

Review of physical and chemical remediation techniques for hydrogen sulfide abatement in a bottom-withdrawal hydropower reservoir

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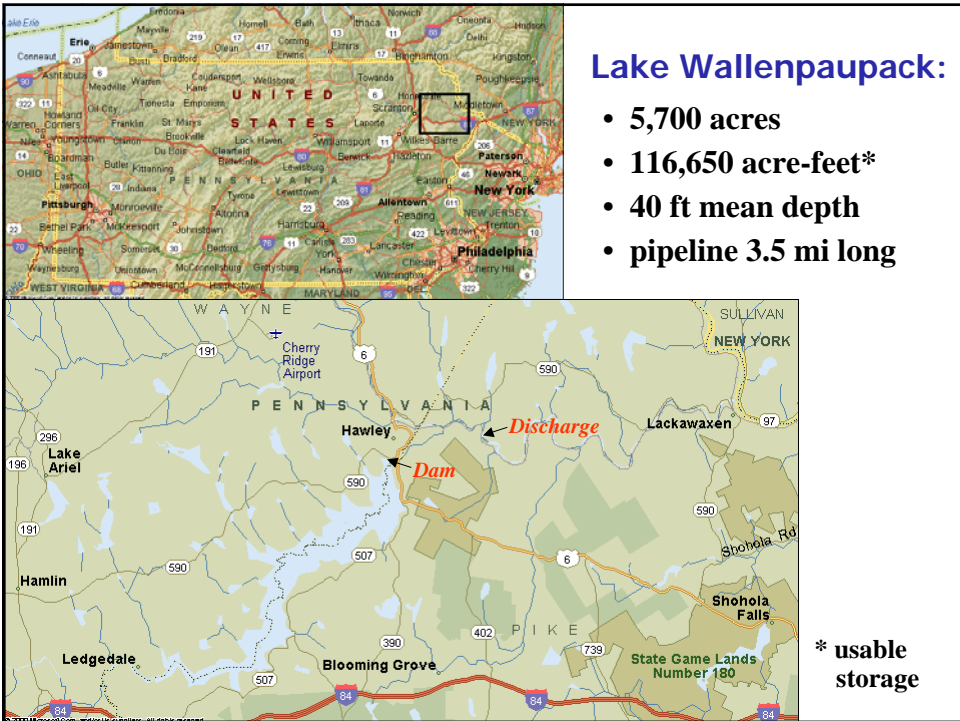
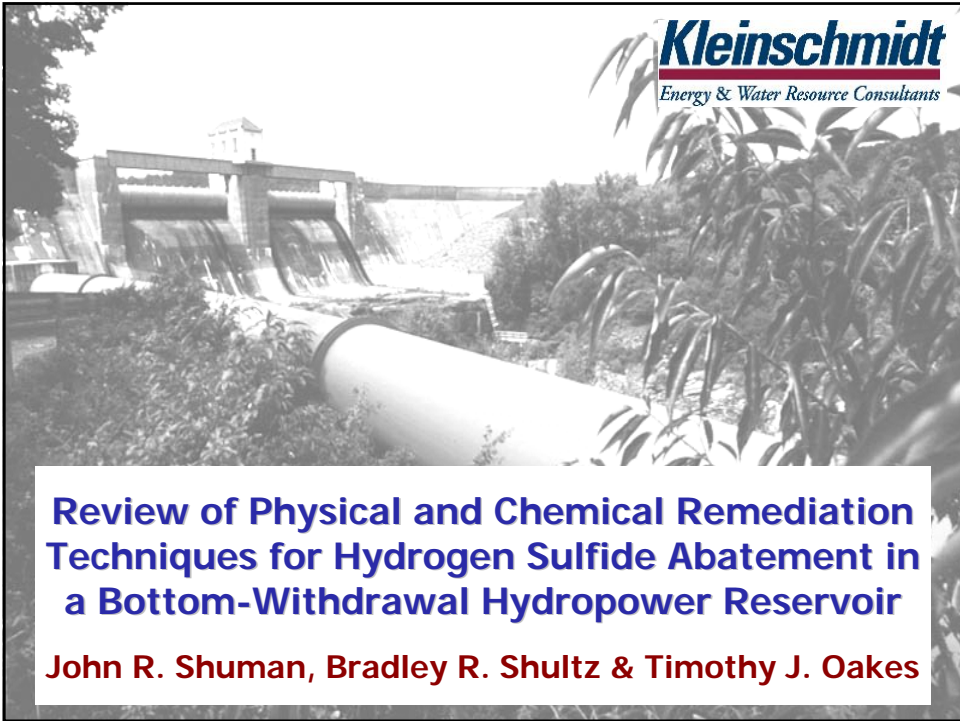
Lake Wallenpaupack is a 5,700-acre impoundment of Wallenpaupack Creek in northeastern Pennsylvania. The reservoir was created in 1924 for hydropower purposes, with a 14-foot diameter bottom withdrawal pipeline extending 3.5 miles to a 44-MW powerstation on the Lackawaxen River. The powerstation is approximately 380 feet lower in elevation than the top of the reservoir surface, and is located on the Lackawaxen River approximately 13 miles above its confluence with the Delaware River. The Project is owned and operated by PPL Holtwood, LLC.

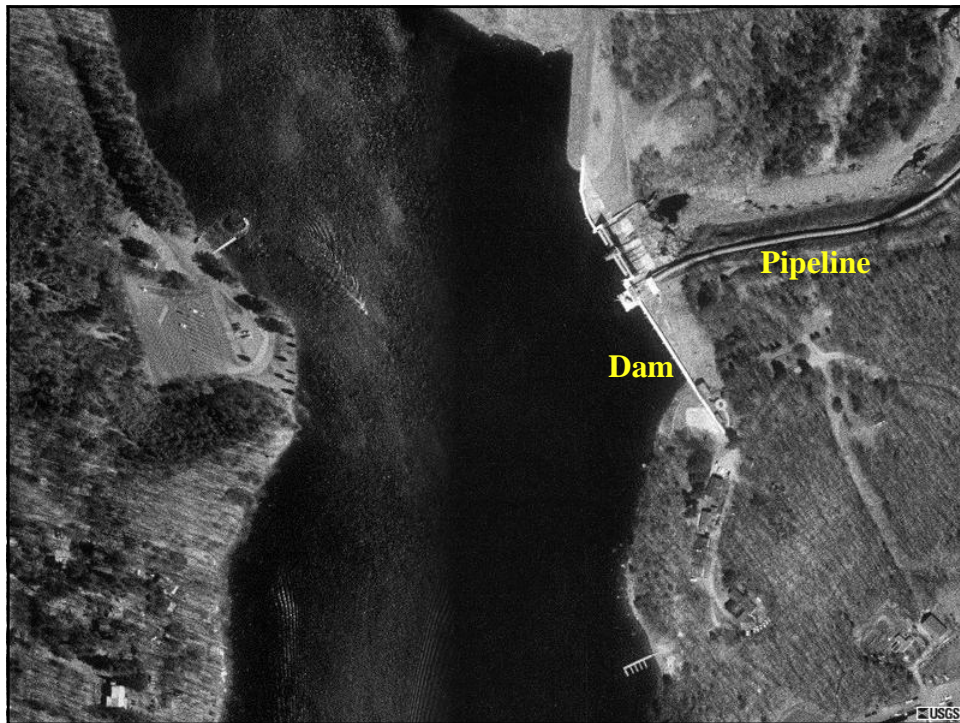
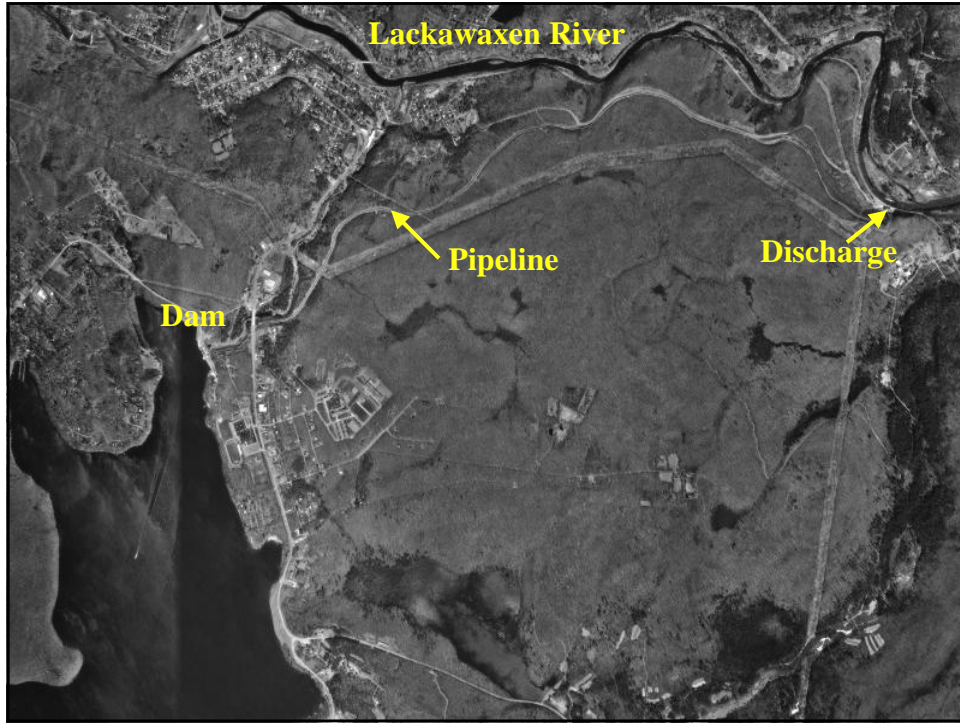
Water is withdrawn from Lake Wallenpaupack at a depth of 40 to 60 feet, with pipeline flow rates ranging from 125 to 1750 cfs and travel time ranging from 0.5 to 6 hours, depending on generation needs. The average water depth in Lake Wallenpaupack is approximately 40 feet. During late summer, the hypolimnion becomes anoxic, and sulfates are reduced to hydrogen sulfide. Preliminary measurements of hydrogen sulfide in August 2001 were approximately 2.0 mg/L in the hypolimnion. In August and September 2001, residents for more than a mile downstream of the powerstation complained that strong sulfide odors persisted when the plant was discharging.

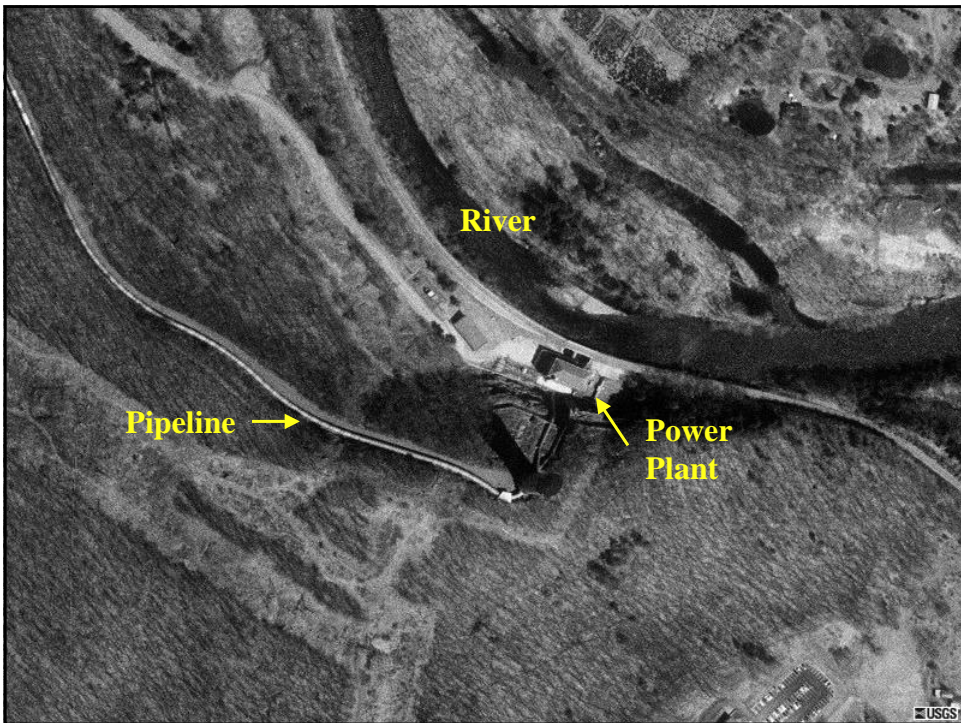
Cold water releases from Lake Wallenpaupack through hypolimnetic withdrawal are essential in supporting a popular stocked trout fishery in the lower Lackawaxen River. Epilimnetic withdrawal is therefore not viewed as a viable option for eliminating the discharge of hydrogen sulfide. Efforts are underway to identify a remediation technique to either prevent hydrogen sulfide formation or significantly reduce it prior to powerstation discharge.

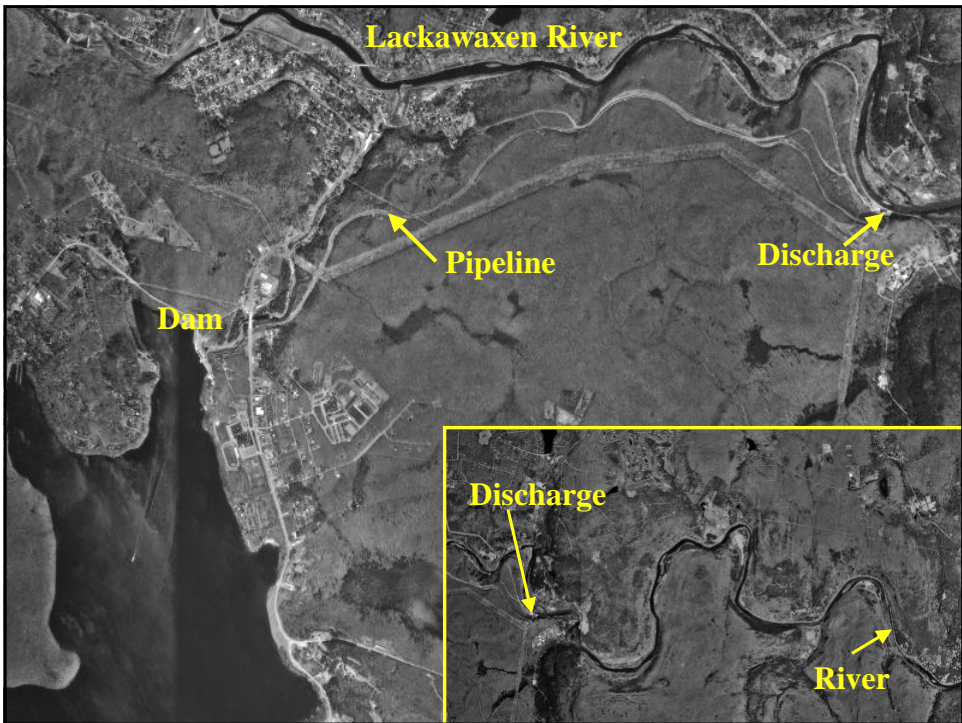
PPL convened a panel of national experts to review potential remediation approaches and identify strategic studies to solve the odor problem. This paper discusses several remediation techniques identified by the panel that will be investigated further, including pH modifications in the lake or pipeline, hydrogen peroxide injection into the pipeline, air diffusion into the pipeline, iron addition to the lake, and in-lake hypolimnetic aeration and controlled thermolayer mixing. These techniques and more detailed investigations of hydrogen sulfide levels and formation are being further investigated.

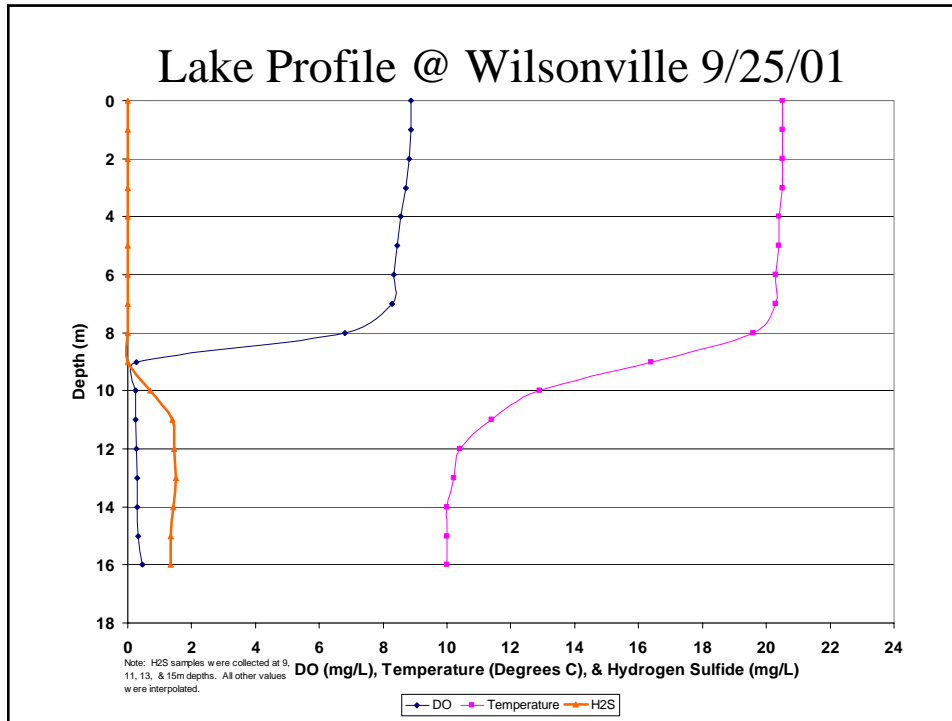
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Nature of the Problem

- Sulfate sources: precipitation, inflow, septic
- Hypolimnetic anoxia during summer - enhanced by organic matter loading
- Sulfate reduced to hydrogen sulfide during anoxia
- Hypolimnetic withdrawal during operation (supports coldwater fishery) - results in tailrace degassing of H₂S
- Need to either prevent formation or enhance removal of H₂S to minimize odor problem

Expert Panel Gathering

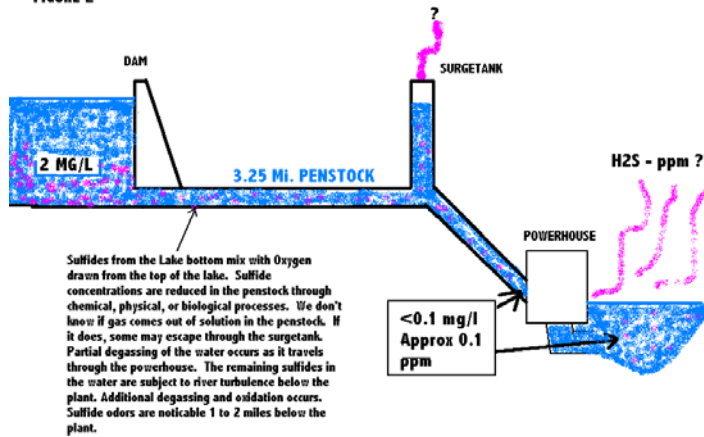
- Robert Wetzel, Univ. North Carolina
- Robert Gambrell, Louisiana State
- Steve Ashby, COE Vicksburg
- George Luther, Univ. Delaware
- Richard Ruane, Reservoir Env. Mgmt., Inc.
- Forest Dierberg, DB Environmental, Inc.
- Yuefeng Xie, Penn State Harrisburg
- Frank Browne, FX Browne, Inc.

Objectives

- **Short-Term:**
 - **In-lake or in-pipeline H₂S control**
 - prevent formation
 - enhance oxidation or precipitation
- **Long-Term:**
 - **Watershed management**
 - reduce sulfate inputs
 - reduce organic matter loading

Current removal of sulfide

FIGURE 2



Pipeline H₂S Removal Techniques



In-Pipe Approaches

- Enhance mixing
 - Immediate dilution effects
 - Longer time-of-travel for oxidation by DO
- Promote oxidation by dissolved oxygen
 - Air bubbler at pipeline intake
 - Add oxygen to air bubbler
- pH modification, chemical oxidation
 - Increase pH (form HS^- , faster oxidation)
 - Add H_2O_2 or Cl^- to oxidize H_2S

H_2S Oxidation by Dissolved Oxygen

May be too slow for the pipeline

<i>Time (min)</i>	<i>Sulfide (mg/L)</i>
0	0.23
1	0.23
3	0.23
5	0.23
10	0.22
30	0.20

DO = 7.6

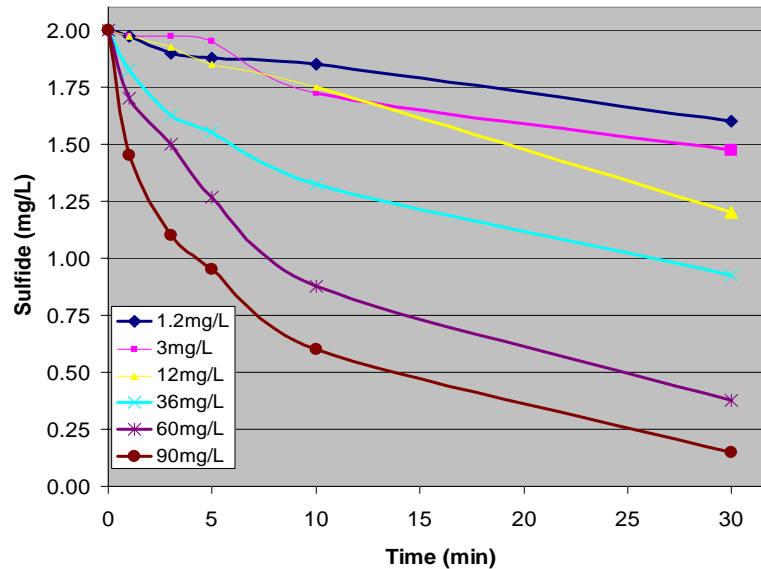
pH Modification Chemical Oxidation

HS^- predominant at $\text{pH} > 7.0$ (no odor)
 S_8 produced at $\text{pH} < 7$ with oxidation

4x H_2O_2 needed at $\text{pH} > 7.5$
2:1 mole ratio H_2O_2 recommended at $\text{pH} = 7$
15-minute H_2O_2 residence time suggested

Oxidants H_2O_2 and NaOCl tested

H_2O_2 as Oxidant with Lake Water



NaOCl as Oxidant with Lake Water

30-minute exposure

Concentrations in mg/L

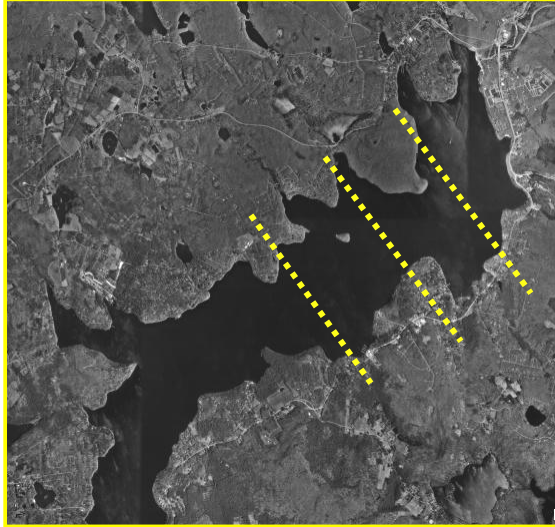
pH = 6.58

NaOCl	Initial H ₂ S	Final H ₂ S	Free Cl ⁻
1	1.725	0.875	0
2	1.650	0.750	0
5	1.825	0.625	0

In-Lake H₂S Remediation Techniques

- Hypolimnetic Aeration
- Iron Addition
- pH Modification

Hypolimnetic Aeration

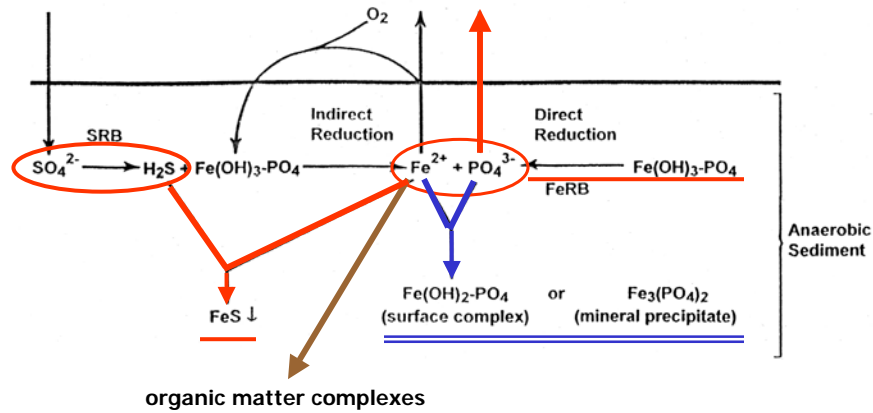


- Maintain thermo-cline (cold water)
- Enhance oxidation of H_2S by oxygen
- Lake volume to treat (oxid. rates)
- Avoid nutrient upwelling

In-Lake Iron Addition

- Under oxic conditions:
 - Fe^{2+} oxidized to Fe^{3+}
 - Fe^{3+} can oxidize H_2S to S_8 at $\text{pH} > 6$
- Under anoxic conditions:
 - Fe^{3+} is reduced to Fe^{2+}
 - Fe^{2+} and H_2S can form FeS_{aq} and $\text{FeS}_2\downarrow$
 - PO_4^{3-} can be released with insufficient Fe

Sulfur - Iron- Phosphorus Cycle Interactions

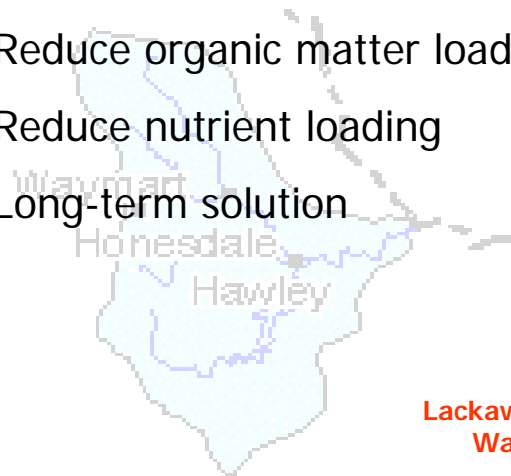


In-Lake pH Modification

- Add limerock in area near intake:
 - to increase pH to about 7.5
 - favors HS^- over H_2S at higher pH's
 - HS^- predominant at $\text{pH} > 7.0$ (no odor)
- Treatment area and longevity unknown

Watershed Management Efforts

- Reduce sulfate/sulfur input
- Reduce organic matter loading
- Reduce nutrient loading
- Long-term solution



Summary of Techniques

- **In-Pipe Remediation:**
 - Enhance mixing
 - Promote oxidation by oxygen
 - pH modification
 - Chemical oxidation (H_2O_2 or $NaOCl$)
- **In-Lake Remediation:**
 - Hypolimnetic aeration
 - Iron addition
 - pH modification
- **Watershed Remediation**
 - Nutrient and organic matter reductions
 - Sulfate/sulfur loading reductions

USGS