Site Cleanup
Remedial Investigation Summary

- Remedial Investigation (RI) / Feasibility Study (FS) Work Plan
  - RI to be conducted in three phases
    - Three individual field sampling events (Steps 1 though 3)
  - Investigation conducted from 2005 to 2010
    - Step 1 included background and area of concern (AOC) surface soil sampling, sediment/surface water sampling, and development of conceptual site model (CSM)
    - Step 2 included initial groundwater investigation and additional surface water delineation
    - Step 3 included horizontal extent of groundwater impacts
- Final RI Report including Human Health and Baseline Ecological Risk Assessments submitted in June 2011

FINAL
REMEDIAL INVESTIGATION REPORT

HENRY'S KNOB FORMER MINE SITE
YORK COUNTY, SOUTH CAROLINA

EPA ID NO. SCN 000 407 376

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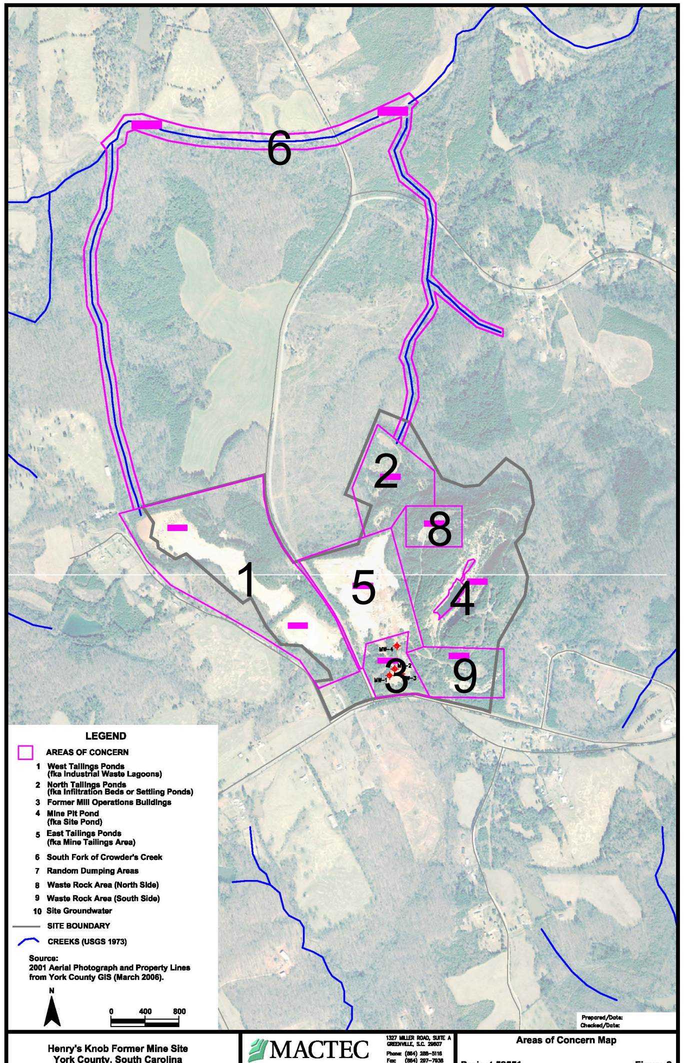
Site Cleanup
Remedial Investigation Summary



- Areas of Concern (AOC)
  - AOC #1 – West Tailings Impoundment
  - AOC #2 – North Tailing Impoundment
  - AOC #3 – Former Mill Buildings (Tailings/Pyrite Storage)
  - AOC #4 – Mine Pit Pond (MPP)
  - AOC #5 – East Tailings Impoundment
  - AOC #6 – Surface Water
  - AOC #7 – Random Dumping Areas
  - AOC #8 – Waste Rock (North)
  - AOC #9 – Waste Rock (South)
  - AOC #10 – Site Groundwater

Site Cleanup
Remedial Investigation Summary

- RI Environmental Sampling
  - surface soil samples
  - surface water samples
  - sediment samples
  - monitoring wells/piezometers
  - residential well samples
  - ecological samples
- Post-RI Environmental Sampling
  - surface and subsurface soil samples
  - test pits
  - whole rock samples
  - monitoring wells/piezometers
  - residential well samples
  - groundwater sampling events

Site Cleanup
Remedial Investigation Conclusions

- Soils
  - No statistical difference between background metals in soils collected from mineralized zone (ore body outcrops) and non-mineralized zone
  - Acid Base Accounting (ABA) and paste pH from AOC surface soil samples indicates capacity to produce acid mine drainage (AMD)
  - Aluminum, iron, and manganese are not particularly elevated in the AOCs when compared to background soils
  - No unacceptable risk to human health or ecological receptors
- Sediment
  - No unacceptable risk to human health or ecological receptors by sediment
- Surface Water (MPP)
  - Surface water in MPP has minimal hydraulic connection with the underlying bedrock and primarily only along strike of ore body
  - Impact to pond water results from acid rock drainage (ARD)

Site Cleanup
Remedial Investigation Conclusions

- Surface Water (Tributaries)
  - AMD impacts associated with leaching from tailings to groundwater generally restricted to headwaters of tributaries
  - pH and concentrations of metals generally improve downstream
  - No unacceptable risk to human health by exposure to surface water
  - Ecological condition of concern for surface water is low pH and acidity
- Groundwater
  - Groundwater is the primary source of potable water in the site area
  - Groundwater is present under water table conditions in both overburden soils formed by the in-place weathering of bedrock and in fractured bedrock
  - Groundwater in site area has relatively low pH (less than 7) and may have elevated metals due to geology, as a result of ARD
  - Groundwater in monitoring wells installed downgradient from tailings impoundments have very low pH and are impacted by AMD

Site Cleanup
Remedial Investigation Conclusions

- Groundwater
  - Based on age of site, history of operations, and release mechanisms, the magnitude and extent of impacts to groundwater are expected to be stable in the future
  - The boundary of groundwater affected by the site appears stable and should not expand, but is expected to persist
  - Non-cancer risk to future use of groundwater as a potable water source due to elevated metals, primarily cobalt and manganese
    - Risk is associated with hypothetical exposure to the highest concentrations of metals reported in site monitoring wells and doesn’t represent risks associated with current use of groundwater as a potable drinking water supply
    - Remedial action objective developed to prevent use of groundwater that contains concentration of metals that pose non-cancer risks to human health
  - Due to abundant metals present in geological formations in site area, it’s difficult to differentiate between AMD-impacted groundwater and naturally occuring groundwater impacted by ARD

Site Cleanup
AMD-Impacted vs ARD-Impacted Groundwater

- AMD is a common environmental impact at former mining sites where iron sulfide minerals (principally pyrite) are present and exposed to water and oxygen, releasing sulfate, iron, and acidity (H^+)
  - A simplistic, overall chemical formula that results in AMD is:

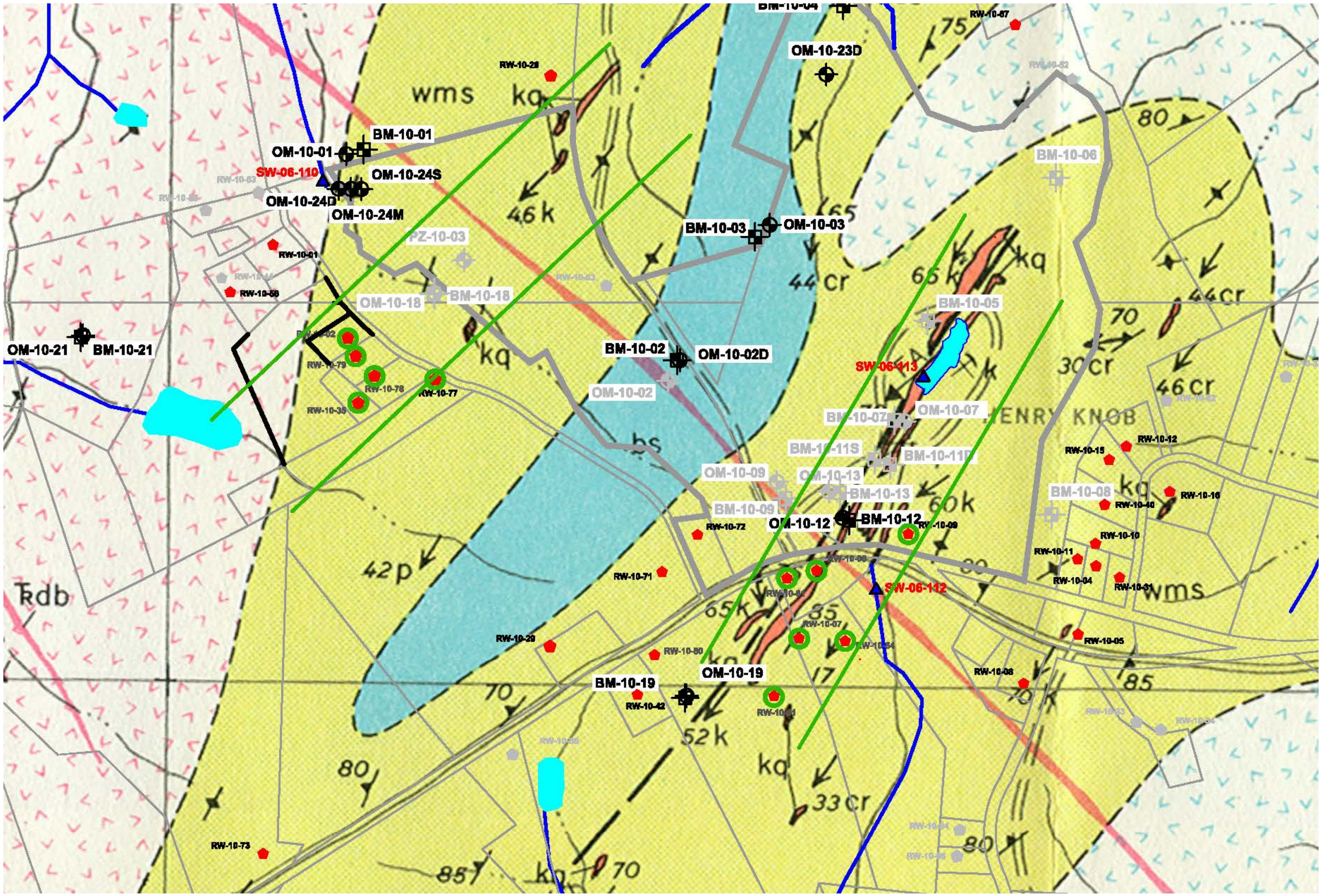
    Pyrite + Oxygen + Water → Iron Precipitates + Acidity

  - Acidic waters also promote the weathering of other minerals
  - Mining and benefication of the ore body resulted in the accumulation of mine residuals in the form of fine-grained tailings and waste rock piles
    - Fine-grained materials, such as tailings, will result in higher oxidation rates due simply to increased surface areas of pyrite exposed to oxygen and water
    - The ability of the tailings to continue to produce acid and leach metals is limited only by the presence and amount of pyrite, soluble salts, oxygen, and the availability of water in the form of infiltrating precipitation
    - Acid Base Accounting (ABA) analysis and paste pH sampling indicated that tailings are a source of AMD, however, waste rock is not a significant source of AMD

Site Cleanup
AMD-Impacted vs ARD-Impacted Groundwater

- Similar acid weathering conditions occur in the absence of mining operations and is commonly called ARD
  - Oxidation of pyrite from in-place bedrock, most notably between the water table and the land surface
  - Increasingly recognized environmental condition at construction sites, transportation corridors, and other areas where bedrock is excavated
  - Evidence of ARD, including exposed outcrops with weathered sulfide minerals and anomalously elevated metals in stream sediments, are all tools used by the mineral exploration geologist to locate sulfide-bearing mineral deposits
  - ARD can an occur in potable wells installed in sulfide-bearing bedrock when oxygen is introduced through the well installation and subsequent pumping
  - ARD has been encountered in private wells along the strike of the ore body as well as along Pat’s Road located along strike of an unmined northwestern kyanite quartzite formation that parallels the ore body at Henry Knob

Site Cleanup
AMD-Impacted vs ARD-Impacted Groundwater



Site Cleanup
AMD-Impacted vs ARD-Impacted Groundwater

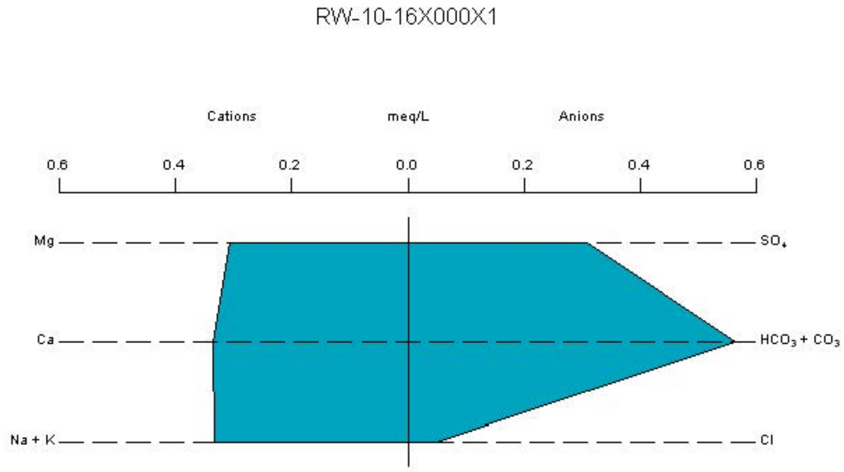
- The area around Henry Knob has a remarkable diversity of rock formations and mineral resources
  - Unusual in the richness and variety of the mineral deposits that they contain
    - Mineral deposits include, among others, kyanite and manganese
    - It has been estimated that the principal deposits in the region contain 40 million tons of rock with 10 to 30 percent kyanite
    - The most significant mining in the area was at Henry Knob, where kyanite was produced with pyrite as a byproduct
  - Mining has played a significant role from the 1700s to the present
- How do we differentiate between groundwater impacted by AMD and naturally-occurring groundwater that may have elevated concentrations of metals, but otherwise no impacts from mining operations?

Site Cleanup
AMD-Impacted vs ARD-Impacted Groundwater

- To differentiate between naturally-occurring metals in groundwater and groundwater that has likely been impacted by AMD, a combination of geochemical signature (Stiff diagrams) and risk-based screening levels was developed
- Both monitoring wells and residential wells were sampled for geochemical parameters that could be used to determine if the samples showed impact from AMD
- The geochemical parameters consisted of major anions (bicarbonate, chloride, and sulfate), major cations (calcium, magnesium, sodium, and potassium), ferrous iron, ferric iron, sulfide, acidity, and total alkalinity
- Analyte composition and anion-cation balances for these geochemical parameters were used to generate Stiff diagrams

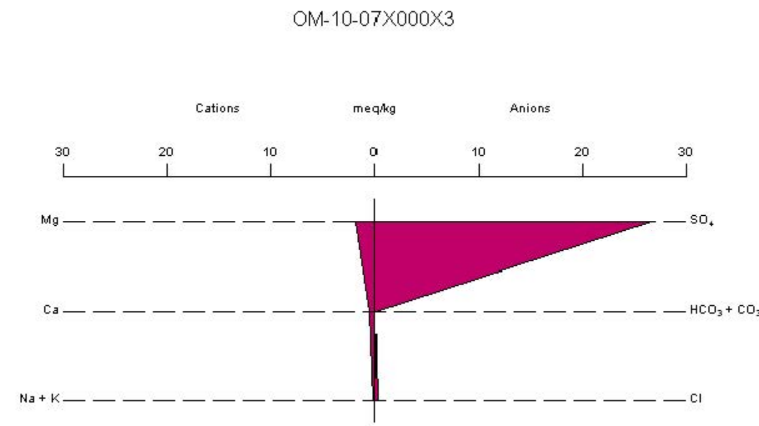
Site Cleanup
AMD-Impacted vs ARD-Impacted Groundwater

- Stiff diagrams are used to describe and compare geochemical differences in groundwater based on charge balances of the cation and anion species by calculating and plotting equivalent charge concentrations in milliequivalents per liter (meq/L)
  - A polygonal shape is created from three parallel horizontal axes extending on either side of a vertical zero axis
  - Cations are plotted on the left side of the zero axis, one to each horizontal axis, and anions are plotted on the right side

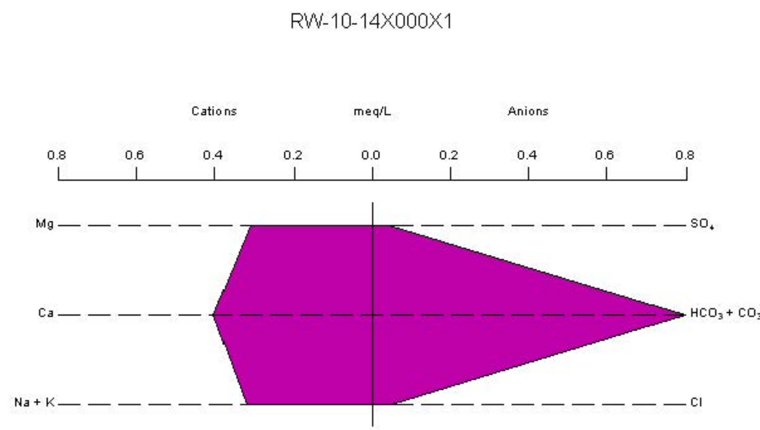


Site Cleanup
AMD-Impacted vs ARD-Impacted Groundwater

- ► The geochemical signature of mine-impacted groundwater indicates a charge imbalance that is skewed toward high sulfate concentrations (relative to the cations) and depleted bicarbonate (due to acidity) consistent with geochemical processes responsible for AMD

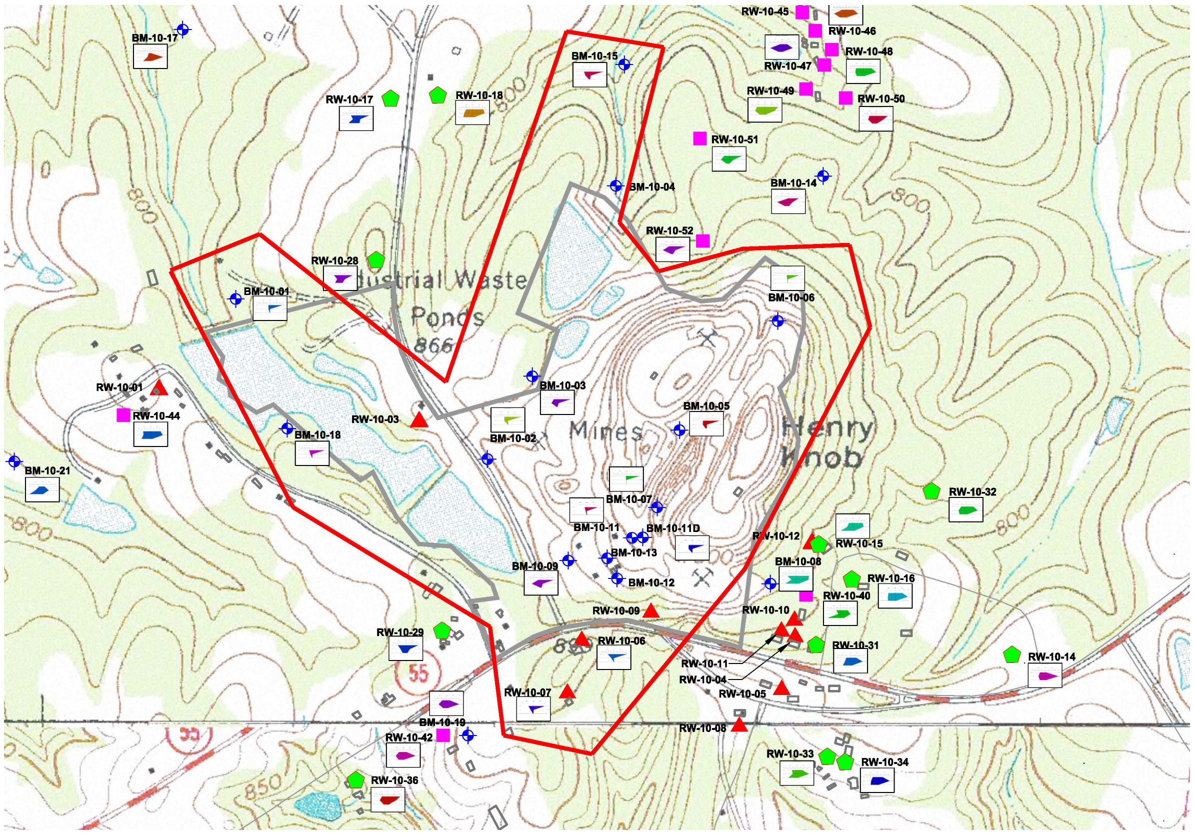


- ► Where the pennant shape of the Stiff diagram was not observed, the groundwater was interpreted to not have been impacted by AMD



Site Cleanup
AMD-Impacted vs ARD-Impacted Groundwater

► Patterns in the Stiff diagrams are useful in making a rapid visual comparison of geochemical data and allows discrimination between water from different sources



Site Cleanup
AMD-Impacted vs ARD-Impacted Groundwater

- Metals were detected in groundwater from the overburden monitoring wells (saprolite), bedrock monitoring wells, and residential water supply wells (most are assumed to be installed in bedrock) at the Site
- Although aluminum, cobalt, and manganese were detected with the most frequency at the site, manganese was the most widespread constituent that exceeded the USEPA Regional Screening Level (RSL) in effect at the time of the RI
- A concentration contour approximately equivalent to the USEPA RSL for manganese was used in conjunction with Stiff diagrams to develop the extent of AMD-impacted groundwater
- Groundwater sample results that exceed the USEPA RSL but do not have Stiff diagrams indicative of AMD were not included within the manganese-impacted groundwater concentration contours

Site Cleanup
AMD-Impacted vs ARD-Impacted Groundwater

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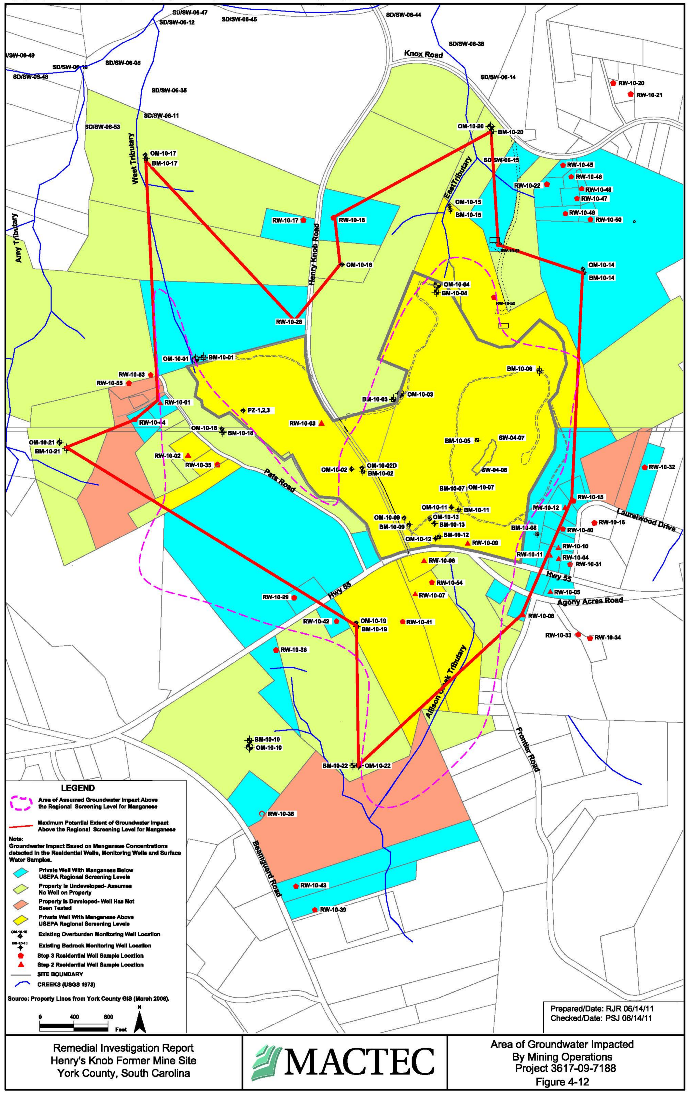
- Figure from RI demonstrating area of groundwater potentially impacted by mining operations
  - Solid red line indicates boundary of potentially AMD-impacted groundwater based on Stiff diagrams combined with manganese concentrations above the USEPA RSL in effect at the time of the RI
  - Dashed purple line indicates a manganese concentration contour approximately equivalent to the USEPA RSL

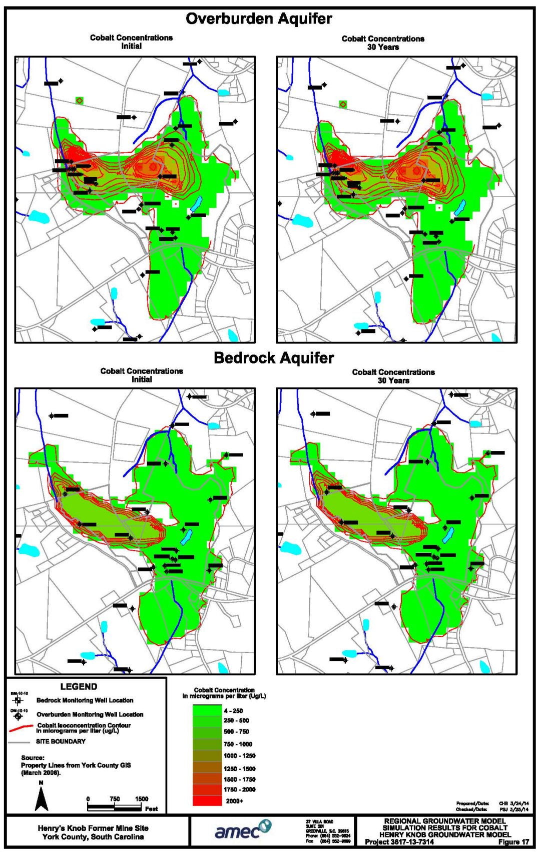


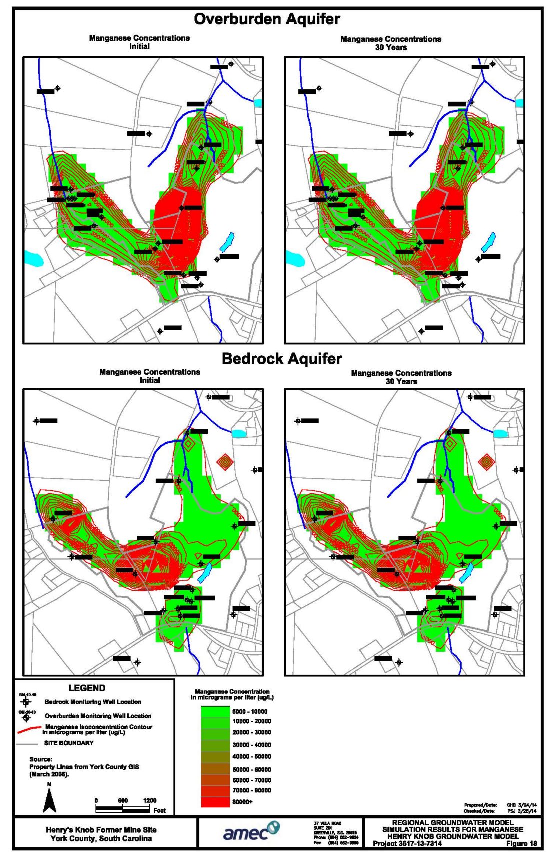
Site Cleanup
Regional/Telescoped Groundwater Model

- Regional 3D flow model developed using MODFLOW with data input, model runs, and model output using MT3E code in Processing Modflow
  - Assess potential impacts of dissolved metals (cobalt and manganese) on regional groundwater quality in site area
  - Further refine CSM
- Telescoped model performed using 3D reactive transport code PHT3D
  - Simulate future transport of low pH groundwater and evaluate groundwater impact to surface water bodies
    - ARD/AMD simulated through oxidation of pyrite
    - Subsequent pH reactive transport determined by site-specific geochemical conditions
  - Evaluate effectiveness of remedial alternatives
    - Monitored natural attenuation (MNA)
    - Impermeable cap over tailings
    - Vegetative cap over tailings
    - Excavation with off-site disposal
    - Excavation with on-site disposal (MPP)

Site Cleanup
Regional/Telescoped Groundwater Model

- Regional 3D flow model, due to high soil/water partitioning coefficient (Kd) for cobalt and manganese, demonstrated no significant plume migration over 30-year modeling period





Site Cleanup
Regional/Telescoped Groundwater Model

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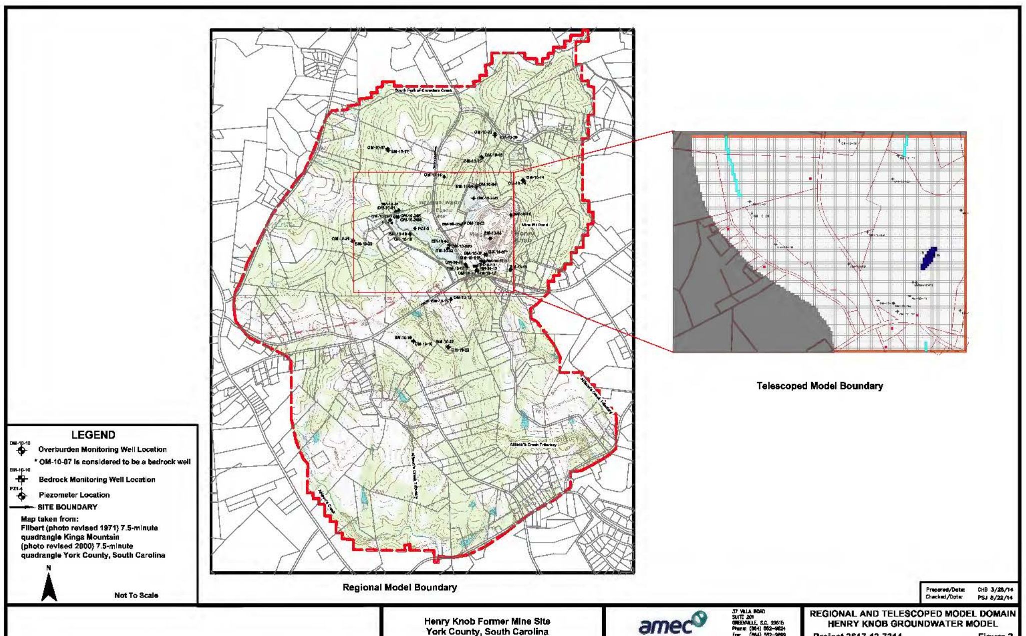
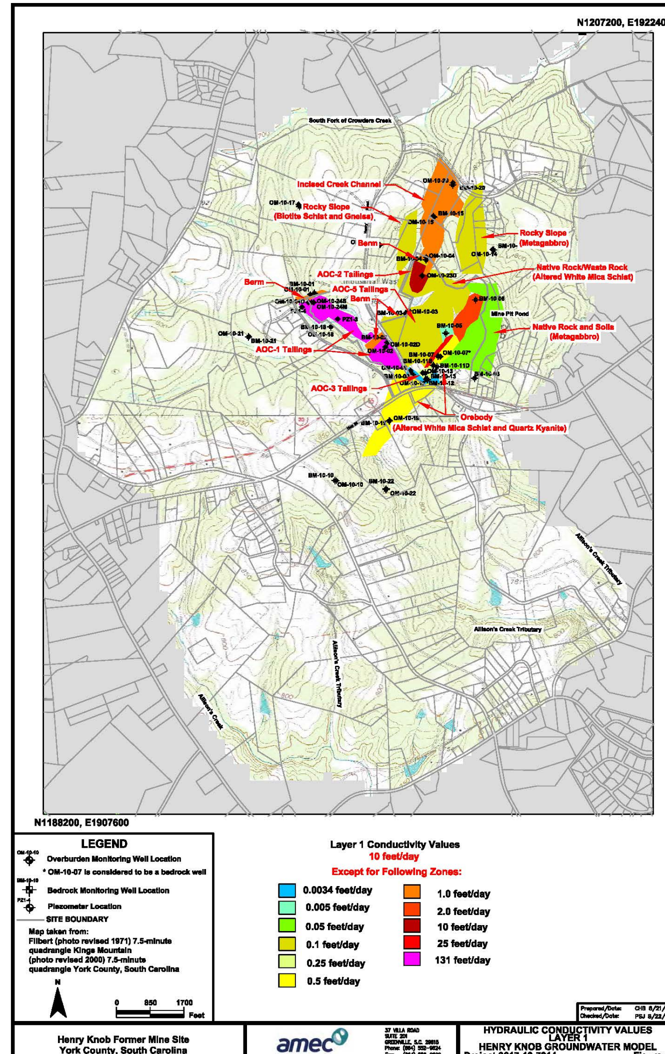
- Telescoped models demonstrated pH distribution over the 30-year modeling period for each simulated remedial alternative
- Most of impacts noted in Layer 1 (shallow) of model (generally equivalent to overburden)



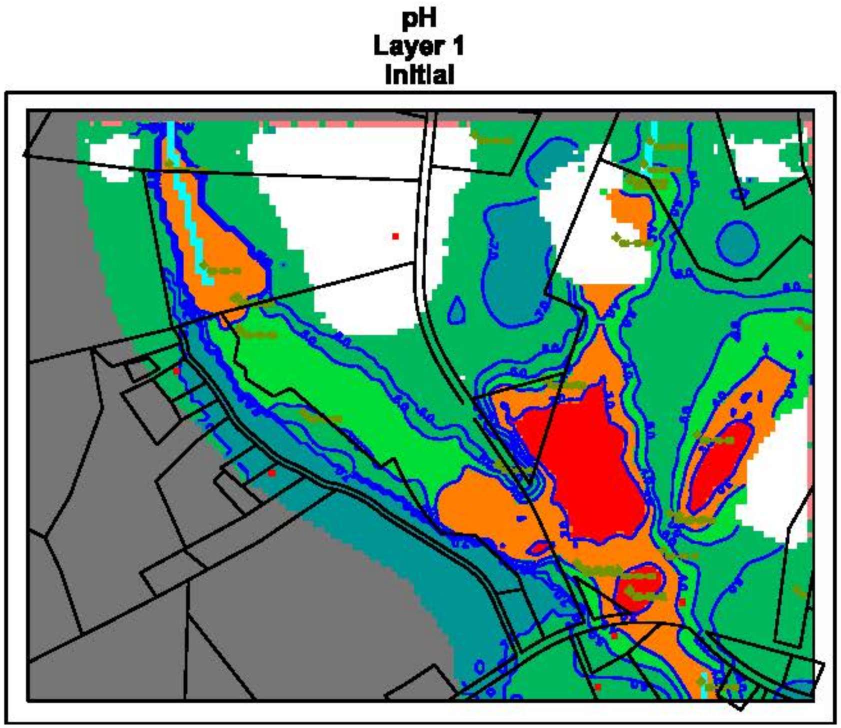


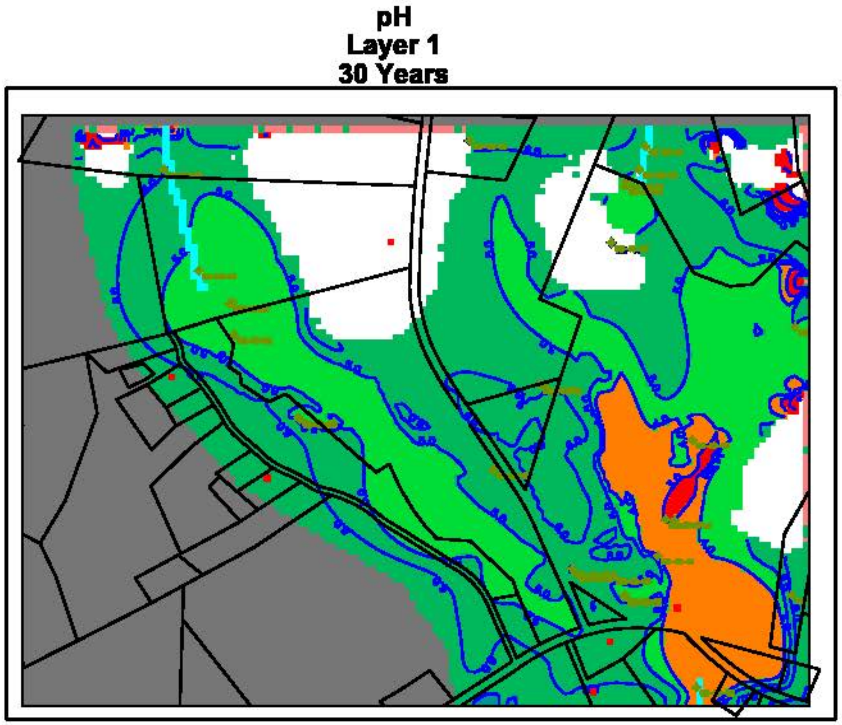
Site Cleanup
Regional/Telescoped Groundwater Model

- No significant changes in pH for MNA alternative
- No significant changes in pH for impermeable cap alternative
- Significant improvement in pH over the 30-year modeling period for vegetative cap and excavation alternatives
  - Due to the relatively high costs for excavation/disposal of the tailings and the increased risk due to vehicular traffic, the installation of a vegetative cover was considered the more feasible alternative
  - Additional model runs performed to simulate buffering of the water in the MPP indicated some pH improvement, but not enough to overcome the ARD generated from the geology of and surrounding the MPP

Site Cleanup
Regional/Telescoped Groundwater Model

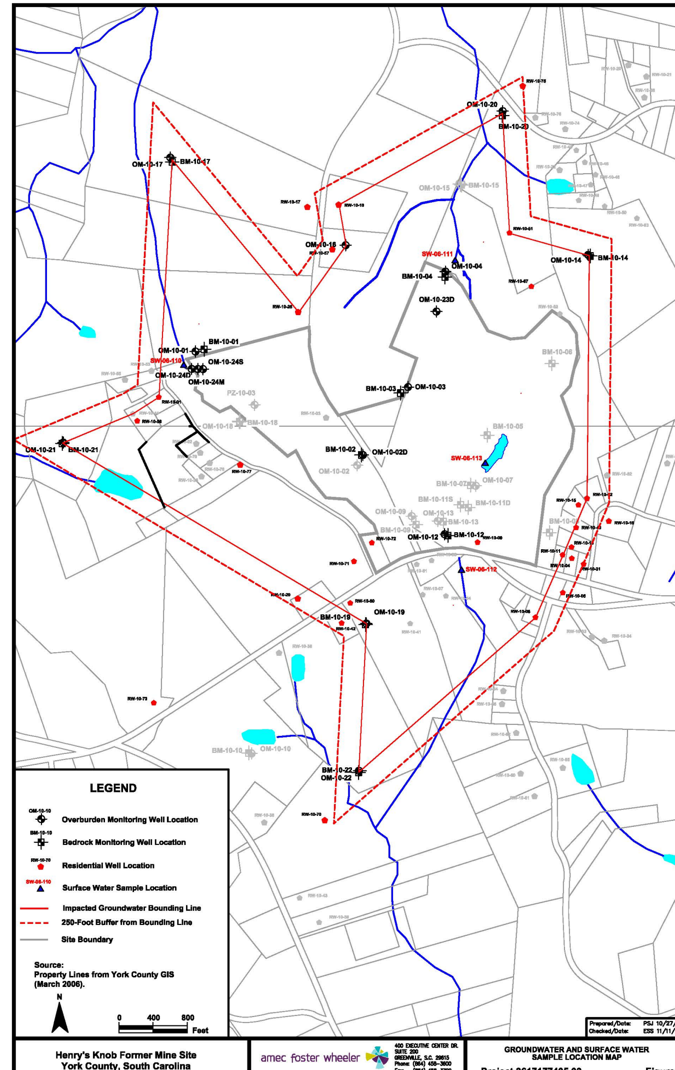
- Vegetative Cover





Site Cleanup
Groundwater Monitoring Program

- Initiated in June 2015
- Objectives
  - Monitor groundwater plume stability in impacted area
  - Monitor surface water concentrations trends over time
  - Monitor effectiveness of treatments systems installed as part of Non-Time Critical Removal Action (NTCRA)
- Term
  - Conduct trend analysis on each monitoring point following completion of baseline sampling
  - Once trend analysis shows metals concentrations are stable or deceasing, monitoring will be terminated



Site Cleanup
Groundwater Monitoring Program

- Locations monitored in the program
  - Bounding wells (defines the extent of groundwater impacted by AMD)
    - 7 overburden monitoring wells and 6 bedrock monitoring wells
    - 8 private water supply wells
  - Interior wells (within area of AMD-impacted groundwater)
    - 9 overburden monitoring wells and 5 bedrock monitoring wells
    - 40 private water supply wells
  - Surface water locations
    - Headwaters of West Tributary, East Tributary, and Allison Creek Tributary
    - MPP
- Baseline Sampling
  - All wells and surface water locations
  - Quarterly for two years
  - Baseline completed in first quarter of 2017

Site Cleanup
Groundwater Monitoring Program

- Subsequent Sampling
  - Bounding monitoring wells, bounding private wells, interior monitoring wells, and interior private wells with metals concentrations below the Remedial Goals (RG) sampled annually
  - Interior wells with metals concentrations above the RG sampled semi-annually
- Problems encountered due to lack of access
  - 15 private wells (3 bounding and 12 interior) could not be sampled due to lack of access from owner
  - Access obtained for 13 of the 15 wells in second/third quarters of 2017
    - Wells will be sampled quarterly for two years unless otherwise abandoned
    - Remaining two wells will not be sampled due to continued lack of access from property owners

Site Cleanup
Groundwater Monitoring Program

- Trend Analyses
  - Bounding Wells
    - Decreasing cobalt concentrations in overburden, bedrock, and private wells
    - Decreasing manganese concentrations overburden wells
    - Decreasing manganese concentrations in over half of bedrock and private wells
    - Wells with increasing manganese concentrations have relatively neutral pH (not indicative of AMD), are significantly below RG for manganese and in many cases, below the secondary maximum contaminant level (SMCL) for manganese
  - Interior Wells
    - Generally decreasing trends for cobalt except where evidence of AMD-impacts noted
    - Generally decreasing trends for manganese