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"SCOTTSDALE UNSALTED": A REVIEW OF ALTERNATIVE SALT-FREE WATER TREATMENT TECHNOLOGIES FOR EFFECTIVE SALINITY MANAGEMENT*

Executive Summary

Water conservation, supply management, sustainable water quality, and salinity reduction are inextricably linked challenges in Scottsdale's water future. Various sources and reports conclude that the Phoenix metropolitan region accumulates salts at an estimated net rate of 1.2 million tons annually. The accumulation ~~presence~~ of salts in the water supply significantly increases the cost of reclaiming water for irrigation and treating water for recharge. ~~threatens to taint sub-surface aquifers and limit the ability of the region to recycle water from both consumer and industrial sources.~~ Sustainability of the regional water supply~~ies~~ requires that the~~is~~ long-term net salts balance ~~must~~ be reduced. ~~-~~ Failure to do so will require municipalities within the region to adopt expensive treatment options. ~~so that there will be sufficient potable water supply to support increases in population and industry.~~

The City currently spends $ 3 Million annually to manage this salinity issue~~s. related to recycling water for injection into existing aquifers and supply to irrigation users.~~ Should current methods fail to keep up with increasing salinity levels, the next option would be the construction of a desalinization plant for the City of Scottsdale which would cost an estimated ~~whose cost would be in excess of~~ $~~-~~90 m~~M~~illion and whose operation would add an additional $~~-~~2 m~~M~~illion to current water management expenses.

One of the significant contributors to the accumulation of salts for the ~~salinity issue facing the~~ City of Scottsdale water treatment is the use of home based water softeners. It is estimated that residential water softeners add between 15 to 20 percent to the salts load from supplies treated and delivered in the service area.~~—.~~

Comment [1]: Is that right to refer to them as salts? Plural - because there is more than one type-- Ca & Mg.

It sounds wrong here

The purpose of this white paper is to provide a qualitative comparison of four ~~(4)~~ salt-free alternative technologies relative to typical residential salt-based water softening and recommend the city ban time-initiated water softeners. This paper provides a comparative evaluation of these alternative technologies.

Comment [2]: Is this where a call to ban the time-initiated could go?

The central conclusion of this report is that the technical and economic assessment of these technologies is evolving and a number of challenges remain to making direct quantitative comparisons between the four options that are currently available. However, one technology - Template Assisted Crystallization (TAC) - appears to be the most effective for those that are available at this time. Finally, the paper offers suggestions for follow up and policy recommendations.

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Problem Statement and Paper Objective

Increasing salinity due to salt build up through continual importation of higher salt water sources (surface water) and advanced treatment of the City's wastewater stream (reclaimed water) for irrigation use and aquifer recharge is a rapidly emerging water management issue for Scottsdale. If salinity levels continue to rise and future salinity limits are imposed by regional jurisdictions, a standalone brine disposal facility could cost Scottsdale an estimated $90 million to construct and $2 million per year to operate (JLSC Strategy for Water Softener Salinity Control and Management, 2014).

Comment [3]: I don't like this phrase 'continual importation.' Suggestion for alternative?

Recent studies indicate that salt reduction at the ~~initial~~ source, ~~reducing salinity~~ before it enters the municipal wastewater stream, is the most cost effective option. Sodium, much of it from residential and commercial water softening, is the single component projected to have the greatest impact on regional salinity. As a result of ~~this~~ increasing salinity, Scottsdale estimates it currently spends $3 million in annual operating costs to remove salinity from potable and reclaimed water supplies.

Comment [4]: Need citation(s)

Comment [5]: Citation needed

Addressing this salinity management concern, in 2008 the City developed an initial assessment of salinity impacts and recommendations for sodium reduction in Scottsdale's reclaimed water supplies. This internal report (referenced in the bibliography) was prepared by Water Resources staff and provided an overview of the salinity concern in the City's water sources. This assessment became the foundation~~, together with more detailed research and analysis in water-wastewater master plan updates,~~ for the City's two year pilot salinity reduction rebate program for residential water softening devices, implemented in July 2014.

~~The initial rebate program, designed to focus on customer-generated salt impacts of residential softener usage, comprises a two-year pilot program.~~ This pilot program tested the rebate approach and dollar amounts for three options ~~focused on three options to reduce residential water softer impacts, test the rebate approach including rebate amount for each option and measure the public's response~~ to mitigate the salinity issue.

This white paper provides a qualitative comparison of four (4) salt-free alternative technologies relative to residential salt-based water softening such as ion exchange. Each of these alternative technologies is typically referred to as water conditioning or treatment through physical or mechanical processes. Water is not chemically softened through these processes. No ion exchange occurs using these water conditioning alternatives to remove the hardness component. Rather, the~~se~~ scale forming components of hard water are modified through water treatment or conditioning such that scale does not build up on home plumbing and appliances.

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The goal of this report is to provide a comparative evaluation of these alternative technologies. With this information the City can provide background and input to residential and commercial customers allowing them to make informed decisions on replacing conventional water softeners. The results of this effort are not exhaustive and should be considered a work in progress. This is because the development of performance standards, device testing and certification of the technologies, by independent industry organizations, are themselves in progress and not complete in all cases. In addition, key operational parameters of interest, such as long-term reliability, annual operating costs and long-term (10 year) capital costs are not universally available .

Comment [6]: Couldn't we just say 'currently, there aren't industry standards available on water conditioning, as there are with water softening devices'

EQAB, however, feels that this assessment of initial information is useful to City decision makers, as well as residential and commercial water customers. This is the context in which this background and these recommendations are provided.

Introduction to Water Salinity and Impacts in Scottsdale

Hardness is caused by compounds of calcium and magnesium, and by a variety of other metals that readily dissolve in water.~~-~~ General guidelines for classification of waters are: 0 to 60 mg/L (milligrams per liter) as calcium carbonate is classified as soft; 61 to 120 mg/L as moderately hard; 121 to 180 mg/L as hard; and more than 180 mg/L as very hard. Most of Arizona has hard water. The minerals in hard water precipitate or interact with the materials in plumbing service lines, plumbing fixtures, dishwashers and other~~comparable pieces of~~ household appliances and commercial equipment. The impact of this chemical reaction is to eventually caus~~eing~~ blockage, mal-function and premature failure of these devices.

In addition, hard water reacts with soap and detergent. The resulting "soap scum", reduces the ability to achieve cleanliness; whether it be personal, related to clothing or related to surfaces such as sink tops, counters and floors.

The presence of hard water is normally addressed through the use of ion exchange water softening systems. These systems require the use of salt (Sodium Chloride) to replenish the ion exchange column once it gets saturated with the Calcium and Magnesium ions from the water. The "back flushing " operation of these systems, which releases large amounts of salt into the waste water stream, is a major contributor to the salinity issue facing the City.

Comment [7]: Is this where we could insert something about time-initiated be demand-initiated ion exchange softeners?

Simply defined salinity is the total amount of both natural and inorganic minerals dissolved in water. Such dissolved minerals are commonly referred to as salts such as sodium, potassium, calcium, magnesium, sulfate and chlorides measured as total dissolved solids (TDS) in milligrams per liter (mg/l).

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Reclaimed water is the only water supply that expands with increased municipal water use. Reclaimed water is also the source most directly and immediately impacted by high salinity. In 2014, the City treated and delivered an estimated 2.1 billion gallons (6,445 acre feet) of reclaimed water for turf irrigation and more than 1.3 billion gallons (3,990 acre feet) of advanced treated reclaimed water to underground storage through recharge. To make the most beneficial use of these reclaimed water supplies, they must be treated to reduce salinity to acceptable levels.

Comment [8]: Do we have or can we get 2015 data? Needs citation.

In the Phoenix metropolitan region, various sources and reports conclude that the region accumulates salt at an estimated net rate of 1.2 million tons annually. The impact and costs of regional salinity are subtle and dispersed across all societal sectors with an estimated increased cost of more than $30 million for the Phoenix metropolitan region. Sustainability of future water supplies will require that this long-term net salt balance must be maintained ~~(and not increase)~~ in order to preserve quality of the existing groundwater and reclaimed water.

Scottsdale continually evaluates salinity loading in reclaimed water supplies and its impacts. Estimates indicate that nearly a third (32 %) of the total salinity is derived from residential and commercial softening diverted into the wastewater stream.

As salinity levels of reclaimed water increase at the same time as reuse of reclaimed water also increases, salinity will itself become an ever increasing management challenge. Therefore, over the long term the two resource issues have compounding impacts and salt sources must be diverted from the regional wastewater treatment stream and reuse cycle. One solution to the salinity issue that can be controlled is diversion of a portion of this contributing salt load from the regional wastewater stream. Water softening from all possible activities is one of those "point of diversion sources" that can be effectively managed through future water salinity policies.

Approach to Technology Assessment

This EQAB effort has been a collaborative endeavor. In addition to independent research, we engaged other informational sources. We invited and benefited from four briefings by City Water Resources staff focused exclusively on salinity management issues and reduction strategies, both before and following adoption of the 2014 salinity rebate program. The Board also hosted and participated in three presentations at monthly Board meetings made jointly by the Arizona Water Quality Association (a state-level non-profit trade organization) representatives and technical and regulatory policy staff of the national Water Quality Association, an international non-profit trade association of the water treatment industry. These sessions included periodic updates of the process for standard development, testing and certification of the salt-less scale reduction (water conditioning) technologies.

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In addition, a representative of the Board participated in meetings of the Arizona Joint Legislative Study (JLS) Committee's Technical Advisory Committee as the advisory committee developed its final report to the JLS, titled *Strategy for Water Softener Salinity Control and Management*, January 22, 2014. (This report is listed in the bibliography for reference.)

In 2013, the Board also reviewed and offered general comments on the draft Project Report titled *Evaluation of Alternatives to Domestic Ion Exchange Water Softeners.* (This final publication is available as a download or hard copy at: https://www.watereuse.org/watereuse-research/08-06-evaluation-of-alternatives-to-domestic-ion-exchange-water-softeners/.) This research study conducted for the WateReuse Research Foundation was a laboratory bench test of four alternative scale reduction treatment devices compared to conventional ion exchange.

Overview of Salt-Free Alternative Technologies

With advances in water softening and conditioning, consumers now have alternatives to traditional salt-based ion exchange softeners. This section provides an overview and comparison of currently available salt-free technologies. These water treatment technologies are commonly referred to as either: 1) salt-based ion exchange water softening or 2) alternative technology salt-free water conditioning through physical and mechanical processes. Each of these technologies is described more completely and summarized in **Appendix A** and **Table 1**.

The four salt-less alternatives evaluated include: capacitive deionization (CDI); electrically induced precipitation (EIP); magnetic water treatment (MWT); and template assisted crystallization (TAC).

Salt-free technologies do not require any drain discharge or special back washing of media in order to function. These technologies function by changing the nature of the dissolved solids so they will not precipitate out of solution as water moves through supply lines and fixtures. Thus salt-free technologies reduce scale build-up of dissolved minerals that cause hardness forming scale but do not chemically soften water. In addition, these technologies do not require the use of additional water to purge their system as opposed to conventional salt based systems which use fresh water as part of their back flush operation.

A fifth alternative is actually an in-home portable exchange tank (PET) service that uses conventional ion exchange water softening in a portable tank for exchange. This option provides an in-home service to the residential user by periodically replacing exhausted ion exchange tanks. Though using ion exchange (IEX) as the softening process, this in-home service is in effect a salt-free alternative at the residential level, since it diverts the self-regeneration brine stream from the municipal wastewater stream to a centralized commercial facility.

Evaluation Criteria

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To compare and make qualitative assessments among the alternative technologies relative to ion exchange softening (IEX), a matrix of the most relevant criteria was developed. These criteria are represented in **Table 1.** The seven key criteria selected include: a salt requirement if any, maximum power requirement to operate the system, the backwash requirement if any, scale removal efficiency, estimated 10-year life cycle capital costs, and two key operational parameters of reliability and annual operating costs. Whenever quantifiable data were available and could be documented, specific data were used for comparisons.

Information on -long-term operational reliability was not often available. Furthermore, in some cases annual operating cost data were incomplete or otherwise not well defined. Therefore estimates and only relative comparisons were used. As such data becomes more readily available rankings based on those criteria be updated. Ongoing development of testing standards, performance test results and certification of specific devices by certifying organizations will be a reliable source for such updated information and improved comparisons.

<u>Summary</u>

The EAQB has determined that there are effective salt-free alternative technologies to salt-based ion exchange water softening. While these technologies do not soften water by direct removal of hardness per se, they do

- provide many of the other benefits of salt-based softening; particularly effective scale prevention. A major benefit to these salt-free water conditioners is that they retain all essential minerals for healthier drinking water.

As illustrated in **Table 1** most alternative technologies require no chemicals or salt, electricity or back flushing for brine discharge and disposal. Furthermore, no additional water is required for their operation. This translates into minimal maintenance compared to softening processes.

Of the technologies under review, TAC performs substantially better than other technologies against the evaluation criteria and demonstrated the most significant potential as an effective option to salt-based softening.

Results and Recommendations

A central conclusion of this effort is that assessment of these technologies is evolving and a number of significant data challenges remain to thoroughly and effectively compare them. The most important unknowns identified by this study are:

1. Verifiable information on life-time operational reliability
2. Long term capital investment and,

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3. Annual operational costs.
4. A lack of accepted standards for evaluating these technologies, resulting in
5. The absence of a certification process that could be conducted by recognized testing organizations.

In some cases there are the standards that are evolving, but actual testing of devices against these performance standards has not yet been started by certifying organizations.

The following conclusions, proposed follow up and policy recommendations are submitted:

1. With no endorsement of brand, manufacturer or vendor, the TAC conditioning technology appears to be both the most advanced and effective based on current testing and verifiable results.
2. Other alternative technologies with some but limited promise ranked in relative order of highest scale removal efficiency and residential application include: 1) capacitive deionization (CDI); 2) electrical induced precipitation (EIP); and 3) magnetic water treatment (MWT);
3. City and EQAB should continue to monitor and interact with WQA and other accredited testing and certification bodies for progress and updates for each of the above technologies as well as new technologies that might develop.

Given the potential impact of increasing salinity on the City's ability to meet the needs of current and future residents, the EAQB strongly recommends that Scottsdale continue a proactive focus on consumer education regarding the use of salt-free versus salt based water conditioners-. Ultimately, the City may need to adopt stronger positive, and negative, incentives to get the public to move from using salt based water conditioning systems to those that are more environmentally friendly or it will pay the price of having to build sophisticated -and costly- municipal systems to extract salt from the existing waste stream system. We suggest the council ban the installation of time-initiated ion exchange water softeners because of the inordinate burden they put on our municipal system for treating reclaimed water.

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Appendix A - Descriptive Summary of Alternative Salt-Free Technologies Relative to Traditional Ion Exchange Water Softening

- Ion Exchange Softening (IEX): An ion exchange water softener (IEX) is the conventional salt-based system. This technology chemically removes hardness ions and softening hard water by exchanging sodium (or potassium) ions for the calcium and magnesium ions of hard water as the water passes through a bed of negatively charged resin beads of sodium ions. This exchange process removes the positively charged hardness particles into a brine solution. The calcium and magnesium ions essentially trade places with the sodium ions and the water is softened. When all the available sodium ions are used producing softened water, the media must be back flushed with salt brine. In contrast to salt-less systems, an ion exchange system produces truly softened water, since the hardness is removed. The major disadvantage to this process is significant salinity is added to the wastewater stream as the media is back flushed of hardness minerals and regenerated. In addition to using salt in the exchange, this process also requires additional water (estimated at 50-100 gallons per regeneration) to continue the next softening cycle.

- Capacitive Deionization Conditioning (CDI): CDI is an electro-chemical treatment process similar to typical water softening requiring regeneration of the media and brine back flushing. In this process, the hardness ions of opposite charges adsorb to charged electrodes. A solution is flushed between negative and positive charged electrodes, and the respective ions move towards their opposite charge. These electrodes acting as ion capacitors become saturated and then reverse their polarity, trapping the ions between the membranes during regeneration. After this, the cell is flushed and clean, ready to be used again. However, CDI does not use salt in this process, making it an eco-friendly choice for water conditioning. The process has high initial capital costs and operating costs due to higher energy requirements and is not a well suited technology for residential uses.

- Electrically Induced Precipitation Conditioning (EIP): This conditioning method physically reduces scale in hard water using an electric field produced by a direct electrical current, which dissolves and precipitates scale forming particles such as calcium and magnesium. Passing through an electric field formed by a series of wires or magnets wrapped around the exterior of a pipe, alters the hardness ions so they precipitate in the water flow and eventually adhere onto an electrode as opposed to on metal surfaces of the plumbing or typical household devices. The special electrode which collects the scale particles requires frequent cleaning to ensure this physical removal process operates efficiently. This technology requires relatively high electrical power input to produce the necessary electric field with relatively low scale removal efficiency. These considerations limit EIP for typical residential applications.

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- Magnetic Water Treatment (MWT): In the magnetic water treatment system, water is flushed through a magnetic field created by a signal cable externally wrapped around a water pipe, which neutralizes the hard minerals in the water for 2-3 hours; hence, the conditioning process is only temporary as the original hardness returns with time and scale from the hardness particles reform and depositing on surfaces. The magnetic field alters the crystals from high to low density particles that keep scale from forming. This unique form of water conditioning is becoming more available to residential customers, but questionable claims and mixed reviews detract from its effectiveness in scale reduction.

- Template Assisted Crystallization Conditioning (TAC): Much like a conventional water softener, TAC methods employ a surface-treated resin bead medium to convert hardness ions to scale-resistant forms. The water passes through the treatment medium which attracts excess dissolved hardness ions (calcium and magnesium) removing them from solution by converting them into harmless, inactive crystals that stay in suspension. These free flowing crystals continue to grow in size while in suspension. The inert particles remain indefinitely suspended without forming scale. However, while an ion exchange softener requires regeneration with addition of salt, TAC methods do not. No maintenance, salt, or even electricity is needed. While ion softeners remove magnesium and calcium ions from water through chemical exchange, TAC systems simply alter the ionic forms of the hardness minerals into a crystalline structure resulting in suspended insoluble particles to reduce scale formation. These particles remain in suspension indefinitely and will not form scale on plumbing surfaces. In addition, taste of TAC conditioned water remains the same.

- Portable Exchange Tank Service (PET): The Portable Exchange Tank (PET) option is actually a form of ion exchange softening but based on in-home service to replace the brine collection tank. This alternative provides soft water to homes and businesses using conventional ion exchange without discharging salt to the wastewater stream at the home or business. When replaced the exhausted portable tanks are regenerated at centralized treatment facilities in a controlled environment with brine reclaimed and reused, reducing the potential for salt discharge. Centralized plant regeneration from portable tanks results in no salt or water discharges to the municipal sewer system. This in-home service in addition to high monthly cost, however, can be intrusive and inconvenient to the customer.

Appendix B – List of Tables and Figure

Tables:

Table 1 – Qualitative Comparison of Alternative Conditioning Technologies Relative to Traditional Salt-based Ion Exchange Water Softening.

Table 2 –Estimated Annual and Comparative O & M and 10-year Life Cycle Costs by Alternative Technology (as adapted from Reference 3 in General Bibliography).

Figure:

Figure 1—Average Estimated and Comparative Capital and O & M Costs by Alternative Technology (as adapted from Reference 3 in General Bibliography).

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Appendix C – General Bibliography of Literature Reviewed or Cited

1. Bureau of Reclamation, 2003, *Central Arizona Salinity Study, Phase I.*
2. Bureau of Reclamation, 2006, *Central Arizona Salinity Study, Phase II.*
3. WateReuse Research Foundation, 2014, *Evaluation of Alternatives to Domestic Ion Exchange Water Softeners, Project Report 08-06*, Fox, et. al. authors.
4. City of Scottsdale, 2014, *Proposed Program for Salinity and Sodium Reduction in Scottsdale's Reclaimed Water*, Internal Water Resources Department Staff Memo.
5. Technical Advisory Committee to Arizona Joint Legislative Committee on Water Salinity Issues, January 22, 2014, *Strategy for Water Softener Salinity Control & Management*, Committee Report.
6. *Water Quality for Dummies, Special Edition* produced by Water Quality Association, 2014.

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Table 1 – Qualitative Comparison of Alternative Treatment Technologies Relative to Traditional Salt-based Ion Exchange Water Softening (1)

Water Treatment Technology	Salt Required	Maximum Power Required (in watts)	Backwash Required	Scale Removal Efficiency	10-Year Life Cycle Cap. Costs*	Operational Parameters** Reliability	Annual Costs
Ion Exchange (IEX)	Yes	50 W	Yes	65 -70 %	Moderate to High	High-salt/water use efficiency improving	Moderate
Capacitive Deionization (CDI)	No	220 W	Yes	83 %	High	ND	High
Electrically Induced Precipitation (EIP)	No	100 W	Yes, to clean electrode	54 %	High	ND	High
Magnetic Water Treatment (MAT)	No	8 W	No	53 %	Low	ND	Low
Template Assisted Crystallization (TAC)	No	None	No	99 %	Low	High, but dependent on water chemistry	Low
Portable Exchange Tank Service (PET)	Yes, portable IEX exchange tank	In central facility only	No, media regenerated at central facility	65 -70 %	High	High	High

(1) Relative comparisons with specific data taken primarily from *Evaluation of Alternatives to Domestic Ion Exchange Water Softeners,* Project Report 08-06, by Fox et.al, prepared for WateReuse Research Foundation, Alexandria, VA, published 2014, supplemented by other independent sources. Relative data and "yes/no" responses are intended for illustrating qualitative comparisons only.

* Responses are expressed as relative range due to limited quantitative data. ** Operational data are incomplete and taken from various sources. (ND = no verifiable data currently available).

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TABLE 2 ANNUAL ESTIMATED O&M, CAPITAL, AND 10-YEAR LIFE CYCLE COSTS BY TECHNOLOGY

Treatment Technology	System ID	Total Annual O&M Costs	Capital Cost	10-year Life Cycle Cost
Electrically Induced Precipitation	EIP 1	$236	$3,000	$5,522
	EIP 2	$184	$4,150	$5,716
	EIP 3	$88	$850	$1,597
	EIP 4	$266	$1,500	$3,768
	Averages	$194	$2,375	**$4,151**
Magnetic water Treatment	MWT 1	$7	$500	$560
	MWT 2	$4	$500	$537
	MWT 3	$7	$750	$810
	MWT 4	$31	$1,299	$1,561
	MWT 5	$7	$750	$810
	Averages	$11	$760	**$855**
Capacitive Deionization	CDI 1	$102	$4,000	**$4,873**
Template Assisted Crystallization	TAC 1	$80	$1,750	$2,432
	TAC 2	$0	$795	$795
	TAC 3	$0	$750	$750
	Averages	$27	$1,098	**$1,326**
Ion Exchange	IEX 1	$168	$1,700	$3,130
	IEX 2	$168	$949	$2,379
	IEX 3	$168	$3,495	$4,925
	Averages	$168	$2,048	**$3,478**

Adapted from Figure 1 – See Figure 1 for detailed notations

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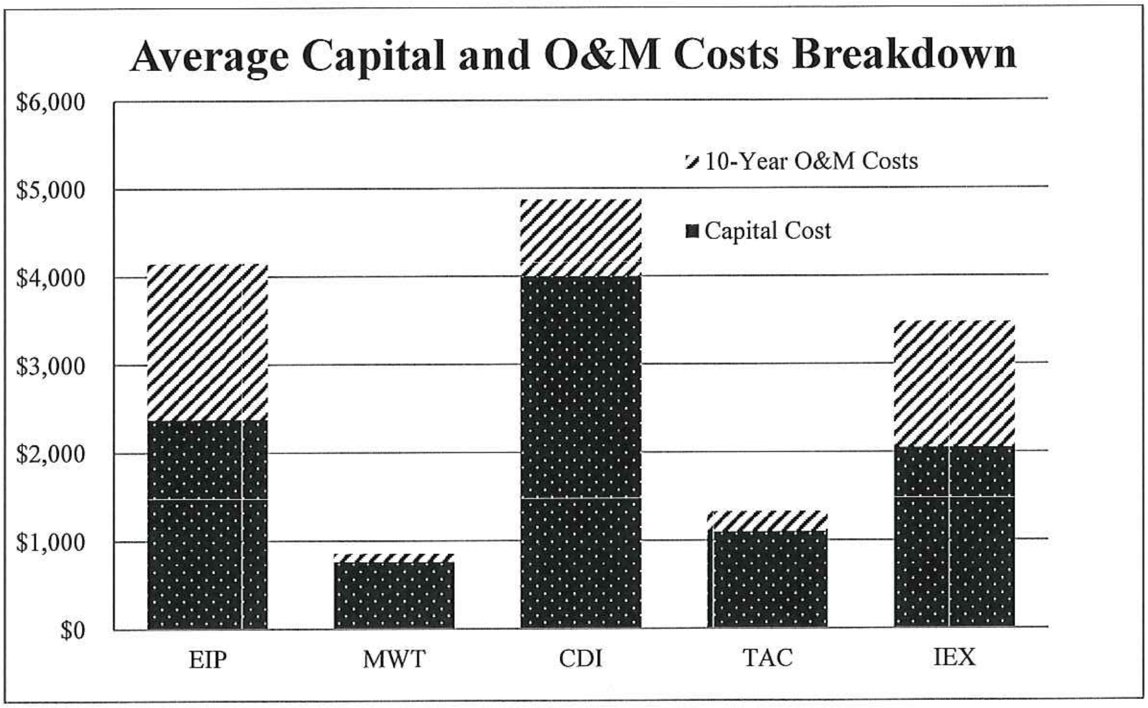

FIGURE 1: AVERAGE LIFE CYCLE COSTS WITH O&M AND CAPITAL COST BREAKDOWN

Based on the data presented in Table 2 and Figure 1, the highest 10-year life-cycle cost of the alternatives reviewed for CDI, and MWT is the lowest. It should be noted that CDI is not currently as readily available to homeowners as other technologies, and the capital cost may decrease as competition is introduced.

Adapted from: Water Reuse Research Foundation 2014, Evaluation of Alternatives to Domestic Ion Exchange Water Softeners, Project Report (3)