



## APPENDIX 2

### DECISION MODEL CRITERIA AND ALTERNATIVE SCORING

**Changes adopted pursuant to project Working Group workshop held January 18, 2007**

<sup>1</sup>Finished Water Quality

- Corrosion removed -- no significant difference among alternatives
- Organic micropollutants and emerging contaminants combined
- Mn, T&O, and TDS/SO<sub>4</sub><sup>2-</sup> added -- significant difference among alternatives

<sup>2</sup>Source Water

- No changes to Boulder staff draft criteria of 01/03/07

<sup>3</sup>Water Treatment/Ops

- Monitoring/remote sensing removed -- 0 weight assigned
- Reliability/redundancy split into 2 criteria

<sup>4</sup>Risk

- Power interruption removed -- no significant difference among alternatives

<sup>5</sup>Environ./Public Accept

- No changes to Boulder staff draft criteria of 01/03/07



## Objectives and Criteria for a Multi-Barrier Approach to Treated Water – Fall 2006

### I. Musts for ALL Alternatives:

#### A. Meet Regulations

#### B. No loss of water yield

1. The City has a water rights portfolio and raw water system facilities that are used to provide sufficient raw water to meet the City's needs in accordance with adopted reliability criteria. The reliability criteria have been used to define the level of water use restrictions that might be needed for droughts with specified recurrence intervals to avoid lowering of reservoirs below safe levels to the point that delivery of water for essential health and safety needs is jeopardized. Any alternative for raw water delivery needs to be capable of maintaining the current expected level of yield of the City's water rights and must not reduce the current level of flexibility in selecting water sources.

### II. Finished Water Quality Criteria

#### A. Pathogens - Health issue. Disease causing organisms.

1. A higher ranking will be given to those alternatives that best address limiting the potential for public health impacts from pathogens. Alternatives will be ranked by:
  - a. Source water vulnerability
    - 1) Pathogen indicator counts
    - 2) Potential for pathogen introduction
  - b. Treatment
    - 1) Log removal and tool box – use regulatory limits
    - 2) Potential for pathogens to pass through treatment process
2. Factors to consider
  - a. The intent of this criterion is to address pathogen risk by selecting the best source water quality and/or treatment techniques
  - b. See attached source water quality table

#### B. Disinfection By-Products (DBPs) - Health issue. Formed when disinfectant (i.e. chlorine) combines with naturally occurring and/or other compounds in the water or from the disinfectant itself.

1. A higher ranking will be given to those alternatives that minimize DBP formation and/or reduce DBP's. Alternatives will be ranked by



- a. Source water
  - 1) Precursors (TOC)
  - 2) Chlorine dosage
- b. Treatment
  - 1) Removal
  - 2) Oxidation and/or absorption of precursors
- 2. Factors to consider
  - a. The intent of this criterion is to address the potential for DBP formation
  - b. Similar average TOC values (3.5 mg/L) are present in Boulder Reservoir, BFC and Carter Lake
  - c. See attached source water quality table

**C. Micro-organic Compounds - Health issue. Man made carbon compounds.**

- 1. A higher ranking will be given to those alternatives that provide the best protection against the introduction and/or removal of organic compounds (ie. pesticides, hydrocarbons) and limits the risk of organic compounds passing on to the consumer in the finished water. Alternatives will be ranked by:
  - 1) Source water vulnerability to organic compounds
  - b. Treatment
    - 1) Contaminants passing through treatment
    - 2) Absorb organic compounds
- 2. Factors to consider
  - a. The intent of this criterion is to evaluate the potential for man made organic compounds to enter the source water and possibly be passed on to consumers
  - b. Potential for organic compounds to enter the source water – intentional, accidental or due to recreation activities
  - c. Standard maintenance activities that can introduce organic compounds
  - d. Potential for non-point source contributions due to precipitation events and agricultural return inflows
  - e. Available source water dilution

**D. Inorganic Compounds - Health issue. Non-natural toxic chemicals such as arsenic and cyanide.**

- 1. A higher ranking will be given to those alternatives that provide the best protection against the introduction and/or removal of toxic inorganic compounds. The alternatives will be ranked by:
  - a. Source water vulnerability to inorganic toxic compounds and chemicals
  - b. Treatment



2. Factors to consider
  - a. The intent of this criterion is to evaluate the potential for non-natural and natural toxic inorganic compounds to enter the source water and possibly be passed on to consumers in the finished water.

**E. Emerging Contaminants** - Health issue. Unregulated contaminants that pose a health risk. Examples are gasoline additives, microbes smaller than Cryptosporidium that are resistant to chlorine, pharmaceutical drugs, new disinfection-by-products and new pesticides.

1. A higher ranking will be given to those alternatives that provide the best protection against the introduction and/or removal of emerging contaminants to the source water and being passed on to consumers in the finished water. The alternatives will be ranked by:
  - a. Source water vulnerability
    - 1) Gasoline additives
    - 2) Microbes smaller than Cryptosporidium that are resistant to chlorine
    - 3) Pharmaceutical drugs
    - 4) New pesticides
    - 5) New disinfection-by-products
  - b. Treatment-removal and absorption capability for all categories of emerging contaminants
2. Factors to consider
  - a. The intent of this criterion is to address the potential for future regulated constituents and plan ahead in a cost effective and proactive manner
  - b. Animal activity
  - c. Non-point sources
  - d. Wastewater discharges

**F. Corrosion**- Health and consumer confidence issue. Aggressive water that will leach harmful metals from pipes into the water (lead and copper).

1. A higher ranking will be given to those alternatives that create the lowest potential for aggressive water. The alternatives will be ranked by:
  - a. Source water
    - 1) Alkalinity
    - 2) pH
    - 3) Sulfate
  - b. Treatment
    - 1) Corrosion control
    - 2) Match Betasso treated water
2. Factors to consider



- a. The intent of this criterion is to provide finished water that is not considered aggressive
- b. A pH below 7.8 is more corrosive
- c. Alkalinity around 48 mg/L is less corrosive
- d. High alkalinity above 100 mg/L increases copper corrosion potential
- e. Low alkalinity increases both lead and copper corrosion potential
- f. See attached source water quality table

### **III. Source Water**

#### **A. Water Rights Yield**

1. Yield of the City's water rights portfolio is maximized over time by fully using direct flow water when available and strategic use of available reservoir storage water. Evaluation of alternatives should consider:
  - a. Ability to manage stored reservoir water throughout the year
  - b. Ability to manage stored reservoir water during droughts
  - c. Access to raw water sources available for direct use
  - d. Potential for increasing water rights yield through enhanced water management or capacity of facilities

#### **B. Consistency of quality and quantity 24/7**

1. A higher ranking will be given to those alternatives that provide the best potential for consistent finished water quality. The alternatives will be ranked by:
2. Source water
  - a. Operational ease of delivering raw water at a consistent flowrate
  - a. Operational ease of delivering raw water of a consistent quality
  - b. Ability to blend raw water sources to improve quality
2. Treatment
  - a. Reliability: Consistent treatment operation year-round with less process failure.
  - b. Efficiency: Minimize chemical usage and operations staff efforts.
3. Facts to consider
  - a. High quality treated water is more easily attained when raw water sources feeding the treatment plant are uniform in both quality characteristics and in flow rate of delivery. The intent of this criterion is to assess the impact on water treatment from inconsistent source water quality, including reliability and efficiency and the need for additional treatment process barriers.

#### **C. Portfolio Flexibility (Flexibility in use of raw water supplies)**

1. System reliability improves with flexibility in selection of raw water sources in response to changes in treated water demands or amount



of raw water available from a source. Evaluation of alternatives should consider:

- a. Number of options available for means of delivering raw water
- b. Ease of changing water sources in response to changing conditions
- c. Seasonal limitations of use on raw water sources

#### **D. Availability of Raw Water Delivery Facilities**

1. Management of raw water sources is made more difficult by facilities that are unavailable for raw water delivery. Evaluation of alternatives should consider:
  - a. Reliability of facilities
  - b. Capacity limitations
  - c. Restrictions on facilities use due to external factors affecting operations or water quality

### **IV. Water Treatment / Operations Criteria**

#### **A. Worker safety**

1. Alternatives will be ranked highest based on least amount of staff interaction or exposure required. The alternatives will be ranked by:
  - a. Chemicals
    - 1) Type (degree of hazard)
    - 2) Amount required
  - b. Processes
    - 1) Type (complexity, hazard)
    - 2) Number (how many processes required)
  - c. Infrastructure maintenance
    - 1) Cleaning grates/strainers at intakes
    - 2) High power
    - 3) Mechanical complexity
  - d. Factors to consider
    - 1) The intent of this criterion is to evaluate the potential risk to staff based on type and amount of chemical required and type and number of processes required.

#### **B. Process Flexibility**

1. Alternatives will receive highest ranking based on the most flexibility in processes (number and type) required. The alternatives will be ranked by:
  - a. Maximizing the maturity and robustness of the technology
  - b. Maximizing the fabrication and engineering design of the various facilities, unit processes and components.
2. Factors to consider



- a. The purpose of this criterion is to compare the need for treatment processes. The more robust and flexible a process is the broader the range of treatment concerns addressed will.
- b. As source water variability and vulnerability increases the number and/or complexity of processes will increase.
- c. Treatment – add table of data to support
  - 1) Oxidation – manganese, turbidity
  - 2) Caustic and/or acid - pH fluctuations
  - 3) Coagulant - turbidity fluctuations

### **C. Reliability/Redundancy**

1. A higher ranking will be given to those alternatives that provide the best potential for consistent finished water quality. The alternatives will be ranked by:
  - a. Source water
    - 1) Operational ease of delivering raw water at a consistent flow rate
    - 2) Operational ease of delivering raw water of a consistent quality
    - 3) Ability to blend raw water sources to improve quality
  - b. Treatment
    - 1) Reliability: Consistent treatment operation year-round with less process failure.
    - 2) Efficiency: Minimize chemical usage and operations staff efforts.
    - 3) Minimize need to adjust treatment processes and/or chemical dosage on regular basis.
  - c. Factors to consider
    - 1) High quality treated water is more easily attained when raw water sources feeding the treatment plant are uniform in both quality characteristics and in flow rate of delivery. The intent of this criterion is to assess the impact on water treatment from inconsistent source water quality, including reliability and efficiency and the need for additional treatment process barriers.

### **D. Maintenance**

1. A higher ranking will be given to alternatives that:
  - a. Minimize the complexity of facilities, unit processes and components
  - b. Maximize the expected life of facilities, unit processes and components
  - c. Maximize the maturity of the technology, fabrication and engineering design of the various facilities, unit processes and components



**E. Monitoring/Remote Operation**

1. A higher ranking will be given to those alternatives that exhibit lower complexity and higher reliability.
  - a.
2. Facts to consider
  - a. The intent of this criterion is to compare the complexity and reliability of the monitoring requirements of each alternative. It does not include the monetary cost of monitoring since this will be part of the monetary evaluation.

**F. Staffing**

1. A higher ranking will be given to those alternatives that minimize the requirements based on these parameters: include:
  - a. Total number of staff
  - b. Expertise of staff
  - c. Supervision
2. Facts to consider
  - a. The intent of this criterion is to compare the staffing requirements of each alternative. It does not include the monetary cost of staffing since this will be part of the monetary evaluation.

**G. Residuals disposal**

1. Alternatives will be ranked by least volume and best quality of residuals.
  - a. Source water
  - b. Treatment
2. Factors to consider
  - a. Locations for residuals disposal are becoming increasingly difficult to find so it is important to minimize the production of residuals. (Recent analyses indicate current residuals may contain low levels of radioactivity making it even more difficult to dispose of.)

**V. Risk**

**A. Unexpected Acute Contamination**

1. A higher ranking will be assigned to those alternatives that best minimize potential public health impacts from such risk. The alternatives will be evaluated by
  - a. Potential for slug-loading of a large amount of harmful contaminant(s) with potential for treatment breakthrough



- b. Potential for slug-loading of contaminant(s) with the capability for disabling or disrupting water service on a temporary or long-term basis
- 2. Facts to consider
  - a. Initial specific risk/contaminant/treatability criteria and assessments for water supplies addressed in this study have been developed as a part of the 2003 Water Utility Vulnerability Study. Further development of detailed source/treatment risk assessment information for these supply/treatment system, as well as for the entire city of Boulder treatment/source portfolio, is currently being planned by the city's utility security work group( with the goal of incorporating the findings into this and other related long-term utility planning efforts).

**B. Unexpected Chronic Contamination**

- 1. A higher ranking will be assigned to those alternatives that best minimize potential public health impacts from such risk. Alternatives will be evaluated by
  - a. Potential for contamination from bodily contact with the source (wild or domestic animal and/or human)
  - b. Potential for contamination from other recreational activities adjacent to supply
  - c. Potential for contamination from outfalls emptying into supplies
- 2. Facts to consider
  - a. The intent of this criterion is to address day-to-day risks due to existing non-point-sources in water supplies. Focus is on contaminants that are difficult to remove or inactivate through treatment and on events that could cause a moderate to significant waterborne disease.
  - b. Initial specific risk/contaminant/treatability criteria and assessments for water supplies addressed in this study have been developed as a part of the 2003 Water Utility Vulnerability Study. Further development of detailed source/treatment risk assessment information for these supply/treatment system, as well as for the entire city of Boulder treatment/source portfolio, is currently being planned by the city's utility security work group( with the goal of incorporating the findings into this and other related long-term utility planning efforts).

**C. Adaptability to Unexpected Future Changes -**

- 1. Future changes in source water quality. A higher ranking will be assigned to those alternatives that best minimize risk of public health impacts from potential future increases in source WQ risks.



- a. The intent of this criterion is to address the tendency toward increased risk over time from contaminant sources noted in (A.2.) as a function of:
  - 1) Local or regional policy(s) regarding activities allowed or encouraged in or near drinking water supplies.
2. Facts to consider
  - a. Increased level of impacting activities over time in popular water supply corridors.
  - b. Increased source contamination risks/loading will increase background public health risks as well as increase the likelihood of peaking events/ waterborne disease outbreak(s). Specific risk information to support this criterion to be developed in risk assessment efforts noted above.
3. Future changes in regulatory standards. A higher ranking will be assigned to those alternatives that best minimize risk of non-compliance with future drinking water standards.
4. Facts to consider
  - a. The intent of this criterion is to address the risk of drinking water quality standards (especially those pertaining to source water risks) becoming significantly more stringent in the future.
  - b. Potential inability for city to meet future standards to the extent that CIP and other planning does not anticipate regulatory dynamics/ upcoming challenges. (See discussion on significant limitations of current standards which contributes to likelihood of increased future stringency).

#### **D. Infrastructure Vulnerability**

1. A higher ranking will be assigned to those alternatives that best minimize risk of damage to infrastructure that would impede purveyance or treatment of the potable water supply. The alternatives will be evaluated by
  - a. Potential for impacts from natural events (i.e. weather-related events)
  - b. Potential for impacts from accidental or intentional events
2. Facts to consider
  - a. The intent of this criterion is to address risks to facilities in sources and treatment which would impede delivery of drinking water to the city's distribution system.
  - b. Why it is a problem: Interferes with reliable delivery of water for drinking and other potable uses and for fire protection.

#### **E. Power interruptions**

3. A higher ranking will be assigned to those alternatives that best minimize risk of power interruptions with potential to impede



- purveyance or treatment of the potable water supply. The alternatives will be evaluated by
- a. Potential for power interruptions affecting the treatment plant processes
  - b. Potential for power interruptions affecting the transmission of water to the distribution system
4. Facts to consider
- a. Power interruptions can result in serious consequences for both water supply and quality. To the extent that an interruption interferes with water treatment plant processes, tap water quality is at risk (including regulatory compliance capability). Water transmission may also be compromised by a power outage to the extent that pumping/ system telemetry are impacted.

#### **F. Chemical Delivery/Usage**

5. A higher ranking will be assigned to those alternatives that best minimize risk from potential chemical delivery interruptions which would impede treatment and public health protection capability. The alternatives will be evaluated by
- a. Potential for treatment chemical interruption (i.e. distance of source from plant, mode of transportation, frequency of deliver)
6. Facts to consider
- a. The intent of this criterion is to address risks to WQ/public health from interruption of availability/ delivery of chemicals required to treat water for potable use.
  - b. Lack of such chemicals in sufficient quantity could preclude the city's ability to treat water to quality or quantity levels needed.

## **VI.Environmental and Public Acceptance**

### **A. Adjacent land use Compatibility**

1. Chemical hazards (us on neighbors)
2. Recreational use (neighbors on us)
3. Development
4. Road crossings

### **B. System-Wide Water Uniformity**

1. The desirability of providing equal water quality to all customers
  - a. Quote from Ridge Dorsey re: Industry need to pretreat water "We could go through our list of permitted industries an give you a count from that select group, but that would not be representative of the entire city. Many industry types such metal plating, electronics



assembly, food/beverage manufacturing, pharmaceutical, R&D labs, even auto washing prefer to use de-ionized water, and sometimes ultra pure (reverse osmosis) water. Potable water for these commercial applications would likely need to be treated to specific industry standards in any location. I'm not aware of any industry that did not locate to Boulder due to water quality."

### **C. Construction Impacts**

1. A higher ranking will be given to those alternatives that exhibit these characteristics:
  - a. Minimizing the impacted land area and associated restoration requirements
  - b. Minimizing underground excavation and associated materials handling
  - c. Minimizing the number of subcontractors and suppliers
2. Facts to consider
  - a. The intent of this criterion is to compare the construction impacts of each alternative. It does not include the monetary cost of construction since this will be part of the monetary evaluation.

### **D. Consumer Confidence**

3. A higher ranking will be given to those alternatives that provide the highest consumer confidence.
  - a. Source
    - 1) Finished water taste, odor, temperature and appearance.
    - 2) Manganese
    - 3) Hardness.
    - 4) Effects on local business
  - b. Treatment
    - 1) match Betasso Treated water
  - c. Facts to consider
    - 1) The intent of this criterion is to evaluate public perception and acceptance of treated water.

### **E. Permitting**

### **F. Energy Requirements**

3. The intent of this criterion is to compare the energy requirements and the secondary affects of these requirements. It does not include the monetary value of the energy requirements since this will be part of the monetary evaluation. The alternatives will be rated based on minimizing the quantity of the following:
  - a. Capacity/load rating (MVA)



- b. Net energy consumption (use minus production) (Mw-hr)
- c. Equivalent amount of coal (tons)
- d. Equivalent amount of SO<sub>2</sub> (tons)
- e. Equivalent amount of NO<sub>x</sub> (tons)
- f. Equivalent amount of CO<sub>2</sub> (tons)

## **VII. Other Criteria**

### **A. Public Acceptance**

The intent of this criterion is to compare the anticipated public acceptance of each alternative. It does not include the monetary cost of any project mitigation designed for public acceptance since this will be part of the monetary evaluation. A higher ranking will be given to those alternatives that exhibit these characteristics:

- a. Minimizing the visual impacts of based on the need for above grade buildings and facilities
- b. Minimizing acquisition of land, easements and right-of-way
- c. Promoting economic sustainability within the city's service area



## **Alternative Scoring Worksheets**



**BRWTF INTEGRATED SOURCE WATER AND TREATMENT STUDY**  
**Appendix 2 – Decision Model Criteria and Alternative Scoring**

**Water Quality: Pathogens**

Crypto Giardia Viruses

Alternative	Treatment Strategy	Score	Comments: Additional log removal
1A	ClO <sub>2</sub>	2	0.02 0.67 0.96
1B	ClO <sub>2</sub> + UV	10	4.02 4.67 1.46
1C	ClO <sub>2</sub> + GAC + UV	10	4.02 4.67 1.46
2A	ClO <sub>2</sub>	2	0.02 0.67 0.96
2B	ClO <sub>2</sub> + UV	10	4.02 4.67 1.46
2C	ClO <sub>2</sub> + AOP	3	0.54 13.16 27.60
3	CLP + ClO <sub>2</sub>	6	1.52* 2.17* 2.46*

\*Based on 1.50 log reduction in E.coli by using CLP

**Water Quality: DBPs**

Alternative	Treatment Strategy	Score	Comments: ClO <sub>2</sub> > O <sub>3</sub> , GAC varies, UV -- no effect
1A	ClO <sub>2</sub>	9	TOC removal varies with GAC life-cycle
1B	ClO <sub>2</sub> + UV	9	
1C	ClO <sub>2</sub> + GAC + UV	9	
2A	ClO <sub>2</sub>	9	
2B	ClO <sub>2</sub> + UV	9	
2C	ClO <sub>2</sub> + AOP	10	
3	CLP + ClO <sub>2</sub>	9	Pipeline gives consistent water quality allowing treatment optimization

UV -- no contribution to DBP reduction  
 ClO<sub>2</sub> -- Effective oxidation of NOM  
 AOP -- Effective oxidation of NOM  
 GAC -- effective adsorption depending on GAC age

**Water Quality: Organic Micropollutants**

Alternative	Treatment Strategy	Score	Comments: AOP > GAC >> UV ≅ ClO <sub>2</sub>
1A	ClO <sub>2</sub>	2	Minimal oxidation
1B	ClO <sub>2</sub> + UV	3	Minimal oxidation and photolytic degradation
1C	ClO <sub>2</sub> + GAC + UV	7	Adsorption varies with contaminant and GAC age
2A	ClO <sub>2</sub>	2	Minimal oxidation
2B	ClO <sub>2</sub> + UV	3	Minimal oxidation and photolytic degradation
2C	ClO <sub>2</sub> + AOP	10	Reservoir dilution + effective oxidation
3	CLP + ClO <sub>2</sub>	8	Source water protection + minimal oxidation -- EDCs have very low concentration



**BRWTF INTEGRATED SOURCE WATER AND TREATMENT STUDY**  
**Appendix 2 – Decision Model Criteria and Alternative Scoring**

**Water Quality: Inorganic Micropollutants**

Alternative	Treatment Strategy	Score	Comments: Reduced As, U, Cr, Pb, Cd, Cu
1A	ClO <sub>2</sub>	6	Oxidant + conventional treatment
1B	ClO <sub>2</sub> + UV	6	Oxidant + conventional treatment
1C	ClO <sub>2</sub> + GAC + UV	6	Oxidant + conventional treatment
2A	ClO <sub>2</sub>	7	Oxidant + conventional treatment
2B	ClO <sub>2</sub> + UV	7	Oxidant + conventional treatment
2C	ClO <sub>2</sub> + AOP	8	Optimized oxidation + conventional treatment
3	CLP + ClO <sub>2</sub>	10	Source water protection + reservoir dilution + oxidant +conventional treatment

**Water Quality: Manganese**

Alternative	Treatment Strategy	Score	Comments
1A	ClO <sub>2</sub>	8	Source water avoidance + effective oxidant
1B	ClO <sub>2</sub> + UV	8	Source water avoidance + effective oxidant
1C	ClO <sub>2</sub> + GAC + UV	8	Source water avoidance + effective oxidant
2A	ClO <sub>2</sub>	7	Variable Mn -- effective oxidation
2B	ClO <sub>2</sub> + UV	7	Variable Mn -- effective oxidation
2C	ClO <sub>2</sub> + AOP	8	Variable Mn + Two stage optimized oxidation
3	CLP + ClO <sub>2</sub>	10	Source water protection + effective oxidation

**Water Quality: Taste and Odor**

Alternative	Treatment Strategy	Score	Comments
1A	ClO <sub>2</sub>	5	Moderately effective oxidant
1B	ClO <sub>2</sub> + UV	5	Moderately effective oxidant
1C	ClO <sub>2</sub> + GAC + UV	7	Moderately effective oxidant, adsorption varies with contaminant and GAC age
2A	ClO <sub>2</sub>	5	Moderately effective oxidant
2B	ClO <sub>2</sub> + UV	5	Moderately effective oxidant
2C	ClO <sub>2</sub> + AOP	10	Optimized oxidation
3	CLP + ClO <sub>2</sub>	8	Source water protection + moderately effective oxidant



**BRWTF INTEGRATED SOURCE WATER AND TREATMENT STUDY**  
**Appendix 2 – Decision Model Criteria and Alternative Scoring**

**Water Quality: TDS and Sulfate**

<b>Alternative</b>	<b>Treatment Strategy</b>	<b>Score</b>	<b>Comments</b>
1A	ClO <sub>2</sub>	3	Seasonal reservoir usage + no treatment
1B	ClO <sub>2</sub> + UV	3	Seasonal reservoir usage + no treatment
1C	ClO <sub>2</sub> + GAC + UV	3	Seasonal reservoir usage + no treatment
2A	ClO <sub>2</sub>	2	Year-round reservoir use + no treatment
2B	ClO <sub>2</sub> + UV	2	Year-round reservoir use + no treatment
2C	ClO <sub>2</sub> + AOP	2	Year-round reservoir use + no treatment
3	CLP + ClO <sub>2</sub>	10	Source water protection



**BRWTF INTEGRATED SOURCE WATER AND TREATMENT STUDY**  
**Appendix 2 – Decision Model Criteria and Alternative Scoring**

**Source Water: Consistency**

Alternative	Treatment Strategy	Score	Comments
1A	ClO <sub>2</sub>	2	Seasonal canal usage with low TDS & sulfate
1B	ClO <sub>2</sub> + UV	2	Seasonal canal usage with low TDS & sulfate
1C	ClO <sub>2</sub> + GAC + UV	2	Seasonal canal usage with low TDS & sulfate
2A	ClO <sub>2</sub>	5	Year-round reservoir use with higher TDS & sulfate, seasonal Mn occurrence
2B	ClO <sub>2</sub> + UV	5	Year-round reservoir use with higher TDS & sulfate, seasonal Mn occurrence
2C	ClO <sub>2</sub> + AOP	5	Year-round reservoir use with higher TDS & sulfate, seasonal Mn occurrence
3	CLP + ClO <sub>2</sub>	10	Year-round CLP with low TDS & sulfate

**Source Water: Water Rights Yield**

Alternative	Treatment Strategy	Score	Comments
1A	ClO <sub>2</sub>	5	Seasonal reservoir usage
1B	ClO <sub>2</sub> + UV	5	Seasonal reservoir usage
1C	ClO <sub>2</sub> + GAC + UV	5	Seasonal reservoir usage
2A	ClO <sub>2</sub>	2	Year-round reservoir usage
2B	ClO <sub>2</sub> + UV	2	Year-round reservoir usage
2C	ClO <sub>2</sub> + AOP	2	Year-round reservoir usage
3	CLP + ClO <sub>2</sub>	10	Year-round CLP usage

**Source Water: Portfolio Flexibility**

Alternative	Treatment Strategy	Score	Comments: Time limit on reservoir storage (use it or lose it)
1A	ClO <sub>2</sub>	5	Requires seasonal reservoir storage
1B	ClO <sub>2</sub> + UV	5	Requires seasonal reservoir storage
1C	ClO <sub>2</sub> + GAC + UV	5	Requires seasonal reservoir storage
2A	ClO <sub>2</sub>	2	Requires year-round reservoir storage
2B	ClO <sub>2</sub> + UV	2	Requires year-round reservoir storage
2C	ClO <sub>2</sub> + AOP	2	Requires year-round reservoir storage
3	CLP + ClO <sub>2</sub>	10	No reservoir storage required



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**Source Water: Availability**

<b>Alternative</b>	<b>Treatment Strategy</b>	<b>Score</b>	<b>Comments: Both BFC and BR ultimately require canal use</b>
1A	ClO <sub>2</sub>	5	Requires seasonal reservoir storage
1B	ClO <sub>2</sub> + UV	5	Requires seasonal reservoir storage
1C	ClO <sub>2</sub> + GAC + UV	5	Requires seasonal reservoir storage
2A	ClO <sub>2</sub>	4	Requires year-round reservoir storage
2B	ClO <sub>2</sub> + UV	4	Requires year-round reservoir storage
2C	ClO <sub>2</sub> + AOP	4	Requires year-round reservoir storage
3	CLP + ClO <sub>2</sub>	10	No limitation on availability



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**Water Treatment/Operations: Worker Safety**

Alternative	Treatment Strategy	Score	Comments
1A	ClO <sub>2</sub>	10	No additional energized equipment and maintenance
1B	ClO <sub>2</sub> + UV	7	Additional energized equipment and maintenance
1C	ClO <sub>2</sub> + GAC + UV	6	Additional energized equipment, maintenance, and GAC replacement
2A	ClO <sub>2</sub>	10	No additional energized equipment and maintenance
2B	ClO <sub>2</sub> + UV	7	Additional energized equipment and maintenance
2C	ClO <sub>2</sub> + AOP	6	Additional energized equipment, maintenance, and chemical handling
3	CLP + ClO <sub>2</sub>	10	No additional energized equipment and maintenance

ClO <sub>2</sub>	0
UV	-3
GAC	-1
AOP	-4
CLP	0

**Water Treatment/Operations: Process Flexibility**

Alternative	Treatment Strategy	Score	Comments
1A	ClO <sub>2</sub>	6	Adjustable oxidation
1B	ClO <sub>2</sub> + UV	8	Adjustable oxidation and UV disinfection
1C	ClO <sub>2</sub> + GAC + UV	8	Adsorption varies with contaminant and GAC age, adjustable UV disinfection
2A	ClO <sub>2</sub>	6	Adjustable oxidation
2B	ClO <sub>2</sub> + UV	8	Adjustable oxidation and UV disinfection
2C	ClO <sub>2</sub> + AOP	10	Greatest flexibility for TOC, DBPs, T&O, Mn
3	CLP + ClO <sub>2</sub>	6	Adjustable oxidation

**Water Treatment/Operations: Process Reliability**

Alternative	Treatment Strategy	Score	Comments: Knowledge and operational control of process(es)
1A	ClO <sub>2</sub>	7	ClO <sub>2</sub> mature (chlorite), source water variability
1B	ClO <sub>2</sub> + UV	6	ClO <sub>2</sub> mature (chlorite), UV adolescent, source water variability
1C	ClO <sub>2</sub> + GAC + UV	5	GAC adolescent, UV adolescent, source water variability
2A	ClO <sub>2</sub>	8	ClO <sub>2</sub> mature (chlorite), source water variability
2B	ClO <sub>2</sub> + UV	7	ClO <sub>2</sub> mature (chlorite), UV adolescent, source water variability
2C	ClO <sub>2</sub> + AOP	7	ClO <sub>2</sub> mature (chlorite), AOP adolescent, source water variability
3	CLP + ClO <sub>2</sub>	10	Pipeline mature, ClO <sub>2</sub> mature (chlorite)

**Source water variability**

BFC	-3
BR	-2
CLP	0

**Technology**

Mature	0
Adolescent	-1
New	-2



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**Water Treatment/Operations: Process Redundancy**

**Barriers**

Alternative	Treatment Strategy	Score	Comments: Maximize barriers
1A	ClO <sub>2</sub>	6	8.0
1B	ClO <sub>2</sub> + UV	8	10.5
1C	ClO <sub>2</sub> + GAC + UV	9	11.5
2A	ClO <sub>2</sub>	6	8.0
2B	ClO <sub>2</sub> + UV	8	10.5
2C	ClO <sub>2</sub> + AOP	10	13.0
3	CLP + ClO <sub>2</sub>	10	13.0

$$\text{Score} = \frac{(n_{\text{barrier}} - 0)}{(N_{\text{barrier}} - 0)} \times 10$$

$n_{\text{barrier}}$  = # barriers in alternative  
 $N_{\text{barrier}}$  = max # barriers in alternatives

**Water Treatment/Operations: Maintenance**

Alternative	Treatment Strategy	Score	Comments: Deducts for each additional maintenance requirement
1A	ClO <sub>2</sub>	10	No additional maintenance
1B	ClO <sub>2</sub> + UV	7	Additional maintenance for UV
1C	ClO <sub>2</sub> + GAC + UV	4	Additional maintenance for GAC (3) and UV
2A	ClO <sub>2</sub>	10	No additional maintenance
2B	ClO <sub>2</sub> + UV	7	Additional maintenance and UV
2C	ClO <sub>2</sub> + AOP	6	Additional maintenance for AOP
3	CLP + ClO <sub>2</sub>	10	No additional maintenance

ClO<sub>2</sub>      0  
 UV            -3  
 GAC          -3  
 AOP          -4  
 CLP          0

**Water Treatment/Operations: Staffing**

Alternative	Treatment Strategy	Score	Comments:	Effort	Expertise	Supervision
1A	ClO <sub>2</sub>	8		-1	0	-1
1B	ClO <sub>2</sub> + UV	7		-1	-1	-1
1C	ClO <sub>2</sub> + GAC + UV	7		-1	-1	-1
2A	ClO <sub>2</sub>	8		-1	0	-1
2B	ClO <sub>2</sub> + UV	7		-1	-1	-1
2C	ClO <sub>2</sub> + AOP	5		-1	-2	-2
3	CLP + ClO <sub>2</sub>	10		0	0	0

Base score =            10    Treatability

<b>BFC</b>	Worst	-1	0	-1
<b>BR</b>	Intermedial	-1	0	-1
<b>CLP</b>	Best	0	0	0



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**Water Treatment/Operations: Residuals Disposal**

Solids: Quantity Quality Chemicals

Alternative	Treatment Strategy	Score	Comments
1A	ClO <sub>2</sub>	7	-1 -2 0
1B	ClO <sub>2</sub> + UV	7	-1 -2 0
1C	ClO <sub>2</sub> + GAC + UV	5	-3 -2 0
2A	ClO <sub>2</sub>	6	-1 -3 0
2B	ClO <sub>2</sub> + UV	6	-1 -3 0
2C	ClO <sub>2</sub> + AOP	5	-1 -3 -1
3	CLP + ClO <sub>2</sub>	10	0 0 0

Base score = 10



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**Risk: Acute Contamination**

Alternative	Treatment Strategy	Score	Comments: Source water protection only, no treatment
1A	ClO <sub>2</sub>	3	Highly vulnerable, BFC
1B	ClO <sub>2</sub> + UV	3	Highly vulnerable, BFC
1C	ClO <sub>2</sub> + GAC + UV	3	Highly vulnerable, BFC
2A	ClO <sub>2</sub>	5	Moderately vulnerable, reservoir dilution
2B	ClO <sub>2</sub> + UV	5	Moderately vulnerable, reservoir dilution
2C	ClO <sub>2</sub> + AOP	5	Moderately vulnerable, reservoir dilution
3	CLP + ClO <sub>2</sub>	10	Minimally vulnerable

**Risk: Chronic Contamination**

Pathogens    Organics    Inorganics

Alternative	Treatment Strategy	Score	Comments: Micropollutants and emerging contaminants
1A	ClO <sub>2</sub>	2	-3    -3    -2
1B	ClO <sub>2</sub> + UV	5	0    -3    -2
1C	ClO <sub>2</sub> + GAC + UV	7	0    -1    -2
2A	ClO <sub>2</sub>	5	-2    -2    -1
2B	ClO <sub>2</sub> + UV	7	0    -2    -1
2C	ClO <sub>2</sub> + AOP	9	0    0    -1
3	CLP + ClO <sub>2</sub>	10	0    0    0

Prevention takes precedence over treatment

Base score =            10

<b>BFC</b>	-3	-3	-3
<b>BR</b>	-2	-2	-2
<b>CLP</b>	-1	-1	-1

ClO <sub>2</sub>	0	0	+1
UV	+3	0	0
GAC	0	+2	0
AOP	+2	+3	+1
CLP	+3	+2	+2

**Risk: Adaptability to Future Regulatory Environment**

Pathogens    Organics    Inorganics

Alternative	Treatment Strategy	Score	Comments
1A	ClO <sub>2</sub>	2	0    0    +1
1B	ClO <sub>2</sub> + UV	5	+3    0    +1
1C	ClO <sub>2</sub> + GAC + UV	7	+3    +2    +1
2A	ClO <sub>2</sub>	2	0    0    +1
2B	ClO <sub>2</sub> + UV	5	+3    0    +1
2C	ClO <sub>2</sub> + AOP	8	+2    +3    +2
3	CLP + ClO <sub>2</sub>	10	+4    +2    +3

Base score =            1

ClO <sub>2</sub>	0	0	+1
UV	+3	0	0
GAC	0	+2	0
AOP	+2	+3	+1
CLP	+3	+2	+2



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**Risk: Infrastructure Vulnerability**

Alternative	Treatment Strategy	Score	Comments: Source water infrastructure contamination only
1A	ClO <sub>2</sub>	4	Highly vulnerable
1B	ClO <sub>2</sub> + UV	4	Highly vulnerable
1C	ClO <sub>2</sub> + GAC + UV	4	Highly vulnerable
2A	ClO <sub>2</sub>	5	Moderately vulnerable, reservoir difficult to decontaminate
2B	ClO <sub>2</sub> + UV	5	Moderately vulnerable, reservoir difficult to decontaminate
2C	ClO <sub>2</sub> + AOP	5	Moderately vulnerable, reservoir difficult to decontaminate
3	CLP + ClO <sub>2</sub>	10	Minimally vulnerable

Both BFC and BR ultimately rely on canal to deliver water

Source	Risk			V. High	-4
	Probability	Severity	Score		
BFC	High	High	4	High	-3
BR	Low	V. High	5	Low	-1
CLP	V. Low	V. Low	10	V. Low	-0

**Risk: Consumable Delivery/Usage**

Alternative	Treatment Strategy	Score	Comments
1A	ClO <sub>2</sub>	10	No Additional risk
1B	ClO <sub>2</sub> + UV	8	
1C	ClO <sub>2</sub> + GAC + UV	5	
2A	ClO <sub>2</sub>	10	No Additional risk
2B	ClO <sub>2</sub> + UV	8	
2C	ClO <sub>2</sub> + AOP	4	
3	CLP + ClO <sub>2</sub>	10	No Additional risk

**Chemical Risk**

ClO <sub>2</sub>	-2
UV	-2
GAC	-3
O <sub>3</sub>	-3
H <sub>2</sub> O <sub>2</sub>	-3



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**Appendix 2 – Decision Model Criteria and Alternative Scoring**

**Environmental and Public Acceptance: Adjacent Land Use Compatibility**

Alternative	Treatment Strategy	Score	Comments
1A	ClO <sub>2</sub>	4	Development, road crossings, recreation
1B	ClO <sub>2</sub> + UV	4	Development, road crossings, recreation
1C	ClO <sub>2</sub> + GAC + UV	4	Development, road crossings, recreation
2A	ClO <sub>2</sub>	4	Development, road crossings, recreation
2B	ClO <sub>2</sub> + UV	4	Development, road crossings, recreation
2C	ClO <sub>2</sub> + AOP	3	Development, road crossings, recreation, LOX delivery
3	CLP + ClO <sub>2</sub>	10	No incompatibilities

Base score = 1  
 LOX delivery 1  
 Development 2  
 Road crossings 2  
 Recreational use 2

**Environmental and Public Acceptance: System Wide Finished Water Uniformity**

Alternative	Treatment Strategy	Score	Comments: Primarily TDS and Sulfate
1A	ClO <sub>2</sub>	3	Higher inorganic content during reservoir use
1B	ClO <sub>2</sub> + UV	3	Higher inorganic content during reservoir use
1C	ClO <sub>2</sub> + GAC + UV	3	Higher inorganic content during reservoir use
2A	ClO <sub>2</sub>	2	Continuously higher inorganic content
2B	ClO <sub>2</sub> + UV	2	Continuously higher inorganic content
2C	ClO <sub>2</sub> + AOP	2	Continuously higher inorganic content
3	CLP + ClO <sub>2</sub>	10	Source water most closely matches Betasso source

**Environmental and Public Acceptance: Construction**

Alternative	Treatment Strategy	Score	Comments
1A	ClO <sub>2</sub>	10	ClO <sub>2</sub>
1B	ClO <sub>2</sub> + UV	7	ClO <sub>2</sub> + UV
1C	ClO <sub>2</sub> + GAC + UV	4	GAC + UV
2A	ClO <sub>2</sub>	10	ClO <sub>2</sub>
2B	ClO <sub>2</sub> + UV	7	ClO <sub>2</sub> + UV
2C	ClO <sub>2</sub> + AOP	6	ClO <sub>2</sub> + AOP
3	CLP + ClO <sub>2</sub>	4	CLP + ClO <sub>2</sub>

ClO<sub>2</sub> 0  
 UV 3  
 GAC 3  
 AOP 4  
 CLP 6



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**Appendix 2 – Decision Model Criteria and Alternative Scoring**

**Environmental and Public Acceptance: Permitting/Regulatory Acceptance**

Alternative	Treatment Strategy	Score	Comments
1A	ClO <sub>2</sub>	10	ClO <sub>2</sub>
1B	ClO <sub>2</sub> + UV	8	ClO <sub>2</sub> + UV
1C	ClO <sub>2</sub> + GAC + UV	6	GAC + UV
2A	ClO <sub>2</sub>	10	ClO <sub>2</sub>
2B	ClO <sub>2</sub> + UV	8	ClO <sub>2</sub> + UV
2C	ClO <sub>2</sub> + AOP	8	ClO <sub>2</sub> + AOP
3	CLP + ClO <sub>2</sub>	6	CLP + ClO <sub>2</sub>

ClO <sub>2</sub>	0
UV	2
GAC	2
AOP	2
CLP	4

**Environmental and Public Acceptance: Consumer confidence**

Pathogens DBPs Organics Inorganics Manganese T&O TDS/SO<sub>4</sub>

Alternative	Treatment Strategy	Score	Comments: Avoidance takes precedence over treatment						
1A	ClO <sub>2</sub>	6	0	+1	0	+1	+2	+2	0
1B	ClO <sub>2</sub> + UV	7	+1	+1	0	+1	+2	+2	0
1C	ClO <sub>2</sub> + GAC + UV	10	+2	+2	+1	+1	+2	+3	0
2A	ClO <sub>2</sub>	7	+1	+1	+1	+2	+1	+1	0
2B	ClO <sub>2</sub> + UV	8	+2	+1	+1	+2	+1	+1	0
2C	ClO <sub>2</sub> + AOP	9	+1	+1	+2	+2	+1	+2	0
3	CLP + ClO <sub>2</sub>	10	+1	+1	+1	+2	+2	+2	+1

Base score = 0

**Avoidance**

BFC	0	0	0	0	+1	+1	0
BR	+1	0	+1	+1	0	0	0
CLP	+1	0	+1	+1	+1	+1	+1

**Treatment**

ClO <sub>2</sub>	0	+1	0	+1	+1	+1	0
UV	+1	0	0	0	0	0	0
GAC	0	+1	+1	0	0	+1	0
AOP	0	0	+1	0	0	+1	0
CLP	0	0	0	0	0	0	+1



**Environmental and Public Acceptance: Energy Requirements**

<b>Alternative</b>	<b>Treatment Strategy</b>	<b>Score</b>	<b>Comments: Based on relative additional energy usage</b>	
1A	ClO <sub>2</sub>	5	\$22,750	5
1B	ClO <sub>2</sub> + UV	3	\$28,663	3
1C	ClO <sub>2</sub> + GAC + UV	3	\$28,663	3
2A	ClO <sub>2</sub>	2	\$32,500	2
2B	ClO <sub>2</sub> + UV	1	\$38,413	1
2C	ClO <sub>2</sub> + AOP	2	\$32,500	2
3	CLP + ClO <sub>2</sub>	10	\$0	10