Hydrosuction Sediment Removal Systems

John Shelley, Ph.D., P.E.
Kansas City District

University of Kansas
LEEP2 Building – Room G415
June 11-15, 2018
Reservoir Sediment Sustainability

“What comes in, must go out!”

Sediment-rich water
Available Storage
Sediment-rich water
Prolonging the life of the reservoir may be desirable, even if full sustainability is not achievable.

From “Quenching the Thirst” (Annandale 2013, data from Basson and Rooseboom 1999, and Sumi 2003)
Lake Dredging Costs

- John Redmond: $6.7/cu yd
- Mission Lake: $6.5/cu yd
- Lake Seminole: $27/cu yd
Hydrosuction

Siphon up the sediment
Hydrosuction

Siphon up the sediment

Bucket Demo:
https://www.youtube.com/watch?v=A8Wksyl4Nnw&feature=youtu.be
Hydrosuction

Siphon up the sediment

Height constraint
Dredging with Downstream Discharge of Sediments
Hydrosuction

Go through the dam, abutment, or spillway
Hydrosuction in the United States

- Experimental installation on Grove Lake, NE
  - 3,000 ft 6-inch PVC pipe
  - Sand balance restored for more than 5 years
Hydrosuction Internationally

Sedicon
Santa Maria HPP, Guatemala
Santa Maria HPP, Guatemala
El Canada Hydrosuction
El Canada Hydrosuction-Connecting to Existing Conduit

Fig. 2.

Bypass connection to existing drainage pipe (a) side view (b) downstream view
El Canada Hydrosuction-Floating Barge
Results

- $\approx 157,000$ cy in first 6 months

<table>
<thead>
<tr>
<th>Year</th>
<th>Concentration</th>
<th>Availability</th>
</tr>
</thead>
<tbody>
<tr>
<td>2012</td>
<td>12%</td>
<td>86%</td>
</tr>
<tr>
<td>2013</td>
<td>9%</td>
<td>98%</td>
</tr>
<tr>
<td>2014</td>
<td>8%</td>
<td>98%</td>
</tr>
</tbody>
</table>
Tuttle Creek Lake Analysis
Hydrosouction Sediment Discharge Rating Curve Based on Pool Elevation

\[ Q_s = -1.27881 \times 10^{-4} x^2 + 3.03656 \times 10^{-1} x - 1.76086 \times 10^2 \]

\[ Q_s = -8.56185 \times 10^{-5} x^2 + 2.03266 \times 10^{-1} x - 1.17853 \times 10^2 \]

\[ Q_s = -6.43283 \times 10^{-5} x^2 + 1.52709 \times 10^{-1} x - 8.85345 \times 10^1 \]

Pool Elevation (z), ft

- 6% Solids
- 8% Solids
- 12% Solids
- Poly. (6% Solids)
- Poly. (8% Solids)
- Poly. (12% Solids)
Table 4. Hydrosuction Effectiveness (Continuous Operation, 2 pipes)

<table>
<thead>
<tr>
<th>Solids Fraction</th>
<th>Average Annual Sediment Discharge</th>
<th>% of Annual Accumulation</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.06</td>
<td>3.1 M yd³</td>
<td>53%</td>
</tr>
<tr>
<td>0.08</td>
<td>4.1 M yd³</td>
<td>70%</td>
</tr>
<tr>
<td>0.12</td>
<td>6.1 M yd³</td>
<td>105%</td>
</tr>
</tbody>
</table>
Operating Within the Pre-dam Concentrations
Farther from dam = longer pipe = more friction = less sediment discharge

Example from Tuttle Creek Lake analysis. Loss in efficiency depends on project-specific features (pipe materials, head difference, etc.)
Hydrosuction for Sand


HYDROSUCTION SEDIMENT-REMOVAL SYSTEMS (HSRS): PRINCIPLES AND FIELD TEST

By Rollin H. Hotchkiss,1 Member, ASCE, and Xi Huang,2 Associate Member, ASCE

ABSTRACT: Hydrosuction sediment-removal systems (HSRS) remove deposited or incoming sediments from reservoirs using the energy represented by the difference between water levels upstream and downstream from a dam. HSRS are briefly described and compared to other reservoir-sediment management options. Hydraulic principles and design procedures are explained and applied to a field test carried out at Lake Atkinson, on the Elkhorn River, in Nebraska. The field study demonstrated that several different inlet shapes are capable of removing deposited sediment at the rate that it enters the reservoir on an annual basis. A ten-step procedure to determine the feasibility of using an HSRS is presented.
Hydrosuction for Fines

- Delta foreset bed
- Delta
- Bottomset bed (fine sediment)
- Turbidity current plunge point
- Normal pool
- Coarse sediment
- Clear water countercurrent set up by turbidity current motion
- Turbidity current
- Muddy lake
- Fine sediment
- Muddy lake deposits
- Channel incision below dam

Generalized Sedimentation Patterns
“...the infinite diversity of the slurries encountered by the dredgeman responds better to the extrapolation of actual test data and operating experience than to academic formulas. However, when data is lacking, formulas may represent the best information available, and indeed may be essential.”
(From Fundamentals of Hydraulic Dredging, Turner 1996)
Simplified Analysis Procedure

1. Collect system parameters
2. Select design parameters
3. Assume a percent solids
4. Compute slurry discharge via standard pipe flow equations
   - Take into account differences in viscosity and density due to solids
5. Multiply the slurry discharge by the assumed percent solids
### What Percent Solids?

#### Table 2. Percent Solids in Documented Hydrosuction Projects

<table>
<thead>
<tr>
<th>% Solids</th>
<th>Reservoir</th>
<th>Location</th>
<th>Sediment Type</th>
<th>Entrainment Mechanism</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>12</td>
<td>El Canada (Year 1)</td>
<td>Guatemala</td>
<td>Clay</td>
<td>Water-jetting</td>
<td>Jimenez, Figueroa, and Jacobsen, 2015</td>
</tr>
<tr>
<td>9</td>
<td>El Canada (Year 2)</td>
<td>Guatemala</td>
<td>Clay</td>
<td>Water-jetting</td>
<td>Jimenez, Figueroa, and Jacobsen, 2015</td>
</tr>
<tr>
<td>8</td>
<td>El Canada (Year 3)</td>
<td>Guatemala</td>
<td>Clay</td>
<td>Water-jetting</td>
<td>Jimenez, Figueroa, and Jacobsen, 2015</td>
</tr>
<tr>
<td>3</td>
<td>Dijindouia</td>
<td>Algeria</td>
<td>Silt and clay</td>
<td>Cutter-head powered by a turbine on the outlet pipe</td>
<td>Fan, 1985</td>
</tr>
<tr>
<td>15</td>
<td>Xiao Huashan</td>
<td>China</td>
<td></td>
<td>Water-jetting</td>
<td>Hotchkiss and Huang, 1995.</td>
</tr>
</tbody>
</table>
Simplified Analysis Procedure

1. Note system parameters
2. Select design parameters
3. Assume a percent solids
4. Compute slurry discharge via standard pipe flow equations
   - Take into account differences in viscosity and density due to solids
5. Multiply the slurry discharge by the assumed percent solids
Pipe Flow Equations

1. Energy equation

2. Headloss equation
Energy Equation
Energy Equation

\[ E_1 - h_L = E_2 \]
Pipe Flow Equations

$$E_1 - h_L = E_2$$

$$E_1 = \frac{P_1}{\gamma} + \frac{v^2}{2g} + z_1$$
Energy Equation

\[ E_1 - h_L = E_2 \]

\[ E_1 = \frac{P_1}{\gamma} + \frac{v^2}{2g} + z_1 \]

\[ E_1 = \text{PE} \]
**Energy Equation**

\[ E_1 - h_L = E_2 \]

\[ E_2 = P_2/\gamma + v^2/2g + z_2 \]
Pipe Flow Equations

\[ E_1 - h_L = E_2 \]

\[ E_2 = \frac{P_2}{\gamma} + \frac{v^2}{2g} + z_2 \]

\[ E_2 = DE + \frac{v^2}{2g} \]

PE (Pool Elevation)

\[ P_1/\gamma \]

\[ v^2/2g \]

1

2

\[ z_1 \]

\[ z_2 = DE \text{ (Discharge Elevation)} \]
Energy Equation

\[ E_1 - h_L = E_2 \]

\[ PE - h_L = DE + \frac{v^2}{2g} \]

\[ \frac{v^2}{2g} = PE - DE - h_L \]

\[ v = \left[ 2g(PE - DE - h_L) \right]^{0.5} \]
Headloss Equation

\[ h_L = f \text{ (fluid properties, velocity, pipe dimensions and properties)} \]

\[ h_L = \frac{V_t^2}{2g} \left[ M + f_1 \left( \frac{L_1}{D} \right) + f_2 \left( \frac{L_2}{D} \right) + \ldots f_n \left( \frac{L_n}{D} \right) \right] \]

\[ f = \frac{0.25}{\left[ \log \left( \frac{\varepsilon}{3.7D} \right) + \left( \frac{5.74}{Re^{0.9}} \right) \right]^2} \]

\[ Re = \rho V_t D / \mu \]

\[ \mu = \mu_w (1 + 2.5\varphi + 14.1\varphi^2) \]

\[ \rho = [(1 - \varphi) + 2.64\varphi](62.4)(0.031081) \]

\[ \Phi = \text{percent solids} \]
Pipe Flow Solution Procedure

- Select a trial velocity
- Compute $h_L$ from fluid and pipe properties
- Solve for velocity from the energy equation
- Compare and adjust the trial velocity
Simplified Analysis Procedure

1. Note system parameters
2. Select design parameters
3. Assume a percent solids
4. Compute slurry discharge via standard pipe flow equations
   ▶ Take into account differences in viscosity and density due to solids
5. Multiply the slurry discharge by the assumed percent solids
Workshop: Tuttle Creek Lake
Workshop: Tuttle Creek Lake

- Multi-purpose pool elevation = 1075 ft
- Assume Minor Losses = 5.5
- 2-ft diameter, commercial steel pipe
- Total pipe length = 7,400 ft
- Discharge Elevation = 1028 ft
Steps

- Follow the document: “How to Perform a Basic Hydrosuction Analysis for Cohesive Material”

- Skip steps related to assessing multiple pool levels or multiple pipe materials (step 1, 12, 18 - 21)