Performance Evaluation

Removal of Perfluorochemicals (PFC's)
with
Point-of-Use (POU) Water Treatment Devices

Final Report

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Prepared for:

State of Minnesota
Minnesota Department of Health

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NOTE: Revised 31 July 2008 - Model No. corrected for Sears Kenmore Elite

Forward

The following is the Final Report on a study that evaluated the ability of commercially available point-of-use (POU) water treatment devices to remove perfluorochemicals from groundwater, performed by Water Science and Marketing, LLC (WSM) under contract with the Minnesota Department of Health (MDH).

The POU devices selected for this study were limited to predefined project criteria such as:

- Devices must include technologies with theoretical capability to reduce the concentration of PFCs from the range of 3 to 10 *u*g/L to less than 0.2 *u*g/L each for PFBA, PFOA, PFOS, and less than 0.5 *u*g/L in total.
- Are specified by the manufacturer/supplier to have a minimum capacity of 500 gallons treated water before replacement and/or service intervals.
- Are certified to an NSF/ANSI standard, or equivalent, for drinking water.
- The manufacturer/supplier is willing to provide commercial support for PFC reduction claims.
- Evaluation of the maximum number of technologies and devices within a predefined test period, budget, and allowable limit PFC analyses.

WSM's test plan consisted of three separate phases:

- **Device Identification and Selection**
- **Initial Performance Screening (Phase I)** to select only those devices demonstrating the most promise for field testing with the limited budget available.
- **Field-Testing (Phase II)** to provide an in-depth evaluation PFC removal capabilities and operational characteristics of the most promising devices identified in Phase I with groundwater from the subject aquifers in Washington County.

Following the results of Phase I, the POU-PFC Workgroup, and WSM met and decided to amend the project plan. A new study was added (Phase I-B) and the existing Phase II study was lengthened from 4 weeks to 13 weeks. This was done to increase the scope of useful data available to the public.

Phase I challenge testing and sample collection was conducted in October and November of 2007 at the Water Quality Association laboratory in Lisle, Illinois, USA. Phase I-B challenge testing and sample collection was conducted in March and April of 2008 at the same laboratory by the same personnel. PFC analysis was conducted by the Minnesota Department of Health, Public Health Laboratory in St. Paul, Minnesota. Phase II was conducted during the period of January through mid-April, 2008 by WSM personnel at the two municipal facilities, Oakdale and St. Paul Park.

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Executive Summary

A new group of chemical contaminants referred to as perfluorochemicals (PFCs) have been discovered in the environment, and are present at low levels in the ground water throughout much of southern Washington County in Minnesota. These new contaminants impact community and non-community public water supplies and private wells.

Many residents within the affected area are considering the purchase of Point-of-Use (POU) water treatment devices to reduce exposure to PFCs through their drinking water. However, little information is available regarding how well these devices perform in the removal of PFCs. In response, the Minnesota Department of Health (MDH) formed a multidisciplinary workgroup to design a study aimed to evaluate PFC removal performance for POU devices. The MDH retained Water Science and Marketing, LLC (WSM) to help design test protocols and to conduct this study.

The study included four separate phases:

1. Device identification and selection
2. Initial in-lab performance evaluation at relatively high concentrations (Phase I)
3. Refined in-lab performance evaluation, at more typical use conditions (Phase I-B)
4. Field-testing in Washington County at two sites, using actual groundwater with PFC contamination (Phase II)

Over 450 companies were canvassed to identify products that their manufacturers believed would be effective in removing PFCs, and were willing to commercially support associated performance claims. Generally, devices represented two categories; devices incorporating the single PFC removal technology of activated carbon (AC) filters, and devices incorporating multiple technologies including reverse osmosis (RO) and AC (RO/AC).

Fourteen devices were included in Phase I (six AC, eight RO/AC) conducted at Water Quality Associations ANSI certified laboratory in Lisle, IL. Five units were included in Phase I-B (three AC and 2 RO/AC). The lab tests were run at high challenge levels, and with both single and multiple PFC molecules. Eleven devices were included in Phase II (four AC and seven RO/AC). Two municipal systems (one in St. Paul Park with only PFBA, one in Oakdale with a mixture of three PFCs) served as the test sites for Phase II.

The test conditions employed within this study represent both typical and severe operational usage patterns. Also, PFC concentrations ranged significantly; from those found in municipal well supplies tested in southern Washington County, to high lab test levels to reflect those found in some private wells, which can be considerably higher than in the municipal supplies.

All eleven devices removed all PFCs in the field test to below quantifiable detection limits. In the refined lab test, two AC devices permitted detectable levels of passage prior to exceeding 500 gallons, although all devices consistently produced water with PFC levels well below the current health limits. Results from this study suggest that when applied, installed, operated and maintained according to manufacturers specifications, the eleven devices included in Phase II

will effectively remove PFC's in concentrations found in southern Washington County's groundwater for up to 500 gallons before service and/or replacement is required.

Abbreviations and Acronyms

AC	Activated Carbon
CSA	Canadian Standards Association
DNQ	Detected, Not Quantified (analytical result with positive detection of the target analyte, but below the level where the technique used can adequately quantify the amount detected).
HBV	Health Based Value (Minnesota Dept Health guide)
HRL	Health Risk Limit (Minnesota Rules, Chapter 4717)
IAPMO	International Association of Plumbing Mechanical Officials
IX	Ion Exchange
MDH	Minnesota Department of Health
ND	Non-Detect (level below which the analytical technique will not find an analyte – such as a PFC)
NSF	NSF International
PHL	Public Health Lab (Minnesota state laboratory)
PFBA	Perfluorobutanoic acid
PFC	Perfluorochemical
PFOA	Perfluorooctanoic acid
PFOS	Perfluorooctane sulfonate
POE	Point-of-Entry (in this report, referring to a water treatment device designed to treat water delivered throughout a residence or business)
POU	Point-of-Use (in this report, referring to a water treatment device designed to treat water to be delivered at one location where drinking water is commonly used such as at a kitchen sink.)
POU-PFC Workgroup	An interdisciplinary group of MDH and US EPA individuals providing technical assistance and over-site to the project.
RO	Reverse Osmosis
TDS	Total Dissolved Solids, a measure of solutes in water, usually determined by conductivity
UL	Underwriters Laboratories
WQA	Water Quality Association
WSM	Water Science and Marketing, LLC

Acknowledgments

Water Science and Marketing (WSM) had overall responsibility for management of execution of the project, including, including protocol development, data analysis and interpretation, and the preparation of this report. WSM personnel designed and fabricated the test stations for Phase II and conducted system operation, monitoring, and data collection associated with field-testing.

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The Minnesota Department of Health served as the project coordinator and liaison with the EPA, and had final decision authority on the test protocols and device selection.

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WSM wishes to thank the manufacturers willing to participate in this evaluation. They are to be commended for providing the water treatment systems within tight schedules, and support with excellent technical and product expertise.

WSM also wishes to thank the Minnesota Department of Health, especially Tom Alvarez for his dedication to this study and valued guidance. As this evaluation represents pioneering work in the area of performance verification testing for POU water treatment devices, a variety of

technical questions arose throughout the study, the answers which may not have direct value to local residents. Tom kept the work on-track while never losing sight for whom this study was for – the residents of southern Washington County.

WSM also offers their sincere gratitude to the MDH Public Health Lab, the City of Oakdale and City of St. Paul Park staff for their cooperation and hospitality during this investigation. We especially wish to thank Paul Swedenborg, Organic Chemistry Supervisor, Public Health Lab, Chris Sonterre, Utility Superintendent, City of Oakdale, and Brian Rumpca, Public Works Assistant Supervisor, City of St. Paul Park.

Chapter 1
Introduction

1.0 Synopsis of Study and Findings

1.1 Background

Perfluorochemicals (PFCs) have been detected at low levels in groundwater in the southeast metropolitan area. Perfluorobutanoic acid (PFBA), perfluorooctanoic acid (PFOA), and perfluorooctane sulfonate (PFOS) are the most widespread PFCs.

PFCs are man-made chemicals that have only existed a few decades, and the discovery of their presence in Minnesota groundwater is very recent. Already, PFCs are found widespread in most of the groundwater drinking water supply across southern Washington County, Minnesota. PFCs have been detected in other Minnesota counties, as well as, and other locations in the US and globally. Additional information is available at:
http://www.pca.state.mn.us/cleanup/pfc/index.html.

Prior to this study, very little information was available to help a private homeowner with removing PFCs from their drinking water. There are no guidelines, no test results, and no standardized protocols to evaluate PFC removal performance of POU water treatment devices.

Results from this study are intended to assist those who wish to reduce their exposure to PFCs in their drinking water in their selection of POU devices/technologies with information that can be supported with performance data from a research based third-party evaluation. As the MDH is not a product certification body, the results of this study are not intended to certify water treatment devices for PFC removal, or similarly, issue a statement of acceptance or rejection, nor product ranking in regards to performance.

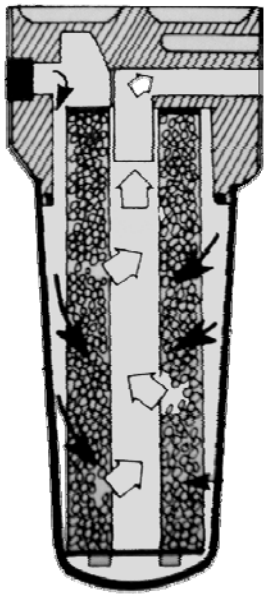
1.2 What is a Point-of-Use (POU) Water Treatment Device?

POU water treatment devices are installed at an individual tap, faucet, or outlet and reduce contaminants at that one point-of-use. POU treatment can serve as effective means of removing contaminants from water used for drinking and cooking in residential and commercial settings. POU treatment devices include systems that utilize several different treatment technologies, such as activated carbon (AC) adsorption, reverse osmosis (RO), or ion exchange (IX).

1.2.1 Description of an Activated Carbon Filter

These devices are simple filter devices, operated in “normal flow” dead-end mode – with one effluent stream comprising the output of the filter. They operate in the same manner as a simple sediment filter cartridge, and come with their own housing and connections for use in the field. See Figure 1-1 below.

Figure 1-1
Activated Carbon Filter

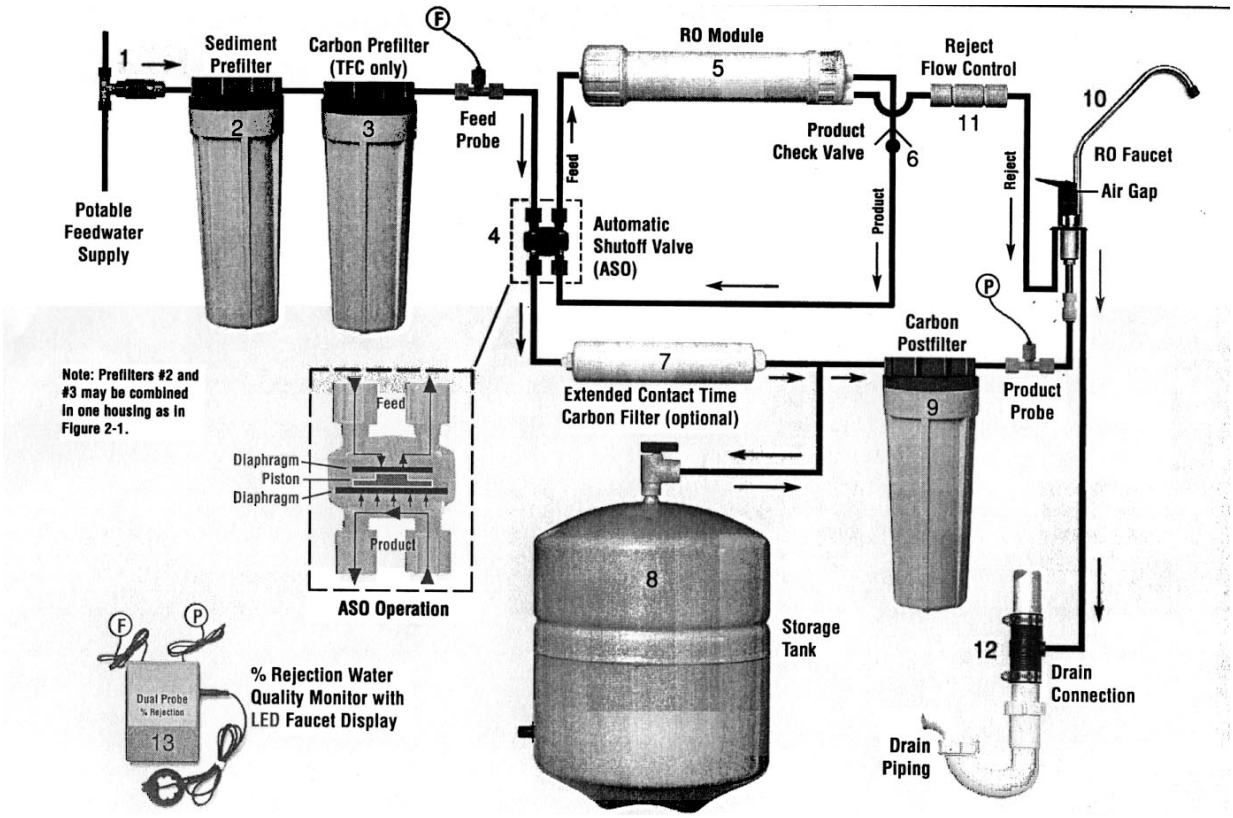


1.2.2 Description of a Reverse Osmosis System

These devices are systems with several interacting but separate unit operations. A typical residential point-of-use RO system is designed and operated as follows:

A prefilter protects the membrane from fouling by sediment. If the membrane is made of the most common polymer, polyamide (PA), that prefilter is an AC media filter, which also removes free chlorine – which oxidizes PA membrane over time and shortens membrane life. The pre-filtered water feeds the RO module and is split into two steams; the permeate (treated water) and concentrate (or "reject"). The permeate is purified as it is forced through the membrane, while the concentrate only passes over or across the membrane, and carries the rejected contaminants to drain. The permeate is routed to a “post-RO” polishing filter, typically made with AC media to remove taste and odor components not removed by the membrane or added by the system materials. Connected off a tee between the RO membrane and post filter is a storage tank, which contains a pressure bladder. When this tank is pressurized to a pre-set point, the pressure cut-off switch stops flow and the system is in shut down mode. This prevents the system from running when no more water can be stored, and prevents excess water (concentrate stream) from going to drain. Following the post-RO filter and the storage tank is the dispensing valve, which the homeowner operates to draw water. In this configuration all water treated for consumption moves serially through three purification devices: the pre-filter, RO membrane, and post filter. See Figure 1-2.

Figure 1-2
RO System Configuration



1.3 Considerations for Using POU Devices

1.3.1 Flow Rate Limitations

Residential water treatment products currently marketed as POU devices deliver much lower flow rates (how fast the water is drawn) than homeowners may be accustomed from a standard water faucet such as located at their kitchen sink. Table 1-1 provides reference to illustrate flow rates produced by devices included within this report.

Table 1-1
Time to Fill Standard Kitchen Containers at Various Flow Rates

Flow Rate	8 Ounce Measuring Cup		12 Ounce Drinking Glass		64 Ounce Pitcher		12 Cup Coffee or Tea Pot		1 Gallon Cooking Pot		3 Gallon Container	
(gpm)	Seconds	Minutes	Seconds	Minutes	Seconds	Minutes	Seconds	Minutes	Seconds	Minutes	Seconds	Minutes
0.8	4.7	0.1	7.0	0.1	37.5	0.6	56.3	0.9	75.0	1.3	225.0	3.8
0.6	6.3	0.1	9.4	0.2	50.0	0.8	75.0	1.3	100.0	1.7	300.0	5.0
0.4	9.4	0.2	14.1	0.2	75.0	1.3	112.5	1.9	150.0	2.5	450.0	7.5
0.2	18.8	0.3	28.1	0.5	150.0	2.5	225.0	3.8	300.0	5.0	900.0	15.0
0.1	37.5	0.6	56.3	0.9	300.0	5.0	450.0	7.5	600.0	10.0	1800.0	30.0
0.05	75.0	1.3	112.5	1.9	600.0	10.0	900.0	15.0	1200.0	20.0	3600.0	60.0

The activated carbon filters included in this evaluation had typical manufacturer rated flow rates of from 0.5 to 0.75 gallons per minute. Dependent upon source water quality, these flow rates may diminish significantly with use.

Due to the nature of RO membrane technology, production rates are lower than what can be achieved with an activated carbon filter. Therefore, pressurized storage tanks are incorporated into systems to collect and store water for later use. This increases the delivery rate and amount available at any time. It also means that the size of the storage tank and the amount of membrane in the system will affect the total availability of finished water.

1.4 Evaluation of POU Devices for PFC Removal from Drinking Water

Since 2006, the City of Oakdale, Minnesota has operated a large scale, municipal filtration plant that removes PFCs with large AC filters. Additional information is available from: http://www.health.state.mn.us/divs/eh/hazardous/sites/washington/oakdalewell.html .

In early 2007, preliminary tests conducted by MDH showed that small, AC, POU pitcher filters and POU faucet-mounted filters were partially effective to reduce PFC exposure, though PFCs increasingly passed the filters as additional water was filtered through them. Additional information is available from:
http://www.health.state.mn.us/news/pressrel/pfc030107.html

The POU water treatment devices evaluated in this study were designed to be installed under-the-counter, connected to household plumbing and deliver treated water through an auxiliary drinking water faucet mounted above an existing sink. The general requirements for each device selected was that it had to be able to reduce specified challenge concentrations of PFBA, PFOS, an PFOA to below specified health affect levels for at least 500 gallons, be certified to meet relevant industry standards, and be available to the public.

To accomplish this objective, a test plan developed by WSM, was reviewed, and accepted by MDH's PFC workgroup. The test plan included three phases including:

1. Device identification and selection (Pre-Phase I),
2. In-lab testing for performance screening (Phase I),
3. Field-testing to provide an in-depth evaluation PFC removal capabilities and operational characteristics of the most promising devices identified in Phase I with groundwater from the subject aquifers in Washington County (Phase II).

1.5 Test Plan Outline

1.5.1 Pre-Phase I

In this phase, companies that make POU water treatment devices who think their device may meet minimum product criteria were identified and contacted. They also needed to believe their products may be effective in removing PFCs, and be willing to provide test devices for non-standardized, extreme end testing.

1.5.2 Phase I

A screening phase intended to find and learn the PFC removal strengths and weaknesses of various devices and the technologies those devices are based on. The test protocols were designed to determine basic PFC removal capability of the water treatment devices, and to show strengths and weaknesses of the underlying technology and significant design components. This included altering of devices only to allow the testing of individual media components. This challenge used PFC spiked water solutions with PFC concentrations at least as high as found in local groundwater in order to provide clear indication of PFC removal capability under the high end of known conditions. In this Phase, the test protocols used were based on NSF/ANSI Standards 53 and 58, which the industry and state governments use to certify these type devices. Devices passing this screening phase would then undergo additional testing in Phase II.

Phase I challenge testing and sample collection was conducted in October and November of 2007 at the WQA testing facility in Lisle, Illinois (see photo 1-1). For this phase of the study, 492 chemical PFC analyses were completed by the PHL, St Paul, Minnesota.

In December 2007 the POU-PFC Workgroup and WSM met, and based upon results from Phase I, decided to amend the existing contract and project plan. A new study was added (Phase I-B) and the existing Phase II study was lengthened from 4 weeks to 13 weeks. This was done to provide the most useful data to the public as soon as possible.

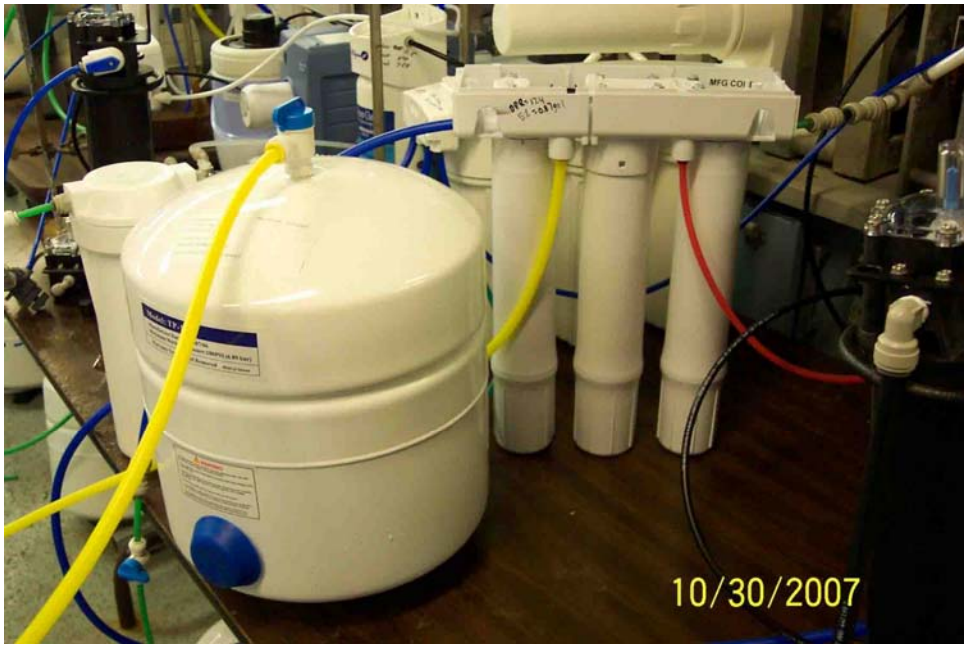


Photo 1-1
Device Being Tested at WQA Lab

1.5.3 Phase I-B

Phase I-B was completed on two RO devices and three AC devices. Different protocols were used compared to Phase I, as described in Chapters 5. All Phase I-B challenge testing was performed by WQA in their testing lab. For this phase of the study, 62 chemical PFC analyses were completed by the PHL.

1.5.4 Phase II

Field-testing was intended to determine the effects of PFC removal from use over time on target groundwater, and to show operational differences between the POUs. Devices showing promising PFC removal capability in Phase I was included in Phase II. Field testing consisted of: (1) testing with water from an Oakdale, Minnesota municipal well that contains multiple PFCs, and (2) testing with water from a St. Paul Park municipal well that contains only PFBA. Two automated field-testing test stations were designed and fabricated by WSM and installed at each site (see Photo 1-2). Each test station was capable of simultaneous operation and monitoring of each of the eleven POU devices selected for Phase II (Seven RO systems and four AC devices).

Field tests included PFC sampling, measurement of flow, TDS, pH, temperature, pressure, and other individual evaluations based upon device type. All Phase II challenge testing was performed by WSM. For this phase of the study, 289 chemical PFC analyses were completed by the PHL.

1. An Oakdale well that contains multiple PFCs.
2. A St. Paul Park well that contains only PFBA.

Two portable field test stations were designed and fabricated by WSM to provide for continuous operation with automatic sampling and data-logging capabilities (see photo 1-2). Each test station was accommodated simultaneous operation and monitoring of each of the eleven POU devices selected for Phase II (seven RO systems and four AC devices).

Phase II was conducted during the period of January through April 2008 by WSM personnel. The PHL performed 289 PFC analyses for this Phase.

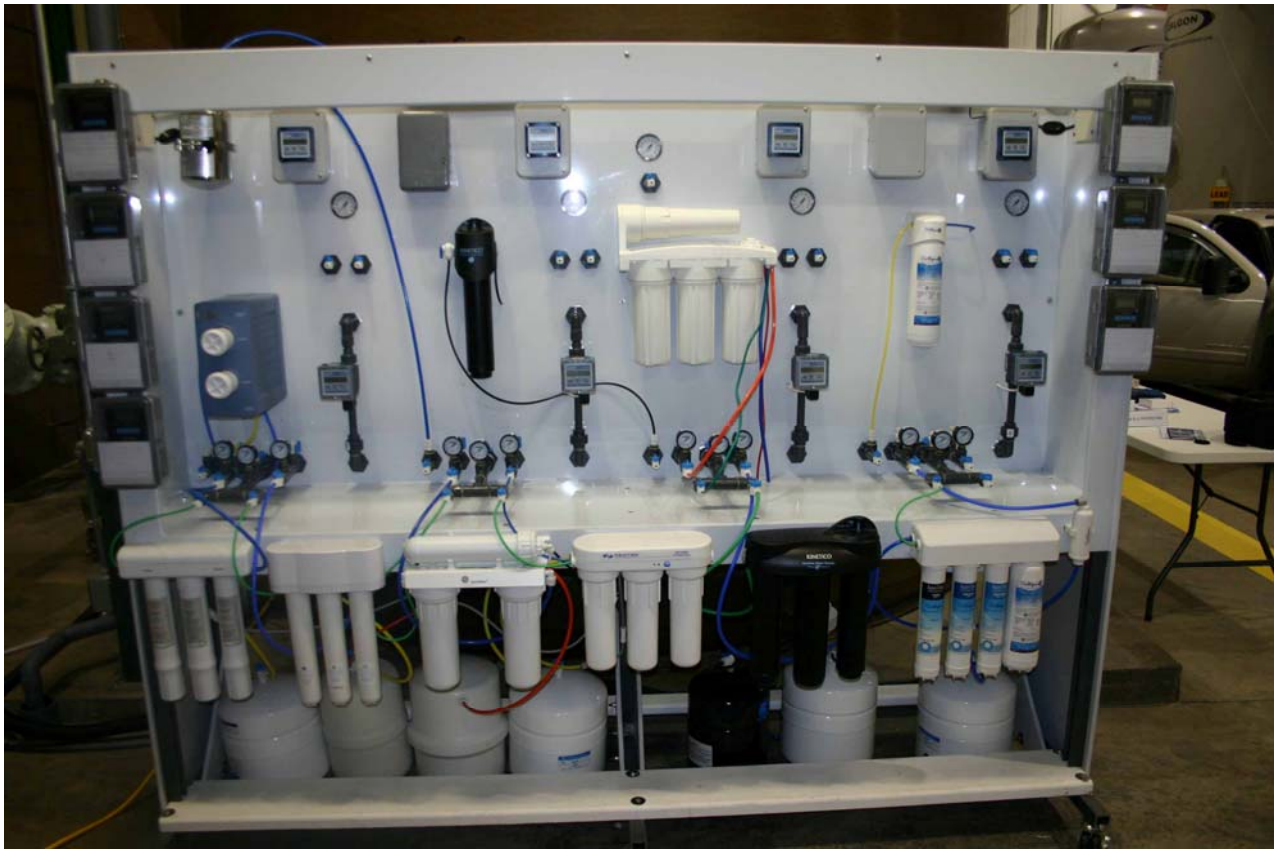


Photo 1-2
WSM Test Station

1.6 Participants and Responsibilities

Water Science and Marketing, a Minnesota Corporation, collaborated with the Water Quality Association (WQA), an Illinois not-for-profit international trade association, to execute, the laboratory device screening part this project – "Phase I" and the additional laboratory study – "Phase I-B". WSM served as the prime contractor, with the WQA under contract to perform defined work assignments.

1.6.1 Minnesota Department of Health

Mr. Tom Alvarez served as the MDH project manager and liaison with WSM. A multi-disciplinary, POU-PFC Workgroup within the MDH: including members of the Well Management Section, Drinking Water Management Section, Health Risk Assessment Section, the Public Health Lab, and the US. Environmental Protection Agency (EPA), Cincinnati, Ohio, approved the project test plan, and made final decisions on the device selection after receiving recommendations from WSM and WQA.

1.6.2 Water Science and Marketing

Philip Olsen and David Paulson are Principals of WSM. Mr. Olsen served as Project Manager, with Mr. Paulson coordinating activities with the WQA for initial device identification and selection and Phase I testing.

1.6.3 Water Quality Association

Tom Palkon, Director of Product Certification, with advice from Joseph Harrison Technical Director, represented the WQA in the execution of Phase I and Phase I-B testing.

Chapter 2
Test Device Selection Process

2.1 General Description

A selection protocol and survey were designed to identify, review, and assess all candidate POU products on the market. Key MDH criteria for the products were:

- Base product technology based on high performance GAC, carbon block, reverse osmosis, exchange resins, mixed bed media, or other devices (including multistage).
- Product certification to an ANSI/NSF point-of-use device standard.
- Technical feasibility for PFC removal from potable water.
- Device configured as point-of-use (POU) potable water treatment.
- Commercially available and considered "shelf ready" units.

At project start, the WQA sent the attached survey (Appendix A) to each of its over 400 member companies. Additionally, WSM reviewed the product listings of all ANSI accredited certification agencies to find those certified products of companies not on the WQA mailing list, who had devices certified to any of the relevant NSF/ANSI point-of-use drinking water treatment standards (NSF/ANSI Standards 42, 53, 58, and 62). These certification agencies are:

- Canadian Standards Association (CSA)
- International Association of Plumbing Mechanical Officials (IAPMO)
- NSF International (NSF)
- Underwriters Laboratories (UL)

Approximately 450 - manufacturers were contacted and invited to submit products for testing. Initial contact was by email or the "contact" mechanisms of the identified company's Internet web sites in September 2007. All commercial products, which met the project's criteria, were identified and the companies marketing these products were contacted.

It was anticipated that more products would be submitted for consideration than the budget would allow to be tested. A selection process was required, and was designed to allow a uniform a process for determining the best candidate devices which met the project criteria, and represented product choices that Minnesota citizens could purchase and use successfully in a residential, POU manner to reduce exposure to PFC s in drinking water.

2.2 Survey

A survey was designed to allow a uniform decision process for the first step of determining the viability of a company's commercial product(s) in the study. WSM and WQA determined if the products met the test criteria and were viable by evaluating the first response. If the products were judged viable, additional information was collected in direct contact follow-up with the

company identified. A brief interview was used to fully qualify the products as meeting the required criteria. See Appendix A for Letter of Introduction and Point-of-Use, Water Treatment Device Survey Form.

2.3 Device Selection

2.3.1 Selection Factors

The desire to test all viable technologies within the MDH criteria, and representative devices employing different categories of adsorbent media (e.g. different membrane and activated carbon types, other adsorbent technologies etc) and different types of Reverse Osmosis (RO) membrane and devices, guided the selection choices and the number of devices tested. Where the timeframe and budget allowed, multiple representative devices were chosen.

WSM and MDH considered the following factors proposing devices to MDH

- Theoretical Viability and Limitations - A review of theoretical PFC removal chemistry/mechanics was made based upon the technology(s) employed by the device.
- Commercial Accessibility – WSM determined and factored the ease in which a homeowner can purchase the device, install, and at a later date have the device maintained/serviced.
- Maximizing the number of different media tested.
- Manufacturer's Commitment – WSM evaluated the manufacturer's stated commitment to commercially support the device for PFC reduction, such as promoting or not allowing a PFC reduction claim associated with the use of their device.
- Ease of Use in a Residential Setting.
- Historical Performance Data - WSM reviewed any historical performance data and associated test protocol(s), for PFCs and chemically similar molecules, in the literature or available from the manufacturer/supplier.
- Environmental Friendly Features - Including waste, disposal factors.

2.3.2 Selection Process Phase I

Products were dropped from consideration if they did not meet the selection criteria, or the companies stated they were not interested in this test, or the companies who failed to respond or follow through in providing the required information by the deadline. Repeat efforts to contact suppliers were made for products that appeared viable per the project criteria.

WSM reviewed products manufacturers submitted for consideration and that had responded in full. Using the criteria listed above, a list of 29 candidate products was prepared by WSM and submitted to the POU – PFC Workgroup for consideration. In discussions during two meetings, WSM addressed POU – PFC Workgroup questions and explained the reasoning for its proposed list of device candidates, and any factors it was aware of to consider for performing the testing. The POU – PFC Workgroup provided further opinion on preferred device attributes. The final selection of devices to be included in this study was made by the POU-PFC Workgroup in early October 2007.

A total of six – activated carbon filter devices met the selection criteria for adsorbent media, and all were selected for Phase I. A greater number of RO systems meeting the selection criteria were submitted for consideration than could be accommodated due to lab capacity, and project time and budget limitations. Eight RO systems were selected.

The selected devices, with the technologies they employ, are shown in Tables 2-1. Detailed summary tables can be found in Appendix A.

2.3.3 Selection Process Phase II

Of the 14 original devices include in Phase I, 11 devices were selected to undergo Phase II field-testing. In reviewing the results of Phase I, the PFC Workgroup and WSM identified limitations in the manner ANSI/NSF protocols had been applied. The RO testing was successful, but devices believed capable of treating 500 gallons were limited to a challenge range of only 25-46 gallons. The flow of RO systems is extremely small compared to the flow of AC devices. RO systems are expected, by ANSI/NSF-58 and by product testing facilities, to continue filtering with the same contaminant reduction capability after 25 gallons of use as 1,000 gallons of use. The POU-PFC Workgroup and WSM challenged whether this concept applies for PFC removal. Some PFC breakthrough occurred on the RO devices but post filters removed any remaining PFCs in the 25-46 gallon range. The devices did not appear to run for a long enough time to create data indicating the ROs would actually meet the 750 gallon challenge (150% of 500 gallons). In addition, the PFC Workgroup and WSM challenged AC device water sampling protocols used by WQA and whether they would apply for PFC contaminant reduction. Those protocols collected water only after many volumes of water were drawn, 10 minutes, and the PFC Workgroup and WSM questioned if this was representative of household water-use patterns.

Based on the outcome of Phase I, the POU-PFC Workgroup and WSM adjusted the test plan to provide the public additional challenge test results with additional lab testing (called “Phase I-B”), and by expanding the Phase II challenge from 4 weeks to 13 weeks. All changes were accomplished using only appropriations already provided and within the overall timeline required

2.4 Devices Selected for Study

Table 2-1 provides a listing of devices originally selected for performance evaluation this study.

Table 2-1
Listing of Devices Included in POU-PFC Study

Device Manufacturer/(Model Number)	PFC Removal Technologies Used		
	Activated Carbon	Reverse Osmosis	Ion Exchange
Access Business Group (eSpring)	X		
Aquion Rainsoft (Hydrefiner P-12 9878)	X		
Culligan (RC-EZ-4)	X		
GE SmartWater (GXSL55F)	X		
Kinetico (MACguard 7500)	X		
Sears Kenmore (Elite 625.385010)	X		
Culligan (Aqua-Cleer)	X	X	
Ecowater (ERO-375E-CP)	X	X	
GE (Merlin)	X	X	
GE (Smartwater GXRM10GBL)	X	X	
Kinetico (Plus Deluxe VX)	X	X	
Pentair (RO-3500EX w/ GS)	X	X	X
3M (SQC-3 (04-045))	X	X	
Watts (Premier WP-4V)	X	X	

Chapter 3
Phase I Performance Screening and Comparative Evaluation

3.1 Phase I Overview of Purpose and Test Site

The challenge testing and sampling was conducted at the WQA Certification Laboratory in Lisle, IL. The Director of Product Certification, Tom Palkon, supervised testing with input from Joe Harrison, Technical Director. The laboratory designated a test bench that shall be used for the study. The test bench was set up in a manner that allowed the maximum number of devices to be tested in parallel.

3.2 Test Solution

Initial QA/QC testing of both the WQA Laboratory's incoming makeup water, and test devices was performed before any testing was started by re-circulating water through the test bench and sampling it for background PFC readings. These samples were sent to the MDH PHL for analyses. PFC concentrations above detection limits were not present in either sample.

Challenge tanks were prepared using the Water Quality Association's city water supply (Lisle, IL) municipal water. Lisle's municipal water supply contains the following average water characteristics:

- Alkalinity – 100 mg/l as CaCO3
- Hardness – 140 mg/l as CaCO3
- TDS – 210 - 230 mg/L
- TOC – 1.7 mg/L
- pH – 7.5
- Chloride – 14 mg/L
- Sulfate – 28 mg/L

The challenge water requirements allowed the water to be used as make-up without modification. Three standard challenge feed stocks were prepared, and repeated as needed to produce enough water for the test, by adding PFCs, to the following separate characteristics:

- PFBA concentration of 10 *u*g/l
- PFOA and PFOS concentration of 3 *u*g/l each
- PFOA and PFOS concentrations of 3 *u*g/l each, and PFBA of 10 *u*g/l

To assure that the PFC concentrations could be made consistently during the test to within desired range, prior to the start of the tests the WQA lab ran verification tests by preparing trial batch tanks with the feedstock supplied by the MDH PHL. Theoretically, calculated amounts of feedstock were added to these challenge tanks, mixed, sampled both at one-quarter hour and again after 24 hours. These samples were sent to the MDH public health lab (PHL) for priority analysis to ensure that the theoretical added PFC volumes would yield the correct

concentrations of the PFCs, and that the tank concentrations were stable for 24 hours. Volumes and chemical additive mass were documented for all feed stock batches, and duplicate samples were collected and saved at WQA under refrigeration for reference.

During the test, samples were collected within 10 to15 minutes of initial mixing and sent with other samples for QA/QC verification of feed PFC concentrations values. Those values are documented in the MDH/PHL lab results (Appendix D) and in the QA/QC section and in Table 4-6.

3.3 Device Challenge and Sample Generation

3.3.1 Activated Carbon Technologies

These devices are simple filter devices, operated in "normal flow" dead-end mode – with one effluent stream comprising the output of the filter. They operate in the same manner as a simple sediment filter cartridge, and come with their own housing and connections for use in the field. They were connected and operated per manufacturer's published specifications and instructions, and preconditioned for this test according to manufacturers' instructions.

One influent sample was collected per tank for QA/QC analysis

Water passing through the units was totalized and the units were challenged, and samples taken at the pre-determined points of percent-of-capacity, until 150% of the capacity was reached. (Table 4-2)

Shutoff mechanism on one device (the Kinetico MACguard 7500) was disabled to allow for a constant flow rate. That unit still cycled 50% on 50% off for 20-minute cycles.

3.3.2 Reverse Osmosis Technologies

These devices are systems with several interacting but separate unit operations. A typical residential point-of-use RO system is designed and operated as follows:

A prefilter protects the membrane from fouling by sediment. If the membrane is made of the most common polymer, polyamide (PA), that prefilter is an AC media filter, which also removes free chlorine – which oxidizes PA membrane over time and shortens membrane life. The pre-filtered water feeds the RO module and is split into two steams; the permeate and concentrate (or reject). The permeate is purified as it is forced through the membrane, while the concentrate only passes over or across the membrane, and carries the rejected contaminants to drain. The permeate is routed to a "post-RO" polishing filter, typically made with AC media to remove taste and odor components not removed by the membrane or added by the system materials. Connected off a tee between the RO membrane and post filter is a storage tank, which contains a pressure bladder. When this tank is pressurized to a pre-set point, the pressure cut-off switch stops flow and the system is in shut down mode. This prevents the system from running when no more water can be stored, and prevents excess water (concentrate stream) from going to drain. Following the post-RO filter and the storage tank is the dispensing valve, which

the homeowner operates to draw water. In this configuration all water treated for consumption moves serially through three PFC removal components: the AC pre-filter, RO membrane, and AC post filter.

As in the ANSI/NSF standard test, in this test the pre-filters were removed from the systems. Since they were AC media, they would have removed an unknown amount of the PFC molecules, obscuring the RO membrane performance results. Although such removal would be a beneficial action in a household installation, the AC prefilter would become saturated with PFCs at an unknown time - but long before it is typically changed out. At this point of prefilter "failure", the RO membrane's performance is essential: it is the main removal media in the RO system. Therefore, the AC pre-filters were removed to allow the performance of the RO membranes to be measured under known conditions.

Since the RO membranes might pass an unknown (but presumably low) amount of PFC, and the post-RO filter may remove that, the post-RO filters were left in place and their performance measured was measured as part of the device performance.

The WQA prepared 500-gallon challenge tanks, as needed each day, using the WQA city water supply spiked with the influent PFCs. One influent sample was collected per tank for QA/QC.

RO test units were set up and conditioned in accordance with the manufacturers instructions. In this case, all of the systems were filled and flushed twice. All pre-filters were removed from the system. WQA installed a sample port after the RO membrane and a sample port after the post filter. One RO system (Pentair RO3500EX w/ GS) had two post-membrane adsorbent filters, and samples were taken after each of these post-filters.

Repeating this cycle three times for each of the three feed solutions, each RO test unit was tested 24 hours per day for seven days, based on the ANSI/NSF Standard 58 protocol as follows:

- Day 1 – samples were drawn from the systems after 4, 12 and 16 hours of operation. The storage tank was emptied after each sample, and only the 16-hour sample was analyzed for PFCs.
- During days 2, 3 and 4 of testing, about 5 % of the system's certified daily product rate was withdrawn from the storage tank every 6 hours. The 6-hour sample was analyzed for PFCs.
- During days 5 and 6, the RO systems remained shut down with water in the system and storage tank under pressure. (the "stagnation period").
- During day 7 – a sample was collected at the start up (144 hours) into the test, the storage tank was emptied, and a final sample was collected after a four-hour period (148 hours). Both samples were analyzed for PFCs.
- At each sample point WQA took two effluent samples. One directly after the RO membrane and one after the systems post filter. The volume of water passing through the post filter was recorded.

For the system with two post-RO adsorbent filters (Pentair RO3500 EX (activated carbon and ion exchange) effluent samples were taken at three locations; after the membrane, after the ion exchange filter and after the post filter.

The GE Merlin system is of different design and does not contain an RO storage tank. For this system, on days 1 and 7, three gallons of water were emptied from the system after 4, 12, and 16 hours of operation. For days 2, 3, and 4 one gallon of water was emptied from the system every 6 hours. On days 5 and 6 the system remained stagnant under pressure.

3.4 Sample Collection, Submission, and Analysis

MDH Public Health Laboratory (PHL) provided WQA with commercial standards of PFOA, PFOS, and PFBA, which had been pre-tested for purity. PHL provided concentrated solutions of these standards (individually and as mixtures) and 250-milliliter, high-density polyethylene sample bottles. Representative bottles from each lot were pre-tested to ensure that effect on analytical results of PFC levels were negligible.

Sampling frequency was based on both MDH objectives as noted in 1.1 above, and based on the industry standard ANSI/NSF Standards for the adsorbent filters and RO systems, Standards 53 and 58, respectively.

3.4.1 Activated Carbon Technologies

Industry standard sample handling procedures were followed. Common feed solution and device-produced water (filtrate) was collected in the MDH-supplied sample bottles, labeled, documented on the master test log, and immediately refrigerated until shipment. The first 5 days of samples (PFBA cycle 1) were accumulated for 5 days and then shipped. Other samples were refrigerated and saved for periods of from 1 to 3 days before shipment. To ship, the samples were placed in coolers with appropriate refrigerant packs and. shipped to the MDH laboratory on a one-day basis to assure proper sample storage at the 2-10 degree Celsius requirement. The PFC molecules are not known to be particularly sensitive to time or temperature degradation effects and it is believed no significant effect on PFC concentrations occurred from this sampling and analyzing protocol.

The challenge and sample protocol was based on the test methods for organics removal verification in ANSI/NSF Standard 53 *Drinking water treatment units -Health effects*. Devices were run for 16 hours a day, in 20 minute each on/off cycle, at the manufacturer-rated maximum flow rate for that device. Samples were collected in the middle of the 20-minute on cycle. Devices were shut down for the intervening 8-hour periods. Filtrate water (post-filter) was discarded to drain. New tanks were mixed as they were depleted.

Samples of filtrate were collected at points defined in the protocol; correlating with approximate waypoints in the rated filter life capacity (e.g. 30, 60, 100, 150% of rated volume capacity). Samples were collected at the midpoint in the “on” or flow-through part of the continuous 20-minute on/20 minute off run cycle

3.4.2 Reverse Osmosis Technologies

The general sampling procedures defined in 3.3.2 above were followed. In the case of the RO systems samples were collected in two places; after the RO membrane and ahead of the post filter – to determine the performance of the RO membrane alone, and after the post- RO filter to - determine the performance of this filter at "polishing" the water by removing any PFC that might pass through the RO membrane. Both samples are reported in the RO system data spreadsheets.

The challenge and sampling protocol was based on the test methods for organics removal verification in ANSI/NSF Standard 58 ***"****Reverse osmosis drinking water treatment systems"*. New tanks were mixed as they were depleted. Tanks were prepared by using WQA city water and adding 1 liter of PFC stock solution to a 500-gallon tank while overhead mixers continually stirred the PFC spiked water for one hour. During testing the tanks were constantly re-circulated to ensure PFC stayed in solution at an equal concentration.

3.5 Instrumentation

WQA used their standard certification bench equipment for testing similar POU devices. These include instruments with the following ranges and nominal accuracies.

3.5.1 Pressure

Pressure gauges with 0 to 100 psig range and plus-minus 1% nominal accuracy.

3.5.2 Flow

GPI digital flowmeters with 0 to 3 gpm range and are within 5% of the actual flow rate.

3.5.3 Thermometer

Oakton thermometer with -328.0 to 1562 degree Fahrenheit range, and plus-minus 0.4 degrees Fahrenheit nominal accuracy.

3.6 Analytical Test Procedures for Perfluorocarbons

All samples generated for PFC analysis were sent to the Minnesota Public Health Lab (PHL) for quantification of the three PFC molecules, which was done by PHL internal standard technique. The lower quantification limit for all three PFC molecules was at 0.2 microgram per liter (*u*g/L) for each analysis [ug/L is essentially equivalent to parts per billion (ppb)]. The detection limit (positive identification) for all three PFC molecules was at 0.05 *u*g/L and shown on the PHL Report of Analytical Results forms as "J 0.05", for example, with a footnote, "The analyte was positively identified. The result is below the report level and is estimated." Detection at levels between and including 0.05 to 0.2 *u*g/L could be made, however, in this range analyses are not quantified with the required degree of confidence to accept the values.

In this report the actual values are only reported if greater than or equal to 0.2 *u*g/L. Values detected but below this quantification limit are reported as detected, not quantified (DNQ).

3.7 QA/QC

3.7.1 Recording Data and Procedures

WQA was responsible for the maintenance of the logbooks and field notebooks. Data was collected and recorded for each day. Data was documented in raw datasheets and on charts from the individual testing instruments. Documentation of field application testing events was facilitated through the use of photographs, data sheets, and chain of custody forms.

WSM retains records and documentation associated with the preparation and collection of water samples under the contract for a minimum of five (5) years.

3.7.2 Chain of Custody

The WQA initiated their standard chain of custody forms for each sample taken, and forwarded these per standard procedure to the MDH Public health Laboratory, with the samples for analyses. See Appendix D for complete Chain of Custody forms.

3.7.3 Datasheets

WQA maintains their original data collection documentation on file for future reference.

Chapter 4
Phase I Results and Discussion and Recommendations for Phase II

4.1 Introduction

The test was run as planned and as described in Chapter 3 without significant deviation. This evaluation was a laboratory-screening test. The set test conditions are conservative, and designed to produce comparisons between devices and may not duplicate those encountered in some actual use conditions of POU devices in the home.

The target goals for the device performance were to reduce to less 0.2 ppb each challenge feed concentrations of 10 parts per billion (ppb, or microgram per liter *u*/L) of PFBA, and 3 ppb each of PFOA and PFOS molecules. When challenged with a mixture of all three PFCs, performance goals were less than 0.2 ppb each and less than 0.5 ppb in total.

Generally, the RO systems performed well against the target requirements, and the AC filters did not. There was one strong exception in each category of devices.

4.2 Limitations

One limitation of Phase I is that as an initial performance screening laboratory test, operating conditions, and sample collection protocols were conservative and set toward extreme ends of anticipated product use ranges to provide meaningful comparisons in performance between devices/technologies. This approach is taken in the ANSI/NSF Standards used as templates for these tests. The resultant data provides insight for which devices/technologies have greater potential for PFC removal. However, since test samples were collected after many volumes of water were drawn (passed through the device) the results may not reflect the PFC removal in typical use patterns. Typically, in a kitchen installation a small volume of water is drawn for drinking and consumed immediately. The water consumed may have been subjected to longer residence periods within the device than in this test. Water inside an AC filter receives additional filtration influences when the residence time of the water in the device is increased. To a varying degree, the real world draw of water for consumption from a POU adsorbent-media device would yield water with more residence time in the media, and therefore potentially lower values of contaminants. This difference will vary considerably by media type; filter construction and actual usage patterns, resulting in differing measured removal rates.

A second limitation of this lab test is that the water used is of a closely defined and consistent quality. While the chemical make-up of water used for Phase I was similar to the groundwater of interest in the East/Southeast-St. Paul metro area, slight variations may affect performance considerably. Further, the test life and therefore exposure to material in the feed water that will foul the separation media was low compared to typical residential use. In a residential application, RO membrane is expected to typically last for at least one year. For instance, organic material (TOC) in the source will affect overall performance both RO membrane and AC technologies as it accumulates on the media surface. Accordingly, the total mass of TOC over time presented to the media was relatively low in this test and the test did not simulate the

same degree of TOC fouling that devices might see at other sites over their lifetime. Such exposure may affect removal performance of both the RO and especially the AC media, where organic material preferential adsorption and fouling can inhibit the removal of target molecules like PFCs.

4.3 Supply Water

The supply water provided to the test devices had a range of alkalinity of 101 to 110, hardness was in the range of 133.5 to 146, TDS was in the range of 213-224, pH had a range of 7.15 to 7.97, TOC had a range of 1.87 to 3.02, chloride was in the range of 13 to 14.3, and sulfate was in the range of 27.4 to 28.8.

4.4 Performance Data - PFC Removal

This test was designed to identify commercially available POU devices that potentially can remove PFCs to safe health limits. It was not designed as research on the mechanisms of removal of perfluorocarbons, or for basic knowledge generation for the difference in media used in water treatment devices.

4.4.1 Activated Carbon Technologies

All Activated Carbon devices tested were filters with media based on activated carbon (AC). The range of activated carbon media varies significantly. These variations depend on several factors, including; differing sources of starting material (e.g. coal and coconut shell etc.), the processing techniques used to activate and regenerate the carbon, proprietary additional treatment techniques and additional chemicals added into the media. Often these additives are intended to remove additional materials that “raw” AC does not remove well (e.g. lead, MTBE fuel additive, etc.). While several different AC media were selected, there was insufficient information available to select a media based on expected performance in removing PFC molecules. All AC filters submitted which met the selection criteria were tested. Table 4-1 lists the AC manufactures and products that were selected for Phase I testing.

Table 4-1
Activated Carbon Devices

Company	Product Name	**Carbon Type**
Culligan	RC-EZ-4	Carbon Block w/Lead Sorbent
Aquion Rainsoft	Hydrefiner P-12 9878	Carbon Bock w/Lead, VOC, MTBE Sorbent
Sears Kenmore Elite	Kenmore 625.385010	Carbon Bock w/Lead Sorbent
Kinetico	MACguard 7500	Block coconut w/Lead, VOC, MTBE Sorbent
Access Business Group	eSpring	Carbon block w/ Binder Material, & Lead Sorbent
GE SmartWater	GXSL55F	Block "blended"

The results for removal of all three PFCs varied substantially by filter device tested. Only one AC filter met all target removal goals over the test life; Culligan RC EZ 4. Two filters did not meet the total PFC goal of the 3-PFC mixture feed even at the first test point; Access eSpring and GE SmartWater GXSL55F. As expected, there was a very strong tendency of filters to allow increased breakthrough (also called "leakage" and "passage") of PFC molecules with increasing operating time, as available sorption sites were taken. No strong correlation for removal and media type was noted.

Table 4-2
SUMMARY - AC FILTERS PERFORMANCE
Select Data Points at Rated Lifetime

1st Tests (PFBA-10 alone) and 2nd Tests (PFOA-3 and PFOS-3)

Device name	Day 1 Initial - Final			~ 30 % capacity			~60 % capacity			~100% capacity			~150% capacity		
	PFBA-10	PFOA-3	PFOS-3	PFBA- 10	PFOA- 3	PFOS- 3	PFBA- 10	PFOA- 3	PFOS- 3	PFBA- 10	PFOA- 3	PFOS- 3	PFBA- 10	PFOA- 3	PFOS- 3
Culligan RC-EZ-4	ND	ND-ND	ND-ND	ND	ND	ND	DNQ	ND	ND	DNQ	ND	ND	DNQ	ND	ND
A. Rainsoft Hydrefiner P-12	ND	ND-ND	ND-ND	ND	ND	ND	0.5	ND	ND	1.7	ND	ND	2.6	ND	ND
Sears Kenmore Elite				DNQ	ND	ND	1.9	ND	ND	4.7	ND	ND	3.9	DNQ	ND
Kinetico MACguard	DNQ	ND-ND	ND-ND	0.2	ND	ND	4.2	1.9	2.1	5	DNQ	DNQ	4.7	0.2	DNQ
Access eSpring	0.7	ND-ND	ND-ND	0.7	ND	ND	6.1	DNQ	ND	8.4	0.4	DNQ	8	0.9	0.3
GE SmartWater GXSL55F	7.3	ND-ND	ND-ND	8.7	0.4	ND	8.9	0.9	DNQ	9.1	2.1	1.7	8.8	2.2	0.6

* first and 2nd tests are 10ppb PFBA alone, and mixture 3 ppb each PFOA and PFOS

3rd Test (all three PFC's mixed: PFBA-10, PFOA-3 and PFOS-3)

Device name	Day 15 Initial - Final			~30 % capacity			60 %capacity			~100% capacity			~150% capacity		
	Mixed	Mixed	Mixed	PFBA- 10	PFOA- 3	PFOS- 3	PFBA- 10	PFOA- 3	PFOS- 3	PFBA- 10	PFOA- 3	PFOS- 3	PFBA- 10	PFOA- 3	PFOS- 3
Culligan RC-EZ-4	ND-ND	ND-ND	ND-ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
A. Rainsoft Hydrefiner P-12	DNQ-DNQ	ND-ND	ND-ND	DNQ	ND	ND	0.3	ND	ND	1.4	ND	ND	1.5	DNQ	ND
Sears Kenmore Elite	ND-ND	ND-ND	ND-ND	1.3	ND	ND	1.6	ND	ND	2.9	DNQ	ND	4.5	DNQ	ND
Kinetico MACguard	ND- 0.2	ND-ND	ND-ND	0.9	ND	ND	1.8	DNQ	ND	2.5	DNQ	ND	3.3	DNQ	DNQ
Access eSpring	ND- 1.2	ND-ND	ND-ND	4.3	DNQ	ND	5.6	DNQ	ND	8	0.3	DNQ	8.2	0.8	0.6
GE SmartWater GXSL55F	ND- 7.8	ND-DNQ	ND-ND	9.3	0.8	0.4	9.5	0.8	0.4	9.6	1.4	1.7	11	1.3	0.2

** third test is mixture of 10ppb PFBA and 3 ppb each of PFOA and PFOS

ND = not detected (< 0.05) DNQ = detected, not quantified (0.05 to 0.2)

In this test and under this sampling protocol, of the five (5) filters that failed to remove the PFCs to the target level, none met the combined total PFC target limit of 0.5 ppb for all three PFCs in the final challenge solution (10 ppb PFBA + 3 ppb each of PFOA and PFOS). For the feed challenge solution of only the PFOA plus PFOS, three (3) filters met the removal criteria over their rated lifetime: Aquion Rainsoft Hydrefiner P-12, Sears Kenmore Elite, and Kinetico MACguard.

The PFBA molecule proved the most difficult to remove. Most filters which passed either the PFOA or the PFOS molecule also passed the PFBA at a higher rate, both as a percentage of feed concentration and as an absolute number (the PFBA was challenged at 10 ppb compared to 3 ppb for both the PFOA and PFOS molecules).

In general, for all filter devices, among the PFC molecules the relationship of passage or leakage was PFBA > PFOA > PFOS.

It is known that AC media is capable of removing all three molecules used in this test, and this has been accomplished in Minnesota groundwater on a municipal basis. The residence time, and other variables, in these municipal treatment installations are undoubtedly engineered to accomplish near complete removal of these molecules.

4.4.2 Reverse Osmosis Technologies

In total, the RO systems performed very well on all three PFC molecules. Five of the eight systems tested had no samples in any test over the target goals of 0.2 ppb limits for each PFC molecule individually, and 0.5 ppb in total; Pentair, CUNO Water Factory, Ecowater, Kinetico and Watts. Two more of the systems had no PFC detected in the finished water - after the post-RO polishing AC filters; GE Smartwater GXRM10G and Culligan Aqua-Cleer. Only one RO membrane had detectable PFC's that it's post-RO filter did not remove; the GE Merlin, a high flow, storage tank-less model.

Table 4-3 lists the RO manufactures and products that were selected for Phase I testing.

Table 4-3
Reverse Osmosis Systems

Company	Product Name
Culligan	Aqua-Cleer
Ecowater	ERO-375E-CP
GE	Merlin
GE	Smartwater GXRM10GBL
Kinetico	Plus Deluxe VX
Pentair	RO-3500EX w/ GS
3M/CUNO/Water Factory	SQC-3 (04-045)
Watts Premier	WP-4V

The PFBA molecule was shown to be the most difficult to remove for RO membranes, with the PFOA contaminant the second most difficult. This pattern was also followed with AC filter removal.

As expected, the higher concentrations of PFCs occurred in the first sample taken after the stagnation periods. See section 4.4.2 below for more discussion on this finding.

Most RO membranes removed or significantly reduced PFC concentrations in the RO permeate. In all but one case, detectable PFC concentrations in the membrane permeate were removed by the post-RO membrane filters to below non-detect limits. Given the low concentrations in the RO permeate, this is expected.

It cannot be concluded on the basis of available information, but it can be speculated that the reason the GE Merlin removed fewer PFCs than the other RO systems is that the GE Merlin is designed to operate at a higher flow rate than others RO. Manufacture literature shows that the GE Merlin's manufacturer, daily processing capacity rating is 748 gallons while the other RO systems' rates vary from 8 to 35 gallons per day. It is well known in the membrane industry that, it is very difficult to keep both the flow high and the purification levels high at the same time.

Table 4-4
RO System Performance: First Test- PFBA

First test - PFBA only Feed concentration	**Day 1 - 12 hour** PFBA- 10	**Day 2 - 30 hour** PFBA- 10	**Day 3 - 54 hour** PFBA- 10	**Day 4 - 78 hour** PFBA- 10	**Day 7 - 144 hour** PFBA-10	**Day 7 – 148 hour** PFBA-10
Culligan Aqua-Cleer - PM	DNQ	DNQ	0.4 ug/L	0.4 ug/L	2.3 ug/L	DNQ
Culligan Aqua-Cleer - PF	ND	ND	ND	ND	ND	ND
Cuno/Water Factory SQC-3	ND	ND	ND	*	ND	ND
Cuno/Water Factory SQC-3	ND	ND	ND	ND	ND	ND
Ecowater ERO-375 – PM	ND	ND	ND	ND	ND	ND
Ecowater ERO-375 – PF	ND	ND	ND	ND	ND	ND
GE Merlin - PM	1.2 ug/L	0.3 ug/L	0.3 ug/L	0.2 ug/L	1.9 ug/L	0.8 ug/L
GE Merlin - PF	1.6 ug/L	2.0 ug/L	1.5 ug/L	1.2 ug/L	2.0 ug/L	1.6 ug/L
GE Smartwater GXRM10G – PM	DNQ	DNQ	DNQ	0.2 ug/L	0.9 ug/L	DNQ
GE Smartwater GXRM10G – PF	ND	ND	ND	ND	ND	ND
Kinetico Plus Deluxe VX - PM	ND	ND	ND	ND	DNQ	ND
Kinetico Plus Deluxe VX - PF	ND	ND	ND	ND	ND	ND
Pentair RO-3500-EX – PM	ND	ND	ND	ND	ND	ND
Pentair RO-3500-EX – PAC	ND	ND	ND	ND	ND	ND
Pentair RO-3500-EX – post IX filter	ND	ND	ND	ND	ND	ND
Watts WP-4V - PM	DNQ	DNQ	DNQ	DNQ	0.2 ug/L	DNQ
Watts WP-4V - PF	ND	ND	ND	ND	ND	ND

Note: PM = Post Membrane sample
PF = Post Final Filter sample
PAC = Post AC Filter sample
IX = Ion Exchange Filter sample

ND = not detected (< 0.5) DNQ = detected, not quantified (0.05 to 0.2 *u*g/L) * = lost sample

Table 4-5
RO System Performance: Second Test- PFOA + PFOS

Second Test PFOA + PFOS	Day 1 – 12 hour		Day 2 - 30 hour		Day 3 – 54 hour		Day 4 – 78 hour		First draw post stagnation Day 7-144hr hour		Day 7 – 148 hour	
	PFOA	PFOS	PFOA	PFOS	PFOA	PFOS	PFOA	PFOS	PFOA	PFOS	PFOA	PFOS
Culligan Aqua-Cleer - post Membrane	ND	ND	ND	ND	ND	ND	ND	ND	DNQ	ND	ND	ND
Culligan Aqua-Cleer - post Final Filter	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Cuno/Water Factory SQC-3	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Cuno/Water Factory SQC-3	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Ecowater ERO-375 - post Membrane	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Ecowater ERO-375 - post Final Filter	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
GE Merlin - post Membrane	0.3 ug/L	ND	0.4 ug/L	ND	0.5 ug/L	DNQ	0.6 ug/L	DNQ	0.9 ug/L	DNQ	ND	ND
GE Merlin - post Final Filter	DNQ	ND	DNQ	ND	DNQ	ND	0/4 ug/L	ND	0.2 ug/L	ND	ND	ND
GE Smartwater GXRM10G - pM	ND	ND	ND	ND	ND	ND	DNQ	ND	0.3 ug/L	ND	ND	ND
GE Smartwater GXRM10G - pF	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Kinetico Plus Deluxe VX - pM	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Kinetico Plus Deluxe VX - pF	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Pentair RO-3500-EX - post Membrane	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Pentair RO-3500-EX - post AC filter	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Pentair RO-3500-EX - post IX filter	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Watts WP-4V - post Membrane	ND	ND	ND	ND	ND	ND	ND	ND	DNQ	ND	ND	ND
Watts WP-4V - post Filter	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND

ND = not detected (< 0.5) DNQ = detected, not quantified (0.05 to 0.2 *u*g/L)

Table 4-6
RO System Performance: Third Test- PFBA + PFOA + PFOS

3rd Test PFBA+PFOA + PFOS	Day 1 - 12 hour			Day 2 - 30 hour			Day 3 - 54 hour			Day 4 - 78 hour			First sample after stagnation Day 7 - 144hour			Day 7 - 148hour		
Concentrations; 10+ 3+ 3 *ug*/L	PFBA	PFOA	PFOS	PFBA	PFOA	PFOS	PFBA	PFOA	PFOS	PFBA	PFOA	PFOS	PFBA	PFOA	PFOS	PFBA	PFOA	PFOS
	----------all values in *ug*/L----------																	
Culligan Aqua-Cleer - post Membrane	0.6	ND	ND	0.4	ND	ND	0.4	ND	ND	0.4	DNQ	ND	2.5	DNQ	ND	DNQ	ND	ND
Culligan Aqua-Cleer - post Final Filter	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Cuno/Water Factory SQC-3	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Cuno/Water Factory SQC-3	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Ecowater ERO-375 - post Membrane	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Ecowater ERO-375 - post Final Filter	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
GE Merlin - post Membrane	1.5	0.3	DNQ	0.2	0.4	0.2	4.3	0.2	DNQ	4.8	0.2	DNQ	5.8	0.3	DNQ	4.6	DNQ	DNQ
GE Merlin - post Final Filter	3.0	DNQ	ND	2.3	DNQ	DNQ	1.0	0.3	DNQ	1.5	0.2	DNQ	1.8	0.3	DNQ	1.8	DNQ	DNQ
GE Smartwater GXRM10G - pM	0.4	ND	ND	0.5	ND	ND	0.2	DNQ	ND	0.4	DNQ	ND	1	0.3	ND	0.2	ND	ND
GE Smartwater GXRM10G - pF	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Kinetico Plus Deluxe VX - pM	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	DNQ	ND	ND
Kinetico Plus Deluxe VX - pF	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Pentair RO-3500-EX - post Membrane	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Pentair RO-3500-EX - post AC filter	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Pentair RO-3500-EX - post IX filter	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Watts WP-4V - post Membrane	DNQ	ND	ND	DNQ	ND	ND	DNQ	ND	ND	DNQ	ND	ND	DNQ	DNQ	ND	DNQ	DNQ	ND
Watts WP-4V - post Filter	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND

KEY: ND = not detected (< 0.5 *u*g/L) DNQ = detected, not quantified (0.05 to 0.2 *u*g/L)

4.5 Performance Data – Operational

4.5.1 Activated Carbon Technology

See section 4.4.1.

4.5.2 Reverse Osmosis Technology

In general, the performance of the RO system membranes did not change over time. This is expected, since the main mechanism of removal of contaminants in a reverse osmosis system is their "physico-chemical" exclusion from the permeate stream. Such effects depend chiefly on the membrane characteristics, which should not change in the short term of this test. There is also some performance dependence on the operational characteristics of a RO-based system, such as pressure, flow rates, and ratio of feed to permeate flow rates ("recovery"). This test was designed to standardize those operational effects, but not determine their effects. Since adsorption is not the primary mechanism of PFC removal within an RO system, saturation of adsorption sites is not a concern in interpreting the results. While there is an AC filter downstream of the RO membrane in all systems tested, PFCs that reach these post-RO filters will only be the amount passing through the membrane. In this test, that amount was very low. Since membrane performance life is measured in years, lifetime was not expected to be an issue for RO systems in a test of 21 days. A lifetime performance evaluation for a normal RO system operation would require a time scale of months to years.

However, RO system performance is fairly complicated and some nuanced results can be expected. One example is the behavior of solutes, including contaminants, during shutdown. When a system is not operating (shut down) and flow of feed, concentrate and permeate is not occurring, molecules will diffuse throughout the contained water, moving from higher concentration to lower. If small and active enough, such molecules may diffuse through the membrane from the feed to the permeate side. This phenomenon is understood to occur in RO systems, so an attempt to account for this is in the certification test protocol written into NSF/ANSI Standard 58. The first sample drawn, after the "stagnation period" in this protocol was designed to sample water from the permeate volume that was subject to such diffusion. In this test, as expected, there was a strong trend that the highest PFC values were in these post-stagnation samples.

Another potential phenomenon is the adsorption of small molecules by a membrane material – including any of the barrier layer, support membrane layer or fabric support layers. The authors are not aware of any studies indicating whether PFC molecules are adsorbed in RO membranes or not, but we consider any adsorption that occurred as unlikely to be significant in this test. To the extent that there is some adsorption, the RO device will appear to be performing better separation early in its life. This phenomenon possibly explains the decreased performance for the PFBA molecule of the worst performing RO system over time, in both the first and third test cycle (days 1-7, 15-21, respectively). This does not explain, however, why the post-RO AC filter values are higher for PFBA than in the permeate stream immediately after the RO, which is an unexpected result. It may be explained by sloughing phenomenon as a result of a minor flow surge during sampling – due to opening the sample valves. However, this was not seen on any of

the other post-RO filters, and would indicate very weak adsorption of the PFBA molecule by that AC media. No strong conclusions on the relatively poorer performance on this unit are made.

4.6 QA/QC Results

4.6.1 Initial Background Contamination

Both the WQA Laboratory's incoming makeup water, and test devices (by re-circulating water through the test bench and sampling it) were samples for background PFC readings before any testing was started. These were sent to the MDH PHL for analyses. There were not any PFCs present at above detection level in either sample.

4.6.2 Initial Challenge Solution PFC Concentration Verification

Step I - Determine if WQA can spike challenge water with PFC and maintain tank stability (one week timeline).

1. Three 50-gallon challenge tanks were prepared with PFOA (3 ug/l), PFOS (3 ug/l) and PFBA (10 ug/l).

- A 50% challenge tank was made by pipetting 100µl of stock solution into a 1L flask filled with the challenge tank water. The flask was mixed and 500mL of this solution was then poured into the challenge tank. The tank was mixed.
- A 100% challenge tank was made by pipetting 100µl of stock solution into a 1L flask filled with the challenge tank water. The flask was mixed and poured into the challenge tank. The tank was mixed.
- A 150% challenge tank was made by pipetting 150µl of stock solution into a 1L flask filled with the challenge tank water. The flask was mixed and poured into the challenge tank. The tank was mixed.

2. Initial samples were taken on 9/20/07 at 1 PM and sent to MDH PHL the same day for analysis. Another sample was taken at 6:30 PM on 9/20/07 and a 24-hour sample was taken at 1 PM on 9/21/07. These samples were sent on 9/21/07 to MDH PHL.

Results were as follows in Table 4-7.

Table 4-7
Challenge Water Samples

Initial Sample	**PFBA**	**PFOA**	**PFOS**
50% PFOA, PFOS, PFBA	4.2ug/l	1.1 ug/l	2.1 ug/l
100% PFOA, PFOS, PFBA	10.3 ug/l	2.7 ug/l	6.6 ug/l
150% PFOA, PFOS, PFBA	14.8 ug/l	3.7 ug/l	8.0 ug/l
6:30PM Sample	**PFBA**	**PFOA**	**PFOS**
50% PFOA, PFOS, PFBA	4.9 ug/l	1.2 ug/l	2.0 ug/l
100% PFOA, PFOS, PFBA	10.6 ug/l	2.7 ug/l	4.6 ug/l
150% PFOA, PFOS, PFBA	13.1 ug/l	3.2 ug/l	6.0 ug/l
24 Hour Sample	**PFBA**	**PFOA**	**PFOS**
50% PFOA, PFOS, PFBA	4.8 ug/l	1.3 ug/l	2.1 ug/l
100% PFOA, PFOS, PFBA	10.6 ug/l	2.7 ug/l	4.8 ug/l
150% PFOA, PFOS, PFBA	13.9 ug/l	3.4 ug/l	5.8 ug/l

3. Three 50-gallon challenge tanks were prepared with PFOA (3 ug/l) and PFOS (3 ug/l).

- A 50% challenge tank was made by pipetting 100µl of stock solution into a 1L flask filled with the challenge tank water. The flask was mixed and 500mL of this solution was then poured into the challenge tank. The tank was mixed.
- A 100% challenge tank was made by pipetting 100µl of stock solution into a 1L flask filled with the challenge tank water. The flask was mixed and poured into the challenge tank. The tank was mixed.
- A 150% challenge tank was made by pipetting 150µl of stock solution into a 1L flask filled with the challenge tank water. The flask was mixed and poured into the challenge tank. The tank was mixed.

4. Initial samples were taken on 9/25/07 at 1:30PM and sent to MN DEP the same day for analysis. Another sample was taken at 9:30AM on 9/26/07 and a 24-hour sample was taken at 1:30PM on 9/26/07. These samples were sent on 9/26/07 to MN DEP

4.6.3 Daily QA/QC Results

The PFC levels were tested daily after mixing and results were within acceptable ranges. They are presented in Table 4-8.

Table 4- 8
PFC Concentration of Feed Tanks BY WQA For Phase I

Day/Tank	Volume (gallons)	Influent		
		PFBA	PFOA	PFOS
Day 1				
Tank A	500	9.2 ug/L	N/A	N/A
Tank B	500	8.8 ug/L	N/A	N/A
Tank C	500	8.7 ug/L	N/A	N/A
Tank D	500	9.0 ug/L	N/A	N/A
Average Influent	2000	8.9 ug/L	N/A	N/A
Day 2				
Tank A	500	8.8 ug/L	N/A	N/A
Tank B	500	8.8 ug/L	N/A	N/A
Tank C	500	8.6 ug/L	N/A	N/A
Tank D	500	N/A	N/A	N/A
Average Influent	2000	8.7 ug/L	N/A	N/A
Day 3				
Tank A	500	9.0 ug/L	N/A	N/A
Tank B	500	8.3 ug/L	N/A	N/A
Tank C	500	8.9 ug/L	N/A	N/A
Tank D	500	N/A	N/A	N/A
Average Influent	2000	8.7 ug/L	N/A	N/A
Day 4				
Tank A	500	9.4 ug/L	N/A	N/A
Tank B	500	9.5 ug/L	N/A	N/A
Tank C	500	10 ug/L	N/A	N/A
Tank D	500	N/A	N/A	N/A
Average Influent	2000	9.6 ug/L	N/A	N/A
Day 5				
Tank A	500	9.3 ug/L	N/A	N/A
Tank B	500	9.2 ug/L	N/A	N/A
Tank C	500	9.1 ug/L	N/A	N/A
Tank D	500	N/A	N/A	N/A
Average Influent	2000	9.2 ug/L	N/A	N/A
Day 6				
Tank A	500	9.4 ug/L	N/A	N/A
Tank B	500	N/A	N/A	N/A
Tank C	500	N/A	N/A	N/A
Tank D	500	N/A	N/A	N/A
Average Influent	2000	9.4 ug/L	N/A	N/A
Day 7				
Tank A	500	8.8 ug/L	N/A	N/A
Tank B	500	N/A	N/A	N/A
Tank C	500	N/A	N/A	N/A
Tank D	500	N/A	N/A	N/A
Average Influent	2000	8.8 ug/L	N/A	N/A
Day 8				
Tank A	500	N/A	2.6 ug/L	2.7 ug/L
Tank B	500	N/A	2.6 ug/L	3.3 ug/L
Tank C	500	N/A	2.7 ug/L	3.3 ug/L

Tank D	500	N/A	N/A	N/A
Average Influent	2000	N/A	2.6 ug/L	3.1 ug/L
Day 9				
Tank A	500	N/A	2.6 ug/L	2.9 ug/L
Tank B	500	N/A	2.5 ug/L	2.9 ug/L
Tank C	500	N/A	2.6 ug/L	2.8 ug/L
Tank D	500	N/A	N/A	N/A
Average Influent	2000	N/A	2.6 ug/L	2.9 ug/L
Day 10				
Tank A	500	N/A	2.6 ug/L	2.6 ug/L
Tank B	500	N/A	2.5 ug/L	2.7 ug/L
Tank C	500	N/A	2.7 ug/L	3.1 ug/L
Tank D	500	N/A	N/A	N/A
Average Influent	2000	N/A	2.6 ug/L	2.8 ug/L
Day 11				
Tank A	500	N/A	3.0 ug/L	3.2 ug/L
Tank B	500	N/A	3.0 ug/L	3.2 ug/L
Tank C	500	N/A	N/A	N/A
Tank D	500	N/A	N/A	N/A
Average Influent	2000	N/A	3.0 ug/L	3.2 ug/L
Day 12				
Tank A	500	N/A	2.8 ug/L	3.1 ug/L
Tank B	500	N/A	2.8 ug/L	3.1 ug/L
Tank C	500	N/A	2.9 ug/L	3.1 ug/L
Tank D	500	N/A	N/A	N/A
Average Influent	2000	N/A	2.8 ug/L	3.1 ug/L
Day 13				
Tank A	500	N/A	2.8 ug/L	3.1 ug/L
Tank B	500	N/A	N/A	N/A
Tank C	500	N/A	N/A	N/A
Tank D	500	N/A	N/A	N/A
Average Influent	2000	N/A	2.8 ug/L	3.1 ug/L
Day 14				
Tank A	500	N/A	2.9 ug/L	3.5 ug/L
Tank B	500	N/A	N/A	N/A
Tank C	500	N/A	N/A	N/A
Tank D	500	N/A	N/A	N/A
Average Influent	2000	N/A	N/A	N/A
Day 15				
Tank A	500	10 ug/L	2.1 ug/L	3.5 ug/L
Tank B	500	10 ug/L	2.2 ug/L	3.3 ug/L
Tank C	500	9.8 ug/L	2.1 ug/L	3.2 ug/L
Tank D	500	9.9 ug/L	2.2 ug/L	3.0 ug/L
Average Influent	2000	9.9 ug/L	2.2 ug/L	3.3 ug/L
Day 16				
Tank A	500	9.1 ug/L	2.3 ug/L	3.1 ug/L
Tank B	500	9.5 ug/L	2.2 ug/L	3.4 ug/L
Tank C	500	N/A	N/A	N/A
Tank D	500	N/A	N/A	N/A
Average Influent	2000	9.3 ug/L	2.3 ug/l	3.3 ug/L
Day 17				
Tank A	500	9.4 ug/L	2.4 ug/L	3.2 ug/L

Tank B	500	10 ug/L	2.3 ug/L	3.5 ug/L
Tank C	500	9.2 ug/L	2.0 ug/L	3.2 ug/L
Tank D	500	N/A	N/A	N/A
Average Influent	2000	9.5 ug/L	2.2 ug/L	3.3 ug/L
Day 18				
Tank A	500	9.1 ug/L	1.9 ug/L	3.3 ug/L
Tank B	500	10 ug/L	2.2 ug/L	3.8 ug/L
Tank C	500	N/A	N/A	N/A
Tank D	500	N/A	N/A	N/A
Average Influent	2000	9.6 ug/L	2.1 ug/L	3.6 ug/L
Day 19				
Tank A	500	9.5 ug/L	2.0 ug/L	3.4 ug/L
Tank B	500	9.1 ug/L	2.2 ug/L	3.3 ug/L
Tank C	500	9.4 ug/L	2.0 ug/L	3.6 ug/L
Tank D	500	N/A	N/A	N/A
Average Influent	2000	9.3 ug/L	2.1 ug/L	3.4 ug/L
Day 20				
Tank A	500	9.8 ug/L	2.1 ug/L	3.2 ug/L
Tank B	500	N/A	N/A	N/A
Tank C	500	N/A	N/A	N/A
Tank D	500	N/A	N/A	N/A
Average Influent	2000	9.8 ug/L	2.1 ug/L	3.2 ug/L
Day 21				
Tank A	500	9.8 ug/L	2.3 ug/L	3.3 ug/L
Tank B	500	N/A	N/A	N/A
Tank C	500	N/A	N/A	N/A
Tank D	500	N/A	N/A	N/A
Average Influent	2000	9.8 ug/L	2.3 ug/L	3.3 ug/L

Relevant naturally occurring water constituents and conditions of the water used for make-up were analyzed daily, and found to be acceptable. They are presented in Table 4-9.

Table 4-9
WQA Lab Feed Influent Water Characteristics

Day	Alkalinity	Hardness	TDS	pH	TOC	Chloride	Sulfate
1	109 mg/L	133.5 mg/L	218.5 mg/L	7.96	2.42 mg/L	14.3 mg/L	29.1 mg/L
2	108 mg/L	134.5 mg/L	217.2 mg/L	7.90	2.80 mg/L	13.0 mg/L	27.4 mg/L
3	106 mg/L	140.0 mg/L	210.3 mg/L	7.96	3.26 mg/L	13.3 mg/L	28.2 mg/L
4	105 mg/L	134.0 mg/L	219.2 mg/L	7.97	3.02 mg/L	13.3 mg/L	28.2 mg/L
5	107 mg/L	135.5 mg/L	219.9 mg/L	7.92	2.78 mg/L	13.4 mg/L	28.3 mg/L
6	106 mg/L	136.0 mg/L	221.9 mg/L	7.90	4.16 mg/L	13.9 mg/L	28.8 mg/L
7	106 mg/L	136.0 mg/L	224.0 mg/L	7.96	3.01 mg/L	13.6 mg/L	28.4 mg/L
8	108 mg/L	135.5 mg/L	224.0 mg/L	7.97	2.87 mg/L	13.9 mg/L	29.0 mg/L
9	110 mg/L	140.0 mg/L	214.4 mg/L	7.68	2.31 mg/L	13.8 mg/L	29.2 mg/L
10	105 mg/L	138.0 mg/L	215.1 mg/L	7.54	2.14 mg/L	13.5 mg/L	28.8 mg/L
11	107 mg/L	146.0 mg/L	219.2 mg/L	7.55	2.49 mg/L	14.3 mg/L	28.6 mg/L
12	105 mg/L	136.0 mg/L	215.8 mg/L	7.61	2.32 mg/L	13.8 mg/L	28.6 mg/L
13	105 mg/L	140.0 mg/L	217.8 mg/L	7.67	2.15 mg/L	14.3 mg/L	28.7 mg/L
14	100 mg/L	146.0 mg/L	214.4 mg/L	7.37	2.05 mg/L	14.0 mg/L	28.8 mg/L
15	103 mg/L	142.0 mg/L	215.8 mg/L	7.30	1.98 mg/L	14.3 mg/L	30.9 mg/L
16	105 mg/L	136.0 mg/L	215.8 mg/L	7.35	3.15 mg/L	14.2 mg/L	28.8 mg/L
17	102 mg/L	138.0 mg/L	215.1 mg/L	7.32	2.97 mg/L	14.2 mg/L	28.6 mg/L
18	105 mg/L	138.0 mg/L	215.1 mg/L	7.42	1.99 mg/L	13.9 mg/L	28.1 mg/L
19	104 mg/L	140.0 mg/L	214.4 mg/L	7.37	1.87 mg/L	13.8 mg/L	27.9 mg/L
20	101 mg/L	140.0 mg/L	213.7 mg/L	7.08	2.16 mg/L	14.0 mg/L	27.9 mg/L
21	105 mg/L	140.0 mg/L	214.4 mg/L	7.15	2.14 mg/L	14.3 mg/L	28.7 mg/L
Range	**101-110**	**133.5-146**	**213-224**	**7.15-7.97**	**1.87-3.02**	**13-14.3**	**27.4-28.8**

4.7 Analytical Laboratory QA/QC

The Public Health Laboratory provided this information on their QA/QC samples for perfluorochemical analysis as performed by the Minnesota Department of Health Public Health Laboratory. Sample analysis followed MDH LIMS analysis code 555 utilizing high-pressure liquid chromatography/mass spectrometry/mass spectrometry. LIMS code 555 includes robust QA/QC incorporating the following criteria within every batch.

1. Samples are collected in contaminant free containers
2. Samples are analyzed within holding time
3. Batch analysis includes no more than 20 samples not including QC
4. A valid analytical batch includes a calibration curve or calibration verification check sample, report level verification check sample, method blank, instrument blank, sample duplicate, spike and spike duplicate, and samples. All QC samples must pass method criteria for sample data to be acceptable. In cases where QC criteria were not met, sample results must be “flagged” on the client report.
5. Quantification is by the internal standard technique.
6. Qualitative identification is based on molecular ion transition to a primary or secondary ion and analyze retention time.

7. A report level of 0.2 ug/L has been determined for each analyze of interest. Positive identification, but estimated quantification, is reported down to 0.05 ug/L.

4.8 Comments and Recommendations

4.8.1 Comments

An important point to note is that the shut down periods are known to affect the two technologies tested here differently. Residence time during shut down in adsorptive media (AC filter) will increase removal of contaminants, while shut down time in an RO system allows potential diffusion through the membrane (for some molecules). These phenomena are discussed in more detail elsewhere in this report.

This test protocol was conservative relative to typical ways that POU filters are used to produce drinking water at the tap, and was designed for screening information. The adsorptive media (AC filters) test was run in a 20 minute on - 20 minute off cycle (flow vs. no-flow condition). Also, all flows were set at the filter's maximum rating. The sampling point was at 10 minutes after flow through the cartridge was initiated, in concert with ANSI/NSF Standard 53 technique. It is highly probable that the first water out of the filter after the shut down cycle would contain substantially less of any of the PFC molecules, and that measured concentrations would increase steadily as more water passed through the filter. The degree of effect and residence time could vary considerably.

As an illustration, if a single person drew a glass of water through a filter at a kitchen tap that had not been used recently, the water would have had a long residence time in the media and adsorption would have been maximized as a result. In contrast, if an entire large family drew drinking water samples, and after water was drawn for cooking, etc, there should be a low residence time in the media for the last water drawn.

The PFBA molecule, perfluorobutanoic acid, is the smallest and presumably most active of the three PFC molecules tested. This may explain its higher passage, although scientific literature on AC removal of these molecules, especially PFBA, is sparse.

It is known PFC molecules identified in Minnesota groundwater are successfully being removed with activated carbon filtration media. This commercial scale filtration undoubtedly is engineered to maximize residence time and other separation factors. It is recommended that in the Phase II testing, sufficient sampling at early points after shut-down periods be made to generate a profile of removal vs. throughput (water volume) and also vs. filter's media volume and device construction. This information could then be used for subjective judgments on the typical use of a POU filter and their implication for filter performance and potable product safety.

4.8.2 Recommendations for Phase II

In addition to providing insight for PFC removal performance and operational reliability/ characteristics of POU devices when subjected to groundwater they are intended to treat in Minnesota over an extended period, Phase II also addressed performance regarding how these devices are typically used within a residential installation.

To secure actual source water quality conditions wells located within the subject groundwater contamination sites were used. One site (municipal well in St. Paul Park) provided water with known concentrations of PFBA, another site (municipal well in Oakdale) provided water with known concentrations of PFBA, PFOA, and PFOS. It is known higher levels of hardness, iron, and lower temperatures from these groundwater sources (vs. water lab test water) will influence operational and PFC removal performance/capacity of devices/technologies evaluated in Phase I.

4.8.2.1 Device Selection for Phase II

Results of Phase I suggest greater variances in PFC removal performance between devices utilizing a single technology, such as an AC filter compared to those incorporating multiple PFC removal technologies, such as an RO system. Although, AC filters sold as stand-alone devices offer a distinct set of features in comparison to RO systems, including initial cost, ease of installation, higher flow rates, and greater daily production capacities.

Based on the outcome of Phase I, the POU-PFC Workgroup and WSM adjusted the test plan to provide the public additional product evaluations by expanding the Phase II challenge from 4 weeks to 13 weeks and include as many different devices as feasible vs. duplicate testing of identical devices. All changes were accomplished using only appropriations already provided and within the overall timeline required

Accordingly, eleven (11) devices were recommended for Phase II testing including four (4) of the six (6) adsorptive (AC) systems, and seven (7) of the eight (8) RO-based systems included in Phase I.

4.8.2.2 Test Plan

Phase I was designed to be conservative and accentuate differences in performance characteristics between technologies/devices. Part of the rationale for this approach was the fact that there was very limited information on PFC removal effectiveness by POU devices. Based on the results for the adsorptive devices especially, WSM recommended Phase II obtain performance data from a broader spectrum of usage conditions, accounting more for how the devices are typically used in a residential setting.

WSM recommended that each AC device be sampled at three (3) collection points immediately after initiation of flow after as scheduled non-use period. Timing of this sample collection sequence was defined jointly by the POU-PFC Workgroup, WQA, and WSM. All POU devices that are tested simultaneously and subjected to hydraulic conditions similar to typical residential

use; including repeated on/off cycling and stagnation periods for RO systems. Each POU device were operated and evaluated in its entirety of water treatment components and/or stages. An automatic end-of-filter-life shut off valves that existed on one manufacturer's devices were disabled in for continued performance evaluation after their rated design capacity.

Due to different operational characteristics between AC filters and RO systems, different protocols were used for operation and sample collection. Specifically:

Water sampling from the expendable AC POU devices consisted of a sequence of three (3) separate samples collected at points representative of volumes used within a residential setting. Such as: ½ minute, 1 minute and at 3 minutes after initiation of flow. These sequences of samples were collected at each of 0, 50, 100, and 150% of the manufacturers' rated capacity. Schedule for on/off cycling for filter operation was 6 minutes - on and 54 minutes off. Testing for all AC devices were scheduled to conclude within period of 30-days.

For RO systems, sampling of the finished water, processed through the entire treatment train of pre-filters, RO membrane and post-filters, included two samples collected ever other week over a period of 90 days of continuous operation. One sample was collected on a Friday, before a 48-hour stagnation period with a second sample collected on the following Monday after the stagnation period. During non-stagnation periods, RO systems were operated continuously while draining each devices treated water storage tank every three hours.

4.8.2.3 Test Station Design for Phase II

To accommodate Phase II objectives, two identical test stations were designed and fabricated by WSM to support continuous device operation (24 hrs/day). Each device selected for continued evaluation in Phase II was operated simultaneously at both field test sites (Oakdale and St. Paul Park).

Process cycle times for each device was controlled via programmable 24-hour timing mechanisms to initiate automatic shut-off valves located on filtrate streams and storage tank drain lines. In addition, 6 minute-on / 54 minute-off cycles for the operation of Activated Carbon filters were controlled via a programmable timer with an adjustable time delay relay in conjunction with electrically initiated valves installed on each filters filtrate line. Total gallons filtered were measured with an in-line flow sensor installed with analog output to a programmable logic controller/monitor (PLC) with data-logging capabilities. The PLC was programmed to discontinue operation of an AC filter at predetermined set points (i.e. 250 gallons) by electrically overriding the 6/54-minute on/off cycle sequence and discontinuing flow through the device. Sample taps and pressure gauges are provided for both influent and filtrate streams.

Operation of RO systems were controlled by timers that were programmed to drain permeate storage tanks via an electrically operated valve every three hours and discontinue this sequence to accommodate for stagnation periods. Sample taps are provided for feed, permeate and concentrate streams and pressure gauges provided for influent and permeate/tank streams.

Additionally, Ports were provided with each pressure gauge for verification of calibration. Station construction includes a structural fiberglass frame, ½" polypropylene sheet material, stainless steel hardware, plumbing components are schedule 80 PVC. Plumbing connections were sealed with PFC-free material.

The following parameters were measured for AC filter:

1. Inlet and outlet pressure (psig)
2. Flow rate
3. Total gallons
4. Frequency and Time of on/off episodes
5. Water Temperature

The following parameters were measured for each RO System:

1. Inlet and outlet pressure range (psig)
2. Concentrate and permeate flow rate (mL/min), plus concentrate and permeate conductivity/TDS (At recorded inlet pressure and 0 psi filtrate pressure).
3. Frequency and Time of on/off episodes (indirect)
4. Total gallons produced (by calculation)
5. Water Temperature

Data was recorded in a logbook for each device with the exception of weekends and holidays. Readings were recorded on a daily basis during the 30-day AC filter evaluation period otherwise recorded on Monday, Wednesday, and Friday of each week with the exception of Presidents Day (February 18, 2008. On that date, data was recorded on Tuesday vs. Monday.

4.8.2.4 Sensor Accuracy

Station pressure gauges accuracy was verified with a NIST traceable pressure gauge. Accuracy of flow meters was verified by measurement of time/volume method using a graduated cylinder.

4.8.3 General Water Quality Characteristics for Field Application Testing

It is understood general water quality characteristics at each well house site are known and remain static. Unless notified of MDH's preference to conduct initial or ongoing analyses for these parameters, WSM believes the expense saved by not testing the contaminants other than TOC and the PFC levels) are better invested in other aspects of this evaluation.

Chapter 5
Phase I-B

5.1 Phase I-B Purpose and Rationale

The POU-PFC Workgroup in the Minnesota Department of Health reviewed the results of the Phase1 and evaluated them against their objectives, as set by the Minnesota Legislature. The Workgroup concluded that further laboratory testing would reveal relevant device performance not obtained in Phase I and not likely to be obtained in Phase II testing. The Workgroup then engaged WSM and WQA in discussions to determine the best approach in both the planned Phase II field-testing, and in a second, abbreviated Phase I-B laboratory test.

The purpose of Phase I (bench testing under controlled conditions) was to screen the performance of an assortment of commercially available POU devices using technologies expected to remove PFCs. As an initial screening test, operating conditions, and sample collection protocols were conservative and set to provide meaningful comparisons in performance between devices/technologies. They were based on the test protocol in the ANSI/NSF Standards and on practices of certification laboratories that test products to those standards. The resultant data defined significant variations in PFC removal performance, but did not reflect the PFC removal performance of the most typical household use patterns. Performance data from Phase I was therefore used to select the most promising devices for continued testing in Phase II of the project, and to select the devices that should give the most relevant data in a limited second laboratory test, Phase I-B.

The PFC Workgroup identified some limitations of the performance profile of the devices gained from Phase I testing that would not be revealed by the planned Phase II test. These limitations included that there was only an assumption the RO based devices, including the post-filters, would perform adequately for at least 500-gallons of treated water volume. Also, the performance of the AC filter devices was not demonstrated for more typical uses in a residential setting.

Addressing this second limitation focuses on PFC removal by the AC filters during short-term water draw. The very conservative NSF/ANSI protocol used in Phase I called for sampling in the mid-point of the draw portion of the on/off cycle during long-term testing. However, the use and consumption of water from a POU filter, such as these AC filter devices, typically involves a short-term water-draw. Examples include the first 10 ounces of water through for a glass of drinking water, or the first half-gallon of water put in a container and cooled for later use or used for cooking. These typical water draws will include the water that has sat in the filter housing for some time, increasing the likelihood of adsorption of contaminants, and therefore removing greater amounts than revealed in Phase I. The PFC Workgroup decided to obtain data on select AC filter devices, in a second laboratory test with high levels of PFC in the feed that would better indicate the early draw performance. The minimum performance lifetime of 500-gallons was used again for a test device lifetime goal.

Regarding the RO systems, the primary limitation of the Phase I results noted by the PFC Workgroup was that a 500 gallon throughput was not achieved. Although it is well known in the industry that RO membranes can produce much more than 500-gallons of purified water before losing efficacy, a part of their lifetime is also calendar time. A one-year membrane replacement schedule is frequently recommended. In a household drawing three gallons of water on a daily average, a year lifetime measured in water treated is about 1,000-gallons. The PFC Workgroup decided to test two RO devices for a minimum 500-gallon throughput. Within a practical time period, this required a lab test protocol that ran the devices more than is typical for residential use.

These RO–based POU devices are usually designed with a pre-filter to protect the RO membrane, and an additional AC filter after the RO membrane. In this second lab test, the PFC samples were only drawn from finished water from the entire device (i.e. after the post-filter and storage tank). Therefore, this new test also measured the performance of the AC pre- and post-filters for 500 gallons. It should be noted that the expected low rate of PFC passage through RO membranes, when combined with the known general ability of AC media to remove trace PFCs, results in a low expectation of PFC passage through the entire device).

5.2 Device Selection

The POU PFC Workgroup in the Minnesota Department of Health reviewed the results of Phase I and concluded that further laboratory testing would elucidate relevant performance not obtained in Phase I and not likely to be obtained in Phase II testing. In Phase I six devices were tested that employed “activated carbon” as a singular treatment media for PFC removal (“AC filters”), one demonstrated no breakthrough during the screening test, two demonstrated significant PFC breakthrough and were eliminated from further evaluation, and three devices demonstrated moderate PFC breakthrough just prior to reaching their rated capacity in gallons throughput. It was recognized that these three devices would likely perform significantly better when subjected to use patterns more typical within a home (shorter time from start to sampling, increasing the residence time). These three AC filters were chosen because the POU-PFC Workgroup desired evaluate performance results a revised sample collection protocol would provide.

In Phase I, for the sake of basic background information, RO systems were sampled for PFC removal after treatment by the RO membrane alone, and after the combined treatment by the membrane and post-membrane AC filter. Therefore performance was determined both in a manner the consumer would not use the water (the first case) and in a manner they would (the second). Of the eight devices tested, four had no PFC passage through the RO membrane alone, one demonstrated PFC passage through both the RO membrane and AC post filter, and three demonstrated minor passage through the RO but not after AC filter. Of these last three devices, one incorporated an AC filter that demonstrated no PFC breakthrough in the Phase I when used as a singular technology (described above). Performance of the post-membrane AC filters for remaining two RO systems was unknown, thus were chosen for continued evaluation as a complete system in Phase I-B.

Devices selected:

- Reverse osmosis systems: Watts WP-4v and GE Smart Water GXRM10G
- AC Filters: Rainsoft/Aquion Hydrefiner P-12, Kinetico MACguard 7500, and Sears Kenmore Elite 625.385010

It is important to note that since PFCs are a relatively new contaminant in drinking water and manufacturer ratings for commercially available POU devices PFC removal capacity are currently not available. The volume capacity ratings used in selecting devices for this evaluation were based on actual or assumed PFC removal but on other criteria that may vary by manufacture. These ratings could be based on experience with general fouling that reduces adsorption efficiency to an unacceptable level, or on a tested lifetime for removing a different specific contaminant, such as lead, arsenic, specific organic pollutants or a mix of organic materials (VOCS).

5.3 Test Site and Equipment

Phase I-B challenge testing and sampling was conducted at the WQA Certification Laboratory in Lisle, IL. The Director of Product Certification, Tom Palkon, supervised testing.

The laboratory designated the same test bench used in Phase I for the study. The limited number of devices selected for testing by the POU PFC Workgroup did not require special modification of the test equipment. The instrumentation used was the same as that used in Phase I.

5.4 Test Protocol

5.4.1 Test Solution

It was determined that the composite PFC challenge solution used in Phase I (PFOA and PFOS concentrations of 3 *u*g/l each, and PFBA of 10 *u*g/l) would be used as the common challenge solution (all devices) in Phase I-B. The same make-up water was used, WQA's water source which is Lisle city water, taken from Lake Michigan. The city water was spiked with the MDH supplied stock PFC solution from Phase I testing. Additional stock solutions were received from MDH on March 25. The QA/QC procedures used in Phase I-B were also used.

5.4.2 Test Procedures -AC Filter Devices

1. Systems were set up and conditioned in accordance with manufacturer's instructions.
2. The test bench is set-up as specified in NSF/ANSI 58 and was the same used by WQA in product certification testing. The outlet faucets supplied with the systems were not used; instead, an automatic ball valve was used for allowing flow and sampling. Influent and effluent water traveled through PVC pipe of the test bench plus customer supplied tubing. Movement of water through the test bench was controlled by a PLC that runs several solenoid valves. The test bench used is also the same as in Phase I testing, which tested

negative for PFC extractables and other potential substances that would interfere with PFC analyses.

3. On/off cycle time was set at a 10/90 ratio, 6 min. on, and 54 min. off each hour.
4. Filter devices were operated 8 hours per day, followed by a 16-hour rest period, 7 days a week.
5. Systems were operated on the schedule above until 750-gallons filtrate (effluent) was accumulated for each filter. (Note: the Kinetico automatic shut off device was removed to ensure that the unit would run continuously.)
6. Flow rates were controlled throughout the test. A needle valve was used to adjust the outlet flow rate as needed. Flow rates were achieved @ 60psig, and set to the manufacturer's maximum flow rate specification as follows:
    - Rainsoft/Aquion Hydrefiner P-12: 0.75 gpm
    - Kinetico MACguard 7500: 0.75 gpm
    - Sears Kenmore Elite: 0.50 gpm
7. Sampling
    a. Influent samples were collected on each feed tank and returned to MDH for PFC analysis, and analyzed at WQA for typical water characteristics.
    b. The initial or "start" day effluent samples were collected at filter start up, then after 1 and 3 minutes of the on cycle. Subsequent scheduled sampling sets points (the 250, 500 and 750-gallon effluent samples) were collected based on a schedule determined for each filter device, which based on to tracer tests run by WQA (see 8.). In order to determine the most appropriate sampling times for each AC filter device design, WQA conducted the WSM tracer test protocol and submitted the data to WSM, who determined the following sampling time/volume schedules:

Test System	**Effluent Sampling Times at 250, 500 and 750 gallon points**
Rainsoft/Aquion Hydrefiner P-12	20 seconds, 1 minute, 3 minutes
Kinetico MACguard 7500	5 seconds, 20 seconds, 3 minutes
Sears Kenmore Elite	8 seconds, 30 seconds, 3 minutes

    c. Sampling points over filter life
        - Day 1
        - 250 gallons
        - 500 gallons
        - 750 gallons

    d. The 500-gallon influent and two of the 750-gallon effluent samples were not tested for PFCs, due to the consistent feed readings noted and to budget limitations.

5.4.3 Test Procedures - RO Based Systems

1. The systems were set up and conditioned in accordance with the manufacturers' instructions, including leaving all pre- and post filters provided in place. The storage tanks were connected and used as received from the suppliers.
2. The test bench was set-up as specified in NSF/ANSI 58 and was the same used by WQA in product certification testing. The outlet faucets supplied with the systems were not used; instead, an automatic ball valve was used for allowing flow and sampling. Influent and effluent water traveled through PVC pipe of the test bench plus customer supplied tubing. Movement of water through the test bench was controlled by a PLC that runs several solenoid valves. The test bench used is also the same as in Phase I testing, which tested negative for PFC extractables and other potential substances that would interfere with PFC analyses.
3. The automatic PLC program continuously fed pressurized water to the devices and emptied the systems' storage tanks, as they reached the pre-set shutdown pressurization point, with treated water 24 hours per day, Monday through Friday. The systems sat under pressure (60psig) Saturday and Sunday. The amount of treated water produced was recorded.
4. Systems were sampled for PFC removal performance twice each week. First at the start of day 1, in order to detect the effect of 'TDS creep' which is known to occur in RO based POU devices. Samples were also taken at the end of day 5 of each week.
5. Sampling times
    a. Influent; once per common feed tank, for spiked PFC concentrations and influent water characteristics)
    b. Effluent; on Day 1 (after start-up) and Day 5 Before shut down) each week until the system reached 500 gallons of water produced or end date is reached.
    c. At each sampling point, the number of gallons that had passed through the unit was recorded.

NOTE 1: RO device effluent samples from days 15 and 29 were lost or not taken.

NOTE 2: Both ROs were tested in parallel using the same procedures, controls, feed tank and test equipment. Despite this, the Watts unit showed significantly lower amounts of permeates than expected. This difference has been evaluated, and it was determined that this was not a result of the test protocol used.

5.5 Sample Collection, Submission, and Analysis

As in the Phase I test, the MDH Public Health Lab (PHL) provided 250-milliliter, high-density polyethylene sample bottles for sample collection. Industry standard sample handling procedures were followed. Common feed solution and device-produced water (filtrate) was collected in the MDH-supplied sample bottles, labeled, documented on the master test log, and immediately refrigerated until shipment to the MDH PHL for analysis. Analytical results on PFC were returned to WQA as they became available.

5.6 QA/QC

5.6.1 WQA Laboratory

The Laboratory used flowmeters, pressure gauges, and a thermometer as measurement instruments in conducting device performance. Per standard WQA Certification Laboratory procedure, pressure gauges and thermometers are calibrated yearly. Flowmeters are calibrated before and after each test. The calibration logs are attached in Appendix G.

The Recording Data and Procedures, Chain of Custody and Datasheets maintenance procedures used in Phase I were also repeated for Phase I-B.

To assure the correct PFC feed concentration was present in the challenge solution, feed tank samples were collected within 10 to15 minutes of initial mixing and sent with other samples for QA/QC verification of feed PFC concentrations values. Those values are documented in the MDH/PHL lab results in Appendix C.

Raw water used for the challenge solution make-up was also analyzed daily to assure it was documented and fell within accepted parameters as addressed in Phase I testing. These are documented in Appendix C.

5.6.2 MDH- PHL Analytical Laboratory QA/QC

The Public Health Laboratory used the same QA/QC procedures as described above for Phase I

Chapter 6
Phase I-B Results and Discussion

6.1 Introduction

The Phase I-B test was run as planned and as described in Chapter 5, with three exceptions. The WQA's lab misplaced two of the RO-based system effluent sample sets. Also, in the allotted time and protocol one of the RO-based systems did not produce the expected total permeate volume, and making 76% of the target test volume. The lab also discontinued the AC filter study at 600 gallons instead of 750 gallons prescribed by the POU-PFC Workgroup

The PFC removal performance varied among the technologies tested, as expected. The RO systems removed all PFC molecules to below the detection limit in every sample tested. The AC filters removed PFC completely early in their test life, but varied in degree of removal towards the end. All data is summarized in Table 6-1.

The trend of which PFC molecules are the most difficult to remove continued in Phase I-B, although the amount of data is small. For the AC filter devices the PFBA molecule passed in higher amounts than PFOA, which in turn passed at slightly higher amounts than PFOS.

6.2 Limitations

Like Phase I and II, Phase I-B was also limited in scope by time and budget restrictions. One device (vs. duplicate) representing each product was evaluated and for RO systems, test samples representing membrane performance alone were not analyzed for PFCs.

All devices were evaluated as a complete unit (the just as they would be purchased and used in a residential setting.

Reverse Osmosis systems incorporate three separate components, each capable of removing PFCs. The RO membrane is understood to last more than a year typically, but any AC pre- or post filter will have a finite adsorptive capacity. Therefore, any test that would determine the capacity of the post RO filters to remove low concentrations of PFCs past the RO membrane would likely take a significant period of time (months to years based upon typical household usage) before it may reach it's PFC removal capacity. This test had a time span of 5 weeks.

Two of the RO-based device effluent sample sets (a set is a sample from each device) were inadvertently not tested. Therefore, only 8 of 10 planned data sets were obtained, and only two of the four theoretically worst case sample points. The two missing data sets are for the start-up sampling after the weekend (62-hour) shut down. This "post-stagnation" period is known to be the point at which POU RO systems may allow more solute passage than they do when in pressurized operation. This is a phenomenon known in the industry as "TDS creep" because a

Table 6-1
Phase I-B AC Performance

Gallons Throughput	**0**									**250**									**500**									**600**								
Device / **Analyte**	PFBA	PFOA	PFOS	PFBA	PFOA	PFOS	PFBA	PFOA	PFOS	PFBA	PFOA	PFOS	PFBA	PFOA	PFOS	PFBA	PFOA	PFOS	PFBA	PFOA	PFOS	PFBA	PFOA	PFOS	PFBA	PFOA	PFOS	PFBA	PFOA	PFOS	PFBA	PFOA	PFOS	PFBA	PFOA	PFOS
Test Day	Day 1									Day 8									Day 16									Day 19								
Sample Taken at	0 seconds			60 seconds			3 minutes			20 seconds			60 seconds			4 minutes			20 seconds			60 seconds			4 minutes			20 seconds			60 seconds			4 minutes		
Rainsoft Hydrefiner P-12	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	n/a	n/a	n/a	ND	ND	ND	n/a	n/a	n/a
Test Day	Day 1									Day 10									Day 16									Day 20								
Sample Taken at	0 seconds			1 Minute			5 minutes			8 seconds			30 seconds			3 minutes			8 seconds			30 seconds			3 minutes			8 seconds			30 seconds			3 minutes		
Sears Kenmore Elite	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.2	ND	ND	0.5	ND	ND	0.7	ND	ND	n/a	n/a	n/a	1.6	ND	ND	n/a	n/a	n/a
Test Day	Day 1									Day 10									Day 22									Day 25								
Sample Taken at	0 seconds			1 Minute			5 minutes			5 seconds			20 seconds			3 minutes			5 seconds			20 seconds			3 minutes			5 seconds			20 seconds			3 minutes		
Kinetico MACguard 7500	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.3	ND	ND	0.3	ND	ND	0.3	ND	ND	1.4	ND	ND	1.9	DNQ	DNQ	2.2	DNQ	ND	n/a	n/a	n/a	2.6	ND	ND	n/a	n/a	n/a

ND = non-detect, or below the detection limit of 0.05 ug/L
DNQ = detected, not quantified - between 0.05 and 0.2 *u*g/L
n/a = not available: sample not tested due to consistent feed readings and budget limitation

temporary increase in salt ions (measured as total dissolved solids or TDS) is noted. This increase is generally understood to result from the diffusion of ions through the membrane to the permeate side under static conditions, which does not occur under dynamic operation. It is not known if PFC molecules also behave in this manner, although it can be speculated that they would not do so at the same rate as the smaller and more active salt ions. The missing data sets are for test weeks 2 and 4, so the performance data at this post stagnation period "weak spot" was obtained only from weeks 1 and 3.

However, no passage was noted in any of these data sets, for either RO device tested. No passage was noted either at initial start up or in the other 5 sample points.

The POU-PFC Workgroup had set the AC Filter device test total volume parameter at 750 gallons, a 50% safety factor over the target of 500-gallons. This is a significant safety factor, not necessarily called for by industry practice or in certification standards. The WQA lab ended the test at a 600-gallon throughput, yielding a smaller safety factor of 20% over the 500-gallon target. Samples were analyzed and reported for these points. Two of the three filters had detectable and quantifiable breakthrough of PFBA molecule at the 500-gallon sample point. As expected they both also had breakthrough, to a higher degree, at the 600-gallon point. How the one AC filter that did not pass any detectable PFC molecules through the 600-gallon point would have performed at 750-gallons is, of course, unknown.

This second lab test was not originally scheduled for nor budgeted in the project thus, required finding more resources and sharing resources for the other work. As a result, the decision was made that the some feed ("influent") PFC samples would not be run –as well as the first and last sample draws of the AC filters at the final (600-gallon) lifetime point. In our opinion this lack of data do not effect the conclusions drawn from this test, although the certainty of the conclusions is reduced somewhat.

Also, there are many types of AC media, and this test did not attempt to determine differences among specific types. More research is needed to state with any certainty conclusions about relative efficacy based on style of filter, which base or treated AC media is used, or variations among the same device manufacturer that may occur. The same can be said of RO-based devices, which have a smaller variation in types of RO membrane, but also rely on the AC pre and post filters which may vary as much as AC Filter only devices.

6.3 Performance Data – PFC Removal

6.3.1 Activated Carbon Technologies

Among the three AC filters tested in Phase I-B, PFC removal performance over the 600-gallon span did vary. Only the Hydrefiner made the initial goal of producing finished water below 0.2 ppb of all PFC molecules for all samples taken through 500 gallons. Two of the filters passed detectable amounts of PFBA chemicals before exceeding the 500-gallon limit. One of these also passed detectable amounts of PFOA and PFOS although they were low concentrations, below the point where they can be accurately quantified. Specific performance data can be compared in

Table 6-1. In all cases, within the 500-gallon volume target and within the 20% realized safety factor, the three filters removed PFCs to below current health advisory levels.

For the two filters that did pass some PFCs, the expected pattern was seen where, during a sample period PFC concentrations increased as increasing sample volume was drawn For example, the Sears Kenmore Elite filter passed twice the concentration of PFBA at 30 seconds compared to 8 seconds run time. It passed 3½ times the concentration at 3 minutes run time. With the Kinetico MACguard 7500 filter the pattern was the same, although not as pronounced. Here the 20-second run time was about one-third higher than at 5 seconds and two-third higher at three minutes. The concentrations in the 500-gallon sample of the MACguard were significantly higher than with the Sears filter, although below health advisory limits. This pattern of increasing PFC concentrations is expected, and reflects the reduced residence time and therefore opportunity for PFC absorption by the media to occur.

These filter devices are typically rated at a flow rate from 0.5 to 0.75 gallons per minute. This means that from 1.5 to 2.25 gallons will have been drawn through the filter by the 3-minute sampling time. These volumes are larger than the typical water draw for consumption in a household setting, although within the volume drawn at one time for some uses. To draw one glass of water to drink will typically take less than 10 seconds. Therefore drinking water from a glass drawn one at a time will have a lower total PFC concentration than a large sample drawn for storage, cooking etc. However, this test demonstrates that for any water drawn up to 3-minutes through a filter in its early life will reduce PFCs very significantly.

This test demonstrates that AC filter devices alone, as a complete treatment device, are also an effective technology. They will definitely have a markedly shorter lifetime than the RO devices, but are proportionally less expensive. Understanding such filter devices need to be changed after a certain volume – or time period used instead - were key to safe use of these devices.

It is very important to understand that the challenge concentration levels of the three PFC chemicals are substantially higher than levels currently detected in Minnesota well water. Therefore, the AC filters in both types of devices should last substantially longer in actual use than they would in a laboratory test such as in Phase I-B. Insight into that lifetime comes from Phases II below.

In summary, AC Filter devices as a group can be said to work well for PFC removal, although they have a finite life that must be considered. It can also be stated that AC filters also lose effectiveness with larger volumes of water drawn at one time. Useful indications of what that lifetime are, measured in gallons, come from all three phases of this project. However, there are many types of AC media, and this test did not attempt to determine differences among specific types More research is needed to state with any certainty conclusions about relative efficacy based on style of filter, which raw or treated AC media is used, or variations among the same device manufacturer may occur.

6.3.2 Reverse Osmosis Technologies

The RO-based devices performed very well over the complete time span of the test, passing no detectable PFC contaminant. Neither the Watts model WP-4V nor GE Smart Water device produced water with any PFC passage detected. Although no insight was gained as to what device design, or media type, would work best, this test adds to the growing body of data that shows that POU RO devices work well to remove PFCs.

Since the bulk of any PFC chemicals in the feed water were demonstrated to have been removed by many RO membranes alone, the PFC removal capacity and lifetime of the AC post-RO filter were much greater than using an AC filter device alone. As expected, and as seen in Phase IA, the capacity of the post-RO filter was adequate for removing trace PFCs that may have passed through the RO membrane for volumes of 500 and 380 gallons of product water. If an AC filter removes a high concentration of PFC chemicals when it is the only removal media, then it can be anticipated that the same media and media volume will perform for a substantially longer time-period in removing the reduced level of PFC molecules that will likely pass an RO membrane. Nevertheless, the capacity, and therefore replacement schedule of post RO AC filters is an issue to consider and address by industry or government.

The GE device produced 504 gallons of finished water and the Watts device produced 382 gallons of water, both with no detectable PFCs. In this test, the Watts device had a lower production rate than anticipated, by 24%, and the goal of 500-gallons throughput was not reached in the test time span. However, based on the other test results in this project, each device can be expected to produce a much larger volume of water with PFC removed below the detection limit.

Further insight into RO systems lifetime is provided in Phase II below.

Table 6-2 lists the Phase I-B RO PFC performance.

Table 6-2
Phase I-B RO Performance

Day	Time Sample Taken	Cumulative Gallons	Device Status in Protocol	Influent (ppb)			Effluent (ppb)		
				PFBA	PFOA	PFOS	PFBA	PFOA	PFOS
GE Smartwater GXRM10GBL									
1	12:00	0	start	8.6	2.0	3.3	ND	ND	ND
5	17:30	105	shut-down	9.3	2.1	3.2	ND	ND	ND
8	10:15	106	restart	8.7	2.1	3.0	ND	ND	ND
12	10:00	210	shut-down	n/a	n/a	n/a	ND	ND	ND
15	Samples not received by MDH Lab								
19	17:00	315	shut-down	n/a	n/a	n/a	ND	ND	ND
22	13:45	336	restart	n/a	n/a	n/a	ND	ND	ND
26	17:00	420	shut-down	11	3.0	3.5	ND	ND	ND
29	Samples not received by MDH Lab								
33	17:00	504	stop	11	3.0	3.4	ND	ND	ND
WATTS (Premier WP-4V)									
1	12:00	0	start	8.6	2.0	3.3	ND	ND	ND
5	17:30	80	shut-down	9.3	2.1	3.2	ND	ND	ND
8	10:15	81	restart	8.7	2.1	3.0	ND	ND	ND
12	10:00	160	shut-down	n/a	n/a	n/a	ND	ND	ND
19	Samples not received by MDH Lab								
22	17:00	240	shut-down	n/a	n/a	n/a	ND	ND	ND
26	13:45	256	restart	n/a	n/a	n/a	ND	ND	ND
29	17:00	320	shut-down	11	3.0	3.5	ND	ND	ND
33	Samples not received by MDH Lab								
36	12:00	382	stop	11	3.0	3.4	ND	ND	ND

ND = non-detect, or below the detection limit of 0.05 ug/L
DNQ = detected, not quantified - between 0.05 and 0.2 *u*g/L
n/a = not available: sample not tested due to consistent feed readings and budget limitation

6.4 Daily QA/QC Results

The PFC levels were tested daily after mixing and results were within acceptable ranges. They are presented in Table 6-3.

Table 6-3
Phase I-B PFC Concentration of WQA Feed Tanks

Day of Sample Concentration	Influent (ppb)		
	PFBA	PFOA	PFOS
Day 1 (3/7/08)	9	2.5	3.2
Day 2 (3/8/08)	8.7	2.2	3.8
Day 3 (3/9/08)	8.7	2.2	3.8
Day 4 (3/10/08)	8.6	2	3.3
Day 5 (3/11/08)	9.3	2.1	3.2
Day 6 (3/12/08)	8.7	2.1	3.1
Day 7 (3/13/08)	8.7	2.1	3.6
Day 8 (3/14/08)	8.7	2.1	3.6
Day 9 (3/15/08)	8.7	2.1	3
Day 10 (3/16/08)	9	2.4	3
Day 11 (3/17/08)	8.5	2.5	2.8
Day 12 (3/18/08)	N/A	N/A	N/A
Day 13 (3/19/08)	N/A	N/A	N/A
Day 14 (3/20/08)	N/A	N/A	N/A
Day 15 (3/21/08)	N/A	N/A	N/A
Day 16 (3/22/08)	N/A	N/A	N/A
Day 17 (3/23/08)	N/A	N/A	N/A
Day 18 (3/24/08)	N/A	N/A	N/A
Day 19 (3/25/08)	N/A	N/A	N/A
Day 20 (3/26/08)	N/A	N/A	N/A
Day 21 (3/27/08)	9.8	2.3	3.3
Day 22 (3/28/08)	N/A	N/A	N/A
Day 23 (3/29/08)	N/A	N/A	N/A
Day 24 (3/30/08)	N/A	N/A	N/A
Day 25 (3/31/08)	N/A	N/A	N/A
Day 26 (4/1/08)	12	3.1	3.4
Day 27 (4/2/08)	12	3	3.4
Day 28 (4/3/08)	11	2.8	3.5
Day 29 (4/4/08)	11	2.8	3.5
Day 30 (4/5/08)	11	3.1	3.4
Day 31 (4/6/08)	11	3.1	3.4
Day 32 (4/7/08)	11	3	3.4
Day 33 (4/8/08)	11	3	3.4
Day 34 (4/9/08)	11	3	3.4
Day 35 (4/10/08)	11	3	3.4
Day 36 (4/11/08)	11	3	3.4

Chapter 7
Phase II Field Verification For PFC Removal
and
Comparative Study of Device Operational Characteristics

7.1 Phase II Purpose and Test Plan

In addition to providing the means to evaluate performance of POU devices/technologies on the actual source water quality of their intended use as the primary subject matter of this study, the test plan for Phase II also addresses performance regarding how these devices are typically used within a residential installation.

7.2 Devices Included

Table 7-1 lists the manufactures and products that were selected for Phase II testing.

Table 7-1
Listing of Devices Included in Phase II

Device Manufacturer/(Model Number)	PFC Removal Technologies Used		
	Activated Carbon	Reverse Osmosis	Ion Exchange
Aquion Rainsoft (Hydrefiner P-12 9878)	X		
Culligan (RC-EZ-4)	X		
Kinetico (MACguard 7500)	X		
Sears Kenmore (Elite 625.385010)	X		
Culligan (Aqua-Cleer)	X	X	
Ecowater (ERO-375E-CP)	X	X	
GE (Smartwater GXRM10GBL)	X	X	
Kinetico (Plus Deluxe VX)	X	X	
Pentair (RO-3500EX w/ GS)	X	X	X
3M/CUNO/Water Factory (SQC-3 (04-045))	X	X	
Watts (Premier WP-4V)	X	X	

7.2.1 Description of Test Sites and Supply Water Chemistry

General water quality characteristics at each well house site are known and remain static. To secure actual source water quality conditions, wells located within the area of known groundwater contamination were used.

Test water is located in south Washington County, Minnesota, contaminated groundwater from two municipal wells drawing from the Jordan Sandstone aquifer. One site (municipal well in St. Paul Park, Well Number 3) provided water with known concentrations of only PFBA (groundwater with approximately 1.5 *ug/L* PFBA). Another site (municipal well in Oakdale, , Well Number 5) provided water with known concentrations of PFBA, PFOA, and PFOS (groundwater with approximately 1.4 *ug/L* PFBA, 0.6 *ug/L* PFOA, 0.9 *ug/L* PFOS). Higher levels of hardness and iron and lower temperatures from these groundwater sources (vs. water lab test water) may influence operational and PFC removal performance/capacity of devices/technologies included in Phase I. Table 7-2 lists the supply water characteristics at each site.

Table 7-2
Supply Water Quality Characteristics

Parameter	Oakdale Well # 5	St. Paul Park Well #3
Total Hardness (mg/l)	234	280
Alkalinity (mg/l)	190	240
Calcium (mg/l)	152	170
Magnesium (mg/l)	82	110
Iron (mg/l)	.08	.089
Manganese (mg/l)	<.02	<.010
Chloride (mg/l)	6.7	8.4
Sulfate(mg/l)	23	31
Potassium (mg/l)	.9	1.6
Totals Solids (mg/l)	270	300
Specific Cond.	408	480
pH	7.6	7.4
Arsenic (ug/L)	<5	-
Barium (ug/L)	<200	-
Cadmium (ug/l)	<1	<10
Chromium 9ug/l)	<50	-
Fluoride (mg/l)	1.9	13.
Lead (ug/l)	<10	<10
Mercury (ug/l)	<.1	-
Nitrate Nitrogen (mg/l)	2.1	3
Selenium (ug/l)	<10	-
Silver (ug/l)	<50	-
Sodium (mg/l)	4.0	3.9
pH of Stability	7.7	7.9

Source: Minnesota Department of Health, Division of Environmental Health, Public Water Supply Data 1989 (Volume 2 of a 3 –volume set)

7.3 Testing Protocols and Details

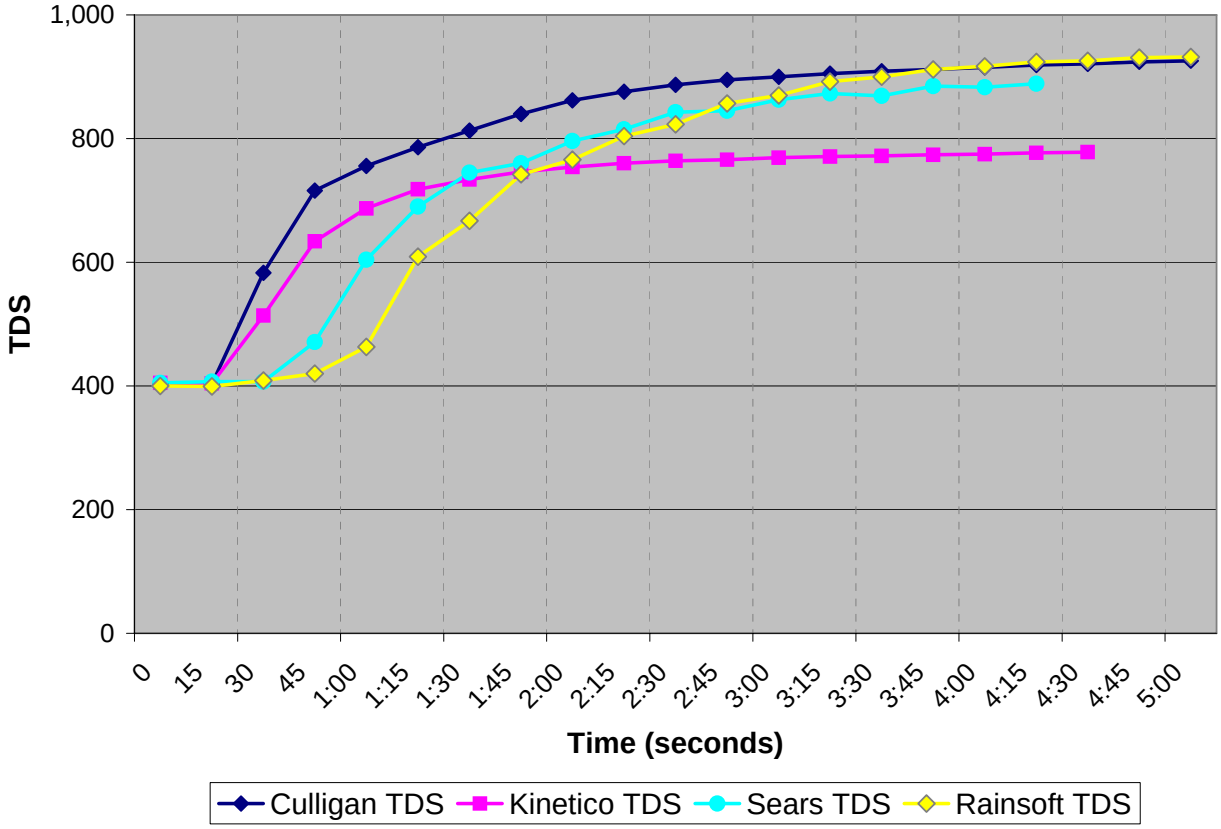
7.3.1 Activated Carbon Devices

AC filters were operated to 150% of their manufacturers rated capacity. Devices were operated with 6-minute-on / 54-minute-off cycles 24 hours/day. Sample collection times were at start-up and again at 50%, 100%, and then 150% of rated capacity.

Sampling Protocol for AC Devices:
Three samples were collected at the end of each collection point defined above. The first of these three was secured no sooner than 54 minutes after any passage of water flow through the filter.

Sample collection sequence for AC devices were developed by WSM and used in both Phase I-B and Phase II. These protocols involved conducting a tracer test. This test included steady state injection of a highly concentrated saline solution into the water supply line the filters inlet while operating at its rated flow rate. Filtrate samples were measured for TDS precisely at the beginning of saline injection and at 10-second intervals there after, until elevated TDS concentrations remain constant. Resultant Time/TDS data was used to plot a curve that can be used to infer relative changes in AC/Water contact time (see Figure 7-1). PFC removal performance is primarily expected to be a function of AC contact time. In addition, while the PFC removal technology within an AC filter is adsorption, as a function of its construction, it also operates a physical filter. Therefore, an AC filter will retain high concentrations on or within the physical vs. adsorption structure. As such, particles detach in response to changing hydraulic conditions within a physical filter. This is especially noted with high particle concentrations measured within a filtrate stream soon after flow is initiated after a steady-state no-flow condition. Given it is currently unknown if PFC's can be entrained within this release, the first two sample collection times were selected to coincide with such a release. This period also represents when homeowners are most likely to be using the filtrate water. Relative to identification of sample collection points with the plotted tracer curve, the first sample collection point is to begin at the base of the vertical incline, the second near its midpoint, then an additional sample after its steady-state plateau is achieved representing minimum AC residence/adsorption time.

Figure 7-1
AC Tracer Test



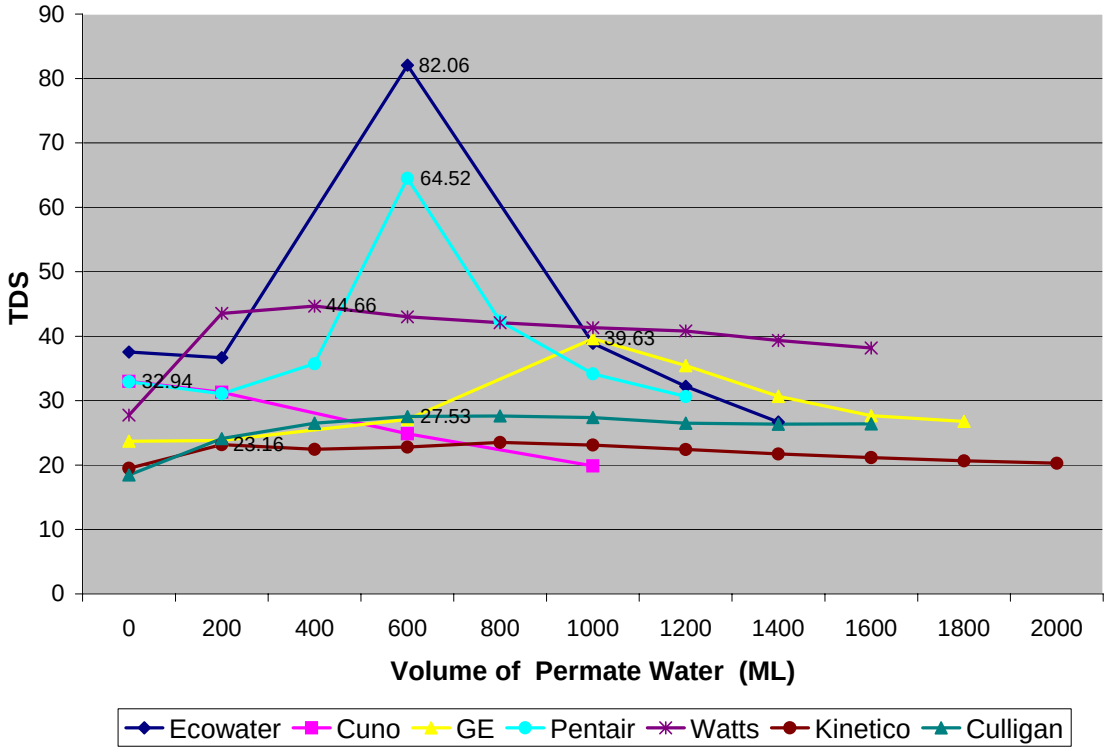
7.3.2 Reverse Osmosis Systems

Sampling RO systems: Samples were representative of water that had been processed through all treatment components included within each system including an AC carbon pre-filter, RO membrane, and AC carbon (and IX) post-filters. Two samples were collected every 2 weeks over a period of 90 days of continuous operation. One sample was be collected on a Friday, before a 48-hour stagnation period with a second sample collected on the following Monday after the stagnation period. Two 72-hour stagnation periods (sample collection on Tuesday) were included within the 90-day test period during the two holiday weekends, Martin Luther King Jr. Day (January 21, 2008), and Presidents Day (February 18, 2008).

Sampling protocols for post-stagnation RO devices were developed by WSM to determine the optimum point for post-stagnation sample collection. After a stagnation period, permeate streams for each device was monitored for elevations in TDS. After post stagnation start-up, RO permeate was sampled in 200 ml increments and TDS measurements recorded. This process was continued until either the TDS concentration returned back to the original measurement or the reading remained constant. Resultant data was plotted (Figure 7-2). Post-stagnation PFC

collection points were chosen to collect sample volumes during periods representing this highest TDS concentration.

Figure 7-2
Maximum Permeate TDS Post-Stagnation Oakdale Test Site



Excluding stagnation periods as defined above, RO systems were operated on a continuous basis maximizing total gallons produced through the RO system and present a most severe challenge in regards to membrane fouling during the 90-day test period. Continuous operation of RO systems included on/off cycling consisting of draining each system's treated water storage tank every three hours. To determine limits of performance of expendable filters used within RO system configurations recommended replacement schedules were not adhered to.

7.4 Design and Operation of Field Test Stations

To accommodate Phase II objectives, two identical test stations were designed and fabricated by WSM for continuous operation and installed at both sites. Devices were operated simultaneously 24 hrs/day. See Photo 7-1

Repeatable 6-minute-on/54-minute-off cycles for AC systems were controlled via a programmable timer an adjustable time delay relay in conjunction with electrically initiated valves installed on each filters filtrate line. Total gallons filtered were measured with an in-line flow sensor installed with analog output to a programmable logic controller/monitor (PLC) with data-logging capabilities. The PLC was programmed to discontinue operation of an AC filter at

predetermined set points (i.e. 250 Gallons) by electrically overriding the 6/54-minute on/off cycle sequence and discontinuing flow through the device. Sample taps and pressure gauges are provided for both influent and filtrate streams.

Operation of RO systems were controlled by timers that were programmed to drain permeate storage tanks via an electrically operated valve every three hours and discontinue this sequence to accommodate for stagnation periods. Sample taps are provided for feed, permeate and concentrate streams and pressure gauges provided for influent and permeate/tank streams.

Additionally, plumbing for each pressure gauge accommodates for quick connect access for verification of calibration and construction includes structural fiberglass, ½" polypropylene sheet material, stainless steel hardware, and schedule 80 PVC plumbing components.

Photo 7-1 shows the test station at the Oakdale Water Treatment Plant.

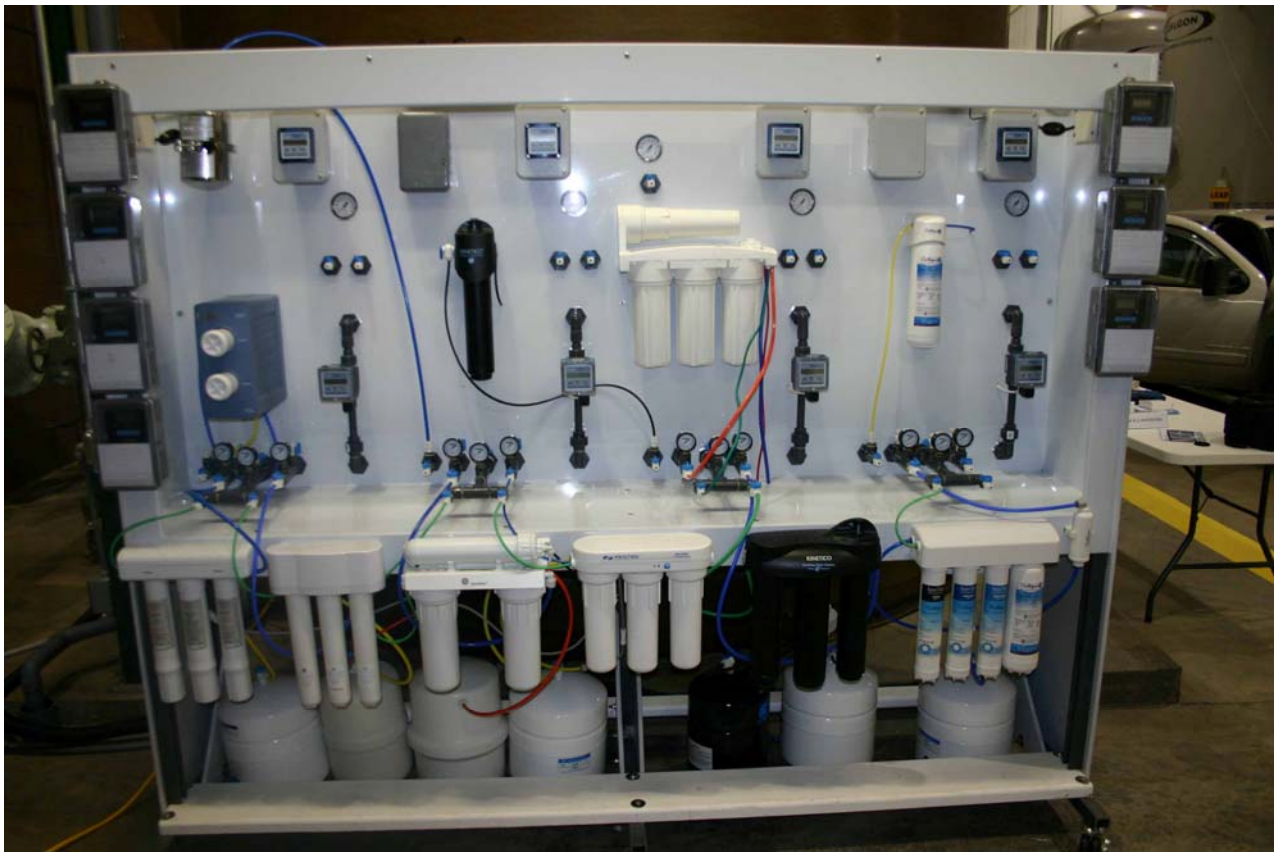


Photo 7-1
Test Station At Oakdale Site

Photos of the individual devices tested on the test station are shown in section 8.5 and in Appendix N.

7.5 Sample Collection, Submission, and Analysis

During the 30 days the AC filters were in operation, data were recorded in a logbook for each device on a daily basis with the exception of weekends and holidays. When the RO systems were in operation alone, data were recorded on Monday, Wednesday, and Friday of each week with the exception of Presidents Day (February 18, 2008. On that date, data was recorded on Tuesday vs. Monday.

7.5.1 Activated Carbon Filters

For Phase II, a programmable logic controller was used in conjunction with an automatic valve to discontinue flow at points representing targeted sample collection points defined above for AC devices. Sample taps were installed on the test station's common influent stream and one for each device's effluent stream. Isolation valves for each device were included.

The following parameters were measured for each expendable (AC) device:

Inlet and outlet pressure (psig)
Flow rate
Total gallons
Frequency and Time of on/off episodes
Water Temperature

7.5.2 Reverse Osmosis Systems

The following parameters were measured for each non-expendable (RO) device:

Inlet and outlet pressure range (psig)
Concentrate and permeate flow rate (ml/min), plus concentrate and permeate conductivity/TDS (At recorded inlet pressure and 0 psi filtrate pressure).
Frequency and Time of on/off episodes
Total gallons produced (by calculation)
Water Temperature

7.5.3 Instrumentation

Verification of accuracy for each sensor/gauge was recorded within WSM's field notebook.

7.5.4 Pressure

Pressure gauge accuracy was verified with a NIST traceable pressure gauge.

7.5.5 Flow

Accuracy of flow meters was verified by measurement of time/volume method using a graduated cylinder.

7.6 Analytical Test Procedures for Perfluorocarbons

All samples generated for PFC analysis were sent to the Minnesota Public Health Lab (PHL) for quantification of the three PFC molecules, which was done by PHL internal standard technique. The lower quantification limit for all three PFC molecules was at 0.2 microgram per liter (*u*g/L) for each analysis [*u*g/L is essentially equivalent to parts per billion (ppb)]. The detection limit (positive identification) for all three PFC molecules was at 0.05 *u*g/L and shown on the PHL Report of Analytical Results forms as "J 0.05", for example, with a footnote, "The analyte was positively identified. The result is below the report level and is estimated." Detection at levels between and including 0.05 to 0.2 *u*g/L could be made, however, in this range analyses are not quantified with the required degree of confidence to accept the values.

In this report for the Phase II studies the actual values are only reported if greater than or equal to 0.2 *u*g/L. Values detected but below this quantification limit are reported as detected, not quantified (DNQ). For the Phase II study, values detected but below the quantification limit are symbolized in tables as "ND". < 0.2 *u*g//L was the treatment goal for all PFCs in this project

7.7 QA/QC

7.7.1 PFC Concentrations in Source Water

For the Phase II PFC analyses were conducted at the beginning of the field-testing period.

7.7.2 Total Dissolved Solids

TDS measurements were taken with a Myron L. Ultameter (Model 6P, Serial No: 615385). Myron L. Company performed calibration; a certification of calibration is included in Appendix I.

7.7.3 pH

TDS measurements were taken with a Myron L. Ultameter (Model 6P, Serial No: 615385). Myron L. Company performed calibration; a certification of calibration is included in Appendix N. Additional verification of pH readings was performed by WMS at the start, during the middle and at the end of the testing period. These calibrations were performed using standardized pH solutions.

7.7.4 Temperature

Temperature measurements were taken with a Myron L. Ultameter (Model 6P, Serial No: 615385). Myron L. Company performed calibration; a certification of calibration is included in Appendix I.

7.7.5 Recording Data and Procedures

WSM was responsible for the maintenance of the logbooks and field notebooks. Data was collected and recorded for each day. Data was documented in bound logbooks and on charts from the individual testing instruments. There was a single field logbook containing all on-site operating data that remained on-site and contains instrument readings, on-site analyses, and any additional comments. Documentation of field application testing events was facilitated through the use of photographs, data sheets and chain of custody forms.

As per contract requirements, WSM will retain records and documentation associated with the preparation and collection of water samples under the contract for a minimum of five (5) years.

7.7.6 Chain of Custody

WSM used the MDH Public Health Laboratory standard chain of custody forms for each sample taken, and forwarded these per standard procedure to the MDH Public Health Laboratory, with the samples for analyses. See Appendix L for a sample of a completed Chain of Custody form.

7.7.7 Log Books

Each page of the logbook is sequentially numbered and carbon copied. Each completed page was signed by the on-duty WSM representative. Errors were crossed with a single line and initialed. Deviations whether by error or by a change in the conditions of either the test equipment or the water conditions were noted in the logbook. WSM maintains their field notebooks on file for future reference.

7.7.8 Electronic Datasheets

A WSM associate entered data into a computer spreadsheet program (Microsoft© Excel) on a daily basis, from the field notebooks and any analytical reports. The database for the project was set up in the form of custom-designed spreadsheets. All data from the field notebooks were entered into the appropriate spreadsheet, and recorded calculations were checked at this time. All details affecting the operation of the equipment also logged in the field notebooks were consolidated and entered into computer spreadsheets. This recording is consistent with standard laboratory practices. A back-up copy of the computer data was maintained off site. See Appendix K for copies of the computer spreadsheets.

Chapter 8
Phase II Results and Discussion

8.1 Introduction

Results of Phase II provide insight for PFC removal performance and operational reliability/ characteristics of POU devices when treating Minnesota groundwater over an extended time-period, and in usage patterns similar to that expected within a residence.

Twenty-two POU devices were operated simultaneously 24 hours/day over the course of the Phase II test period. Phase II involved field-testing, monitoring, and sampling the 11 POU devices each at two municipal wells in southern Washington County. The Oakdale Well has multiple PFCs and the St. Paul Park Well has only PFBA present in their groundwater supplies. In contrast to the Phase I and 1B laboratory studies, each device at each well site was challenged with a natural groundwater supply, without increasing the existing PFC concentration, or modifying its chemistry or temperature. In addition, the more highly mineralized and colder groundwater occurring at the well sites was expected to impose additional, more realistic performance constraints on the POU devices' performance.

The Phase II study included a variety of investigations intended to challenge and monitor the operational characteristics of each device and help asses each device's suitability for PFC protection in household situations. In addition, WSM monitored for changes in operational performance of each device. In addition to PFC removal performance, this data compares and contrasts the general productivity, efficiency, and similarities/dissimilarities between devices.

It is noted devices supplied by Culligan denoted "For Field Testing Only". Given original product selection criteria including evaluation of commercially available products WSM queried Culligan regarding the above notation. Their response is included in Appendix B

8.2 Supply Water

The supply water quality parameters measured at the two sites remained fairly constant. The average temperature at the Oakdale was 12.0°C, with minimum and maximum temperatures of 11.0 and of 13.3°C. The temperature varied somewhat more at the St. Paul Park site due to the city switching between wells for a period of approximately 2 weeks. This resulted in a temperature average of 6.2°C, with minimum and maximum values of 4.4 and 7.9°C. The TDS readings at the Oakdale site averaged 401 ppm, and 433 ppm at St. Paul Park. The pH readings at the Oakdale site averaged 7.9, while the St. Paul Park site averaged 7.3.

The 2-week period of time when the city of St. Paul Park switched from Well #3 to Well #2 did not have an effect on the PFC content or overall water quality of the supply water. Review of historical data comparing the two wells noted a slightly elevated level of PFBA (1.5 ppb compared to 1.2 ppb), and an elevated level of PFPeA (0.005 ppb compared to 0.000 ppb). These changes are not expected to have effected on device performance for PFC removal.

Historical data were reviewed and verified that the PFC levels were constant for the previous 6 months before the Phase II test period. Well water analyses were conducted immediately prior to the start of testing field-testing, and verified the expected levels of PFCs was present. Table 8-1 lists the PFC concentrations at each test site.

Table 8-1
Supply Water PFC Concentrations

PFC Contaminant	Report Level	Oakdale Well #5		St Paul Park Well #3	
		Collection Date	Reading	Collection Date	Reading
PFBA	0.2 *u*g/L	1/25/08	1.4 *u*g/L	1/18/08	1.5 *u*g/L
FPPeA	0.2 *u*g/L	1/25/08	DNQ	1/18/08	DNQ
PFHxA	0.2 *u*g/L	1/25/08	DNQ	1/18/08	DNQ
PFOA	0.2 *u*g/L	1/25/08	0.6 *u*g/L	1/18/08	DNQ
PFBS	0.2 *u*g/L	1/25/08	<.0.2 *u*g/L	1/18/08	DNQ
PFHxS	0.2 *u*g/L	1/25/08	DNQ	1/18/08	DNQ
PFOS	0.2 ug/L	1/25/08	0.9	1/18/08	DNQ

ND = non-detect, or below the detection limit of 0.05 ug/L
DNQ = detected, not quantified - between 0.05 and 0.2 *u*g/L

8.3 Performance Data - PFC Removal

8.3.1 Activated Carbon Filters

The results for removal of the three PFC molecules varied only slightly by filter device tested. All four AC filters met the target removal goals through 150% of manufacturers noted capacity (or 750 gallons) over the test life at each site.

At Oakdale PFBA was detected in the Kinetico MACguard 7500 filtrate at 500 and 750-gallon throughput, although concentrations were below quantifiable limits.

At St. Paul Park, PFBA was detected upon initial system start-up in the Rainsoft device filtrate, but again below quantifiable limits. Thereafter, PFCs were not detected in water samples collected throughout a volume of 1,000 gallons, double its rated capacity. A possible explanation for this early leakage anomaly is that air within the AC carbon block had not been fully displaced by water prior to start of the filter test, reducing the available AC surface area, thus adsorption efficiency.

Results are shown in Table 8-2.

Table 8-2
Phase II Activated Carbon Device PFC Removal Results

DEVICE	0%									50%									100%									150%								
	PFBA	PFOA	PFOS	PFBA	PFOA	PFOS	PFBA	PFOA	PFOS	PFBA	PFOA	PFOS	PFBA	PFOA	PFOS	PFBA	PFOA	PFOS	PFBA	PFOA	PFOS	PFBA	PFOA	PFOS	PFBA	PFOA	PFOS	PFBA	PFOA	PFOS	PFBA	PFOA	PFOS	PFBA	PFOA	PFOS
Oakdale																																				
Sample Taken at	15 seconds			40 Seconds			3 minutes			15 seconds			40 Seconds			3 minutes			15 seconds			40 Seconds			3 minutes			15 seconds			40 Seconds			3 minutes		
Sears Kenmore Elite 625.385010	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Sample Taken at	30 seconds			1:10 seconds			4 minutes			30 seconds			1:10 seconds			4 minutes			30 seconds			1:10 seconds			4 minutes			30 seconds			1:10 seconds			4 minutes		
Aquion Rainsoft Hydrefiner P-12 9878	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Sample Taken at	3 seconds			15 Seconds			3 minutes			3 seconds			15 Seconds			3 minutes			3 seconds			15 Seconds			3 minutes			3 seconds			15 Seconds			3 minutes		
Kinetico MACguard 7500	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	**DNQ**	ND	ND	ND	ND	ND	**DNQ**	ND	ND	**DNQ**	ND	ND	**DNQ**	ND	ND
Sample Taken at	10 seconds			30 Seconds			3 minutes			10 seconds			30 Seconds			3 minutes			10 seconds			30 Seconds			3 minutes			10 seconds			30 Seconds			3 minutes		
Culligan RC-EZ-4	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
St. Paul Park																																				
Sample Taken at	8 seconds			20 Seconds			3 minutes			8 seconds			20 Seconds			3 minutes			8 seconds			20 Seconds			3 minutes			8 seconds			20 Seconds			3 minutes		
Sears Kenmore **Elite 625.385010**	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Sample Taken at	20 seconds			1 minute			4 minutes			20 seconds			1 minute			4 minutes			20 seconds			1 minute			4 minutes			20 seconds			1 minute			4 minutes		
Aquion Rainsoft Hydrefiner P-12 9878	**DNQ**	ND	ND	**DNQ**	ND	ND	**DNQ**	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Sample Taken at	3 seconds			15 Seconds			3 minutes			3 seconds			15 Seconds			3 minutes			3 seconds			15 Seconds			3 minutes			3 seconds			15 Seconds			3 minutes		
Kinetico MACguard 7500	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Sample Taken at	10 seconds			30 Seconds			3 minutes			10 seconds			30 Seconds			3 minutes			10 seconds			30 Seconds			3 minutes			10 seconds			30 Seconds			3 minutes		
Culligan RC-EZ-4	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND

ND = non-detect, or below the detection limit of 0.05 ug/L
DNQ = detected, not quantified - between 0.05 and 0.2 *u*g/L

8.3.2 Reverse Osmosis Systems

All RO systems at both sites reduced PFC concentrations to non-detectable limits in all samples taken over the test period. Drinking water production by device, over the 13-week test period ranged from 481gallons to 943 gallons. Exceptional PFC removal performance in Phase II is a result of screening RO membranes in Phase I from continued testing, PFC removal performance of membranes within systems included in Phase II, and each RO system incorporating up to 3 AC filters within their design. Regarding treatment volume capacities of AC filters used within RO systems, it is noted those located after the membrane are exposed to limited concentrations of PFCs and serve as more of a PFC scavenging component. However, it is important to understand that the downstream AC filters will have a finite life and require replacement. However, given that the AC media capacity is based on total mass loading, one can expect much higher volume capacities from post vs. pre–membrane AC filters or those used alone as a singular PFC removal device. Table 8-3 summarizes the Phase II PHL Analytical Results.

Table 8-3
Summary of Phase II RO Device PFC Removal Performance

Device	PFC Contaminate	Report Level	Oakdale Well #5		St Paul Park Well #3	
			# of Samples	Result	# of Samples	Result
Culligan Aqua-Cleer						
	PFBA	0.2 *u*g/L	12	ND	14	ND
	PFOA	0.2 *u*g/L	12	ND	14	ND
	PFOS	0.2 *u*g/L	12	ND	14	ND
Cuno SQC-304-045						
	PFBA	0.2 *u*g/L	12	ND	14	ND
	PFOA	0.2 *u*g/L	12	ND	14	ND
	PFOS	0.2 *u*g/L	12	ND	14	ND
Ecowater ERO-375E-CP						
	PFBA	0.2 *u*g/L	12	ND	14	ND
	PFOA	0.2 *u*g/L	12	ND	14	ND
	PFOS	0.2 *u*g/L	12	ND	14	ND
GE Smartwater GXRM10GBL						
	PFBA	0.2 *u*g/L	12	ND	14	ND
	PFOA	0.2 *u*g/L	12	ND	14	ND
	PFOS	0.2 *u*g/L	12	ND	14	ND
Kinetico Plus Deluxe VX						
	PFBA	0.2 *u*g/L	12	ND	14	ND
	PFOA	0.2 *u*g/L	12	ND	14	ND
	PFOS	0.2 *u*g/L	12	ND	14	ND
Pentair RO-3500-EX						
	PFBA	0.2 *u*g/L	12	ND	14	ND
	PFOA	0.2 *u*g/L	12	ND	14	ND
	PFOS	0.2 *u*g/L	12	ND	14	ND
Watts WP-4V						
	PFBA	0.2 *u*g/L	12	ND	14	ND
	PFOA	0.2 *u*g/L	12	ND	14	ND
	PFOS	0.2 *u*g/L	12	ND	14	ND

ND = not detected (< 0.5)
DNQ = detected, not quantified (0.05 to 0.2 *u*g/L)

The permeate or filtrate production of RO devices is known to correlate to feed stream temperature, since colder water results in a proportionate reduction in RO permeate flux. This effect was noted at both sites and while production rate results lower than those specified by device manufacturers, are in line with expectations with feed water temperatures experienced at both test sites.

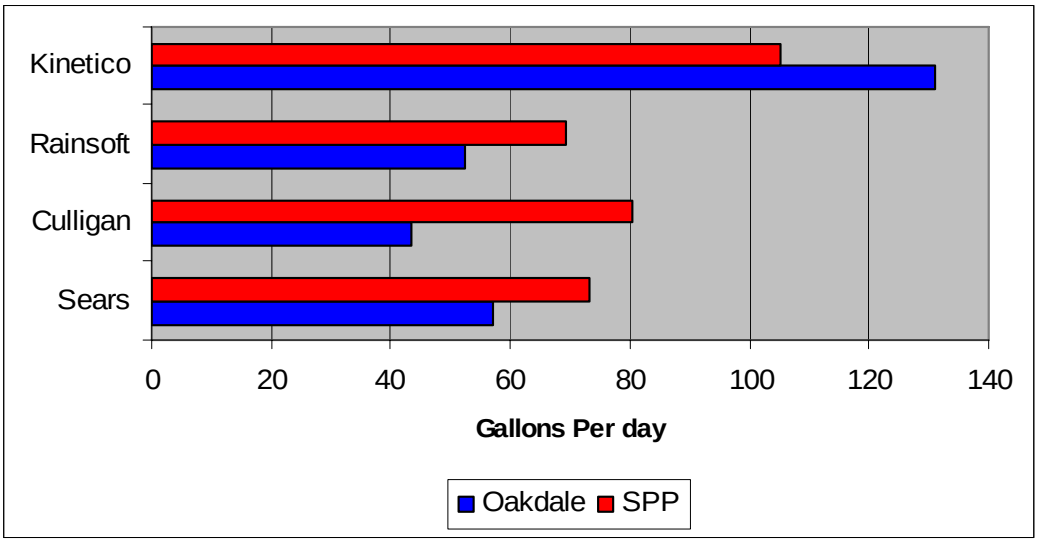
Also, feed water temperature is not known to have a significant effect on RO membrane rejection of molecules like PFCs. Since in Phase II the RO permeate alone was not measured, PFC removal performance at a lower temperature cannot be compared to Phase I results.

8.4 Performance Data - Comparative Operational

8.4.1 Activated Carbon Technologies

Figure 8-1 illustrates the calculated total average gallons per day drinking water production of each AC device measured at the two sites. This Figure represents total gallons produced to the manufacturers specified filter life of 500 gallons.

Figure 8-1
Average AC Drinking Water Production (Gallons Per Day)



Note: Data reflects test conditions with filters producing water for one 6-minute period per hour.

The flow rate through all filters such as the AC devices evaluated in this study will decrease over time; the rate of decrease is dependent upon source water quality and filter design. Over the duration of the test period and beyond manufactures rated lifetime of 500-gallons, significant differences are noted in flow rate decay between sites. While flow rates decayed quite rapidly for two AC filters with groundwater provided at the Oakdale site. The same two filters did not demonstrate such decay with the groundwater quality provided at St. Paul Park. Figure 8-2 demonstrates the differences among filters on the same water source, and between filters.

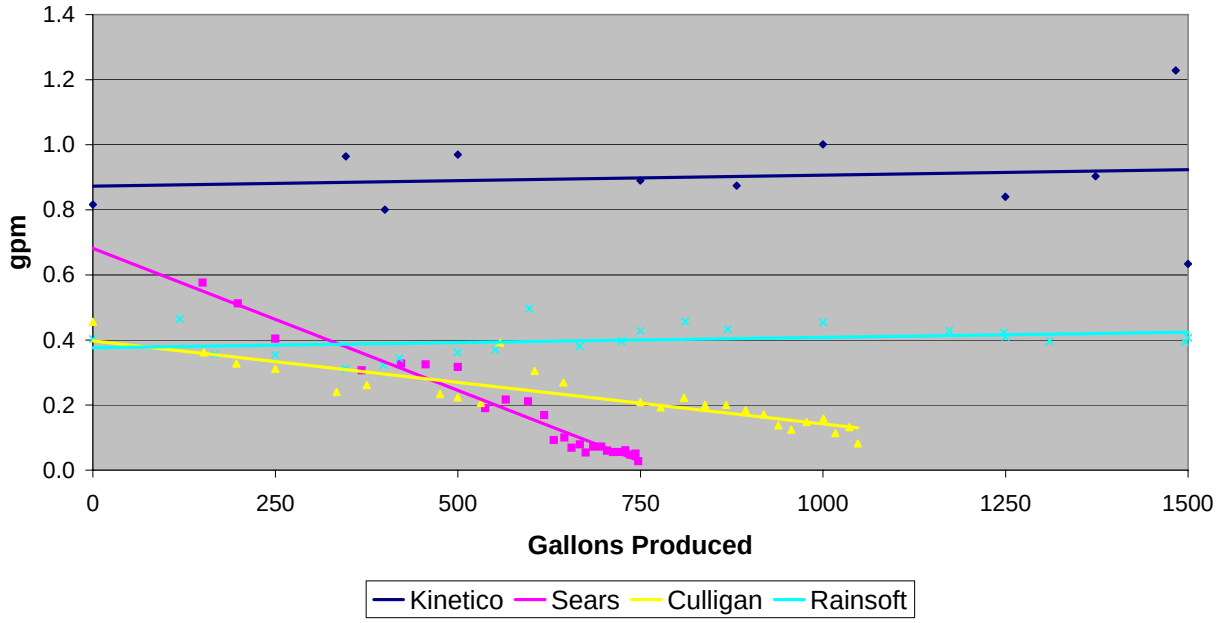
The following parameters were measured for each AC filter over 150% of the manufacturer design capacity:

1. Inlet pressure (psig). It was noted outlet pressure cannot be accessed due to internal flow restrictors installed by the manufacturer
2. Flow rate (gpm)
3. Total gallons (gal)
4. Frequency and Time of on/off episodes (indirect)
5. Water Temperature (°C)

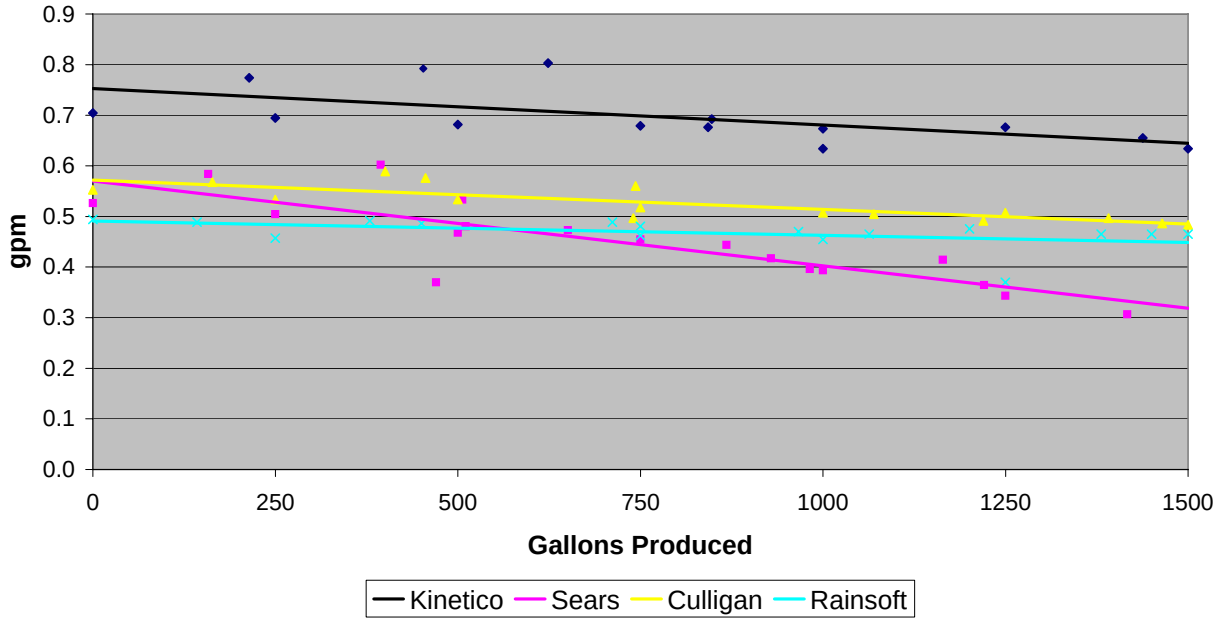
Individual device operational parameters are located under Sections 8.5.1.

Figure 8-2
Comparative Flow Rate vs. Total Gallons Produced Per AC Device

Oakdale Site



St. Paul Park Site



8.4.2 Reverse Osmosis Systems

For RO systems, the sample collection plan called for one sample be collected every other Friday, before a 48-hour shut-down ("stagnation period") with a second sample collected on the following Monday after the stagnation period. One 72-hour stagnation period (sample collection on Tuesday) was included within the 90-day test period during the Presidents Day (February 18, 2008) holiday weekend.

The following operational parameters were measured for each RO system over a 13-week period with stagnation periods:

1. Inlet and tank pressure range (psig)
2. Concentrate and permeate flow rate (ml/min), plus concentrate and permeate conductivity/TDS (At recorded inlet pressure and 0 psi filtrate pressure).
3. Frequency and Time of on/off episodes
4. Total gallons produced (by calculation)
5. Water Temperature

Individual device operational parameters are located under Sections 8.6.2.

Comparative operational performance between devices are represented in Figures 8-3 and 8-4. Both figures use a normalized % scale with 100% representing the best performing device for each parameter.

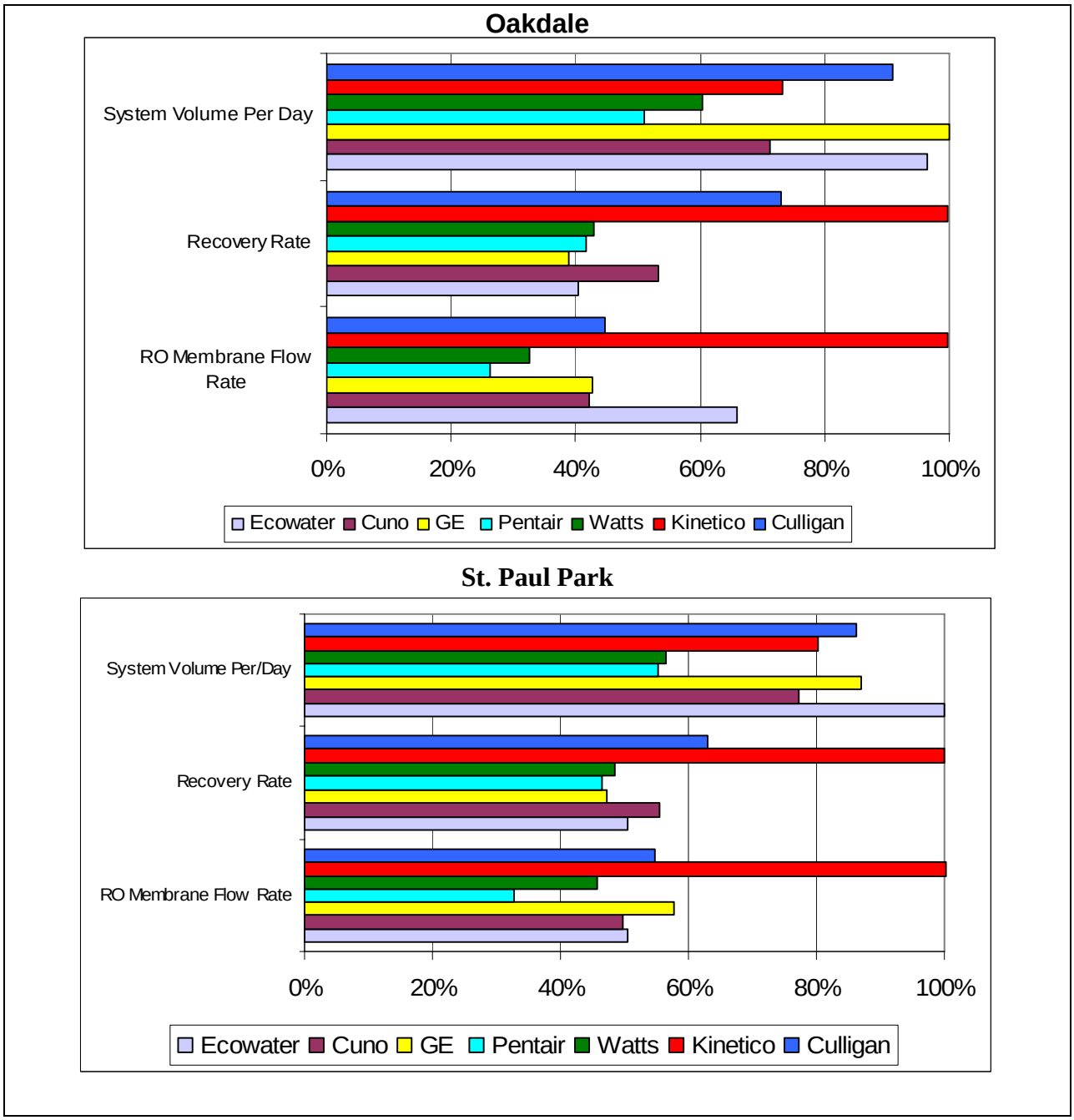
Figure 8-3 includes:

System Volume Produced/Day as influenced by pressurized treated water storage tank size and discharge of its contents every three hours as prescribed within this study's test plan.

Membrane Flow Rate reflects comparative flow rate through each devices membrane alone when subjected to identical operating conditions including a zero -outlet pressure condition to remove any affect of storage tank capacity.

Recovery Rate Because reverse osmosis systems create wastewater as a byproduct of the membrane treatment process, systems are often compared by this ratio (e.g. water produced vs. wasted). In this regard, higher recovery rates translate to greater water use efficiency. Refer to Figure 8-5 for results specific to recovery rates.

Figure 8-3
Comparative Summary Water Production Performance between RO – Based Systems



Note: 1.**100% is representative of best performing system.**
2. System volume per day is influenced by treated water storage tank size and discharge of its contents every three hours.
3. RO membrane flow rate is based upon permeate flow rate zero tank pressure

Note that while the Kinetico system's membrane demonstrated superior production performance, average volume produced per day is comparatively low. The opposite trend is noted for the GE system. What accounts for this variation in system performance is the size of pressure tank used in RO system configurations and test-plan criteria requiring drainage of this tank every three hours. The tank option supplied with the Kinetico test system had a capacity of 1.5 gallons, while the tank option supplied with GE's test system had a capacity of 2.5 gallons.

As RO system pressure tanks fill, backpressure is exerted on the membrane. This reduces the net driving pressure across the membrane, thus reducing flow rate (RO flow rate is directly proportional to net driving hydraulic pressure). Since larger tanks will accept more treated water before affecting membrane performance, the fixed three-hour tank drain cycle used in this study, allowed systems with lower RO membrane flow rates (with larger storage tanks) to achieve greater daily production volumes compared to RO systems demonstrating higher membrane flow rates.

It is notable that regarding RO system tank size many manufacturers offer a selection of sizes to choose from.

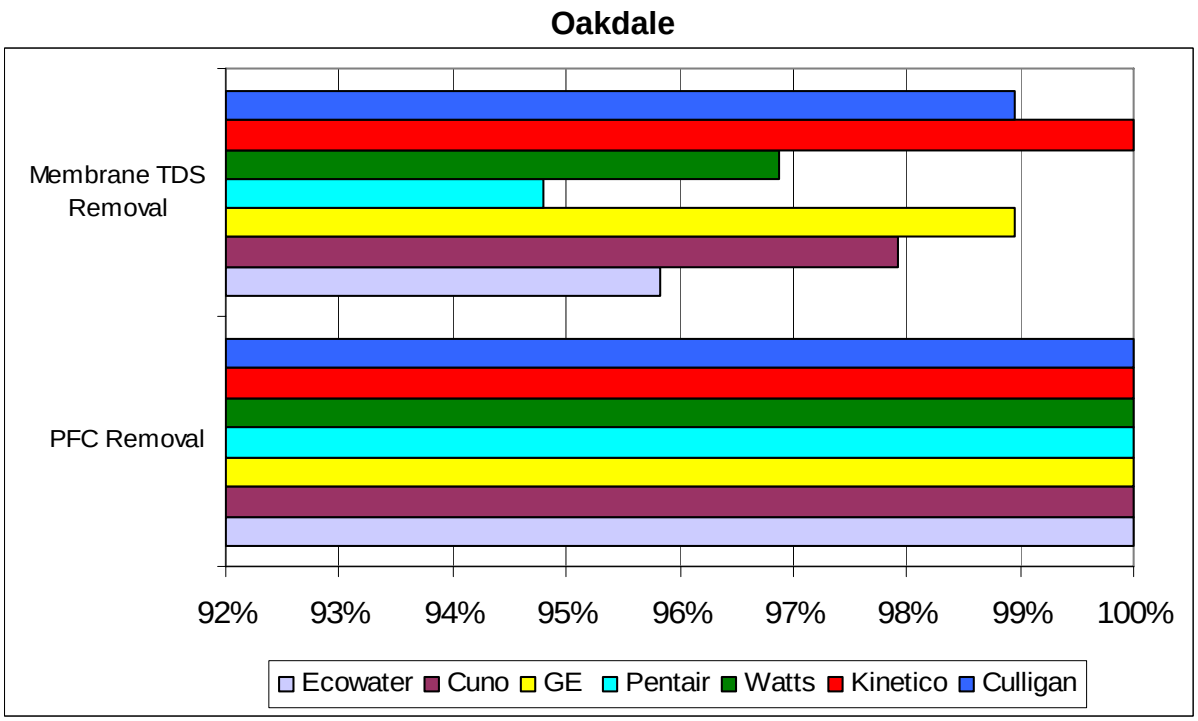
Figure 8-4 includes:

> Membrane TDS Removal - reflects general performance of the membranes ability to remove total dissolved solids (TDS) (a standard measurement of a membranes ability to remove solutes).
>
> PFC Removal – Because all devices in Phase II were evaluated as they would be purchased and used by a consumer, PFC removal results reflect performance of the RO membrane in combination with activated carbon.

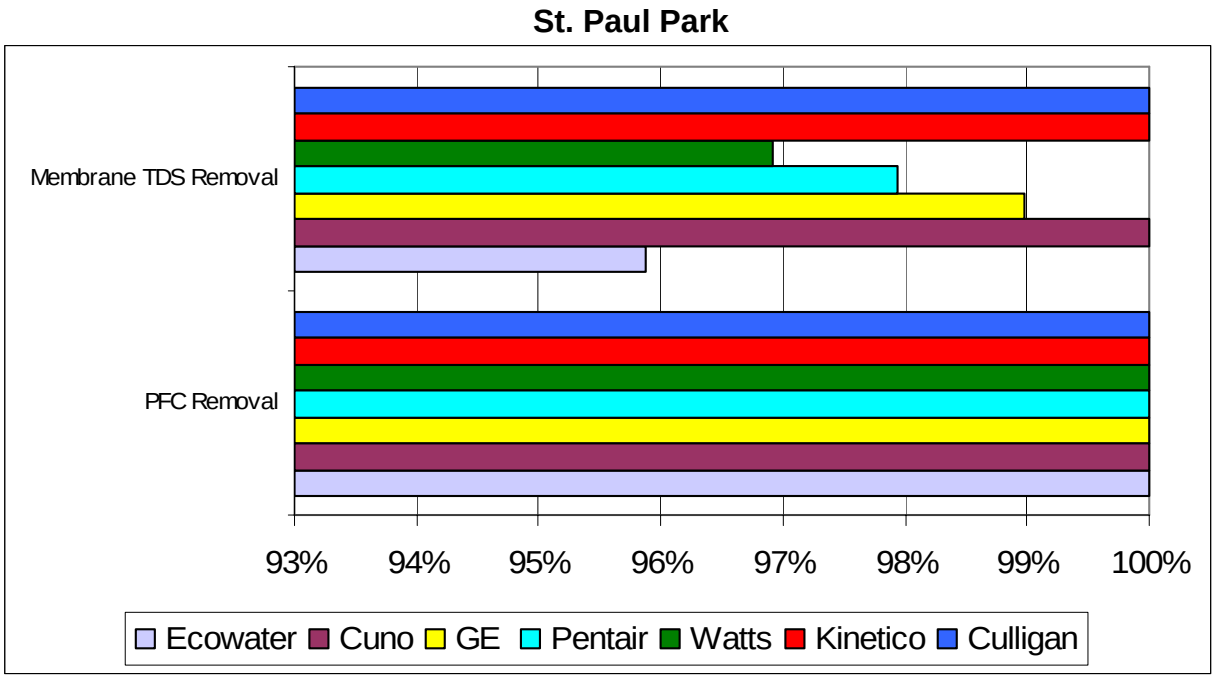
These TDS removal rates, or salt rejection performance, fall within the expected ranges and all represent what is typically considered satisfactory performance for POU devices.

The performance differences between sites and among the different RO-based devices tested was fairly consistent, and cause no concern for either the general operation and performance during this test, or for PFC removal capability.

Figure 8-4
Summary of RO – Based Systems- PFC & TDS Removal Performance



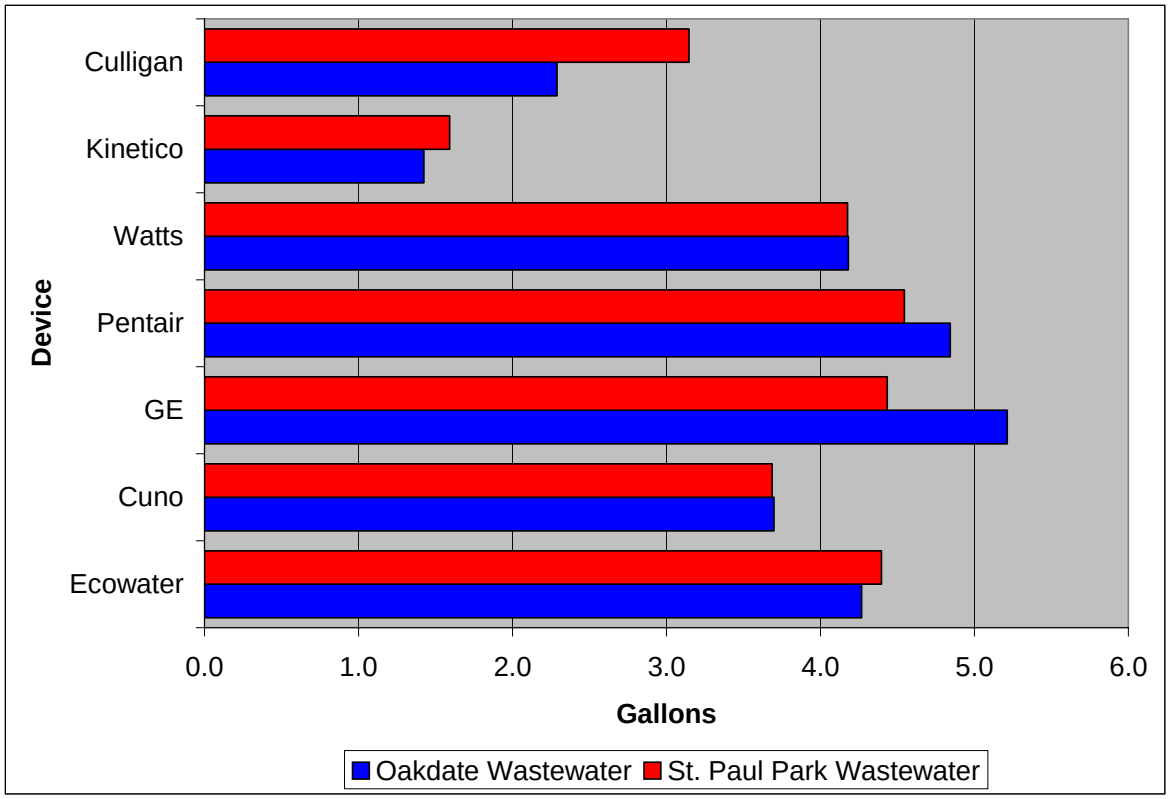
Note: 100% is representative of best performing system.



Note: 100% is representative of best performing system.

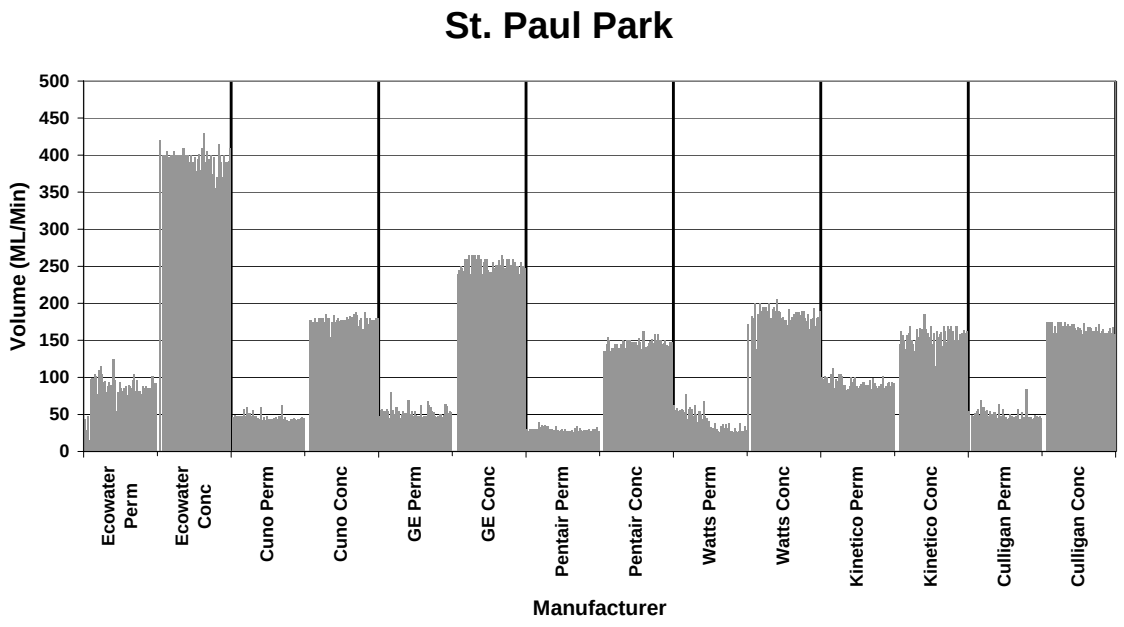
Figure 8-5 offers another representation of Recovery Rate, described with the relationship between the number of gallons discharged to waste to produce one (1) gallon of treated water.

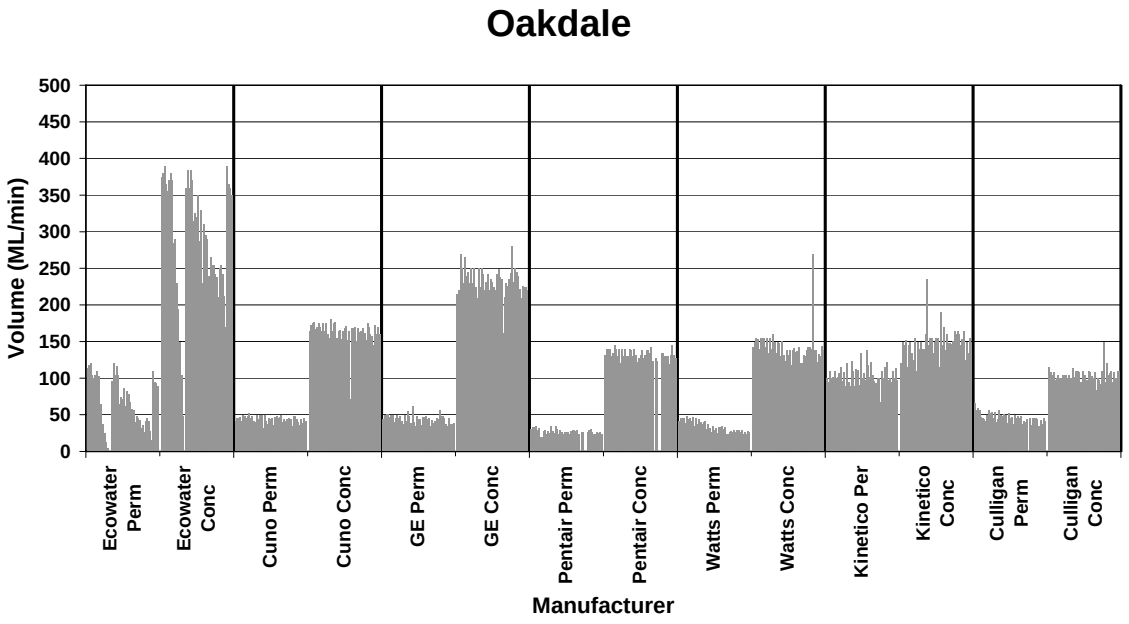
Figure 8-5
Volume Comparison of 1-Gallon Produced vs. Gallons to Waste for RO – Based Systems



Concentrate and permeate flow rate (ml/min) for each device by test site are also demonstrated in histogram format in Figure 8-6.

Figure 8-6
Permeate vs. Concentrate Flow Rate Per Device





Recovery rate [(Permeate Flow/(Concentrate + Permeate Flow) x 100%] for each device by test site during the 13-week test period is demonstrated in Figure 8-7.

Figure 8-7
Recovery Rate at Zero Outlet Pressure

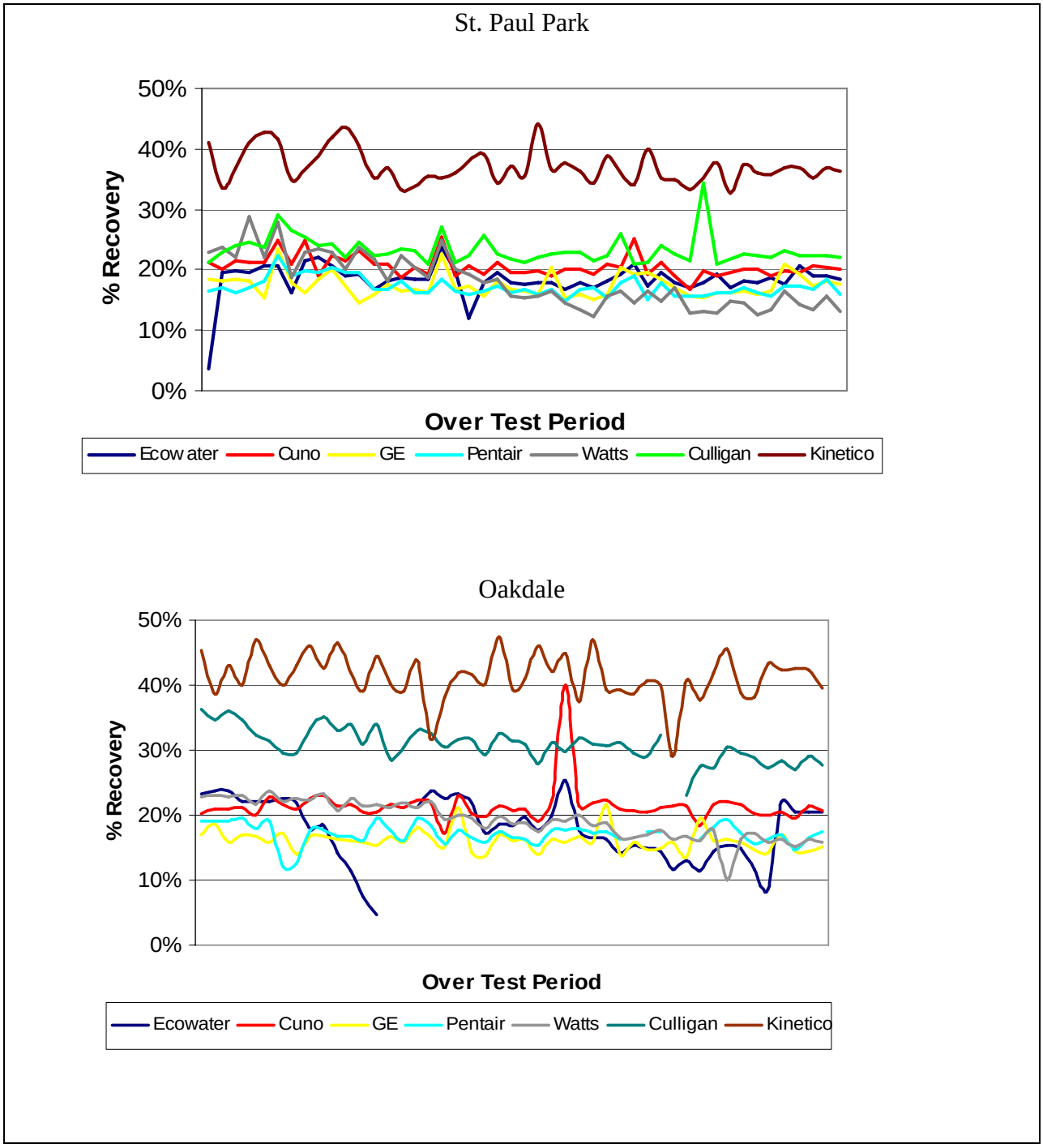
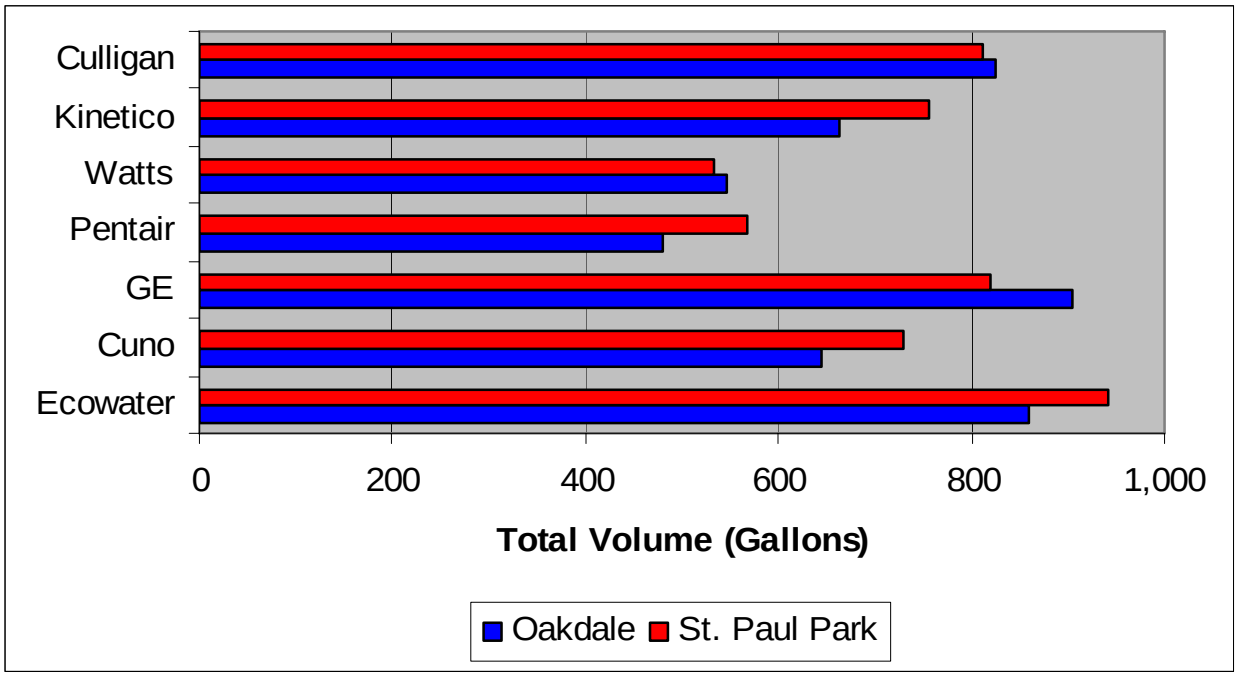


Figure 8-8 demonstrates the total gallons of drinking water produced over the 13-week test period by site. Total volume is influenced by treated water storage tank size and discharge of its contents every three hours (Refer to section 8.4.2)

Figure 8-8
Total Volume Produced (Gallons) Over Test Period



Note: Does not provide accurate comparison of membrane performance. Above results take into account treated water storage tank size and test protocol requiring discharge of its contents every three hours.

8.5 Phase II Individual Device Comments & Results

Activated Carbon devices were tested in accordance with the protocols detailed in Section 7.2.1. Reverse Osmosis devices were tested in accordance with the protocols detailed in Section 7.2.2.

8.5.1 Activated Carbon Technologies

8.5.1.1 Culligan - RC-EZ-4

Photo 8-1
Culligan RC-EZ-4

Manufacturer Specifications

Feed Water	
Temperature Range	40-100°F (4.4 – 37°C)
Pressure Range	30-100 psi
Turbidity	5 NTU max
Performance	
Rated Capacity	500 gallons (1,893 L)
Service Flow Rate	0.5 gpm

Source: Manufacturer literature, tested and certified by NSF International to NSF/ANSI Standard 42 and Standard 53.

Manufacturers Recommend Service Schedule
500 gallons or maximum six (6) months.

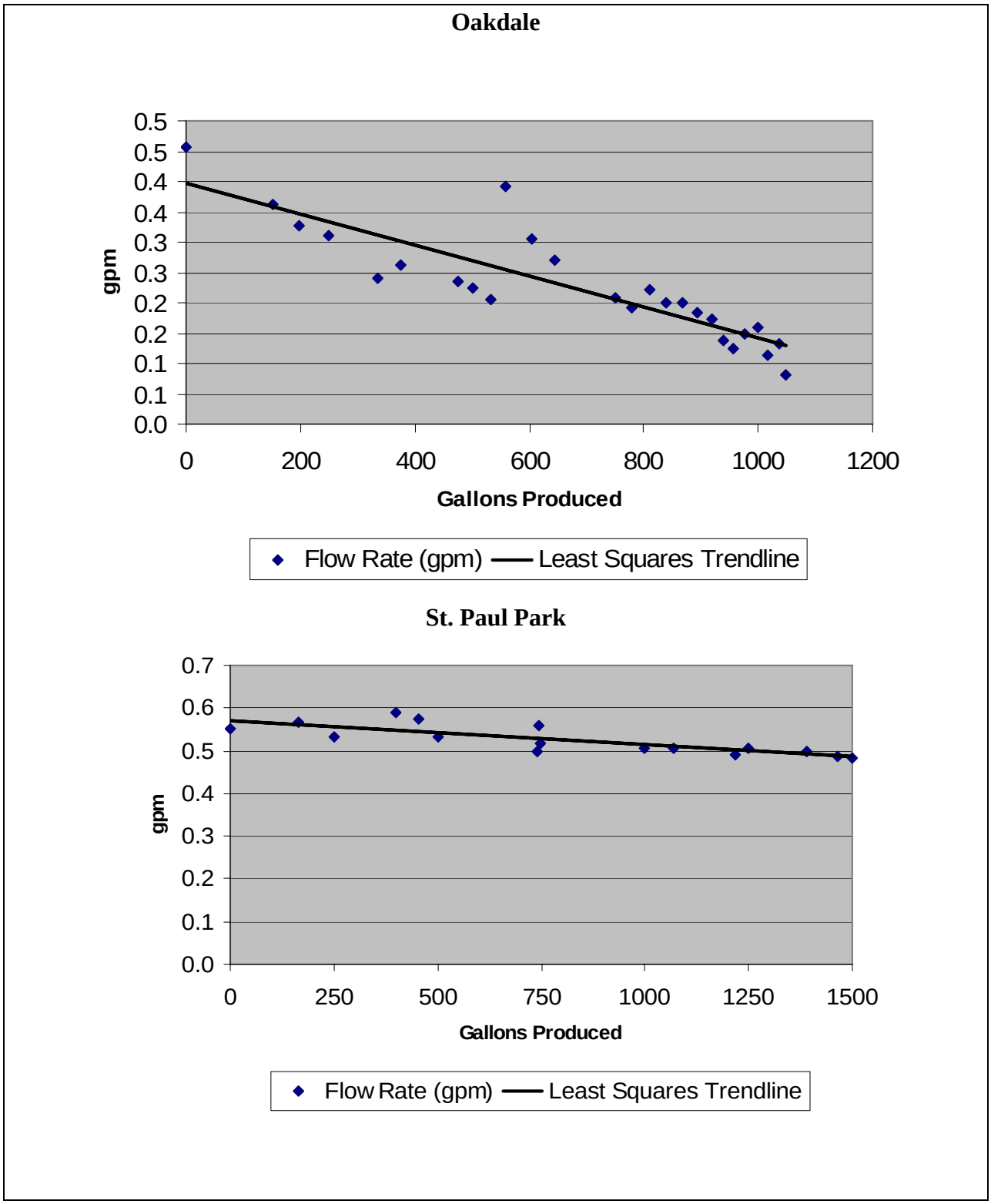
Pilot Test Comments
The supply water and operating conditions were within range of the manufacturers specifications. Table 8-4 lists the Culligan AC operating parameters during the testing period. Upon MDH instruction, AC filters provided by the manufacturer denoting "For Field Testing Only" were not used. Instead, Culligan RC-EZ-4 filters purchased from local retail stores were evaluated in this study.

Table 8-4
Culligan AC Supply Water Parameters (March 5, 2008 to April 21, 2008)

Parameter	# of readings	Average	Minimum	Maximum	Standard Deviation
St Paul Park					
Inlet Pressure (psig)	18	58	56	58	0.5
Flow Rate (L/Min)	17	2.0	1.8	2.2	0.1
Frequency an Time of on/off episodes	Continuous operation at 6 minutes on, 54 minutes off per hour through-out duration of test				
Water Temperature (°C)	18	6.2	4.4	7.9	0.9
Oakdale					
Inlet Pressure (psig)	26	50	40	56	4.5
Flow Rate (L/Min)	25	.8	.3	1.5	.3
Frequency an Time of on/off episodes	Continuous operation at 6 minutes on, 54 minutes off per hour through-out duration of test				
Water Temperature (°C)	25	12.0	11	13.3	.6

Field-testing on the Culligan AC established an average drinking water production rate range of 0.2 to 0.5 gallons per minute as illustrated in Figure 8-9 below.

Figure 8-9
Culligan AC Flow Rate vs. Total Gallons Produced



8.5.1.2 Kinetico - MACguard 7500

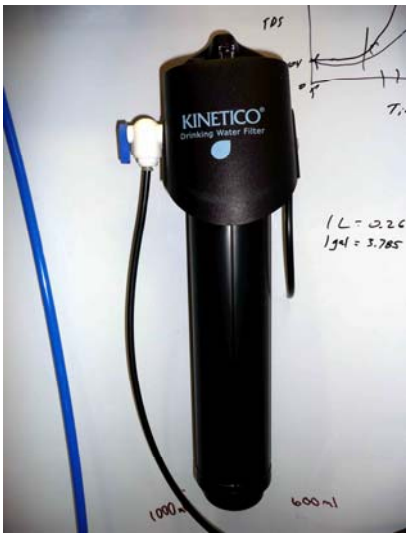


Photo 8-2
Kinetico MACguard 7500

Manufacturer Specifications

Feed Water	
Temperature Range	35 - 100°F (2 - 38°C)
Pressure Range	20-120 psi
Turbidity	
Performance	
Rated Capacity	500 gallons (1,892 L)
Service Flow Rate	.75 gpm (2.84 L/Min)

Source: Manufacturer literature, tested and certified by NSF International to NSF/ANSI Standard 42 and Standard 53.

Manufacturers Recommend Service Schedule

Kinetico MACguard will automatically shut off after 500 gallons have been filtered by the system.

Pilot Test Comments

The supply water and operating conditions were within range of the manufacturers specifications. Table 8-5 lists the Kinetico AC operating parameters during the testing period. This feature was disabled for this evaluation.

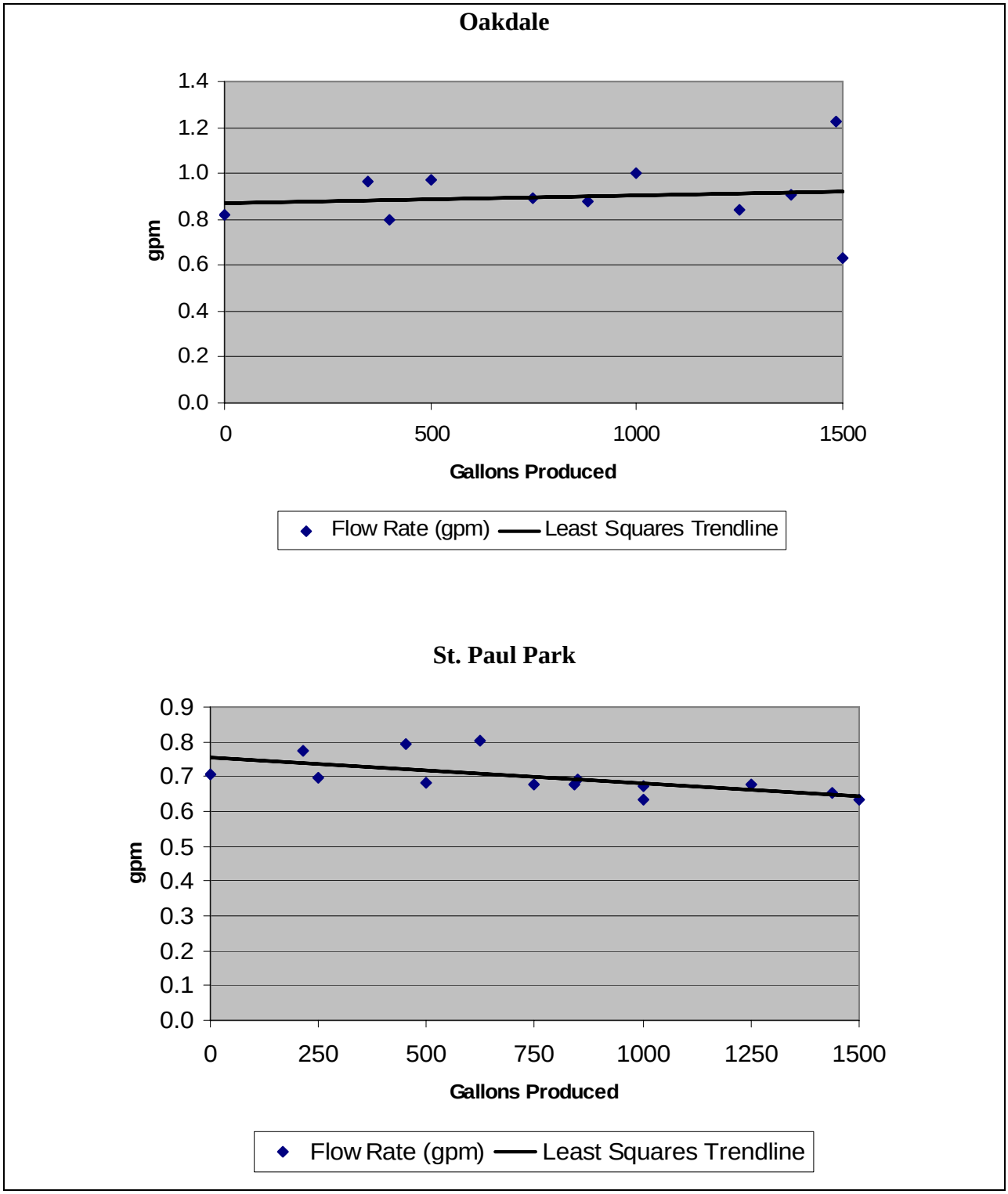
\

Table 8-5
Kinetico AC Supply Water Parameters (March 4, 2008 to April 21, 2008)

Parameter	# of readings	Average	Minimum	Maximum	Standard Deviation
St Paul Park					
Inlet Pressure (psig)	16	58	56	64	1.7
Flow Rate (L/Min)	15	2.7	2.4	3.04	0.2
Frequency an Time of on/off episodes	Continuous operation at 6 minutes on, 54 minutes off per hour through-out duration of test				
Water Temperature (°C)	18	6.2	4.4	7.9	0.9
Oakdale					
Inlet Pressure (psig)	11	52	46	55	3.2
Flow Rate (L/Min)	10	3.4	2.4	4.7	.6
Frequency an Time of on/off episodes	Continuous operation at 6 minutes on, 54 minutes off per hour through-out duration of test				
Water Temperature (°C)	11	11.7	11	12.2	0.4

Field-testing on the Kinetico AC established an average drinking water production rate range of 0.7 to 0.9 gallons per minute as illustrated in Figure 8-10 below.

Figure 8-10
Kinetico AC Flow Rate vs. Total Gallons Produced



8.5.1.3 Rainsoft - Hydrefiner P-12 9878

Manufacturer Specifications

Feed Water	
Temperature Range	50-100°F (10 – 37.8°C)
Pressure Range	40-100 psi
Turbidity	
Performance	
Rated Capacity	500 gallons (1,890 L)
Service Flow Rate	0.75 gpm

Source: Manufacturer literature, tested and certified by NSF International to NSF/ANSI Standard 42 and Standard 53.

Manufacturers Recommend Service Schedule
500 gallons or testing for PFC's in filtrate water 2 times a year minimum.

Photo 8-3
Aquion Rainsoft Hydrefiner P-12 9878

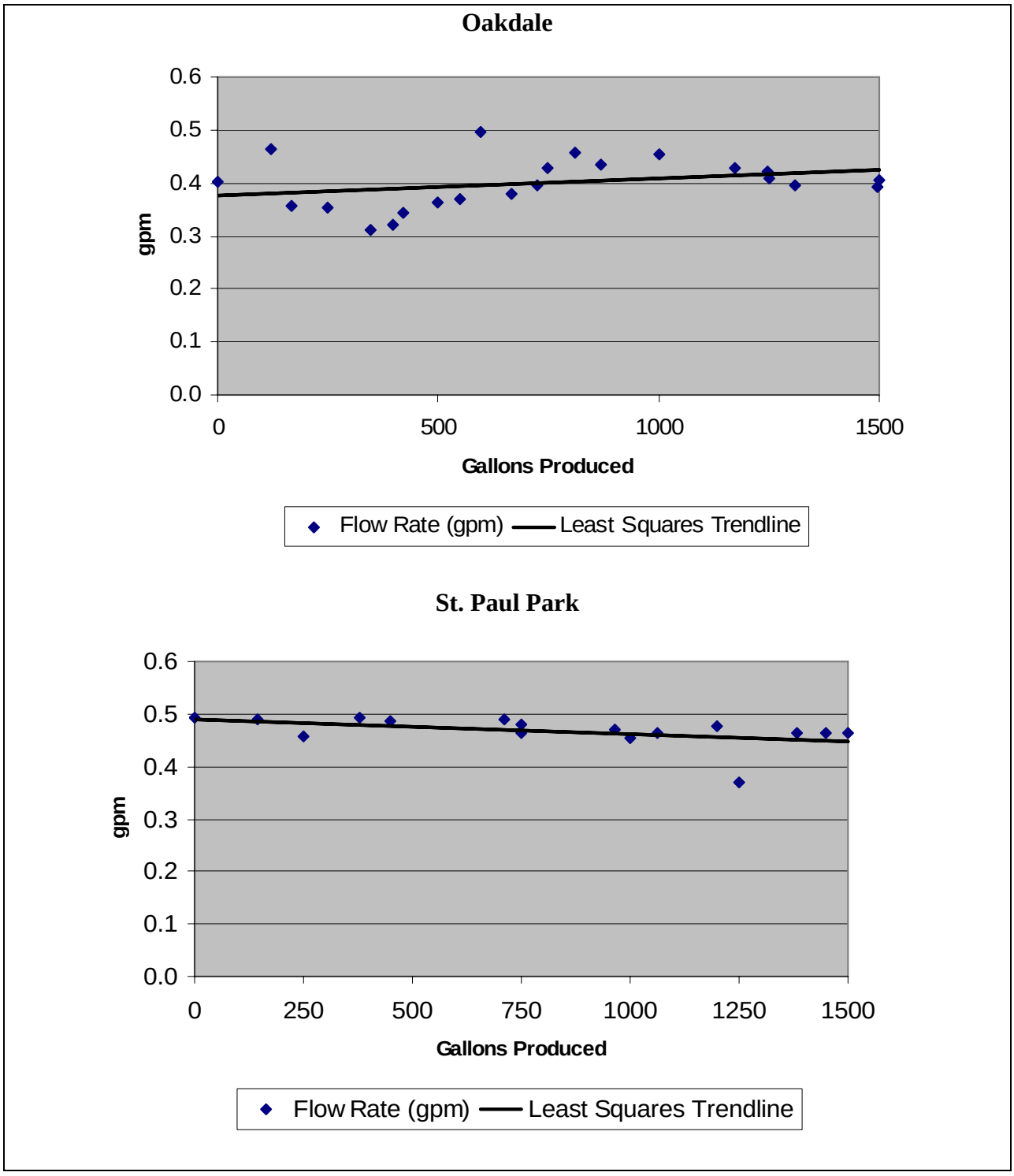
Pilot Test Comments
The supply water temperature at the St. Paul Park site was below the suggested range of the manufacturers specifications. The remaining operations conditions were within range of the manufacturers specifications. Table 8-6 lists the Rainsoft AC operating parameters during the testing period.

Table 8-6
Rainsoft AC Supply Water Parameters (March 5, 2008 to April 21, 2008)

Parameter	# of readings	Average	Minimum	Maximum	Standard Deviation
St Paul Park					
Inlet Pressure (psig)	18	58	56	58	.05
Flow Rate (L/Min)	17	1.8	1.4	1.9	0.1
Frequency an Time of on/off episodes	Continuous operation at 6 minutes on, 54 minutes off per hour through-out duration of test				
Water Temperature (°C)	18	6.2	4.4	7.9	0.9
Oakdale					
Inlet Pressure (psig)	22	50	42	56	4.7
Flow Rate (L/Min)	21	1.5	1.2	1.9	.2
Frequency an Time of on/off episodes	Continuous operation at 6 minutes on, 54 minutes off per hour through-out duration of test				
Water Temperature (°C)	22	12	11	13.3	0.6

Field-testing on the Rainsoft AC established an average drinking water production rate range of 0.4 to 0.5 gallons per minute as illustrated in Figure 8-11 below.

Figure 8-11
Rainsoft AC Flow Rate vs. Total Gallons Produced



8.5.1.4 Sears Kenmore Elite 625.385010

Manufacturer Specifications

Feed Water	
Temperature Range	40 - 100°F (5 - 40°C)
Pressure Range	30-125 psi
Turbidity	
Performance	
Rated Capacity	*500 gallons
Service Flow Rate	0.5 gpm

Source: Manufacturer literature, tested and certified by NSF International to NSF/ANSI Standard 42 and Standard 53.
* Per Manufacturer specificationsS for this study.

Manufacturers Recommend Service Schedule
500 gallons or every 6 months.

Photo 8-4
Sears Kenmore Elite 625.385010

Pilot Test Comments
Unit installed at St. Paul Park site developed a water leak within the device manifold, system manifold was replaced, and original test filters installed in replacement housing. The supply water temperature at the St. Paul Park site was slightly below the suggested range of the manufacturers specifications. The remaining operations conditions were within range of the manufacturers specifications. Table 8-7 lists the Sears AC operating parameters during the testing period.

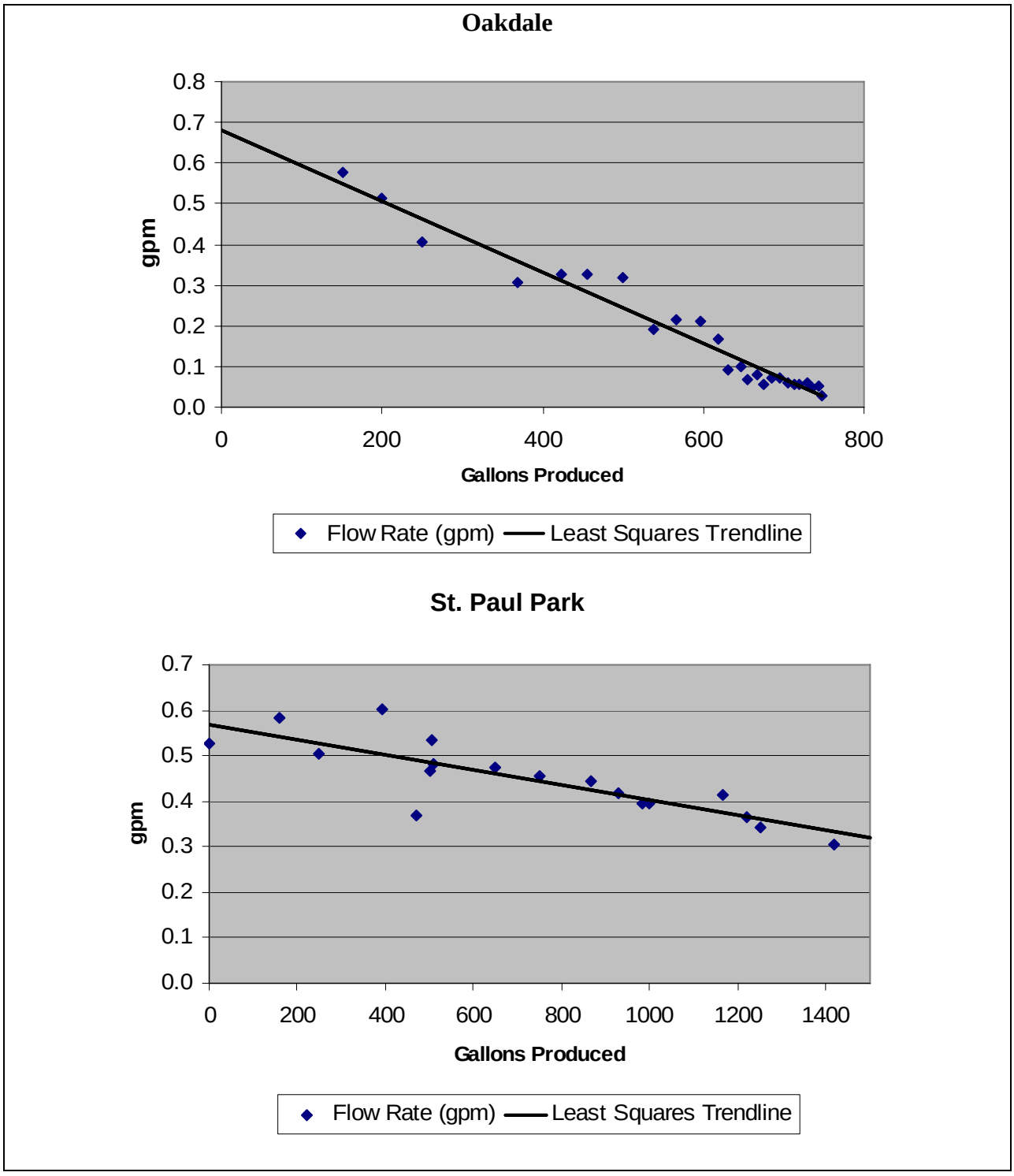
Table 8-7
Sears AC Supply Water Parameter (March 5, 2008 to April 21, 2008)

Parameter	# of readings	Average	Minimum	Maximum	Standard Deviation
St Paul Park*					
Inlet Pressure (psig)	20	58	56	58	0.5
Flow Rate (L/Min)	19	1.7	1.2	2.5	.04
Frequency an Time of on/off episodes	Continuous operation at 6 minutes on, 54 minutes off per hour through-out duration of test				
Water Temperature (°C)	18	6.2	4.4	7.9	0.9
Oakdale					
Inlet Pressure (psig)	26	50	40	58	4.3
Flow Rate (L/Min)	25	.7	.1	2.2	.06
Frequency an Time of on/off episodes	Continuous operation at 6 minutes on, 54 minutes off per hour through-out duration of test				
Water Temperature (°C)	25	12.0	11	13.3	.06

Note: Sears device shut down for 3 days due to leakage in device.

Field-testing on the Sears AC established an average drinking water production rate range of 0.2 to 0.4 gallons per minute as illustrated in Figure 8-12 below.

Figure 8-12
Sears AC Flow Rate vs. Total Gallons Produced

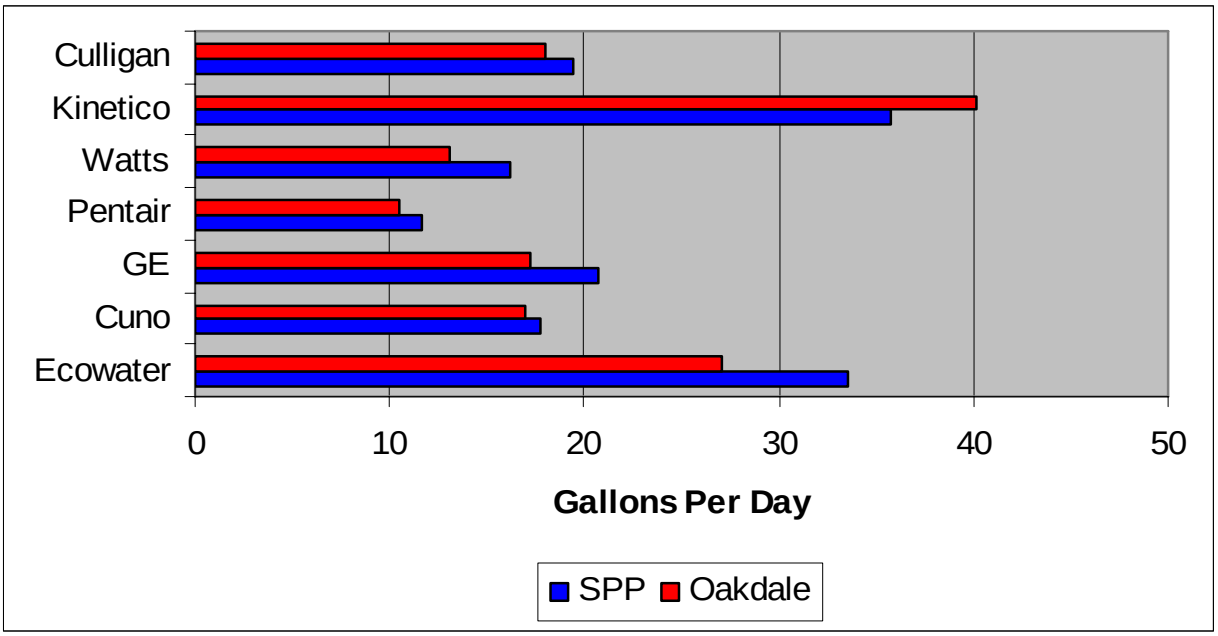


8.5.2 Reverse Osmosis Technologies

Each manufacturer has various treated water holding tanks available with the purchase of the RO units. Because this variation in system configuration of commercially available RO systems confounds total volume production results when all sample test devices are subjected to fixed operational conditions as required by experimental design, resultant data is skewed by this variation (refer to section 8.4.2). Project budget limitations prevented inclusion of various tank size options per device. Therefore, average volume production/device presented in this section is based upon flow rate measurements secured with zero (0) psi system outlet pressure to serve as a constant test variable. Figure 8-13 below illustrates the total average gallons per day drinking water production of each RO device measured zero outlet pressure at the two sites.

Conversely, total volumes produced/system over the test period (Figure 8.8) provides actual volume produced/device and serves to illustrate affect caused by variation in system tank size.

Figure 8-13
Average Drinking Water Production for RO – Based Systems (Gallons Per Day)



8.5.2.1 Culligan - Aqua-Cleer

Manufacturer Specifications

Feed Water	
Temperature Range	33 - 100°F (1 - 38°C)
Pressure Range	40-120 psi
Turbidity	0 – 10 NTU
Total Dissolved Solids (TDS)	0 – 2500 ppm (0-250 mg/L)
pH	5-10
Chlorine	0-3 ppm (0-3 mg/L)
Chloramine	0-3 ppm (0-3 mg/L)
Hardness	0-10 gpm
Iron	0-1 ppm (0-1 mg/L)
Performance	
Service Flow Rate	30 gpd (119 L/day)
Standard Conditions	
Storage Tank Volume	

Source: Manufacturer literature, tested and certified by NSF International to NSF/ANSI Standard 42 and Standard 53.

Photo 8-5
Culligan Aqua-Cleer

Manufacturers Recommend Service Schedule

To keep the Aqua-Cleer system operating properly, it is necessary to change the filters and sanitize the system periodically. Typically, this should be done on an annual basis. Service frequency may vary depending on local water conditions. High sediment, chlorine, turbidity or hardness levels may require more frequent service. .

Pilot Test Comments

The supply water and operating conditions were within range of the manufacturers specifications. Table 8-8 lists the Culligan RO supply water parameters measured during the testing period.

WSM discovered two membranes were supplied with the Culligan system. One membrane manufactured by Dow and one manufactured by GE. While it is unknown which membrane was used in Phase I and I-B, membranes manufactured by GE were used in Phase II.

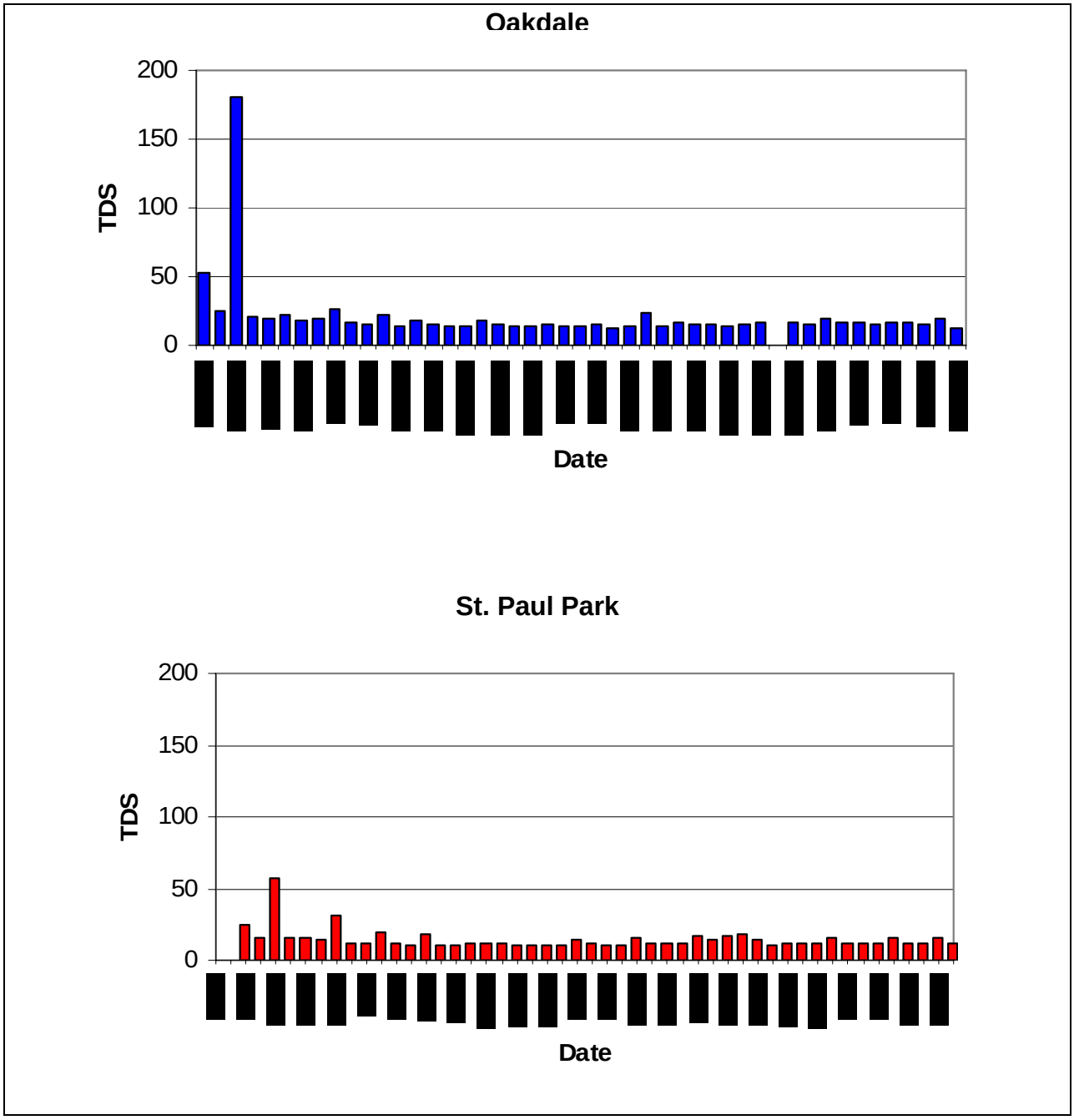
Upon MDH instruction, the AC post filter RC-EZ-4 (far right component in photo 8-5) provided by the manufacturer denoting “For Field Testing Only” was not used. Instead, it was replaced with a Culligan RC-EZ-4 filter purchased from a local retail store. Other replacement components could not be sourced in advance of the Phase II test period, although they are expected to be commercially available before publication of this study.

Table 8-8
Culligan RO Supply Water Parameters (January 15, 2008 to April 18, 2008)

Parameter	# of readings	Average	Minimum	Maximum	Standard Deviation
St Paul Park					
Inlet Water Pressure (psig)	49	57.9	56	61	1.1
Inlet Water Temperature (°C)	47	6.7	4.4	11.2	1.5
Tank Water Pressure (psig)	46	22.2	3	60	14.6
Permeate TDS	48	14.6	10.2	56.7	7.4
Concentrate TDS	48	538.5	472	588.4	29.3
Permeate flow rate (ml/min)	49	50.8	43	84	7.5
Concentrate flow rate (ml/min)	47	166.7	149	175	6.2
Recovery Rate (%)	47	23%	21%	34%	2%
Oakdale					
Inlet Water Pressure (psig)	47	49.2	40	58	4.3
Inlet Water Temperature (°C)	46	11.6	9.9	13.3	.08
Tank Water Pressure (psig)	42	17.3	4	37	9.3
Permeate TDS	46	21	12.1	180	24.7
Concentrate TDS	47	544.1	384.7	601	42.1
Permeate flow rate (ml/min)	46	46.8	35	65.5	6.5
Concentrate flow rate (ml/min)	47	105	84	150	9.4
Recovery Rate (%)	46	33%	29%	36%	3%

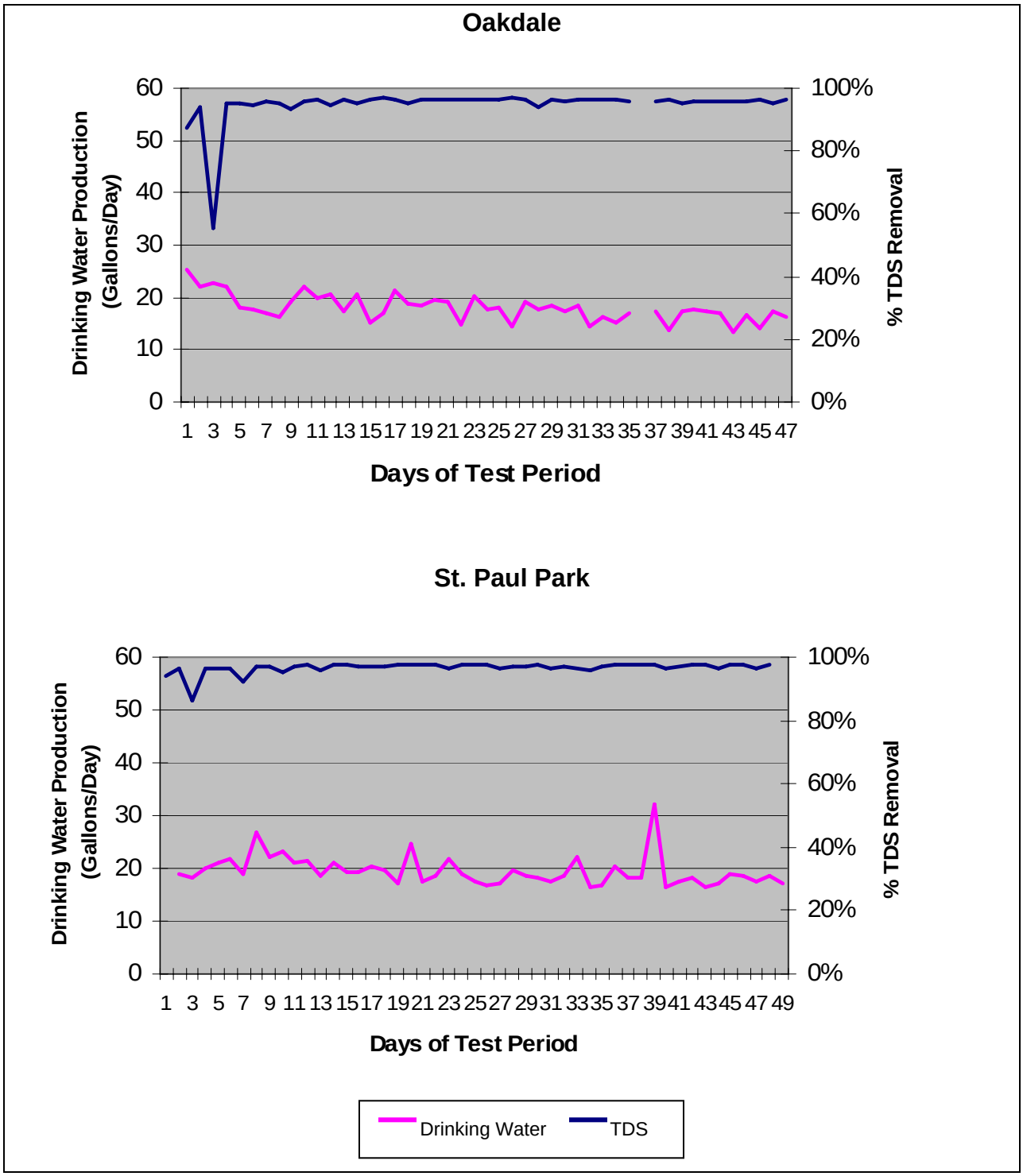
Figure 8-14 illustrates the Culligan permeate TDS measurements at the two test sites. The TDS readings were consistent per site, with the exception of one outlier noted at the device startup at the St. Paul Park site. The TDS spike noted at the St. Paul Park site on 1/23/08 was due to a concentrate line shut off overnight.

Figure 8-14
Culligan RO Permeate TDS



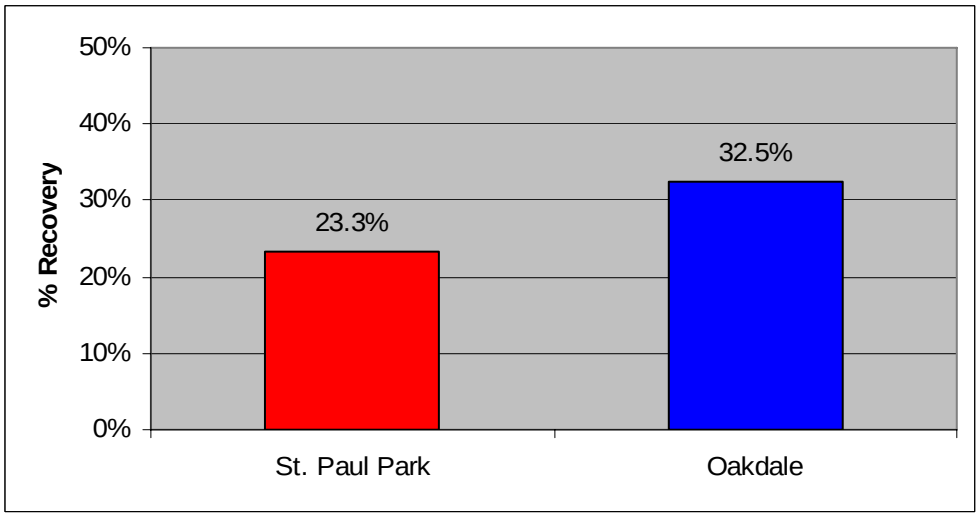
Field-testing on the Culligan RO established an average drinking water production rate at the two sites between 18 and 19.5 gallons per day, as illustrated in Figures 8-15 below.

Figure 8-15
Culligan RO Drinking Water Production
And Membrane TDS Removal Performance Over Duration of Test Period



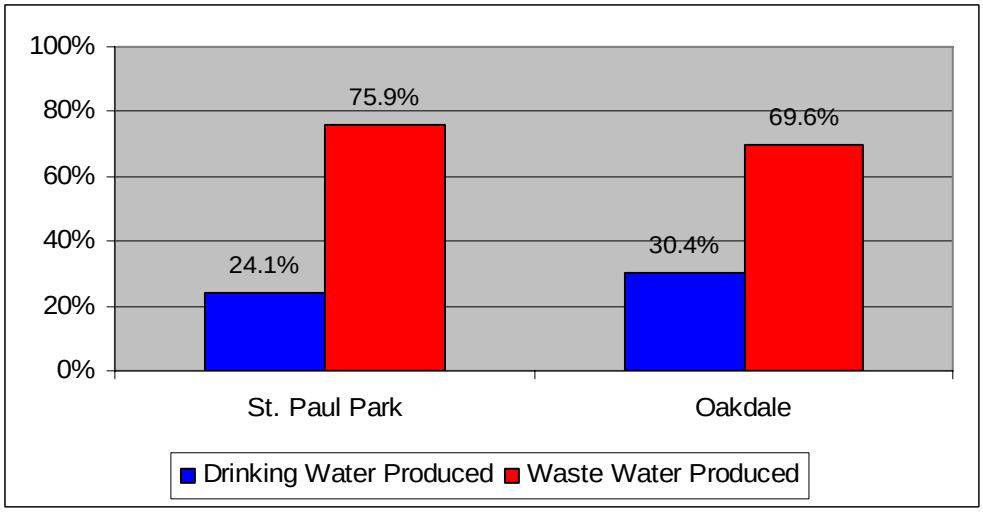
The average recovery rate (Permeate Flow/(Concentrate + Permeate Flow)) for the Culligan RO is illustrated in Figure 8-16.

Figure 8-16
Culligan Aqua-Cleer Average Recovery Rate at Zero Outlet Pressure



As shown in the below Figure 8-17, for each one (1) gallon of drinking water produced, there was an average of 2.7 gallons of wastewater produced.

Figure 8-17
Culligan Aqua-Cleer Average % Drinking Water Produced vs. % to Waste At Zero Outlet Pressure



8.5.2.2 Cuno – SQC-304-045

Manufacturer Specifications

Feed Water	
Temperature Range	40 - 100°F (4.4 - 38°C)
Pressure Range	40-100 psi
Turbidity	<1 NTU
Maximum Total Dissolved Solids (TDS)	2000 ppm
pH	4-11
Manganese	<0.05 mg/L
Hardness	<350 mg/L
Iron	<0.1 mg/L
Hydrogen Sulfide	0
Performance	
Service Flow Rate	8.28 gal/day (31.35 L/day)

Source: Manufacturer literature, tested and certified by NSF International to NSF/ANSI Standard 42 and Standard 58.

Photo 8-6
Cuno SQC 304-045

Manufacturers Recommend Service Schedule

Sediment Prefilter and Carbon Post filter should be changed at a minimum of six months depending on feed water quality. Membrane should be changed as required based on periodic TDS rejection test or an on-site monitor (PR). The maximum recommended service life is 36 months.

Pilot Test Comments

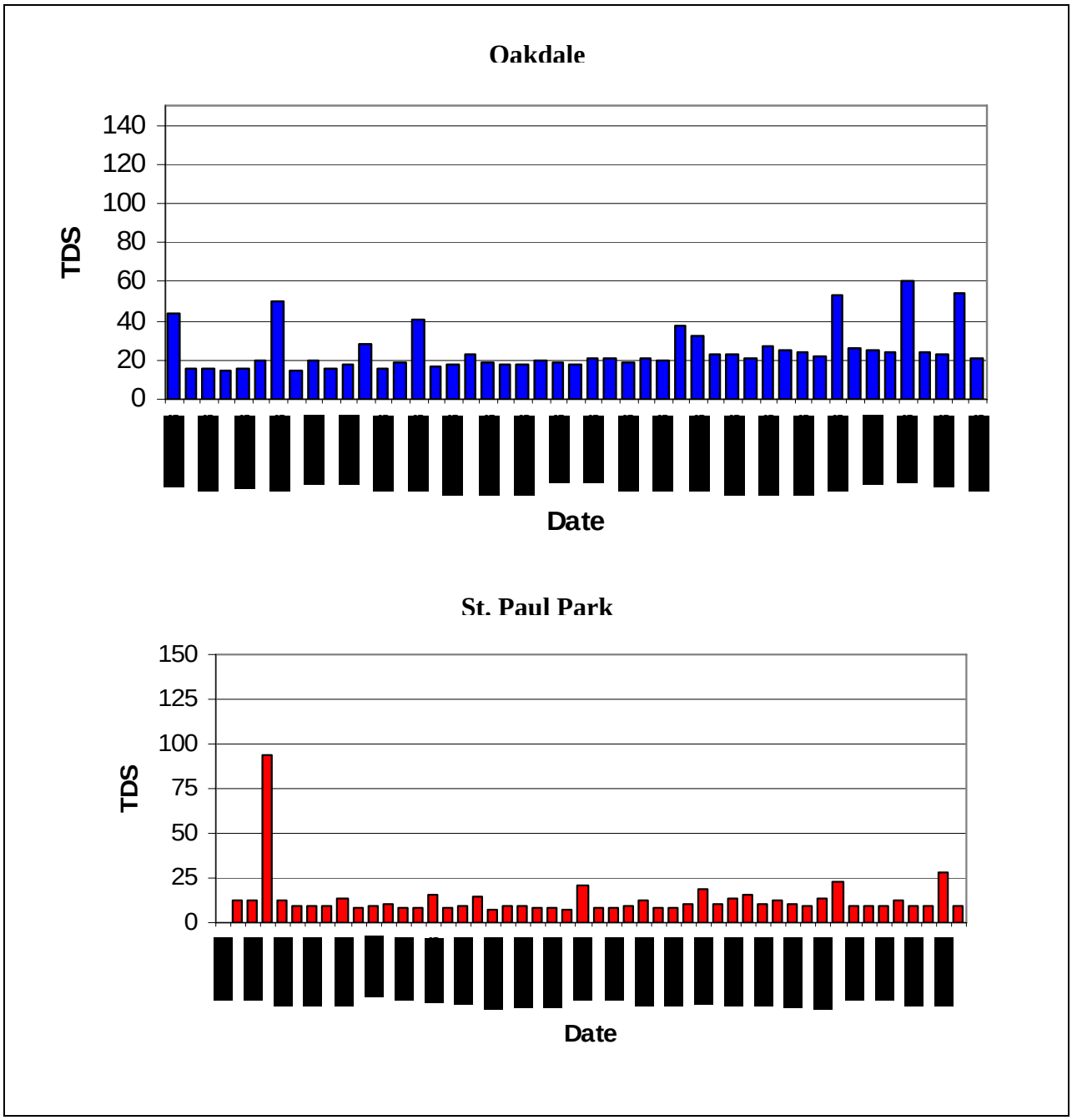
The supply water and operating conditions were within range of the manufacturers specifications. Table 8-9 lists the Cuno RO supply water parameters measured during the testing period.

Table 8-9
Cuno RO Supply Water Quality (January 15, 2008 to April 18, 2008)

Parameter	# of readings	Average	Minimum	Maximum	Standard Deviation
St Paul Park					
Inlet Water Pressure (psig)	50	57.9	56	60	1.1
Inlet Water Temperature (°C)	49	6.8	4.4	11.2	1.5
Tank Water Pressure (psig)	45	22.6	4.0	56	12.8
Permeate TDS	49	13	7.6	94	12.5
Concentrate TDS	49	528.6	479.9	611.4	31.9
Permeate flow rate (ml/min)	49	46.4	36	63	5.4
Concentrate flow rate (ml/min)	47	178.2	155	188	5.5
Recovery Rate (%)	47	21%	17%	26%	2%
Oakdale					
Inlet Water Pressure (psig)	47	50.4	40	57	4.2
Inlet Water Temperature (°C)	46	11.4	6.9	13.3	1.2
Tank Water Pressure (psig)	42	13.5	3	27	4.8
Permeate TDS	47	24.7	14.6	60.9	11.2
Concentrate TDS	47	389.4	336	796.3	47
Permeate flow rate (ml/min)	47	44.3	32	52	4.4
Concentrate flow rate (ml/min)	47	163.8	72	180	15.8
Recovery Rate (%)	47	21%	17%	23%	3%

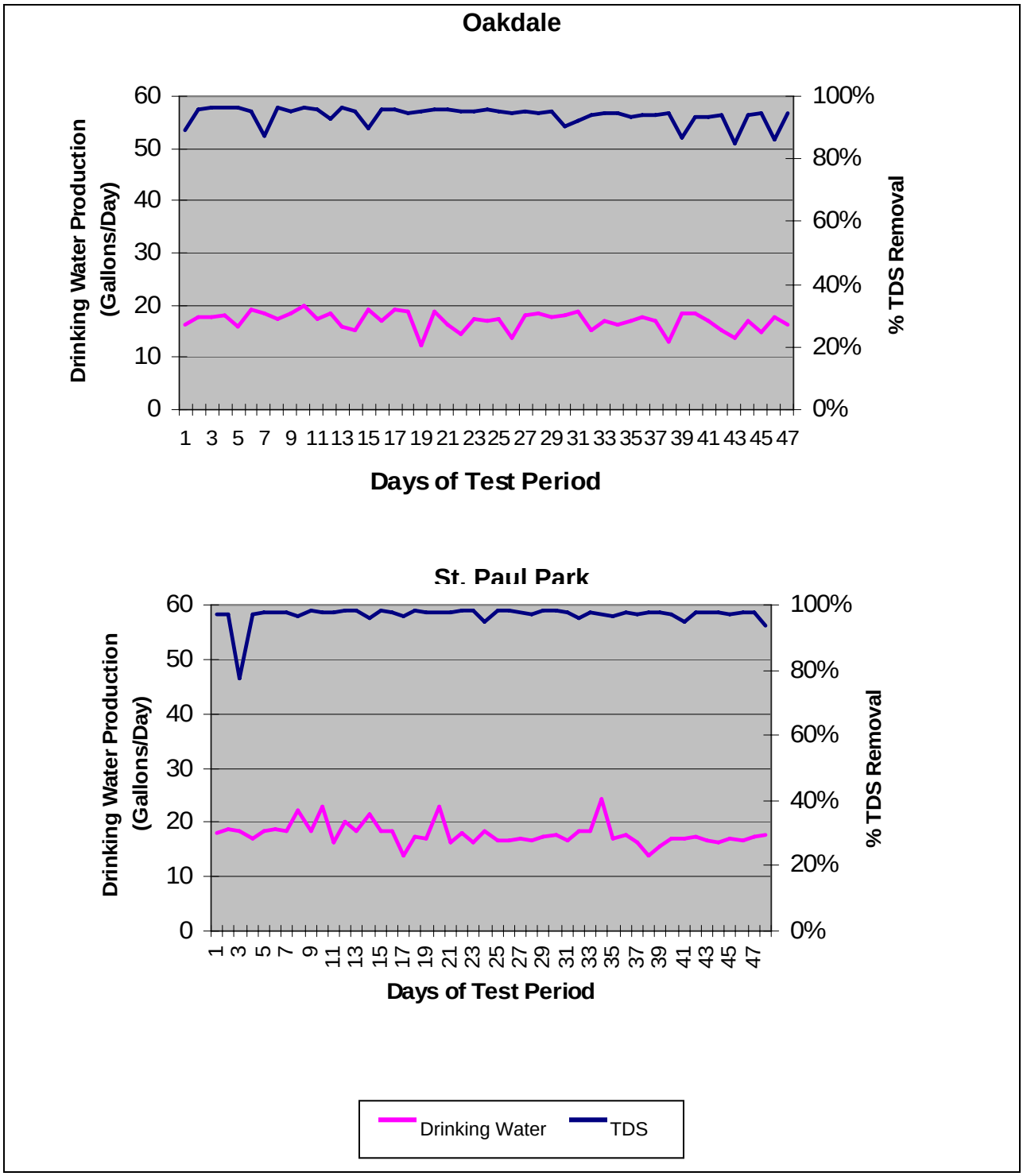
Figure 8-18 illustrates the Cuno RO permeate TDS measurements at the two test sites. The TDS readings were consistent per site, with the exception of one outlier noted during the device startup period at the St. Paul Park site.

Figure 8-18
Cuno RO Permeate TDS



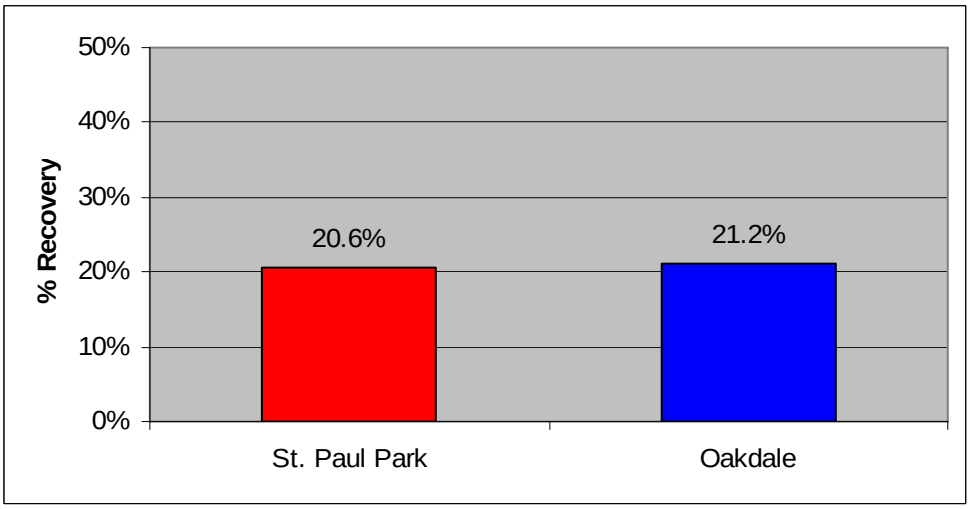
Field-testing on the Cuno RO established an average drinking water production rate at the two sites between 17.0 and 17.8 gallons per day, as illustrated in Figures 8-19 below.

Figure 8-19
Cuno RO Drinking Water Production
And Membrane TDS Removal Performance Over Duration of Test Period



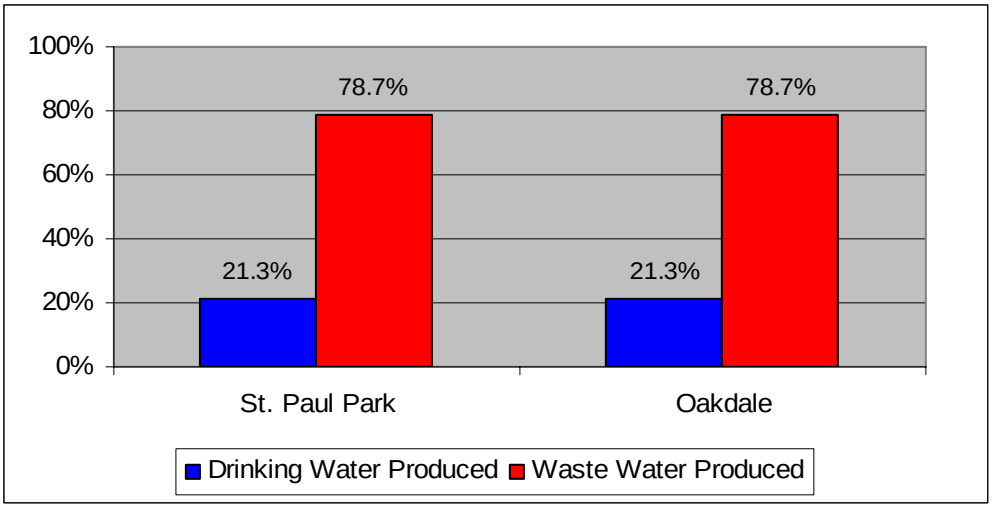
The average recovery rate (Permeate Flow/(Concentrate + Permeate Flow)) for the Cuno RO is illustrated in Figure 8-20.

Figure 8-20
Cuno RO Average Recovery Rate at Zero Outlet Pressure



As shown in the below Figure 8-21, for each one (1) gallon of drinking water produced, there were an average of 3.7 gallons of wastewater produced.

Figure 8-21
Cuno RO Average % Drinking Water Produced
vs. % to Waste At Zero Outlet Pressure



8.5.2.3 Ecowater - ERO-375E-CP

Photo 8-7
Ecowater ERO-375-CP

Manufacturer Specifications

Feed Water	
Temperature Range	40 - 100°F (5 - 38°C)
Pressure Range	40-100 psi
Maximum Total Dissolved Solids (TDS)	2000 mg/L
pH	4-11
Manganese	0 mg/L
Hardness	171 mg/L
Iron	0 mg/L
Hydrogen Sulfide	0 mg/L
Chlorine	2.0 mg/L
Performance	
Rated Service Flow	17.4 gal/day

Source: Manufacturer literature, tested and certified by NSF International to NSF/ANSI Standard 58.

Manufacturers Recommend Service Schedule
At least every 6 months, replace the pre-filter and post filter cartridges or when the yellow LED flashes. Replace the RO membrane cartridge when the percent rejection of total dissolved solids (TDS) is less than shown in the specifications. Replace the battery one per year.

Pilot Test Comments
The supply water at both the St. Paul Park and Oakdale site was above the manufacturers specifications for iron. The remaining water characteristics were within range of the manufacturers specifications. Table 8-10 lists the Ecowater RO supply water parameters measured during the testing period.

The TDS concentrations at Oakdale would increase and permeate flow decrease as the system's reached its loading capacity. This was observed twice at the Oakdale site. Upon pre-filter replacement, the TDS levels would decrease and permeate flow increase to previous levels.

The manufacturer specifications recommend a maximum concentration of 0 mg/L of iron in the source water supply, both the St. Paul Park and the Oakdale site had supply water iron readings in the range of 0.08.

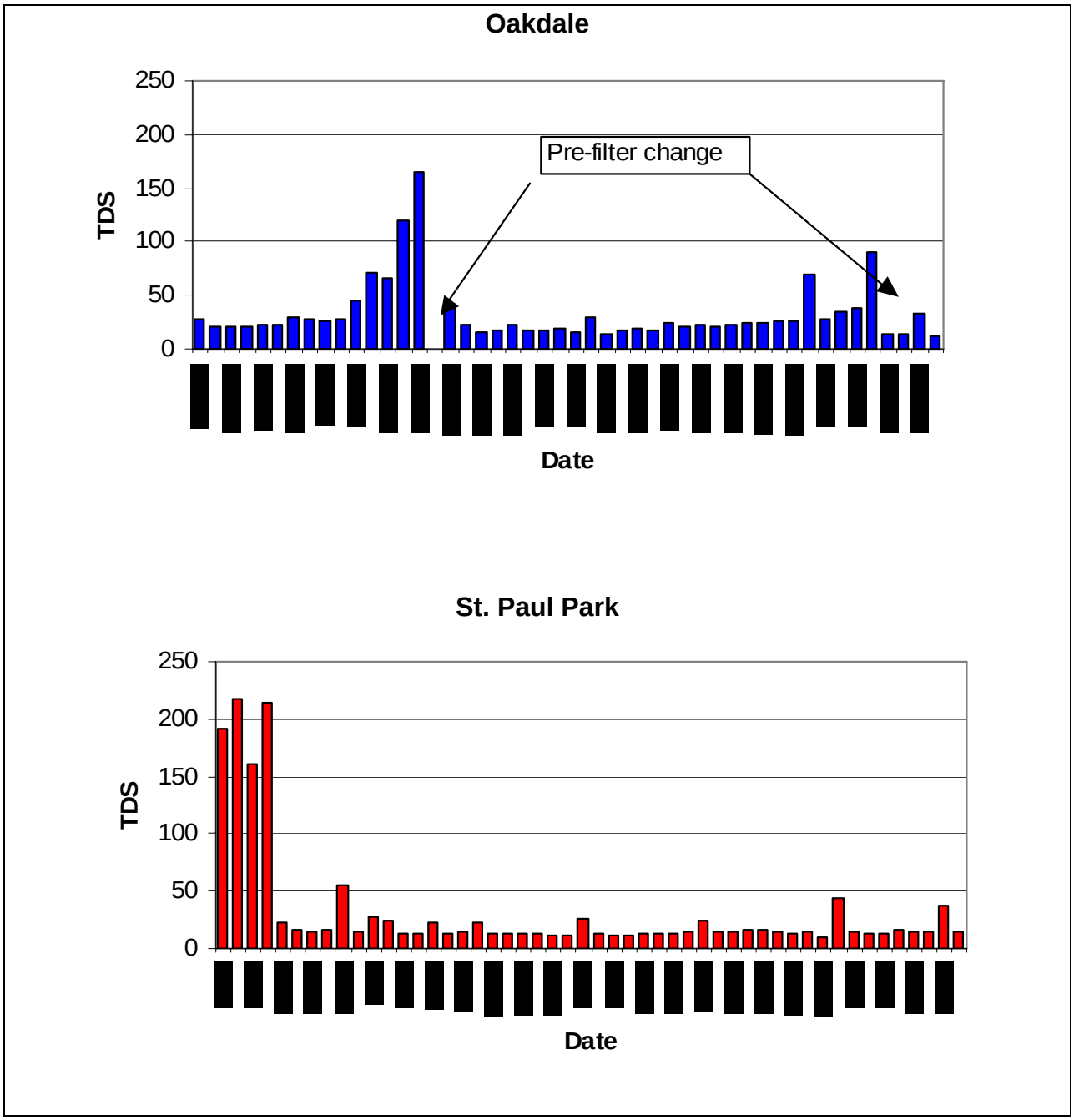
Table 8-10
Ecowater RO Supply Water Parameters (January 15, 2008 to April 18, 2008)

Parameter	# of readings	Average	Minimum	Maximum	Standard Deviation
St Paul Park					
Inlet Water Pressure (psig)	50	57.8	56	60	1.0
Inlet Water Temperature (°C)	49	6.8	4.4	11.2	1.5
Tank Water Pressure (psig)	47	29.4	7.0	48	10.9
Permeate TDS	50	31.8	10.2	217	50
Concentrate TDS	48	519.9	480.8	644	31.3
Permeate flow rate (ml/min)	50	86.5	15	125	19.5
Concentrate flow rate (ml/min)	48	396.	355	430	13.2
Recovery Rate (%)	47	19%	12%	24%	3%
Oakdale*					
Inlet Water Pressure (psig)	48	50.4	41	58	4.4
Inlet Water Temperature (°C)	47	11.4	6.9	13.3	1.2
Tank Water Pressure (psig)	41	14.9	3	34	9.2
Permeate TDS	47	32.9	12	164.8	28.7
Concentrate TDS	46	464.1	280	517	41.6
Permeate flow rate (ml/min)	47	69.1	0	121	34.5
Concentrate flow rate (ml/min)	47	294.9	48	390	80.4
Recovery Rate (%)	47	19%	5%	24%	5%

* Note: Pre-filter on RO replaced on 2/19/08 & 4/7/08

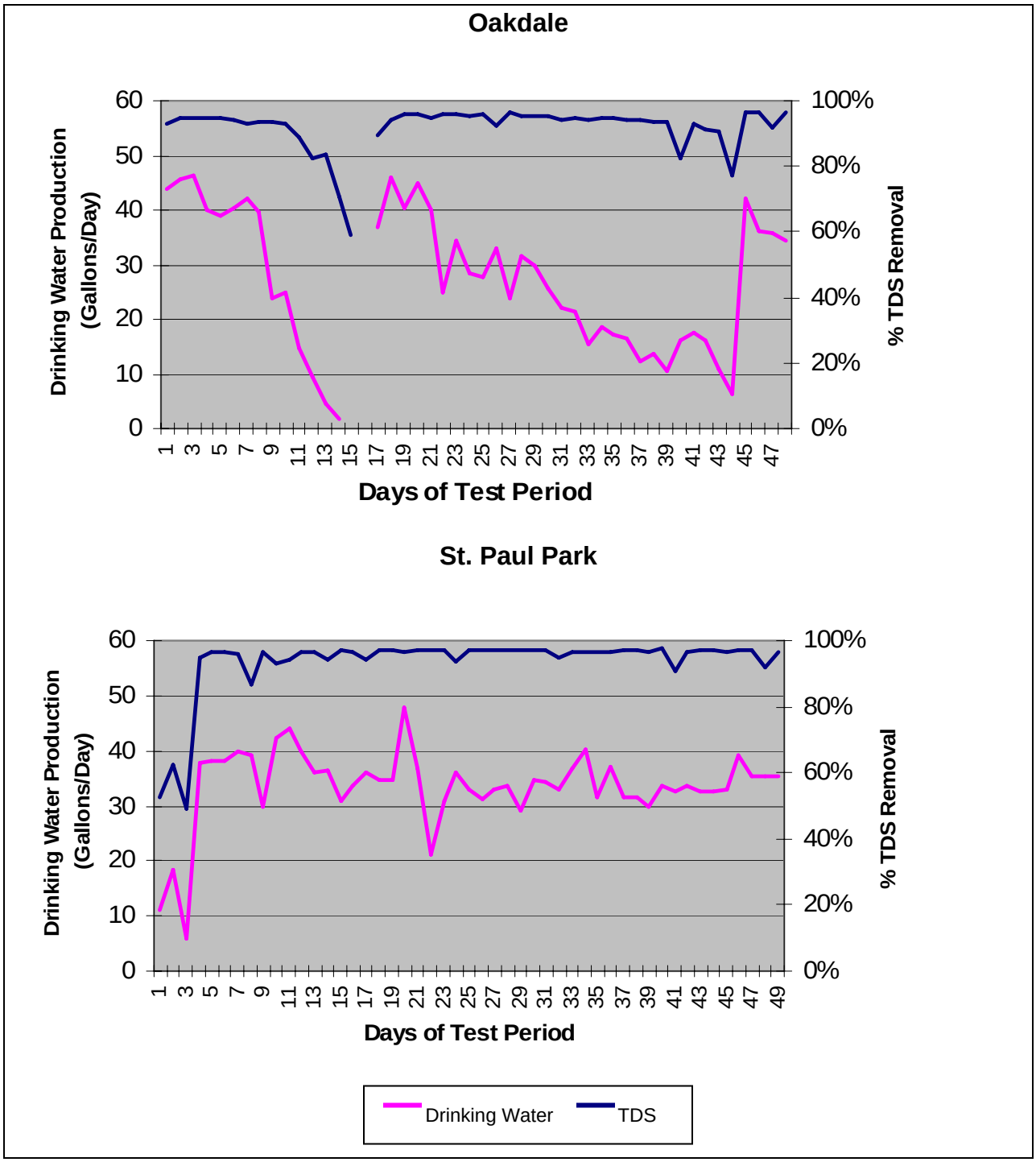
Figure 8-22 illustrates the Ecowater RO permeate TDS measurements at the two test sites. Elevated TDS readings at the St. Paul Park site were observed during start-up, WSM contacted the manufacture and on 1/17/08 new pre-filters and RO elements were installed.

Figure 8-22
Ecowater Permeate TDS



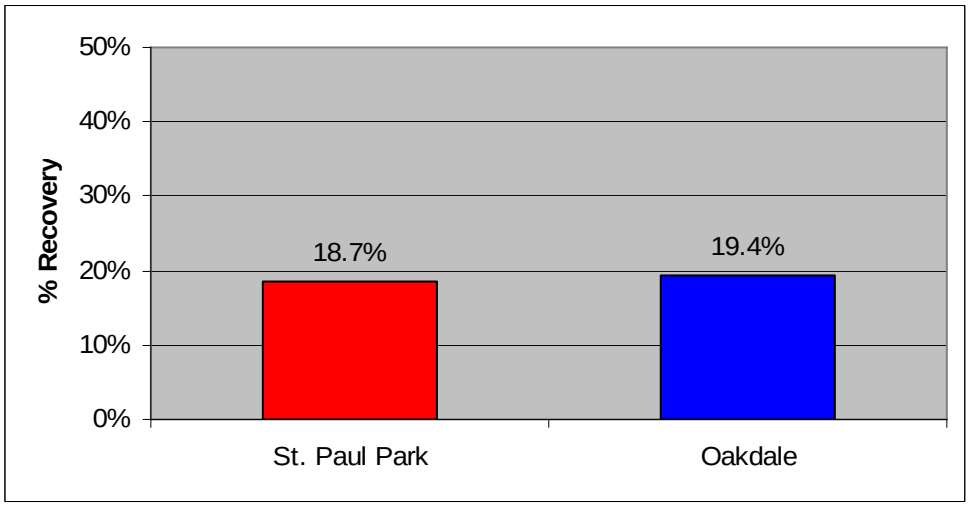
Field-testing on the Ecowater RO established an average drinking water production rate at the two sites between 27.1 and 33.6 gallons per day, as illustrated in Figures 8-23 below.

Figure 8-23
Ecowater RO Drinking Water Production
And Membrane TDS Removal Performance Over Duration of Test Period



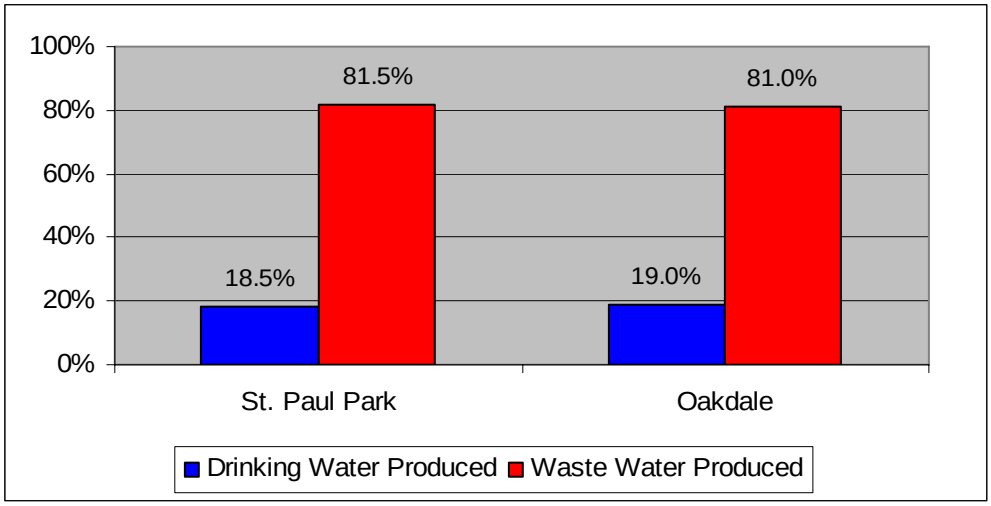
The average recovery rate (Permeate Flow/(Concentrate + Permeate Flow)) for the Ecowater RO is illustrated in Figure 8-24.

Figure 8-24
Ecowater RO Average Recovery Rate at Zero Outlet Pressure



As shown in the below Figure 8-25, for each one (1) gallon of drinking water produced, there were an average of 4.3 gallons of wastewater produced.

Figure 8-25
Ecowater RO Average % Drinking Water Produced vs.
% to Waste At Zero Outlet Pressure



8.7.2.4 GE - Smartwater GXRM10GBL

Manufacturer Specifications

Feed Water	
Temperature Range	40 - 100°F (5 - 38°C)
Pressure Range	40-125 psi
Maximum Total Dissolved Solids (TDS)	2000 mg/L
pH	4-10
Manganese	0 mg/L
Hardness	171 mg/L
Iron	0 mg/L
Hydrogen Sulfide	0 mg/L
Chlorine	2.0 mg/L
Performance	
Service Flow Rate	10 gal/day

Source: Manufacturer literature, tested and certified by NSF International to NSF/ANSI Standard 58.

Photo 8-8
GE Smartwater GXRM10GBL

Manufacturers Recommend Service Schedule
Product water should be tested a minimum of every six months.

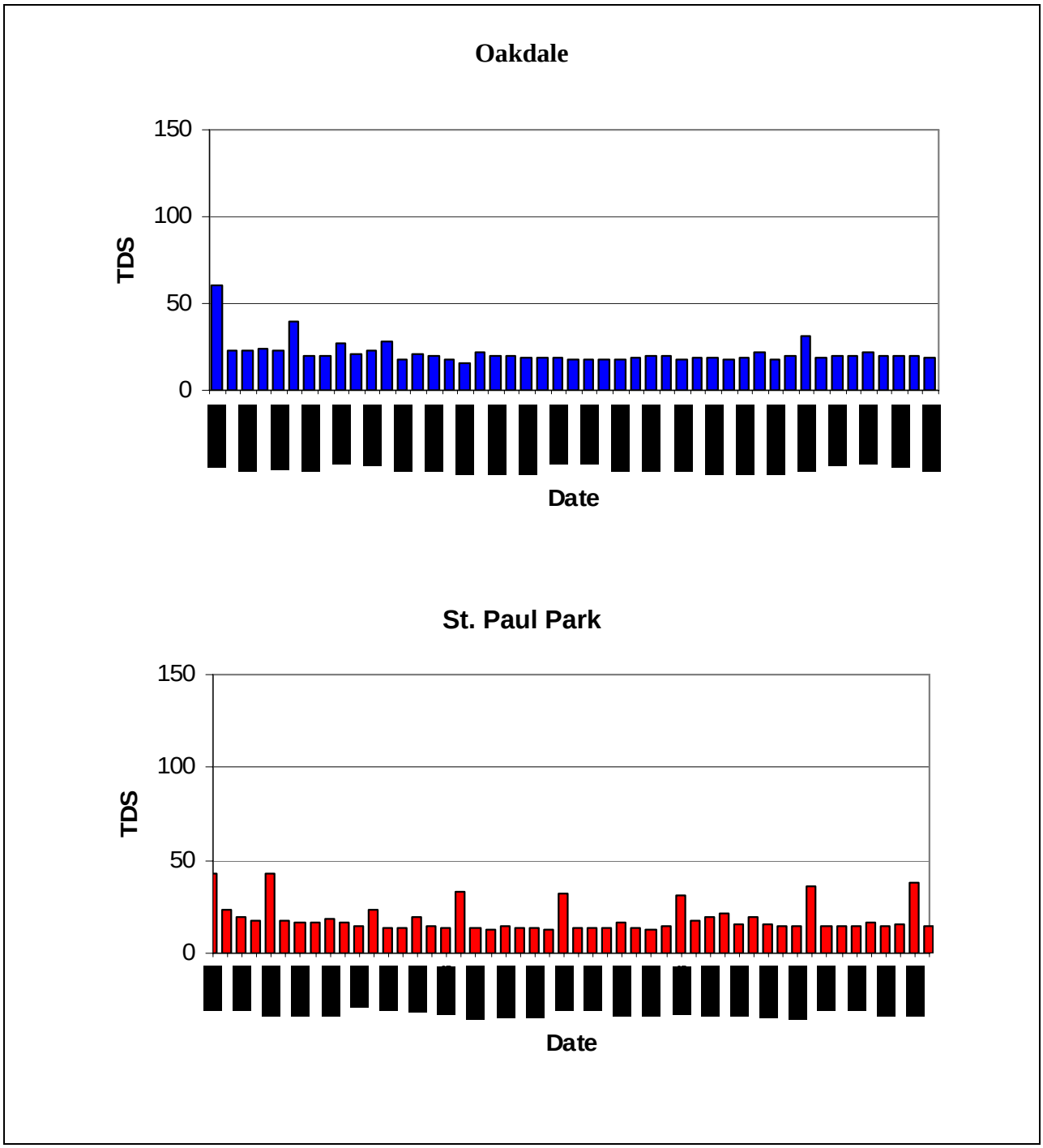
Pilot Test Comments
The supply water at both the St. Paul Park and Oakdale site was above the manufacturers specifications for iron and hardness. The remaining water characteristics were within range of the manufacturers specifications. Table 8-11 lists the GE RO supply water parameters measured during the testing period.

Table 8-11
GE RO Supply Water Parameters (January 15, 2008 to April 18, 2008)

Parameter	# of readings	Average	Minimum	Maximum	Standard Deviation
St Paul Park					
Inlet Water Pressure (psig)	50	57.8	55	61	1.2
Inlet Water Temperature (°C)	49	6.8	4.4	11.2	1.5
Tank Water Pressure (psig)	45	19.3	0	67	13.6
Permeate TDS	50	18.7	12.9	43	7.9
Concentrate TDS	50	498.1	78.3	628.6	68.6
Permeate flow rate (ml/min)	50	53.7	44.5	80	7
Concentrate flow rate (ml/min)	47	253.3	240	265	7.8
Recovery Rate (%)	47	147%	15%	24%	2%
Oakdale					
Inlet Water Pressure (psig)	47	50	40	56	3.9
Inlet Water Temperature (°C)	46	11.4	6.9	13.3	1.2
Tank Water Pressure (psig)	42	16.2	7	33	6.2
Permeate TDS	47	21.5	15.7	60.7	7.1
Concentrate TDS	47	466.6	397	529.3	20.1
Permeate flow rate (ml/min)	47	44.8	34	62	5.9
Concentrate flow rate (ml/min)	47	233.4	162	280	18.5
Recovery Rate (%)	47	17%	14%	21%	2%

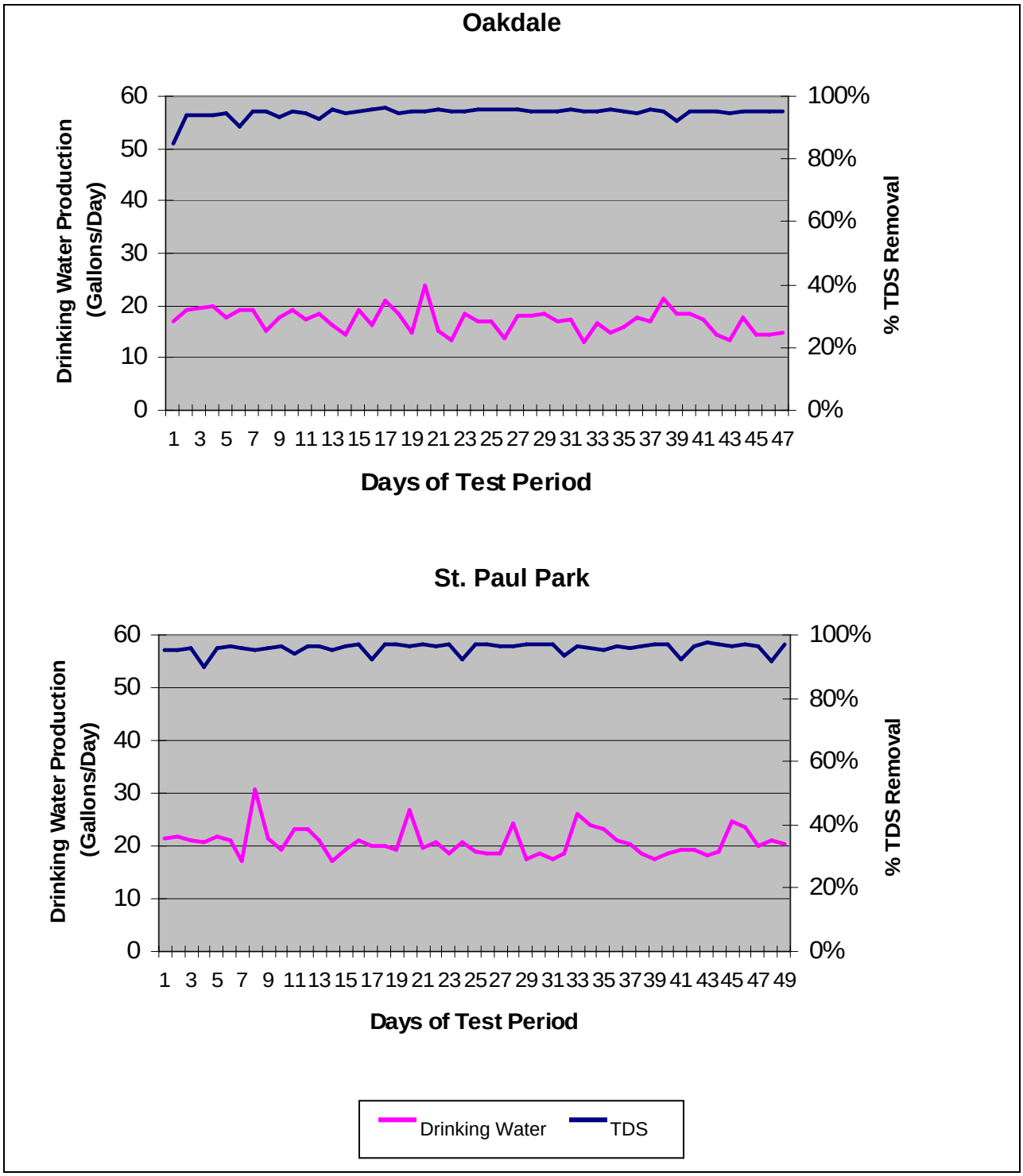
Figure 8-26 illustrates the GE RO permeate TDS measurements at the two test sites. The TDS readings were consistent per site, with the exception of the device startup at the Oakdale site. The elevated readings noted at the St. Paul Park site are in direction correlation with the stagnation periods.

Figure 8-26
GE RO Permeate TDS



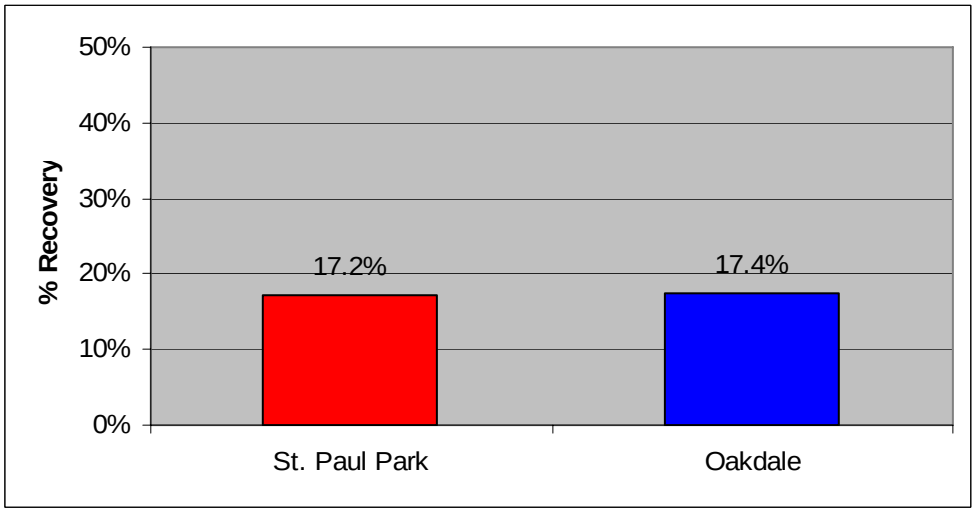
Field-testing on the GE RO established an average drinking water production rate at the two sites between 17.0 and 20.7 gallons per day, as illustrated in Figures 8-27 below.

Figure 8-27
GE RO Drinking Water Production
And Membrane TDS Removal Performance Over Duration of Test Period



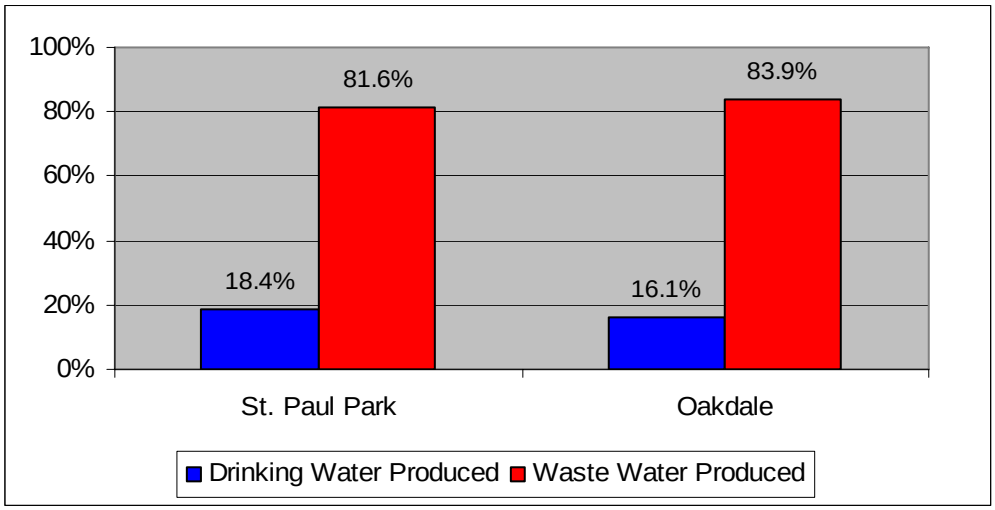
The average recovery rate (Permeate Flow/(Concentrate + Permeate Flow)) for the GE RO is illustrated in Figure 8-28.

Figure 8-28
GE RO Average Recovery Rate at Zero Outlet Pressure



As shown in the below Figure 8-29, for each one (1) gallon of drinking water produced, there were an average of 4.8 gallons of wastewater produced.

Figure 8-29
GE RO Average % Drinking Water Produced
vs. % to Waste At Zero Outlet Pressure



8.5.2.5 Kinetico Plus Deluxe VX

Photo 8-9
Kinetico Plus Deluxe VX

Manufacturer Specifications

Feed Water	
Temperature Range	35 - 100°F (2 - 38°C)
Pressure Range	35-100 psi
Maximum Total Dissolved Solids (TDS)	3000 mg/L
pH	3-11
Hardness	0-10 gpg
Iron	0 -.1 ppm
Performance	
Service Flow Rate	75 gal/day

Source: Manufacturer literature, tested and certified by NSF International to NSF/ANSI Standard 42, NSF/ANSI Standard 53, and NSF/ANSI Standard 58.

Manufacturers Recommend Service Schedule
To ensure optimum performance, continued warranty coverage and that your system continues to comply with NSF and WQA certification standards, you must replace the prefilter and postfilter cartridges annually or upon system shutoff, whichever occurs first.

Pilot Test Comments
The supply water and operating conditions were within range of the manufacturers specifications. Table 8-12 lists the Kinetico RO supply water parameters measured during the testing period.

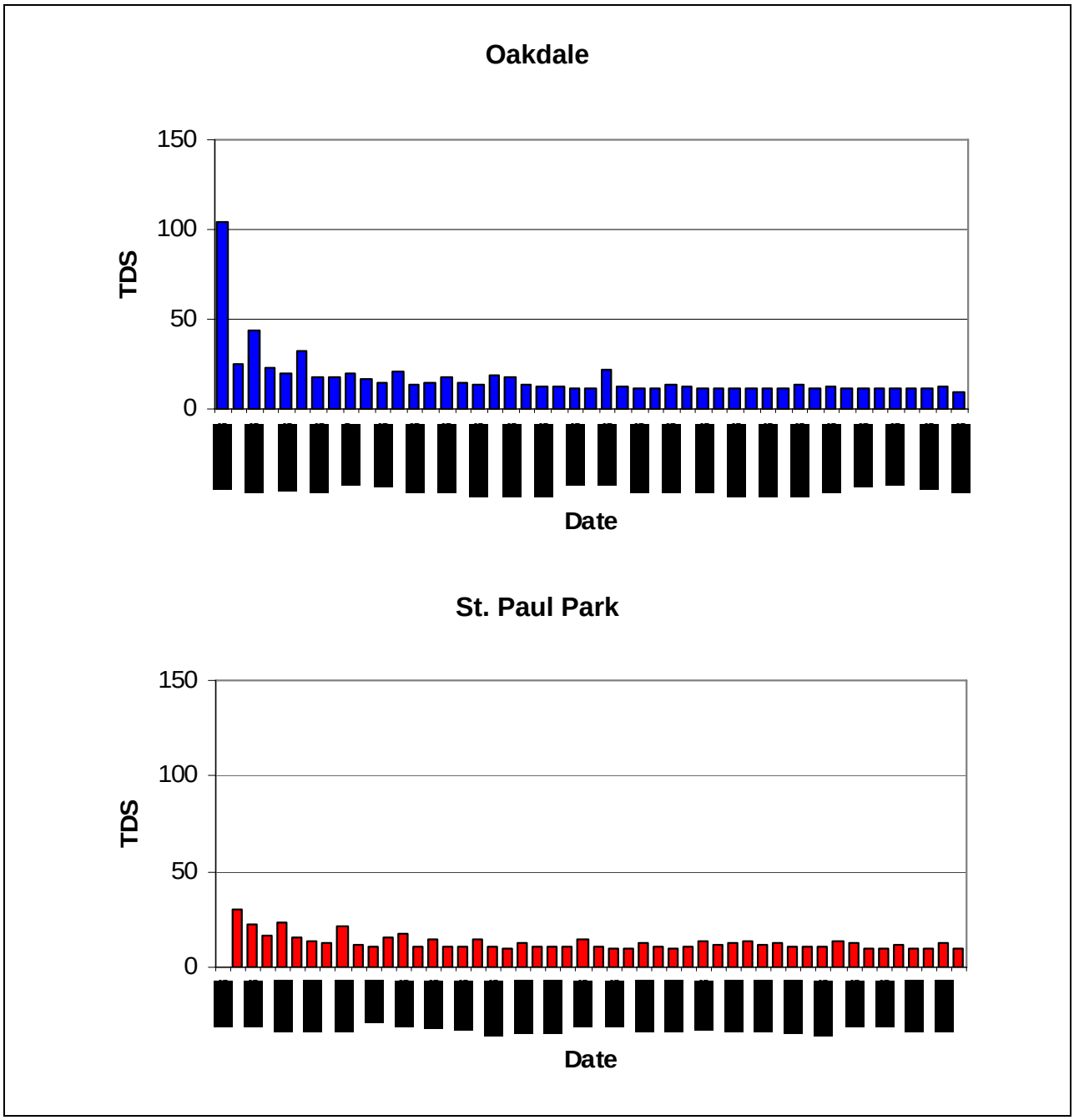
Table 8-12
Kinetico RO Supply Water Parameters (January 15, 2008 to April 18, 2008)

Parameter	# of readings	Average	Minimum	Maximum	Standard Deviation
St Paul Park					
Inlet Water Pressure (psig)	50	57.8	56	61	1.1
Inlet Water Temperature (°C)	49	6.8	4.4	11.2	1.5
Tank Water Pressure (psig)	45	32.2	6	57	10.9
Permeate TDS	49	12.9	9.7	30.6	4.1
Concentrate TDS	49	670.8	525.3	754.2	48.6
Permeate flow rate (ml/min)	50	93.2	82	112	7
Concentrate flow rate (ml/min)	47	157.8	115	185	11.6
Recovery Rate (%)	47	37%	33%	44%	3%
Oakdale					
Inlet Water Pressure (psig)	47	49.4	40	58	4.6
Inlet Water Temperature (°C)	46	11.6	9.9	13.3	0.6
Tank Water Pressure (psig)	42	25	0	36	7.6
Permeate TDS	47	17.2	9.5	104	14.3
Concentrate TDS	47	666.6	450.9	707	69.9
Permeate flow rate (ml/min)	47	104.7	68	138	12.4
Concentrate flow rate (ml/min)	47	149	110	235	19.7
Recovery Rate (%)	47	42%	32%	47%	4%

The Kinetico RO system was observed leaking during the testing period. The RO device was inspected and a poor fitting "O" ring was discovered to be the source of the leak. WSM contacted Kinetico for assistance on this problem and was informed that issue had already been discovered and corrected. (Reference: "Temporary Hold on Drinking Water System Cartridge Production", Management Communiqué Bulletin No: 467. Dated 10/20/07, & "Drinking Water System Cartridge Production", Management Communiqué Bulletin No: 489, Dated 11/20/07). New "O" ring was installed, no further leaking was observed.

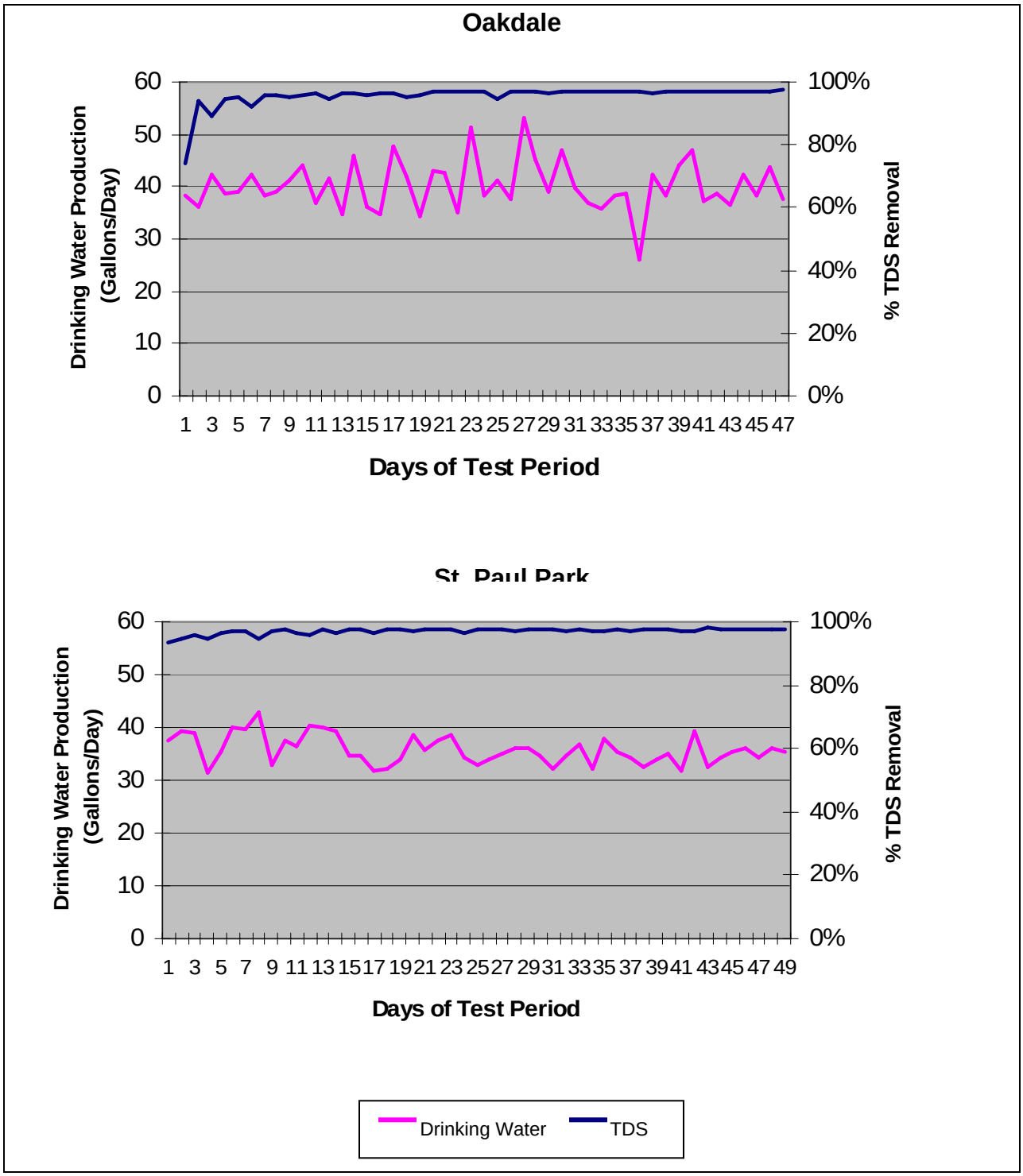
Figure 8-30 illustrates the Kinetico permeate TDS measurements at the two test sites. The TDS readings were consistent per site, with the exception of one outlier noted during the device startup period at the Oakdale site.

Figure 8-25
Kinetico RO Permeate TDS



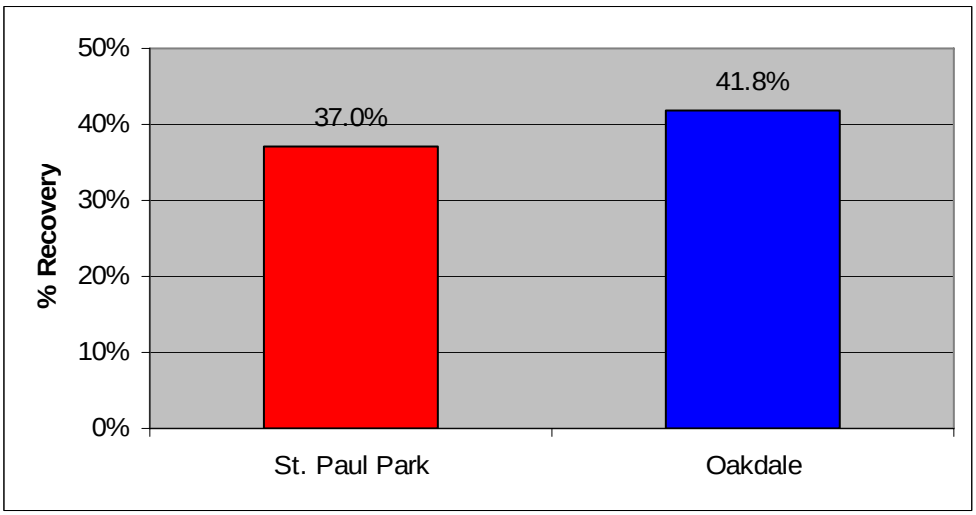
Field-testing on the Kinetico RO established an average drinking water production rate at the two sites between 40.2 and 35.71 gallons per day, as illustrated in Figures 8-31 below.

Figure 8-31
Kinetico RO Drinking Water Production
And Membrane TDS Removal Performance Over Duration of Test Period



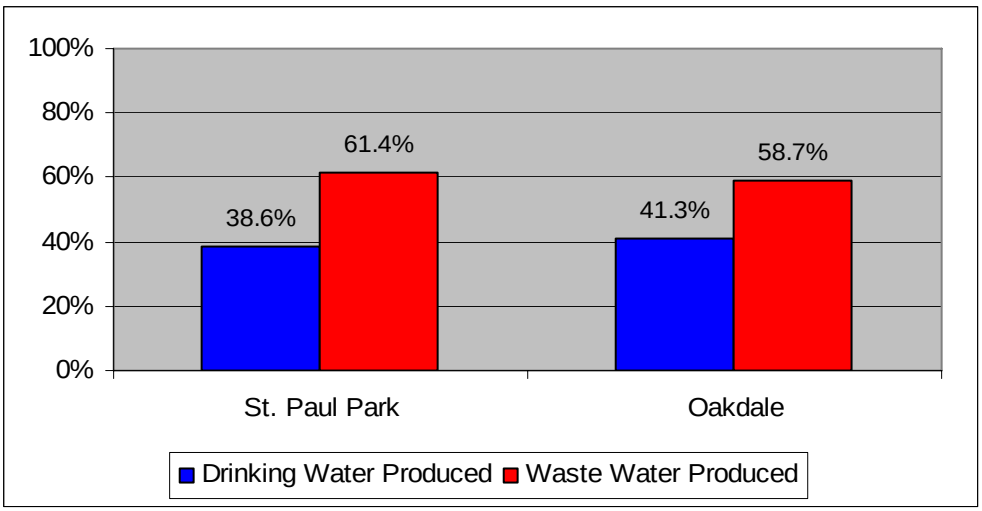
The average recovery rate (Permeate Flow/(Concentrate + Permeate Flow)) for the Kinetico RO is illustrated in Figure 8-32.

Figure 8-32
Kinetico RO Average Recovery Rate at Zero Outlet Pressure



As shown in the below Figure 8-33, for each one (1) gallon of drinking water produced, there were an average of 1.5 gallons of wastewater produced.

Figure 8-33
Kinetico RO Average % Drinking Water Produced
vs. % to Waste At Zero Outlet Pressure



8.5.2.6 Pentair - RO-3500EX with prototype GS post-RO ion exchange

Manufacturer Specifications

Feed Water	
Temperature Range	40 - 100°F (4.4 – 37.8°C)
Pressure Range	40-100 psi
Maximum Total Dissolved Solids (TDS)	< 1500 ppm
Turbidity	1 NTU Max.
pH	4-11
Manganese	<0.1 mg/L
Hardness	171 mg/L
Iron	<0.1 mg/L
Hydrogen Sulfide	<0.1 mg/L
Chlorine	<2.0 mg/L
Performance	
Service Flow Range	7.6 gal/day

Source: Manufacturer literature

Photo 8-10
Pentair RO-3500EX w/GS

Note: This device was a standard model Pentair RO system, but with a prototype ion exchange filter cartridge incorporated after the post-RO AC cartridge – an added polishing filter that Pentair is considering in a new model. The PFC Workgroup selected this prototype four-media system for both Phase I and Phase II since it was the only device offered with ion exchange media.

Manufacturers Recommend Service Schedule

The USL-NCR pre-filter cartridge should be replaced every 4 months, or earlier if feed water quality is highly turbid, and when the changing the membrane. The USL-CC post-polishing filter cartridge should be replaced at least every 12 months and when changing the membrane. The ROM-230T membrane and the ROM-230TN membrane should be replaced every 12-24 months.

Pilot Test Comments

The supply water and operating conditions were within range of the manufacturer's specifications with the exception of hardness. Table 8-13 lists the Pentair RO supply water parameters measured during the testing period.

Table 8-13
Pentair RO Supply Water Parameters (January 15, 2008 to April 21, 2008)

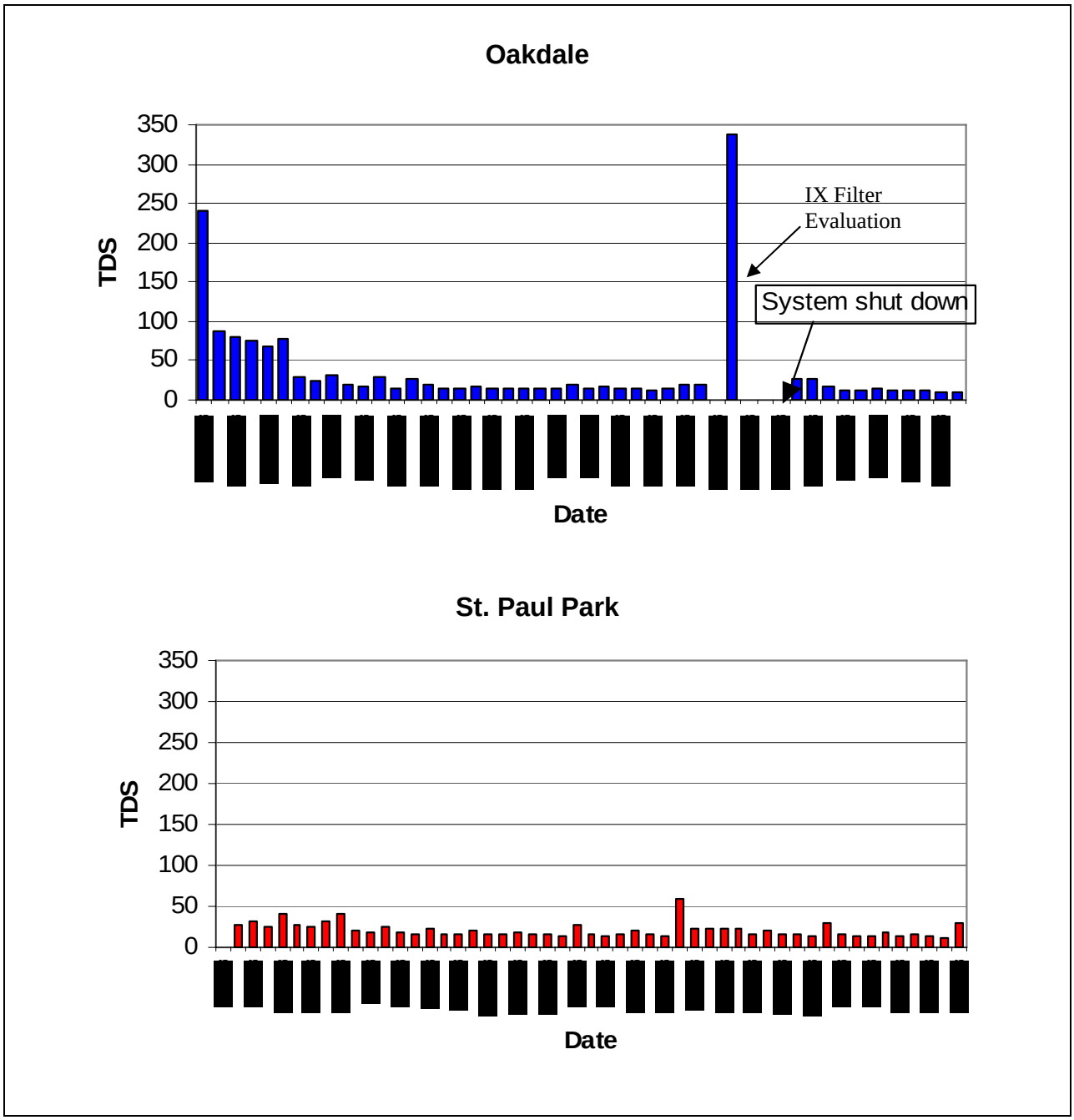
Parameter	# of readings	Average	Minimum	Maximum	Standard Deviation
St Paul Park					
Inlet Water Pressure (psig)	51	57.8	56	61	1.1
Inlet Water Temperature (°C)	51	6.9	4.4	11.2	1.5
Tank Water Pressure (psig)	46	25.4	4	58	21.6
Permeate TDS	50	21.1	12.2	58.6	8.6
Concentrate TDS	50	494.5	418.3	550	32.9
Permeate flow rate (ml/min)	51	30.4	26	40	2.8
Concentrate flow rate (ml/min)	48	146.8	135	162	5.8
Recovery Rate (%)	47	17%	15%	22%	2%
Oakdale*					
Inlet Water Pressure (psig)	48	49.9	40	58	3.9
Inlet Water Temperature (°C)	47	11.5	6.9	13.3	1.1
Tank Water Pressure (psig)	41	16.3	0	45.0	13.7
Permeate TDS	45	36.1	9.4	338.7	59.6
Concentrate TDS	45	1456.2	328.8	482.8	27.9
Permeate flow rate (ml/min)	45	27.5	20	34	3.6
Concentrate flow rate (ml/min)	45	132.9	118	145	6.8
Recovery Rate (%)	44	17%	12%	20%	2%

* Note - System shut down for additional TDS testing 3/24-3/26/08

Figure 8-34 illustrates the Pentair RO permeate TDS measurements at the two test sites. The TDS readings at the Oakdale site demonstrated elevated readings during the beginning for the test period. For the first 10 days of the test period, the TDS readings were in the range of 69 to 240 ppm. Further evaluation of the Pentair device was initiated to determine the cause of the elevated TDS readings. The ion exchange post filter was replaced on 3/20/08 to try and recreate the elevated readings. At start-up after this change out, TDS readings spiked to 860 TDS. The device was allowed to run continuously, and TDS readings returned to within normal ranges within 8 days. Subsequent testing demonstrated conductive material was being released from the prototype ion exchange cartridge. Subsequent testing by WSM and the PHL was unsuccessful in identification of this material. The device manufacturer was contacted, and after investigation, they determined that their ion exchange resin supplier had provided resin that had not been properly rinsed and was not tested by Pentair due to the timetable of this project. Subsequent testing performed by Pentair indicated the presence of chloride in association with an H+ cation. The TDS spike detected in Phase 2 represented the flush-out of this residue from the post-filter cartridge. It required several days and approximately 100 gallons of permeate to completely flush this material from the resin.

It should be noted that the Pentair RO-3500 EX device (the current commercially available model) with no ion exchange resin cartridge is expected to perform as well for PFC removal.

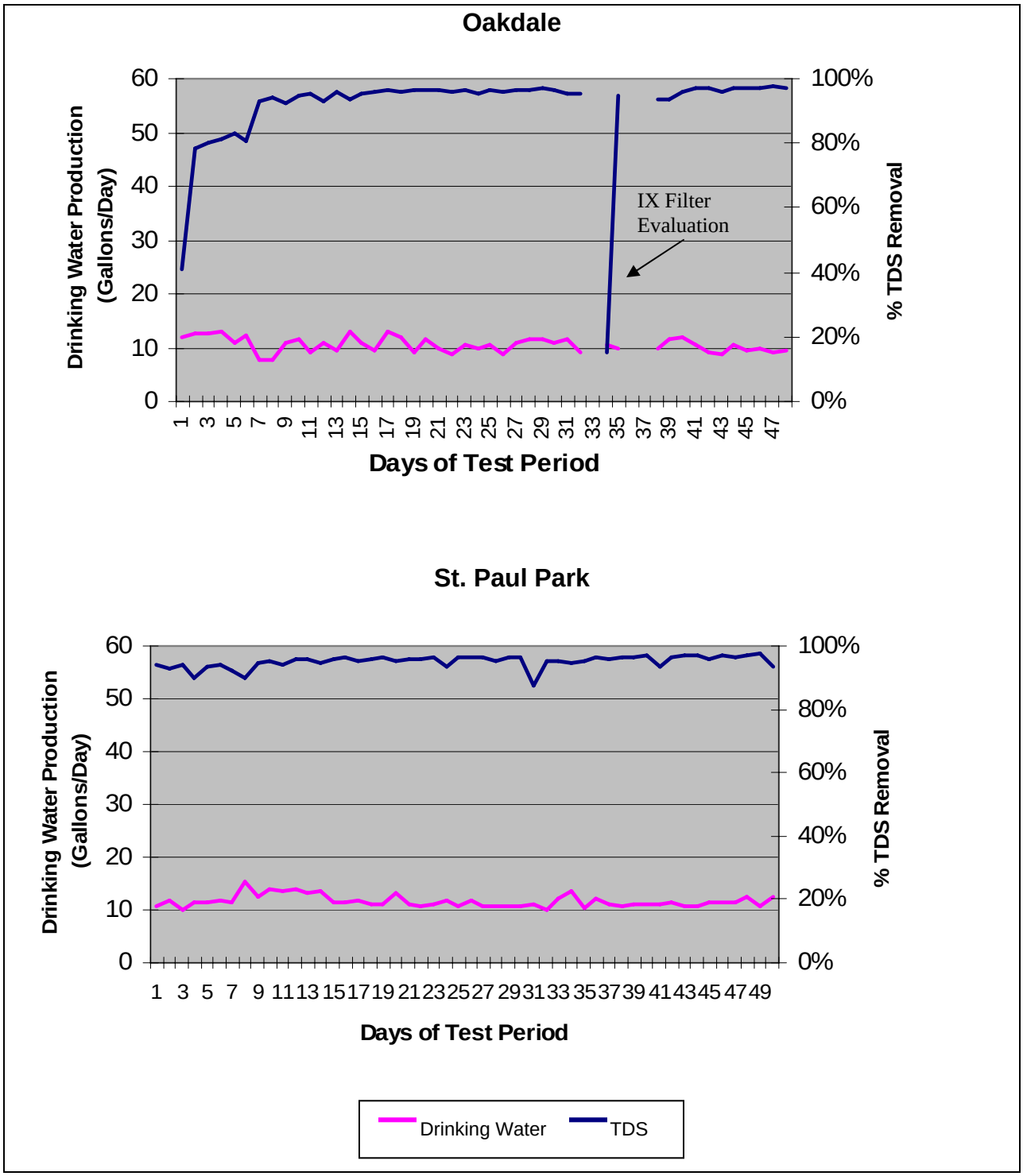
Figure 8-34
Pentair RO Permeate TDS



Due to lower than expected permeate flow rates, the Pentair RO was operated for an additional four (4) days of continuous operation at 0 psi tank pressure. This was done to achieve the challenge goal of 500-gallons.

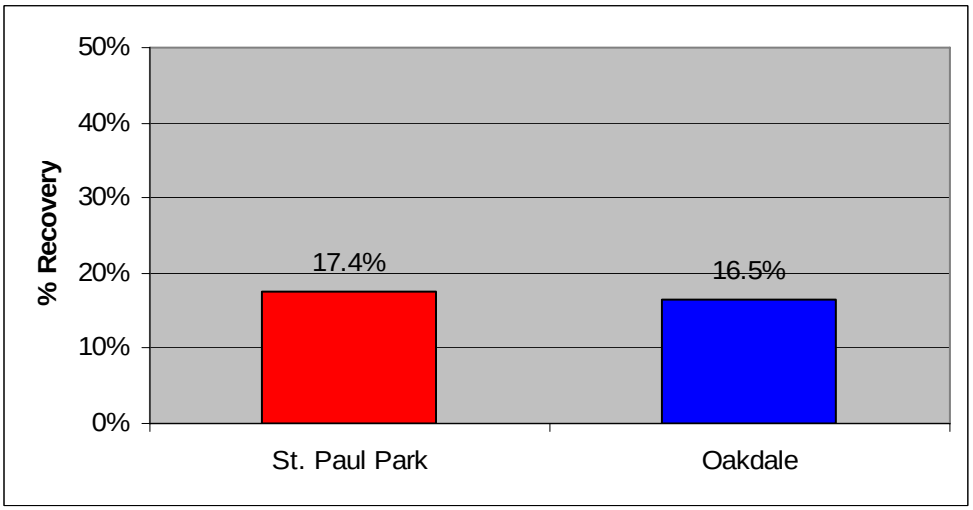
Field-testing on the Pentair RO established an average drinking water production rate at the two sites between 10.5 and 11.7 gallons per day, as illustrated in Figures 8-35 below.

Figure 8-35
Pentair RO Drinking Water Production
And Membrane TDS Removal Performance Over Duration of Test Period



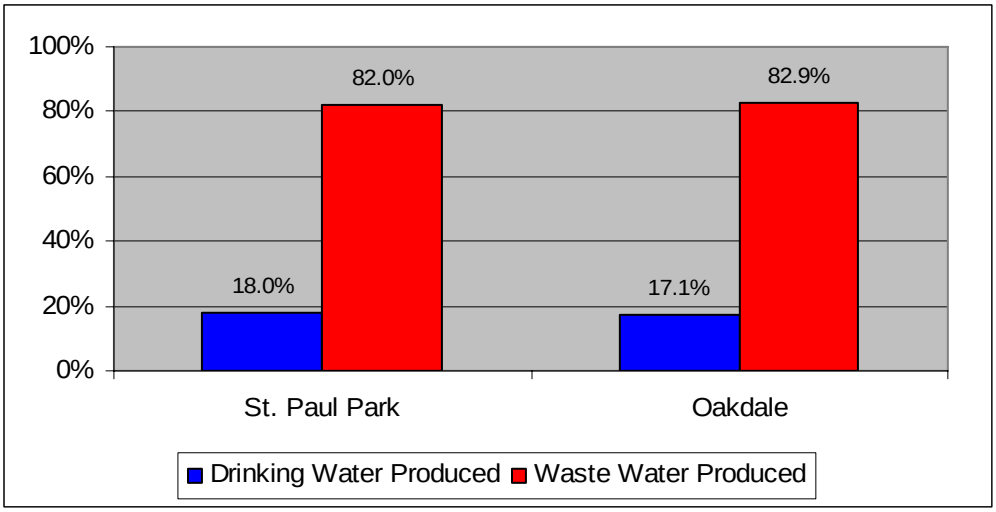
The average recovery rate [(Permeate Flow/(Concentrate + Permeate Flow) x 100%] for the Pentair RO is illustrated in Figure 8-36.

Figure 8-36
Pentair RO Average Recovery Rate at Zero Outlet Pressure



As shown in the below Figure 8-37, for each one (1) gallon of drinking water produced, there were an average of 4.7 gallons of wastewater produced.

Figure 8-37
Pentair RO Average % Drinking Water Produced
vs. % to Waste At Zero Outlet Pressure



8.5.2.7 Watts Premier - WP-4V

Manufacturer Specifications

Feed Water	
Temperature Range	40 - 100°F (4.4 – 37.8°C)
Pressure Range	40-85 psi
Maximum Total Dissolved Solids (TDS)	< 1800 ppm
Turbidity	< 5 NTU.
pH	2-11
Hardness	170 ppm
Iron	<0.1 mg/L
Performance	
Service Flow	9 gal/day

Source: Manufacturer literature, tested and certified by NSF International to NSF/ANSI Standard 53 and NSF/ANSI Standard 58.

Photo 8-11
Watts Premier WP-4V

Manufacturers Recommend Service Schedule

The sediment and carbon pre-filter should be replaced every 6 months. Replace the VOC Block post-filter every 12 months or 600 gallons. Membranes have a life expectancy between 2 and 5 years, depending on the incoming water conditions and the amount of use of the RO system. The product water should be tested periodically to verify that the system is performing satisfactorily.

Pilot Test Comments

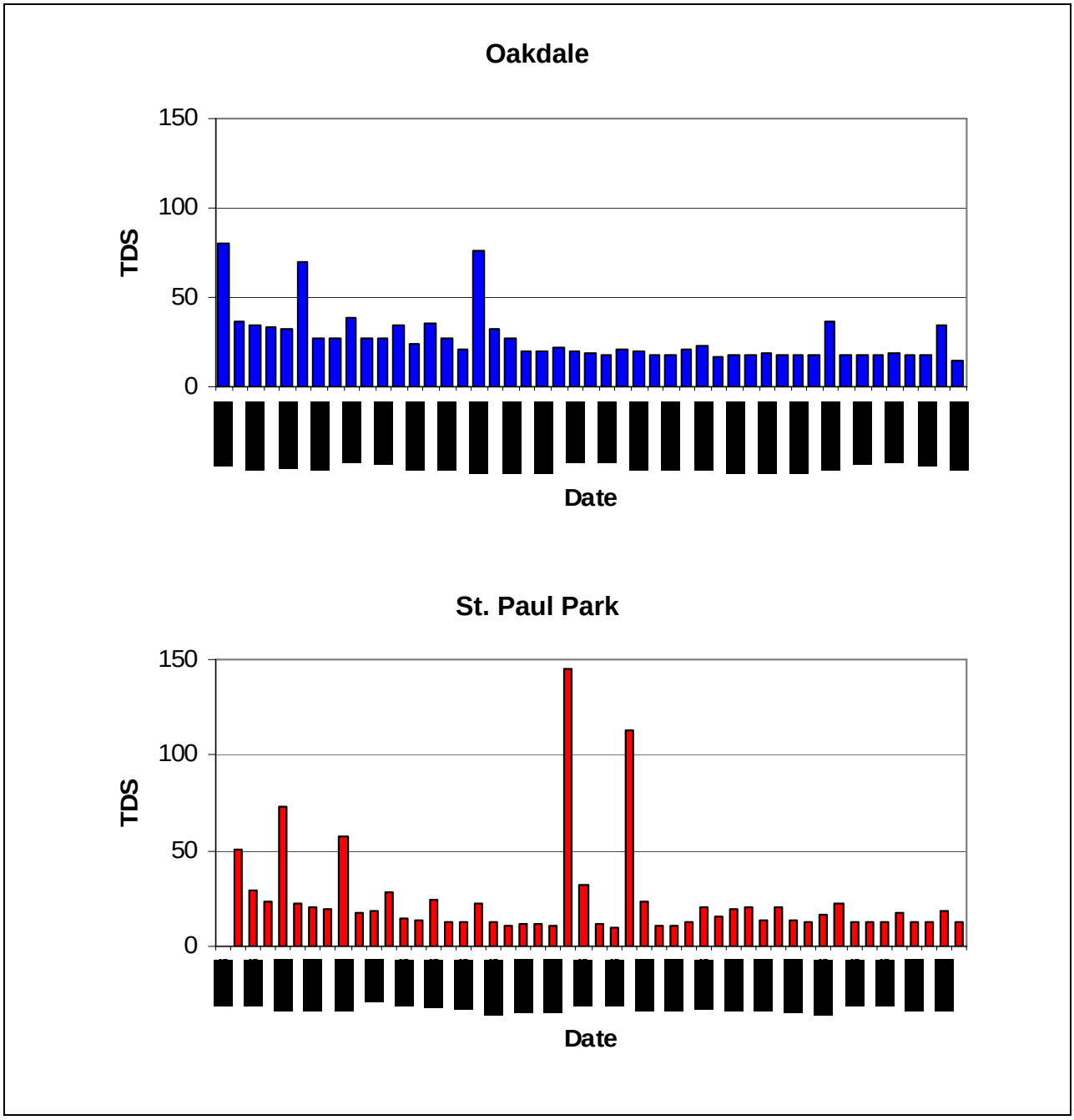
The supply water and operating conditions were within range of the manufacturers specifications except for hardness. Table 8-14 lists the Watts RO supply water parameters measured during the testing period.

Table 8-14
Watts RO Supply Water Parameters (January 15, 2008 to April 18, 2008)

Parameter	# of readings	Average	Minimum	Maximum	Standard Deviation
St Paul Park					
Inlet Water Pressure (psig)	50	57.9	56	61	1.1
Inlet Water Temperature (°C)	48	6.8	4.4	11.2	1.5
Tank Water Pressure (psig)	45	20.3	4	49	14.8
Permeate TDS	49	24	10	144.9	25.2
Concentrate TDS	49	518	425	710.4	38.5
Permeate flow rate (ml/min)	50	42.5	26	77	13.2
Concentrate flow rate (ml/min)	48	184.6	138	205	10.9
Recovery Rate (%)	47	18%	12%	29%	4%
Oakdale					
Inlet Water Pressure (psig)	47	49.2	40	50	3.8
Inlet Water Temperature (°C)	46	11.6	9.9	13.3	.08
Tank Water Pressure (psig)	42	15.3	6	35	9.1
Permeate TDS	47	26.8	14.7	80	14.4
Concentrate TDS	47	478.9	384.1	515.6	26.1
Permeate flow rate (ml/min)	47	34.2	23	48	7.6
Concentrate flow rate (ml/min)	47	142.8	118	270	21.6
Recovery Rate (%)	47	22%	19%	24%	3%

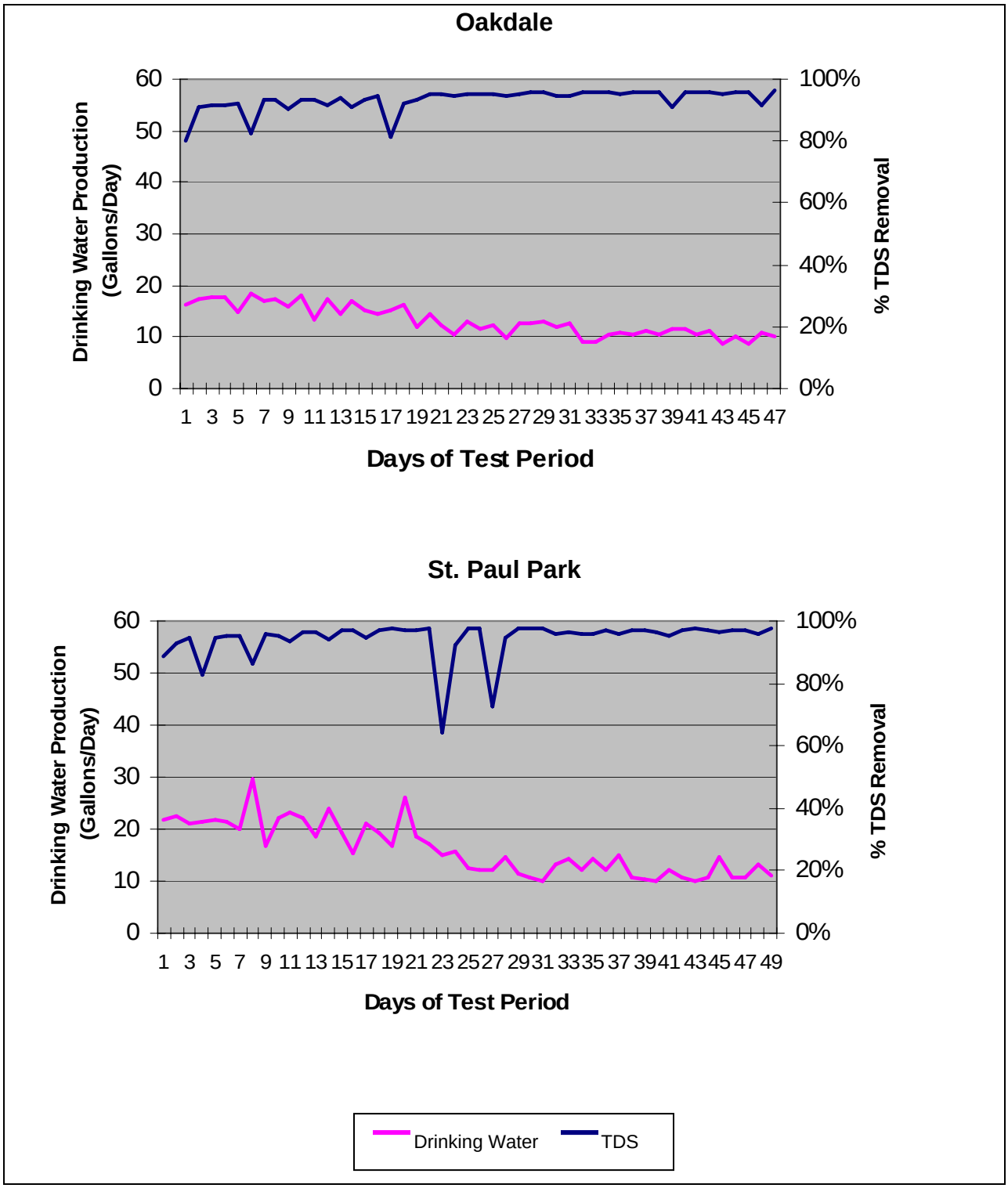
Figure 8-38 illustrates the Watts RO permeate TDS measurements at the two test sites. The TDS readings were consistent per site, with the exception of a couple values. On 2/22/08 at the Oakdale site a supply value closed overnight, which lead to an elevated TDS measurement. On 2/29/08 and 3/7/08 at the St. Paul Park site a concentrate line valve was shut off leading to the elevated readings as well.

Figure 8-38
Watts Permeate TDS



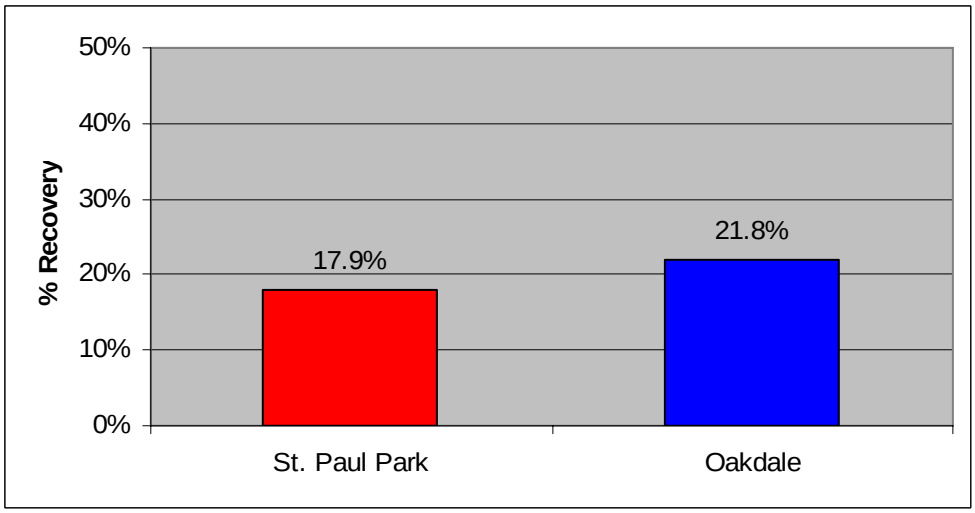
Field-testing on the Watts RO established an average drinking water production rate at the two sites between 13.1 and 16.1 gallons per day, as illustrated in the Figure 8-39 below.

Figure 8-39
Watts RO Drinking Water Production
And Membrane TDS Removal Performance Over Duration of Test Period



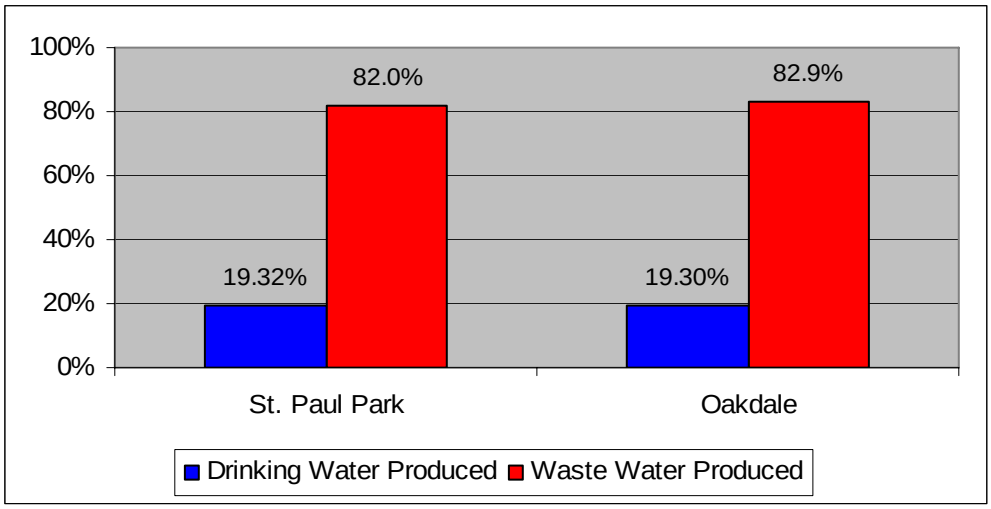
The average recovery rate (Permeate Flow/(Concentrate + Permeate Flow)) for the Watts RO is illustrated in Figure 8-40.

Figure 8-40
Watts RO Average Recovery Rate at Zero Outlet Pressure



As shown in the below Figure 8-41, for each one (1) gallon of drinking water produced, there were an average of 4.2 gallons of wastewater produced.

Figure 8-41
Watts RO Average % Drinking Water Produced
vs. % to Waste At Zero Outlet Pressure



8.6 QA/QC

8.6.1 Analytical Laboratory QA/QC

The Public Health Laboratory provided this information on their QA/QC samples for perfluorochemical analysis as performed by the Minnesota Department of Health Public Health Laboratory. Sample analysis followed MDH LIMS analysis code 555 utilizing high-pressure liquid chromatography/mass spectrometry/mass spectrometry. LIMS code 555 includes robust QA/QC incorporating the following criteria within every batch.

1. Samples are collected in contaminant free containers
2. Samples are analyzed within holding time
3. Batch analysis includes no more than 20 samples not including QC
4. A valid analytical batch includes a calibration curve or calibration verification check sample, report level verification check sample, method blank, instrument blank, sample duplicate, spike and spike duplicate, and samples. All QC samples must pass method criteria for sample data to be acceptable. In cases where QC criteria are not met sample results must be "flagged" on the client report.
5. Quantification is by the internal standard technique.
6. Qualitative identification is based on molecular ion transition to a primary or secondary ion and analyze retention time.
7. A report level of 0.2 ug/L has been determined for each analyze of interest. Positive identification, but estimated quantification, is reported down to 0.05 ug/L.

8.6.2 Sensor Accuracy

Accuracy of pressure gauges was verified with a NIST traceable pressure gauge. Accuracy of flow meters was verified by measurement of time/volume method using a graduated cylinder. Verification of accuracy for each sensor/gauge was recorded within WSM's field notebook.

Chapter 9
Conclusions, Observations and Recommendations

9.1 Conclusions

The primary objective of this study was to evaluate commercially available residential POU water treatment devices for their ability to remove PFC molecules down to accepted health limits. In August 2007, MDH enacted a rule with Health Risk Limit (HRLs) for PFOA and PFOS of 0.5 ppb and 0.3 ppb, respectively, under emergency rule making authority granted by the Minnesota Legislature. In February 2008, MDH issued a Health Based Value (HBV) for PFBA of 7 ppb based on studies conducted over the previous year. An HBV is similar to an HRL, but has not been formally enacted through rulemaking. In this evaluation, the analytical quantification limit was 0.2 ppb for each of the three PFC molecules and with a detection limit down to 0.05 ppb.

9.1.1 Effective Devices

Based upon the results of this study those seeking treatment for PFC removal from their drinking water can be reasonably assured that all point-of-use devices evaluated in Phase I-B and Phase II (refer to Table 9-1) will provide effective treatment when applied and used in accordance to manufacturers' specifications for up to 500 gallons of treated water.

Table 9-1
Successful POU Water Treatment Devices for PFC Removal

Device Manufacturer/(Model Number)	PFC Removal Technologies Used		
	Activated Carbon	Reverse Osmosis	Ion Exchange
Aquion Rainsoft Hydrefiner (P-12 9878)	X		
Culligan (RC-EZ-4)	X		
Kinetico (MACguard 7500)	X		
Sears Kenmore (Elite 625.385010)	X		
Culligan (Aqua-Cleer)	X	X	
Ecowater (ERO-375E-CP)	X	X	
GE (Smartwater GXRM10GBL)	X	X	
Kinetico (Plus Deluxe VX)	X	X	
Pentair (RO-3500EX w/ GS)	X	X	X
3M/CUNO/Water Factory (SQC-3 (04-045))	X	X	
Watts (Premier WP-4V)	X	X	

9.1.2 Fouling Effect on PFC Removal

During the field test on actual groundwater, the fouling of media (known to occur in both media types tested here) did not have a measurable effect on PFC removal. No impact on either the activated carbon adsorption mechanism, or the RO membrane rejection mechanism, was noted from the accumulation of matter on these media.

9.1.3 Temperature Effect on PFC Removal

The colder water temperature of the field tests compared to the lab tests had no measurable effect on PFC removal

9.1.4 RO Performance Over Time

For the RO-based systems, no loss of PFC removal performance was measured over 13 weeks and throughput volumes up to 960 gallons. This matches expectations based on the well understood aspects of RO membrane lifetime, and also matches expectations based on the results of the two laboratory tests in this project.

9.1.5 AC Performance Over Time

For the AC filter devices in general, an increasing loss of PFC removal performance at throughput volumes starting near the end of rated life was noted, as detailed earlier. This matches expectations based on the well understood AC removal mechanisms, and also matches expectations based on the results of the two laboratory tests in this project

9.2 Observations and Recommendations

9.2.1 Need for Media Replacement and Proper Operation

It is important to understand that all such devices will only perform as well as they are properly applied, operated, and maintained. It is also important to understand that activated carbon filters use an adsorptive mechanism of removal, and therefore have a finite life based on the amount of adsorbing contaminants (including PFCs) present in the feed water. Periodic filter replacement is required.

9.2.2 Removal Effectiveness for Different Media Types

As noted there are several different media types for both RO and AC available to device manufacturers. The scope of this study did not allow determination of relative differences among the RO membranes, or AC media available in POU devices. Further study is required to determine if certain media variants are superior or inferior.

9.2.3 Current Product Certification Ratings

The NSF/ANSI certification standards allow for ratings of removal for some organic molecules. It should be noted that water treatment device certification to current NSF/ANSI standards for the removal of organic contaminants cannot be used to suggest performance for PFC removal.

9.2.4 Water Draw Rate of Commercially Available POU Devices

A practical aspect of this study was that its scope was limited to devices currently marketed as POU products. By design, these devices deliver lower flow rates than homeowners are accustomed to receiving from drinking water faucets alone. Accordingly, those homeowners that desire to reduce the concentration of PFC's from the water they use for drinking, cooking, etc. must be willing to accept that it will take longer to draw water for these purposes through a POU treatment device. Given this limitation, it is recommended that larger AC filters be evaluated for PFC removal as they may provide homeowners with similar PFC reduction as those included the current evaluation, but at flow rates they are accustomed to. Such AC filters are generally marketed for whole house treatment applications (or point-of-entry devices).

For those who prefer assurance in removing the maximum level of PFCs possible, devices incorporating both reverse osmosis and activated carbon technologies (RO systems) may be preferred over devices incorporating a singular adsorptive technology such as an AC filter. With this preference comes the cost of lower daily production capacity, reductions in flow rate relative to storage tank depletion, and initial purchase price. Conversely, devices utilizing activated carbon alone offer simplicity of installation, greater daily production, and will maintain higher and more consistent production flow rates.

9.2.5 Refined Effort at PFC Removal Characterization

Since this project represents the first comprehensive, independent study evaluating the ability of residential water treatment systems to remove PFC's, the POU - PFC Workgroup and WSM took a conservative approach in the development of test methodology and protocols. While the performance data resulting from these efforts is provided with confidence, as previously discussed these test methods should be refined and enhanced with continued testing and validation.

9.2.6 Technical Factors Affecting Device Performance

The scope of this project did not include investigating PFC removal mechanisms by the media tested, or how device design and operational characteristics of residential water treatment devices will affect performance. Those questions require greater investigation. However, based on current knowledge some of these issues are known and were addressed by the test protocol.

9.2.6.1 Adsorption Filters

All Activated Carbon devices tested were filters with media based on activated carbon (AC). The range of activated carbon media varies significantly. These variations depend on several

factors, including; differing sources of starting material (e.g. coal and coconut shell etc.), the processing techniques used to activate and regenerate the carbon, proprietary additional treatment techniques and additional chemicals added into the media. Often these additives are intended to remove additional materials that "raw" AC does not remove well (e.g. lead, MTBE fuel additive, etc.). While several different AC media were included within the devices selected for this evaluation, further study is required to determine optimal carbon specification and related residence time for PFC removal.

Further, to the degree to which PFC molecules are inhibited from adsorption or entrapment as an AC filter is used was addressed only in a limited fashion, and so is still an open question. While adsorption of PFCs may be the primary mechanism of removal, it is known that the porous nature and packing characteristics of the AC media also provides for physical entrapment of particles. An AC filter is a particle, as well as, an adsorptive filter. It is well understood that particle filters designed to accumulate significant concentrations of contaminants on and within the filtration media may release particles with change in flow hydraulics (known as "particle sloughing"). This is especially noted when flow stops and restarts, where particle counts within the filtrate can increase by orders of magnitude.

Table 9-2
RO System Performance: First Test- PFBA

First test - PFBA only Feed concentration	**Day 1 - 12 hour** PFBA- 10	**Day 2 - 30 hour** PFBA- 10	**Day 3 - 54 hour** PFBA- 10	**Day 4 - 78 hour** PFBA- 10	**Day 7 - 144 hour** PFBA-10	**Day 7 – 148 hour** PFBA-10
GE Merlin - PM	1.2 ug/L	0.3 ug/L	0.3 ug/L	0.2 ug/L	1.9 ug/L	0.8 ug/L
GE Merlin - PF	1.6 ug/L	2.0 ug/L	1.5 ug/L	1.2 ug/L	2.0 ug/L	1.6 ug/L
Note: PM = Post Membrane sample PF = Post AC Filter sample						

Greater understanding of how strongly differing variants of PFC's are bond to different species/chemistries of activated carbon medias is needed. Also, it is recommended that AC filter test methodologies used for performance evaluation be designed to collect filtrate samples in association with measured increases in particle concentration.

9.2.6.2 <u>RO Membranes</u>

It was determined that the optimum period for sample collections included water drawn after post-stagnation periods (see section 7.2.2). In Phase II the POU devices were evaluated as complete units, as they would be purchased and used within a residential setting. TDS measurements were taken from sample taps located after post-membrane treatment components. While pre-stagnation water had been voided from the storage tank in advance of shutdown, significant volumes remained within post-membrane components, which would mix with the start-up permeate from the system. Therefore, due to this dilution, recorded TDS measurements at post-stagnation sampling points understate actual new permeate levels.

One dataset from Phase I provides insight regarding the observations made above (Table 9-2) where the results suggest release of PFBA from a post RO membrane AC filter.

This important because within a residential application, RO systems normally do not operate on a continuous basis; water is only drawn on a periodic basis. For some installations (e.g. families with kids in school and working parents) this may translate to morning and evening hours. In others such as vacation homes, or in locations of infrequent use (such as in bathrooms, guest quarters, and recreational areas), water may be drawn only once per day, week or longer. Therefore a RO-based system may be in extended periods of stagnation, and the entire stored volume may be affected by stagnation phenomenon. It is expected the post-AC filter will be capable of removing these contaminants (in this case PFCs), but in these cases the post-filter life may be shorter.

9.2.7 Residential Water Use Patterns and Further Study

Since patterns of use (as noted above) can vary dramatically in ways that may affect PFC removal, this study cannot be said to validate RO systems performance for **all** residential applications without qualification.

The performance of both RO systems and AC filters are influenced by the manner they are used within a household setting. While some US household data on total gallons used per day and volume per use is available, in order to either speculate on or design test protocols to demonstrate PFC removal performance under the range of possible circumstances, hydraulic conditions a water treatment device will be subjected to (e.g. on/off cycles, length/frequency of stagnation periods and fluctuations in pressure and flow rate)

9. 3 Summation

Due to the urgent need to provide scientifically supportable and research-based performance information for homeowners pursuing PFC removal solutions, it was necessary to design this study within a limited budget and secure data within the shortest feasible period of time. As a result, a limited number of commercially available equipment/technology options could be included within this study. Performance results from this small sample set of the vast number of commercially available POU devices can only provide inference vs. assurance regarding how other devices/systems of similar design may perform. It is also noted that of all devices meeting selection criteria for this study, only 14 were included. When subjected to the test conditions included in the current study, 3 or 20% (one RO-Based system and two AC filters) of the selected sample set would not be recommended for PFC removal.

In addition, the orientation of this study was device vs. technology driven. Greater understanding of PFC removal mechanisms and operational characteristics/limitations of the component technologies applied within such devices/systems require further investigation. Water treatment device manufacturers, product certification organizations, and public health protection agencies are encouraged to:

1. Refine the test methodologies used in this study.
2. Develop standardized testing methodologies for device operation, sampling and analytical techniques.
3. Investigate mechanisms of PFC removal, and application and operational criteria that may be affected by those mechanisms.
4. Evaluate additional potential base technologies for PFC removal or destruction.
5. Promote the evaluation of a greater number of POU and POE devices for PFC removal.

Chapter 10
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