INTRODUCTION

From December 17, 1999 through March 24, 2000, the University Area Joint Authority (UAJA) pilot tested a recycled water facility consisting of Microfiltration and Reverse Osmosis. The facility was constructed and operated for the validation of the reclamation of 3.0 Million Gallons per Day (MGD) of secondary effluent from the existing UAJA wastewater treatment facility for the purposes of water reuse and streamflow augmentation. This pilot testing, and its associated analysis, is known as the Phase I Microfiltration Pilot Testing for the Beneficial Reuse Project.

The Beneficial Reuse Project is the selected alternative of the Centre Region for the treatment and reuse of the expected 3.0 MGD of wastewater resulting from growth and infill of the existing UAJA sanitary sewer service area until 2020. As part of an ongoing analysis by UAJA, the Phase I Pilot Testing comprises one of the four reports that summarize the Beneficial Reuse Alternative. The other reports are the Transmission Corridor Report, Wastewater Treatment Facility Basis of Design, and Centre Region Act 537 Plan.

This document is a summation of the results of the operability and water quality data collected from the operation of the pilot plant, the present worth analysis of the operation of the various microfiltration units, and recommendations for the design and implementation of a full-scale facility to be located at UAJA.

PILOT TESTING OVERVIEW

The Pilot Testing for the recycling of UAJA secondary effluent had several purposes. First and foremost, the Pilot Testing results would be utilized to validate that UAJA could create a water supply that met or exceeded all Safe Drinking Water Act (SDWA) parameters, along with several other water quality indicators. Secondly, the pilot testing would allow UAJA to gain familiarization with membrane filtration technologies. Lastly, the Pilot Testing would be structured to create a competitive analysis of the various

membrane filtration manufacturer's equipment. This competitive analysis allows UAJA to procure the most cost-effective and operable equipment for full-scale implementation.

Based upon a review of existing projects and consultation with UAJA staff, a two-tiered pilot testing process was created. The ultimate project was projected to include Microfiltration (MF) or Ultrafiltration (UF) for a first stage treatment, with final hyperfiltration to be provided by Reverse Osmosis (RO). If multiple manufacturers of MF/UF and RO were competing simultaneously, it was felt that the proper interpretation of water quality data and present worth operation costs would be difficult. To focus on the individual processes, UAJA decided to pursue a Phase I Pilot Test that would include a competitive analysis between MF and UF manufacturers, while keeping the subsequent RO units homogeneous. A second pilot testing period (Phase II) was projected after the completion of Phase I Testing and selection of the most advantageous MF/UF unit. In keeping with the two phases of pilot testing, the pilot testing facilities and water quality analysis protocols were tailored to multiple pilot tests.

MICROFILTRATION/ULTRAFILTRATION UNIT SELECTION

In May of 1999, UAJA sent Request for Proposals to approximately 85 manufacturers of Microfiltration and Ultrafiltration Water Treatment Systems. The Request for Proposal contained background material and water quality data for the UAJA facility and listed the following for information to be provided by the manufacturer (Complete RFP contained in Appendix A):

1. Your firm's interest in participating in this program.
2. Summary of results with your equipment at similar pilots and full-scale facilities (two to four examples) including operating conditions, dates, and a third party contact name with telephone number.
3. Details about your proposed pilot equipment, including a brief description and completion of the attached table.
4. Please include a sketch showing the location of meters and gauges to assist us in the preparation of data collection sheets. In addition, please include copies of data collection forms that you would propose be used and a description of any automatic data collection equipment that would be included with the pilot rental.
5. The availability of your pilot equipment for the scheduled time period. Please include a completed version of this statement, "If selected for this program and notified by _____, our pilot unit will be available on-site by September 13, 1999. "
6. Please describe the level of technical support that your firm would provide to the pilot program,

including the frequency and duration of regular visits by your support staff and the number of days (or hours) advance notification required before support staff would arrive on-site for a non-scheduled visit. As part of the regular visits, that would be included as part of the pilot rental fee (if any), please include the level of effort by your staff for initial commissioning and training, decommissioning, and periodic membrane chemical cleanings. In addition, please state the cost of any non-scheduled site visits.

7. Please verify that the type of equipment that you propose for the pilot program is commercially available as full-scale equipment.
8. Summary of the proposed operating conditions (flux, pressure, major flow rates (instantaneous, peak, and daily average), interval between backwash and/or pulse, duration of backwash and/or pulse, any recommended pretreatment (including, if recommended, 500-micron backwashable screen and chemical disinfection, such as chloramination).
9. Simple block flow diagram with a table of major flow rates for the pilot unit and for the proposed full-scale system.
10. Budget cost of full-scale equipment to produce 3.6 MGD (amount required to feed RO Units to produce 3.0 MGD of reclaimed water) of filtered water at the proposed operating conditions. (Please note that a binding agreement on costs may be required to proceed from Phase 1 to Phase 2 testing.)
11. Rental fees and other costs, if any, for the proposed pilot equipment.
12. Any other requirements or pertinent information.
13. Technologies that are submitted as alternatives to microfiltration/ultrafiltration will be reviewed and considered for inclusion within the Phase I Pilot Testing.

Of the manufacturers that were sent RFP's, six responded to UAJA's request. The manufacturers that expressed an interest in testing at UAJA were:

- Cochrane, Inc.
- Ionics, Inc.
- Koch Membrane Systems
- Pall Corporation
- U.S. Filter/MEMCOR
- Zenon Environmental, Inc.

The manufacturers that responded varied in level of experience with water reclamation and the complete proposals from the manufacturers are contained in Appendix B. A review of the proposals indicated that Cochrane, Inc. and Zenon Environmental, Inc. had not complied with the requested information. Specifically, Cochrane, Inc. failed to provide full-scale implementation costs, along with references. Zenon Environmental, Inc. had proposed a product that differed from the MF/UF proposal requirements.

Specifically, Zenon Environmental produces two forms of Ultrafiltration units. The first provides vacuum ultrafiltration of secondary effluent and was the product that was specifically requested. The second product provided treatment of raw wastewater directly to ultrafiltered effluent. This process is known as a membrane bioreactor, and was an option that UAJA wanted to evaluate further outside of the Phase I Pilot Testing.

However, Zenon Environmental's failure to provide an option for competitive analysis removed them from the Phase I Pilot Testing.

A summation of the Phase I Pilot Testing Proposals is included in Table 1. Of the remaining manufacturers, UAJA decided to pilot test Koch Membrane Systems, Pall Corporation, and U.S. Filter/MEMCOR. All of these manufacturers had significant experience in wastewater reclamation and had established references and data from facilities such as Water Factory 21 in California.

PILOT TESTING IMPLEMENTATION

During the summer of 1999, UAJA completed two projects to construct the pilot testing facilities for the Phase I Testing. First, a new maintenance building was constructed on the northeastern corner of the UAJA property for the enclosure of the pilot units. With the Pilot Testing occurring throughout the winter months, a heated facility was needed for proper operation and ease of sampling and maintenance. Secondly, a utility water system was constructed from the existing filter building to the new Pilot Testing Building. A schematic of the utility water system is shown in Exhibit 1. This utility water system allowed UAJA to provide a constant supply of water to the Pilot Testing Facility even with multiple pilot units backwashing (varying flow rate).

In addition to the constructed facilities, UAJA procured instrumentation for on-line monitoring of several water quality parameters. The units that were procured were as follows:

- Hach 1720D Process Turbidimeters
- Hach 1900WPC Laser Particle Counters
- Hach Surface Scatter 6 Process Turbidimeter
- Hach Aquatrend/SOM and Signal Output Module
- Hach Aquaview+ Dedicated Data Management Software

With the large expense the process instruments can represent, UAJA purchased enough units to completely monitor raw water turbidity, MF/UF turbidity, and raw water particle counts. One additional 1720D turbidimeter and two additional particle counters were

TABLE 1 -- SUMMATION OF PROPOSALS
RECEIVED FOR MICROFILTRATION/ULTRAFILTRATION PILOT TESTING

Manufacturer	Number of References	Notification Date [1]	Flow Rate (gpm)	Pilot Testing Fees	Full Scale Cost	Add'lt Equip Required
Cochrane, Inc.	0	NP	10.0	$ 16,750	NP	None
Ionics, Inc.	2	07/15/1999	13.5	$ 4,500	$ 2,000,000	10 SCFM @ 80 psi
Koch Membrane Systems	3	08/13/1999	16.0	$ 6,000	$ 2,745,000	None
Pall Corporation	54	07/01/1999	10.0	$ 11,500	$ 2,150,000	15 SCFM @ 90 psi
US Filter/MEMCOR	115	07/01/1999	18.0	$ 8,500	$ 2,400,000	None
Zenon Environmental	4	6/31/99	8.0[2]	$ 30,000 (3)	$ 5,400,000	None

NP -- Not Provided

(1) Date the Manufacturer requires notification of selection to guarantee the delivery of equipment by September 15, 1999

(2) Zenon Environmental proposal indicated a flow rate less than the specified 10.0 gpm

(3) Zenon Environmental proposed a 6 month pilot test instead of the 3 month requested. Their cost for 6 months is listed.

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utilized to monitor various process streams for data collection. A schematic of the instrumentation installed is shown in Exhibit 2.

The individual pilot units all had variable operational demands, however all required power and compressed air for complete operation. The specific characteristics of the units are contained in Appendix B.

PILOT TESTING PROTOCOL

The Protocol established for the Pilot Testing had two components and was developed by UAJA Staff and Board Members; UAJA's Consultants, and the Department of Environmental Protection. The first component of the Pilot Testing Protocol was the development of Water Quality Parameters for Analysis. Since Pennsylvania had adopted both the EPA Primary and Secondary Water Quality Parameters, both sets of standards were included. One battery of EPA Primary and Secondary Analysis was to be completed on the Raw Water and each of the Microfiltration Effluents at the initiation of the Phase I Pilot Testing. A second battery of testing was to be completed at the end of the testing. The complete list of EPA Primary and Secondary Water Quality Parameters is shown in Appendix C.

To supplement the EPA Parameters, the Beneficial Reuse Project Management Team (PMT) selected the following other water quality constituents:

- Chemical Oxygen Demand (COD)
- Fecal Coliform
- Total Coliform
- Total Organic Carbon
- Total Dissolved Solids
- Total Suspended Solids

The second set of parameters for the Phase I Pilot Testing Protocol were operational. To verify the manufacturer's performance after the conclusion of the pilot testing, UAJA personnel would record operational data throughout the day. The parameters to be monitored by UAJA personnel are as follows:

Table 3 -- Protocol for Phase I Pilot Testing

Sampling Protocol #1		
Characterize Pilot Plant Influent		
Parameter	**Frequency**	**Type**
COD	2/Week	On-Site
Fecal Coliform	2/Week	On-Site
Flow	Continuous	On-Line
Particle Counts	Continuous	On-Line
pH	Daily	On-Site
Pressure	Continuous	On-Line
Priority Pollutants*	Once	Lab
Temperature	Daily	On-Site
Total Coliform	2/Week	On-Site
Total Dissolved Solids	2/Week	On-site
Total Organic Carbon	2/Week	Lab
Total Suspended Solids	2/Week	On-Site
Turbidity	Continuous	On-Line

Sampling Protocol #2		
Microfiltration Performance		
Parameter	**Frequency**	**Type**
COD	2/Week	On-Site
Fecal Coliform	2/Week	On-Site
Flow	Continuous	On-Line
Particle Counts	Continuous	On-Line
pH	Daily	On-Site
Pressure	Continuous	On-Line
Temperature	Daily	On-Site
Total Coliform	2/Week	On-Site
Total Dissolved Solids	2/Week	On-site
Total Organic Carbon	2/Week	Lab
Total Suspended Solids	2/Week	On-Site
Turbidity	Continuous	On-Line

* Pennsylvania Priority Pollutant List (Attached)

Sampling Protocol #3		
Monitor Reverse Osmosis Performance		
Parameter	**Frequency**	**Type**
COD	2/Week	On-Site
Fecal Coliform	2/Week	On-Site
Flow	Continuous	On-Line
Particle Counts	Continuous	On-Line
pH	Daily	On-Site
Pressure	Continuous	On-Line
Total Coliform	2/Week	On-Site
Total Dissolved Solids	2/Week	On-site
Total Organic Carbon	2/Week	Lab
Total Suspended Solids	2/Week	On-Site
Turbidity	Continuous	On-Line

- Turbidity
- MF/UF Feed Flow (gpm)
- MF/UF Filtrate Flow (gpm)
- MF/UF Transmembrane Pressure (TMP)
- MF/UF Feed Pressure (psi)
- MF/UF Filtrate Pressure (psi)
- Water Temperature (Deg F)
- RO Product Flow (gpm)
- RO Recirculation Flow (gpm)
- RO Reject Flow (gpm)
- RO Feed Pressure (psi)
- RO Reject Pressure (psi)
- RO Product TDS (ppm)

The complete water quality and operational protocol, along with measurement frequency, is shown in Table 3.

WATER QUALITY TESTING RESULTS

Water quality testing was conducted throughout the length of the Pilot Testing and according to the proposed protocol. Complete water quality analyses are in Appendix D, and the average water quality conditions are summarized for the Raw Water, Koch UF Effluent, Pall MF Effluent, and U.S. Filter MF Effluent in Table 4 through Table 7.

As seen in the combined water quality of the MF/UF effluents, the Phase I recycled water does not comply with all water quality goals set for the final product water. While all trace contaminants are non-existent, three parameters in particular require further treatment. The first contaminant is nitrates (NO_3^-). The total nitrogen and nitrates that are remaining in the Phase I recycled water are too high for immediate distribution. With the upgrading of the UAJA facility as part of the overall Beneficial Reuse Project, Biological Nutrient Removal (BNR) will be incorporated (see Basis of Design Report). The addition of BNR will greatly reduce total nitrogen and should remove this parameter from concern.

The second parameter of concern is Total Dissolved Solids (TDS). While TDS is not an indicator of pathogenic or viral activity, it is an aesthetic parameter established by the EPA and PA DEP. UAJA's Phase I recycled water exceeds the Maximum Contaminant

Table 4

Raw Water Sampling Results
Phase I Pilot Testing

Pollutant	Results	Units
COD	30.8	(mg/L)
TDS	576.5	(mg/L)
Total Coliform	194	#/100mL
Fecal Coliform	329	#/100mL
TOC	7.344	(mg/L)
TSS	0.5423	(mg/L)
pH	6.88	
EPA Primary Pollutants		
VOLATILES		
Benzene	ND	ug/l
Carbon tetrachloride	ND	ug/l
o-Dichlorobenzene	ND	ug/l
p-Dichlorobenzene	ND	ug/l
1,2-Dichloroethane	ND	ug/l
1,1-Dichloroethylene	ND	ug/l
t-1,2-Dichloroethylene	ND	ug/l
c-1,2-Dichloroethylene	ND	ug/l
Dichloromethane	ND	ug/l
1,2-Dichloropropane	ND	ug/l
Ethyl benzene	ND	ug/l
Monochlorobenzene	ND	ug/l
Styrene	ND	ug/l
Tetrachloroethylene	ND	ug/l
Toluene	ND	ug/l
1,2,4-trichlorobenzene	ND	ug/l
1,1,1-trichloroethane	ND	ug/l
1,2,3-trichloroethane	ND	ug/l
Thichloroethylene	ND	ug/l
Vinyl chloride	ND	ug/l
Total xylenes	ND	ug/l
SOC PARAMETERS		
Alachlor	ND	ug/l
Atrazine	ND	ug/l

Pollutant	Results	Units
Benzo(a)pyrene	ND	ug/l
Carbofuran	ND	ug/l
Chlordane	ND	ug/l
2,4-D	ND	ug/l
Dalapon	ND	ug/l
Dibromochloropropane	ND	ug/l
Di(2-ethylhexyl)adipate	ND	ug/l
Di(2-ethylhexyl)phthalate	1.245	ug/l
Dinoseb	ND	ug/l
Diquat	ND	ug/l
Endothall	ND	ug/l
Endrin	ND	ug/l
Ethylene dibromide (EDB)	ND	ug/l
Glyphosate	ND	ug/l
Heptachlor	ND	ug/l
Heptachlor epoxide	ND	ug/l
Hexachlorobenzene	ND	ug/l
Hexachlorocyclopentadiene	ND	ug/l
Lindane	ND	ug/l
Methoxychlor	ND	ug/l
Oxamyl (Vydate)	ND	ug/l
Pentachlorophenol	ND	ug/l
Picloram	ND	ug/l
Simazine	ND	ug/l
2,3,7,8-TCDD (Dioxin)		ug/l
Toxaphene	ND	ug/l
2,4,5-TP (Silvex)	ND	ug/l
PCB PARAMETERS		
Arochlor-1016	ND	ug/l
Arochlor-1221	ND	ug/l
Arochlor-1232	ND	ug/l
Arochlor-1242	ND	ug/l
Arochlor-1248	ND	ug/l
Arochlor-1254	ND	ug/l

Pollutant	Results	Units
Arochlor-1260	ND	ug/l
TTHM PARAMETERS		
Chloroform	5.65	mg/l
Bromodichloromethane	ND	mg/l
Dibromochloromethane	ND	mg/l
Bromoform	ND	mg/l
RADIOLOGICALS		
Gross alpha	0.464+/-0.43	pci/l
Gross beta (& Photon Activity)	14.91+/-1.4	mrem/yr
Radium 226 & 228		pci/l
INORGANIC PARAMETERS		
Antimony	ND	mg/l
Arsenic	0.0025	mg/l
Barium	ND	mg/l
Beryllium	ND	mg/l
Cadmium	ND	mg/l
Chromium	0.006	mg/l
Free cyanide	0.013	mg/l
Fluoride	0.300	mg/l
Mercury	ND	mg/l
Nickel	ND	mg/l
Selenium	ND	mg/l
Thallium	ND	mg/l
Copper	0.0135	mg/l
Lead	0.051	mg/l
Nitrate	16.15	mg/l
Nitrite	0.51	mg/l
Nitrate + Nitrite	16.66	mg/l
EPA Secondary Pollutants		
Aluminum	1.1	mg/L
Chloride	160.5	mg/L
Color	16	color unit
MBAS	0.0625	mg/L

Pollutant	Results	Units
Iron	0.1075	mg/L
Manganese	0.03	mg/L
pH	6.9	units
Silver	0.0065	mg/L
Sulfate	60.3	mg/L
TDS	576.5	mg/L
Zinc	0.0665	mg/L
Langlier index	-0.9	N/A
Odor	3	TON

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These results are an average of all samples taken. Complete data is available upon request.

Table 5

Memcor MF Sampling Results
Phase I Pilot Testing

Pollutant	Results	Units
COD	18	(mg/L)
TDS	595.5	(mg/L)
Total Coliform	1	#/100mL
Fecal Coliform	0	#/100mL
TOC	5.700	(mg/L)
TSS	0.0401	(mg/L)
pH	6.89	
EPA Primary Pollutants		
VOLATILES		
Benzene	ND	ug/l
Carbon tetrachloride	ND	ug/l
o-Dichlorobenzene	ND	ug/l
p-Dichlorobenzene	ND	ug/l
1,2-Dichloroethane	ND	ug/l
1,1-Dichloroethylene	ND	ug/l
t-1,2-Dichloroethylene	ND	ug/l
c-1,2-Dichloroethylene	ND	ug/l
Dichloromethane	ND	ug/l
1,2-Dichloropropane	ND	ug/l
Ethyl benzene	ND	ug/l
Monochlorobenzene	ND	ug/l
Styrene	ND	ug/l
Tetrachloroethylene	ND	ug/l
Toluene	ND	ug/l
1,2,4-trichlorobenzene	ND	ug/l
1,1,1-trichloroethane	ND	ug/l
1,2,3-trichloroethane	ND	ug/l
Thichloroethylene	ND	ug/l
Vinyl chloride	ND	ug/l
Total xylenes	ND	ug/l
SOC PARAMETERS		
Alachlor	ND	ug/l
Atrazine	ND	ug/l

Pollutant	Results	Units
Benzo(a)pyrene	ND	ug/l
Carbofuran	ND	ug/l
Chlordane	ND	ug/l
2,4-D	ND	ug/l
Dalapon	ND	ug/l
Dibromochloropropane	ND	ug/l
Di(2-ethylhexyl)adipate	ND	ug/l
Di(2-ethylhexyl)phthalate	1.09	ug/l
Dinoseb	ND	ug/l
Diquat	ND	ug/l
Endothall	ND	ug/l
Endrin	ND	ug/l
Ethylene dibromide (EDB)	ND	ug/l
Glyphosate	ND	ug/l
Heptachlor	ND	ug/l
Heptachlor epoxide	ND	ug/l
Hexachlorobenzene	ND	ug/l
Hexachlorocyclopentadiene	ND	ug/l
Lindane	ND	ug/l
Methoxychlor	ND	ug/l
Oxamyl (Vydate)	ND	ug/l
Pentachlorophenol	ND	ug/l
Picloram	ND	ug/l
Simazine	ND	ug/l
2,3,7,8-TCDD (Dioxin)		ug/l
Toxaphene	ND	ug/l
2,4,5-TP (Silvex)	ND	ug/l
PCB PARAMETERS		
Arochlor-1016	ND	ug/l
Arochlor-1221	ND	ug/l
Arochlor-1232	ND	ug/l
Arochlor-1242	ND	ug/l
Arochlor-1248	ND	ug/l
Arochlor-1254	ND	ug/l

Pollutant	Results	Units
Arochlor-1260	ND	ug/l
TTHM PARAMETERS		
Chloroform	5.61	mg/l
Bromodichloromethane	ND	mg/l
Dibromochloromethane	ND	mg/l
Bromoform	ND	mg/l
RADIOLOGICALS		
Gross alpha	1.05+/-0.52	pci/l
Gross beta (& Photon Activity)	15.4+/-1.4	mrem/yr
Radium 226 & 228		pci/l
INORGANIC PARAMETERS		
Antimony	ND	mg/l
Arsenic	0.0022	mg/l
Barium	ND	mg/l
Beryllium	ND	mg/l
Cadmium	ND	mg/l
Chromium	ND	mg/l
Free cyanide	ND	mg/l
Fluoride	0.340	mg/l
Mercury	ND	mg/l
Nickel	ND	mg/l
Selenium	0.00575	mg/l
Thallium	ND	mg/l
Copper	0.011	mg/l
Lead	0.0505	mg/l
Nitrate	14.4	mg/l
Nitrite	0.35	mg/l
Nitrate + Nitrite	15.995	mg/l
EPA Secondary Pollutants		
Aluminum	0.115	mg/L
Chloride	179	mg/L
Color	14.5	color unit
MBAS	0.0625	mg/L

Pollutant	Results	Units
Iron	0.1225	mg/L
Manganese	0.025	mg/L
pH	6.85	units
Silver	0.005	mg/L
Sulfate	60.1	mg/L
TDS	595.5	mg/L
Zinc	0.07	mg/L
Langlier index	-0.85	N/A
Odor	3	TON
Safe Drinking Water		
Calcuim	49.8	mg/l
Magnesium	12	mg/l
Potassium	11.8	mg/l
sodium	96.8	mg/l
Strontium	0.26	mg/l
Carbonate	ND	mg/l
Bicarbonate	72	mg/l
Phosphorus	ND	mg/l
Orthohosphorus	0.12	mg/l
Alkalinity	72	mg/l
Boron	0.26	mg/l
Hardness as CaCO3	172	mg/l
Sulfide	ND	mg/l
DO	5.4	mg/l

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May 2000

These results are an average of all samples taken. Complete data is available upon request.

Table 6

Pall MF Sampling Results
Phase I Pilot Testing

Pollutant	Results	Units
COD	19	(mg/L)
TDS	600	(mg/L)
Total Coliform	0	#/100mL
Fecal Coliform	0	#/100mL
TOC	6.100	(mg/L)
TSS	0.0001	(mg/L)
pH	7.10	
EPA Primary Pollutants		
VOLATILES		
Benzene	ND	ug/l
Carbon tetrachloride	ND	ug/l
o-Dichlorobenzene	ND	ug/l
p-Dichlorobenzene	ND	ug/l
1,2-Dichloroethane	ND	ug/l
1,1-Dichloroethylene	ND	ug/l
t-1,2-Dichloroethylene	ND	ug/l
c-1,2-Dichloroethylene	ND	ug/l
Dichloromethane	ND	ug/l
1,2-Dichloropropane	ND	ug/l
Ethyl benzene	ND	ug/l
Monochlorobenzene	ND	ug/l
Styrene	ND	ug/l
Tetrachloroethylene	ND	ug/l
Toluene	ND	ug/l
1,2,4-trichlorobenzene	ND	ug/l
1,1,1-trichloroethane	ND	ug/l
1,2,3-trichloroethane	ND	ug/l
Thichloroethylene	ND	ug/l
Vinyl chloride	ND	ug/l
Total xylenes	ND	ug/l
SOC PARAMETERS		
Alachlor	ND	ug/l
Atrazine	ND	ug/l

Pollutant	Results	Units
Benzo(a)pyrene	ND	ug/l
Carbofuran	ND	ug/l
Chlordane	ND	ug/l
2,4-D	ND	ug/l
Dalapon	ND	ug/l
Dibromochloropropane	ND	ug/l
Di(2-ethylhexyl)adipate	ND	ug/l
Di(2-ethylhexyl)phthalate	0.955	ug/l
Dinoseb	ND	ug/l
Diquat	ND	ug/l
Endothall	ND	ug/l
Endrin	ND	ug/l
Ethylene dibromide (EDB)	ND	ug/l
Glyphosate	ND	ug/l
Heptachlor	ND	ug/l
Heptachlor epoxide	ND	ug/l
Hexachlorobenzene	ND	ug/l
Hexachlorocyclopentadiene	ND	ug/l
Lindane	ND	ug/l
Methoxychlor	ND	ug/l
Oxamyl (Vydate)	ND	ug/l
Pentachlorophenol	ND	ug/l
Picloram	ND	ug/l
Simazine	ND	ug/l
2,3,7,8-TCDD (Dioxin)		ug/l
Toxaphene	ND	ug/l
2,4,5-TP (Silvex)	ND	ug/l
PCB PARAMETERS		
Arochlor-1016	ND	ug/l
Arochlor-1221	ND	ug/l
Arochlor-1232	ND	ug/l
Arochlor-1242	ND	ug/l
Arochlor-1248	ND	ug/l
Arochlor-1254	ND	ug/l

Pollutant	Results	Units
Arochlor-1260	ND	ug/l
TTHM PARAMETERS		
Chloroform	6	mg/l
Bromodichloromethane	4.49	mg/l
Dibromochloromethane	ND	mg/l
Bromoform	ND	mg/l
RADIOLOGICALS		
Gross alpha	0.72+/-0.46	pci/l
Gross beta (& Photon Activity)	16.2+/-1.4	mrem/yr
Radium 226 & 228		pci/l
INORGANIC PARAMETERS		
Antimony	ND	mg/l
Arsenic	ND	mg/l
Barium	ND	mg/l
Beryllium	ND	mg/l
Cadmium	ND	mg/l
Chromium	ND	mg/l
Free cyanide	ND	mg/l
Fluoride	0.325	mg/l
Mercury	ND	mg/l
Nickel	ND	mg/l
Selenium	0.006	mg/l
Thallium	ND	mg/l
Copper	0.018	mg/l
Lead	0.0505	mg/l
Nitrate	15.6	mg/l
Nitrite	0.295	mg/l
Nitrate + Nitrite	16.99	mg/l
EPA Secondary Pollutants		
Aluminum	0.21	mg/L
Chloride	178.5	mg/L
Color	11.75	color unit
MBAS	0.0625	mg/L

Pollutant	Results	Units
Iron	0.055	mg/L
Manganese	0.025	mg/L
pH	6.75	units
Silver	0.005	mg/L
Sulfate	58.4	mg/L
TDS	600	mg/L
Zinc	0.06	mg/L
Langlier index	-1.05	N/A
Odor	2.6	TON

HRG, Inc.
May 2000

These results are an average of all samples taken. Complete data is available upon request.

Table 7

Koch MF Sampling Results
Phase I Pilot Testing

Pollutant	Results	Units
COD	20	(mg/L)
TDS	624	(mg/L)
Total Coliform	0	#/100mL
Fecal Coliform	0	#/100mL
TOC	5.800	(mg/L)
TSS	0.0910	(mg/L)
pH	6.91	
EPA Primary Pollutants		
VOLATILES		
Benzene	ND	ug/l
Carbon tetrachloride	ND	ug/l
o-Dichlorobenzene	ND	ug/l
p-Dichlorobenzene	ND	ug/l
1,2-Dichloroethane	ND	ug/l
1,1-Dichloroethylene	ND	ug/l
t-1,2-Dichloroethylene	ND	ug/l
c-1,2-Dichloroethylene	ND	ug/l
Dichloromethane	ND	ug/l
1,2-Dichloropropane	ND	ug/l
Ethyl benzene	ND	ug/l
Monochlorobenzene	ND	ug/l
Styrene	ND	ug/l
Tetrachloroethylene	ND	ug/l
Toluene	ND	ug/l
1,2,4-trichlorobenzene	ND	ug/l
1,1,1-trichloroethane	ND	ug/l
1,2,3-trichloroethane	ND	ug/l
Thichloroethylene	ND	ug/l
Vinyl chloride	ND	ug/l
Total xylenes	ND	ug/l
SOC PARAMETERS		
Alachlor	ND	ug/l
Atrazine	ND	ug/l

Pollutant	Results	Units
Benzo(a)pyrene	ND	ug/l
Carbofuran	ND	ug/l
Chlordane	ND	ug/l
2,4-D	ND	ug/l
Dalapon	ND	ug/l
Dibromochloropropane	ND	ug/l
Di(2-ethylhexyl)adipate	ND	ug/l
Di(2-ethylhexyl)phthalate	1.51	ug/l
Dinoseb	ND	ug/l
Diquat	ND	ug/l
Endothall	ND	ug/l
Endrin	ND	ug/l
Ethylene dibromide (EDB)	ND	ug/l
Glyphosate	ND	ug/l
Heptachlor	ND	ug/l
Heptachlor epoxide	ND	ug/l
Hexachlorobenzene	ND	ug/l
Hexachlorocyclopentadiene	ND	ug/l
Lindane	ND	ug/l
Methoxychlor	ND	ug/l
Oxamyl (Vydate)	ND	ug/l
Pentachlorophenol	ND	ug/l
Picloram	ND	ug/l
Simazine	ND	ug/l
2,3,7,8-TCDD (Dioxin)	ND	ug/l
Toxaphene	ND	ug/l
2,4,5-TP (Silvex)	ND	ug/l
PCB PARAMETERS		
Arochlor-1016	ND	ug/l
Arochlor-1221	ND	ug/l
Arochlor-1232	ND	ug/l
Arochlor-1242	ND	ug/l
Arochlor-1248	ND	ug/l
Arochlor-1254	ND	ug/l

Pollutant	Results	Units
Arochlor-1260	ND	ug/l
TTHM PARAMETERS		
Chloroform	6.86	mg/l
Bromodichloromethane	ND	mg/l
Dibromochloromethane	ND	mg/l
Bromoform	ND	mg/l
RADIOLOGICALS		
Gross alpha	1.14+/-0.52	pci/l
Gross beta (& Photon Activity)	16.1+/-1.4	mrem/yr
Radium 226 & 228		pci/l
INORGANIC PARAMETERS		
Antimony	ND	mg/l
Arsenic	ND	mg/l
Barium	ND	mg/l
Beryllium	ND	mg/l
Cadmium	ND	mg/l
Chromium	ND	mg/l
Free cyanide	ND	mg/l
Fluoride	0.510	mg/l
Mercury	ND	mg/l
Nickel	ND	mg/l
Selenium	0.009	mg/l
Thallium	ND	mg/l
Copper	0.015	mg/l
Lead	0.001	mg/l
Nitrate	16.5	mg/l
Nitrite	ND	mg/l
Nitrate + Nitrite	16.5	mg/l
EPA Secondary Pollutants		
Aluminum	ND	mg/L
Chloride	186	mg/L
Color	11.5	color unit
MBAS	ND	mg/L

Pollutant	Results	Units
Iron	0.07	mg/L
Manganese	0.02	mg/L
pH	6.5	units
Silver	0.008	mg/L
Sulfate	59.3	mg/L
TDS	624	mg/L
Zinc	0.06	mg/L
Langlier index	-1.3	N/A
Odor	4.0	TON

HRG, Inc.
May 2000

These results are an average of all samples taken. Complete data is available upon request.

Table 8

Reverse Osmosis Sampling Results
Phase I Pilot Testing

Pollutant	Results	Units
COD	1	(mg/L)
Total Coliform	0	#/100mL
Fecal Coliform	0	#/100mL
TOC	0.600	(mg/L)
TSS	0.0834	(mg/L)
pH	6.65	

These results are an average of all samples taken. Complete data is available upon request.

Level (MCL) by approximately 150 mg/l and will require further treatment. Typical treatment methods include lime softening, ion exchange columns, nanofiltration, and reverse osmosis.

The final water quality parameter is Total Organic Carbon (TOC). TOC is often used in reuse projects as an overall indicator of water quality; however, little scientific background has been established on this topic. UAJA, the Beneficial Reuse PMT, and local water authorities have set a goal of 1.0 mg/l of TOC for the recycled water. TOC's averaged between 6.0 and 7.0 mg/l for the various MF and UF units. Further treatment will be required to reduce TOC and typical methods include coagulation and filtration, activated carbon, nanofiltration, and reverse osmosis.

OPEARATIONAL ANALYSIS

Throughout the Pilot Testing, the manufacturers of the various MF and UF units would manipulate the operational setpoints to optimize treatment and cost of operation. The parameters that varied included TMP, flux (flow per cross-sectional area, i.e. gallons per square foot per day, gfd), and pressure. Optimally, the manufacturer would find an operational profile that would increase the time between chemical cleanings of the membranes, allowing for longer operating time at lower pressures.

For a set of operational parameters to be considered valid for consideration of the full-scale equipment, a minimum of three weeks of data collection was established. Upon completion of the Phase I Pilot Testing, the manufacturers reviewed their data and performance and provided proposals that summarized their operation and detailed projected operational and capital costs. The specific parameters that were requested from the manufacturers is as follows:

1. A complete scope of supply and cost estimate for a 3.40 MGD Microfiltration system, including but not limited to, microfiltration units, feed pumps, recirculation pumps, chemical addition, bulk chemical storage, process air supply, process air storage, instrumentation, inter-unit piping, microstraining (200 to 500 microns), electrical distribution and supply, and SCADA interface and control.

2. Estimated annual operation costs for microfiltration system, including electrical consumption (utilize $ 0.025 per kWh) and chemical consumption. Include all unit process for both parameters, including feed water pressurization, compressor operation, etc.
3. Layout drawings and process and instrumentation diagrams for full-scale implementation.
4. Detailed estimates for membrane life and replacement costs. Project life is assumed to be 20 years for purposes of Present Worth Analysis.
5. Detailed calculations on the amount of wastewater generated from the microfiltration system. Waste flows should include reject water, backwash water, cleaning waste, etc.

The complete manufacturer's proposals are contained in Appendix E.

To verify the operational parameters of the manufacturer's proposals and to determine the most cost-effective MF/UF units, UAJA and its consultants performed a Present Worth Analysis of the three units. Present Worth compares capital, operational, and maintenance costs to determine the total cost of a selected alternative. One way of understanding Present Worth Analysis is to view it as the total amount of money needed to purchase, operate, and maintain a particular component for the life of the project (i.e. twenty years). The parameters evaluated for the Phase I Pilot Testing were:

1. **Capital Cost** – This parameter includes the purchase price of the MF/UF Equipment, interconnecting process piping, shipping and freight, and building size based upon equipment footprint.

2. **Membrane Replacement** – The individual membrane columns have variable life and the replacement of these columns can be a significant cost. This parameter evaluated the number of membrane replacements needed during the project life and the cost.

3. **Electrical Consumption** – Total consumption of electrical consumption including feed flow pressurization, chemical cleanings, and process air.

4. **Chemical Consumption** – Total consumption of chemicals for pretreatment, cleanings, and neutralization of chlorine for subsequent RO treatment.

5. **Wastewater Processing** – Each of the MF/UF units rejects a portion of the overall flow for backwashing, cleaning, etc. While this waste flow does not require difficult treatment in the conventional wastewater treatment plant, it does require an upsizing of the basins for proper hydraulic residence times.

This charge represents the additional capital cost to provide proper hydraulic residence time in the upsized treatment tanks.

The Present Worth Analysis for the Phase I Pilot Testing included these five parameters and the specific unit costs for each is listed below:

Project Life:	20 years
Annual Debt Service Interest:	4%
Building Cost per ft^2:	$ 65.00
Rate of Inflation for Membrane Columns:	3%
Centrifugal Pump Efficiency:	87.5%
Metering Pump Efficiency:	50.0%
Motor Efficiency:	85.0%
Power Cost per kWh:	$ 0.025
Cost per Pound of Caustic:	$ 0.40
Cost per Pound of Citric:	$ 1.00
Cost per Pound of Sodium Hypochlorite:	$ 1.00
Cost per Pound of Sodium Bisulfite:	$ 0.62
Capital Cost Charge per Gallon per Day of Reject:	$ 0.623

With these parameters established, the Present Worth Analysis was completed and each individual analysis was reviewed by its respective manufacturer. The complete Present Worth Analysis for each of the manufacturers is contained in Appendix F and the results of the competitive analysis is shown in Table 8.

Table 8
Competitive Analysis of Present Worth for Microfiltration/Ultrafiltration
UAJA Beneficial Reuse Project

Parameter	U.S. Filter/MEMCOR	Pall Corporation	Koch Membrane Systems
Capital Cost	$ 1,755,766.00	$ 1,704,310.00	$ 1,710,400.00
Membrane Replacement	$ 532,933.50	$ 468,783.00	$ 854,468.00
Annual Operations & Maintenance Costs	$ 21,020.62	$ 46,511.79	$ 81,526.24
Reject Wastewater Processing	$ 235,001.95	$ 111,484.20	$ 275,333.67
Total Present Worth	$ 2,836,495.78	$ 2,976,556.34	$ 4,053,108.29

CONCLUSIONS AND RECOMENDATIONS

Based upon the operation of the pilot facility and analysis of water quality and process parameters, HRG offers the following conclusions and recommendations for the full-scale implementation of Microfiltration/Ultrafiltration for the UAJA Beneficial Reuse Project:

1. **Microfiltration/Ultrafiltration is not sufficient alone to completely produce recycled water that meets all established water quality limits (SDWA and Local Parameters).** The water produced by the MF/UF units is acceptable for irrigation and other non-contact uses, however does not meet the SDWA due to nitrates and total dissolved solids. The nitrates will be removed with the installation of Biological Nutrient Removal in the WWTP Upgrade, however the TDS will remain untreated. Additionally, the locally established limit of 1.0 mg/l of Total Organic Carbon was not achieved. Further treatment processes, such as nanofiltration or reverse osmosis, will be required.

2. **Microfiltration/Ultrafiltration used in conjunction with Reverse Osmosis produced recycled water that exceeded all established water quality limits.** The RO units that followed the MF/UF units and met all established water quality limits, reducing Total Dissolved Solids and Total Organic Carbon below 100 mg/l and 1.0 mg/l respectively. Additionally, no synthetic organics or volatile organics were found to be present in the RO permeate.

3. **Based upon the Present Worth Analysis, the manufacturer that provided the lowest overall cost to UAJA was U.S. Filter/MEMCOR.** U.S. Filter/MEMCOR was lower than Pall Corporation by approximately $ 140,000.00 and less than Koch Membrane Systems by approximately $ 1,216,000.00.

4. **U.S. Filter/MEMCOR should be pursued as the Microfiltration/Ultrafiltration of choice for the Beneficial Reuse Project and agreements to guarantee the proposed pricing be executed (included with Proposal from U.S. Filter MEMCOR).**