Final Report

Washington Aqueduct
Future Treatment Alternatives Study

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Introduction and Goals

Washington Aqueduct (WA) operates two water treatment plants (WTPs), Dalecarlia and McMillan, and sells potable drinking water to its wholesale customers: the District of Columbia Water and Sewer Authority (DC Water), Arlington County, Virginia, and the City of Falls Church, Virginia. The combined service areas serve approximately one million customers in the District of Columbia and Northern Virginia. The source water for both WTPs is the Potomac River.

In April 2009, WA initiated a Future Treatment Alternatives Study (FTAS) to develop a decision process that would allow WA and its wholesale customers to systematically and transparently assess, on an ongoing basis, whether additional (or alternative) treatment should be provided that goes beyond the level of treatment required to meet Safe Drinking Water Act regulations.

When a drinking water utility meets applicable regulations, any decision to incorporate additional, advanced treatment must be embraced by stakeholders and ratepayers who will need to support and fund the project. The water utility has the responsibility to be a good steward of public resources. Thus, the decision to provide advanced treatment should be based on a clear treatment objective, an understanding of the type and degree of improvement that can be expected with the change, and an understanding of the likely environmental impacts, the capital and operating costs, and any other factors that are important to the community. The water utility also must consider the possibility of unintended negative consequences of any treatment change.

This FTAS provides the basis for understanding site-specific water quality challenges that WA may face now and in the future, selecting corresponding treatment objectives, and understanding the ramifications of various approaches. The FTAS has resulted in the creation of a transparent, flexible decision process that can incorporate new information as conditions evolve. Using the new decision process, the project team identified and ranked water quality challenges that WA could face, based on existing information, and ultimately identified three viable mitigation strategies that could address those challenges. WA used this information to craft a Drinking Water Quality Enhancement Plan for Customer Board consideration in the 2012 Capital Planning cycle.

The consulting firm ARCADIS/Malcolm Pirnie and its subcontractor, Latis Associates, provided project management, workshop facilitation, technical expertise, and engineering support for this FTAS.

Integral to the FTAS was an Expert Panel consisting of national and international leaders from the fields of water quality and treatment, public health, environmental engineering and sciences, and energy. The Panel consisted of a balanced representation of consulting, academic, regulatory, and utility practitioners who provided guidance and independent review of the FTAS approach and execution. Additional subject matter experts were consulted on specific topics throughout the project. Many of the experts are actively involved in the latest water industry research. In fact, two of the expert panel members and one of the subject matter experts have received the AP Black Award, the most prestigious research award within the water industry. Only 37 individuals have received this award since it was established in 1967. Furthermore, almost all of the expert panelists have had direct involvement in the development and interpretation of drinking water regulations, policies, and methods.

WA also sought the expertise of individuals and advocacy groups within and outside of the drinking water field to contribute to the dialogue on drinking-water challenges and mitigation strategies. This Stakeholder Panel was invited to actively participate in project workshops. The group included representatives with expertise in watershed protection, public health, medicine, affordability, public education, and drinking water regulations.

Table 1 lists the Expert Panel, the subject matter experts, and the Stakeholder Panel.

The FTAS's goals can be summarized as follows:

- Develop a decision process to systematically and transparently accomplish the following:
  - Identify and prioritize drinking water quality challenges that WA faces
  - For the highest priority challenges, identify appropriate mitigation strategies, taking existing treatment capabilities into consideration
  - Evaluate and compare alternative mitigation strategies
- Apply the decision process using currently available information to develop a Drinking Water Quality Enhancement Plan for addressing the highest-priority water quality challenges that can be foreseen today

Several terms are used throughout this report that have a specific meaning for this FTAS. A glossary is presented in Table 2. Figure 1 illustrates these concepts with a conceptual presentation of a mitigation strategy. The mitigation strategy consists of one or more individual treatment processes forming a treatment train. Treatment is supplemented by non-treatment efforts (for water quality challenges that are not amenable to treatment). The example mitigation strategy is able to address six of seven hypothetical water quality challenges (C1-C7).

Table 3 outlines the key steps in the decision process that were developed through this FTAS. It is included here to provide an overview of the project. Each of the steps described in the table corresponds to a section of this report.

Table 1. Study Participants and Affiliations

Role	Participants
Consulting Team Facilitation	Mr. Ed Means, Malcolm Pirnie
Expert Panel	Dr. Phil Singer (Chair), University of North Carolina Mr. Joel Bluestein, ICF Resources Mr. Plato Chen, Washington Suburban Sanitary Commission Mr. Mike Hotaling, Newport News Waterworks Dr. Stephen Hrudey, University of Alberta Dr. Audrey Levine, US EPA Dr. Kimberly Jones, Howard University Dr. Kirk Nowack, Malcolm Pirnie Dr. Alexa Obolensky, Philadelphia Water Department Dr. Vern Snoeyink, University of Illinois Dr. Vanessa Speight, Latis Associates Dr. Scott Summers, University of Colorado
Subject Matter Experts	Dr. Richard Bull, MoBull Consulting Dr. Terry Councell, USDA Mr. Ian Douglas, City of Ottowa Dr. Richard Pleus, Intertox Inc. Ms. Gretchen Bruce, Intertox Inc. Dr. Robert Tardiff, independent consultant
Stakeholder Panel	Dr. Dana Best, Children's National Medical Center Ms. Erica Michaels Brown, Association of Metropolitan Water Agencies Mr. Andrew Fellows, Clean Water Action Mr. Brian Kane, Board Member, Arlington Partnership for Affordable Housing Dr. Yanna Lambrinidou and Mr. Ralph Scott, Parents for Nontoxic Alternatives Mr. Alan Roberson, American Water Works Association

Table 2. Glossary of Terms Used in the Future Treatment Alternatives Study

Term	Definition
Water quality challenge	A water quality challenge is an individual parameter (e.g., atrazine) or a group of parameters (e.g., unregulated byproducts of chlorine disinfection) or phenomenon (e.g., nitrification) that may exist at an undesirable level, in either the drinking water source (i.e., the Potomac River) or the finished drinking water leaving the WTPs, or in water within the distribution system and at consumers' taps.
Treatment process	A treatment process is one unit process (e.g., ozone, GAC, etc.)
Treatment train	A treatment train is a group of processes intended to be implemented together.
Non-treatment effort	Effort other than treatment, such as public education or watershed protection, that addresses one or more water quality challenges.
Mitigation strategy	Treatment train and non-treatment efforts that, taken together, address some or all of the high-priority water quality challenges.
Utility risk	The risk that the utility may produce undesirable water, through potential health effects of unregulated contaminants, through exceedance of aesthetic levels, or through regulatory non-compliance.
Criteria level (CL)	For each water quality challenge, the CL is the lowest corresponding regulatory level, health advisory level, or level related to aesthetic guidelines.
Occurrence threshold (OT)	Numerical value comparing the measured level of a parameter to its criteria level. OT= C/CL where: C = the maximum observed concentration of the contaminant CL = the criteria level
Drinking Water Quality Enhancement Plan (DWQEP)	The specific mitigation strategy recommended by WA that was developed as a result of the FTAS.

Figure 1. Conceptual Presentation of Mitigation Strategy Combining Treatment Train and Non-Treatment Efforts to Address Multiple Water Quality Challenges (C1-C7)

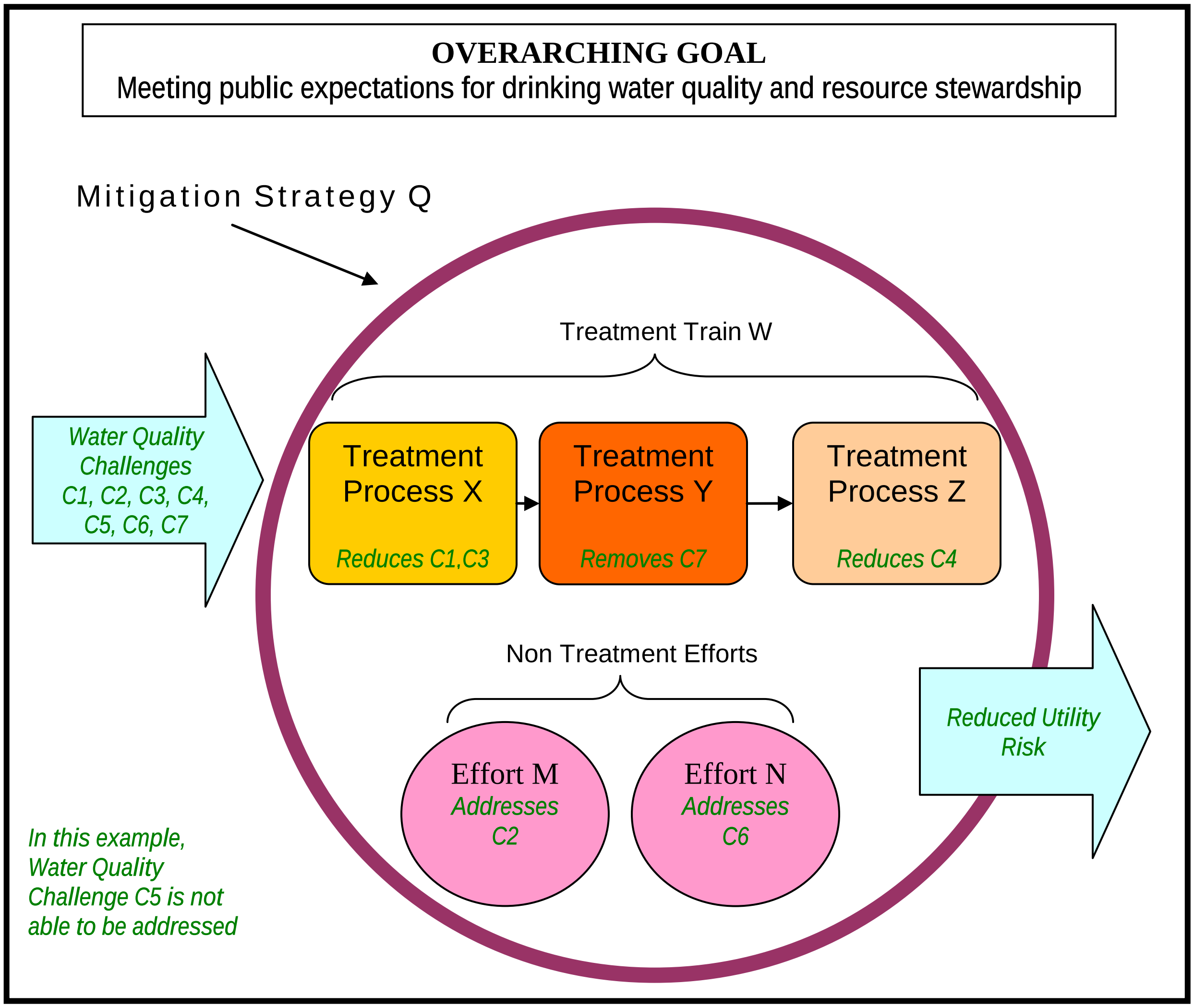


Table 3. Summary of FTAS Process

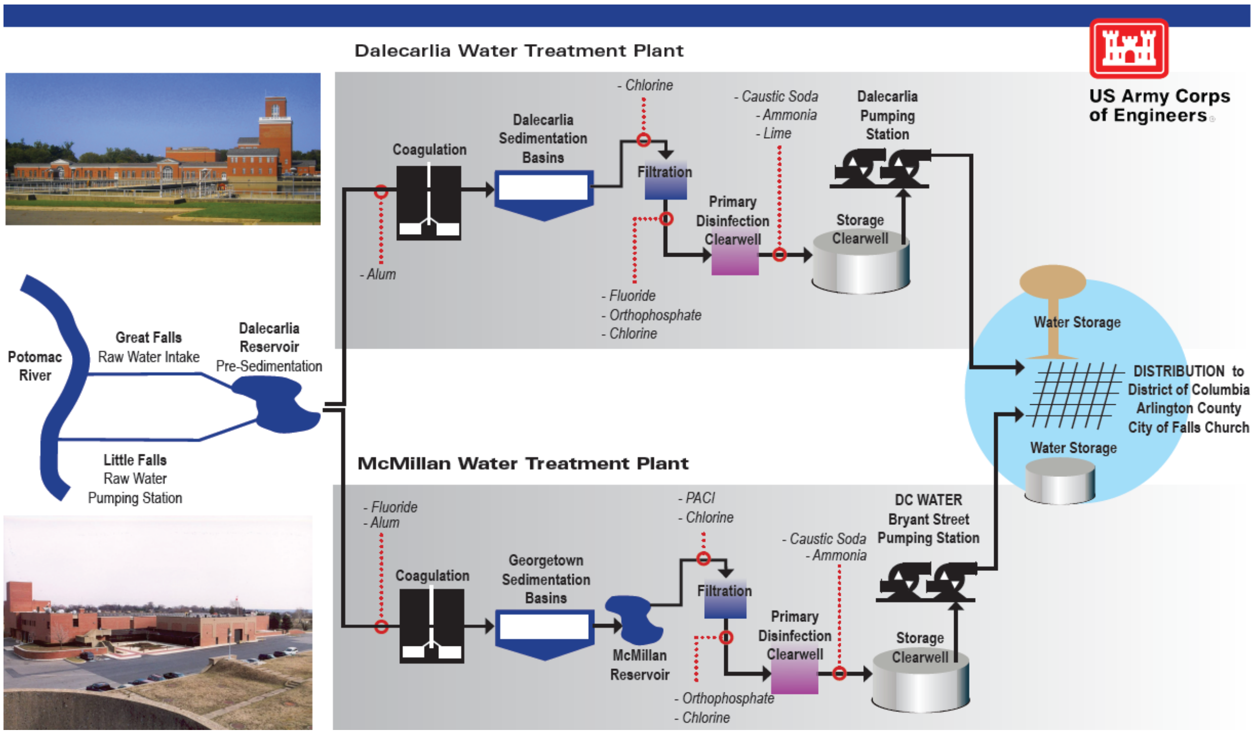
Key Steps in FTAS Decision Process	Report Section
Assess WA's current treatment performance and compliance with drinking water regulations.	WA's Current Treatment Performance and Compliance with SDWA Regulations
Prioritize water quality challenges (existing and future).	Water Quality Challenges and Priorities
Identify treatment processes capable of treating high-priority challenges and combine them into logical treatment trains.	Drinking Water Treatment Alternatives Identification
Develop criteria for evaluating alternative treatment trains; score each treatment train; and shortlist three viable treatment trains. Identify non-treatment efforts for water quality challenges that are not amenable to treatment.	Evaluation of Alternative Treatment Trains
Add non-treatment efforts to the shortlisted treatment trains to develop three viable mitigation strategies for consideration.	Viable Mitigation Strategies
Use the viable mitigation strategies to guide development of a Drinking Water Quality Enhancement Plan (DWQEP) that addresses foreseeable water quality challenges; incorporate DWQEP capital expenditures into Capital Plan. Convene Expert Panel and update FTAS in 2015 and every five years thereafter with new information that becomes available.	Implementation Recommendation

WA's Current Treatment Performance and Compliance with SDWA Regulations

The project team analyzed WA historical data and summarized treatment performance and water quality data to serve as a basis for comparison for proposed future risk mitigation activities.

The source water for WA is the Potomac River. The Potomac River Basin comprises about 58 percent forested land, 32 percent agricultural land, 4 percent developed land, and 5 percent wetlands and water. WA operates two water treatment plants (WTPs) with nominal capacity of 220 MGD (Dalecarlia WTP) and 120 MGD (McMillan Plant WTP). These are depicted in Figure 2.

Figure 2. Schematic Diagram of WA Treatment Facilities



NOTES:

* Only the main unit processes and chemical feeds are included in this diagram

** The addition of caustic soda at both plants began in the summer of 2011

The primary goals of water treatment are turbidity removal and disinfection. Turbidity (particle) removal is important because removing particles removes larger pathogens and those that are attached to inert particles and also makes the water aesthetically acceptable. Disinfection inactivates pathogens that remain in the water following particle removal steps. Particle removal occurs via three sequential processes:

- Coagulation – causes particles to stick together
- Sedimentation – large particles settle out
- Filtration – small particles captured in filter media

These processes (collectively) also remove natural organic material.

Influent turbidity at WA typically ranges from 2 to more than 100 NTU (water leaving Dalecarlia Reservoir). The coagulation and settling processes typically reduce turbidity to below 1 NTU. The combined filtered effluent turbidity meets WA's internal optimization goal (less than 0.1 NTU 95% of the time), well within the regulatory requirements of the Interim Enhanced Surface Water Treatment Rule, which allow up to 0.3 NTU 95% of the time.

To meet the turbidity goals, the McMillan WTP at times must limit its water production to approximately 60 MGD. The water that enters the McMillan WTP can be difficult to filter at times; usually, this condition occurs during the summer months, and algal activity within the Georgetown and/ or McMillan reservoirs is suspected to be an important factor. Existing optimization measures to improve the settled water turbidity, such as addition of permanganate or filter-aid chemicals ahead of the McMillan WTP, have demonstrated only limited effectiveness and are subject to dosage constraints because they can lead to different problems, such as excessive filter headloss or buildup and of manganese in the McMillan reservoir and eventual release of manganese in the finished water. Historically, the Dalecarlia WTP has been able to offset the loss of water production at the McMillan WTP. There are limitations, however, to the flexibility of the distribution system to accommodate this offset; thus, WA is exploring options to increase the McMillan WTP capacity to its 120 MGD design production rate (or some other deliberately chosen capacity) year-round.

WA uses free chlorine for primary disinfection. Chlorine is a powerful disinfectant that rapidly inactivates many pathogens. Chlorine is applied upstream of the filters and first clearwell at each WTP. Ammonia is added after first clearwell to convert free chlorine to monochloramine, which is a more persistent residual disinfectant within the distribution system. Monochloramine also forms fewer regulated disinfection by-products than free chlorine.

WA achieves a high level of pathogen inactivation with current disinfection practices, easily meeting the requirements set forth in the Surface Water Treatment Rule.

In addition to turbidity removal and disinfection, water treatment regulations also cover specific contaminants that may appear in the raw water or are formed in the distribution system:

- Disinfection by-products
- Corrosion by-products
- Other regulated contaminants

DBPs are formed when free chlorine reacts with natural organic matter. Two groups of DBPs are regulated:

- Trihalomethanes (THMs) – 4 species
- Haloacetic acids (HAAs) – 5 species

When WA adds ammonia the free chlorine in the water forms monochloramine, essentially halting THM and HAA formation. Since WA began utilizing monochloramine for secondary disinfection, the running annual average concentrations of THMs and HAAs have consistently been less than 80 µg/L (total THM) and 60 µg/L (HAA5), allowing easy compliance with the Stage 1 DBP Rule requirements and leaving WA and its wholesale customers well-positioned for compliance with Stage 2 DBP Rule, which will require running annual averages at each compliance location in the distribution system to be met.

The Stage 1 DBP Rule also includes requirements for removing DBP precursors (natural organic matter) prior to chlorination. DBP precursor levels measured as total organic carbon (TOC). TOC removal rates for both WA plants consistently exceed the Stage 1 requirements.

Treated drinking water can be corrosive and cause metals such as lead, copper and iron to be released from distribution system pipes. WA employs the following corrosion control practices to limit the impacts of corrosion:

- Orthophosphate addition – orthophosphate reacts with metals to form a protective scale on the inner walls of distribution system pipes, thereby reducing corrosion rates.
- pH control – pH maintained within a range that corresponds to low corrosion rates (via addition of caustic soda at both WTPs and lime at the Dalecarlia WTP).

In addition to the requirements for turbidity removal, disinfection, and corrosion control, there are 87 primary drinking water standards (set by EPA) that regulate:

- Volatile organic chemicals (VOCs)
- Synthetic organic chemicals (SOCs)
- Inorganics
- Radionuclides

WA consistently complies with all these standards.

The project team confirmed the premise of this FTAS: WA consistently complies with all of the requirements set forth in the Safe Drinking Water Act regulations. In the remaining steps of the FTAS, then, WA considered measures that go beyond current regulatory requirements to enhance drinking water quality.

Water Quality Challenges and Priorities

The project team sought to identify, screen, and prioritize potential water quality challenges of relevance for WA so that an appropriate mitigation strategy, including both treatment and non-treatment efforts, could be planned. The framework developed in this project allows examination of a wide range of potential contaminants so that reasonable actions for each can be assigned. The assigned actions consider the degree of uncertainty in factors such as the frequency and extent of occurrence of a contaminant in WA's drinking water, the potential for exposure of consumers to the contaminant via the drinking water pathway, and the health outcomes for those exposed.

For the purposes of this FTAS, water quality challenges were prioritized based on an evaluation of "utility risk," representing the risk or perceived risk that the utility may produce undesirable water, through potential health effects of unregulated contaminants, through exceedance of aesthetic levels, or through regulatory non-compliance.

Table 4 summarizes the four steps in the prioritization process:

Table 4. Summary of Water Quality Challenge Prioritization Steps

Prioritization Step	Description
Identification	Prepare broad list of water quality challenges that water utilities could face.
Preliminary Screening	Narrow down list of water quality challenges to those that occur, are likely to occur, or may pose a regulatory, aesthetic or human health risk for WA.
Prioritization	Calculate an occurrence threshold (OT) using regulatory, human health advisory, and aesthetic levels and occurrence data to flag parameters for further evaluation.
Classification for Action	Evaluate supplemental data and consider uncertainty associated with either the health data or occurrence data to classify each priority water quality challenge into a four-quadrant action grid.

Each of these steps will be discussed in detail in this section.

Identification

An initial list of potential water quality challenges was created by first considering contaminants already regulated under the SDWA. Next, contaminants under consideration for regulation that have been identified in the SDWA Candidate Contaminant Listing (CCL) process were added. Contaminants that have EPA drinking water health advisories were also listed, along with contaminants considered to have a potential health risk by the World Health Organization (WHO). Finally, other literature sources were sought that identify emerging contaminants of concern. The FTAS also considered the potential for changes in raw water quality due to, for example, climate change, dam management, and upstream waste water treatment plant (WWTP) discharges. The initial list included over seven hundred contaminants spanning multiple categories. Resources that were used for identifying potential drinking water contaminants in the FTAS are summarized in Table 5.

Table 5. Resources for Identification of Potential Contaminants

Source	Data Available
USEPA CCL3	List of contaminants under consideration
USEPA 2009 Drinking Water Standards and Health Advisories	List of contaminants with health advisory levels
WHO	List of contaminants considered to have a potential health risk
Other literature sources	Lists of contaminants of concern (e.g., EDCs and pharmaceuticals, Snyder et al., 2008)

Once an initial list of potential contaminants was developed, WA identified sources of occurrence data for those contaminants. Occurrence data sources included WA's routine compliance data and process control data, WA wholesale customer data, and data from third party collaborative research with other federal agencies.

In the mid 2000s, WA participated in the United States Geological Survey (USGS) National Water Quality Assessment (NWQA) and United States Department of Agriculture (USDA) Pesticide Data Program (PDP) studies, which collected data for a number of persistent inorganic and organic contaminants, including pesticides, pharmaceuticals and personal care products (PPCPs), and other anthropogenic contaminants, on a monthly or bimonthly basis (for a period of two years in each case), providing a rich occurrence database for WA to draw upon for many unregulated contaminants. In addition, WA collected data as required under the Unregulated Contaminant Monitoring Rules (UCMR), participated in an EPA study on perchlorate occurrence in the Potomac River, and conducted supplemental voluntary monitoring. Table 6 summarizes sources of contaminant occurrence data that WA drew upon for the FTAS.

Table 6. Sources of Contaminant Occurrence Data for WA

Source	Occurrence Data Available
Washington Aqueduct	Regulated contaminants, UCMR, and other special studies
USEPA	Perchlorate
USDA (2006-7)	Pesticides and pharmaceuticals
USGS (2003-5)	DBPs Pesticides (herbicides, fumigants, fungicides, insecticides) Gasoline-, pavement-, and combustion-related compounds, Solvents, manufacturing additives, organic synthesis compounds, refrigerants and propellants Personal care/ domestic use products, and plant- or animal-derived biochemicals

Preliminary Screening

As the first step in identifying priorities within the universe of water quality challenges, the extent and quality of the existing occurrence data were evaluated. Contaminants that have been monitored but never detected were not retained for further consideration unless there was reason to believe that future occurrence may be different than the historical occurrence. Water quality challenges that met the following criteria were identified and retained for further scrutiny:

- contaminants that have been shown to occur in the raw or finished water,
- other contaminants that are of concern because of their potential occurrence and/or toxicity as described in the literature
- additional contaminants nominated by the FTAS's Expert Panel

Table 7 summarizes, by category, the number of contaminants initially included in the comprehensive list and those remaining as priority contaminants after the preliminary screening.

Table 7. Summary of Preliminary Contaminant Screening Process

Category	Initial Number of Contaminants Considered	Number of Contaminants Selected for Prioritization
Microbial Contaminants	25	25
Inorganic Contaminants[1]	45	37
Radionuclides	6	2
Pesticides	295	99
Pharmaceuticals and Personal Care Products[2]	137	105
Other Organic Compounds	175	78
Nanomaterials	10	10
Aesthetic Compounds[1]	3	3
Disinfection By-Products	52	44
Distribution System Issues	5	5
Total	**753**	**408**

NOTES:

[1] To avoid double counting, those inorganic contaminants that are also considered as aesthetic compounds were only included in the inorganic contaminants category in this table.

[2] Although endocrine disruptors are commonly listed alongside PPCPs, in this case they were not considered together because individual EDCs were included in other categories (e.g., inorganic contaminants, pesticides)

Occurrence Threshold

To discern the highest priority challenges among the approximately 400 contaminants that were flagged for review in the preliminary screening, WA first identified a concentration of interest, as determined by either (1) drinking water regulation, (2) aesthetic needs, or (3) health risks, and termed it "criteria level" (CL). Next, an occurrence threshold (OT) was calculated to compare the reported concentration (C) of an individual contaminant to its respective criteria level (CL).

$$OT = C/CL$$

where:

OT= the occurrence threshold
C = the maximum observed concentration of the contaminant
CL = the criteria level

The OT allowed WA to identify the relative importance of different contaminants or groups of contaminants. In calculating the OT, the maximum detected concentration in any single sample of either raw or finished water was used along with the minimum CL. This was a cautious approach to avoid failing to capture potentially relevant information.

For those contaminants identified as having an OT greater than 0.1 (that is, the maximum detected level was at or above 10 percent of the relevant CL), additional evaluation was performed on an individual basis to determined if the OT was justified or anomalous. This involved an analysis of such factors as frequency of detection, laboratory detection limits, and removal of contaminants in the current treatment process.

The strategy for this FTAS was to obtain CLs from existing published drinking water standards or criteria that have been adopted by regulatory agencies or otherwise reviewed for applicability to drinking water, rather than from individual studies on specific contaminants. Because this is an active field of research, data sources published in the past two years were preferred. The following data sources were used to populate the CL data, in order of preference:

- USEPA published Drinking Water Standards and Health Advisory Levels (USEPA, 2009a)
- 2009 USEPA Candidate Contaminant List 3 (USEPA, 2009b; USEPA, 2009c)
- WHO Drinking Water Advisory Levels (2008)
- Australian Guidelines for Water Recycling (EPHC, 2008)
- Water Research Foundation study - Toxicological Relevance of Endocrine Disrupting-Compounds (EDCs) and Pharmaceuticals in Drinking Water (Snyder et al., 2008)

During the FTAS, California’s Office of Environmental Health Hazard Assessment issued a draft public health goal (in December 2010) for hexavalent chromium, which was used as the source of the CL for this parameter.

The CL component of the OT calculation was based on the minimum value among the maximum contaminant level (MCL), drinking water equivalent level, or drinking water goal. If none of those values was available, a CL was calculated from the Acceptable Daily Intake (ADI), Tolerable Daily Intake (TDI) or Reference Dose (RfD) using a 70 kg person consuming 2 L of water per day or for a 10-6 lifetime cancer risk (Snyder et al., 2008; Toccalino et al., 2008). For aesthetic CLs, secondary maximum contaminant levels and other industry recommended levels were used in the OT calculation.

The basis for development of each of the different types of CL values was not the same. For example, MCLs are developed using both health impact information and other considerations, such as analytical capabilities (e.g., detection limits), treatment options, and affordability. Therefore the MCL may not represent the drinking water occurrence level at which no adverse effects would be expected. It was beyond the scope of this FTAS to derive health-based CL values for specific contaminants, and therefore existing published values were employed, acknowledging the limitations for rigorous health risk comparisons. Use of these CLs to screen contaminants for further evaluation was deemed acceptable and appropriate for meeting FTAS goals.

Of the 753 contaminants, about 20 percent lacked occurrence data, and about 33 percent lacked CL data. Where data were lacking, the Expert Panel applied judgment to determine whether to add the contaminant to the high priority list.

To illustrate the calculation of the OT, Table 8 presents occurrence data and CL data for select inorganic water quality challenges. The contaminants appearing in the table are among those that triggered further Expert Panel and project team scrutiny, to determine whether and how they should be classified for any utility risk mitigation action. Classification for action is the subject of the next section.

Table 8. OTs Exceeding 0.1 for Select Inorganic Contaminants

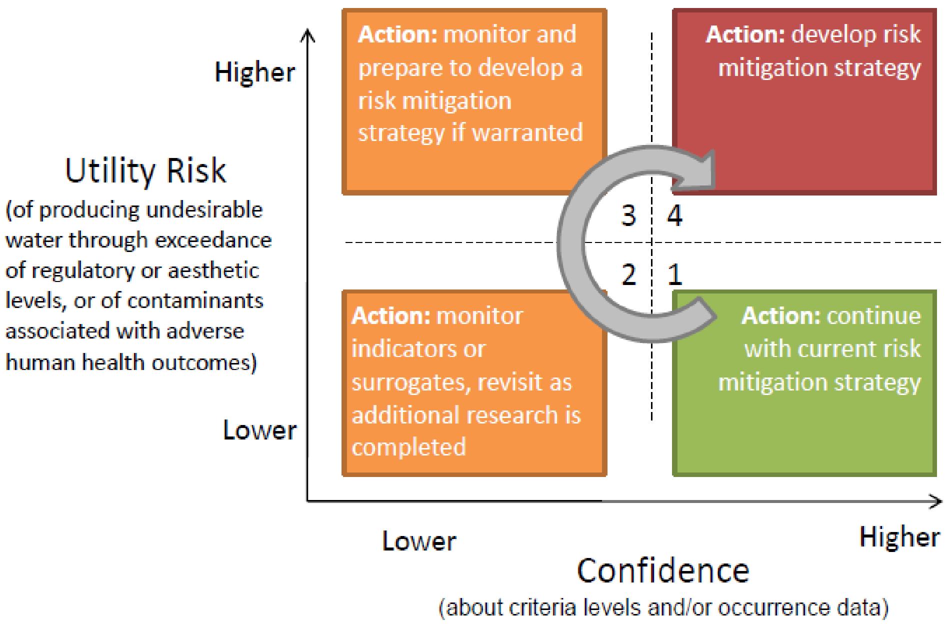
Contaminant	MCL (mg/L)	Occurrence (mg/L)			CL (mg/L)	OT	Adverse Effect	CL Source
		Mean	Max	Loc.				
Aluminum	NR	0.36	2.39	Raw Water	0.2	11.95	Colored water	USEPA SMCL
Chlorate	NR	-	0.12	Sodium Hypo-chlorite Solution	0.7	0.17	Thyroid dysfunction	WHO DWG
Chromium-6	NR	0.000076	0.00014	Distribution System	0.00002	7.00	Cancer via inhalation, possible cancer via ingestion	CA Draft PHG
Iron	NR	0.27	1.63	Raw Water	0.3	5.42	Metallic taste, red staining	USEPA SMCL
Perchlorate	NR	<RL	0.0086	Raw Water	0.015	0.57	Thyroid dysfunction, suspected EDC	USEPA Interim HA

Classification for Action

A four-quadrant classification approach was used to prioritize contaminants into categories of action (adapted from CWN, 2010) by first characterizing the “utility risk” and then qualitatively characterizing the degree of confidence associated with this value.

The quadrants were defined by orthogonal axes representing utility risk and the confidence associated with available information. The utility risk level (y-axis value) was determined by the OT or, for those contaminants lacking data to calculate an OT, by the estimated potential for risk in the opinion of the project team and Expert Panel. The utility risk determination had uncertainty stemming from the underlying CL and/or occurrence information or its applicability to drinking water. This uncertainty was incorporated into the analysis through use of the horizontal (x-) axis representing confidence. Thus, the quality of utility risk information was considered for prioritization of actions. Under this approach, "higher" confidence means "better" information and "lower" confidence means "poorer" information. The four-quadrant approach is illustrated in Figure 3.

Figure 3. Four-Quadrant Classification of Contaminants



Adapted from Canadian Water Network (CWN, 2010)

Four categories of action used in this approach can be described generally as:

Quadrant 1 (lower utility risk / higher confidence): continue with current risk mitigation strategy. Contaminants in this quadrant are well-understood and occur at low levels or are adequately addressed by current treatment, or both. For a contaminant to be assigned to Quadrant 1, there needed to have been an adequate amount of monitoring data available to characterize the occurrence, with observed concentrations below regulatory limits, and the contaminants had to have been studied and/or regulated so that their health effects were well understood.

Quadrant 2 (lower utility risk / lower confidence): monitor indicators or surrogates and revisit as additional research is completed. Contaminants in this quadrant had less available information regarding health or aesthetic effects due to drinking water exposure. These contaminants were somewhat understood to have minimal impact on human health associated with exposure via drinking water. They occurred at lower levels or had limited data upon which to assess their occurrence.

Quadrant 3 (higher utility risk / lower confidence): monitor and prepare to mitigate risk if warranted. Contaminants in this quadrant occurred at higher levels than others, or had the potential to occur at high levels as indicated by higher OT values, but were lacking certainty regarding human health or aesthetic impacts and/or their occurrence in drinking water.

Quadrant 4 (higher utility risk / higher confidence): develop risk mitigation strategy. Contaminants in this quadrant had sufficient health or aesthetic level OT values to warrant further investigation, and occurred (or could occur) at levels of concern. Contaminants that have been proposed for future regulatory determination and that have demonstrated occurrence in drinking water generally were assigned to this category. Regulated contaminants with levels of occurrence near the regulatory limits were also assigned to this category.

High Priority Water Quality Challenges

The water quality challenges that were ultimately deemed to be of highest priority for WA at the time of this work (2009-2012)—that is, those categorized in Quadrant 4 after preliminary screening, subsequent evaluation of OT, and finally expert consideration based on higher utility risk and higher confidence in the data—are the fourteen challenges listed in Table 9.

Table 10 identifies the water quality challenges assigned to Quadrant 3, implying that WA should continue to track developments that could shift one or more of these contaminants into Quadrant 4 or to a lower quadrant. It is important to emphasize that the high priority challenges facing WA may change in the future as new information becomes available.

To ensure that the water quality challenge could be addressed appropriately by various treatment trains or overall mitigation strategies, it was necessary to specify where the challenge presented itself. For example, the utility risk associated with lead occurrence at WA is low in the source and finished water, but is higher in the distribution system.

Table 9. Summary of High Priority Water Quality Challenges (Quadrant 4)

Number	Description
1.	*Cryptosporidium* (and other chlorine- resistant pathogens)
2.	Bacteria / protozoa (including, *inter alia, Giardia Lamblia*, *Legionella*, *Mycobacterium* spp, and *amoebae*)
3.	Viruses (and other UV- resistant pathogens)
4.	Regulated DBPs [Total trihalomethanes (TTHMs) / Five haloacetic acids (HAA5)]
5.	Unregulated nitrogenous DBPs, including NDMA and other nitrosamines
6.	Atrazine, simazine, and their degradates
7.	Perchlorate
8.	Hexavalent chromium in the finished water and/or distribution system
9.	Manganese
10.	Lead release in the distribution system
11.	Nitrification in the distribution system
12.	Iron release, cloudiness, and red water in the distribution system
13.	Earthy / musty taste & odor (MIB and geosmin) in the finished water and/or distribution system
14.	Chlorinous taste & odor in the distribution system

Table 10. Summary of Water Quality Challenges Warranting Continued Tracking (Quadrant 3)

Number	Description
1.	Cyanobacteria and cyanobacterial toxins
2.	Aluminum
3.	Nitrate
4.	Metolachlor and its degradates
5.	2,4-Dichlorophenoxdyacetic (2,4-D)
6.	Epichlorohydrin
7.	Acrylamide

Drinking Water Treatment Alternatives Identification

Treatment Processes Considered

Table 11 presents a list of the individual treatment processes considered in the FTAS for addressing the fourteen high priority water quality challenges. The project team identified the majority of the treatment processes included in the table, and the Expert Panel provided guidance on specialty processes that are less common in large-scale drinking water treatment, such as ion exchange. It is noteworthy that WA's existing conventional treatment plants are capable of addressing some, but not all, of the parameters identified. All high priority water quality challenges, including those currently addressed by existing treatment, were carried through the FTAS analysis to ensure that under any changed treatment regime, they would continue to be addressed.

Treatment Train Combinations

The various process options presented in Table 11 were combined to formulate treatment train alternatives aimed at addressing WA's high priority water quality challenges. The high priority contaminants spanned multiple categories and did not necessarily respond to the same types of treatment, complicating the analysis.

Engineering expertise was applied to develop logical trains that consisted of compatible unit processes with appropriate pretreatment and process redundancy, with the overall goal of developing trains that could treat some or all of the high priority water quality challenges. In all, 120 treatment train alternatives were included for consideration at WA. The evaluation of these treatment trains is the subject of the next section of the report.

Table 12 summarizes the 120 treatment train alternatives that were developed in the FTAS. To simplify the analysis of such a wide range of potential treatment alternatives, the following assumptions were made:

- Each train was assumed to include conventional coagulation/flocculation/settling using the existing WA treatment facilities.
- All alternatives were assumed to include provisions for improving the filterability of water entering the McMillan WTP. The best strategy for achieving this has not yet been determined.
- All treatment trains assumed the use of monochloramine for secondary (residual) disinfection in the distribution system. (In a later step in the project, the option of using free chlorine, rather than monochloramine, as a secondary disinfectant was explicitly considered.)
- Changes in the use of fluoride at WA were not considered during the FTAS. Fluoride is added at the request of the jurisdictions served by WA as a public health benefit for dental prophylaxis and has no other role in water treatment.
- Treatment trains were evaluated first, and non-treatment efforts were considered later for addressing specific water quality challenges that could not be adequately addressed via the treatment trains that were ultimately short-listed.

The next section of the report discusses the evaluation of the 120 alternative treatment trains.

Table 11. Drinking Water Treatment Processes Considered in FTAS

Existing or Future Treatment	Treatment Process and Primary Benefit(s)
Existing Treatment	Conventional coagulation / flocculation
	Conventional sedimentation
	Granular media filtration
	Free chlorination (for pre-oxidation and primary disinfection)
	Chloramination (for secondary disinfection)
	Chemical addition (pH control and orthophosphate) for corrosion control
Potential Future Enhancements	Improve filterability of water entering the McMillan WTP by: • Optimizing use of McMillan Reservoir[1] • Installing a dedicated onsite clarification system (e.g., dissolved air flotation, plate settlers or ballasted flocculation)
	Enhance existing DBP control strategy, by: • Moving the ammonia feed point (and reducing free chlorine contact time) • Increasing the coagulant dose • Installing acid feed system for enhanced coagulation • Changing coagulants
	Increase use of permanganate for oxidation of manganese
	Install chlorine dioxide for oxidation of manganese
	Improve powdered activated carbon (PAC) facilities for taste and odor control
	Install ozone, or ozone + peroxide (an advanced oxidation process, or AOP) for oxidation / degradation of multiple contaminants
	Install ultraviolet irradiation (UV), or UV + peroxide (UV-based AOPs) for improved pathogen inactivation and oxidation / degradation of multiple contaminants
	Convert to biologically active filters (BAF) to increase the biological stability of the finished water
	Install granular activated carbon (GAC) filter adsorbers to remove DBP precursors, taste-and-odor-causing compounds, and other organic contaminants
	Install low-pressure (LP) membranes for improved particle and pathogen removal
	Install reverse osmosis (RO) membranes for removal of dissolved contaminants
	Install post-filter GAC contactors for adsorption of multiple contaminants
	Install ion exchange (IX), including fixed bed and mixed / suspended IX, for removal of TOC and inorganic contaminants
	Convert to free chlorine (year-round) for secondary disinfection to eliminate the risk of nitrification

NOTES:
[1] Throughout the remainder of this FTAS it was assumed that, at a minimum, WA will seek to improve the filterability at the McMillan settle water. However, additional detailed study will be necessary to select the most appropriate solution.

Table 12. FTAS Treatment Train Alternatives

Train No.	Pre-Oxidant	PAC	Coagulation/Sedimentation	Secondary TOC Removal	Intermediate Oxidation	Filtration	2nd Stage Filtration	Interstage Disinfection	Polishing	Primary Disinfection	Secondary Disinfection
0*	None	None	Conventional	None	Cl2	Granular Media	None	None	None	Free Cl2	Monochloramine
1	None	None	Imp. McM Filterability	None	Cl2	Granular Media	None	None	None	Free Cl2	Monochloramine
2	None	PAC	Imp. McM Filterability	None	Cl2	Granular Media	None	None	None	Free Cl2	Monochloramine
3	MnO4	None	Imp. McM Filterability	None	Ozone AOP	BAF	None	None	None	Free Cl2	Monochloramine
4	MnO4	None	Imp. McM Filterability	None	UV AOP	BAF	None	None	None	Free Cl2	Monochloramine
5	MnO4	None	Imp. McM Filterability	None	None	GAC Filter Adsorber	None	None	None	Free Cl2	Monochloramine
6	MnO4	None	Imp. McM Filterability	None	None	LP Memb.	None	None	None	Free Cl2	Monochloramine
7	MnO4	PAC	Imp. McM Filterability	None	None	LP Memb.	None	None	None	Free Cl2	Monochloramine
8	MnO4	None	Imp. McM Filterability	None	Ozone AOP	BAF	LP Memb.	None	None	Free Cl2	Monochloramine
9	MnO4	None	Imp. McM Filterability	None	UV AOP	BAF	LP Memb.	None	None	Free Cl2	Monochloramine
10	MnO4	None	Imp. McM Filterability	None	None	LP Memb.	Reverse Osmosis	None	None	Free Cl2	Monochloramine
11	None	None	Imp. McM Filterability	None	Cl2	Granular Media	None	UV (Crypto)	None	Free Cl2	Monochloramine
12	None	PAC	Imp. McM Filterability	None	Cl2	Granular Media	None	UV (Crypto)	None	Free Cl2	Monochloramine
13	MnO4	None	Imp. McM Filterability	None	None	GAC Filter Adsorber	None	UV (Crypto)	None	Free Cl2	Monochloramine
14	None	None	Imp. McM Filterability	None	Cl2	Granular Media	None	None	GAC Contactors	Free Cl2	Monochloramine
15	MnO4	None	Imp. McM Filterability	None	Ozone AOP	BAF	None	None	GAC Contactors	Free Cl2	Monochloramine
16	MnO4	None	Imp. McM Filterability	None	UV AOP	BAF	None	None	GAC Contactors	Free Cl2	Monochloramine
17	MnO4	None	Imp. McM Filterability	None	None	LP Memb.	None	None	GAC Contactors	Free Cl2	Monochloramine
18	MnO4	None	Imp. McM Filterability	None	Ozone AOP	BAF	LP Memb.	None	GAC Contactors	Free Cl2	Monochloramine
19	MnO4	None	Imp. McM Filterability	None	UV AOP	BAF	LP Memb.	None	GAC Contactors	Free Cl2	Monochloramine
20	None	None	Imp. McM Filterability	None	Cl2	Granular Media	None	UV (Crypto)	GAC Contactors	Free Cl2	Monochloramine
21	None	None	Imp. McM Filterability	None	Cl2	Granular Media	None	None	Ion Exchange (IX)	Free Cl2	Monochloramine
22	None	PAC	Imp. McM Filterability	None	Cl2	Granular Media	None	None	Ion Exchange (IX)	Free Cl2	Monochloramine
23	MnO4	None	Imp. McM Filterability	None	Ozone AOP	BAF	None	None	Ion Exchange (IX)	Free Cl2	Monochloramine
24	MnO4	None	Imp. McM Filterability	None	UV AOP	BAF	None	None	Ion Exchange (IX)	Free Cl2	Monochloramine
25	MnO4	None	Imp. McM Filterability	None	None	GAC Filter Adsorber	None	None	Ion Exchange (IX)	Free Cl2	Monochloramine
26	MnO4	None	Imp. McM Filterability	None	None	LP Memb.	None	None	Ion Exchange (IX)	Free Cl2	Monochloramine
27	MnO4	PAC	Imp. McM Filterability	None	None	LP Memb.	None	None	Ion Exchange (IX)	Free Cl2	Monochloramine
28	MnO4	None	Imp. McM Filterability	None	Ozone AOP	BAF	LP Memb.	None	Ion Exchange (IX)	Free Cl2	Monochloramine
29	MnO4	None	Imp. McM Filterability	None	UV AOP	BAF	LP Memb.	None	Ion Exchange (IX)	Free Cl2	Monochloramine
30	None	None	Imp. McM Filterability	None	Cl2	Granular Media	None	UV (Crypto)	Ion Exchange (IX)	Free Cl2	Monochloramine
31	None	PAC	Imp. McM Filterability	None	Cl2	Granular Media	None	UV (Crypto)	Ion Exchange (IX)	Free Cl2	Monochloramine
32	MnO4	None	Imp. McM Filterability	None	None	GAC Filter Adsorber	None	UV (Crypto)	Ion Exchange (IX)	Free Cl2	Monochloramine
33	None	None	Imp. McM Filterability	None	Cl2	Granular Media	None	None	GAC Contactors + IX	Free Cl2	Monochloramine
34	MnO4	None	Imp. McM Filterability	None	Ozone AOP	BAF	None	None	GAC Contactors + IX	Free Cl2	Monochloramine
35	MnO4	None	Imp. McM Filterability	None	UV AOP	BAF	None	None	GAC Contactors + IX	Free Cl2	Monochloramine
36	MnO4	None	Imp. McM Filterability	None	None	LP Memb.	None	None	GAC Contactors + IX	Free Cl2	Monochloramine
37	MnO4	None	Imp. McM Filterability	None	Ozone AOP	BAF	LP Memb.	None	GAC Contactors + IX	Free Cl2	Monochloramine
38	MnO4	None	Imp. McM Filterability	None	UV AOP	BAF	LP Memb.	None	GAC Contactors + IX	Free Cl2	Monochloramine
39	None	None	Imp. McM Filterability	None	Cl2	Granular Media	None	UV (Crypto)	GAC Contactors + IX	Free Cl2	Monochloramine

Train No.	Pre-Oxidant	PAC	Coagulation/Sedimentation	Secondary TOC Removal	Intermediate Oxidation	Filtration	2nd Stage Filtration	Interstage Disinfection	Polishing	Primary Disinfection	Secondary Disinfection
40	None	None	Imp. McM Filterability	Suspended IX	Cl2	Granular Media	None	None	None	Free Cl2	Monochloramine
41	None	PAC	Imp. McM Filterability	Suspended IX	Cl2	Granular Media	None	None	None	Free Cl2	Monochloramine
42	MnO4	None	Imp. McM Filterability	Suspended IX	UV AOP	BAF	None	None	None	Free Cl2	Monochloramine
43	MnO4	None	Imp. McM Filterability	Suspended IX	None	LP Memb.	None	None	None	Free Cl2	Monochloramine
44	MnO4	PAC	Imp. McM Filterability	Suspended IX	None	LP Memb.	None	None	None	Free Cl2	Monochloramine
45	MnO4	None	Imp. McM Filterability	Suspended IX	UV AOP	BAF	LP Memb.	None	None	Free Cl2	Monochloramine
46	None	None	Imp. McM Filterability	Suspended IX	Cl2	Granular Media	None	UV (Crypto)	None	Free Cl2	Monochloramine
47	None	PAC	Imp. McM Filterability	Suspended IX	Cl2	Granular Media	None	UV (Crypto)	None	Free Cl2	Monochloramine
48	ClO2	None	Imp. McM Filterability	None	Ozone AOP	BAF	None	None	None	Free Cl2	Monochloramine
49	ClO2	None	Imp. McM Filterability	None	UV AOP	BAF	None	None	None	Free Cl2	Monochloramine
50	ClO2	None	Imp. McM Filterability	None	None	GAC Filter Adsorber	None	None	None	Free Cl2	Monochloramine
51	ClO2	None	Imp. McM Filterability	None	None	LP Memb.	None	None	None	Free Cl2	Monochloramine
52	ClO2	PAC	Imp. McM Filterability	None	None	LP Memb.	None	None	None	Free Cl2	Monochloramine
53	ClO2	None	Imp. McM Filterability	None	Ozone AOP	BAF	LP Memb.	None	None	Free Cl2	Monochloramine
54	ClO2	None	Imp. McM Filterability	None	UV AOP	BAF	LP Memb.	None	None	Free Cl2	Monochloramine
55	ClO2	None	Imp. McM Filterability	None	None	LP Memb.	Reverse Osmosis	None	None	Free Cl2	Monochloramine
56	ClO2	None	Imp. McM Filterability	None	None	GAC Filter Adsorber	None	UV (Crypto)	None	Free Cl2	Monochloramine
57	ClO2	None	Imp. McM Filterability	None	Ozone AOP	BAF	None	None	GAC Contactors	Free Cl2	Monochloramine
58	ClO2	None	Imp. McM Filterability	None	UV AOP	BAF	None	None	GAC Contactors	Free Cl2	Monochloramine
59	ClO2	None	Imp. McM Filterability	None	None	LP Memb.	None	None	GAC Contactors	Free Cl2	Monochloramine
60	ClO2	None	Imp. McM Filterability	None	Ozone AOP	BAF	LP Memb.	None	GAC Contactors	Free Cl2	Monochloramine
61	ClO2	None	Imp. McM Filterability	None	UV AOP	BAF	LP Memb.	None	GAC Contactors	Free Cl2	Monochloramine
62	ClO2	None	Imp. McM Filterability	None	Ozone AOP	BAF	None	None	Ion Exchange (IX)	Free Cl2	Monochloramine
63	ClO2	None	Imp. McM Filterability	None	UV AOP	BAF	None	None	Ion Exchange (IX)	Free Cl2	Monochloramine
64	ClO2	None	Imp. McM Filterability	None	None	GAC Filter Adsorber	None	None	Ion Exchange (IX)	Free Cl2	Monochloramine
65	ClO2	None	Imp. McM Filterability	None	None	LP Memb.	None	None	Ion Exchange (IX)	Free Cl2	Monochloramine
66	ClO2	PAC	Imp. McM Filterability	None	None	LP Memb.	None	None	Ion Exchange (IX)	Free Cl2	Monochloramine
67	ClO2	None	Imp. McM Filterability	None	Ozone AOP	BAF	LP Memb.	None	Ion Exchange (IX)	Free Cl2	Monochloramine
68	ClO2	None	Imp. McM Filterability	None	UV AOP	BAF	LP Memb.	None	Ion Exchange (IX)	Free Cl2	Monochloramine
69	ClO2	None	Imp. McM Filterability	None	None	GAC Filter Adsorber	None	UV (Crypto)	Ion Exchange (IX)	Free Cl2	Monochloramine
70	ClO2	None	Imp. McM Filterability	None	Ozone AOP	BAF	None	None	GAC Contactors + IX	Free Cl2	Monochloramine
71	ClO2	None	Imp. McM Filterability	None	UV AOP	BAF	None	None	GAC Contactors + IX	Free Cl2	Monochloramine
72	ClO2	None	Imp. McM Filterability	None	None	LP Memb.	None	None	GAC Contactors + IX	Free Cl2	Monochloramine
73	ClO2	None	Imp. McM Filterability	None	Ozone AOP	BAF	LP Memb.	None	GAC Contactors + IX	Free Cl2	Monochloramine
74	ClO2	None	Imp. McM Filterability	None	UV AOP	BAF	LP Memb.	None	GAC Contactors + IX	Free Cl2	Monochloramine
75	ClO2	None	Imp. McM Filterability	Suspended IX	UV AOP	BAF	None	None	None	Free Cl2	Monochloramine
76	ClO2	None	Imp. McM Filterability	Suspended IX	None	LP Memb.	None	None	None	Free Cl2	Monochloramine
77	ClO2	PAC	Imp. McM Filterability	Suspended IX	None	LP Memb.	None	None	None	Free Cl2	Monochloramine
78	ClO2	None	Imp. McM Filterability	Suspended IX	UV AOP	BAF	LP Memb.	None	None	Free Cl2	Monochloramine
79	None	None	Imp. McM Filterability	None	Cl2	Granular Media	None	None	None	Reduced Free Cl2	Monochloramine
80	None	PAC	Imp. McM Filterability	None	Cl2	Granular Media	None	None	None	Reduced Free Cl2	Monochloramine
81	MnO4	None	Imp. McM Filterability	None	None	LP Memb.	None	None	None	Reduced Free Cl2	Monochloramine

Train No.	Pre-Oxidant	PAC	Coagulation/Sedimentation	Secondary TOC Removal	Intermediate Oxidation	Filtration	2nd Stage Filtration	Interstage Disinfection	Polishing	Primary Disinfection	Secondary Disinfection
82	MnO4	PAC	Imp. McM Filterability	None	None	LP Memb.	None	None	None	Reduced Free Cl2	Monochloramine
83	None	None	Imp. McM Filterability	None	Cl2	Granular Media	None	UV (Crypto)	None	Reduced Free Cl2	Monochloramine
84	None	PAC	Imp. McM Filterability	None	Cl2	Granular Media	None	UV (Crypto)	None	Reduced Free Cl2	Monochloramine
85	None	None	Imp. McM Filterability	None	Cl2	Granular Media	None	None	Ion Exchange (IX)	Reduced Free Cl2	Monochloramine
86	None	PAC	Imp. McM Filterability	None	Cl2	Granular Media	None	None	Ion Exchange (IX)	Reduced Free Cl2	Monochloramine
87	MnO4	None	Imp. McM Filterability	None	None	LP Memb.	None	None	Ion Exchange (IX)	Reduced Free Cl2	Monochloramine
88	MnO4	PAC	Imp. McM Filterability	None	None	LP Memb.	None	None	Ion Exchange (IX)	Reduced Free Cl2	Monochloramine
89	None	None	Imp. McM Filterability	None	Cl2	Granular Media	None	UV (Crypto)	Ion Exchange (IX)	Reduced Free Cl2	Monochloramine
90	None	PAC	Imp. McM Filterability	None	Cl2	Granular Media	None	UV (Crypto)	Ion Exchange (IX)	Reduced Free Cl2	Monochloramine
91	ClO2	None	Imp. McM Filterability	None	None	LP Memb.	None	None	None	Reduced Free Cl2	Monochloramine
92	ClO2	PAC	Imp. McM Filterability	None	None	LP Memb.	None	None	None	Reduced Free Cl2	Monochloramine
93	ClO2	None	Imp. McM Filterability	None	None	LP Memb.	None	None	Ion Exchange (IX)	Reduced Free Cl2	Monochloramine
94	ClO2	PAC	Imp. McM Filterability	None	None	LP Memb.	None	None	Ion Exchange (IX)	Reduced Free Cl2	Monochloramine
95	None	None	Imp. McM Filterability	None	Cl2	Granular Media	None	None	GAC Contactors	Free Cl2	Free Cl2
96	MnO4	None	Imp. McM Filterability	None	Ozone AOP	BAF	None	None	GAC Contactors	Free Cl2	Free Cl2
97	MnO4	None	Imp. McM Filterability	None	UV AOP	BAF	None	None	GAC Contactors	Free Cl2	Free Cl2
98	MnO4	None	Imp. McM Filterability	None	None	LP Memb.	None	None	GAC Contactors	Free Cl2	Free Cl2
99	MnO4	None	Imp. McM Filterability	None	Ozone AOP	BAF	LP Memb.	None	GAC Contactors	Free Cl2	Free Cl2
100	MnO4	None	Imp. McM Filterability	None	UV AOP	BAF	LP Memb.	None	GAC Contactors	Free Cl2	Free Cl2
101	None	None	Imp. McM Filterability	None	Cl2	Granular Media	None	UV (Crypto)	GAC Contactors	Free Cl2	Free Cl2
102	None	None	Imp. McM Filterability	None	Cl2	Granular Media	None	None	GAC Contactors + IX	Free Cl2	Free Cl2
103	MnO4	None	Imp. McM Filterability	None	Ozone AOP	BAF	None	None	GAC Contactors + IX	Free Cl2	Free Cl2
104	MnO4	None	Imp. McM Filterability	None	UV AOP	BAF	None	None	GAC Contactors + IX	Free Cl2	Free Cl2
105	MnO4	None	Imp. McM Filterability	None	None	LP Memb.	None	None	GAC Contactors + IX	Free Cl2	Free Cl2
106	MnO4	None	Imp. McM Filterability	None	Ozone AOP	BAF	LP Memb.	None	GAC Contactors + IX	Free Cl2	Free Cl2
107	MnO4	None	Imp. McM Filterability	None	UV AOP	BAF	LP Memb.	None	GAC Contactors + IX	Free Cl2	Free Cl2
108	None	None	Imp. McM Filterability	None	Cl2	Granular Media	None	UV (Crypto)	GAC Contactors + IX	Free Cl2	Free Cl2
109	ClO2	None	Imp. McM Filterability	None	Ozone AOP	BAF	None	None	GAC Contactors	Free Cl2	Free Cl2
110	ClO2	None	Imp. McM Filterability	None	UV AOP	BAF	None	None	GAC Contactors	Free Cl2	Free Cl2
111	ClO2	None	Imp. McM Filterability	None	None	LP Memb.	None	None	GAC Contactors	Free Cl2	Free Cl2
112	ClO2	None	Imp. McM Filterability	None	Ozone AOP	BAF	LP Memb.	None	GAC Contactors	Free Cl2	Free Cl2
113	ClO2	None	Imp. McM Filterability	None	UV AOP	BAF	LP Memb.	None	GAC Contactors	Free Cl2	Free Cl2
114	ClO2	None	Imp. McM Filterability	None	Ozone AOP	BAF	None	None	GAC Contactors + IX	Free Cl2	Free Cl2
115	ClO2	None	Imp. McM Filterability	None	UV AOP	BAF	None	None	GAC Contactors + IX	Free Cl2	Free Cl2
116	ClO2	None	Imp. McM Filterability	None	None	LP Memb.	None	None	GAC Contactors + IX	Free Cl2	Free Cl2
117	ClO2	None	Imp. McM Filterability	None	Ozone AOP	BAF	LP Memb.	None	GAC Contactors + IX	Free Cl2	Free Cl2
118	ClO2	None	Imp. McM Filterability	None	UV AOP	BAF	LP Memb.	None	GAC Contactors + IX	Free Cl2	Free Cl2
119	MnO4	None	Imp. McM Filterability	None	None	LP Memb.	Reverse Osmosis	None	None	Free Cl2	Free Cl2
120	ClO2	None	Imp. McM Filterability	None	None	LP Memb.	Reverse Osmosis	None	None	Free Cl2	Free Cl2

NOTES:

* Treatment train alternative No. 0 represents existing treatment at WA.

Evaluation of Alternative Treatment Trains

The following steps describe the evaluation and comparison of alternative treatment trains:

- Identify and define a set of evaluation criteria.
- Assign weights to the evaluation criteria that correspond to their relative importance in the decision process.
- Score the treatment train alternatives for each evaluation criterion.
- Multiply the score by the weight of each evaluation criterion.
- Sum the weighted scores for each treatment train alternative, place them in ranked order, and discuss the rankings among the Experts and Stakeholders.

Evaluation Criteria

Workshops and meetings were conducted with Experts, Stakeholders, and Wholesale Customers to seek input on how alternative treatment trains (and ultimately complete mitigation strategies) should be compared. Several community values emerged as important factors, which are discussed in this section. A five-point scale was developed for each criterion to allow for scoring of each treatment train alternative via commercial decision software. The scale for each criterion spanned the range of values that were associated with the respective criterion. The evaluation criteria are listed below:

- Water quality improvement (which considers the additional health risk reduction afforded by the treatment, improved aesthetics, and compatibility of the treated water with the distribution system)
- Environmental and community impacts
- Financial costs
- Special risk issues and engineering feasibility

Water Quality Improvement

The Water Quality Improvement criterion was defined as the degree to which each treatment train alternative might improve water quality beyond what is currently achieved with the existing treatment process. The relative effectiveness of various strategies for the mitigation of water quality challenges will differ according to the particular challenge and its associated treatment objective. Therefore, each high-priority water quality challenge was treated as a separate criterion for scoring and screening the treatment train alternatives.

Table 13 summarizes the effectiveness of each of the unit treatment processes of Table 11 in treating the high priority water quality challenges. Table 13 was developed by considering not only the nature of the contaminant and the treatment process, but also the expected occurrence level and frequency of each contaminant and the degree of treatment by the process that would significantly improve public health protection or aesthetics. The degree of improvement was factored into the score that the specific treatment process received for each challenge. In some cases, treatment of one contaminant would actually increase the level of another contaminant; thus, the scoring had to account for such outcomes. Treatment processes that did not make a difference for a specific water quality challenge do not appear in the table.

Table 13. Effectiveness of Alternative Treatments Compared to Existing Treatment

Water Quality Objective	Degree Of Incremental Improvement Over Existing Treatment				
	3 = Significant Improvement	**2 = Moderate Improvement**	**1 = Nominal Improvement**	**0 = Baseline / Existing Treatment**	**-1 = Potential Decline in Effectiveness**
Microorganisms and Indicators					
Cryptosporidium (and other chlorine- resistant pathogens)	▪ LP membranes* ▪ UV disinfection	-	▪ Improve settled water quality at McMillan ▪ Post-filter GAC contactors ▪ Ozone	▪ Existing treatment	-
Bacteria / Protozoa (including Giardia lamblia, Legionella, Mycobacterium spp.*, and amoebae)*	-	-	▪ LP membranes* ▪ UV disinfection ▪ Ozone	▪ Existing Treatment	-
Viruses (and other UV-resistant pathogens)	-	-	▪ LP membranes* ▪ Ozone	▪ Existing treatment	-
Disinfectants / Disinfection Byproducts					
Regulated TTHMs / HAA5	-	-	▪ Reverse osmosis ▪ Post-filter GAC contactors ▪ Ozone, or Ozone-AOP + BAF ▪ GAC filter adsorbers ▪ Suspended IX	▪ Existing treatment	-
Unregulated Nitrogenous DBPs including NDMA and other nitrosamines	-	▪ Free chlorine for secondary disinfection (implies GAC post filter adsorption) ▪ RO ▪ Ozone	▪ Post-filter GAC contactors (with monochloramine as secondary disinfectant)	▪ Existing treatment	▪ Reduced free chlorine contact time (assuming monochloramine used for secondary disinfection) ▪ IX (anion exchange resins especially in presence of nitrite, either fixed bed or suspended IX)

Water Quality Objective	Degree Of Incremental Improvement Over Existing Treatment				
	3 = Significant Improvement	**2 = Moderate Improvement**	**1 = Nominal Improvement**	**0 = Baseline / Existing Treatment**	**-1 = Potential Decline in Effectiveness**
Pesticides (and their degradates)					
Atrazine, Simazine, and their degradates	▪ RO ▪ Post-filter GAC contactors ▪ PAC	▪ GAC filter adsorbers ▪ Ozone/Peroxide + BAF ▪ UV/Peroxide + BAF	-	▪ Existing treatment	-
Inorganics (from source water and treatment)					
Perchlorate	▪ IX ▪ RO	-	-	▪ Existing treatment	-
Hexavalent Chromium	-	▪ IX ▪ RO	-	▪ Existing treatment	-
Manganese	-	-	-	▪ Existing treatment	▪ Any process that doesn't allow for pre-filter chlorine addition (GAC filter adsorbers, BAF, LP membranes)
Distribution System Corrosion and Nitrification					
Lead	-	-	-	▪ Existing treatment (orthophosphate 2.5 mg/L, pH 7.7 =/- 0.1)	▪ RO ▪ IX
Nitrification	▪ Free chlorine as a secondary disinfectant	▪ Ozone/ BAF ▪ RO	▪ Post-filter GAC contactors ▪ GAC filter adsorbers	▪ Existing treatment	
Iron release, cloudiness, and red water	-	-	▪ Free chlorine as a secondary disinfectant	▪ Existing treatment	▪ RO ▪ IX

Water Quality Objective	Degree Of Incremental Improvement Over Existing Treatment				
	3 = Significant Improvement	**2 = Moderate Improvement**	**1 = Nominal Improvement**	**0 = Baseline / Existing Treatment**	**-1 = Potential Decline in Effectiveness**
Perception and Aesthetics					
Earthy / Musty Taste & Odor (MIB and geosmin)	▪ Post-filter GAC contactors ▪ Ozone/Peroxide or UV/Peroxide ▪ RO	▪ GAC filter adsorbers ▪ PAC	-	▪ Existing treatment	-
Chlorinous Taste & Odor	-	-	-	▪ Existing treatment	-

* Refers to ultrafiltration (UF)

Environmental and Community Impacts

The second major evaluation factor was Environmental and Community Impacts. This criterion was made up of four sub-criteria as discussed below.

Energy Usage and Emissions

The Energy Usage and Emissions criterion was defined as the degree to which each treatment train alternative generates additional greenhouse gas emissions (beyond what is generated by the existing treatment process). Table 14 lists the energy usage assumption for each treatment process in terms of metric tons of carbon dioxide emissions produced per year.

Table 14. Energy Usage and Emissions by Technology

Treatment Process	Energy Usage and Emissions (metric tons CO_2/year)
Chlorine Dioxide	2,000
PAC[1]	500
Improve Filterability at McMillan	TBD
Suspended Ion Exchange (e.g., MIEX)	2,000
Ozone + Peroxide (Ozone AOP)	7,000
UV + Peroxide (UV AOP)	16,500
Biological Filters	9,500
GAC Filter Adsorbers[2]	47,500
Low-pressure Membrane Filters	36,500
Post-filter GAC Contactors[3]	47,500
UV Disinfection	3,500
Reverse Osmosis	90,500
Fixed Bed Ion Exchange	27,000

NOTES:
[1] The PAC energy usage and emissions were revised based on data that was not available at the time Volume III was prepared; a 0.2 mg/L PAC dosage (year-round) was assumed, which is equivalent to the estimated yearly total PAC usage of approximately 13,000 lbs. Assuming that there is one moderate episode (lasting a week) per year.
[2] GAC replacement once a year
[3] GAC replacement once every two years

Resource Consumption

The Resource Consumption criterion was defined as the degree to which each treatment train alternative requires the use of additional chemicals and/or media, beyond what is used in the existing treatment process. Resource consumption assumptions for each treatment process are listed in Table 15.

Safety

Safety was defined as the degree to which any treatment train alternative requires the use of hazardous chemicals, which could pose increased risk to the community or to treatment plant personnel. No public safety concerns were identified in this analysis. Table 16 summarizes the operator safety assumptions used in the analysis.

Table 15. Chemical and Media Resource Consumption

Treatment Process	Potential Changes to the Treatment Process	Total Resource Needs (tons/year)
Permanganate	Prolonged and increased use of Potassium Permanganate	100
Chlorine Dioxide	Addition of Chlorine Dioxide	200
PAC[2]	Increased use of PAC	50
Improve Filterability at McMillan	Increased addition of PACl or other chemicals, depending on the process selected	TBD
Suspended Ion Exchange (e.g., MIEX)	Use of salt for media regeneration	8,800
Ozone + Peroxide (Ozone AOP)	Addition of Ozone and Hydrogen Peroxide	1,000
UV + Peroxide (UV AOP)	Addition of Hydrogen Peroxide	2,400
Biological Filters	Occasional GAC replacement	1,000
GAC Filter Adsorbers	Regular GAC replacement	4,800
Low-pressure Membrane Filters	Use of membrane cleaning chemicals	400
Post-filter GAC Contactors	Regular GAC replacement	5,200
Reverse Osmosis	Use of membrane cleaning chemicals	1,600
Ion Exchange	Regular Resin replacement	1,500

NOTES:

[1] The PAC consumption was revised based on data that was not available at the time Volume III was prepared; a 0.2 mg/L PAC dosage (year-round) was assumed, which is equivalent to the estimated yearly total PAC usage of approximately 13,000 lbs. Assuming that there is one moderate episode (lasting a week) per year.

Table 16. Operator Safety Considerations

Operator Safety Risk Level	None	Low	Medium	High
Sodium Permanganate		X		
Chlorine Dioxide		X		
PAC	X			
Improve Filterability at McMillan	X			
Suspended Ion Exchange (e.g., MIEX)	X			
Ozone + Peroxide (Ozone AOP)			X	
UV + Peroxide (UV AOP)			X	
Granular Media Filters or Biological Filters	X			
GAC Filter Adsorbers		X		
Low-Pressure Membrane Filters		X		
Post-filter GAC Contactors		X		
UV Disinfection		X		
Reverse Osmosis		X		
Fixed Bed Ion Exchange	X			

Residuals Production

The Residuals Production sub-criterion is defined as the degree to which each treatment train alternative produces additional residuals (beyond what is produced by the existing treatment process). This criterion also considers whether the residuals could be classified as hazardous, which would create challenges concerning treatment and disposal. Table 17 and Table 18 show estimated residuals production assumptions used in the analysis.

Table 17. Estimated Residuals Production by Technology

Treatment Strategy	Estimated Solid Waste (tons/year)	Estimated Liquid Waste (MGD)
Permanganate	-	-
Chlorine Dioxide	-	-
PAC[1]	50	-
Improve FIlterability at McMillan	TBD	TBD
Suspended Ion Exchange (e.g., MIEX)	-	-
Ozone + Peroxide (Ozone AOP)	-	-
UV + Peroxide (UV AOP)	-	-
Granular Media Filters[2]	-	-
Biological Filters	900	-
GAC Filter Adsorbers	4,800	-
Low-pressure Membrane Filters	-	10
Post-filter GAC Contactors[3]	4,700	
UV Disinfection	-	-
Reverse Osmosis	-	15
Fixed Bed Ion Exchange	3,500	-

NOTES:

[1] The PAC consumption was revised based on data that was not available at the time Volume III was prepared; a 0.2 mg/L PAC dosage (year-round) was assumed, which is equivalent to the estimated yearly total PAC usage of approximately 13,000 lbs. Assuming that there is one moderate episode (lasting a week) per year.

[2] GAC replacement once a year; this assumes that the spent GAC would be sent to a landfill; if the GAC is reactivated, these residual waste values would be greatly reduced

[3] GAC replacement once every two years, this assumes that the spent GAC would be sent to a landfill; if the GAC is reactivated, these residual waste values would be greatly reduced

Table 18. Classification of Residuals Production by Technology

Treatment Strategy	Minimal	Moderate	Significant	Notes
Permanganate	X			
Chlorine Dioxide	X			
PAC	X			
Improve Filterability at McMillan	TBD			
Ozone + Peroxide (Ozone AOP)	X			
UV + Peroxide (UV AOP)	X			
Granular Media Filters or Biological Filters	X			
GAC Filter Adsorbers		X		
Low-pressure Membrane Filters		X		Chemical cleaning wastes require neutralization and dechlorination prior to sewer discharge
Post-filter GAC Contactors		X		
UV Disinfection	X			
Reverse Osmosis			X	Concentrated liquid waste stream potentially hazardous, may not be accepted by the WWTP
Fixed Bed Ion Exchange (IX)		X		Spent resin potentially hazardous, also
Suspended Ion Exchange (e.g., MIEX)			X	Brine waste stream potentially hazardous

Special Risk Issues

The Special Risk Issues criterion was used to capture potential reliability risks or unintended negative consequences associated with the treatment train alternatives, such as the risk of compliance monitoring violations with chlorine dioxide, or sole-source procurement issues which accompany certain treatment processes or products, like low pressure membrane replacement filters. These items are summarized in Table 19.

Table 19. Summary of Special Risk Issues

Treatment Strategy	Special Risk Issues
Permanganate	Manganese build-up in McMillan Reservoir
Chlorine Dioxide	Increased risk of wholesale customer Tier 1 Public Notice violations based on distribution system monitoring requirements
PAC	None
Improve Filterability at McMillan	Production limitations at the McMillan Plant[1]
Suspended Ion Exchanged (e.g., MIEX)	Only one well-established source, overseas supplier[2,3,4]
Ozone + Peroxide (Ozone AOP)	Bromate formation Unknown oxidation byproducts
UV + Peroxide (UV AOP)	Unknown oxidation byproducts Potential mercury release due to lamp breakage (with associated notification requirements)
Granular Media Filters, Biological Filters, or GAC Filter Adsorbers	Loss of filtration in the event of a treatment upset[5]
Low-pressure Membrane Filters	Sole-source replacement filters
Post-filter GAC Contactors	None
UV Disinfection	Potential mercury release due to lamp breakage (with associated notification requirements)
Reverse Osmosis	None[2]
Ion Exchange (IX)	None[2,4]

NOTES:

[1] This risk was considered only in the one treatment train alternative which did not include improved filterability at the McMillan Plant (the baseline alternative). Improving filterability of the settled water would likely allow for increased filter loading rates.

[2] Corrosion impacts associated with ion exchange and reverse osmosis were captured in the water quality scoring rubric (see Table 4-2).

[3] A second supplier of suspended IX resin (PWN Technologies) has recently emerged in the market. It remains to be seen whether this company will be a reliable source.

[4] NDMA impacts associated with IX were captured in the water quality scoring rubric (see Table 4-2).

[5] Loss of filtration is not an issue when media filters are followed by LP membrane filters.

Financial Cost

The Financial Cost criterion was used to evaluate and compare treatment trains on the basis of total costs. It is defined as the net present worth of capital and operations and maintenance (O&M) costs for each treatment train alternative, assuming a 30-year project lifespan and 4% interest. Table 20 shows the individual costs associated with each technology, which were summed to develop total treatment train costs for each alternative. Present worth financial costs ranged from $0 (baseline alternative) to $2.3 billion for the most expensive of the 120 treatment trains evaluated.

Table 20. Summary of Capital, O&M and Present Worth Financial Cost Estimates for Individual Treatment Processes

Technology	Capital Cost ($M)[1]	O&M Cost ($M/yr)[1]	Present Worth Financial Cost ($M)[1,2]
Permanganate	$0.08	$0.5	$10
Chlorine Dioxide	$20	$3	$70
PAC[3]	$7	$0.4	$10
Improved Filterability at McMillan[4]	TBD		
Suspended Ion Exchange (e.g., MIEX)	$200	$4	$270
Ozone AOP	$100	$9	$260
UV AOP	$100	$7	$220
BAF	$10	$3	$60
GAC Filter Adsorbers	$80	$20	$430
LP Membranes (Submerged)	$300	$10	$470
Reverse Osmosis	$400	$20	$750
Ultraviolet Disinfection (designed for *Cryptosporidium*)	$40	$0.9	$60
GAC Contactors	$200	$20	$550
Fixed Bed Ion Exchange	$400	$30	$920
Reconfiguring 1st Clearwell	$8	$0	$10

NOTES:

[1] The capital and O&M costs were rounded to one significant figure and the total present worth in each case was calculated using these rounded values.

[2] Present worth financial cost based on a 30-year project lifespan, and 4% interest. An equipment life expectancy of 30 years was assumed for all technologies.

[3] The PAC costs were revised based on data that was not available at the time Volume III was prepared; a 0.2 mg/L PAC dosage (year-round) was assumed, which is equivalent to the estimated yearly total PAC usage of approximately 13,000 lbs. Assuming that there is one moderate episode (lasting a week) per year.

[4] The appropriate strategy for improving the filterability of the settled water at McMillan has not yet been selected, thus no cost are available. If onsite clarification is selected, the capital and O&M costs would be $50M and $3M/year, respectively.

Subcriteria Weighting

Water Quality Improvement

Although the screening and prioritization steps narrowed the list of hundreds of possible water quality challenges to just fourteen challenges, no single treatment process or even treatment train could effectively address all of these simultaneously. The project team recognized a need to rank the priority (Quadrant 4) challenges and use the rankings to weight each of the water quality improvement subcriteria so that mitigation strategies would favor the more important concerns among the fourteen challenges.

To accomplish this ranking, a standard approach for comparing relative risks was used:

$$R = P \times CS \times (1-E)$$

Where:
R = relative risk posed by the challenge, compared to other high priority challenges
P = probability of occurrence of the challenge above the CL (Criteria Level)
CS= magnitude of the consequences of occurrence of the challenge above the CL
E= effectiveness of the existing treatment

For each parameter, the probability of occurrence (P), the potential consequences of occurrence (CS), and the relative effectiveness of WA's existing treatment process in controlling it (E) were judged on a scale (0.9=high, 0.5= medium, 0.1= low). In this way, the project team could consider such questions as "Is this water quality challenge likely to cause acute health effects at the expected occurrence levels?" and "Is this challenge likely to occur intermittently or persistently?" and "What are the consequences of this contaminant occurring above the CL in the drinking water?"

Table 21 shows the assumptions for each of the factors in this equation, and the outcome of this weighting is illustrated in Figure 4. As shown in the figure, the weighting also factored in a small contribution from water quality challenges from Quadrant 3.

As can be seen from Figure 4, four water quality challenges emerged that were ranked equivalently as the top water quality drivers among the fourteen high priority water quality challenges:

- *Cryptosporidium*
- Nitrification in the distribution system
- Earthy-musty tastes and odor in the finished water or the distribution system
- Iron release/cloudiness/red water in the distribution system

Although lead was not ranked among the highest four priorities in this process, WA and the project team recognize that it is critically important that lead levels at the consumer's tap be as low as possible; thus, any treatment that might adversely affect lead levels was penalized in the water quality improvement scoring.

Figure 4. Outcome of Weighting of Water Quality Improvements

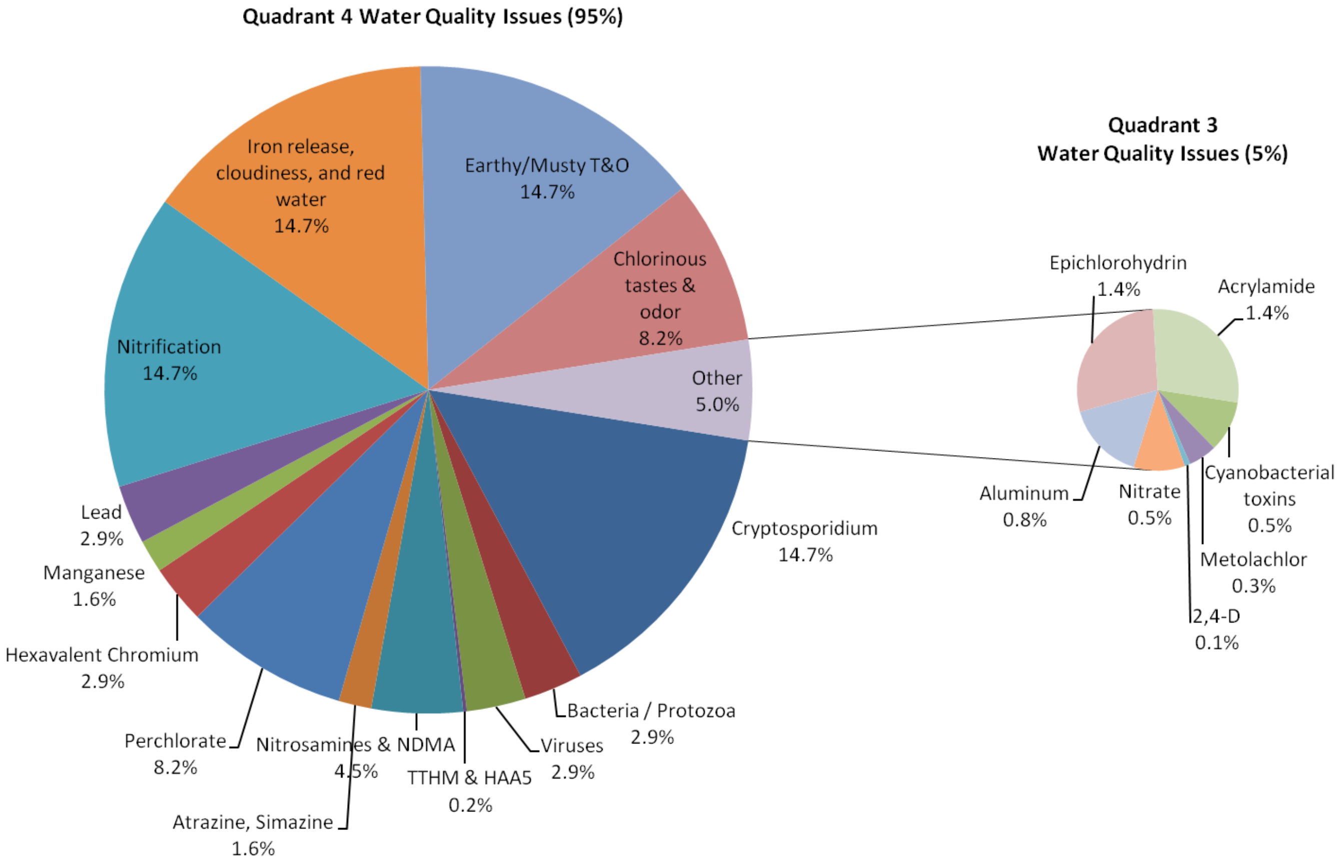


Table 21. Assumptions for Weighting of Water Quality Improvement Subcriteria

Parameter	Probability of Occurrence (Low, Medium, High)	Consequences of Occurrence (Low, Medium, High)	Description of Existing Treatment	Effectiveness (Low, Medium, High)	R (in percent)
Microorganisms and Indicators					
Cryptosporidium (and other chlorine-resistant pathogens)	High	High	Conventional treatment, meeting requirements for CFE and IFE performance	Medium	14.7
Bacteria / Protozoa (including *Giardia lamblia, Legionella, Mycobacterium* spp., and *amoebae*)	High	High	Conventional treatment, free chlorine contact for primary disinfection, IESWTR compliant filtration, meeting requirements for CFE and IFE performance	High	2.9
Viruses (and other UV-resistant pathogens)	High	High	Conventional treatment, free chlorine contact for primary disinfection	High	2.9
Disinfectants / Disinfection Byproducts					
Regulated Total Trihalomethanes (TTHMs) / Five Haloacetic Acids (HAA5)	Low	Medium	Enhanced coagulation, free chlorine contact for primary disinfection, monochloramine for secondary disinfection	High	0.2
Unregulated Nitrogenous DBPs including NDMA and other nitrosamines	Medium	Medium	Enhanced coagulation, free chlorine contact for primary disinfection, chloramine for secondary disinfection	Medium	4.5
Pesticides (and their degradates)					
Atrazine, Simazine, and their degradates	Medium	Low	N/A	Low	1.6
Inorganics (from source water and treatment)					
Perchlorate	Medium	Medium	N/A	Low	8.2
Hexavalent Chromium	High	Low	N/A	Low	2.9
Manganese	High	Medium	Free chlorine applied before filters	High	1.6

Distribution System Corrosion and Nitrification					
Lead	High	High	OCCT has been designated as Orthophosphate 2.5 mg/L and pH 7.7 +/- 0.1	High	2.9
Nitrification	High	High	Cl2 to NH3 ratio >4 and Free ammonia <0.15 mg/L	Medium	14.7
Iron release, cloudiness, and red water	High	High	2.5 mg/L orthophosphate	Medium	14.7
Perception and Aesthetics					
Earthy / Musty Taste & Odor (MIB and geosmin)	Medium	High	PAC at < 20 mg/L	Low	14.7
Chlorinous Taste & Odor	High	Medium	Monochloramine for secondary disinfection with intermittent free-chlorine changeover Target disinfectant residual=3.7 mg/L	Medium	8.2

Weighting Scenario Sensitivity Analysis

Once the scoring rubrics for each evaluation criterion were developed, as detailed in the preceding sections, the overall score of each treatment train could be calculated. Figure 5 depicts the relative rankings of the 120 treatment train alternatives when the four primary evaluation criteria (water quality improvement, financial cost, special risk issues, and environmental / community impacts) were each weighted at 25 percent.

The top twelve treatment trains are shown in Figure 6. WA's existing treatment train ranks among them. In addition, four trains involving UV disinfection and two involving post-filter GAC contactors ranked among the top twelve.

To better understand the nuances and limitations of the scoring rubrics, a sensitivity analysis was conducted as follows. Three weighting scenarios were developed to compare treatment trains when each of three evaluation criteria-- water quality improvement, cost, and energy--were emphasized (see Table 22). These three criteria are in keeping with the triple bottom line approach to measuring project success. The results provided insight into the trade-offs associated with different treatment alternatives and helped to support a better understanding of the available options.

Table 22. Criteria Weighting Scenarios

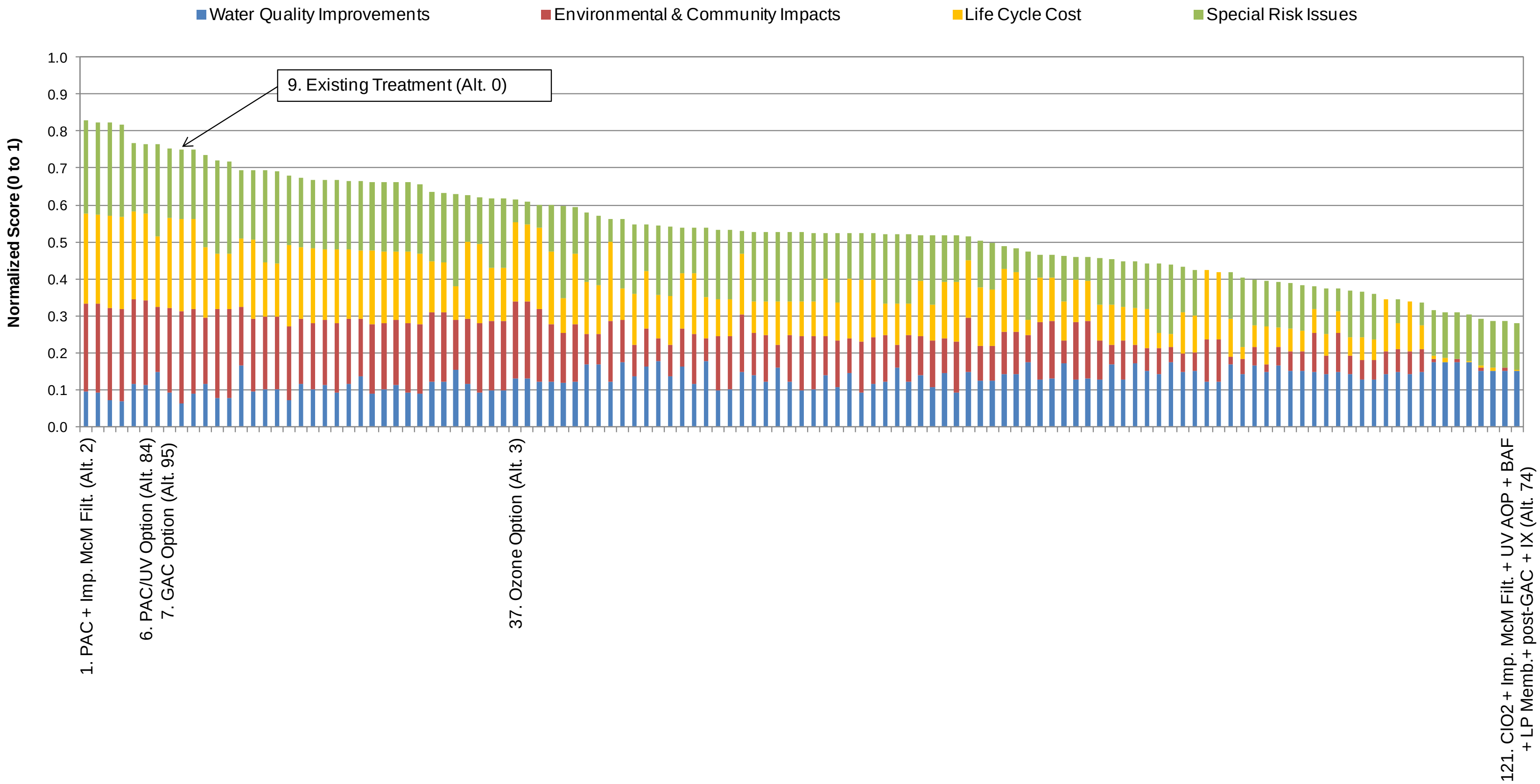
Criteria / Criteria Category	Scenario A	Scenario B	Scenario C
Water Quality	80%	6%	6%
Cost	6%	80%	6%
Energy	6%	6%	80%
Others (Special Risk Issues, Resource Consumption, Safety, and Residuals Production)	2% each	2% Each	2% each
TOTAL	100%	100%	100%

The various sensitivity analyses allowed the project team and the Expert Panel to consider all 120 treatment train alternatives and then select three viable treatment trains that represent reasonable approaches to enhancing drinking water quality. Figures 7, 8 and 9 show the relative rankings of the 120 treatment train alternatives for scenarios A, B and C, respectively.

Figure 10 shows the top 12 treatment trains that emerge when water quality improvement is emphasized (and cost and energy consumption/emissions are not considered strongly). The trains tend to include multiple advanced treatment processes (such as alternative 105, which includes post GAC, UV, and BAF as well as free chlorine disinfection). None of the treatment trains in Figure 10 appears under the other two weighting scenarios; not unexpectedly, substantial water quality enhancements via treatment improvements would only be accomplished with a significant investment of money and energy.

As can be seen from Figure 11 and Figure 12, the treatment trains that emerged as the top prospects under the Energy weighting scenario and the Cost weighting scenario were similar; thus, total project costs appear to be dominated by the annual energy costs.

Figure 5. Balanced Scenario for Treatment Train Alternative Scores (Equally Weighted Primary Criteria)

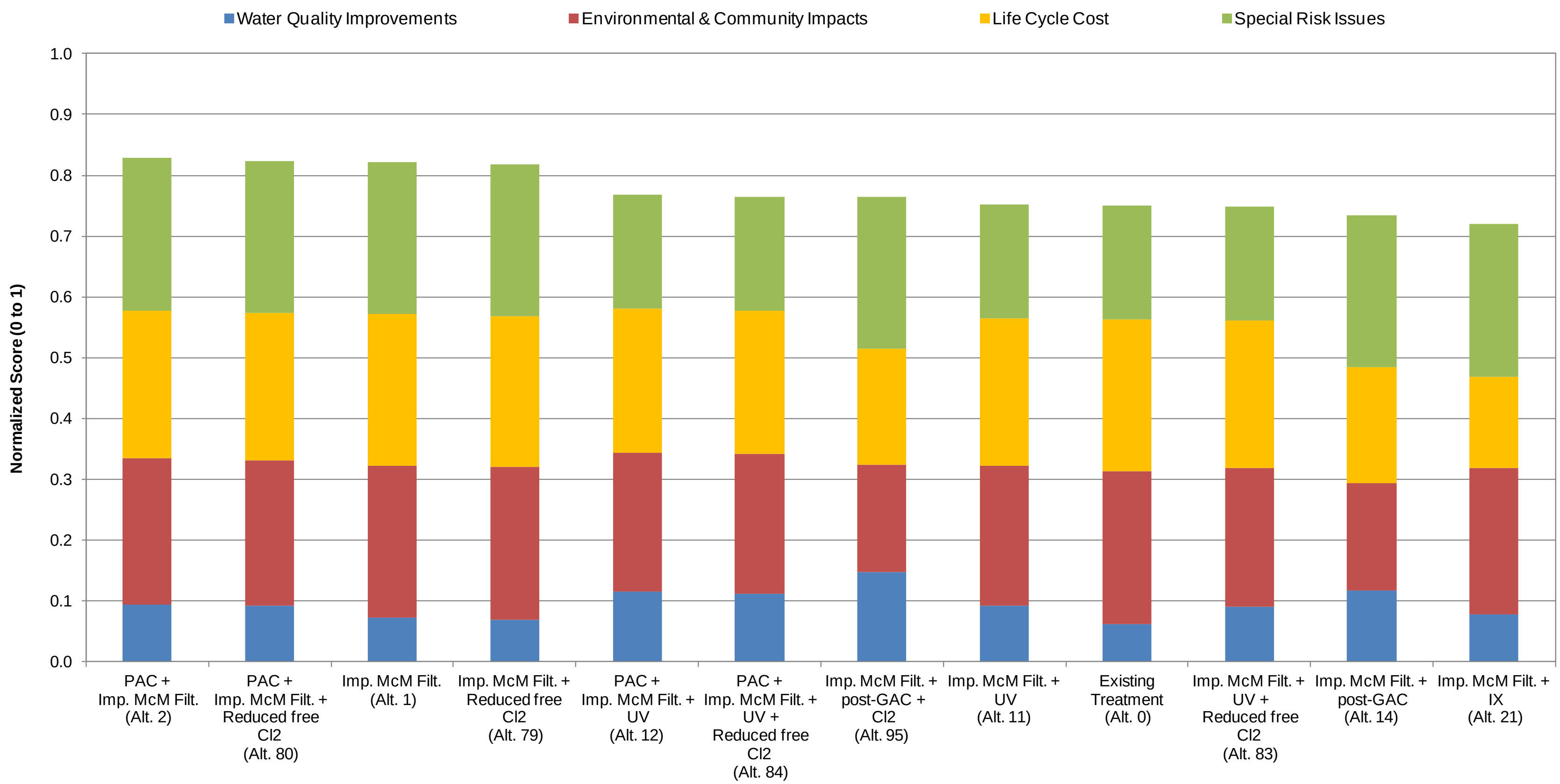


NOTES:

*The following weights were used in the Balanced Scenario: Water Quality Improvements = 25%; Life Cycle Cost = 25%; Special Risk Issues = 25%; Environmental & Community Impacts = 25% (Energy Usage and Emissions = 50%; Resource Consumption = 16.7%; Safety = 16.7%; and Residuals Production = 16.7%)

Imp. McM Filt. = Improve filterability at the McMillan WTP; UV = Ultraviolet disinfection; post-GAC = post-filter Granular Activated Carbon contactors; Cl_2 = free chlorine for secondary disinfection (discontinuing the use of monochloramine); IX = Ion Exchange; MnO_4 = Permanganate(Sodium or Potassium) for pre-oxidation; UF = ultrafiltration membranes; RO = reverse osmosis; ClO2 = chlorine dioxide for pre-oxidation; O3 AOP = ozone + peroxide, an advanced oxidation process; BAF = biologically active filtration; UV AOP = UV + peroxide (positioned ahead of the filters, therefore not for disinfection)

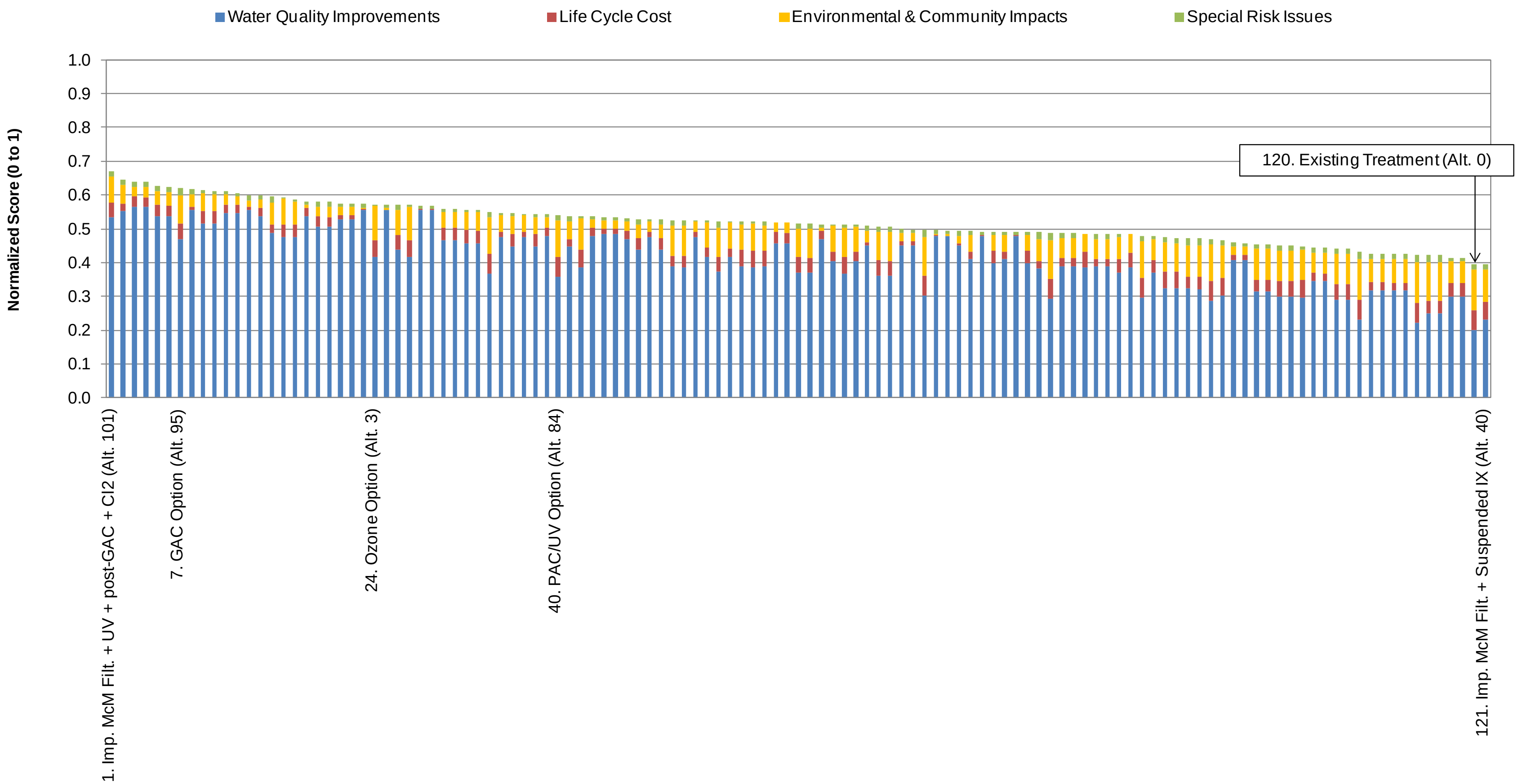
Figure 6. Top 12 Scoring Alternatives for Balanced Scenario*



NOTES:
*The following weights were used in the Balanced Scenario: Water Quality Improvements = 25%; Life Cycle Cost = 25%; Special Risk Issues = 25%; Environmental & Community Impacts = 25% (Energy Usage and Emissions = 50%; Resource Consumption = 16.7%; Safety = 16.7%; and Residuals Production = 16.7%)

Imp. McM Filt. = Improve filterability at the McMillan WTP; UV = Ultraviolet disinfection; post-GAC = post-filter Granular Activated Carbon contactors; Cl_2 = free chlorine for secondary disinfection (discontinuing the use of monochloramine); IX = Ion Exchange; MnO_4 = Permanganate(Sodium or Potassium) for pre-oxidation; UF = ultrafiltration membranes; RO = reverse osmosis; ClO2 = chlorine dioxide for pre-oxidation; O3 AOP = ozone + peroxide, an advanced oxidation process; BAF = biologically active filtration; UV AOP = UV + peroxide (positioned ahead of the filters, therefore not for disinfection)

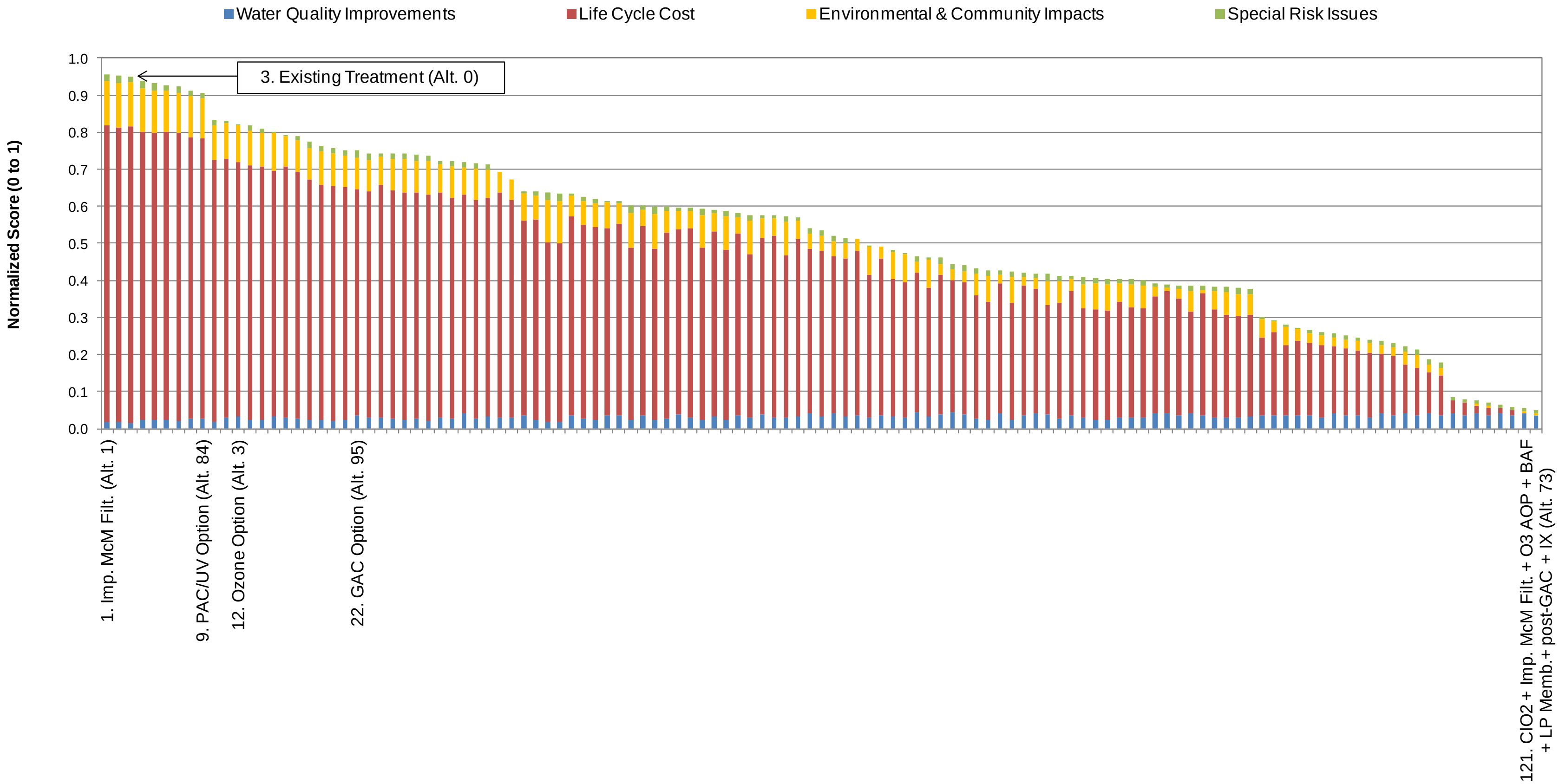
Figure 7. Alternatives Scoring Results for Scenario A*



NOTES:
*The following weights were used in Scenario A: Water Quality Improvements = 80%; Life Cycle Cost = 6%; Energy Usage and Emissions = 6%; Special Risk Issues = 2%; Resource Consumption = 2%; Safety = 2%; and Residuals Production = 2%

Imp. McM Filt. = Improve filterability at the McMillan WTP; UV = Ultraviolet disinfection; post-GAC = post-filter Granular Activated Carbon contactors; Cl_2 = free chlorine for secondary disinfection (discontinuing the use of monochloramine); IX = Ion Exchange; MnO_4 = Permanganate(Sodium or Potassium) for pre-oxidation; UF = ultrafiltration membranes; RO = reverse osmosis; ClO2 = chlorine dioxide for pre-oxidation; O3 AOP = ozone + peroxide, an advanced oxidation process; BAF = biologically active filtration; UV AOP = UV + peroxide (positioned ahead of the filters, therefore not for disinfection)

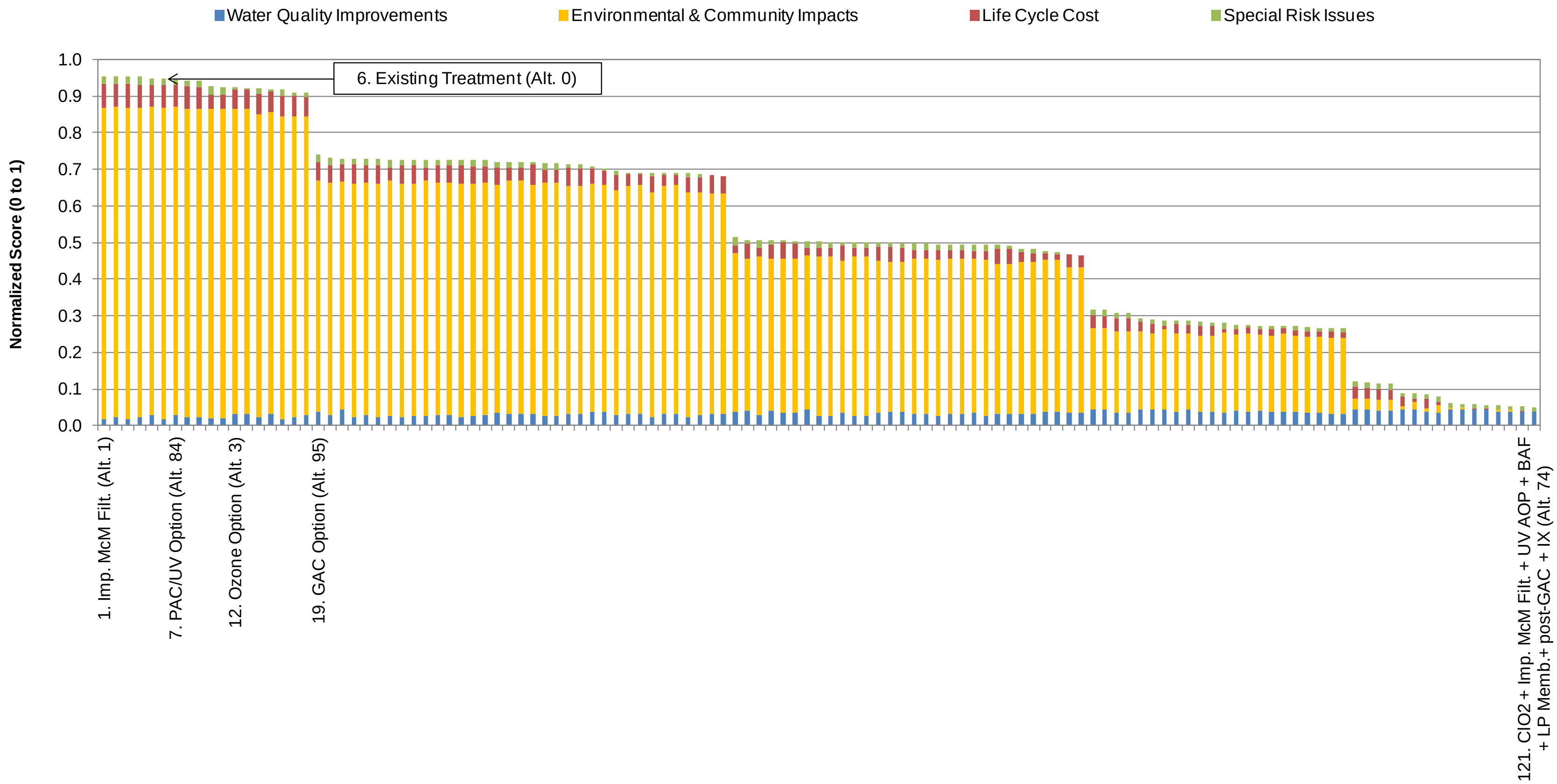
Figure 8. Alternatives Scoring Results for Scenario B*



NOTES:
*The following weights were used in Scenario B: Water Quality = 6%; Life Cycle Cost = 80%; Energy Usage and Emissions = 6%; Special Risk Issues = 2%; Resource Consumption = 2%; Safety = 2%; and Residuals Production = 2%

PAC = Powder Activated Carbon; Imp. McM Filt. = Improve filterability at the McMillan WTP; UV = Ultraviolet disinfection; Reduced free Cl_2 = reconfiguring the clearwells to reduce free chlorine contact time prior to adding ammonia (to form monochloramine for secondary disinfection);IX = Ion Exchange; MnO_4 = Permanganate(Sodium or Potassium) for pre-oxidation; O3 AOP = ozone + peroxide, an advanced oxidation process; BAF = biologically active filtration; LP membranes = Low-pressure membranes; ClO2 = Chlorine dioxide

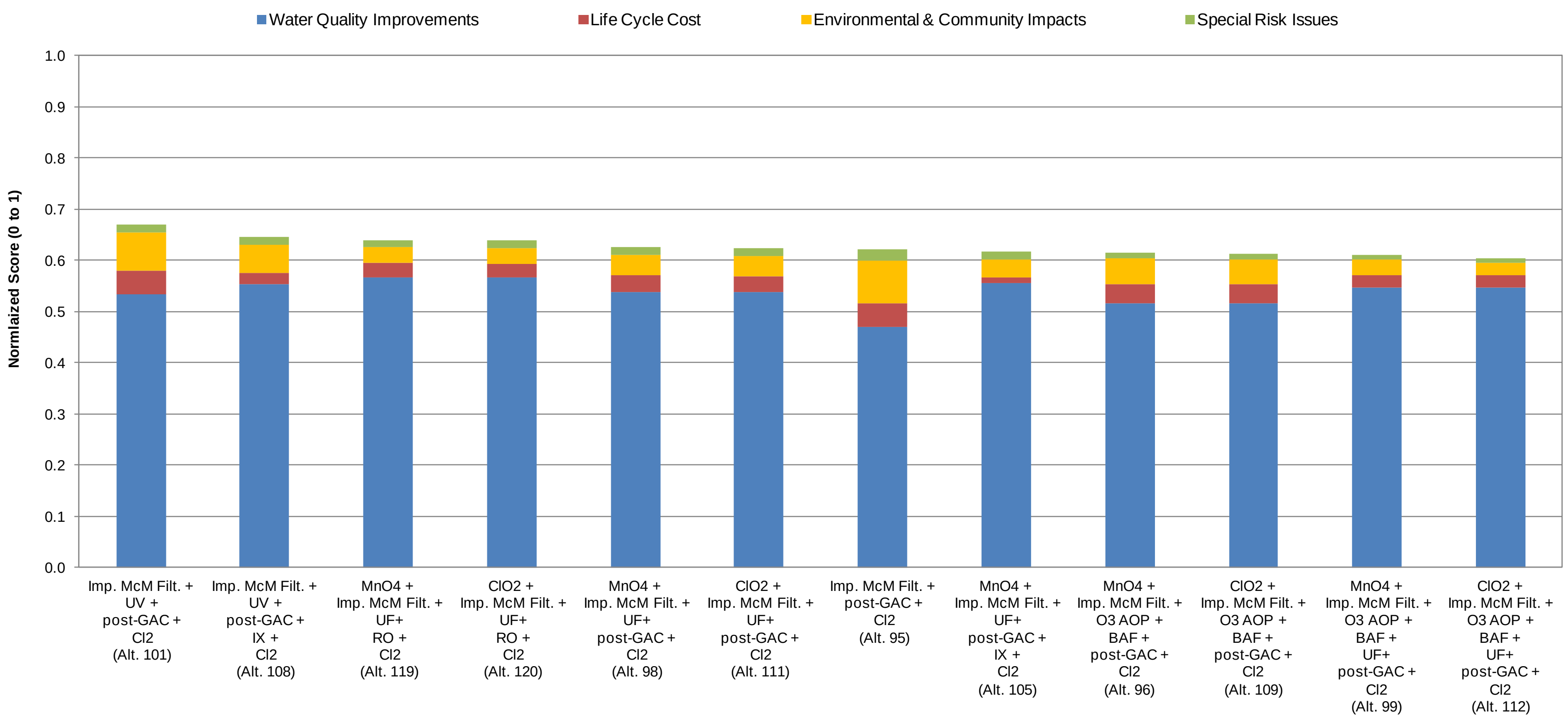
Figure 9. Alternatives Scoring Results for Scenario C*



NOTES:
*The following weights were used in Scenario C: Water Quality = 6%; Life Cycle Cost = 6%; Energy Usage and Emissions = 80%; Special Risk Issues = 2%; Resource Consumption = 2%; Safety = 2%; and Residuals Production = 2%

PAC = Powder Activated Carbon; Imp. McM Filt.. = Improve filterability at the McMillan WTP; UV = Ultraviolet disinfection; Reduced free Cl_2 = reconfiguring the clearwells to reduce free chlorine contact time prior to adding ammonia (to form monochloramine for secondary disinfection); MnO_4 = Permanganate(Sodium or Potassium) for pre-oxidation; O3 AOP = ozone + peroxide, an advanced oxidation process; BAF = biologically active filtration; ClO2 = chlorine dioxide for pre-oxidation; LP membranes = Low-pressure membranes

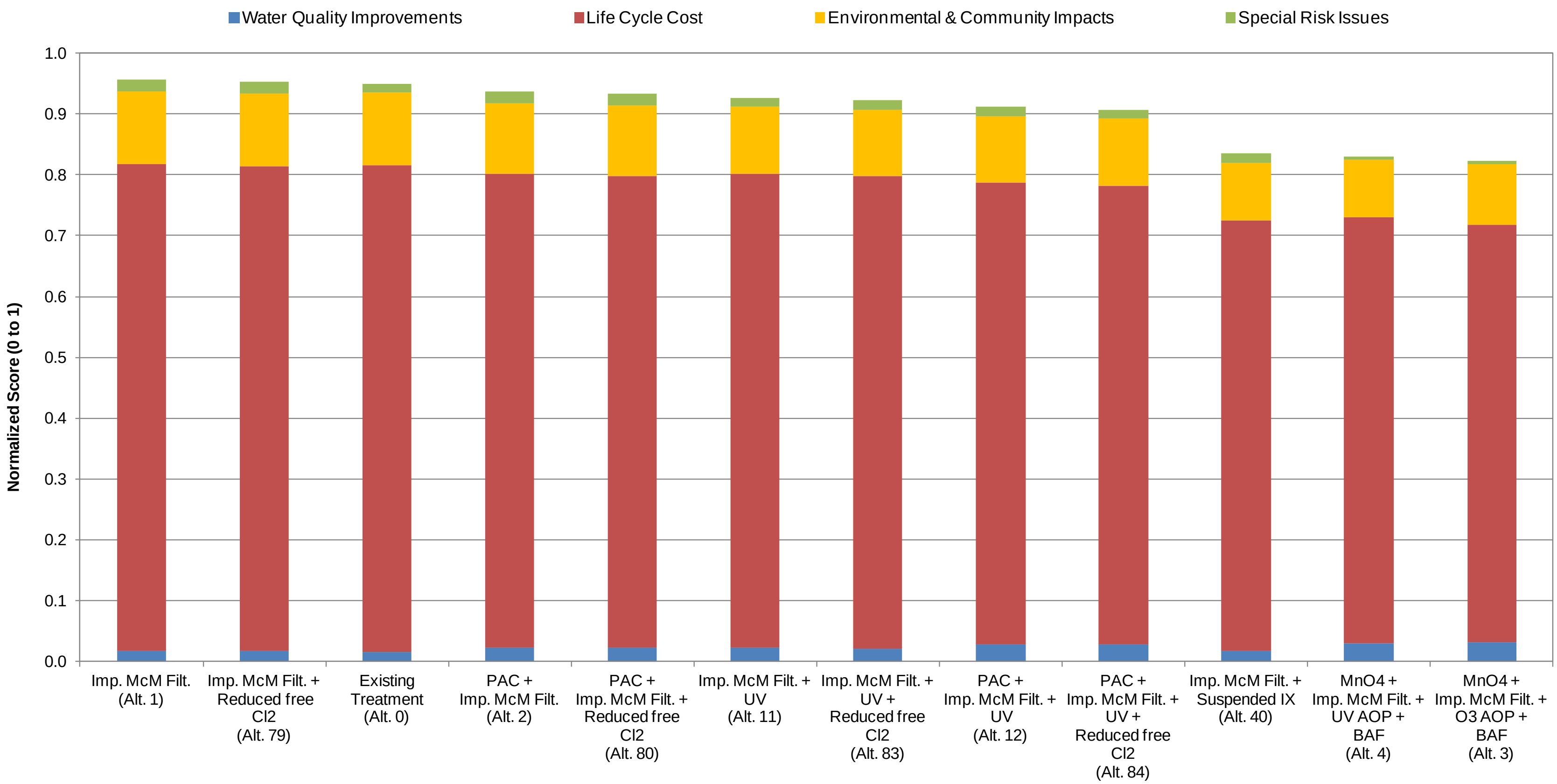
Figure 10. Top 12 Scoring Alternatives for Scenario A*



NOTES:
*The following weights were used in Scenario A: Water Quality Improvements = 80%; Life Cycle Cost = 6%; Energy Usage and Emissions = 6%; Special Risk Issues = 2%; Resource Consumption = 2%; Safety = 2%; and Residuals Production = 2%

Imp. McM Filt. = Improve filterability at the McMillan WTP; UV = Ultraviolet disinfection; post-GAC = post-filter Granular Activated Carbon contactors; Cl_2 = free chlorine for secondary disinfection (discontinuing the use of monochloramine); IX = Ion Exchange; MnO_4 = Permanganate(Sodium or Potassium) for pre-oxidation; UF = ultrafiltration membranes; RO = reverse osmosis; ClO2 = chlorine dioxide for pre-oxidation; O3 AOP = ozone + peroxide, an advanced oxidation process; BAF = biologically active filtration; UV AOP = UV + peroxide (positioned ahead of the filters, therefore not for disinfection)

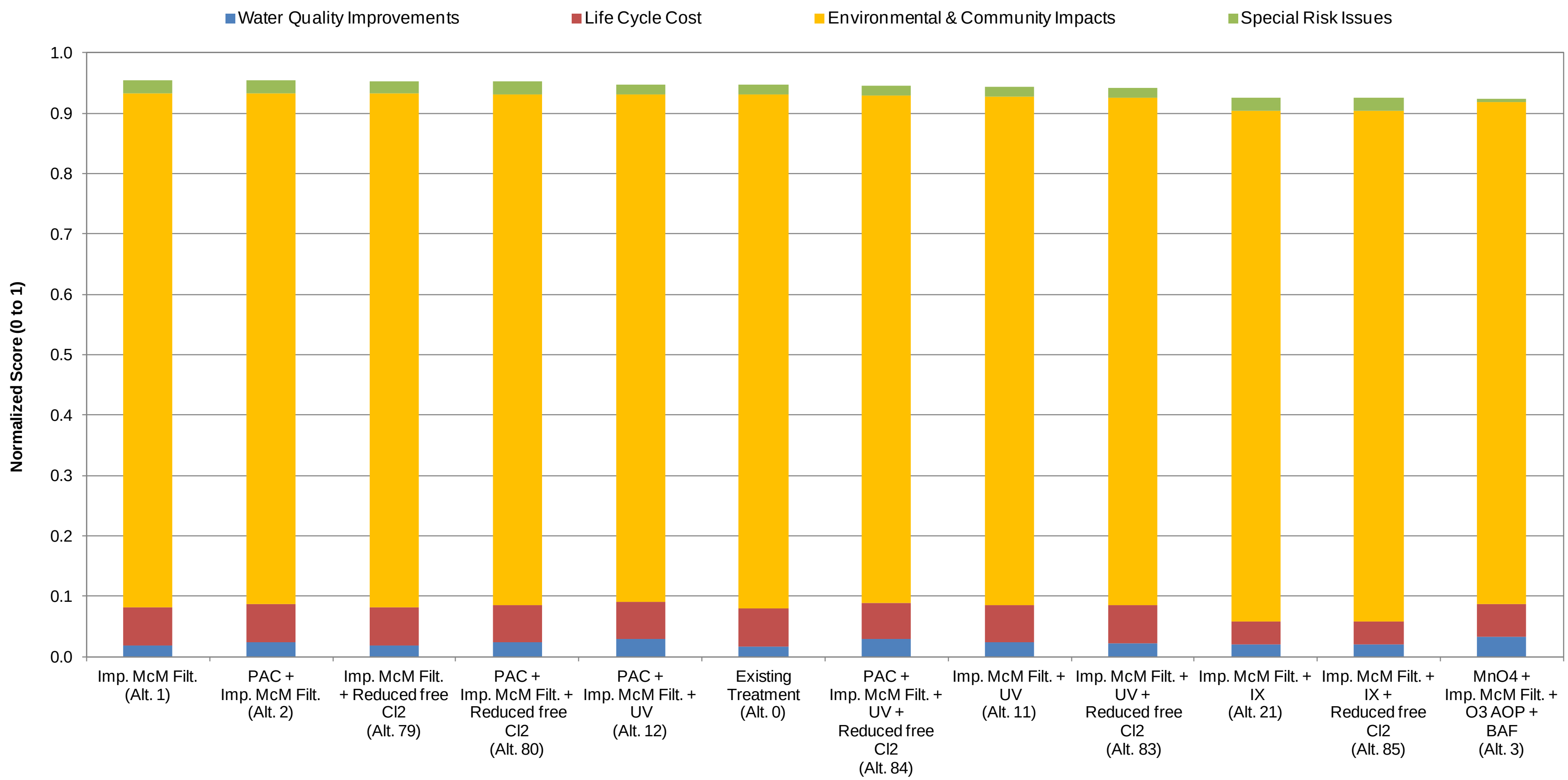
Figure 11. Top 12 Scoring Alternatives for Scenario B*



NOTES:
*The following weights were used in Scenario B: Water Quality = 6%; Life Cycle Cost = 80%; Energy Usage and Emissions = 6%; Special Risk Issues = 2%; Resource Consumption = 2%; Safety = 2%; and Residuals Production = 2%

PAC = Powder Activated Carbon; Imp. McM Filt. = Improve filterability at the McMillan WTP; UV = Ultraviolet disinfection; Reduced free Cl_2 = reconfiguring the clearwells to reduce free chlorine contact time prior to adding ammonia (to form monochloramine for secondary disinfection);IX = Ion Exchange; MnO_4 = Permanganate(Sodium or Potassium) for pre-oxidation; O3 AOP = ozone + peroxide, an advanced oxidation process; BAF = biologically active filtration;

Figure 12. Top 12 Scoring Alternatives for Scenario C*



NOTES:
*The following weights were used in Scenario C: Water Quality = 6%; Life Cycle Cost = 6%; Energy Usage and Emissions = 80%; Special Risk Issues = 2%; Resource Consumption = 2%; Safety = 2%; and Residuals Production = 2%

PAC = Powder Activated Carbon; Imp. McM Filt.. = Improve filterability at the McMillan WTP; UV = Ultraviolet disinfection; Reduced free Cl_2 = reconfiguring the clearwells to reduce free chlorine contact time prior to adding ammonia (to form monochloramine for secondary disinfection); MnO_4 = Permanganate(Sodium or Potassium) for pre-oxidation; O3 AOP = ozone + peroxide, an advanced oxidation process; BAF = biologically active filtration; ClO2 = chlorine dioxide for pre-oxidation

Treatment Train Shortlisting

The evaluation criteria weighting scenarios used in treatment train scoring demonstrated that the choice of advanced treatment processes would largely depend on the willingness of consumers to expend money and consume energy to provide incremental improvements in water quality. The more money and energy expended, the more high-priority water quality challenges that could be treated.

The evaluation of alternatives did not identify any unique treatment processes that would address a large number of the high priority water quality challenges. For certain water quality challenges, such as perchlorate or hexavalent chromium, the associated risk could only be lowered by including treatment processes that have not yet been proven feasible for large scale operations.

Through a series of workshops and conference calls, the project team and the expert panel carefully reviewed and analyzed the available technologies to determine the most effective treatments for the high priority water quality challenges. Ultimately, UV, ozone, and granular activated carbon were selected for more detailed review. These three processes were viewed as being either more effective in addressing specific challenges and/or providing a wide range of water quality benefits. Post-filter GAC contact was chosen for further review because it is the one treatment process that was judged to allow a significant improvement with respect to the challenge of nitrification, because it would allow a return to free chlorine year-round. UV disinfection and ozonation are advanced treatment processes that have been implemented by neighboring utilities treating Potomac River source water. The project team then developed three treatment train alternatives that employ these three processes and vetted them with the Expert Panel, who concurred that these were the most appropriate treatment trains for WA.

It is important to note that the three trains do not reflect low, medium, and high degrees of treatment. All three treatment trains represent high degrees of treatment, albeit for different water quality challenges, different treatment objectives, and entirely different treatment outcomes. All three trains also have gaps in their coverage of at least some of the fourteen high priority water quality challenges.

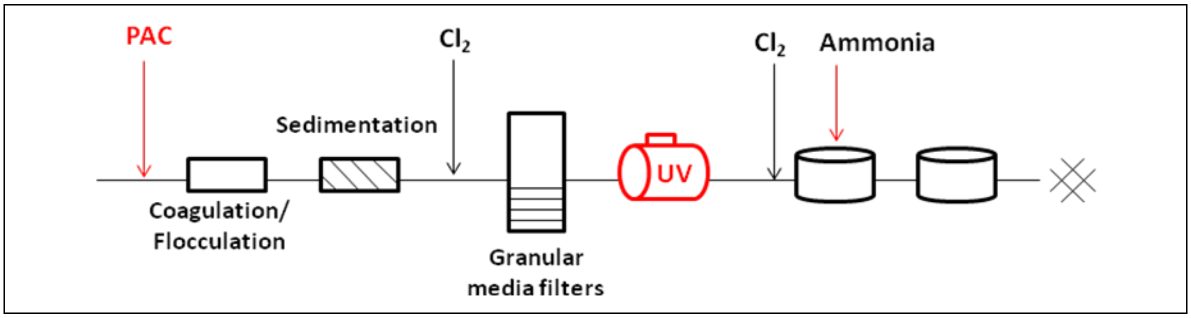
To illustrate this point, consider the UV/PAC strategy and the GAC strategy. If microbial pathogen inactivation were the only project driver, then UV/PAC might be the logical choice and the GAC strategy would not be a good choice. (Cincinnati Water Works, one of the largest and most well known plants employing post-filter GAC adsorption, has recently added UV to its treatment train to enhance its barriers against microbial pathogens.) Conversely, if tastes and odors in the source water and treatment plant were the only priority, the GAC or Ozone strategies might be more appropriate choices than UV/PAC.

The three treatment trains that were shortlisted are discussed below.

UV/ PAC Treatment Train. This train emphasizes mitigation of the following:

- tastes and odors attributed to source water and treatment
- chlorine-resistant microbial pathogens, such as *Cryptosporidium*

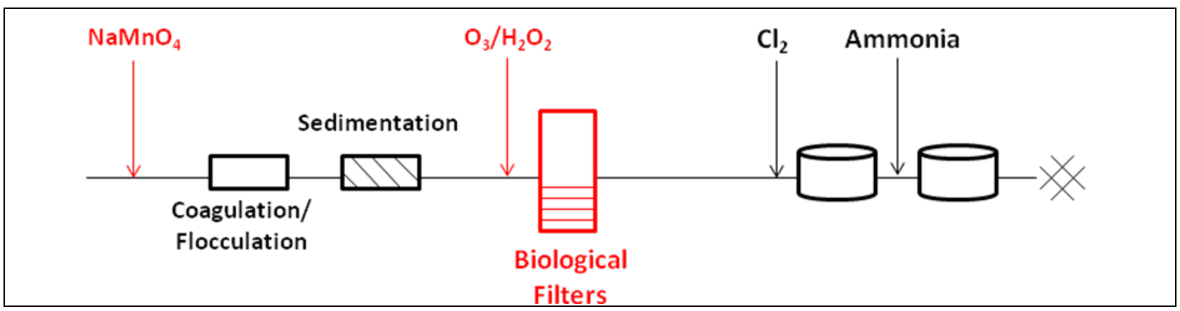
Figure 13. Process Flow Diagram for UV/PAC Treatment Train



Ozone Treatment Train. This train emphasizes mitigation of the following:

- tastes and odors attributed to source water and treatment
- disinfection byproducts

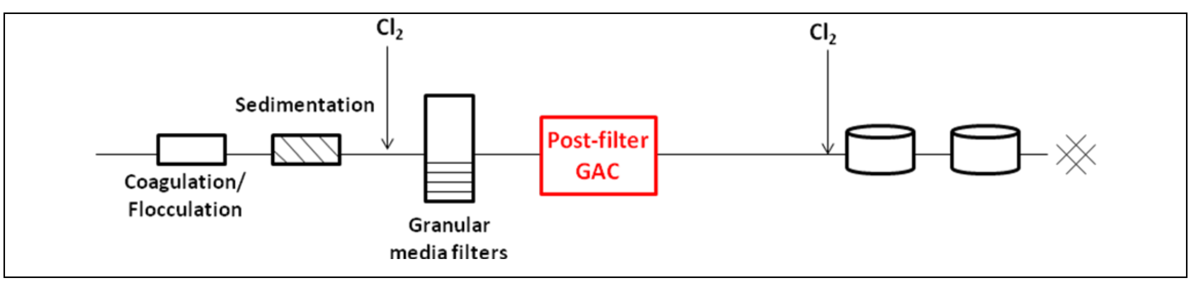
Figure 14. Process Flow Diagram for Ozone Treatment Train



GAC Treatment Train. This train emphasizes mitigation of the following:

- tastes and odors attributed to source water and treatment
- disinfection byproducts
- nitrification
- pesticides

Figure 15. Process Flow Diagram for GAC Treatment Train



It is also important to recognize some subtleties in the evaluation. For example, ozone treatment can be used to meet various treatment objectives. However, the choice of treatment objective, such as *Cryptosporidium* inactivation, taste and odor control, or disinfection byproduct reduction, may require different ozone facilities designs and dosing/ operating strategies, which will in turn affect the costs, energy consumption, and other evaluation criteria; thus, it is important in such cases to specify the objective(s) for which a unit process is being considered.

Another important consideration is that ozone plus biofiltration could potentially allow for conversion to free chlorine for secondary disinfection. This will depend on whether O3/BAF can achieve the necessary DBP precursor removal rates. A previous study entitled *Dalecarlia Pilot Plant and DBP Studies* (Malcolm Pirnie, 1997) suggested that this may not be possible; thus, further evaluation would be needed to fully vet this combination. It is noteworthy that the neighboring utility Fairfax Water employs ozone plus biofiltration, yet continues to use monochloramine for residual disinfection. Another neighboring utility WSSC plans to comply with DBP requirements through a combination of free chlorine, very low-pH coagulation, and very aggressive distribution system management. Such an approach may also be possible for WA and its customers; however, the likelihood of its success (at allowing a return to free chlorine) is even lower than with O3/BAF.

Regarding nitrification, the most effective treatment-based approach to address this challenge is converting to free chlorine for secondary disinfection. This in fact, will eliminate nitrification. As indicated in Table 13, both O3/BAF and post-filter GAC contactors could potentially reduce the risk of nitrification when feeding monochloramine--if it could be shown that they lower the disinfectant demand of the finished water and remove biodegradable organic carbon. However, as long as monochloramine serves as the secondary disinfectant, distribution system management will continue to be the most important measure to control nitrification--more effective than either of these advanced treatment options used in conjunction with monochloramines.

Each of the three shortlisted treatment trains is capable of addressing only two of the four highest priority water quality challenges identified through the Water Quality Improvement weighting process (see Table 9)--*Cryptosporidium*, nitrification, earthy-musty taste and odor, and red water. None of the three short-listed strategies was expected to address the fourth highest priority water quality challenge (red water, iron release, cloudiness in the distribution system.)

Efforts to address water quality challenges that are not capable of being addressed through treatment are the subject of the next section.

Non-Treatment Efforts

Four of the fourteen high priority water quality challenges are not addressed by any of the three shortlisted treatment trains discussed in the previous section:

- Perchlorate
- Hexavalent chromium
- Iron release, cloudiness, and red water
- Chlorinous tastes and odors

In addition, the following high priority water quality challenges are not fully addressed by all three shortlisted treatment trains:

- *Cryptosporidium* and other chlorine-resistant pathogens
- Atrazine, simazine, and their degradates
- Lead
- Nitrification

For contaminants not addressed through treatment, the FTAS identified non-treatment efforts. Even contaminants that can be addressed through treatment, such as *Cryptosporidium* (which can be treated with UV disinfection), may also be addressed via non-treatment efforts, such as improved or targeted watershed protection.

Non-treatment efforts for improving drinking water quality can be implemented across different scales and locations, ranging from watersheds to individual households. Therefore this summary applies not only to Washington Aqueduct (WA) but also to its customers (DC Water, Arlington and Falls Church) and to private individuals, where applicable. Furthermore, WA serves customers in multiple jurisdictions (states, counties, districts) and efforts to implement non-treatment strategies may require the assistance of other entities.

Watershed Protection Programs

Watershed protection programs fundamentally address drinking water quality concerns by preventing or minimizing the introduction of contaminants into water sources. In many cases, the costs associated with watershed protection can be less than treatment costs to remove contaminants, particularly for contaminants occurring at low concentrations requiring advanced treatment technologies for removal. For contaminants with no feasible treatment alternatives, watershed protection may be the only possible risk mitigation strategy.

The Interstate Commission on the Potomac River Basin (ICPRB) was founded in 1940 to help the basin states and federal government enhance, protect and conserve the water and associated land resources. Under the guidance of the ICPRB, the Potomac Drinking Water Source Protection Partnership (DWSPP) is a voluntary association of government agencies and water suppliers focused on protecting the drinking water source for the Washington Metropolitan Region. WA is a founder and active participant in the DWSPP. Currently, there are five issues that the DWSPP is working to address:

- New contaminants
- Disinfection by-products
- Early warning / early response to contamination events
- Urban issues
- Pathogens

The Potomac River Basin encompasses 14,670 square miles across four states; thus, achieving drinking water quality goals through effective watershed protection would require a significant investment. The cost for increased involvement by WA could be estimated as equivalent to the salary of a new director of watershed protection programs plus the cost of outreach efforts such as public relations campaigns.

Public Education

WA and/or its customer utilities could consider increasing involvement in public education for issues related to water quality. Options for increased public education activities include updates to the website, development of materials for specific contaminants, partnering with new stakeholders such as health advocacy groups, and public information campaigns. The cost for such programs could be estimated as equivalent to the salary of a new public information director.

Increased access to information via website

The public is increasing using the internet as its primary source of information so it is critical for water utilities to have accurate, understandable, and updated data available online. WA could update its website and provide more detailed information on water issues. Coordination with customer utility websites is an important factor in delivering a consistent and accurate message.

Development of specialized materials for individual contaminants

To target consumers that might be affected by specific contaminants, WA could develop and publish specialized materials on its website. These materials could also be distributed to local health agencies, doctors, and hospitals. Materials could discuss the occurrence of contaminants, ability of point-of-use devices to remove contaminants, and related topics. While the use of these materials would provide valuable information for a small group of affected customers, such a program is unlikely to broadly change public perception about water quality issues.

Partnering with health organizations to provide specialized information

To further educate concerned customers who are looking for information about a specific disease and/or contaminant, water utilities could partner with disease advocacy groups (e.g. the American Cancer Society) to provide specialized information and materials. These materials would be useful for specific, affected customers but would be unlikely to broadly change public perception about water quality issues.

Public information campaigns in the media

WA could consider hiring a public relations director and/or consultant to undertake a public information campaign in the media. Such a campaign might include developing TV commercials, print ads, and other public information materials to reach a broader audience. Many water utilities have successfully implemented these types of campaigns, primarily related to a specific issue such as conversion to chloramine. The cost for public information campaigns is generally significant so materials should be targeted to address the issues of greatest concern.

Distribution System Programs

For some contaminants, there may be options to change or improve distribution system practices or infrastructure to reduce consumer exposure. While distribution system programs are not directly under the control of WA, they should be considered as part of a holistic program to provide the best possible water to consumers. Options for distribution system programs to address high priority water quality issues include pipe replacement and nitrification control programs.

Lead service line replacement

To reduce lead concentrations, lead service line replacement is often recommended. Recent research has shown that partial lead service line replacement (of the utility-owned portion of the line) may not provide protection and full service line replacement (of both the utility- and customer-owned portions) is recommended if the utility-owned portion is to be replaced. In 2004, DC WASA estimated the cost of partial lead service line replacement for all affected customers to be approximately $350 million.

Cast-iron pipe replacement

Unlined cast-iron pipes have been associated with loss of disinfectant residual, increased corrosion rates, colored water (red water), and increase in bacterial growth in distribution systems. Cleaning and cement mortar or other types of lining of cast-iron mains can be an effective means of improving distribution system water quality. In areas of distribution systems where corrosion of cast-iron pipe is severe, full replacement of the mains may be the only option to stop the adverse effects because changes in water chemistry at the treatment plant cannot repair the pipes or eliminate corrosion. Re-lining is about one-third the cost and can significantly lessen the disruption of full main replacement; thus, in some cases, it is a viable alternative to replacing a water main.

Nitrification control

WA and its customer systems have undertaken significant efforts to control nitrification in the distribution system, including:

- Maintenance of high mass ratio of chlorine to ammonia (>4:1)
- Real-time monitoring and management of free ammonia levels leaving the WTPs
- Maintenance of high disinfectant residual levels within the distribution system
- Focused monitoring of nitrification parameters in storage facilities and elsewhere in the distribution system
- Storage tank exercise and mixing programs

- Tank cleaning activities
- Coordination of nitrification response activities
- Systematic flushing
- Cleaning, lining, and replacement of water mains

Additional efforts to control nitrification could include booster chlorination/ chloramination within the distribution system or additional distribution system improvements aimed at managing water age (reducing long residence times) within the distribution system.

Chlorine residual management

During the FTAS, customer complaints about chlorinous tastes and odors emerged as an aesthetic concern. The origin of these complaints is not fully understood. Complaints may increase during transition times when WA and its customer systems opt to use a free chlorine residual, typically for about six weeks in the spring, to facilitate distribution system flushing activities, or when cold weather slows down the normal chlorine decay so that customers receive higher levels of chlorine. An improved understanding of the causes of chlorinous odor complaints for each of WA's customer systems, coupled with improved knowledge of the minimum finished water chlorine residual that is acceptable to the customer utilities, may allow WA to target a lower finished water total chlorine residual. Accomplishing this without compromising disinfection during critical cold-weather periods may require improvements within the WA clearwells.

Household Programs

Individual consumers can undertake their own activities to reduce their exposure to contaminants. An important question to consider in the implementation of household programs is the extent of water utility involvement, which could range from none to providing educational materials to purchase, installation and maintenance of household devices. Options for household programs include:

Point of Use Devices

Commercial point-of-use (POU) devices are readily available and already in use by many private individuals. These devices can remove some of the contaminants of concern although the removals depend on the type of device, the contaminant concentration and frequency of occurrence, and the maintenance history of the device. Additional educational materials may need to be provided to consumers to help them select the device that is most appropriate for specific contaminants of concern.

Lead-free Faucets and Appurtenances

Individual consumers can choose to install lead-free faucets, fittings and other appurtenances within their household plumbing to reduce their exposure to lead.

Replacement of Household Plumbing

Individual consumers can replace lead pipe and old galvanized pipe (which may act as a sink/ source for lead for households with a lead service line), copper pipe with lead solder, and related items within their household to reduce their exposure to lead.

Summary of Applicable Non-Treatment Efforts

Table 23 summarizes the types of non-treatment efforts that may be useful in addressing the high priority water quality challenges that were not fully addressed via all three shortlisted treatment trains. However, the degree to which the non-treatment efforts would be effective against the water quality challenges would need to be studied.

Table 23. Summary of Applicable Non-Treatment Efforts

Water Quality Challenge		Watershed Protection	Public Education	Distribution System Programs	Household Programs
1	*Cryptosporidium* (and other chlorine-resistant pathogens)	x	x		x
5	Unregulated nitrogenous DBPs including NDMA and other nitrosamines				
6	Atrazine, Simazine, and their degradates	x	x		x
7	Perchlorate	x	x		x
8	Hexavalent chromium	x	x		x
10	Lead		x	x	x
11	Nitrification			x	
12	Iron release, cloudiness, and red water			x	x
14	Chlorinous taste and odor		x	x	x

Viable Mitigation Strategies

The three risk mitigation strategies shown in Table 24 were developed by combining the short-listed treatment train alternatives with select non-treatment efforts (to address challenges where treatment was either not possible, insufficient, or impractical). This table also provides a summary of the key elements and considerations for each strategy with respect to the primary criteria.

Table 24. Viable Risk Mitigation Strategies for Enhancing Water Quality

		Risk Mitigation Strategy		
		UV/PAC Strategy	**Ozone Strategy**	**GAC Strategy**
Criteria		***Emphasis:*** ***Microbial Pathogens*** ***T&O***	***Emphasis:*** ***DBPs*** ***T&O***	***Emphasis:*** ***DBPs*** ***T&O*** ***Nitrification***
Water Quality Challenges				
1	*Cryptosporidium* (and other chlorine-resistant pathogens)	**Add UV disinfection**	Enhance watershed protection Improve communication of water quality issues on website Develop specialized information on specific contaminants Partner with health organizations to provide specialized information	Enhance watershed protection Improve communication of water quality issues on website Develop specialized information on specific contaminants Partner with health organizations to provide specialized information
2	Bacteria / Protozoa (including *Giardia lamblia*)	Addressed through existing treatment		
3	Viruses (and other UV-resistant pathogens)	Addressed through existing treatment		
4	Regulated Total Trihalomethanes (TTHMs) / Five Haloacetic Acids (HAA5)	**Reconfigure clearwells to reduce free chlorine contact time**	**Remove additional DBP precursors via biofiltration (10-20% depending on site conditions)**	**Remove DBP precursors via post-filter GAC contactors** **Switch to free chlorine for secondary disinfection**
5	Unregulated Nitrogenous DBPs including NDMA and other nitrosamines	**Investigate and manage effects of adding polymer and/or relocating ammonia feed point (if possible)**	**Investigate and manage effects of adding polymer and/or relocating ammonia feed point (if possible)** **Improve oxidation of precursors by adding ozone**	**Investigate and manage effects of polymer addition** **Switch to free chlorine for secondary disinfection**

Criteria		Risk Mitigation Strategy		
		UV/PAC Strategy	Ozone Strategy	GAC Strategy
		Emphasis: ***Microbial Pathogens*** ***T&O***	***Emphasis:*** ***DBPs*** ***T&O***	***Emphasis:*** ***DBPs*** ***T&O*** ***Nitrification***
6	Atrazine, Simazine, and their degradates	**PAC (incidental removal only)** Enhance watershed protection Improve communication of water quality issues on website Develop specialized information on specific contaminants Partner with health organizations to provide specialized information	**Investigate use of Ozone AOP** Enhance watershed protection Improve communication of water quality issues on website Develop specialized information on specific contaminants Partner with health organizations to provide specialized information	**Add post-filter GAC contactors**
7	Perchlorate	Enhance watershed protection Improve communication of water quality issues on website Develop specialized information on specific contaminants Partner with health organizations to provide specialized information		
8	Hexavalent Chromium	Enhance watershed protection Improve communication of water quality issues on website Develop specialized information on specific contaminants Partner with health organizations to provide specialized information		
9	Manganese	Addressed through existing treatment	**Add continuous sodium permanganate + biological filters**	Addressed through existing treatment
10	Lead	Replace lead service lines	Replace lead service lines Conduct pipe loop studies	Replace lead service lines Conduct pipe loop studies
11	Nitrification	Increase distribution system nitrification prevention measures	Increase distribution system nitrification prevention measures **Investigate reducing AOC levels via biofiltration**	**Switch to free chlorine for secondary disinfection**
12	Iron release, cloudiness, and red water	Further distribution system study required to identify causes of iron release Evaluate options for distribution system infrastructure renewal		
13	Earthy / Musty Taste and Odor (MIB and geosmin)	**Improve PAC treatment**	**Add Ozone AOP**	**Add post-filter GAC contactors**
14	Chlorinous Taste and Odor	Further distribution study needed to develop optimal levels of disinfectant leaving WTP and to identify causes of chlorinous taste and odor complaints		

	Criteria	Risk Mitigation Strategy		
		UV/PAC Strategy	**Ozone Strategy**	**GAC Strategy**
		Emphasis: ***Microbial Pathogens*** ***T&O***	***Emphasis:*** ***DBPs*** ***T&O***	***Emphasis:*** ***DBPs*** ***T&O*** ***Nitrification***
Environmental and Community Impacts				
1	Energy Usage and Emissions	4,000 metric tons CO_2/year	16,500 metric tons CO_2/year	47,500 metric tons CO_2/year
2	Resource Consumption[1]	Increase use of PAC Total: 50 tons/year	Increase use of Permanganante Increase use of Ozone Total: 2,100 tons/year	Regular GAC replacement Total:5,200 tons/year
3	Safety	Low safety concern associated with the mercury content of UV lamps	Medium safety concern associated with the liquid oxygen production system needed for ozone generation	No additional safety concern
4	Residuals Production	50 tons solid waste/year	900 tons solid waste/year	4,800 tons solid waste/year
Special Risk Issues				
-	-		Manganese build-up in McMillan Reservoir Bromate formation and other unknown oxidation byproducts	
Financial Costs[2]				
1	Capital Cost	PAC System: $7M	Permanganate: $0.08M	Post-filter GAC: $200M
		UV system: $40M	O3/H2O2: $100M	-
		1st Clearwell Reconfiguration: $8M	BAF: $10M	-
		Total: $55M	Total: $110M	Total: $200M
2	Annual O&M Cost	PAC System: $0.3	Permanganate: $0.5M	Post-filter GAC: $30M
		UV system: $0.9M	O3/H2O2: $9M	-
		1st Clearwell Reconfiguration: -	BAF: $3M	-
		Total: $1.2M	Total: $12.5M	Total: $30M
3	Present Worth Cost[3]	$80M	$330M	$550M

NOTES:
[1] The total resource requirement for a particular alternative reflects its potential impact on truck traffic. An alternative requiring more resources will likely result in more truck traffic than an alternative requiring fewer resources.
[2] Expected accuracy range = -15-30% and +20-50% (per AACE Class 4 feasibility-level classification of estimate).
3 Present worth financial cost based on a 4% interest rate and a 30-year lifespan

Drinking Water Quality Enhancement Plan (DWQEP)

Washington Aqueduct and its Customer Board have used the FTAS process presented in the preceding sections of this report to develop a Drinking Water Quality Enhancement Plan (DWQEP). The DWQEP balances systematic enhancements with responsible stewardship of financial resources and natural resources. The DWQEP elements will be incorporated into the Capital Plan. The DWQEP elements are summarized in Table 25.

Table 25. DWQEP Components

Component	Description
McMillan WTP Capacity Study	Determine the capacity of the McMillan WTP needed to meet demands.
Nitrification Study	Support efforts of WA Customer systems to understand and control the factors that affect nitrification.
Study and Implement Non-Treatment Strategies - Source Protection	Work with Potomac Drinking Water Source Protection Partnership to improve watershed protection
Study and Implement Non-Treatment Strategies - Consumer Education	Work with the American Water Works Association, the Association of Metropolitan Water Agencies, the Water Research Foundation, the Metropolitan Washington Council of Governments, and other stakeholders to improve consumer education on drinking water and human health topics of specific local interest.
Study Filterability Improvements for McMillan WTP	Pending the outcome of the McMillan WTP Capacity Study, identify the factors that limit filtration (and, consequently, water production) and develop control measures.
UV Disinfection of Cryptosporidium Desktop Study	Undertake preliminary planning to prepare for the possible implementation of ultraviolet disinfection if needed in the future.