Impact of Coal Mine Reclamation Using Coal Combustion By-products (CCBs) on Groundwater Quality:

Two Case Studies

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Reclaiming Abandoned Mine Land Using FGD Materials

- Flue gas desulfurization materials
  - FGD synthetic gypsum
  - FGD by-product (calcium sulfite) stabilized with fly ash and lime (fixated FGD Material)

- Benefits of using FGD materials for AML reclamation
  - Neutralize AMD or encapsulate AMD producing materials
  - Re-contour highwalls in surface mines
  - Subsidence control in underground mines
  - Provide alternative to landfilling
Projects Carried out by OSU on Coal Mine Reclamation

**Overall Objective:** Increase high-volume utilization of FGD materials (stabilized sulfite FGD and FGD gypsum) for reclamation at abandoned and active Ohio coal mine sites in a manner that is beneficial to environment, public health and safety, and economically viable for utility industry.

- Phase I Study (Reclamation potential, FGD gypsum properties) – completed (final report online)
- **Phase II Study (Conesville demo, Cardinal demo, grout pilot project)** – in progress
- Phase III Study (Gavin AMD demo) – in progress
- Impacts of Reclamation and Remining on Watersheds – in progress
- Assessment of Stream Resources at Coal Remining Sites - in progress
Conesville Five Points Demonstration Project

- Reclamation of abandoned highwall (1,200 feet long, 60 to 100 feet in height)
- Large-volume use of Conesville FGD gypsum (about 1 million tons) in combination with Conesville stabilized sulfite FGD
Reclamation Progress at Conesville Site
Reclamation Progress at Conesville Site
Reclamation Progress at Conesville Site
Cardinal Star Ridge Demonstration Project

- Star Ridge site near Cardinal landfill (selected in consultation with industrial sponsors and Ohio DNR)

- Reclamation at permitted surface coal mine site of a highwall (250 feet long, 10 to 60 feet in height)

- Medium-volume use of Cardinal FGD gypsum (about 0.5 million tons) in combination with onsite spoil
Cardinal Construction Progress

11/29/2012
Water Quality Monitoring Program

The primary objective is to evaluate the impact of reclamation on water quality of the uppermost aquifers underlying the sites.

Approaches

- Collecting monthly groundwater samples from monitoring wells installed around the reclamation sites using a low-flow purging and sampling procedure.
- Monitoring the water quality of surface water bodies within or adjacent to the project sites.
- Assessing the leaching properties of the backfilling FGD materials.
Conesville Five Points Sampling Sites
Cardinal Star Ridge Sampling Sites
Sampling

- **Pre-reclamation**
  - Conesville: 11/2009 to 7/2011 (18 months)
  - Cardinal: 7/2010 to 3/2012 (21 months)
  - Establishing background water quality data

- **Site preparation**
  - Conesville: 8/2011 to 12/2011 (5 months)
  - Cardinal: 4/2012-8/2012 (5 months)

- **Reclamation**
  - Conesville: 1/2012 to present
  - Cardinal: 9/2012-present

The water monitoring at both sites will continue throughout the reclamation stage, as well as after the reclamation is completed.
Background Water Quality

- Background water qualities were determined based more than 18 months of monitoring
  - Provides sufficient sample size to estimate variations of background water qualities
  - Establishes upper prediction limit (UPL), a “not-to-exceed” threshold value, for each of the 34 monitoring parameters, used for evaluating if significant changes occur during and after reclamation.

- Concentration levels of As, Be, Cd, Co, Cr, Tl, Zn, and V were frequently below the limits of detection.

- Concentration levels of Al, Cu, Se, and Pb were always below the limits of detection in all water samples.
Impact of Reclamation on Water Quality

Data collected after 8/2012 when reclamation start
Constituents Exceeding UPL

- Conesville Five Points site
  - MW-0901: Si
  - MW-0902: P, B, Si, and Tl, Na, and Cl
  - MW-1001: Alkalinity, Ba, and Si,
  - MW-0904: Conductivity, TDS, sulfate, Ca, Mg, B, Fe, Mn, Na, Ba, Cd, Sb, Si, and Sr,
  - MW-0905: Si,
  - MW-0906: Conductivity, sulfate, B, Ba, Co, Si, and Tl
- Oxford Pond: Na, Ba, Si, and Cl
Leakage of leachate from FGD materials?

MW-0904

Ca, Mg, and sulfate were from the same minerals
What has caused the changes?

- MW-0904

- X reclamation
- X site preparation
- X background
Constituents Exceeding UPL

- Cardinal Star Ridge site
  - OAE-1001: B.
  - OAE-1002: TDS, sulfate, K, Ca, Mg, Mn, Ba, Cr, Si, Sr, and Tl.
  - OAE-1003: pH, K, B, Mo, As, Li, and Sr.
  - OAE-1005: K, Na, and Li
Pit 22 and OAE-1002

- Hierarchical cluster analysis
  - Group water samples into classes on the basis of 16 parameters, i.e., pH, conductivity, alkalinity, TDS, Cl-, SO$_4^{2-}$, K, Ca, Mg, B, Fe, Mn, Na, Ba, Si, Sr
  - Water in OAE-1002 was similar to the surface water accumulated in Pit 22 before reclamation start
Leakage of leachate from FGD materials?

- OAE-1002

![Graphs showing relationship between calcium-magnesium (Ca+Mg) and sulfate (SO₄²⁻) concentrations for background and backfilling samples.](image-url)
Optimizing Sampling Frequency

- Reviewing current sampling frequency
  - Most of water samples are collected on a monthly basis.
  - More than 2 years of data are available after reclamation began.
  - Will sufficient information still be provided from data with a reduced sampling frequency?

- Autocorrelation of data
  - Tendency for a system to remain in the same state from one observation to the next
  - The information content of highly autocorrelated data does not increase with increase of sample size
  - The minimal sampling interval for each of the selected monitoring constituents
    - Lag one Markov test and subsampling test
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<th>SWL</th>
<th>Cond.</th>
<th>TDS</th>
<th>SO$_4^{2-}$</th>
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**Recommended Sampling Frequency**

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Conesville Data Subsampling Test

\[ ARD(\%) = \frac{|x_{\text{subset}} - x_{\text{base}}|}{x_{\text{base}}} \times 100\% \]
Summary

- High volume FGD materials have been placed since the reclamation started
  - Connesville: over 900,000 tons as of 8/2014
  - Cardinal: over 450,000 tons

- Changes of water qualities at both sites were statistically significant after reclamation started.
  - Ca, sulfate, Mg, Ba, Co, Fe, Mn, Na, Ba, Cd, Sb, Si, and/or Sr, exceeded the upper prediction limits (UPLs) in one or more of the sampling locations
  - In addition, significant incline or decline trends in the concentrations of major monitoring parameters during the reported reclamation period had also been identified
Summary (continued)

- However, the water quality impacts observed at two sites are unlikely due to leakage of FGD leachate (i.e., FGD gypsum and/or fixated FGD material).

- Change of hydrogeological conditions at the site is transforming the geochemical processes to a new equilibrium/steady state.

- Reclamation progress
  - Conesville: ~70% of capacity
  - Cardinal: backfilling is completed and is encapsulating the fill with spoil.

- Bimonthly and quarterly sampling frequencies can provide similar information return as monthly sampling
Dewatering of Pit 22 started

Start of backfilling

Date

6/1/10  12/1/10  6/1/11  12/1/11  6/1/12  12/1/12  6/1/13  12/1/13  6/1/14  12/1/14

SWL, ft
## Cardinal Star Ridge Site

### Lag One Autocorrelation Coefficient, \( r \)

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<th>SWL</th>
<th>Cond.</th>
<th>TDS</th>
<th>( \text{SO}_4^{2-} )</th>
<th>Cl(^-)</th>
<th>Ca</th>
<th>Mg</th>
<th>Na</th>
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<td>64.9</td>
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<td><strong>Average</strong></td>
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Constituents

SWL  pH  Cond.  Alk.  TDS  Cl  SO4  Hg  K  Ca  Mg  B  Fe  Mn  Na  Ba  Cr  Ni  Sb  Si  Sr

Average Relative Deviation, %

15%

Cardinal Data Subsampling Test

\[ ARD(\%) = \left( \frac{\bar{x}_{subset} - \bar{x}_{base}}{\bar{x}_{base}} \right) \times 100\% \]
Effect of East Pond Recharge

- MW-0904
  - Collects water from minespoil layer
  - Has similar dominating cations and anions as waters from minespoil layers (MW-0902 and MW-0903) but with lower concentrations
  - Recharge from East Pond might have caused the dilution.
  - Concentrations of TDS and major ions are higher in MW-0906 than in MW-0904, indicating dissolution process as groundwater moving downstream
Mine Reclamation with FGD Materials

Phase I

- Bedrock
- Highwall
- Fixated FGD material
- Mine Overburden Piles
- FGD Gypsum Structural Fill
Mine Reclamation with FGD Materials

Vegetation
Bedrock
Highwall
Fixated FGD material/gypsum/fly ash
Mine Overburden Piles

Phase II
If the elevated Ca and Sulfate are from FGD gypsum

Leachate samples collected from the underdrains of the Conesville FGD landfill