear to be much if any surface irrigation return flow at 91st Avenue. Periodic urban storm runoff may have occasionally reached the 91st Avenue site in the year or two preceeding the test, but have not been observed since the test started. The urban runoff would generally have less salinity than municipal effluent but could have more of other types of contaminants that may survive during recharge and would be difficult to remove without nanofiltration. There are several landfills located upstream from the nanofilter test site that may have polluted the recharged groundwater used as influent to the nanofilter. In view of these observations the assumption that water pumped from the well does in fact represent mainly recharged municipal effluent with a strong possibility of additional contamination from urban runoff and landfills.

The percent of salinity removed in the product water went from 84 percent on May 14 down to 68% on May 24 back up to 82% on July 29. This removal percentage was dependent, as expected, on the total salinity of the influent. The salinity of the influent would be approximately 1000 ppm in the Phoenix area during average times when 60 percent of the domestic water was coming from surface water sources. At this average salinity it appears that the removal percentage would be approximately 80%. This rate of removal lowers the TDS to a value equivalent to the best groundwater in the state.

The percent of hardness removed is the most dramatic. The removal ranged from 95% on May 14 down to 88% on May 24 back up to 95% on July 29. The resulting water is as soft as the best groundwater in the state. Nanofiltration is a very effective water softener having a very high removal rate of the larger molecules, calcium and magnesium.

The sulfate and bicarbonate removal were similarly high whereas the smaller nitrate molecules were not as readily removed. The nitrate levels in the influent were quite low however due to the fact that the municipal effluent had been recharged, removing most of the ammonia before it had a chance to combine with oxygen and become nitrates. This is a very important function of the pre-treatment using basin recharge of the municipal effluent. The EPA allowable limit for nitrates is 10 ppm as nitrogen so the product water is well below that in all of the samples taken. In fact the Arizona Testing Laboratories, independent analysis of water collected July 29, showed nitrates as being less than the detectable level of 0.2 ppm as nitrogen. See Table 2.

The analyses of the influent, product and reject waters show a level of phosphates below the detectable limit of 0.8 ppm. This indicates that phosphates are removed during the recharge process. This was previously demonstrated by Bouwer et al (1980). Phosphates are highly absorbed by the soil in the recharge process. This is important in that the reject water is much lower in phosphates than the municipal effluent. This is desirable since phosphates are a nutrient that causes growth in flowing streams or when the municipal effluent is used for cooling water. It is one of the compounds specifically mentioned in the water quality criteria for the contract for cooling water for the Palo Verde Nuclear Power Plant.

8. Effect of Nanofiltration on Organic Content

Analytical Considerations

One of the main goals of the nanofiltration test on recharged municipal effluent was to evaluate the effectiveness of nanofiltration for removing dissolved organics including trihalomethane (THM) precursors from the recharged municipal wastewater. One of the prime reasons in using nanofiltration as a treatment technology is to remove the THM precursors and reduce their formation potential to an acceptable level.

In order to analyze the performance of the nanofilter unit for removal of these precursors, samples were put through extensive analyses. The analyses were done on the water entering the nanofilter (influent), the water processed by the unit (product), and the waste stream from the unit (reject). The completed data base gives a clear picture of the degree of treatment achieved by nanofiltration.

Each sample was processed and analyzed as described below. The analytical procedures performed on each sample included the following:

1. pH-measurement of acidity.
2. Turbidity-measurement of the suspended material.
3. Conductivity-indicator of dissolved solids.
4. Bromide-measurement of bromide ion concentration which is of interest when forming brominated species of THM's.
5. UV Absorbance-surrogate measurement of the dissolved humic material; a major source of THM's.
6. Dissolved Organic Carbon (DOC) - surrogate measurement of total potential THM precursors.
7. Trihalomethane Formation Potential (THMFP) - determinant of the amount of Chloroform, Bromodichloromethane, Chlorodibromomethane, and Bromoform that is formed over a defined period of time after a known chlorine dose is applied.

The procedures followed in the Environmental Engineering laboratory were conducted by Bruce C. Alleman and supervised by Dr. Gary Amy. They are as follows: Samples from the nanofiltration unit were obtained by Dr. C Brent Cluff and his staff and were delivered, on ice, to the laboratory

where they were stored in a refrigerator until analyzed. The samples were put through the following analytical procedures.

The first measurements were made on the raw water. These included pH, turbidity and conductivity. A Corning pH meter model 125 was used for pH determinations. Turbidities were determined using a Hach model 2100A turbidimeter. Conductivity measurements were made on a Myron L pDS conductivity meter. After these analyses, a one-liter aliquot of the raw water was placed in a glass container sealed with a Teflon-lined cap and stored at 4 degrees C for possible future need.

The next step was fractionation of each sample. This included separating the sample into different fractions by passing them through membranes (filters) with different pore sizes. The raw water was first filtered through a prewashed Gelman Science 0.45 micrometer (μm) membrane. This step provided an operational definition of "dissolved" material in the water. Before filtration, it was necessary for each membrane to be washed with five 20 milliliter aliquots of Milli-Q grade water followed by one 100 milliliter wash to remove any organic material from the filter and avoid sample contamination. Five hundred milliliters of sample were passed through each membrane before it was replaced. Replacing the membrane was necessary to maintain the effective pore size. The filtrate from the 0.45 μm membranes was then analyzed for conductivity and bromide. Bromide was measured with an Orion 94-35 bromide ion specific electrode.

Following filtration through the 0.45 μm membranes, the samples were further fractionated into apparent molecular weight ranges. This was accomplished with the use of Amicon's 200 milliliter stirred cells and Amicon's ultrafiltration membranes. The membranes used and their respective cutoff sizes were:

1. Amicon YC05; membrane molecular weight cutoff of 500
2. Amicon YM2; membrane molecular weight cutoff of 1,000
3. Amicon YM5; membrane molecular weight cutoff of 5,000
4. Amicon YM10; membrane molecular weight cutoff of 10,000

The ultrafiltration procedure started with "washing" the membrane to remove any organic contaminants. One hundred fifty milliliters of Milli-Q water were passed through each membrane prior to sample processing. Next 180 milliliters of sample were placed in the cells and filtered at 50 psi. One hundred fifty milliliters of permeate were collected and the remaining 30 milliliters were discarded. In theory, the permeates only contain material with molecular weights smaller than the cutoffs of the membranes as previously described.

The fractions of each sample were then analyzed for conductivity, UV absorbance, and dissolved organic carbon (DOC). UV absorbance was measured using a Perkin Elmer Hitachi 200 Spectrophotometer and DOC was measured on a Dohrmann DC-80 Total Organic Carbon Analyzer. Once DOC concentrations were determined chlorine doses were calculated for the THMFP experiments.

Trihalomethane formation potential (THMFP) experiments were conducted in 120 milliliter serum bottles with Teflon septum seals. An incubation period of seven days and a temperature of 20 degrees Centigrade was used. Sodium hypochlorite was used as the source of chlorine for these tests.

The chlorine dose rate was 3:1. Prior to spiking with chlorine, the samples were neutralized to pH 7.0 with sodium hydroxide.

At the completion of the seven day incubation period, the samples were checked for a chlorine residual using the DPD colorimetric method. Verification of a positive chlorine residual was necessary to ensure that the THMFP was not chlorine limited. Further chlorine reactions were quenched using a 0.1 normal sodium thiosulfate solution.

Following the quenching of the chlorine reactions, the samples were analyzed for THM's using a Hewlett Packard 5790 gas chromatograph (GC) equipped with Megabore DB-1 large bore capillary column and an electron capture detector (ECD). Signals were recorded on a Hewlett 3392A integrator. The GC method used an injector temperature of 250 degrees C and a detector temperature of 280 degree C. An initial column temperature of 45 degrees C was held for 4.00 minutes, and then was increased at 20 degrees C/minute up to a final temperature of 120 degrees C which was held for 3.75 minutes. The total GC run time was 10 minutes.

The THM method used a liquid/liquid extraction consisting of five milliliters of pesticide grade pentane injected into the serum bottles. The bottles were then vigorously shaken for two minutes. Shaking for two minutes provided ample contact between the two liquid phases to allow the THM's to be transferred into the pentane. The pentane then separates from the water and forms a pentane layer on the surface of the water. A 2 microliter aliquot of the pentane was then injected into the GC and the resultant concentrations recorded.

Results and Discussion

The source of the recharged municipal effluent used in the test was the treated municipal effluent from the 23rd Avenue treatment plant flowing in a stream within 200 feet south of the test site. The effluent from the 91st Avenue treatment plant flows in a stream approximately 800 feet north of the plant. It is doubtful that much of the water recharged from this stream would reach the test well but this stream was tested anyway. The results of these two tests taken May 20 are given in Table 3 along with the results of the organic tests.

These data indicate the excellent rejection of DOC and THM precursors by the nanofilter. By the end of the test there was a 86% removal of DOC and a 90% removal of the trihalomethane formation potential (THMFP). It can be noted that the organics removal is accompanied by good inorganic dissolved solids as reflected by the conductivity data. The DOC reductions are shown in Figure 5.

It is noteworthy that the initial values of organics in the groundwater decreased over the 30 day test as the well was developed. As was seen earlier there was also a decrease in salinity during this same time. The initial values were close to those of the source of the recharged effluent (the secondary effluent stream from the 23rd Avenue plant). Even though the values at the close of the test had decreased they were still greater than those reported by Dr. Herman Bouwer at the 23rd

Table 3
Summary of Nanofilter (NF) Feed and Product Water Characteristics
Groundwater/Recharged Effluent Sample Series

| Sample | DOC (mg/L) | UV Abs (cm ⁻¹) | THMFP (ug/L) | Conductivity (umhos/cm) | pH | Temp (C) | Turb (NTU) |
|-------------------------|---------------|-------------------------------|-----------------|----------------------------|------|-------------|---------------|
| Ef1-Plnt-A ¹ | 11.3 | .157 | 12 ³ | 1300 | 7.31 | n/a | 3.2 |
| Ef1-Plnt-B ² | 7.13 | .114 | 288 | 1300 | 8.66 | n/a | 18 |
| GW-Feed-5/14 | 6.92 | .148 | 472 | 2150 | 7.61 | 23 | 2.8 |
| GW-Prod-5/14 | 1.11 | .010 | 95 | 340 | 6.36 | | 0.2 |
| GW-Feed-5/17 | 6.96 | .166 | 315 | 2050 | 7.48 | 23 | 4.8 |
| GW-Prod-5/17 | 1.01 | .011 | 32 | n/a | 6.45 | | <0.1 |
| GW-Feed-5/28 | 7.00 | .168 | 345 | 2150 | 7.43 | 23 | 2.1 |
| GW-Prod-5/28 | 0.35 | .004 | n/a | 670 | 6.70 | | <0.1 |
| GW-Feed-6/6 | 5.16 | .132 | 176 | 1450 | 7.35 | 23 | n/a |
| GW-Prod-6/6 | 0.71 | <.001 | 39 | 535 | 6.73 | | <0.1 |
| GW-Feed-6/15 | 4.78 | .121 | 411 | 1600 | 7.53 | 23 | 4.1 |
| GW-Prod-6/15 | 0.65 | n/a | 41 | 440 | 6.58 | | <0.1 |

¹Secondary treated effluent from 91st Avenue plant

²Secondary treated effluent from 23rd Avenue plant

³Negative free chlorine residual

Additional data from samples in November and December are in Appendix A.

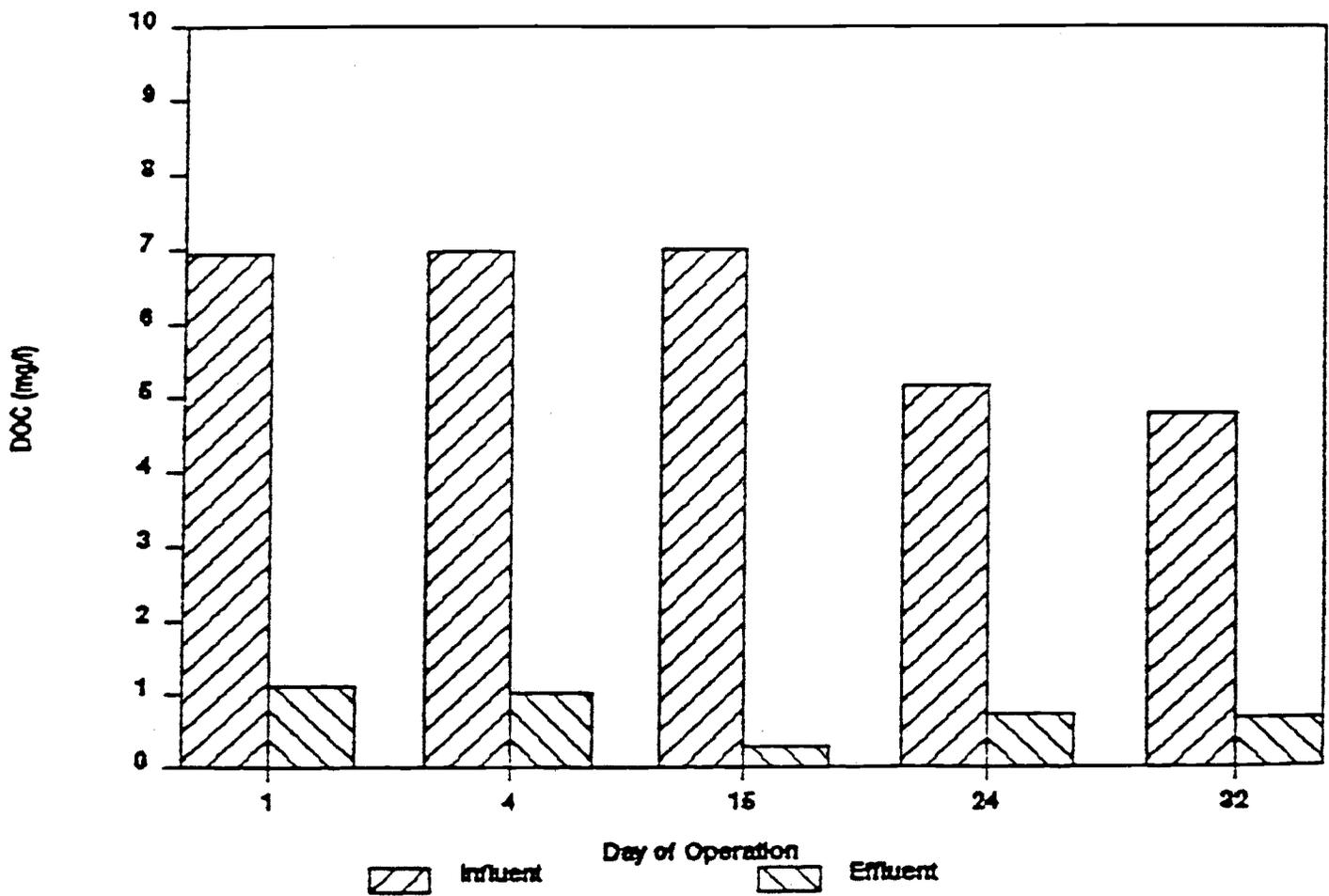


Figure 5: Dissolved Organic Carbon (DOC) Versus Day of Operation of Nanofilter using Recharged Municipal Effluent

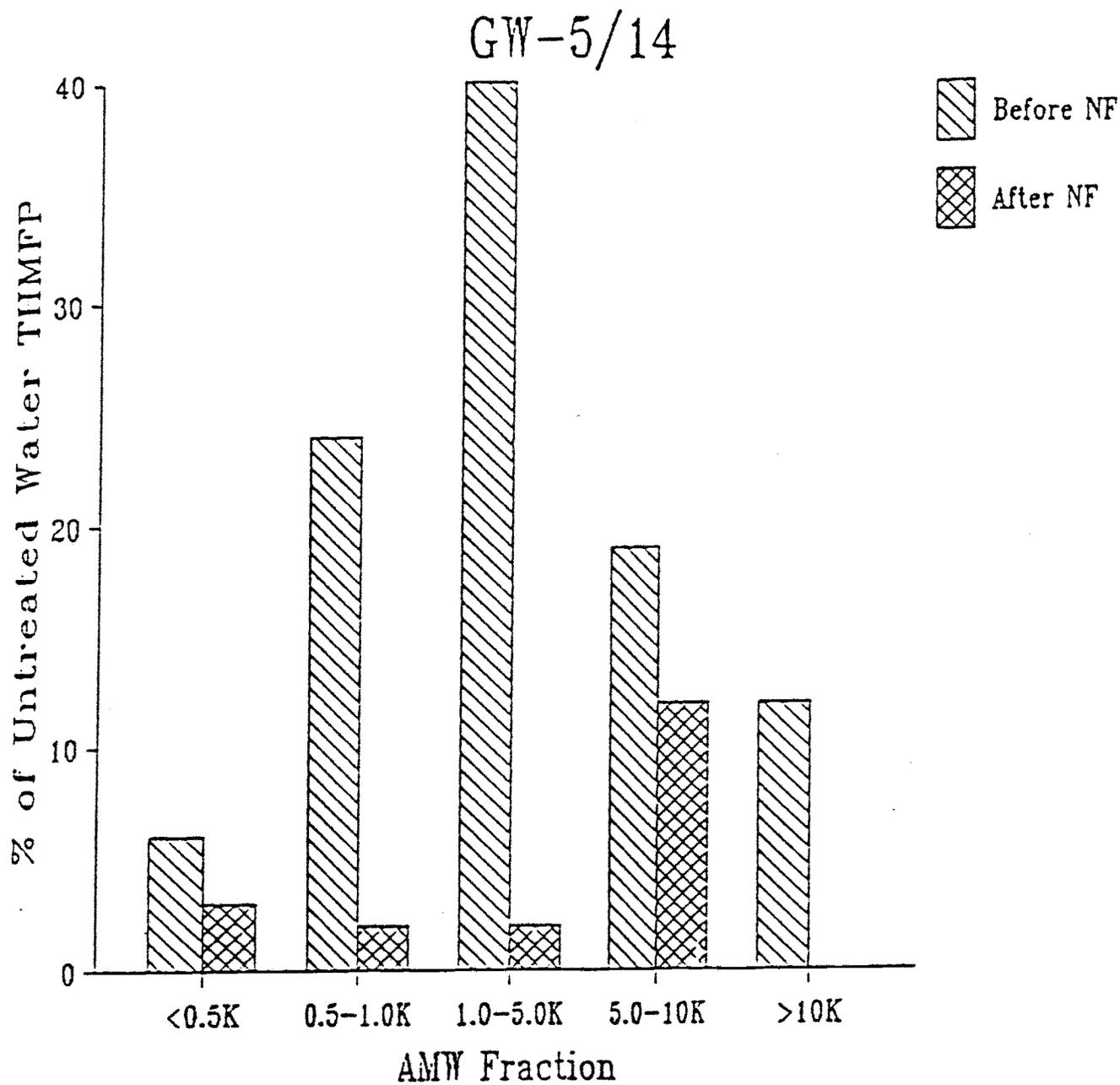


FIG. 6: AMW Distribution of THMFP Before and After Nanofiltration: GW-5/14.

GW-5/14

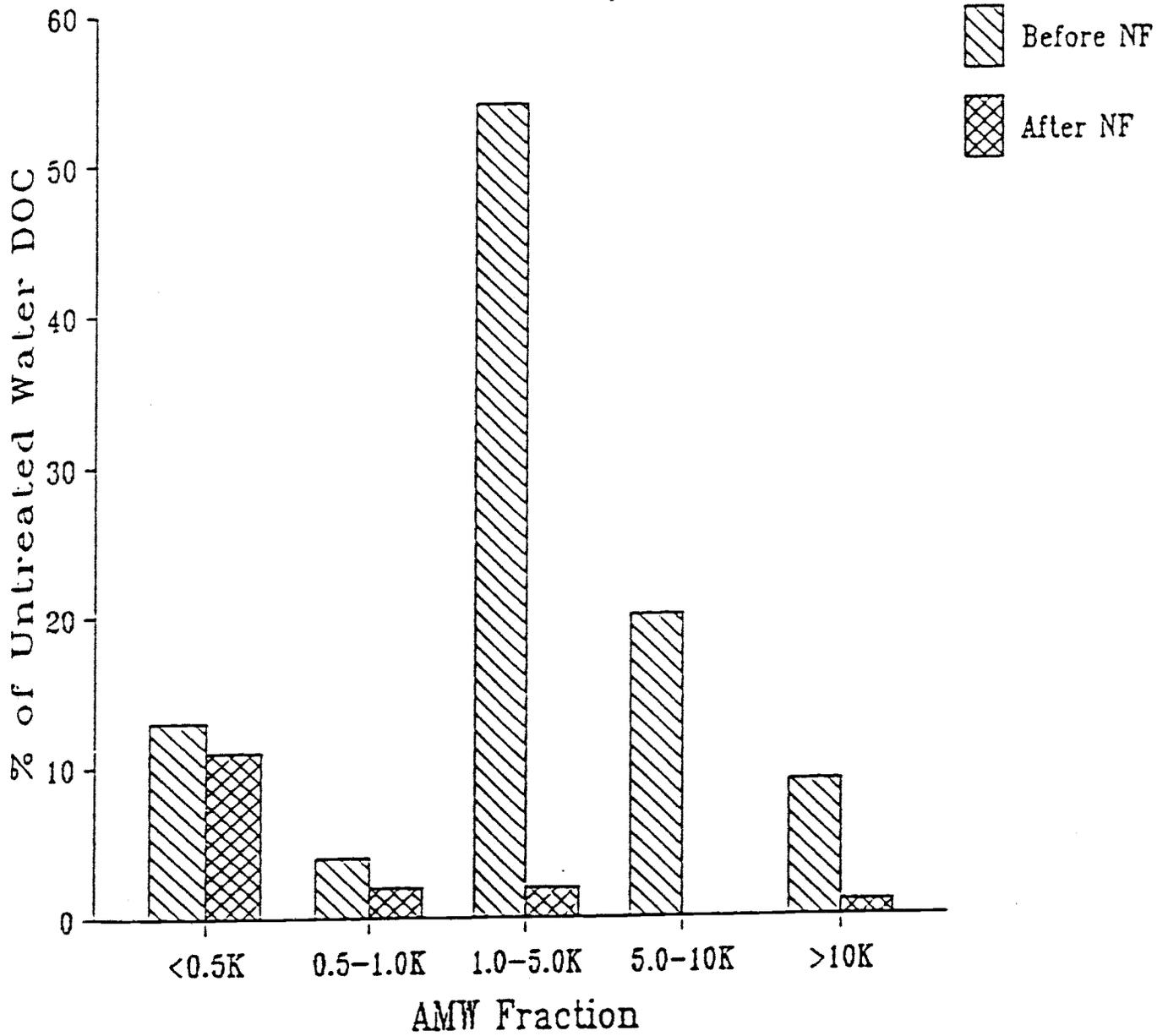


FIG. 7 AMW Distribution of DOC Before and After Nanofiltration: GW-5/14.

Avenue recharge site. This may indicate that the sorptive capacity of soil/aquifer material for organic matter decreases over time. Additional testing of this characteristic is needed.

The various samples were characterized according to apparent molecular weight (AMW) distributions based on both DOC and THMFP. These are shown in Figures 6 & 7 for the first samples taken on May 14. This data indicated that most of the DOC and THM precursors were in the molecular range that were easily removed by the nanofilter.

9. Microbiological Results For Nanofilter Testing at the 91st Avenue Test Site

Introduction

Microbiological testing of the Nanofilter (NF) units was conducted to determine the quality of the product water as well as the influent and reject stream waters. Testing was conducted on a series of samples from units installed in the field at the 91st Avenue test site. Samples were evaluated for total coliforms and coliphage. Selected samples were also tested for enteric viruses. The ability of the nanofilter unit to remove viruses was tested in the laboratory using water seeded with poliovirus.

Methodology

Heterotrophic Plate Count

The total number of heterotrophic bacteria present in the water samples was determined using the membrane filtration technique. Duplicate one mL and 0.1 mL volumes of the water samples were filtered through Gelman 4.5 um pore size gridded membranes which were then placed onto R₂A plates. The cultures were incubated at room temperature for 4-7 days and colonies were enumerated.

Total Coliform Count

Total coliform counts were performed on selected water samples. The membrane filter (MF) technique was employed as described in Standard Methods for the Examination of Water and Wastewater (APHA, 1985). A 100 mL volume of the sample water was passed through a membrane as described in the section above. The filter membranes were placed on m-endo agar and incubated at 37°C for 48 hours. The filters were examined and typical coliform colonies exhibiting a green sheen were enumerated.

Detection of Naturally Occurring Enteric Viruses

A large volume of water (minimum 40 L) was passed through an MK positively charged filter for the adsorption of enteric viruses. The filters were brought to the laboratory on ice and processed through a series of delution and reconcentration steps as described by Gerba et al. (1985). Detection of naturally occurring enteric viruses involved inoculation of buffalo green monkey kidney cell (BGM) monolayers. The cell

monolayers were checked for evidence of cytopathic effect (CPE) for two weeks.

Poliovirus Challenge Studies

The NF70 nanofilter unit which had been in use in the field at the Union Hills Water Treatment test site was transported to the laboratory on ice. This filter was identical with the filter at 91st Avenue except it was 4-inches in diameter. The results from this test was included here because the two filters were otherwise identical. The fact that one filter had been used with recharged municipal effluent and the other had been used with CAP water would not affect the results of the test. The nanofilter tested had been used for a 30-day test using Central Arizona Project (CAP) water prior to its being removed and taken to Tucson. After getting the filter back to the microbiology laboratory in Tucson the filter was flushed with several liters of dechlorinated tap water. Poliovirus LSc-1 (approximately 10^5 PFU/mL) was added to 15 L of dechlorinated tap water in a 20 L pressure vessel. The virus suspension was passed through the Nanofilter using nitrogen gas at 20 psi and samples of the product water, reject water stream, and influent were taken at various time intervals. The samples were stored at -20°C . At the time of assay the samples were diluted in Tria buffer and inoculated onto BGM cell monolayers using an agar overlay technique (Gerba and Goyal, 1982). The monolayers were rinsed, stained with crystal violet, and virus plaques were enumerated after 48 hours incubation at 37°C . The negative control was inoculated with sterile Tris buffer rather than with a poliovirus sample.

Coliphage Assay

The number of coliphage present in a water sample was determined using a modified agar overlay technique as described by Adams (1959). Approximately 1 mL of a water sample was placed into 3 mL of molten (49°C) tryptic soy broth with 1% agar. Approximately 1 mL of a 3-6 hour old shaker culture of *E. coli* was also added to the molten agar. This suspension was vortexed to evenly distribute the bacterial cells and potential coliphage and then poured onto a tryptic soy agar plate. Once solidified the plates were incubated at 37°C for 18 hours. Coliphage plaques or clearing zones in the bacterial lawn were enumerated.

Results

The results for microbiological testing performed on the 91st Avenue nanofilter samples are given in Tables 4 and 5. Data obtained from samples taken innitially are shown in Table 4. Coliphage were present at a level of 2.5 plaque forming units per mL (PFU/mL) in the 91st Avenue municipal effluent. No coliphage were detected in either the nanofilter product water or in the influent or nanofilter reject water samples. Heterotrophic plate counts or total coliforms were not done on these samples.

Data in Table 5 is from samples taken from the nanofilter unit after 30 days use at the 91st Avenue test site. Coliphage were found in the nanofilter product water, however no coliphage were detected in the nanofilter influent or reject water. It appeared that the coliphage reading in the nanofilter product water was a questionable data point at

Table 4
Bacteriological Results from Nanofilter Testing
91st Avenue Site - Initial Samples Taken

| Sample Water | Coliphage (PFU/mL) | HPC (CFU/vol.) | Total Coliforms (TC/100 mL) |
|---------------------------------|-----------------------|-------------------|--------------------------------|
| Nanofilter product water | 0 | ND | ND |
| Nanofilter influent water | 0 | ND | ND |
| Nanofilter reject water | 0 | ND | ND |
| 23rd Ave. municipal effluent | 0 | ND | ND |
| 91st Ave. municipal effluent | 2.5 | ND | ND |

Coliphage PFU/mL = plaque forming units per mL of sample water tested.

HPC = heterotrophic plate count (total plate count).

CFU/mL = colony forming units per mL of sample water tested.

TC = Total Coliforms per 100mL.

ND = Not determined.

Additional data from samples taken in November and December, 1988 are in Appendix A.

Table 5
Bacteriological Results from Nanofilter Test
91st Avenue Site After 30 Days in Use

| Sample Water | Coliphage (PFU/mL) | HPC (CFU/vol.) | Total Coliforms (TC/100mL) |
|------------------------------|-----------------------|-------------------|-------------------------------|
| Nanofilter product water | 1* | 0/10mL | 0 |
| Nanofilter influent water | 0 | TNTC/10mL | 10 |
| Nanofilter reject water | 0 | TNTC/10mL | 9 |
| 91st Avenue pond | 0 | TNTC/1mL | 110 |

*Data point was questioned since the influent and reject samples were zero. The test was rerun on Oct 7, 1988 with no coliphage detected.

Additional data from samples taken in November and December, 1988 are in Appendix A.

Coliphage PFU/mL = plaque forming units per mL of sample water tested

HPC = heterotrophic plate count (total plate count)

CFU/mL = colony forming units per mL of sample water tested

TC = Total Coliforms per 100 mL

TNTC = too numerous to count

best since it was not in either the influent or reject water, therefore the test was rerun on October 7, 1988. This second test indicated there was no coliphage in the product, influent or reject water. This confirmed the error in the earlier reading. The earlier reading may have been as a result of contamination from a 10 foot tube the product water went through before the sampling occurred. In the second test the product water was sampled as it first came out of the nanofilter.

Heterotrophic plate count organisms were not detected in the nanofilter product water, whereas there were high levels of HPC organisms in the nanofilter influent and reject water. Total coliforms were present in all water samples tested except for the nanofilter product water.

Large volumes of water (150 L) were processed for testing for enteric viruses. No viruses were detected in any of the samples using tissue culture methods.

The results from the poliovirus challenge studies are given in Table 6. Approximately 2×10^5 PFU/mL poliovirus was present in the influent water. No poliovirus was detected in the nanofilter product and approximately 76.2% was recovered in the nanofilter reject water.

Discussion

Testing of nanofilter units was conducted at the 91st Avenue and CAP test site at the Union Hills Treatment Plant. Testing of water samples taken from these units showed that they were capable of the removal of coliform organisms and heterotrophic plate count organisms. The first tests made for coliphage as shown in Table 4 indicated that it was not present in the influent, product or reject water. However the second test, made after 30 days, indicated that the product water sample was positive for coliphage, but the influent and reject water samples were negative. It appeared that this was a questionable data point at best so the test was rerun on October 7, 1988. This later test showed that there was no coliphage in the product, influent or reject water. (This is indicated in the footnote of Table 5.)

The coliphage was present in the 91st Avenue municipal stream (See Table 4) and not present in the influent to the nanofilter (which is repumped recharged effluent). It was also not present in a nearby surface pond caused by excavation of sand and gravel below the groundwater table (See Table 5). It appears from this data that the recharge process removes the coliphage contamination.

Seeded studies using poliovirus determined that after 30 days of use in the field that the nanofilter with a NF70 Filmtec element was able to remove greater than 5 \log_{10} values of virus. Poliovirus was selected for this test since it has been isolated from sewage contaminated water and is a test organism in the EPA's protocol for testing of microbiological purifier units.

The following background information is provided to aid in evaluation of the results:

(1) Although HPC levels in drinking water are not mandated by Federal laws it is proposed that levels be less than 500 CFU/mL. The product water from the nanofilter unit did not exceed these limits.

(2) Federal drinking water standards require that potable water contains less than 1 total coliform per 100 mL of water. The nanofilter unit effectively removed these organisms from the water as evidenced in the data presented above.

(3) Coliphage testing was conducted due to the prevalence of this type of virus in raw and possibly treated sewage effluents. It has been proposed by many investigators that these virus may be a good indicator of enteric virus contamination. There are no standards set for coliphage in water.

(4) To ensure that enteric viruses are absent in drinking water, Federal Regulations require that any drinking water treatment process removal at least 4 logs (99.9990) of enteric virus from the raw water source. The nanofilter unit without any disinfection exceeded this requirement. Currently with conventional filtration 4 log removals are achieved by flocculation, filtration and disinfection. The use of nanofilters could be used to justify reduced levels of disinfection during the water treatment process.

In conclusion, the nanofilter units tested under the conditions given at the time of water sampling, were able to effectively remove bacteria and virus from water. Testing for parasitic protozoan removal (*Giardia lamblia* and *Cryptosporidium*) was not done in the initial 30 day test, since the nanofilter removed much smaller bacteria and virus it would be expected to be very effective against the much larger parasitic protozoans. Testing for parasitic protozoans was done as a part of a more extensive testing from samples taken in November and, 1988. These tests verified that the product water does not contain parasitic protozoans. See Appendix C. The removal of parasitic protozoans such as *Giardia Lamblia* is very important since it requires 10 times as much chlorine to kill them compared with virus and bacteria in conventional treatment.

One other microbiology test reported in Appendix C, as required under the SWDA of 1986, is the bacteria *Legionella*. If the nanofilter is effective against other bacteria and viruses it should be effective in removing *Legionella*. As reported in Appendix C the product water did not contain *Legionella*. Further studies of testing the nanofilter unit according to the EPA guidelines for testing of microbiological purifiers may be applicable.

Table 6. Recovery of Poliovirus From Water Passed Through A Nanofilter Unit

| Sample | Mean PFU/mL |
|-----------------------|-----------------------|
| Influent Seeded Water | 2.1 X 10 ⁵ |
| Reject Water | 1.6 X 10 ⁵ |
| Product Water | 0 |

10. Additional Economic Considerations

Additional costs of pretreatment and costs of reuse of the reject stream would have to be added to the cost of nanofiltration. The basic pretreatment used in this study was natural recharge. It proved to be effective, so that the fiber 5 micron filter required changing every 14 days. This frequency of changing will probably be reduced as the newly dug well becomes more fully developed. As shown in the discussion concerning organics there was a reduction in DOC over the 30 day test. Additional studies should be conducted to see if a slow sand filter would be cost effective in further reducing the frequency of changing of the 5 micron prefilter and cleaning of the nanofilter. This type of filter is described in the CAP nanofilter report. Additional tests are also needed to see if the slow sand filter can be substituted for recharge as a pretreatment where conditions are not suitable for recharge. This is particularly important for interceptor type plants which may be built upgradient from the sewage treatment plant where the water is needed for (1) landscape irrigation, (2) recharge into the potable aquifer or (3) direct utilization into the domestic system.

The rapid sand filtration similar to what the City of El Paso uses in their wastewater treatment plant proposes might be utilized as a pretreatment to the nanofilter instead of recharging. This may require modification of the operation of the filter. Perhaps the rapid sand filter could be operated at a higher rates since limitations imposed by the U.S. Environmental Protection Agency (EPA) would be waived as long as the product water was filtered through the nanofilter. On the other hand the successful operation of the nanofilter might require lower rates and pressure through the rapid sand filter to reduce changing of the 5 micron prefilter and cleaning of the nanofilter.

Administration buildings for a 40 mgd expanded plant and a five million gallon storage reservoir are already included in the Ft. Myers

\$0.50/1000 gallons cost estimate for their 20 million gallon per day (mgd) plant so these features would not be included in determining pretreatment costs.

The other costs involved with the use of the nanofilter concerns the utilization of the reject stream. In Ft Myers, the reject stream will be used for irrigation of a nearby city owned golf course. Since only a single element was tested in this project the rejection level was relatively high, ranging from 71 to 84.6 percent. Most inland reverse osmosis plants are operated at a 15 percent rejection level. Because nanofiltration is used with water of lower salinity than reverse osmosis and does not remove as high a percentage of the salinity, the product water, at a 15-20 percent rejection level, can still be used for irrigation, recreation and cooling for power plants. As stated above Ft Myers is going to use their reject water to irrigate a nearby city owned golf course. In the Phoenix area the Palo Verde power plant could continue to be used to utilize the reject stream.

For those communities who do not have a power plant the reject stream from the nanofilter could be further treated by a brackish water (1000-10000 ppm) reverse osmosis filter operating at a pressure of 250-300 psi. The additional cost of this would be approximately \$1.00/1000 gallon and would remove 1/2 of the fresh water from the reject stream. Since this cost is applied against only 15 percent of the incoming stream, the overall added cost to the product water would be \$0.075/1000 gallons. The use of brackish reverse osmosis on the nanofilter reject stream could reduce the final reject water to approximately 7.5 percent of the total. This amount of reject water could be run into evaporation ponds for an interim period. In the future, when the community needed more water the remaining reject stream can be softened using conventional lime softening then the brackish reverse osmosis can again be used to remove as much as 70 to 80 percent of the fresh water. This would reduce the final reject stream to approximately 3 to 4 percent of the incoming stream. The cost of the lime softening plus the brackish reverse osmosis would be approximately \$1.50/1000 gallons of the 7.5% reject stream or approximately another \$0.075/1000 gallons added on to the cost of the product water for a total of \$0.15/1000 gallons of product water.

Using the above scheme a relatively few acres of lined reservoir would be needed for final evaporation of the remaining brine. This reservoir would be compartmented and kept shallow to maximize evaporation. High density 30 mil polyethylene plastic at \$7500/acre (plus installation costs) could be used to line the reservoir. The total cost of this reservoir and supply line would not be excessive probably in the order of 2-3 cents per thousand gallons of product water if the land were available at reasonable costs. The evaporation pond would reduce the final reject stream to dry salt, which could either be sold or landfilled.

11. Conventional Treatment Plant

The removal of THM and TOX precursors from surface water with conventional treatment is very difficult even when ozone is used as the primary disinfectant. In the final report on Tucson Water's pilot plant on

Ozone Life Cycle Cost Analysis (Carollo, 1987) page III-8, it is clearly stated that the use of ozone does not reduce the THM precursors. The exact quotation is: "Although ozone reduced the rate of formation of THMs during the first two hours of chlorine contact, it evidently did not remove THM precursors because after an incubation period of five days at higher chlorine doses, the THMs were approximately equal for both ozonated and non-ozonated samples".

Chloramines are sometimes used as the secondary disinfectant to reduce THM levels. Boyle Engineering Corp. in their report on the selection of a treatment plant for the City of Ft. Myers indicated that EPA would by 1991 provide restrictions on harmful bi-products, TOX compounds, so they concluded that "implementation of the chloramine and ozone options would only provide a short-term solution to the City's current water problem" (City of Ft. Myers, 1987). Other scientists have warned about using chloramines instead of chlorine (Smallowitz, 1986) (Johnson & Jensen, 1986).

As indicated above it is difficult to significantly reduce DOC using conventional treatment. Activated charcoal is expensive and requires constant monitoring to make sure it is effective. The City of Denver has shown that reverse osmosis is effective in renovating municipal effluent, but it is more expensive than nanofiltration.

There is a cost saving in reducing the salinity in municipal effluent before it is used for domestic water. For a TDS concentration decrease of 400 ppm according to Waterstone and DeCook (1988) each household will save \$100/ year for extra soap, replacement of appliances etc. These water quality savings need to be included in any cost analysis made of the nanofiltration method.

12. Nanofiltration, a Potential Solution

The nanofilter appears to solve several problems in reusing the municipal effluent supply. It removes more salinity than was added as the water passed through the municipal system. The product water from nanofiltration will also be softer than the domestic water that it originated from. Finally nanofiltered recharged municipal effluent will contain fewer dissolved organics and THM's than the parent water. The recharge/nanofilter treatment will also eliminate bacteria and viruses and presumably the much larger parasitic protozoans.

Arizona residents, in general, do not fully understand the dangers of disinfectant bi-products, THMs and TOX compounds. They do not understand that bathing and inhaling vapor from THM contaminated water appears to be equally as dangerous as drinking the water (Peterson, 1988) (Brown et al., 1984) (Caldwell, 1986). The danger from inhaling vapors from water containing chloroform (the principal THM) was discussed in a recent issue of Woman's Day (Cunningham, 1988). The readers were warned to take shorter and colder showers and use the dish washer and clothes washer when the room in which they were located was not occupied. The reader was not told what causes the chloroform to be in the water. With these types of risks bottled water is not the answer. The risk from both drinking and bathing

are additive (Peterson, 1988). Thus one could have a combined risk of 1 death in 1500 people and still meet the EPA 100 part per billion (ppb) THM standard (National Academy of Science, 1977).

Conventional treatment of municipal effluent to turn it into potable water is not the answer. There would be too many dissolved organics and too much salinity and hardness. The nanofilter will reduce all of these components to a low level so that the water will not only be safe to drink it will taste as good as some of the best groundwater in the state.

Nanofiltration of secondary treated municipal effluent in interceptor plants will produce a water in close proximity to an irrigation demand for landscaped areas including golf courses. In these interceptor plants the pretreatment would be done by a slow sand filter which simulates the natural recharge used in this 30 day test. The slow sand filter was found to be very effective pretreatment for nanofiltration of CAP water. This is described in Cluff et al (1989). One advantage of the interceptor plants is the water can be made available close to the landscape irrigation demand. Also with nanofiltration, excess water available in the winter can be easily recharged either using streambed, basins or well injection since the nanofiltered water will be as good or better quality with respect to salinity, hardness and dissolved organics than the native groundwater.

13. Summary

The use of nanofiltration of recharged municipal effluent greatly improved the quality of the water. Nanofiltration by the end of the test was removing 82% of the salinity, 95% of the hardness, 86% of the dissolved organics, DOC, and 90% of the THMFP. The product water was shown to be free of all viruses and bacteria and all of the much larger parasitic protozoans. The product water also has an excellent taste.

All of the contaminants required to be regulated under the Safe Drinking Water Act (SDWA) of 1986 for which tests are available were tested for samples taken in November and December, 1988. See Appendix A. Tests for some of the contaminants specified in the 1986 Act have not been formulated yet. All available tests for contaminants were run showing that nanofiltered recharged municipal wastewater more than meets the present and proposed future EPA standards. It is expected from known contaminant removal processes that the combination of basin or streambed recharge and nanofiltration will prove to be an effective treatment for most if not all of the remaining listed contaminants in the SWDA of 1986 for which testing procedures are not yet available. Additional testing is needed to show how much of the organic contamination removal comes from the recharge phase of treatment process and how much is removed by the nanofilter. The extensive tests under the 1986 SWDA as shown in Appendix A were not run on the recharged municipal effluent which was the influent to the nanofilter. The tests were run only on the product water.

A further advantage of the nanofilter is that as it ages it compresses, and as it compresses it is even more effective in removal of impurities.

The use of the nanofilter on recharged municipal effluent would allow our communities to greatly reduce their demand for fresh water supplies. In most cases it would be a better quality domestic water than the cities are presently using and better than much of the water that is available from the water farms, which is the alternate source of water for our growing communities.

The use of the nanofilter would solve existing and potential salt balance and other types of water pollution problems. Conventionally treated effluent is presently being used upgradient for irrigation in the Tucson area. However this water is generally two or three times as salty as the native groundwater in these areas. Continued irrigation with this water in those areas will eventually degrade the aquifer. In addition expensive upgradient pipeline systems are not used in the winter time when there is no irrigation demand. If nanofiltration were used it would greatly reduce the salt buildup in our aquifers from irrigation and the pipelines could be used to move water and strategically recharge product water in upgradient areas presently experiencing drawdowns of the water table.

With the influx of new people moving into the urban areas of Arizona it may not be possible to preserve the air quality or open space or prevent increased traffic congestion, but with nanofiltration, a good quality water supply can be preserved at a reasonable cost.

14. Acknowledgments

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APPENDIX B

Water Resource Experts Contacted About using Nanofilters

Argo, David, Engineer, Black & Veatch, Santa Ana, Ca. 714 557 1675.

Bonfield, Jesse, Pure Solutions, Phoenix Az., 602 437 1355.

Edwards, Eddie, Project Manager, Boyle Engineering Corp, Ft Myers, Fla, 813 337 3838.

Elder, Douglas, Engineer, Black & Veatch, Kansas City, Kansas, 913 339 2000.

Guidry, John, Engineer, Boynton Beach Utility Dept, Fla., 305 738 7460.

Hickman, Carl E., Consulting Engineer, Cave Creek, Az. 602 488 4644.

Hull, Charles, Engineer, (formerly with Factory 21, Orange Ct., Ca), Escondido, Ca. 619 489 1766.

Kiefer, Curtis A., Engineer, Stone & Webster Engineering Corp., Fort Lauderdale, Fla., 305 791 3226.

Perlman, John, UOP Fluid Systems, San Diego, Ca., 619 695 3840.

Proffit, Keith, Black & Veatch, Dare County, North Carolina, 919 672 3600.

Taylor, James F., Director Environmental Systems Engineering Institute, University of Central Fla., Orlando, 305 275 2841.

Sanzs, William, Filmtec Corp., San Diego, Ca., 619 485 7840.

Smith, Terry D., Manager, Brackish Water Marketing, Filmtec, Midland, Michigan, 517 636 3923.

Warner, Robert, Engineer, Stone & Webster Engineers, Denver, Col., 303 741 7147.

Watson, Bruce, Engineer, DSS Engineers, Ft Lauderdale, Fla., 305 791 3226.

Watson, In, Engineer, Ft Myers Florida, 813 334 0442.



THE UNIVERSITY OF ARIZONA
TUCSON, ARIZONA 85721

COLLEGE OF ENGINEERING AND MINES

WATER RESOURCES RESEARCH CENTER
GEOLOGY BUILDING RM 318
(602) 621-7607

January 25, 1989

John F. Long
5035 W. Camelback
Phoenix, AZ 85031.

Dear John,

Attached is Dr. Charles P. Gerba's discussion on water samples from the nanofilter product water of the recharged municipal effluent at the 91st Avenue test site in Phoenix. The Microbiology Laboratory under Dr. Gerba's direction ran the six tests covering the microbiology contaminants required to be regulated under the Safe Water Drinking Act (SWDA) of 1986 and found the levels to be zero. The heterotrophic plate count for which there is no present standard was also tested and found to have a count of 157/ml, which is well below the proposed standard of 500/ml. See the attached table from Dr. Gerba.

Dr. Gary Amy and his graduate student, Mr. Peter Tsakayikas (Ph.D. Candidate) reviewed the data for organics while Dr. Gordon Dutt and his graduate student, Mr. Saud Amer, (Ph.D. Candidate) reviewed the data for inorganics. See the attached letters. The product water meets all present and projected primary standards for organics and inorganics. The nanofilter research team at the University of Arizona found that Arizona Testing Laboratories and their subcontractors had run all of the available tests on the original list of 83 contaminants of the SWDA of 1986 plus the seven changes made to the original list. There are nine contaminants for which tests are not yet available. For the eighty one contaminants checked for which tests are available nanofilter product water of the recharged municipal effluent meets all of the remaining 1986 SWDA existing and anticipated minimum contaminants to be set tentatively by 1991. In almost all cases the levels were below the detectable limit and therefore are either non-existent or unmeasurable using existing technology.

In addition to the above tests, Arizona Testing Laboratories and their subcontractors also ran analysis for approximately 100 additional contaminants, including all of the chemicals on the EPA's priority list of drinking water contaminants for which tests are available. In all of the test results the contaminants were below the detectable limit or below EPA's existing or anticipated future standards.

All of the radionuclides were run and found to be either non detectable or below the detectable limit except for radon which was found to be at less than half of the anticipated 200 pCi/liter EPA standard to be announced in the future. This future anticipated standard was given to us by the Controls For Environmental Pollutions Inc. Laboratory in New Mexico in a telephone call on Jan 19, 1989. There is no EPA set limits for radon at the present time.

It is noteworthy that the combination of recharge followed by nanofiltration produces potable water from a chlorinated secondary effluent. In this combination, groundwater recharge serves as a "pretreatment" step while nanofiltration functions as a "polishing" treatment step.

In conclusion our evaluation based on the data of more than 180 tests run by the Arizona Testing Laboratory and their subcontractors and from the Department of Microbiology indicates that the nanofilter product water from recharged municipal effluent will meet all of the existing drinking water standards under the 1986 SWDA minimum contaminant levels (MCL's) as well as future anticipated MCL's to be tentatively set by 1991.

Yours Truly,

C. Brent Cluff

C. Brent Cluff, Ph.D.
Associate Hydrologist

cc: Dr. Gary Amy
Dr. Gordon Dutt
Dr. Charles Gerba



THE UNIVERSITY OF ARIZONA
TUCSON, ARIZONA 85721

UNIVERSITY DEPARTMENT OF MICROBIOLOGY AND IMMUNOLOGY

BUILDING #90
AC 602 621-6903

January 25, 1989

Mr. John F. Long
Post Office Box 14029
Phoenix, AZ 85063

Dear Mr. Long:

This letter is to certify that we have tested the nanofilter treated water plus coliform, fecal coliform, and heterotrophic bacteria, as well as enteric parasites Giardia and Cryptosporidium, and enteric viruses. These tests are designed to ensure that the water is microbiologically safe for consumption. The coliform test is the standard indicator test to ensure the sanitary quality of drinking water. Drinking water should contain no detectable levels of coliform or fecal coliform bacteria. It has been recognized over the last two decades that the traditional indicators do not always reflect the occurrence of disease causing parasites and viruses. As a result the U.S. Environmental Protection Agency has proposed in their Surface Treatment Rule that treated water be free of detectable enteric viruses and Giardia. They have also served notice that they are considering regulating Cryptosporidium. None of these agents were detected in the nanofilter treated water.

The U.S. Environmental Protection Agency will be requiring that any drinking water treatment system be capable of removing 99.9% of Giardia and 99.99% of the enteric viruses present. The nanofilter system would easily meet these requirements and exceed them. This is because of the large size of the parasites. Enteric viruses would also be excluded because of their size.

Sincerely,

Charles P. Gerba, Ph.D.
Professor
Microbiology and Immunology

CPG:jk



The University of Arizona

College of Engineering and Mines
Department of Civil Engineering
and Engineering Mechanics
Tucson, Arizona 85721
(602) 621-2266

January 24, 1989

Memorandum

TO: Brent Cluff, Water Resources Research Center

FROM: Gary Amy, Environmental Engineering *Gary Amy*

RE: Organics Analysis of Nanofilter Product Water

Both my graduate student, Mr. Peter Tsakanitas (Ph.D. Candidate), and I have reviewed the organics analysis performed by Arizona Testing Laboratories and associates. In no case did a measured value exceed a regulated values for the spectrum of organics, including volatile organic chemicals (VOCs) and synthetic organic chemicals (SOCs). This observation is based on both present and projected levels for regulated organic contaminants.



THE UNIVERSITY OF ARIZONA
TUCSON, ARIZONA 85721

COLLEGE OF AGRICULTURE

DEPARTMENT OF SOIL AND WATER SCIENCE
429 SHANTZ BUILDING #38
(602) 621-1646

January 25, 1989

Dear Mr. Cluff:

Based on the analysis by Arizona Testing Laboratories the Nonofilter product water was found to meet all current and proposed drinking water standards for inorganic constituents.

Sincerely,

Gordon R. Dutt
Professor

GRD:erl

ARIZONA DEPARTMENT OF ENVIRONMENTAL QUALITY

ROSE MOFFORD, GOVERNOR
RANDOLPH WOOD, DIRECTOR

November 28, 1988

Mr. John F. Long
John F. Long Foundation, Inc.
P.O. Drawer 14029
Phoenix, Arizona 85063

Re: Arizona Department of Environmental Quality's Review and Recommendations on the Nanofilter Project.

Dear Mr. Long,

The Arizona Department of Environmental Quality (ADEQ) very much appreciated the opportunity to review and comment on the "Project Report: Test of Nanofilter Method of Treating Recharge Municipal Effluent" by Dr. C. Brent Cluff, et al; visit the nanofilter test project site; and discuss the opportunities nanofiltration can provide.

In general, nanofiltration appears to be a very exciting new technology that can provide Arizonan's with an economical alternative to better and more fully utilize and improve the quality of its water resources. Of particular interest is the potential that nanofiltration offers in the conversion of municipal waste water effluent to a potable water resource. A more immediate and practical application of interest, however, is the ability of the nanofilter to resolve existing problems with and improve current potable water resources (e.g., Apache Junction Nanofilter Project). Moreover, nanofiltration appears to be able to reduce significantly the amount of dissolved salts, trihalomethane precursors, and organic materials in providing an economical pretreatment for waters that are planned for recharge or reuse (such as waters from municipal effluent and the Central Arizona Project). Such pretreatment is needed in many cases and would reduce surface and subsurface impacts from reuse waters and, under a recharge scenario, enhance the quality of the receiving aquifer. Also, such pretreatment would reduce current quality problems associated with effluent discharges from municipal waste water facilities under certain restrictive federal National Pollution Discharge Elimination System (NPDES) permit requirements.

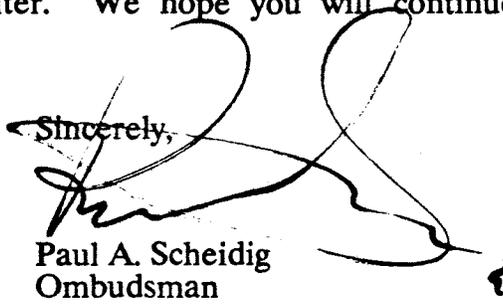
Even though there appear to be numerous benefits, the nanofilter process needs further examination and demonstration of its effectiveness and usefulness. ADEQ believes that Dr. C. Brent Cluff, et al, have provided a good report, which identified the numerous positive results of nanofiltration. Additional research of nanofiltration, however, appears to be warranted. A number of physical tests (viral, bacteriological, parasitical, and chemical) of the nanofilter are still needed to demonstrate its true effectiveness in rendering municipal effluent potable. These additional testing regimes, which I understand are being performed currently by the Arizona Testing Laboratory, are needed not only to qualify the effectiveness of the nanofilter but also to quell suspicion and apprehension towards the safe use of treated effluent as a potable or other full body contact water resource.

The Department of Environmental Quality is An Equal Opportunity Affirmative Action Employer

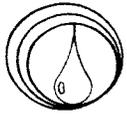
Mr. John F. Long
November 28, 1988
Page 2

Again, ADEQ appreciated the opportunity to review the report and discuss the positive benefits and additional testing needs of the nanofilter. ADEQ believes that the nanofilter technology can benefit Arizona and other arid climates where water resources are scarce and precious commodities. Moreover, the Department encourages you to continue to pursue the examination and implementation of this new and useful technology. ADEQ would be pleased to continue to lend you any further oversight assistance it can in the development of the nanofilter. We hope you will continue to keep us apprised of your progress.

Sincerely,

A handwritten signature in black ink, appearing to read 'Paul A. Scheidig', written over the word 'Sincerely,'. The signature is fluid and cursive, with a large loop at the end.

Paul A. Scheidig
Ombudsman



Arizona Testing Laboratories

817 West Madison Street □ Phoenix, Arizona 85007 □ 602/254-6181

January 25, 1989

John F. Long Homes
Attn: Mr. Rod Kayes
Post Office Box 14029
Phoenix, Arizona 85063

Dear Mr. Kayes:

I am writing this letter at the request of Dr. Brent Cluff to explain any discrepancies between the enclosed letter dated November 4, 1988 and the revised reports dated January 23, 1989.

First of all it should be noted that all currently regulated chemicals under the Safe Drinking Water Act (SDWA) have been tested and listed in the aforementioned reports. Secondly, over 100 other chemicals either unregulated or suspected for future regulation were analyzed. Most of these chemicals are part of Tables sent along with the letter of November 4, 1988. These Tables were copies from New Dimensions in Safe Drinking Water, American Water Works Association, 1987.

As part of our service, we combined Tables, removed the redundancies and crossed out several compounds for which there are no current EPA methods available. Upon further review we found other compounds could not be detected by previously acceptable methods (i.e. Acrylamide, Method 525; Aldicarb, Method 632).

In summary, the analytical reports provided by this laboratory and its subcontractors are a comprehensive list of suspected contaminants in water for which there are currently approved analytical methods.

If you have any further questions please contact me at 254-6181.

Respectfully yours,

ARIZONA TESTING LABORATORIES

Robert J. Drake
General/Laboratory Manager

RJD:aml
cc: Dr. Brent Cluff

REVISED REPORT

01/23/89



Arizona Testing Laboratories

817 West Madison · Phoenix, Arizona 85007 · Telephone 254-6181

For: John F. Long Homes
Attn: Rod Kayes
P.O. Box 14029
Phoenix, Arizona 85063

Date: January 11, 1989

Lab. No.: 262201

Sample: Water

Marked: Sampled: 11/21/88, 10:00 a.m.
Product Water From Nanofiller

Received: 11/21/88

Submitted by: Same

REPORT OF LABORATORY TESTS

METHOD 603:

| | | |
|---------------|-------|------|
| Acrolein | < 50. | ug/L |
| Acrylonitrile | < 50. | |

METHOD 504:

| | | |
|----------------------|----------|------|
| Ethylene Dibromide | < 0.0001 | ug/L |
| Dibromochloropropane | < 0.0002 | |

< = Less Than The Detection Limit Given

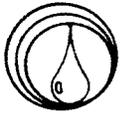
Respectfully submitted,

ARIZONA TESTING LABORATORIES

Robert J. Drake

REVISED REPORT

01/23/89



Arizona Testing Laboratories

817 West Madison · Phoenix, Arizona 85007 · Telephone 254-6181

For: John F. Long Homes
Attn: Mr. Rod Kayes
Post Office Box 14029
Phoenix, Arizona 85063

Date: December 22, 1988

Lab. No.: 262201

Sample: Water

Marked: Sampled: 11/21/88, 10:00 a.m.
Product Water From Nanofiller

Received: 11/21/88

Submitted by: Same

REPORT OF LABORATORY TESTS

| | | | | | |
|------------------------|---------|------|---------------|--------|------|
| pH | 6.8 | | Hardness | 51. | mg/L |
| Total Dissolved Solids | 240 | mg/L | Iron | < 0.1 | |
| Arsenic | 0.026 | | Magnesium | 2.8 | |
| Barium | < 0.5 | | Manganese | 0.090 | |
| Cadmium | < 0.005 | | Sodium | 79. | |
| Chromium | < 0.01 | | Sulfate | < 3.0 | |
| Fluoride | 0.2 | | Zinc | < 0.05 | |
| Lead | < 0.002 | | Nitrite-N | < 0.02 | |
| Mercury | < 0.001 | | Aluminum | < 0.05 | |
| Nitrate-N | < 0.2 | | Antimony | < 0.02 | |
| Selenium | < 0.005 | | Molybdenum | < 0.05 | |
| Silver | < 0.02 | | Vanadium | < 0.05 | |
| Alkalinity | 46. | | Thallium | < 0.02 | |
| Calcium | 16. | | Beryllium | < 0.01 | |
| Chloride | 120. | | Uranium | < 0.5 | |
| Copper | < 0.05 | | Total Cyanide | < 0.01 | |
| Nickel | < 0.05 | | Strontium | < 0.1 | |
| Boron | 0.47 | | Ammonia-N | < 0.1 | |

< = Less Than The Detection Limit Given

Respectfully submitted,

ARIZONA TESTING LABORATORIES

Robert J. Drake



Arizona Testing Laboratories

817 West Madison · Phoenix, Arizona 85007 · Telephone 254-6181

For: John F. Long Homes
Attn: Mr. Rod Kayes
Post Office Box 14029
Phoenix, Arizona 85063

Date: December 7, 1988
Lab. No.: 262201

Sample: Water

Marked: Product water from nanofiller
Sampled: 11/21/88 @1000

Received: 11/21/88

Submitted by: Same

REPORT OF LABORATORY TESTS

METHOD 508

| | | |
|--------------------|--------|------|
| Alpha BHC | < 0.01 | ug/L |
| Lindane | < 0.01 | |
| Beta BHC | < 0.01 | |
| Alachlor | < 0.10 | |
| Heptachlor | < 0.01 | |
| Delta BHC | < 0.05 | |
| Aldrin | < 0.01 | |
| Heptachlor Epoxide | < 0.50 | |
| Endosulfan I | < 0.05 | |
| PP' - DDE | < 0.01 | |
| Dieldrin | < 0.01 | |
| Endrin | < 0.05 | |
| PP' - DDD | < 0.02 | |
| Endosulfan II | < 0.05 | |
| PP' - DDT | < 0.02 | |
| Endrin Aldehyde | < 0.05 | |
| Endosulfan Sulfate | < 0.20 | |
| Methoxychlor | < 0.10 | |
| Chlordane | < 0.05 | |
| Toxaphene | < 0.20 | |
| Total PCB | < 0.50 | |

< = less than

Respectfully submitted,

ARIZONA TESTING LABORATORIES

Robert J. Drake

REVISED REPORT

01/23/89



Arizona Testing Laboratories

817 West Madison · Phoenix, Arizona 85007 · Telephone 254-6181

For: John F. Long Homes
Attn: Rod Kayes
P.O. Box 14029
Phoenix, Arizona 85063

Date: December 22, 1988

Lab. No.: 262201

Sample: Water

Marked: Sampled: 11/21/88, 10:00 a.m.
Product Water From Nanofiller

Received: 11/21/88

Submitted by: Same

REPORT OF LABORATORY TESTS

METHOD 502.2

| | | | |
|--------------------------|---|-----|------|
| Dichlorodifluoromethane | < | 0.5 | ug/L |
| Chloromethane | < | 0.5 | |
| Vinyl Chloride | < | 0.5 | |
| Bromomethane | < | 0.5 | |
| Chloroethane | < | 0.5 | |
| Trichlorofluoromethane | < | 0.5 | |
| 1,1-Dichloroethylene | < | 0.5 | |
| Methylene Chloride | < | 0.5 | |
| trans-1,2-Dichloroethene | < | 0.5 | |
| 1,1-Dichloroethane | < | 0.5 | |
| 2,2-Dichloroethane | < | 0.5 | |
| cis-1,2-Dichloroethene | < | 0.5 | |
| Chloroform | < | 0.5 | |
| Bromochloromethane | < | 0.5 | |
| 1,1,1-Trichloroethane | < | 0.5 | |
| 1,1-Dichloropropene | < | 0.5 | |
| Carbon Tetrachloride | < | 0.5 | |
| Benzene | < | 0.5 | |
| 1,2-Dichloroethane | < | 0.5 | |
| Trichloroethylene | < | 0.5 | |
| 1,2-Dichloropropane | < | 0.5 | |
| Bromodichloromethane | < | 0.5 | |
| Dibromomethane | < | 0.5 | |
| Toluene | < | 0.5 | |
| 1,1,2-Trichloroethane | < | 0.5 | |
| Tetrachloroethylene | < | 0.5 | |
| 1,3-Dichloropropane | < | 0.5 | |
| Dibromochloromethane | < | 0.5 | |

< = less than

Respectfully submitted,

ARIZONA TESTING LABORATORIES

Robert J. Drake

REVISED REPORT

01/23/89



Arizona Testing Laboratories

817 West Madison · Phoenix, Arizona 85007 · Telephone 254-6181

For: John F. Long Homes
Attn: Rod Kayes
P.O. Box 14029
Phoenix, Arizona 85063

Date: December 22, 1988

Lab. No.: 262201

Sample: Water

Marked: Sampled: 11/21/88, 10:00 a.m.
Product Water From Nanofiller

Received: 11/21/88

Submitted by: Same

REPORT OF LABORATORY TESTS

METHOD 502.2

| | | |
|---------------------------|-------|------|
| Chlorobenzene | < 0.5 | ug/L |
| Ethylbenzene | < 0.5 | |
| 1,1,1,2-Tetrachloroethane | < 0.5 | |
| m-Xylene | < 0.5 | |
| p-Xylene | < 0.5 | |
| o-Xylene | < 0.5 | |
| Styrene | < 0.5 | |
| Isopropyl Benzene | < 1.0 | |
| Bromoform | < 0.5 | |
| 1,1,2,2-Tetrachloroethane | < 0.5 | |
| 1,2,3-Trichloropropane | < 1.0 | |
| n-Propyl Benzene | < 1.0 | |
| Bromobenzene | < 1.0 | |
| 1,3,5-Trimethyl Benzene | < 1.0 | |
| 2-Chlorotoluene | < 1.0 | |
| 4-Chlorotoluene | < 1.0 | |
| tert-Butyl Benzene | < 1.0 | |
| 1,2,4-Trimethylbenzene | < 1.0 | |
| sec-Butyl Benzene | < 1.0 | |
| p-Isopropyl Toluene | < 1.0 | |
| 1,3-Dichlorobenzene | < 0.5 | |
| 1,4-Dichlorobenzene | < 0.5 | |
| n-Butyl Benzene | < 1.0 | |
| 1,2-Dichlorobenzene | < 0.5 | |
| 1,2,4-Trichlorobenzene | < 0.5 | |
| Hexachlorobutadiene | < 1.0 | |
| Naphthalene | < 1.0 | |
| 1,2,3-Trichlorobenzene | < 0.5 | |

< = less than

Respectfully submitted,

ARIZONA TESTING LABORATORIES

Robert J. Drake



Arizona Testing Laboratories

817 West Madison · Phoenix, Arizona 85007 · Telephone 254-6181

For: John F. Long Homes
Attn: Rod Kayes
P.O. Box 14029
Phoenix, Arizona 85063

Date: January 11, 1989

Lab.No.: 262201

Sample: Water

Marked: Sampled: 11/21/88, 10:00 a.m.
Product Water From Nanofiller

Received: 11/21/88

Submitted by: Same

REPORT OF LABORATORY TESTS

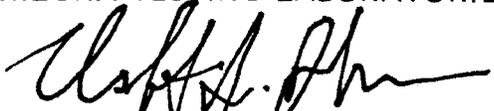
METHOD 525 - BASE/NEUTRAL EXTRACTABLES

| CAS NUMBER | | | |
|------------|--------------------------------|-------|------|
| 111-44-4 | bis (-2-Chloroethyl) Ether | < 5.7 | ug/L |
| 62-75-9 | N-Nitrosodimethylamine | < 20. | |
| 541-73-1 | 1,3-Dichlorobenzene | < 1.9 | |
| 106-46-7 | 1,4-Dichlorobenzene | < 4.4 | |
| 95-50-1 | 1,2-Dichlorobenzene | < 1.9 | |
| 39638-32-9 | bis (-2-Chloroisopropyl) Ether | < 5.7 | |
| 621-64-7 | N-Nitroso-di-n-Propylamine | < 10. | |
| 67-72-1 | Hexachloroethane | < 1.6 | |
| 98-95-3 | Nitrobenzene | < 1.9 | |
| 78-59-1 | Isophorone | < 2.2 | |
| 111-91-1 | bis (-2-Chloroethoxy) Methane | < 5.3 | |
| 120-82-1 | 1,2,4-Trichlorobenzene | < 1.9 | |
| 91-20-3 | Naphthalene | < 1.6 | |
| 77-47-4 | Hexachlorocyclopentadiene | < 10. | |
| 87-68-3 | Hexachlorobutadiene | < 0.9 | |
| 91-58-7 | 2-Chloronaphthalene | < 1.9 | |
| 131-11-3 | Dimethyl Phthalate | < 1.6 | |
| 208-96-8 | Acenaphthylene | < 3.5 | |
| 83-32-9 | Acenaphthene | < 1.9 | |
| 121-14-2 | 2,4-Dinitrotoluene | < 5.7 | |
| 606-20-2 | 2,6-Dinitrotoluene | < 1.9 | |
| 84-66-2 | Diethyl Phthalate | < 22. | |
| 7005-72-3 | 4-Chlorophenyl-phenylether | < 4.2 | |

< = less than

Respectfully submitted,

ARIZONA TESTING LABORATORIES


Robert J. Drake

01/23/89



Arizona Testing Laboratories

817 West Madison · Phoenix, Arizona 85007 · Telephone 254-6181

For: John F. Long Homes
 Attn: Rod Kayes
 P.O. Box 14029
 Phoenix, Arizona 85063

Date: January 11, 1989

Lab.No.: 262201

Sample: Water

Marked: Sampled: 11/21/88, 10:00 a.m.
 Product Water From Nanofiller

Received: 11/21/88

Submitted by: Same

REPORT OF LABORATORY TESTS

METHOD 525 - BASE/NEUTRAL EXTRACTABLES

| CAS NUMBER | | | ug/L |
|------------|-------------------------------|--------|------|
| 86-30-6 | N-Nitrosodiphenylamine | < 10. | |
| 86-73-7 | Fluorene | < 1.9 | |
| 101-55-3 | 4-Bromophenyl-phenylether | < 1.9 | |
| 118-74-1 | Hexachlorobenzene | < 1.9 | |
| 85-01-8 | Phenanthrene | < 5.4 | |
| 120-12-7 | Anthracene | < 1.9 | |
| 84-74-2 | Di-n-Butylphthalate | < 2.5 | |
| 92-87-5 | Benzidine | < 44. | |
| 206-44-0 | Fluoranthene | < 2.2 | |
| 129-00-0 | Pyrene | < 1.9 | |
| 85-68-7 | Butylbenzylphthalate | < 2.5 | |
| 91-94-1 | 3,3'-Dichlorobenzidine | < 16.5 | |
| 56-55-3 | Benzo (a) Anthracene | < 7.8 | |
| 117-81-7 | bis (-2-Ethylhexyl) Phthalate | < 2.5 | |
| 218-01-9 | Chrysene | < 2.5 | |
| 117-84-0 | Di-n-Octyl Phthalate | < 2.5 | |
| 205-99-2 | Benzo (b) Fluoranthene | < 4.8 | |
| 207-08-9 | Benzo (k) Fluoranthene | < 2.5 | |
| 50-32-8 | Benzo (a) Pyrene | < 2.5 | |
| 193-39-5 | Indeno (1,2,3-cd) Pyrene | < 3.7 | |
| 53-70-3 | Dibenz (a,h) Anthracene | < 2.5 | |
| 191-24-2 | Benzo (g,h,i) Perylene | < 4.1 | |
| 1746-01-6 | Dioxin (2,3,7,8-TCDD) | * | |

< = less than

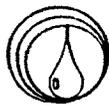
*No Identifiable Ions

Page 2 of 2

Respectfully submitted,

ARIZONA TESTING LABORATORIES

Robert J. Drake



Arizona Testing Laboratories

817 West Madison Street □ Phoenix, Arizona 85007 □ 602/254-6181

For: John F. Long Homes
 Attn: Mr. Rod Kayes
 Post Office Box 14029
 Phoenix, Arizona 85063

Date: November 23, 1988

Lab. No.: 201501-03

Sample: Water

Marked: Sampled: 10-20-88, 10:30 a.m.
 Sampled by: Steven Hankins of
 Arizona Testing Laboratories

Received: 10-20-88

Submitted by: Arizona Testing Laboratories

REPORT OF LABORATORY TESTS

| | <u>Influent</u> | <u>Product</u> | <u>Reject</u> | |
|---|-----------------|----------------|---------------|------|
| Arsenic | 0.031 | < 0.01 | 0.028 | mg/L |
| Barium | < 0.05 | < 0.05 | < 0.05 | |
| Cadmium | < 0.005 | < 0.005 | < 0.005 | |
| Chromium | < 0.01 | < 0.01 | < 0.01 | |
| Fluoride | 0.7 | 0.2 | 0.8 | |
| Lead | 0.0082 | < 0.002 | 0.0073 | |
| Mercury | < 0.001 | < 0.001 | < 0.001 | |
| Nitrate, N | 2.8 | 1.4 | 3.7 | |
| Selenium | < 0.005 | < 0.005 | < 0.005 | |
| Silver | < 0.02 | < 0.02 | < 0.02 | |
| Alkalinity | 350 | 100 | 390 | |
| Calcium | 120 | 8.7 | 140 | |
| Chloride | 540 | 140 | 570 | |
| Copper | 0.12 | < 0.05 | < 0.05 | |
| Total Hardness | 510 | 35 | 580 | |
| Iron | 0.68 | < 0.1 | 0.29 | |
| Magnesium | 51 | 3.4 | 56 | |
| Manganese | 1.6 | 0.080 | 1.6 | |
| Sodium | 390 | 110 | 410 | |
| Sulfate | 220 | < 3 | 240 | |
| Total Dissolved Solids | 1600 | 330 | 1700 | |
| Zinc | 0.063 | < 0.05 | 0.084 | |
| pH | 7.6 | 6.7 | 7.3 | |
| Total Phosphorus, P | 0.59 | < 0.01 | 0.55 | |
| Ortho Phospahte, P | 0.44 | < 0.01 | 0.46 | |
| Bromide | < 5 | < 5 | < 5 | |
| Dissolved Organic Carbon | 11.2 | 1.4 | 12.0 | |
| Turbidity, NTU | 1.5 | < 0.1 | 0.5 | |
| Conductivity, millimhos/cm | 2800 | 590 | 2900 | |
| *Total Coliform Bacteria, MPN/100 ml | 17 | < 2 | 8 | |
| *Fecal Coliform Bacteria, MPN/100 ml | 7 | < 2 | < 2 | |

*tests started 10/20/88, 1:20 p.m.

< = less than the detection
 limit given

cc: Dr. Brent Cluff, WRRRC

Respectfully submitted,

ARIZONA TESTING LABORATORIES

Steven Hankins
 Steven Hankins



THE UNIVERSITY OF ARIZONA
TUCSON, ARIZONA 85721

UNIVERSITY DEPARTMENT OF MICROBIOLOGY AND IMMUNOLOGY

BUILDING #90
AC 602 621-6903

February 24, 1989

Dr. Brent Cluff
Department of Hydrology
University of Arizona

Dear Dr. Cluff:

Please find enclosed the results from the microbiological tests conducted on the Nanofilter product water sample collected on December 5, 1988. If you have any questions, please call.

Sincerely,

A handwritten signature in cursive script that reads 'Susan Kutz'.

Susan Kutz, Ph.D.

SK:jk
encl



THE UNIVERSITY OF ARIZONA
TUCSON, ARIZONA 85721

UNIVERSITY DEPARTMENT OF MICROBIOLOGY AND IMMUNOLOGY

BUILDING #90
AC 602 621-6903

MICROBIOLOGICAL TESTING OF NANOFILTER PRODUCT WATER

| | |
|---------------------------------|---------------|
| Heterotrophic plate count (HPC) | 157 CFU/ml |
| Total coliforms | 0/100 ml |
| Fecal coliforms | 0/100 ml |
| <u>Giardia</u> | 0/181 l |
| <u>Cryptosporidium</u> | 0/181 l |
| <u>Legionella</u> | none detected |
| enteric viruses | none detected |
| turbidity | 0.35 NTU |

Water sample collected December 5, 1988

APPENDIX B

Water Resource Experts Contacted About using Nanofilters

Argo, David, Engineer, Black & Veatch, Santa Ana, Ca. 714 557 1675.

Bonfield, Jesse, Pure Solutions, Phoenix Az., 602 437 1355.

Edwards, Eddie, Project Manager, Boyle Engineering Corp, Ft Myers, Fla, 813 337 3838.

Elder, Douglas, Engineer, Black & Veatch, Kansas City, Kansas, 913 339 2000.

Guidry, John, Engineer, Boynton Beach Utility Dept, Fla., 305 738 7460.

Hickman, Carl E., Consulting Engineer, Cave Creek, Az. 602 488 4644.

Hull, Charles, Engineer, (formerly with Factory 21, Orange Ct., Ca), Escondido, Ca. 619 489 1766.

Kiefer, Curtis A., Engineer, Stone & Webster Engineering Corp., Fort Lauderdale, Fla., 305 791 3226.

Perlman, John, UOP Fluid Systems, San Diego, Ca., 619 695 3840.

Proffit, Keith, Black & Veatch, Dare County, North Carolina, 919 672 3600.

Taylor, James F., Director Environmental Systems Engineering Institute, University of Central Fla., Orlando, 305 275 2841.

Sanzs, William, Filmtec Corp., San Diego, Ca., 619 485 7840.

Smith, Terry D., Manager, Brackish Water Marketing, Filmtec, Midland, Michigan, 517 636 3923.

Warner, Robert, Engineer, Stone & Webster Engineers, Denver, Col., 303 741 7147.

Watson, Bruce, Engineer, DSS Engineers, Ft Lauderdale, Fla., 305 791 3226.

Watson, In, Engineer, Ft Myers Florida, 813 334 0442.

THM CONTROL USING MEMBRANE TECHNOLOGY FORT MYERS CASE STUDY

**Eddie D. Edwards, PE - Managing Engineer
Boyle Engineering Corporation**

**Ian Watson, PE - President
Rostek Services, Inc.**

**Donald C. McKenna - Public Works Administrator
City of Fort Myers**

ABSTRACT

In 1986, the City of Fort Myers, Florida studied three different water treatment processes to reduce the trihalomethane (THM) formation in their potable water system. The City's 50-year old lime softening plant produces water with THMs of over 400 ug/l, well over the current THM regulatory limit of 100 ug/l. Faced with the need for additional capacity and the requirement to meet current and proposed future THM limits, Fort Myers selected the new softening membrane technology for implementation in a new 20-MGD water treatment facility.

On the basis of the year-long pilot scale study, softening membranes were shown to out perform the more conventional lime softening alternatives in the treatment of Fort Myers' water, and at an overall cost comparable to the conventional alternatives. As required in the on-going design of the new treatment facility, early bidding of the membranes has been completed. Recent on-site pilot scale testing by the selected membrane manufacturer has confirmed the results of the City's study relative to both treatment efficiencies and costs.

FORT MYERS EXISTING SYSTEM

The City of Fort Myers, Florida, located on the southwest Gulf of Mexico coastline of Florida, receives raw water supplies from the freshwater Caloosahatchee River. The river water, high in natural organics and color, is pumped and distributed to a series of recharge canals in the City's 500 acre wellfield site. A series of about 20 shallow wells, ranging in depths of 20 to 40 feet, remove up to 11 MGD of groundwater from the recharged surficial aquifer.

This water is then treated at the City's 50 year-old lime softening plant with a rated capacity of about 10 MGD (annual average day). This capacity is expected to be exceeded by 1991. Typical raw and finished water quality levels are shown in Table 1 for those parameters of primary interest in this study.

**TABLE 1
TYPICAL EXISTING WATER QUALITY LEVELS**

| ITEM | RAW | FINISHED |
|-----------------------|---------|------------------|
| Color (CU) | 65-70 | 7.5 |
| THMFP (ug/l) | 500-600 | 400 ⁺ |
| Total Hardness (mg/l) | 200-250 | 130 [±] |

Rapid population growth and the need to reduce the levels of THMs in the water distribution system prompted the City to analyze new treatment technologies for implementing expanded treatment capacity.

Three alternative treatment processes were examined in the overall study through jar testing, literature reviews, and pilot scale testings. These alternatives included those determined to be the most viable for THM control in Fort Myers waters, namely: 1) chloramines as an alternate disinfectant following lime softening; 2) lime softening with ozone for precursor oxidation; and 3) membrane softening. The results from this testing program were then used to develop projected design criteria for full-scale plants using each process and preliminary engineering was performed for cost projections. A cost analysis was then performed utilizing the present worth method of comparison, as well as, a non-cost analysis of the three alternatives. The study began in early 1986 and was concluded in early 1987. This paper primarily addresses the testing and results obtained on the softening membrane process.

Membrane Study Concept and Protocol

Although some test work has been performed in Florida under the auspices of an EPA-sponsored study, the long term testing done to date utilized only one membrane type. Since Boyle Engineering Corporation, and its membrane consultant Rostek Services, Inc. were aware that other membranes were available that at least claimed appropriate characteristics, it was decided that it would be in the best interests of the City of Fort Myers to conduct a carefully structured pilot test with several representative membranes. There was also some evidence to suggest that the effectiveness of the membranes relative to THM precursor removal could be "site specific", since some variation in performance had been noted from site to site in the aforementioned EPA study.

As a result, the City authorized a membrane test program at the existing Fort Myers Water Treatment Plant on Anderson Avenue. The program was to be carried out while other techniques for trihalomethane control were being evaluated. Those membrane manufacturers known to have publicized a product with characteristics applicable to this study were contacted, and invited to participate in the test by providing six elements of 4" diameter. In return, each manufacturer would receive a copy of the test report, and if they so desired, would have the membranes returned after the completion of the program. Six manufacturers were contacted and five responded positively resulting in the delivery of six sets of membrane elements as shown in Table 2.

**TABLE 2
MEMBRANES TESTED**

| NAME | MEMBRANE | TYPE |
|-----------------|----------------|-------------------|
| * FilmTec | NF-70 | Composite |
| * Toray | SU-210S | Composite |
| * DeSal | VLP3 | Composite |
| * DeSal | C60/90 | Cellulose Acetate |
| * Fluid Systems | 4231LP | Cellulose Acetate |
| * Hydranautics | 400-S-CPA-1500 | Composite |

A portable, fully self-contained 50,000 gpd pilot scale plant was designed for fabrication and operation by City personnel. With four pressure vessels the different membranes could be tested in parallel or in multiple stage operations. Cartridge filters of 5 micron rating were provided, along with appropriate pretreatment chemical feeds, an in-line booster pump, pressure gauges, flow meters and sampling ports.

The objective of this pilot scale testing program was to allow evaluation of the softening membrane process relative to treatment efficiencies and ultimate projected full scale capital and operating costs, compared to the other alternatives. When evaluating membrane performance, it is normal to attempt to maximize productivity and salt rejection while attempting to minimize the capital and operating cost variables.

With the need to examine all the dependent variables properly, the test program protocol was developed to evaluate the membranes based on three primary parameters:

- 1) THM precursor rejection
- 2) Specific flux (a measure of energy efficiency)
- 3) Conductivity and Hardness rejection

As a result, five test runs were established to allow variations in pretreatment, recoveries and membranes. Routine data collection and laboratory work was scheduled for once each shift (three times a day), this work being performed by the treatment plant personnel. The testing program resulted in a total of almost 3000 hours operating time.

Test Results

The results of the overall study, specific to the water of Fort Myers, showed that the softening membrane process could provide better treatment capabilities than either the chloramines or ozone processes when these are utilized in a lime softening treatment train. Although all these processes would provide finished waters within the current regulatory or suggested limits for color, hardness and THMs, the softening membranes provided consistently lower final concentrations than the other processes. Further, based on the projected costing of full-scale 20 MGD plants for each process, a total present worth analysis over a 20-year period resulted in present worths which were within 10 to 15% of each other, approximately equal to the accuracy of the costing projections in this study. Therefore, the alternatives are considered equivalent in overall costs.

On the basis of primarily non-cost considerations, the study recommended the design and construction of a new 20 MGD softening membrane plant in the City of Fort Myers.

Plant Design and Membrane Bidding

Late in 1987, design began on the new softening membrane plant in Fort Myers. As different types of membranes (composite or CA) had been shown to be effective on Fort Myers water, pre-bidding of the membranes and their associated equipment was required in order to allow design of the varied pre- and post-treatment facilities specific to each type of membrane.

The design team, Boyle Engineering and Rostek Services, was aware that in the almost two years since the beginning of the City's pilot scale testing program new softening membranes were available on the general market. An unique bid package and process was recommended and utilized which promoted competition between those membranes previously evaluated and the newer ones now available. Because of the magnitude of the project (and the subsequent large number of membrane elements required) the engineers directly contacted known membrane suppliers worldwide rather than the

supplier's original equipment manufacturers (OEM's) as was typically done in the industry. Through these discussions, a bid package was developed which defined the basic operating parameters desired by the City (parameters developed in the earlier process evaluation study), treatment efficiencies desired for given constituents, and a suggested system layout for the membrane process equipment. The membrane suppliers were required to provide bid costs for the membranes, related equipment and control system package, as well as specific operational data for their membrane being bid. Based on the data provided and a given bid evaluation formula agreed to by all parties, the bids would be evaluated on an overall cost basis including capital and projected operating costs. Bids were allowed on the basic system layout provided, as well as alternate layouts suggested by the suppliers.

As the suppliers were required to provide a bonded 5 year warranty on their membranes and operational projections, the selected overall low bidder was required to perform further pilot scale testing in Fort Myers to validate their operational data and to show that the given membrane would provide the treatment levels desired.

A total of eleven alternate bids were received from three suppliers. The low bidder, Hydranautics, has recently completed their proof-testing of the membrane they submitted. The membrane, developed and manufactured by Nitto-Denko Corporation of Japan, the parent company of Hydranautics, is made of a polyvinyl derivative material and was not included in the previous pilot scale program.

Table 3 presents a comparison of the treatment efficiencies and operational data developed in the earlier study (conceptual design) to those received in Hydranautics' bid and to those developed in the Hydranautics' proof test.

**TABLE 3
GENERAL RESULTS TO DATE**

| ITEM | CONCEPTUAL DESIGN | BID (1) | PROOF TEST (2) |
|---|-------------------|-------------|----------------|
| Capital Costs (12 MGD-membranes & equip only) | \$4,500,000± | \$3,550,000 | - |
| Pressure vessels/4 MGD train | 132 | 96 | 96 |
| Membranes/4 MGD train | 792 | 672 | 672 |
| Average Flux, GFD | 15.8 | 16.9 | 16.9 |
| Feed Pressure, Clean | 147 | 116 | <116 |
| Feed Pressure, Dirty | 177 | 137 | <137 |
| Recovery (%) | 90 | 90 | 90 |
| Interstage Booster | Yes | No | No |
| THMFP (96 Hr, ug/l) | 20-30 | <50 | 31-43 |
| Tot. Hrdns. (perm, mg/l CaCO ₃) | 30+ | >30 | 110 |
| Color (PCU) | N.D. | <1 | <1 |

- (1) Per Hydranautics Proposal No. P-3063-207
(2) Per Hydranautics Proof Test (Concluded August 1988)
(3) N.D. = Non Detectable

Conclusion

The use of the softening membrane process in Fort Myers was recommended and selected over other alternatives on the basis of a long-term pilot scale testing program run specifically on the City's raw water. Unlike most prior membrane studies which utilized only one membrane, Fort Myers' program utilized the results obtained from six different membranes to develop average expected operational criteria and estimated capital and operating costs in a full-scale plant.

Through a unique early bidding and follow-up proof testing program in the design of the new treatment plant, the successful application of softening membranes in Fort Myers was further confirmed. By promoting open competition, the bidding process allowed the selection of a membrane and membrane material not previously tested.

The Hydranautics' proof test membrane produced better overall quality permeate, at the required recovery, and at greater energy efficiency than was projected in the original pilot scale study. The proof test results even exceeded the data projected by Hydranautics in their bid package. These findings are additionally reassuring considering that the proof test was conducted during the period of highest expected organic loading over the annual wellfield cycle in Fort Myers.

Capital costs are lower than original projections. Operating efficiencies are better and resultant operating costs should be lower than original projections. Overall treatment is more compatible (i.e. permeate hardness is not as low) to the City's desires, sufficiently meeting regulatory limits and recommended levels.

The softening membrane process is well suited to the needs of the City of Fort Myers and its on-going implementation is an exciting municipal application of this new process.