Solids Production as a Tool to Assess Cost-Effectiveness of Alternative Source Water Treatment

Whitney Sandelin, PE - West Yost Associates
Kalen Dodd, PE - City of Santa Cruz
Terry McKinney - City of Santa Cruz
Goals

• Estimating total solids production is important

• Utilities can develop a site-specific solids production model using a simple process

• Solids production can help utilities make decisions about water production
Outline

- Introduction: Graham Hill Water Treatment Plant
- Development of Model
- Model Results
- Cost Implications
- Path Forward
• Design capacity 20 mgd (18 mgd finished water plus 10% recycle streams)
• Supplies 95% of City’s water
Typical raw water quality

- Turbidity < 10 Nephelometric Turbidity Units (NTU)
- Total Organic Carbon (TOC) < 4 mg/L
Water treatment process

Oxidation, carbon adsorption, secondary coagulation, flocculation, sedimentation, filtration, chlorine disinfection
Winter rains can increase San Lorenzo River turbidity to more than 50 NTU

- Currently, GHWTP switches to Loch Lomond supply instead of treating high-turbidity water

Considering treating the high-turbidity San Lorenzo River source water

- Treatment of high-turbidity water up to 18 mgd would allow storage of excess water in ground water basins during winter
Potential impacts of treating higher turbidity water include increases in:

- Sedimentation basin sludge production
- Filter backwash frequency
- Residuals volume and sludge to be dewatered
- Total dry solids production at GHWTP
Existing residuals handling facilities

• Reclaimed Water Tank
• Two Lamella Clarifiers
• Sludge Storage Tank
• Residuals discharged to sewer or Sludge Storage Tank for long term storage
Introduction

• **Primary Question**: At GHWTP can existing residuals handling facilities accommodate treatment of higher turbidity water?

• **Approach**: Develop model to estimate mass of residuals stream

• **Challenges**:
  – Daily solids production data not calculated or collected
  – Amount and dry solids fraction in stored solids (in the WTP’s Sludge Storage Tank) not recorded or known
  – Solids contribution from turbidity unknown
**Objective:** Estimate the amount of solids produced for various flow and turbidity scenarios

- **Inputs**
  - Treated water flow rate
  - Ratio of turbidity to suspended solids
  - Chemical dosages (coagulant, powdered activated carbon, polymer, permanganate)

- **Analysis and Output**
  - Convert turbidity and chemical dosage data to dry solids production per MG treated
  - Dry solids (dry lbs) produced per day at anticipated flow rates
Model Development

Estimate mass of solids produced from suspended solids and chemical addition using equation from AWWA Research Foundation publication (*Water Treatment Residuals Engineering*, 2006)

\[ S = 8.34Q(aC + bTu + DOC_R + A) \]

- \( S \) = solids produced (dry lbs/day)
- \( Q \) = plant flow (mgd)
- \( a \) = solids produced / coagulant added
- \( C \) = coagulant addition (mg/L)
- \( b \) = Suspended solids: turbidity ratio
- \( Tu \) = raw water turbidity (NTU)
- \( DOC_R \) = nonfilterable raw water TOC removed (mg/L)
- \( A \) = additional solids producing chemicals added
Developed relationship between raw water turbidity and total suspended solids (TSS)
  - Three months of paired turbidity and TSS data were collected, including during high turbidity events
Model Development

Turbidity & Suspended Solids Contribution

Ratio for solids to turbidity for Turbidity < 10 NTU

![Graph showing the ratio of solids to turbidity for turbidity values less than 10 NTU. The x-axis represents turbidity (NTU) ranging from 0 to 10, and the y-axis represents TSS (mg/L) ranging from 0 to 20. The graph displays a trend where TSS increases with increasing turbidity.]
Model Development

Turbidity & Suspended Solids Contribution

Ratio for solids to turbidity for Turbidity < 60 NTU
Model Development: Turbidity & Suspended Solids Contribution

- Relationship is not linear

<table>
<thead>
<tr>
<th>Turbidity</th>
<th>Sample Size</th>
<th>TSS (mg/L)/Turbidity (NTU)</th>
</tr>
</thead>
<tbody>
<tr>
<td>60 NTU &lt; x ≤ 100 NTU</td>
<td>12</td>
<td>2.1 mg/L/NTU</td>
</tr>
<tr>
<td>30 NTU &lt; x ≤ 60 NTU</td>
<td>11</td>
<td>2.1 mg/L/NTU</td>
</tr>
<tr>
<td>20 NTU &lt; x ≤ 30 NTU</td>
<td>8</td>
<td>2.0 mg/L/NTU</td>
</tr>
<tr>
<td>10 NTU &lt; x ≤ 20 NTU</td>
<td>13</td>
<td>1.4 mg/L/NTU</td>
</tr>
<tr>
<td>x ≤ 10 NTU</td>
<td>76</td>
<td>1.0 mg/L/NTU</td>
</tr>
</tbody>
</table>
Use suspended solids : turbidity ratios to estimate the concentration of solids in the raw water using the following equations:

\[ S = 8.34Q(aC + bTu + DOC_R + A) \]

<table>
<thead>
<tr>
<th>Turbidity</th>
<th>Equation</th>
</tr>
</thead>
<tbody>
<tr>
<td>$20 \text{ NTU} &lt; x \leq 100 \text{ NTU}$</td>
<td>$S = 8.34 \times Q \times \text{Turbidity} \times \left(\frac{2.1 \text{ mg}}{1 \text{ NTU}}\right)$</td>
</tr>
<tr>
<td>$10 \text{ NTU} &lt; x \leq 20 \text{ NTU}$</td>
<td>$S = 8.34 \times Q \times \text{Turbidity} \times \left(\frac{1.4 \text{ mg}}{1 \text{ NTU}}\right)$</td>
</tr>
<tr>
<td>$x \leq 10 \text{ NTU}$</td>
<td>$S = 8.34 \times Q \times \text{Turbidity} \times \left(\frac{1.0 \text{ mg}}{1 \text{ NTU}}\right)$</td>
</tr>
</tbody>
</table>
Dry solids production for each chemical

- Chemical dosage \((A, \text{ mg/L})\)
- Raw water flow rate \((Q, \text{ mgd})\)
- Molar mass of chemical added \((\text{g/mol})\)
- Molar mass of solid formed during reaction \((\text{g/mol})\)

\[
\text{Solids Production} \left( \frac{\text{lbs}}{\text{day}} \right) = 8.34 \frac{\text{lbs}}{\text{gal}} \times Q \times A \times \frac{\text{mass formed solid}}{\text{mass chemical added}}
\]
Model Development  Chemical Contribution

- **Example: Acidified Aluminum Sulfate (A7)**
  - Ratio of solid formed to chemical added
    - A7 (acidified alum used as coagulant)
      - \( \text{Al}_2(\text{SO}_4)_3 + 14.0 \text{ H}_2\text{O} \) (waters of hydration) = 594.3 g/mol
    - Aluminum hydroxide formed
      - \( 2 \{\text{Al(OH)}_3\} + 6 \text{ H}_2\text{O} = 264.09 \text{ g/mol} \)
    - Ratio = 0.44 lbs \( \text{Al(OH)}_3 + 3 \text{ H}_2\text{O} / 1.00 \text{ lb Al}_2(\text{SO}_4)_3 + 14.0 \text{ H}_2\text{O} \)
Example: Acidified Aluminum Sulfate (A7)

- Volumetric Dosage: 40 ppm = 18.5 mg/L (as “alum”)
  - Convert from volumetric dosage to mass dosage
  - 3.86 lbs available aluminum sulfate/1 gallon A7

\[
\text{Dosage} \left( \frac{mg}{L} \right) = 40 \text{ ppm} \times \frac{3.86 \text{ lbs alum}}{8.34 \text{ lbs gal solution}}
\]

\[
\text{Dosage} \left( \frac{mg}{L} \right) = 18.5 \text{ mg/L}
\]
Model Development

Chemical Contribution

• Example: Acidified Aluminum Sulfate (A7)
  – Calculate solids produced

\[
\text{Solids Production} \left( \frac{lbs}{day} \right) = 8.34 \frac{lbs}{gal} \times Q \times A \times \frac{\text{mass formed solid}}{\text{mass chemical added}}
\]

\[
\text{Solids Production} = 8.34 \frac{lbs}{gal} \times 20 \text{ mgd} \times 18.5 \text{ mg/L} \times \frac{0.44 \text{ lbs Al(OH)3 + 3 H}_2\text{O}}{1.00 \text{ lb Al}_2(\text{SO}_4)_3 + 14.0 \text{ H}_2\text{O}}
\]

\[
\text{Solids Production} = 1,357.8 \text{ lbs/day}
\]
### Chemical Added

<table>
<thead>
<tr>
<th>Chemical Added</th>
<th>Dry Solids Produced</th>
<th>Solids Production</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acidified Alum (A7)</td>
<td>Aluminum Hydroxide 2 {Al(OH)}_3 + 6 H\textsubscript{2}O</td>
<td>0.44 lbs dry solids/lb A7</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1.7 lbs per ppm per MG</td>
</tr>
<tr>
<td>Powdered Activated Carbon (PAC)</td>
<td>-</td>
<td>1 lb dry solids/lb PAC</td>
</tr>
<tr>
<td></td>
<td></td>
<td>8.3 dry lbs per mg/L per MG</td>
</tr>
<tr>
<td>Filter Polymer</td>
<td>-</td>
<td>1 lb dry solids/lb Polymer</td>
</tr>
<tr>
<td></td>
<td></td>
<td>8.3 dry lbs per mg/L per MG</td>
</tr>
<tr>
<td>Permanganate (KMnO\textsubscript{4})</td>
<td>Manganese Dioxide MnO\textsubscript{2}</td>
<td>0.55 lbs dry solids/lb KMnO\textsubscript{4}</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4.6 dry lbs per mg/L per MG</td>
</tr>
</tbody>
</table>
Model Development

Chemical Contribution

- Performed jar testing to determine chemical dosages required to treat higher turbidity source water
- Coagulant dosages for normal, low turbidity water are to be lower than dosages required to treat higher turbidity water
- Input dosage into model
Model Results

- Proportion of total solids contributed by raw water turbidity (suspended solids) increases as the raw water turbidity increases.
- At higher turbidities (30-40 NTU), dry solids predominately made up of suspended solids removed from the raw water.
- At low turbidities (2-5 NTU), dry solids production is dominated by coagulant and PAC dosages’ solids.
- Solids stored at 0.5% (no existing thickening process at the plant)
- Treatment of 18 mgd raw water with turbidity above 2 NTU exceeds sewer discharge limit
- GHWTP will rapidly exhaust available space (in as little as two days) when treating high turbidity water
Cost Implications

• Model indicates that solids production will be substantially greater when treating high turbidity source water compared to treating typical low turbidity source water
  – As much as seven times the current limit permitted for disposal via the sewer
  – Requires new or modified facilities to dewater solids onsite
  – New solids dewatering system will cost approximately $4 million

• Jar testing showed that higher turbidity source water requires higher coagulant dosages
  – Increase of the $/mgd unit cost of treating water
Summary and Conclusions

- Residual solids production can be modeled with readily available flow and chemical dosage information.
- Model development helps plants to understand:
  - Total solids production
  - Maximum flows and turbidity that may be treated without exceeding capacity of existing systems.
- Implications for GHWTP:
  - Existing facilities are substantially undersized for treatment of source water > 2 NTU at 18 mgd.
  - Allowed design criteria for an appropriately sized onsite dewatering system to be developed.
  - Design criteria informed development of an opinion of probable construction cost for the required facilities.
Summary and Conclusions

- At GHWTP, treating source water when turbidity exceeds 2 NTU is currently not cost-effective or practical using existing facilities.
- In the future, solids dewatering facilities must be constructed if high turbidity water will be treated.
- GHWTP is currently delaying treating source water with higher turbidity.
Acknowledgements

Craig Thompson, PE, BCEE  
*West Yost Associates*

Jeff Wanlass, PE  
*West Yost Associates*

Dimas Reyes  
*City of Santa Cruz*