The Business Case for a Comprehensive Wastewater Master Plan

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  – Amy Hanna

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In 2010, Durham Initiated a Wastewater Master Planning Effort

Energy
Reduce (as much as possible)

Clean Water
Reuse (as much as possible)

Nutrients
Recover (as much as possible)
City of Durham is Located in the Middle of North Carolina
Durham Wastewater Overview
Key Issues the Master Plan Addressed

- **Nutrients**
  - Falls Lake Rules
  - Jordan Lake Rules

- **WRF needs through build-out**

- **Near-term (20 year) and long-term strategies**

- **Wet weather**

- **Reuse Feasibility**

- **Outside-the-fence approaches**
  - Flow diversion
  - Source control
  - I/I reduction

- **Biosolids land application requirements**

- **Energy Management**

- **Emerging contaminants**
South Durham WRF (SDWRF)

- 20 MGD rated capacity
- 10.8 MGD current annual average
- Jordan Lake Rules
Jordan Lake Rules (2009)

- Purpose: Improve Jordan Lake water quality
- In 2012: Limit TP load reduced to 0.23 mg/L at permitted flows
- By 2016: Limit TN load to equivalent of 3 mg/L concentration at permitted flows
## Nutrient Design Criteria – SDWRF

<table>
<thead>
<tr>
<th></th>
<th>Original Design 20 mgd</th>
<th>Master Plan</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Current Annual Average Flow 10.8 mgd</td>
</tr>
<tr>
<td><strong>Total Nitrogen (lb/yr)</strong></td>
<td>334,850</td>
<td></td>
</tr>
<tr>
<td><strong>Total Nitrogen (mg/L)</strong></td>
<td>5.50</td>
<td>5.64</td>
</tr>
<tr>
<td><strong>Total Phosphorus (lb/yr)</strong></td>
<td>N/A</td>
<td></td>
</tr>
<tr>
<td><strong>Total Phosphorus (mg/L)</strong></td>
<td>0.5 (summer) 2.0 (winter)</td>
<td>0.43</td>
</tr>
</tbody>
</table>

Conventional Treatment Sufficient
Nutrient Effluent Criteria as a Function of Flow Projections – SDWRF

Jordan Lake Rules

Equivalent Effluent TP Concentration to Meet TMDL (mg/L)

Equivalent Effluent TN Concentration to Meet TMDL (mg/L)

Effluent TN Limit (mg/L)

Effluent TP Limit (mg/L)
North Durham WRF (NDWRF)

- 20 MGD rated capacity
- 10.5 MGD current annual average
- Falls Lake Rules
Falls Lake Rules (2011)

- Purpose: Improve Falls Lake water quality
- Model showed Ellerbe Creek had highest nutrient loadings to lake
- Stage 1 (2016): limit TN load equivalent to 3 mg/L at current flows
- Stage 2 (2036): decrease TN load by 30%
  - Point sources bear majority of this burden
# Nutrient Design Criteria – NDWRF

<table>
<thead>
<tr>
<th></th>
<th>Stage 1 - 2016</th>
<th>Stage 2 - 2036</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Original Design 20 mgd</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Current Annual Average Flow</strong></td>
<td>10.5 mgd</td>
<td></td>
</tr>
<tr>
<td><strong>2031 Projected Annual Average Flow</strong></td>
<td>14.9 mgd</td>
<td></td>
</tr>
<tr>
<td><strong>Design Flow 20 mgd</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Buildout Flow 24 mgd</strong></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

| **Total Nitrogen (lb/yr)**     | 97,720         | 67,269         |
| **Total Nitrogen (mg/L)**      | 3.06           | 2.15           |
| **Total Phosphorus (lb/yr)**   | 10,637 (Ph 1)  | 3,669 (Ph 2)   |
| **Total Phosphorus (mg/L)**    | 0.33           | 0.23           |

- Requires Advanced Treatment

**Note:** Summer values are higher than winter values for phosphorus.
Nutrient Effluent Criteria as a Function of Flow Projections – NDWRF

Graph showing the relationship between Equivalent Effluent TP Concentration to Meet TMDL (mg/L) and Equivalent Effluent TN Concentration to Meet TMDL (mg/L) over time. The graph includes two stages:

- **Stage 1**: Falls Lake Rules, marked by a green triangle line.
- **Stage 2**: Falls Lake Rules, marked by a green triangle line.

The x-axis represents the years from 2010 to 2055, while the y-axis represents the equivalent effluent concentrations from 0 to 10 for TP and from 0 to 2 for TN.
SDWRF NUTRIENT REMOVAL ANALYSIS
South Durham Historical Performance – Effluent Yearly TN Averages

20-year TN goal = 3.9 mg/L
South Durham Historical Performance – Effluent TP

Near-term TP Limit 0.23 mg/L
Enhancements to SDWRF (SDWRF Alternatives Analysis)

<table>
<thead>
<tr>
<th></th>
<th>Alternative 1</th>
<th>Alternative 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>5-Stage w/carbon</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Denitrification Filters</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>MBBR</td>
<td></td>
<td>X</td>
</tr>
</tbody>
</table>
SDWRF Lowest Cost Alternative was 5-Stage + Denite Filters

- No new BNR tanks needed
- Utilize existing flocculation zone for organic N removal
- Multi-point chemical addition for P removal
- Supplemental carbon
- Build denitrification filters if/when needed
North Durham Historical Performance – Effluent Nitrogen Yearly Averages

20-year TN goal = 2.18 mg/L
N Speciation

Total Nitrogen

- Ammonia, NH$_3$-N
- Nitrate / nitrite, NO$_x$-N
- Soluble (dissolved) organic N
- Particulate organic N

Effective nitrification

Effective denitrification

Chemical coagulation Adsorption

Solids separation
Dissolved Organic Nitrogen (DON) Contains a Refractory Portion (RDON)

- RDON is the unbiodegradable component of soluble organic N (and TN)
- Sources
  - Influent
  - Biological production
- Part of the TN limit
- RDON is not exempt from TN standard
- DON @ NDWRF 0.63 mg/L
- DON @ SDWRF 0.79 mg/L
North Durham Historical Performance – Effluent Ammonia

![Graph showing effluent ammonia levels from January 2002 to January 2011. The graph includes Ammonia and 30-day moving average lines.](image-url)
North Durham Historical Performance – Effluent Phosphorus

Near-term TP Limit 0.23 mg/L
Summary of NDWRF Near-term Nutrient Compliance Approach

• Meet the new limits using conventional technology for as long as possible

• Robust design criteria
  – No process upsets/ammonia spikes
  – Significant online instrumentation will be required
  – Improvements in nitrification safety factor

• 20-year TP goals doable with conventional technology
  – Multi-point chemical addition when needed

• Nitrogen removal will drive when new technologies are needed
### Enhancements to Existing BNR Process (NDWRF Alternatives Analysis)

<table>
<thead>
<tr>
<th></th>
<th>Alternative 1 5-Stage BNR + Flocculation + Denitrification Filters</th>
<th>Alternative 2 5-Stage BNR + Flocculation + Denitrification Filters + Ion Exchange</th>
<th>Alternative 3 5-Stage BNR + Membrane Bioreactors</th>
<th>Alternative 4 5-Stage BNR with IFAS + Flocculation + Denitrification Filters</th>
</tr>
</thead>
<tbody>
<tr>
<td>Additional BNR Tanks</td>
<td>X</td>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Flocculation Zone</td>
<td>X</td>
<td>X</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Denitrification Filters</td>
<td>X</td>
<td>X</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>MBRs</td>
<td></td>
<td></td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Ion Exchange</td>
<td></td>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>IFAS</td>
<td></td>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Supplemental carbon</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
</tbody>
</table>

All alternatives offer combinations to achieve full nitrification.
NDWRF Lowest Cost Near-Term Alternative was 5-Stage BNR + Flocculation + Denitrification Filters

- Provide 2 additional BNR tanks (8 total) + carbon
- Flocculation zone for organic N removal
- Deep bed denitrification filters to trim nitrogen and phosphorus
- Multi-point chemical addition for P removal
Long-term Nutrient Compliance Approach Requires Technology to Meet TN ≤ 1 mg/L

- **Viable today**
  - Microfiltration (MF) + reverse osmosis (RO)
  - MF + Ion exchange (IX)
  - MBR + RO
    - No MBR + RO plants ≥ 0.5 mgd in operation
  - MBR + IX

- **Potentially viable in the future**
  - PC + MF + RO
  - BNR + Conventional filtration (CF) + IX
  - BNR + Ozone + GAC
### Facilities Meeting Ultra-low Nitrogen Limits

<table>
<thead>
<tr>
<th>Project</th>
<th>Location</th>
<th>Regulated Limit</th>
<th>Process</th>
</tr>
</thead>
<tbody>
<tr>
<td>Luggage Point AWTP</td>
<td>Australia</td>
<td>&lt; 1.2 mg/L TN</td>
<td>BNR + MF/RO</td>
</tr>
<tr>
<td>Gibson Island AWTP</td>
<td>Australia</td>
<td>&lt; 1.2 mg/L TN</td>
<td>BNR + MF/RO</td>
</tr>
<tr>
<td>Bundamba AWTP</td>
<td>Australia</td>
<td>&lt; 1.2 mg/L TN</td>
<td>BNR + MF/RO</td>
</tr>
<tr>
<td>South District WRP RO Pilot</td>
<td>Miami-Dade County, FL</td>
<td>&lt; 0.5 mg/L NH$_3$ (&lt; 10 mg/L TN)</td>
<td>BNR + MF/RO</td>
</tr>
<tr>
<td>Gwinnett County F. Wayne Hill WWTP</td>
<td>Lawrenceville, GA</td>
<td>&lt; 0.4 mg/L NH$_3$</td>
<td>BNR + Ozone + GAC</td>
</tr>
<tr>
<td>Kranji WRF</td>
<td>Singapore</td>
<td>&lt; 0.5 mg/L NH$_3$ as N, &lt; 10 mg/L NO$_3$ as N,</td>
<td>BNR + MF/RO</td>
</tr>
<tr>
<td>South Caboolture</td>
<td>Australia</td>
<td>&lt; 1 mg/L TN</td>
<td>BNR + Ozone + GAC</td>
</tr>
<tr>
<td>Plantation AWTP</td>
<td>Florida</td>
<td>TN &lt; 1.5 mg/L, TP &lt; 0.02 mg/L</td>
<td>BNR + MF + RO</td>
</tr>
</tbody>
</table>

None of the MF/RO plants are full forward flow with peaking factor plants.
RO Systems – Physical Barriers Capable of Retaining Ammonia, Nitrate, Nitrite, and Orthophosphate
Reverse Osmosis

• High rejection, high pressure membranes, more commonly used for desalination

• Typical nutrient removal
  – Ammonia: 50%
  – Nitrate: 80-90%
    • Membrane specific
    • Better at higher pH
  – Phosphate: >90%

• Creates extremely high quality effluent
MF/UF + RO

- Very expensive
- No full-flow with peaking factor applications in the world
- Some wastewater applications of 1Q peaking factor, i.e., Australia and Orange County, CA
- Energy hog – 200+ psi
MF/UF + RO (continued)

- Huge carbon footprint to removal marginal pound of N
- Capital cost ballpark - $15/gal, $30/gal for brine
- Brine disposal major issue in Durham, NC
Brine Treatment/Disposal is a Major Issue in Implementation of RO in this Region

• Brine disposal options typically include:
  – Surface water discharge
  – Large evaporation ponds
    • Land intensive
  – Deep well injection
    • Not permissible in NC
  – Experimental processes, i.e., zero liquid discharge (ZLD)

• ZLD
  – Involves heating, concentrating, and evaporating methods
  – Solids are landfilled
  – Extremely expensive
Technology Review Summary

- Meeting LOAT challenging, requires:
  - Diligent monitoring
  - Online instrumentation
  - Skilled operators
  - Lots of money

- Little worldwide precedent for using LOAT to meet Falls-Lake-type nutrient limits
City Decided to Plan for Worst-case in Terms of Footprint and Price -- MF/RO Facilities

- Capital cost (MF + RO) = $199,000,000
- O&M present worth = $230,000,000
  - Includes chemicals, energy (large carbon footprint), and maintenance

$430 Million Challenge

Potential response to challenge includes reuse…
REUSE FEASIBILITY STUDY
Reuse is an Attractive Alternative

- Reclaimed water does not have to meet the stringent nutrient standards
- Every gallon of water reused is less pounds of N and P discharged under plant’s NPDES permit
- High cost of advanced treatment creates opportunity for a lower cost solution
<table>
<thead>
<tr>
<th>Year</th>
<th>Projected Flow (MGD)</th>
<th>Required Equivalent Effluent TN Conc. w/o Reuse (mg/L)</th>
<th>Effluent TN Limit with Reuse (LOCT) (mg/L)</th>
<th>Required Reuse to Maintain LOCT Treatment (MGD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2012</td>
<td>10.8</td>
<td>2.97</td>
<td></td>
<td>0.00</td>
</tr>
<tr>
<td>2020</td>
<td>12.6</td>
<td>2.55</td>
<td></td>
<td>0.00</td>
</tr>
<tr>
<td>2030</td>
<td>14.7</td>
<td>2.18</td>
<td>2.50</td>
<td>1.87</td>
</tr>
<tr>
<td>2040</td>
<td>17.6</td>
<td>1.28</td>
<td>2.50</td>
<td>8.65</td>
</tr>
<tr>
<td>2050</td>
<td>21.6</td>
<td>1.04</td>
<td>2.50</td>
<td>12.65</td>
</tr>
<tr>
<td>2056</td>
<td>24</td>
<td>0.94</td>
<td>2.50</td>
<td>15.05</td>
</tr>
<tr>
<td>(Build-Out)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Reuse Feasibility Study Considered Two Approaches

• Approach #1:
  – Low hanging fruit
  – Existing customers – large users
  – Existing billing records

• Approach #2:
  – Include customers in Approach #1
  – Include residential and agricultural opportunities
  – Existing customers and future growth
### Approach #1 vs. #2 Reuse Programs

<table>
<thead>
<tr>
<th>Approach</th>
<th>Projected ADF (MGD)</th>
<th>Total Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>App #1</td>
<td>1.9</td>
<td>$21.9 M</td>
</tr>
<tr>
<td>App #2</td>
<td>15.8</td>
<td>$100.1 M</td>
</tr>
</tbody>
</table>

**RCW flow may recover/divert:**
- App #1 = 14,500 lbs N / year
- App #2 = 120,000 lbs N / year
Reuse May Deferr the Need for Advanced Treatment Solution

- TN Target w/o Reuse
- TN Target with Reuse
- WW Flow Projection
- Average Daily Reuse Quantity Target

- TN limit w/o reuse
- Reuse target (mgd) to utilize conventional solution
- TN limit w/reuse

Effluent TN Goal (mg/L) vs Year

- WW Flow
## Reuse May Save on the Order of $300M

<table>
<thead>
<tr>
<th>Description</th>
<th>Avg Daily Reuse Flow to Avoid Advanced Treatment (MGD)</th>
<th>Avg Daily Reuse Demand Identified (MGD)</th>
<th>Reuse Program Costs</th>
<th>Advanced Treatment Costs</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Capital</td>
<td>O&amp;M</td>
</tr>
<tr>
<td>2011-2030</td>
<td>1.9</td>
<td>1.9</td>
<td>$22</td>
<td>$0.4</td>
</tr>
<tr>
<td>2031-2056</td>
<td>15</td>
<td>15.8</td>
<td>$78</td>
<td>$5.9</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td></td>
<td>$100</td>
<td>$6.3</td>
</tr>
</tbody>
</table>

- **Capital Cost Savings with Reuse Program**: $99
- **O&M Cost Savings with Reuse Program**: $224
- **Total Cost Savings with Reuse Program**: $323
Environmental Impacts of Conventional Technology also Orders of Magnitude < MF/RO

- C footprint for LOAT is 1-2 orders of magnitude higher than LOCT
SUMMARY
Summary

• Advanced treatment to meet TN limits < 1 mg/L
  – Expensive
  – Most common approach is MF/RO
  – Other options will be viable in future

• Reuse
  – May avoid/defer advanced treatment saving on the order of $300M

• City will develop a Reuse Master Plan to map out a detailed strategy for reuse implementation over the next several decades
OTHER HIGHLIGHTS OF THE MASTER PLAN
CIP Projects were Identified and Tied to a Trigger

1. Regulatory Change
2. Condition of the Equipment
3. Increased Flows
4. Operations Benefit
5. Internal Policy Change
6. Economic Benefit
Sidestream Treatment was a Big Component of this Study

These biological nitrogen removal alternatives had great operational benefit and paybacks of 1-3 years.

Sludge Liquor Treatment

**Biological Treatment**

1. Bio-augmentation of nitrification/denitrification
   - In-Nitri
   - BABE process
   - New York AT3
   - MAUREEN process

2. Nitrogen removal by nitration and denitrification
   - SHARON process

3. Nitrogen removal by de-ammonification
   - ANAMMOX process
   - DEMON process
   - CANON process

**Physio-Chemical Treatment**

4. Struvite (MAP) precipitation
   - OSTARA process
   - PhosPaq process
   - Multiform Harvest

5. Coagulant-Aided precipitation
   - Alum
   - Ferric Chloride
   - Aluminum Sulfate

6. Ammonia Stripping
   - Hot Air
   - Steam

7. Ion exchange in selective resins
   - ARP process

8. Breakpoint Chlorination

Struvite recovery was evaluated for P removal

Compared with alum precipitation
## Evaluated Nitrogen Removal Sidestream Treatment Options on $/lb N removed

### Cost to Remove 1 lb of Nitrogen in Sidestream

<table>
<thead>
<tr>
<th>Category/Parameter</th>
<th>Units</th>
<th>Nitritation/Deammonification</th>
<th>Nitritation/Denitrification</th>
<th>Bioaugmentation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost per pound TN removed (capital)</td>
<td>$/lb</td>
<td>$0.74</td>
<td>$0.60</td>
<td>$0.82</td>
</tr>
<tr>
<td>Cost per pound TN removed (O&amp;M)</td>
<td>$/lb</td>
<td>$0.39</td>
<td>$1.04</td>
<td>$1.32</td>
</tr>
<tr>
<td>Total</td>
<td>$/lb</td>
<td>$1.13</td>
<td>$1.65</td>
<td>$2.14</td>
</tr>
</tbody>
</table>
### Sidestream Nitrogen Removal Also Deferred the Need for New BNR Tanks by 10 Years

<table>
<thead>
<tr>
<th></th>
<th>Year BNR Upgrade needed</th>
<th>NPC (2031)</th>
</tr>
</thead>
<tbody>
<tr>
<td>No Sidestream Treatment</td>
<td>Year X</td>
<td>$84,047,000</td>
</tr>
<tr>
<td>SidestreamTreatment</td>
<td>Year X + 10</td>
<td>$77,493,000</td>
</tr>
<tr>
<td><strong>Cost Savings</strong></td>
<td></td>
<td>$6,554,000</td>
</tr>
</tbody>
</table>
Struvite Precipitation Processes for Sidestream P & N Removal Were Evaluated

Ostara's Pearl® Process

- Upper section of reactor is a clarification section. Flow is recycled to increase removal rates and portion of flow is discharged to head of WWTP.

- Smaller particles remain in reactor increasing in size until heavy enough to fall towards bottom of reactor.

- Larger particles fall to the bottom and are harvested.

- Harvested pellets from reactor dried and bagged for shipping off site.

- Centrate Streams (side streams) NH₄⁺ + PO₄³⁻

- Reactor Feed Pump

- Recycle Pump

- Returns to head of WWTP

- Caustic

- Magnesium Chloride

- Equalized Centrate Feed Tank
Struvite Precipitation Options Were Evaluated and Paybacks Calculated

<table>
<thead>
<tr>
<th></th>
<th>Crystallizer option 1</th>
<th></th>
<th>Crystallizer option 2</th>
<th></th>
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<tbody>
<tr>
<td></td>
<td>North</td>
<td>South</td>
<td>North</td>
<td>South</td>
</tr>
<tr>
<td>Capital costs</td>
<td>$4,891,000</td>
<td>$4,591,000</td>
<td>$2,258,500</td>
<td>$1,958,500</td>
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<tr>
<td>Operating costs</td>
<td>0</td>
<td>0</td>
<td>$1,077,000</td>
<td>$1,037,400</td>
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<tr>
<td>Present worth cost</td>
<td>$4,891,000</td>
<td>$4,591,000</td>
<td>$3,335,000</td>
<td>$2,995,900</td>
</tr>
<tr>
<td>Payback compared to</td>
<td>15</td>
<td>25</td>
<td>5</td>
<td>22</td>
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<tr>
<td>alum addition (years)</td>
<td></td>
<td></td>
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</table>
### Comprehensive Wastewater MP Allowed Analysis of Complex Issues

Does the eventual need for microfiltration justify spending the money for MBR in the near-term, or does it make sense to defer and continue to build clarifiers in the near-term?

No. It still makes sense to defer.

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Year</th>
<th>Alternative A - Conventional Now, MF + RO Later</th>
<th>Alternative B - MBR Now, RO Later</th>
<th>Alternative C - Conventional Now, MBR + RO Later</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stage 1</td>
<td>2016</td>
<td>Conventional</td>
<td>MBR</td>
<td>Conventional</td>
</tr>
<tr>
<td>Stage 2</td>
<td>2036</td>
<td>MF + RO</td>
<td>RO</td>
<td>MBR + RO</td>
</tr>
<tr>
<td>Stage 1 Capital Cost ($M)</td>
<td>$32</td>
<td>$76</td>
<td>$32,</td>
<td></td>
</tr>
<tr>
<td>Stage 2 Capital Cost ($M)</td>
<td>$199</td>
<td>$141</td>
<td>$212</td>
<td></td>
</tr>
<tr>
<td>Net present Cost of O&amp;M ($M)</td>
<td>$229</td>
<td>$242</td>
<td>$229</td>
<td></td>
</tr>
<tr>
<td>Net Present Cost ($M)</td>
<td>$381</td>
<td>$467</td>
<td>$389</td>
<td></td>
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</tbody>
</table>
In summary, comprehensive master plans identify the lowest cost alternatives that consider a variety of complex issues.
Questions and Contact Information

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