HRSD’s Vision for Managed Aquifer Recharge in Eastern Virginia

Charles B. Bott, PhD, PE, BCEE
Director of Water Technology and Research
Who/What is HRSD?

- Provide wastewater treatment for 18 localities (250 mgd treatment capacity)
- Serve 1.7 million people (20% of all Virginians)
- Independent political subdivision with Governor appointed Commission
HRSD costs are rising to treat water to higher standards.

Treated water currently discharged to area waterways – no beneficial use.
The Challenges/Opportunities for HRSD

• ~$750M in Nutrient Removal Upgrades by 2021

• ~$2.2B in Consent Decreed Mandated Upgrades to Reduce Sanitary Sewer Overflows over 20 years

• Very large managed aquifer recharge effort pending
  – Indirect potable reuse?
  – ~120 MGD
  – ~$1B
SWIFT – Sustainable Water Initiative for Tomorrow

- Treat water to meet drinking water standards and replenish the aquifer with clean water to:
  - Provide regulatory stability for wastewater treatment
  - Reduce nutrient discharges to the Bay
  - Reduce the rate of land subsidence
  - Provide a sustainable supply of groundwater
  - Protect the groundwater from saltwater contamination
Figure 11. Section illustrating layering in the Virginia Coastal Plain aquifer system from west to east. Elevation relative to North American Vertical Datum of 1988 (NAVD88). Modified from McFarland and Bruce (2006).
• Artesian wells in early 1900s – groundwater wells required valves not pumps!

• In about 100 years have gone from water levels at 31 feet above sea level to 200± feet below.
Modelled Potomac Aquifer water levels with and without SWIFT.
What is the travel time of the injected water?

*Approximately 180 years to travel one mile*

- Recharge water velocity decelerates rapidly as it moves from the injection site.
- Model predictions range from 3 to 29 feet/year.
- Data from the SWIFT Research Center ⇒ refinement of recharge velocities and travel times.

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**Upper Potomac Aquifer**

![Graph showing Lagrangian Radial Velocity and Travel Time vs Radial Distance (ft/d)](image)
Land subsidence – *we are sinking*

- According to USGS
  - Up to 50% of relative sea-level rise may be due to land subsidence
  - Up to 50% of land subsidence may be due to aquifer compaction
Impact on nutrient reductions

Nansemond Completed
James River Completed
Army Base Completed
VIP Completed
Chesapeake-Elizabeth Offline

James River Basin Total Nitrogen

WLA – Nutrient Waste Load Allocation in lbs/yr

Similar results with TP and TSS and in other river basins.

Sustainable Water Initiative for Tomorrow
## Potential to offset stormwater reductions

<table>
<thead>
<tr>
<th></th>
<th>Approximate total credits due to SWIFT</th>
<th>Regional Stormwater Reduction Needs*</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Nitrogen</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>James</td>
<td>2,900,000</td>
<td>63,039</td>
</tr>
<tr>
<td>York</td>
<td>250,000</td>
<td>19,114</td>
</tr>
<tr>
<td><strong>Phosphorus</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>James</td>
<td>250,000</td>
<td>13,088</td>
</tr>
<tr>
<td>York</td>
<td>16,000</td>
<td>3,887</td>
</tr>
</tbody>
</table>

* DEQ Regulated Stormwater w/o federal lands
Executed nutrient trading agreements with 11 localities
The Challenges/Opportunities for HRSD

• ~$750M in Nutrient Removal Upgrades by 2021

• ~$2.2B in Consent Decreed Mandated Upgrades to Reduce Sanitary Sewer Overflow
  – RWWMP in the form of an Integrated Plan, October 2017

• Very large managed aquifer recharge effort pending
  – Indirect potable reuse?
  – ~120 MGD
  – ~$1B (over 10 years)
## Water Supply Augmentation Approaches (Indirect Potable Reuse)

<table>
<thead>
<tr>
<th>Indirect Potable Reuse Approaches</th>
<th>Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>De Facto</strong></td>
<td>Common throughout the world (e.g., Mississippi River, Colorado River, etc...)</td>
</tr>
<tr>
<td>Surface Water Augmentation</td>
<td>Upper Occoquan Service Authority (Northern Virginia); Gwinnett County (Georgia); Singapore NEWater</td>
</tr>
<tr>
<td>GW Recharge via Spreading Basins</td>
<td>Montebello Forebay (Los Angeles, CA); El Paso (Texas); Chino Basin (Chico, CA)</td>
</tr>
<tr>
<td>GW Recharge via Direct Injection</td>
<td>GWRS (Orange County, CA); West Basin (CA); Los Alamitos (Long Beach, CA); Scottsdale Water Campus (AZ)</td>
</tr>
</tbody>
</table>
Advanced water treatment alternatives

**Carbon Based**

- FLOC/SED-OZONE-BAC-GAC-UV
- Aquifer Injection

**Membrane Based**

- MF-RO-UVAOP
- Aquifer Injection
- River Outfall

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Typical Approach to Developing Finished Water Goals for Groundwater Recharge

• Meet all primary Maximum Contaminant Levels (MCLs) regulated by the USEPA in the SDWA
• Provide multiple barriers to pathogens and organics (including chemicals)
• Aquifer compatibility
• Hazard Analysis and Critical Control Points
  • Action level exceedance will prevent water from entering the recharge well
The SWIFT Pilot
Membrane-Based Pilot
Carbon-Based Pilot
Soil Columns to evaluate Soil Aquifer Treatment
SWIFT Pilot Testing Results

• Both trains meet drinking water quality standards
• All primary MCLs (regulated) are being met
• All secondary MCLs are being met, except in the Carbon-based AWT system:
  – TDS (salt) is slightly above 500 mg/L (50%/95% = 523/550 mg/L)
  – Sulfate and chloride are consistently less than 250 mg/L

• Topics:
  – Pathogen removal
  – TOC
  – Emerging contaminants
  – Bromate, 1,4-dioxane, NDMA
Aquifer Compatibility: inject similar water quality to that in the aquifer:

• Ionic strength/TDS - Prevent swelling, repulsion, and migration of clay mineral fragments
  – Within ½-order of magnitude of aquifer (TDS ~ 1,400 – 4,800 mg/L)
  – Major ions should match to prevent clay ion exchange
    ○ Calcium (~30 mg/L) and sodium (~1,000 mg/L)

• EPA secondary MCL for TDS = 500 mg/L

• Pilot values for Carbon-based AWT:
  – 50th Percentile: 541 mg/L
  – 99th Percentile: 635 mg/L

• Recommendation:
  – Given high ionic strength of aquifer, aquifer compatibility should take precedence over finished water TDS limit
  – No specific TDS limit; targets will be created for compatibility
SWIFT Research Center
(1 MGD AWT + recharge well + monitoring wells)
Location of facility within Nansemond TP site
Process Flow Diagram for SWIFT Research Center

- Carbon treatment process selected to ensure aquifer compatibility
SWIFT Research Center
(1 MGD AWT + recharge well + monitoring wells)
SWIFT Research Center
(1 MGD AWT + recharge well + monitoring wells)
Recharge Well (SWIFT Water)

Monitoring Well (MW_SAT)

MW_SAT_1
MW_SAT_2
MW_SAT_3
MW_SAT_4
MW_SAT_5
MW_SAT_6
MW_SAT_7
MW_SAT_8
MW_SAT_9
MW_SAT_10
MW_SAT_11

UPA

MPA

LPA

Flute Sample Panel
Recharge Well (SWIFT Water)

~1 year

MW_UPA  MW_MPA  MW_LPA
# Finished Water Quality Preliminary Targets

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Proposed Regulatory Limit</th>
<th>Water Quality Goal (non-regulatory)</th>
</tr>
</thead>
<tbody>
<tr>
<td>MCLs</td>
<td>Meet all primary MCLs</td>
<td>N/A</td>
</tr>
<tr>
<td>TN</td>
<td>5 mg/L monthly average; 8 mg/L max daily</td>
<td>Secondary Effluent CCP Action Limit for TIN = 6 mg/L</td>
</tr>
<tr>
<td>Turbidity</td>
<td>IFE &lt;0.15 NTU 95% of time &amp; never &gt; 0.3 NTU in two consecutive measurements</td>
<td>CCP Action Limit at 0.10 NTU to initiate backwash or place filter in standby</td>
</tr>
<tr>
<td>TOC</td>
<td>4 mg/L monthly average 6 mg/L maximum</td>
<td>COP Action Limit at 4 mg/L, laboratory 10 day average</td>
</tr>
<tr>
<td>Total coliform</td>
<td>&lt; 2 CFU / 100 mL; 95% of time; Not to exceed geometric mean of 3 CFU/100 mL, based on a running calculation of 20 days of daily samples for total coliforms.</td>
<td>CCPs to achieve 12 LRV for viruses and 10 LRV for Crypto &amp; Giardia</td>
</tr>
<tr>
<td>E. Coli</td>
<td>Non-detect</td>
<td></td>
</tr>
<tr>
<td>Unreg Chemicals</td>
<td>None</td>
<td>Monitor suite of chemicals and address as necessary</td>
</tr>
<tr>
<td>Total Dissolved Solids</td>
<td>None</td>
<td>Monitor PAS compatibility</td>
</tr>
</tbody>
</table>
Design to Achieve Expected Pathogen LRVs – 12/10/10 including SAT (NWRI Recommendation)

Operate to achieve using CCPs

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Log Reduction Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Coag/Sed (+BAC)</td>
</tr>
<tr>
<td>Enteric Viruses</td>
<td>2</td>
</tr>
<tr>
<td>Cryptosporidium</td>
<td>4</td>
</tr>
<tr>
<td>Giardia</td>
<td>2.5</td>
</tr>
</tbody>
</table>
Unregulated Chemical Constituents that are of Public Health Interest  
*(Final Report of an NWRI Independent Advisory Panel: Recommended DPR General Guidelines and Operational Requirements for New Mexico, 2016)*

<table>
<thead>
<tr>
<th>Chemical</th>
<th>Criterion</th>
<th>Carbon-based Train Conc.</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>1,4-Dioxane</td>
<td>1 µg/L</td>
<td>0.34-0.39 µg/L&lt;sup&gt;1&lt;/sup&gt;</td>
<td>CCL3; CA Notification limit</td>
</tr>
<tr>
<td>17-B-estradiol</td>
<td>TBD (ng/L range)</td>
<td>&lt;0.005 µg/L&lt;sup&gt;2&lt;/sup&gt;</td>
<td>CCL3</td>
</tr>
<tr>
<td>DEET</td>
<td>200 µg/L</td>
<td>&lt;0.010 µg/L&lt;sup&gt;2&lt;/sup&gt;</td>
<td>Minnesota Health guidance value</td>
</tr>
<tr>
<td>Ethinyl Estradiol</td>
<td>TBD (ng/L range)</td>
<td>&lt;0.005 µg/L&lt;sup&gt;2&lt;/sup&gt;</td>
<td>CCL3</td>
</tr>
<tr>
<td>NDMA</td>
<td>10 ng/L</td>
<td>6.6 -14 ng/L&lt;sup&gt;3&lt;/sup&gt;</td>
<td>CCL3; CA Notification limit</td>
</tr>
<tr>
<td>Perchlorate</td>
<td>6 µg/L</td>
<td>&lt; 4 µg/L&lt;sup&gt;4&lt;/sup&gt;</td>
<td>CA Notification limit</td>
</tr>
<tr>
<td>PFOA +PFOS</td>
<td>70 ng/L</td>
<td>&lt; 60 ng/L&lt;sup&gt;5&lt;/sup&gt;</td>
<td>USEPA Health Advisory</td>
</tr>
<tr>
<td>TCEP</td>
<td>5 µg/L</td>
<td>&lt;0.010 µg/L&lt;sup&gt;2&lt;/sup&gt;</td>
<td>Minnesota Health guidance value</td>
</tr>
</tbody>
</table>

1. Based on 3 samples in finished water  
2. Based on 8 samples in finished water  
3. Based on 9 samples in finished water  
4. Based on 4 samples in pilot feed  
5. Based on 1 sample in finished water
Unregulated chemical constituents that provide information on the effectiveness of treatment  
*(Final Report of an NWRI Independent Advisory Panel: Recommended DPR General Guidelines and Operational Requirements for New Mexico, 2016)*

<table>
<thead>
<tr>
<th>Chemical</th>
<th>Criterion</th>
<th>Carbon-based Train FW Conc.</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cotinine</td>
<td>1 µg/L</td>
<td>&lt;0.010 µg/L&lt;sup&gt;2&lt;/sup&gt;</td>
<td>Surrogate for low MW, partially charged cyclics</td>
</tr>
<tr>
<td>Primidone</td>
<td>10 µg/L</td>
<td>&lt; 0.005 µg/L&lt;sup&gt;2&lt;/sup&gt;</td>
<td></td>
</tr>
<tr>
<td>Phenyltoin</td>
<td>2 µg/L</td>
<td>No data</td>
<td></td>
</tr>
<tr>
<td>Meprobamate</td>
<td>200 µg/L</td>
<td>&lt; 0.005 µg/L&lt;sup&gt;2&lt;/sup&gt;</td>
<td>High occurrence in WWTP effluent</td>
</tr>
<tr>
<td>Atenolol</td>
<td>4 µg/L</td>
<td>&lt; 0.005 µg/L&lt;sup&gt;2&lt;/sup&gt;</td>
<td></td>
</tr>
<tr>
<td>Carbamazepine</td>
<td>10 µg/L</td>
<td>&lt; 0.005 µg/L&lt;sup&gt;2&lt;/sup&gt;</td>
<td>Unique structure</td>
</tr>
<tr>
<td>Estrone</td>
<td>320 µg/L</td>
<td>&lt; 0.005 µg/L&lt;sup&gt;2&lt;/sup&gt;</td>
<td>Surrogate for steroids</td>
</tr>
<tr>
<td>Sucralose</td>
<td>150 mg/L</td>
<td>Range: &lt;0.1 to 61 µg/L (GAC1)</td>
<td>Surrogate for water soluble, uncharged chemicals, moderate MW</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Range: &lt;0.1 to 0.32 µg/L (GAC2)</td>
<td></td>
</tr>
<tr>
<td>Triclosan</td>
<td>2100 µg/L</td>
<td>&lt;0.010 µg/L&lt;sup&gt;2&lt;/sup&gt;</td>
<td>Chemical of interest</td>
</tr>
</tbody>
</table>

1. In most cases, criterion based on drinking water equivalent concentration for lowest therapeutic dose divided by 1,000 or 10,000 to provide a safety factor.
2. Based on 8 samples in finished water.
Next Steps

• Establish Monitoring and Oversight Program
  – Legislation was introduced in January 2018

• Conduct outreach to private well owners in partnership with the Virginia Extension Service

• Obtain EPA Permit for Recharge Well at Research Center

• Commence operations at Research Center
  – Producing 1 million gallons per day of SWIFT Water and pumping into the thirsty Potomac Aquifer in northern Suffolk

• Begin extensive data gathering at Research Center
2016-2017
- Pilot AWT system operating since June 2016
- Soil column tests to evaluate soil aquifer treatment
- Working with VA Dept of Health to identify existing private wells around recharge sites
- Preparing for full-scale implementation
- MS4 trade agreements with Hampton Roads localities
- NWRI independent panel transition to SWIFT oversite and monitoring entity

2018
- SWIFT Research Center with 1 MGD recharge well

2020
- Permits issued for full scale facilities

2020 to 2030
- Construction through phased implementation

2030 Fully operational
- ~120 MGD of clean water recharging the aquifer
Pilot Evaluation: Carbon vs Membrane Pathogens

- Both trains provide similar quantifiable log removal credit for viruses, *Cryptosporidium*, and *Giardia*, and demonstrated complete removal of Male specific coliphage (virus) (>8 log removal) in challenge testing.

<table>
<thead>
<tr>
<th>Pathogen Indicators</th>
<th>Carbon Train Finished Water</th>
<th>Membrane Train Finished Water</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total coliform, 99th percentile</td>
<td>&lt;1 MPN/100mL</td>
<td>1</td>
</tr>
<tr>
<td>E coli, 99th percentile</td>
<td>&lt;1 MPN/100mL</td>
<td>&lt;1 MPN/100mL</td>
</tr>
<tr>
<td>MS2 Challenge Test</td>
<td>&gt; 8-log removal</td>
<td>&gt; 8-log removal</td>
</tr>
<tr>
<td>Pepper Mild Mottle Virus</td>
<td>&gt;5.9 log removal</td>
<td>&gt;5.9 log removal</td>
</tr>
</tbody>
</table>
Average Total Organic Carbon (TOC) removal in both treatment processes during pilot operation.

Sustainable Water Initiative for Tomorrow
**Pilot Evaluation: Carbon vs Membrane Contaminants of Emerging Concern**

- A suite of 96 CECs analyzed in both treatment processes
- Treatment case study for 8/31/16
  - Only constituents detected by analysis are displayed in chart
  - Multi-barrier approach is shown by decrease in concentration through the treatment process
- All values shown in ng/L (parts per trillion)

<table>
<thead>
<tr>
<th>Contaminant</th>
<th>Pilot Feed</th>
<th>O3 Eff</th>
<th>BAC Low</th>
<th>GAC Low</th>
<th>RO Eff</th>
<th>UVAOP Eff</th>
</tr>
</thead>
<tbody>
<tr>
<td>4-nonylphenol</td>
<td>1100</td>
<td>320</td>
<td>&lt;100</td>
<td>&lt;100</td>
<td>100</td>
<td>&lt;100</td>
</tr>
<tr>
<td>Acesulfame-K</td>
<td>1100</td>
<td>360</td>
<td>290</td>
<td>&lt;20</td>
<td>&lt;20</td>
<td>&lt;20</td>
</tr>
<tr>
<td>Iohexal</td>
<td>7500</td>
<td>4000</td>
<td>1400</td>
<td>&lt;10</td>
<td>31</td>
<td>&lt;10</td>
</tr>
<tr>
<td>Sucralose</td>
<td>43000</td>
<td>28000</td>
<td>12000</td>
<td>&lt;100</td>
<td>140</td>
<td>130</td>
</tr>
<tr>
<td>Primidone</td>
<td>130</td>
<td>46</td>
<td>21</td>
<td>&lt;5</td>
<td>&lt;5</td>
<td>&lt;5</td>
</tr>
<tr>
<td>TCEP</td>
<td>140</td>
<td>130</td>
<td>45</td>
<td>&lt;10</td>
<td>&lt;10</td>
<td>&lt;10</td>
</tr>
</tbody>
</table>

Sustainable Water Initiative for Tomorrow
Average number of CECs detected

<table>
<thead>
<tr>
<th>CECs (ng/L)</th>
<th>S1</th>
<th>S3</th>
<th>S4.1</th>
<th>S4.2</th>
<th>S5.1</th>
<th>S5.2</th>
<th>S8</th>
<th>S10</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pilot Feed</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>O3 Eff</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BAC1 Eff</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BAC2 Eff</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GAC1 Eff</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GAC2 Eff</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>RO Eff</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>UVAOP Eff</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>n (sampling events)</td>
<td>15</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>13</td>
<td>13</td>
<td>3</td>
<td>9</td>
</tr>
<tr>
<td>Average # detected throughout operation</td>
<td>25</td>
<td>16</td>
<td>11</td>
<td>10</td>
<td>6</td>
<td>3</td>
<td>2</td>
<td>1</td>
</tr>
</tbody>
</table>
Emerging contaminants – Carbon based

**Average of total mass (ng/L)**

- Pilot Feed: 80521
- O3 Eff: 54304
- BAC High: 43524
- BAC Low: 40180
- GAC High: 19091
- GAC Low: 4633

**Average # detected**

- Pilot Feed: 25
- O3 Eff: 13
- BAC High: 11
- BAC Low: 10
- GAC High: 5
- GAC Low: 3

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Bromate can be controlled by addition of preformed monochloramine.

**Ozone Dose v. Bromate Formation**

Bromide: 390-430 μg/L   TOC: ~5.9mg/L   Temperature: 15-17
Now plotting Vs Virus LRV (approx.)

Virus LRV v. Bromate Formation

Sustainable Water Initiative for Tomorrow
1,4 Dioxane removal in Carbon-based AWT
N-Nitrosodimethylamine (NDMA) removal in carbon and membrane processes emphasizing importance of BAC and GAC EBCT
N-Nitrosodimethylamine (NDMA) removal in carbon and membrane processes emphasizing importance of BAC and GAC EBCT.