Cr(VI) Critical Research Needs

• Safe Drinking Water Act regulatory analysis needs:
  – Health effects
  – Occurrence
  – Treatment technologies (feasibility, residuals, and cost)
  – Analytical methods

• WaterRF Cr(VI) Information Exchange Forum:
  – August 18-19, 2011
  – Assembled industry experts to exchange state-of-the-science information about hexavalent chromium (Cr(VI)) with drinking water utilities and regulatory agencies
  – Identified additional information and research that is needed by water utilities and regulators, building on preliminary work by AWWA
Cr(VI) Research Roadmap

**Potential Chromium(VI)**

MCL

**Sources and Fate**
- Contribution of treatment chemicals (NSF, WaterRF #4404)
- Fate through treatment and distribution (WaterRF #4404, #4449)
- *Disinfection impacts on Cr(III) and Cr(VI) transitions*
- Contribution of corrosion

**Communication**
- Communication strategies for utilities (WaterRF RFP #4457)

**Treatment and Costs**
- Treatment case study protocol (WaterRF #4418)
- Cost of compliance estimate (WITAF, WaterRF #4432)
- Utility treatment case studies to assess water quality impact, residuals management, and cost (WaterRF #4365, 4423, 4445, 4449, RFP #4450)
- *Evaluation of novel treatment options*

**Detecion**
- QA/QC of Cr(VI) and total chromium methods (EPA, WaterRF #4404)

**Occurrence**
- Existing data analysis (WaterRF #4414)
- National low level occurrence (EPA UCMR3)

**Health Effects**
- Pharmacokinetics and mode of action (ToxStrategies)

**Cr(III) and Cr(VI) transitions**
- Contribution of corrosion

**Detection**
- QA/QC of Cr(VI) and total chromium methods (EPA, WaterRF #4404)
<table>
<thead>
<tr>
<th>Project #</th>
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</tr>
</thead>
<tbody>
<tr>
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<td>Approved, Draft report due 2 yrs from start</td>
</tr>
<tr>
<td>4450</td>
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<td>RFP May 1, 2012</td>
</tr>
<tr>
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<td>Core Messages for Priority Contaminants of Emerging Concern</td>
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</tr>
</tbody>
</table>
WaterRF Cr(VI) Resources

- State of the Science of Hexavalent Chromium in Drinking Water
  - Laurie McNeill, Utah State University
  - Project #4404
  - [http://waterrf.org/ProjectsReports/ProjectPapers/Lists/PublicProjectPapers/Attachments/2/4404_ProjectPaper.pdf](http://waterrf.org/ProjectsReports/ProjectPapers/Lists/PublicProjectPapers/Attachments/2/4404_ProjectPaper.pdf)

- Guidelines for Hexavalent Chromium Treatment Testing
  - Nicole Blute, Issam Najm, Chad Seidel, Phil Brandhuber
  - Project #4418

- Archived Webcasts
  - Subscribers Only
  - [http://waterrf.org/Resources/Webcasts/Pages/default.aspx](http://waterrf.org/Resources/Webcasts/Pages/default.aspx)
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Hexavalent Chromium: Cost Implications of a Potential MCL
AWWA WITAF #320 / WaterRF #4432

advancing the science of water
Project Team:

Ying Wu, Arcadis

Chris Corwin, Jacobs Engineering

Issam Najm, Water Quality & Treatment Solutions, Inc.

Nicole Blute, Hazen and Sawyer

Chad Seidel, Jacobs Engineering
Hexavalent Chromium: Cost Implications of a Potential MCL

AWWA WITAF #320 / WaterRF #4432

Chad Seidel, Ph.D., P.E.; Jacobs Engineering Group, Inc.
Nicole Blute, Ph.D., P.E.; Hazen and Sawyer, P.C.
Issam Najm, Ph.D., P.E.; WQTS, Inc.

Thursday, May 31, 2012
Acknowledgements

• Project Team
  – Chad Seidel and Chris Corwin, Jacobs
  – Nicole Blute and Ying Wu, Arcadis
  – Issam Najm, WQTS, Inc.

• Advisors
  – Matt Corson and Joseph Marcinko, American Water
  – Roy Wolfe and Heather Collins, Metropolitan Water District of Southern California
  – Tarrah Henrie, California Water Service Company
  – Steve Via, AWWA
  – Alice Fulmer, Water Research Foundation
Overview

- Current regulatory status
- Initial project objectives
- Approach
  - Occurrence data
  - Treatment performance
  - Treatment costs
  - Cost implications
- Conclusions
- Next steps
Current Regulatory Status

• USEPA
  – 100 µg/L Total Cr MCL
  – According to Administrator, “likely” to regulate Cr(VI)
  – Regulatory process would take up to two years
    • Completion of human health assessment study
    • Ensuing public comment period
  – IRIS update delayed awaiting new health impacts information on both oral and inhalation exposure
  – UCMR3 sampling to include both Cr(VI) and total chromium
  – Congressional pressure being applied
Current Regulatory Status

• California DPH
  – Current 50 µg/L Total Cr MCL
  – Statutory mandate to develop Cr(VI)-specific MCL
  – Intend to release a draft MCL for public comment by July 2013
  – Considering 2, 5, 10, 15, 20, 25 µg/L
  – Another 2 years to finalize MCL development and rulemaking
  – Seeking additional information to support process
    • Analytical methods
    • Occurrence
    • Treatment performance and cost
  – Legislative pressure being applied
<table>
<thead>
<tr>
<th></th>
<th>Current Total Cr MCL</th>
<th>Total Cr MCLG</th>
<th>Current Total Cr MCL</th>
<th>Potential Cr(VI) MCL</th>
<th>Cr(VI) PHG</th>
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<tbody>
<tr>
<td>USEPA</td>
<td>100</td>
<td>0</td>
<td>50</td>
<td>2</td>
<td>0.02</td>
</tr>
<tr>
<td>California DPH</td>
<td></td>
<td></td>
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</tbody>
</table>
Chromium Regulatory Timeline
Courtesy of Steve Via, AWWA

Federal – SDWA Timeline (EPA has options for approaching a rulemaking)

1. IRIS Review Final (<12/2011)
2. Administrator’s Discretion
3. Proposed Rule(s) (<7/2015)¹
   - Reg Det 3 Proposal (<7/2012)
   - Reg Det 3 Final (<7/2013)¹
5. Final Rule(s) (<1/2017)¹
   - Final MCL (7/2015???)
   - Six-Year 3 Notice (3/2016)
   - <4 yr rule-making process

PHG Final (7/2011)
Draft MCL (7/2013)

California MCL Timeline

NOTE: SDWA provides 3 years to come into compliance with a new standard and if approved by state 2 additional years for capital improvements.
Chromium Regulatory Timeline
Courtesy of Steve Via, AWWA

Federal – SDWA Timeline (EPA has options for approaching a rulemaking)

1. IRIS Review Final
   (12/2011)

2. Administrator’s Discretion
   ≤ 4 year rule-making process
   (time to propose and finalize rule)

3. UCMR3 Monitoring
   (1/2013 – 12/2015)

   Proposed Rule(s)
   (7/2015)

   Six-Year 3 Notice
   (3/2016)

   Final Rule(s)
   (1/2017)

   Final MCL
   (7/2015)

   Draft MCL
   (7/2013)

   PHG Final
   (7/2011)

   California MCL Timeline

   NOTE: SDWA provides 3 years to come into compliance with a new standard and if approved by state 2 additional years for capital improvements.
Initial Project Objectives

- Communicate potential cost implications of a Cr(VI) standard
- Define practical limits of demonstrated treatment technologies
- Identifying key limitations and information gaps
Approach

- Occurrence Data
- Treatment Performance
- Treatment Cost
- Cost Implications
Approach

- Occurrence Data
  - WaterRF
  - USEPA
  - California DPH

- Treatment Performance

- Treatment Cost

- Cost Implications
Occurrence Data

• Water Research Foundation 4414, *National Occurrence Analysis of Total and Hexavalent Chromium*
  – Chad Seidel, Ph.D., P.E.
  Chris Corwin, Ph.D., P.E.
  *Jacobs Engineering Group, Inc.*
  – Rajiv Khera, P.E.
  *U.S. Environmental Protection Agency*
# Occurrence Data

<table>
<thead>
<tr>
<th>Source</th>
<th>WaterRF</th>
<th>USEPA</th>
<th>California DPH</th>
</tr>
</thead>
<tbody>
<tr>
<td>Database</td>
<td>NCBOS</td>
<td>6YR2</td>
<td>UCMR</td>
</tr>
<tr>
<td>States</td>
<td>41</td>
<td>46</td>
<td>California</td>
</tr>
<tr>
<td>Samples</td>
<td>Raw</td>
<td>Treated</td>
<td>Raw and Treated</td>
</tr>
</tbody>
</table>

### Cr(Total) Samples

<p>| | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>MDL</td>
<td>0.6 µg/L</td>
<td>1 - 50 µg/L</td>
<td>1 - 50 µg/L</td>
</tr>
<tr>
<td>Non-Detect</td>
<td>39%</td>
<td>84%</td>
<td>49%</td>
</tr>
</tbody>
</table>

### Cr(VI) Samples

<p>| | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>MDL</td>
<td>0.2 µg/L</td>
<td>None</td>
<td>1 µg/L or less</td>
</tr>
<tr>
<td>Non-Detect</td>
<td>57%</td>
<td></td>
<td>13%</td>
</tr>
</tbody>
</table>
Occurrence Data

- 6YR2 (n.d. = 0.25 * MRL)
- EPAs Bayesian Estimate (6YR2)
- NCBOS
- 6YR2 nd = 0

Cumulative Probability vs. Total Chromium (µg/L)
CDPH: Total vs Hexavalent Chromium Speciation by Source Water

0-100 µg/L

GW (n=4,837)
SW (n=1,167)

0-10 µg/L

GW (n=4,837)
SW (n=1,167)
USEPA 6YR2 Total Chromium
Maximum Entry Point (75th Percentile) by CWS

> 20 µg/L

Less than 5 µg/L not shown due to data limitations
USEPA 6YR2 Total Chromium
Maximum Entry Point (75th Percentile) by CWS

- Less than 5 µg/L not shown due to data limitations
- 10 - 20 µg/L
- > 20 µg/L

Legend:
- Black dots: > 20 µg/L
- Red dots: 10 - 20 µg/L
- Green dots: 5 - 10 µg/L
USEPA 6YR2 Total Chromium
Maximum Entry Point (75th Percentile) by CWS

Less than 5 µg/L not shown due to data limitations.
USEPA 6YR2 Total Chromium
Maximum Entry Point (75th Percentile) by CWS

Number of Entry Points by State
USEPA 6YR2 Total Chromium Maximum Entry Point (75th Percentile) by CWS

Percent of Entry Points by State
CDPH: Hexavalent Chromium

75th Percentile of Entry Points by Utility

- > 10 µg/L
- 5 - 10 µg/L
- 1 - 5 µg/L
National Estimates

Percent of Systems with Entry Point Total Chromium 75th Percentile > Threshold

<table>
<thead>
<tr>
<th>Threshold (µg/L)</th>
<th>All Systems</th>
<th>Groundwater Systems</th>
<th>Surface Water Systems</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>6YR2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>8.7</td>
<td>9.4</td>
<td>4.1</td>
</tr>
<tr>
<td>10</td>
<td>4.7</td>
<td>5.1</td>
<td>1.8</td>
</tr>
<tr>
<td></td>
<td>NCBOS</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>9.4</td>
<td>11.4</td>
<td>5.3</td>
</tr>
<tr>
<td>10</td>
<td>1.8</td>
<td>1.8</td>
<td>1.8</td>
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</table>

Comparison with USEPA Arsenic Rule (Mean Finished Arsenic Concentration)

<p>| | | |</p>
<table>
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<tr>
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<tbody>
<tr>
<td>10</td>
<td>5.3</td>
<td>0.8</td>
</tr>
</tbody>
</table>
National Estimates

Entry Points with Total Chromium 75th Percentile Estimated > Threshold

- 6YR2 n.d.=0
- 6YR2 n.d.=0.25*MRL
- NCBOS
Approach

Occurrence Data
- WaterRF
- USEPA
- California DPH

Treatment Performance
- Strong Base Anion Exchange
- Weak Base Anion Exchange
- Reduction Coagulation Filtration
- Reverse Osmosis

Treatment Cost

Cost Implications
Established Treatment Alternatives

Strong Base Anion Exchange (SBA-IX)  Reverse Osmosis (RO)
Demonstrated Treatment Alternatives

Weak Base Anion Exchange (WBA-IX)

Reduction Coagulation Filtration (RCF)
Developing Treatment Alternatives

Chemical Reductive Media (CRM)  Biological Reduction and Filtration
# Treatment Performance Summary

<table>
<thead>
<tr>
<th>Technology</th>
<th>Treatment Goal (ug/L)</th>
</tr>
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<tbody>
<tr>
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<td>20</td>
</tr>
<tr>
<td>Strong Base Anion Exchange (SBA-IX)</td>
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<tr>
<td>Weak Base Anion Exchange (WBA-IX)</td>
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<tr>
<td>Reduction Coagulation Filtration (RCF)</td>
<td></td>
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<tr>
<td>Reverse Osmosis (RO)</td>
<td></td>
</tr>
<tr>
<td>Chemical Reductive Media (CRM)</td>
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<tr>
<td>Biological Reduction and Filtration</td>
<td></td>
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</table>

- **Demonstrated performance**
- **Inadequate performance**
- **Insufficient data to project**
## Approach

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<tr>
<th>Occurrence Data</th>
<th>Treatment Performance</th>
<th>Treatment Cost</th>
<th>Cost Implications</th>
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<td></td>
<td></td>
</tr>
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<td>• USEPA</td>
<td>• Weak Base Anion Exchange</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• California DPH</td>
<td>• Reduction Coagulation Filtration</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>• Reverse Osmosis</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Capital</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>• O&amp;M</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Total Annual</td>
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# Treatment Cost

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<tr>
<th>Treatment</th>
<th>Cost Sources</th>
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<tbody>
<tr>
<td>WBA</td>
<td>Glendale, CA cost curves</td>
</tr>
<tr>
<td>RCF</td>
<td>Glendale, CA cost curves</td>
</tr>
<tr>
<td>SBA</td>
<td>Combination of engineer’s estimate, Glendale, CA cost curves, USEPA cost curves for arsenic compliance, surveys of existing full-scale nitrate and arsenic SBA treatment installations</td>
</tr>
<tr>
<td>RO</td>
<td>USEPA RO cost curves for arsenic compliance</td>
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</tbody>
</table>

- Glendale, CA cost curves supported by WaterRF, USEPA, California Proposition 50, ACWA funding
## Treatment Cost

<table>
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<th>Treatment</th>
<th>Cost Limitations</th>
</tr>
</thead>
<tbody>
<tr>
<td>WBA</td>
<td>Limited to Glendale, CA</td>
</tr>
<tr>
<td>RCF</td>
<td>Limited to Glendale, CA</td>
</tr>
<tr>
<td>SBA</td>
<td>Disagreement between cost sources; performance limited to Glendale, CA</td>
</tr>
<tr>
<td>RO</td>
<td>Dated cost curves</td>
</tr>
</tbody>
</table>

- **Other limitations**
  - Challenging to apply across a diverse range of treatment flow rates and water quality conditions
  - May not adequately address residuals disposal feasibility and site-specific constraints that impact costs
  - No forecast of technology selection by source; presenting range of potential costs instead
Treatment Cost

Treatment Goal = 10 µg/L
## Approach

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<th>Cost Implications</th>
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<td>• Capital</td>
<td>• National</td>
</tr>
<tr>
<td>• USEPA</td>
<td>• Weak Base Anion Exchange</td>
<td>• O&amp;M</td>
<td>• Community</td>
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<tr>
<td></td>
<td>• Reverse Osmosis</td>
<td></td>
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</tr>
</tbody>
</table>
Initial National Cost Implications

Capital ($Billions)

- **Upper Bound Estimate**
- **Lower Bound Estimate**

DRAFT
Initial National Cost Implications

Annual O&M ($Billions/year)

- **Upper Bound Estimate**
- **Lower Bound Estimate**

**DRAFT**
Initial National Cost Implications

Total Annual ($Billions/year)

- Upper Bound Estimate
- Lower Bound Estimate

DRAFT
## Initial National Cost Implications

### SDWA Regulations in 2011 Dollars

<table>
<thead>
<tr>
<th>Threshold (ug/L)</th>
<th>Total Annual Costs ($Billions/year)</th>
<th>Capital Costs ($Billions)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hexavalent Chromium</td>
<td></td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>$0.6</td>
<td>$3.0</td>
</tr>
<tr>
<td>10</td>
<td>$1.1</td>
<td>$4.7</td>
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<tr>
<td>(Lower Bound Estimates)</td>
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<tr>
<td>5</td>
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<td>$24</td>
</tr>
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<td>$49</td>
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</table>

### Comparison to Other SDWA Rules

<table>
<thead>
<tr>
<th>Rule</th>
<th>Total Annual Costs ($Billions/year)</th>
<th>Capital Costs ($Billions)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surface Water Treatment Rule</td>
<td>$1.6</td>
<td>$5.8</td>
</tr>
<tr>
<td>Stage 1 Disinfection Byproducts Rule</td>
<td>$1.0</td>
<td>$3.5</td>
</tr>
<tr>
<td>Arsenic Rule</td>
<td>$0.5</td>
<td>$4.1</td>
</tr>
</tbody>
</table>

Adapted from Raucher and Cromwell 2004
Key Limitations / Information Gaps

• Uncertainty in occurrence estimates, particularly at lower concentrations
• Capital and O&M costs estimates limited to just a few demonstrations/installations
• Many cost components may not be adequately included
  – Residuals disposal
  – Site specific constraints
Conclusions

• California Cr(VI) or revised total Cr MCL is coming soon
  – Participate in informing the regulatory development process

• Widespread occurrence across U.S and in California drinking water sources
  – Groundwater chromium mostly hexavalent

• Limited demonstration of treatment technologies across representative water sources
  – Treatment costs anticipated to be high based on limited current state of knowledge
Next Steps

• Journal paper that can be cited by regulatory community
  – Identify information needs as the regulatory process moves forward in California and at USEPA

• Refine assumptions in the existing analysis, particularly SBA costs

• Describe costing methodology to facilitate development of local cost estimates by individual water systems
Questions?

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