Influences of Reclaimed Mines on Landscape-Level Ecosystem Services: A Case Study from Appalachia

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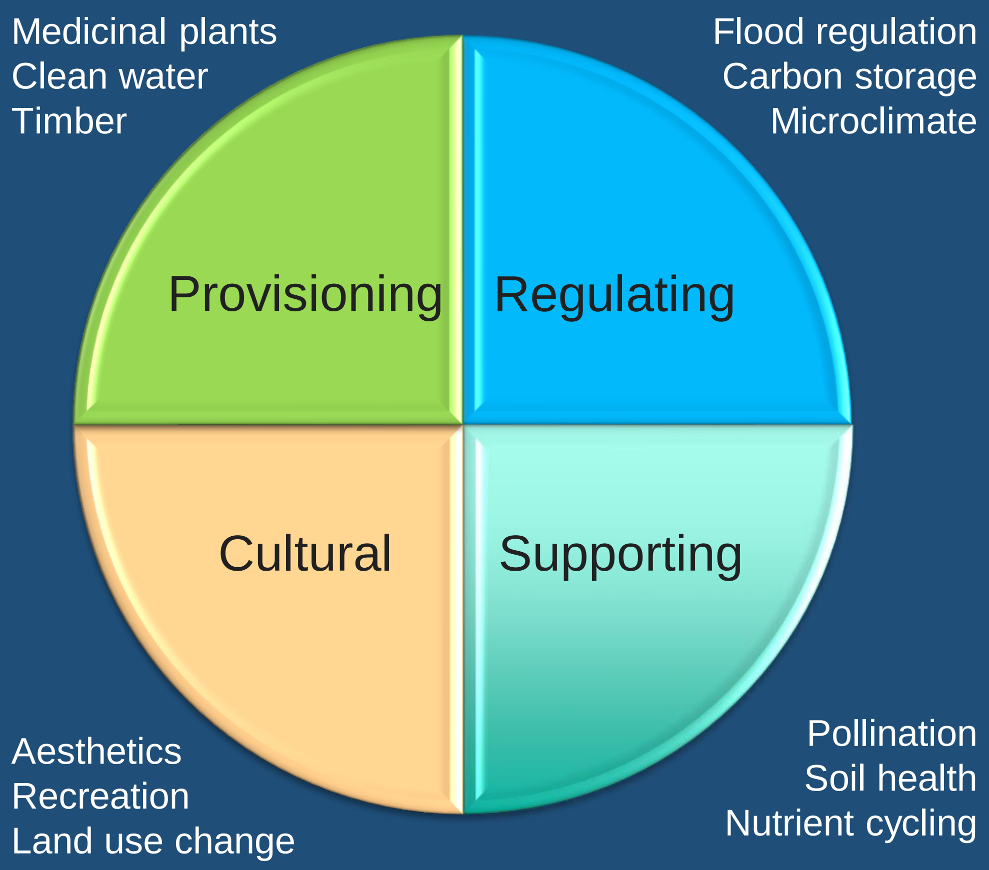
Goals and Study Approach

Goal: Explore the impacts of surface mining and reclamation on landscape-level processes

Study approach: literature review and analyze landscape-level impacts of case study area

Surface Mining Impacts on Ecosystem Services

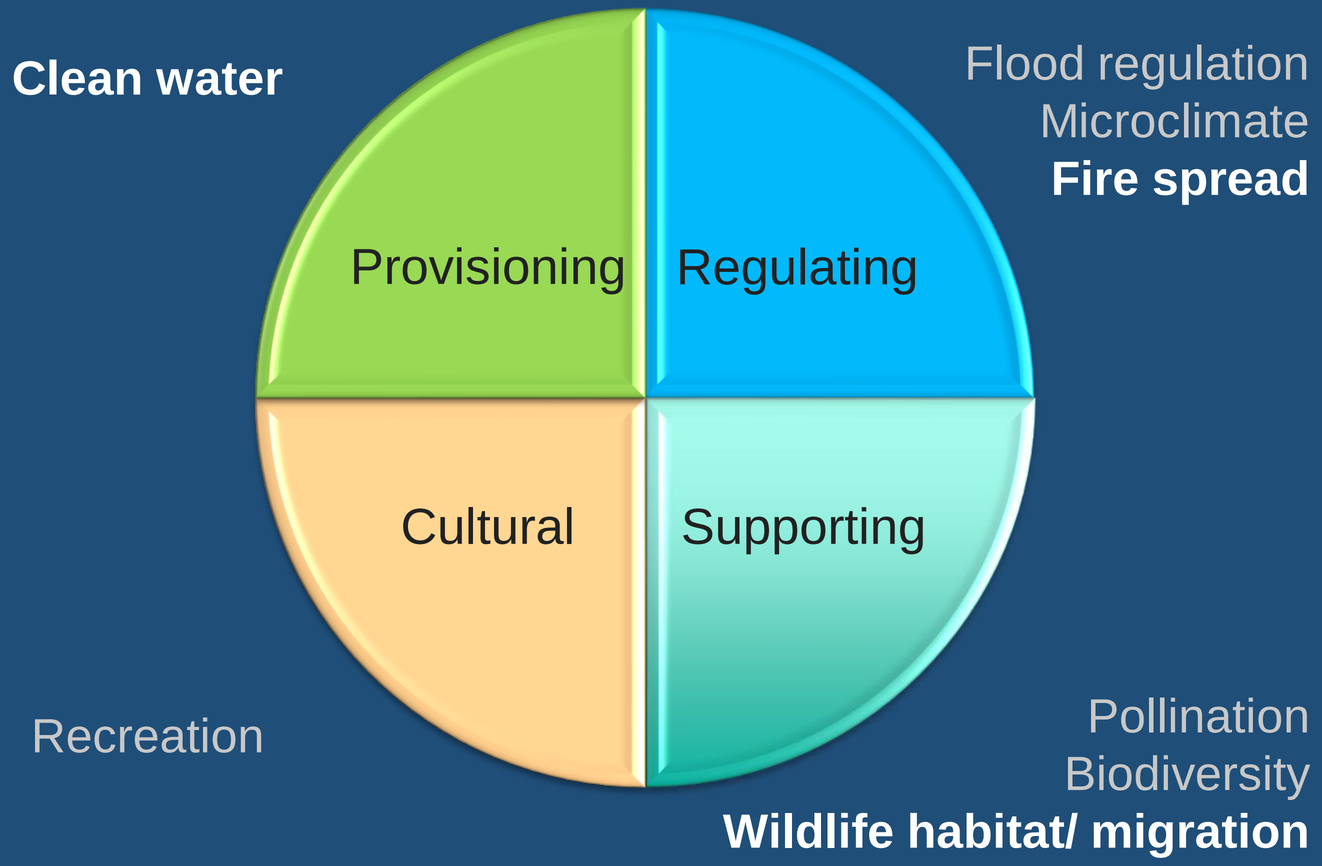
- Surface mining operations, particularly large-scale open-pit mining, can fundamentally reshape the project and landscape levels.
- The impacts may extend beyond the immediate excavation area (project level), causing a "cascade effect" that may diminish or enhance ecosystem functions and their ability to provide appropriate services.
- An understanding of the **project-level and landscape-level changes** are critical for designing Ecological **Restoration** strategies, which may include alternate development such as eco-parks or the repurposing of mine voids for pumped storage, or alternate energy sources.



Project-level and Landscape-Level Ecosystem Services

Landscape-Level Services

Landscape-level ecosystem services involve processes and flows that occur across a broad area, and often include a mosaic of land use types.



Alteration of Hydrology and Hydrological Cycles

Surface mining fundamentally reshapes the physical landscape, disrupting the natural movement and storage of water.

- **Topographic Reconfiguration**: Removal of overburden and creation of pits permanently redirects natural surface drainage and destroys headwater streams.

- **Aquifer Disruption**: Excavation may intersect the water table, causing groundwater to seep into pits and dewater surrounding rock layers and can dry up local wells.

- **Runoff Dynamics**: Land clearing and soil compaction from heavy machinery can reduce infiltration rates that may lead to increased peak flows and a higher risk of downstream flooding.

- **Mine Void Formation**: Post-mining pits often transition into artificial lakes, which may lack the ecological connectivity of natural water bodies.

Water Quality Impacts

- Acid mine drainage is the most persistent chemical challenge in mining, occurring when sulfide-bearing minerals are exposed to air and water. Oxidation of minerals like pyrite produces sulfuric acid.

- Metal Leaching: High acidity dissolves heavy metals (aluminum, iron, manganese) from the surrounding waste rock, carrying them into the watershed.

- Ecological Toxicity: Low pH levels and high metal concentrations are not good for most aquatic life and can render water supplies unusable for decades.

- Visual Indicators: The "Yellow Boy" phenomenon—bright orange ferric-hydroxide precipitates—coats stream beds, smothering benthic habitats.

- High sediment loads destroy habitat for fish and aquatic invertebrates.

Physical and Salinity Impacts

Beyond acidity, mining introduces physical pollutants and alters the fundamental chemistry of freshwater systems.

- **Sedimentation and Siltation**: Massive land disturbance increases erosion. Fine sediments "choke" streams, burying spawning grounds and reducing light penetration (turbidity).
- **Total Dissolved Solids (TDS):** Mining releases minerals previously trapped deep underground, significantly increasing water salinity and electrical conductivity.
- **Sulfate Loading**: Common in coal regions, high sulfate concentrations can affect the taste of drinking water and disrupt the physiological balance of freshwater species.
- **Hardness Alteration**: Increased calcium and magnesium levels can lead to scaling in downstream industrial and domestic infrastructure.

Mitigation and Management Strategies

Modern engineering and biological approaches are essential to minimize long-term environmental liability.

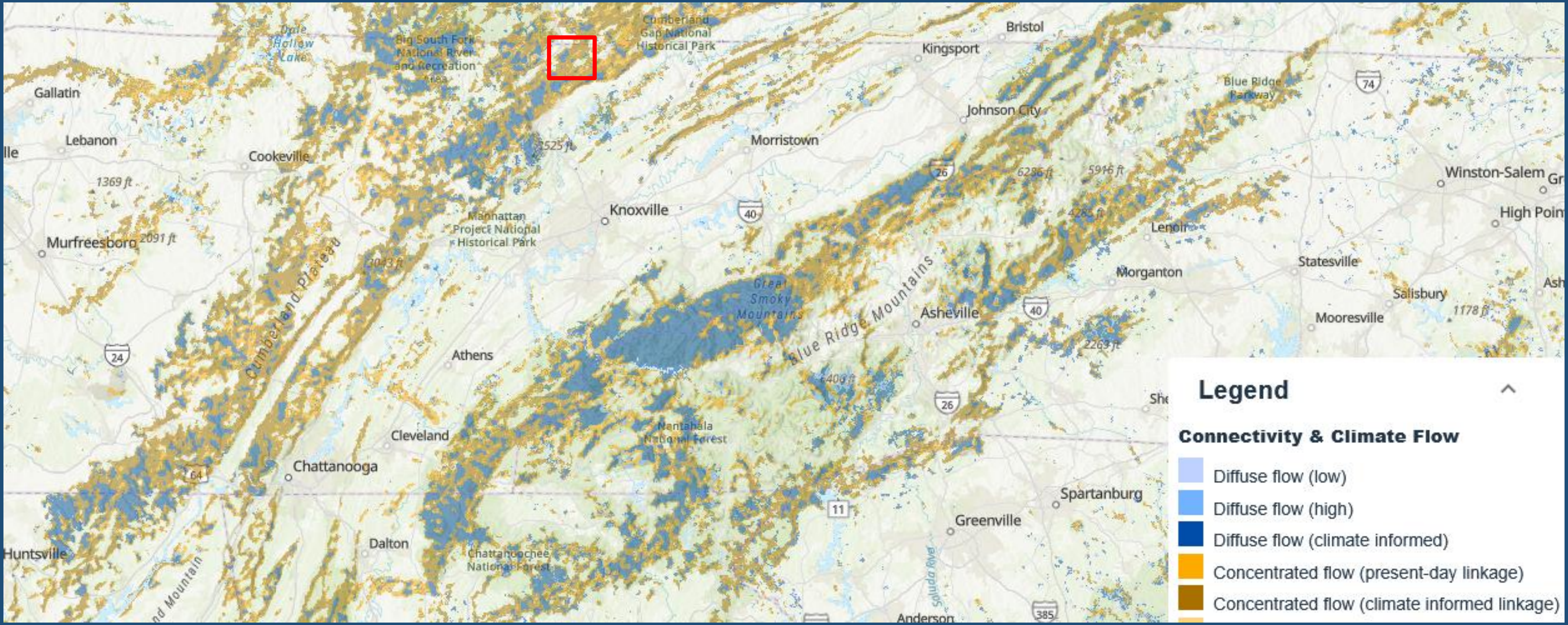
- Source Control: Segregating acid-forming materials and using liners or "caps" to prevent water and oxygen from reaching reactive waste.
- Water Treatment Systems:
- Active: Chemical neutralization plants (e.g., lime dosing) for immediate, high-volume treatment.
- Passive: Constructed wetlands and anaerobic settling ponds that use natural biological processes to remove metals.
- Concurrent Reclamation: Immediate stabilization of spoil heaps with vegetation to minimize erosion and runoff.
- Diversion Engineering: Constructing permanent channels to bypass clean upstream water around the disturbed site

Wildfire spread

Depends on weather, but also on factors we can control during reclamation:

- Slopes – faster spread on steeper slopes, particularly when the wind is upslope
- Fuels (vegetation)
  - Grasses - more easily ignited and faster spread
    - high continuity contributes to spread
  - Forest – slower spread but more severe
    - broadleaf less flammable than coniferous
- Barriers – roads, gullies and wetlands

Wildlife and biodiversity



- The Nature Conservancy Resilient Land Mapping Tool v2.0.63

Application of Foundations for Ecological Restoration and Management: Case Study

65-acre coal mine located around TN-KY Border north of Knoxville.

Contour mining began in 2007 and reclamation was completed in 2016.

Concurrent reclamation activities were consistent with industry standards and federal laws.

Summary of Project Level Assessments Presented in 2025 (Chugh and Franklin, 2025)

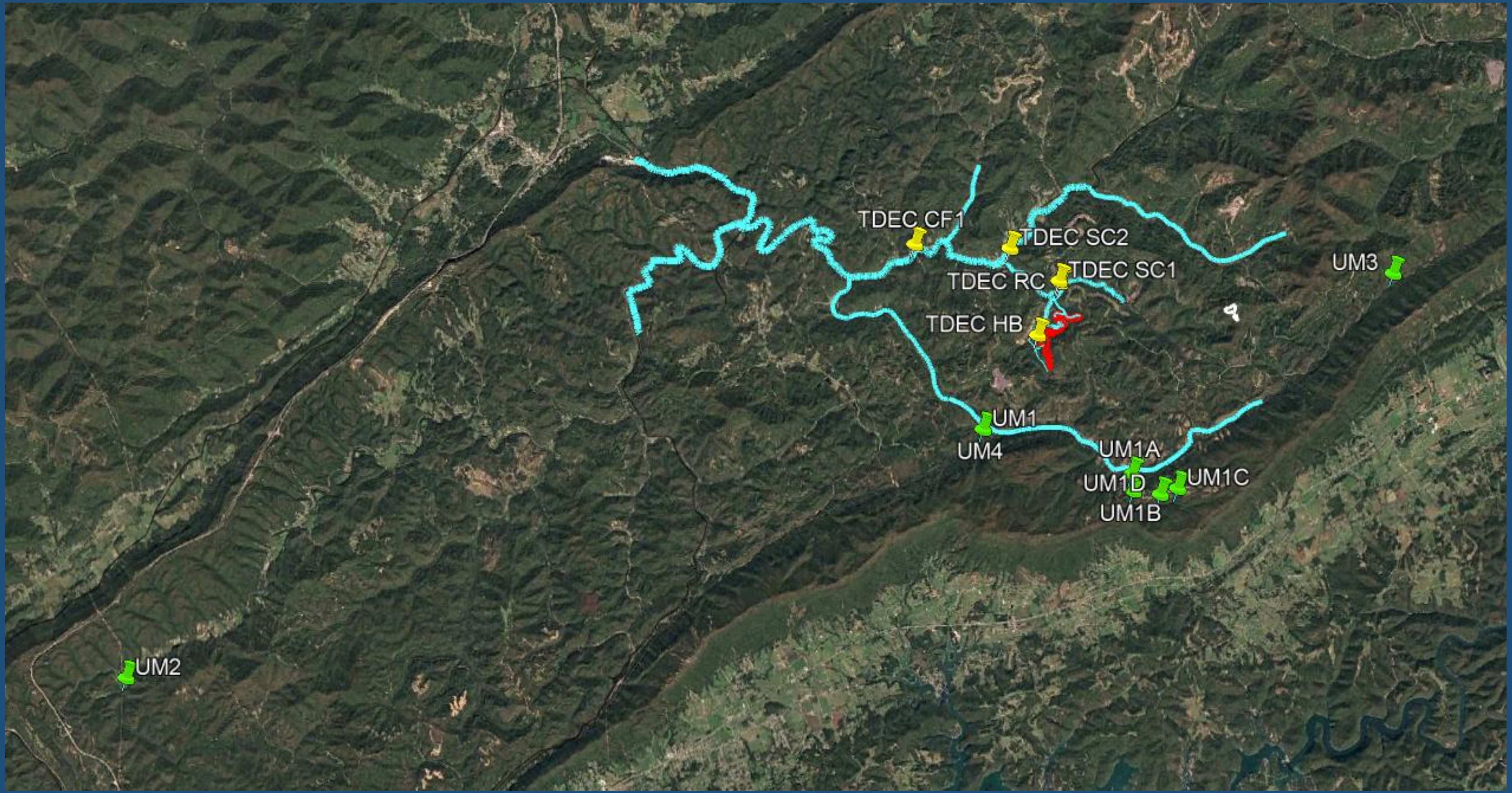
- Graded slope, bulk density, and Cu content were positively correlated with vegetation. Relatively shallow slopes had higher soil bulk density and poor vegetation.
- The flat areas, or “benches”, were generally all haul roads or staging areas. The most compacted had a sparse to dense cover of native grasses with few trees.
- Vegetation was not correlated with soil pH, CEC, MC, soil texture, or clay size fraction.

Impacts at the Landscape Level: Water Quality - Methods

Data from Tennessee Division of Environment and Conservation for the Clear Fork watershed.

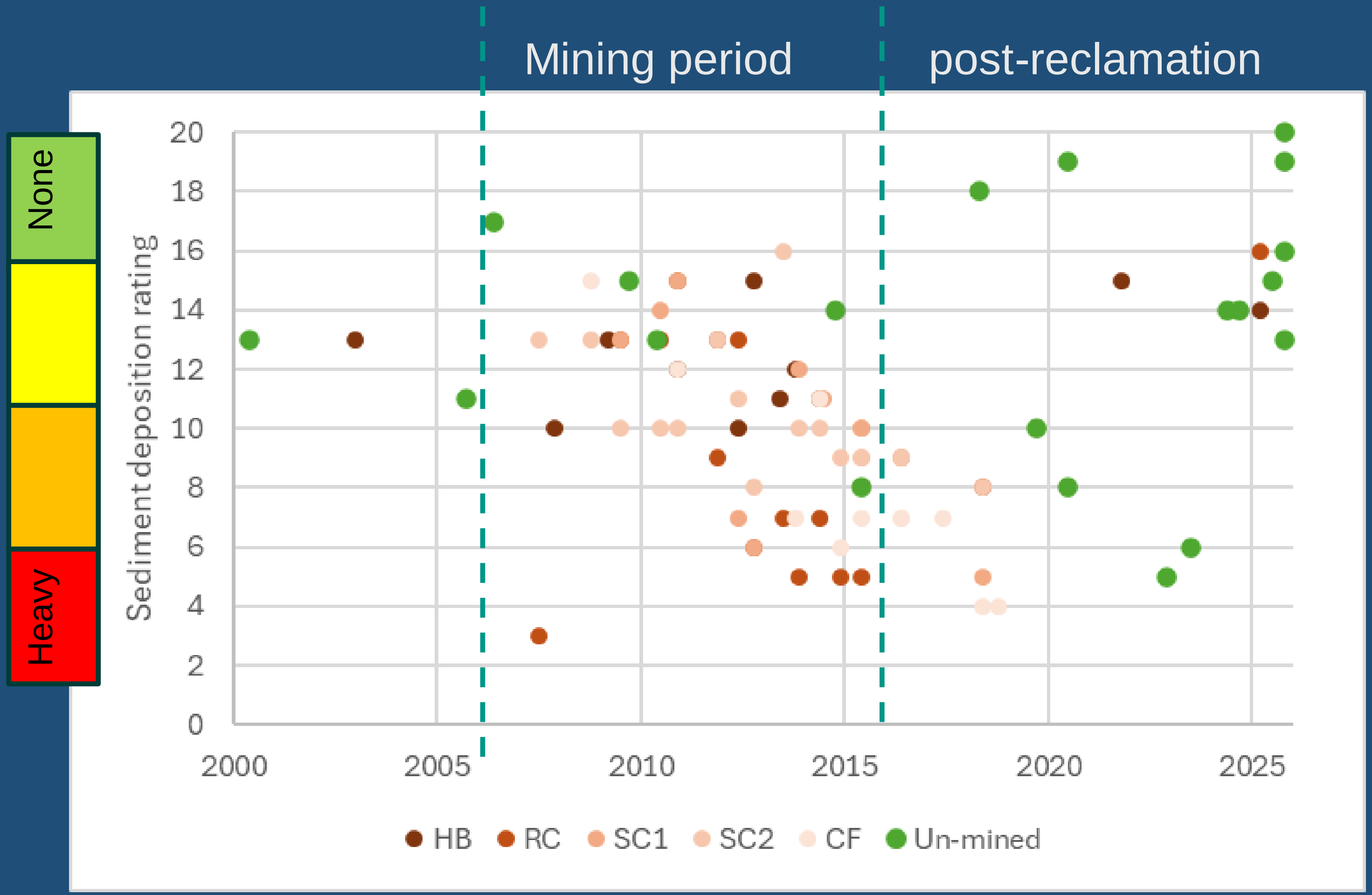
5 monitoring sites in drainage area of our site:
HB → RC → SC1 → SC2 → CF

5 monitoring sites within the watershed that do not have mining upstream

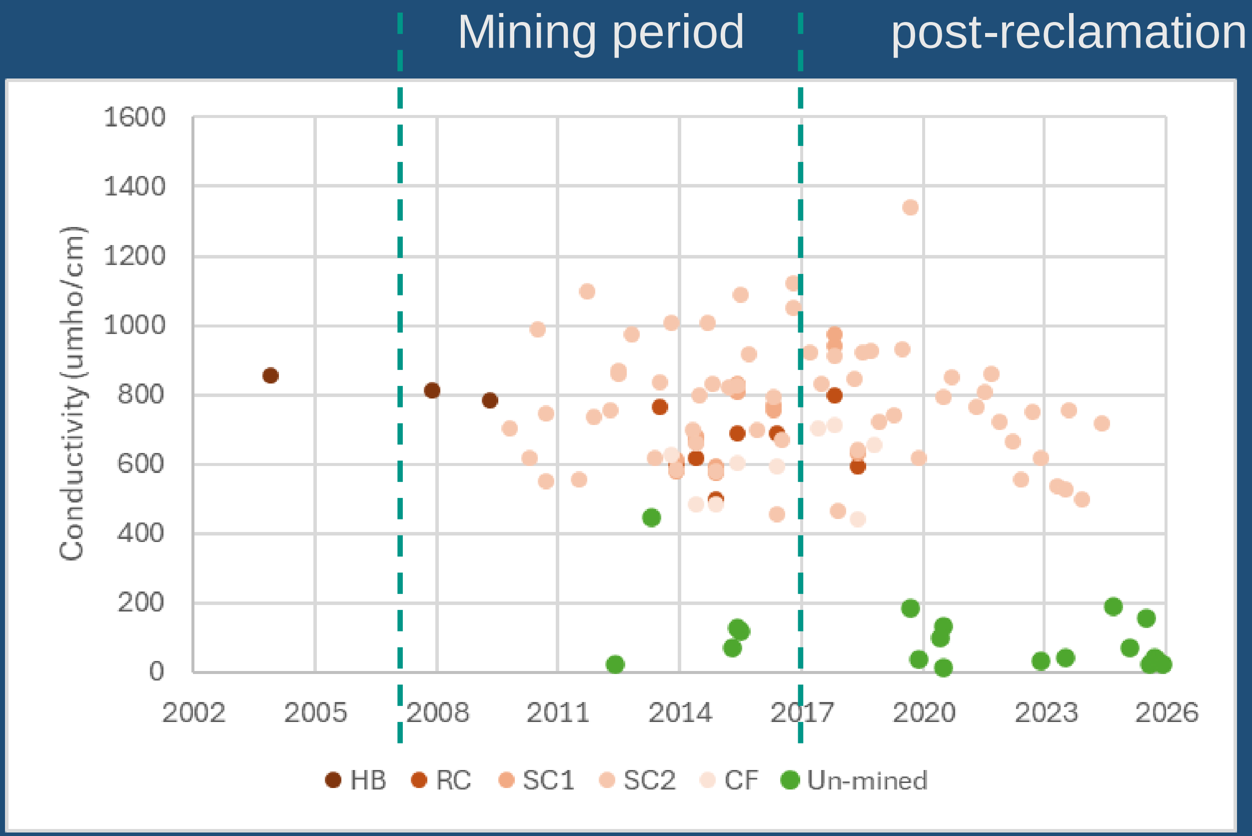


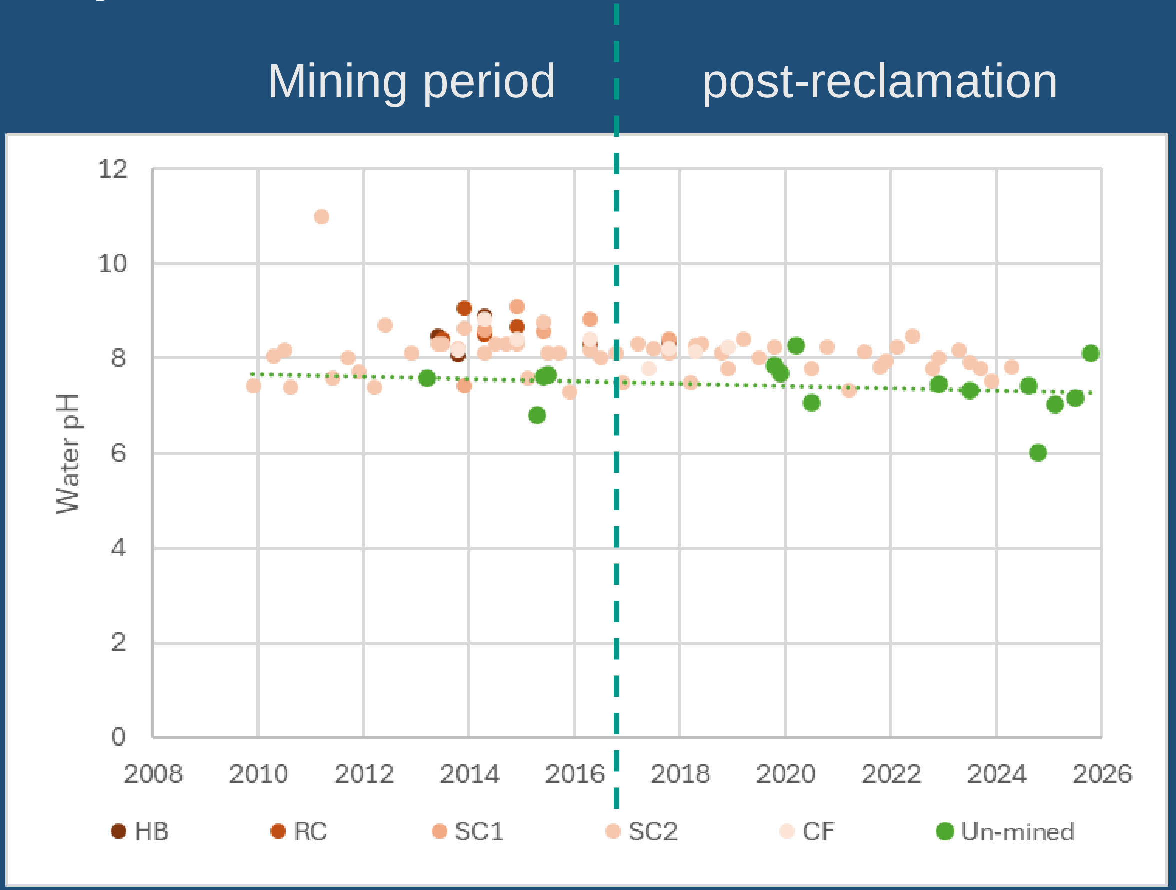
Results: Sediment Deposition in Area Waterways

- Moderate levels of sediment deposition was seen in streams during the mining period. (mined poorer than unmined, $p \leq 0.05$)
- Ratings have returned to pre-mined values.
- Streams in un-mined areas were impacted by other disturbances to an extent that was similar to that of mining.



Results: Water quality in Area Waterways





Mined .> unmined, p≤ 0.05, difference remains after reclamation

Mined .> unmined, p≤ 0.05, difference remains after reclamation

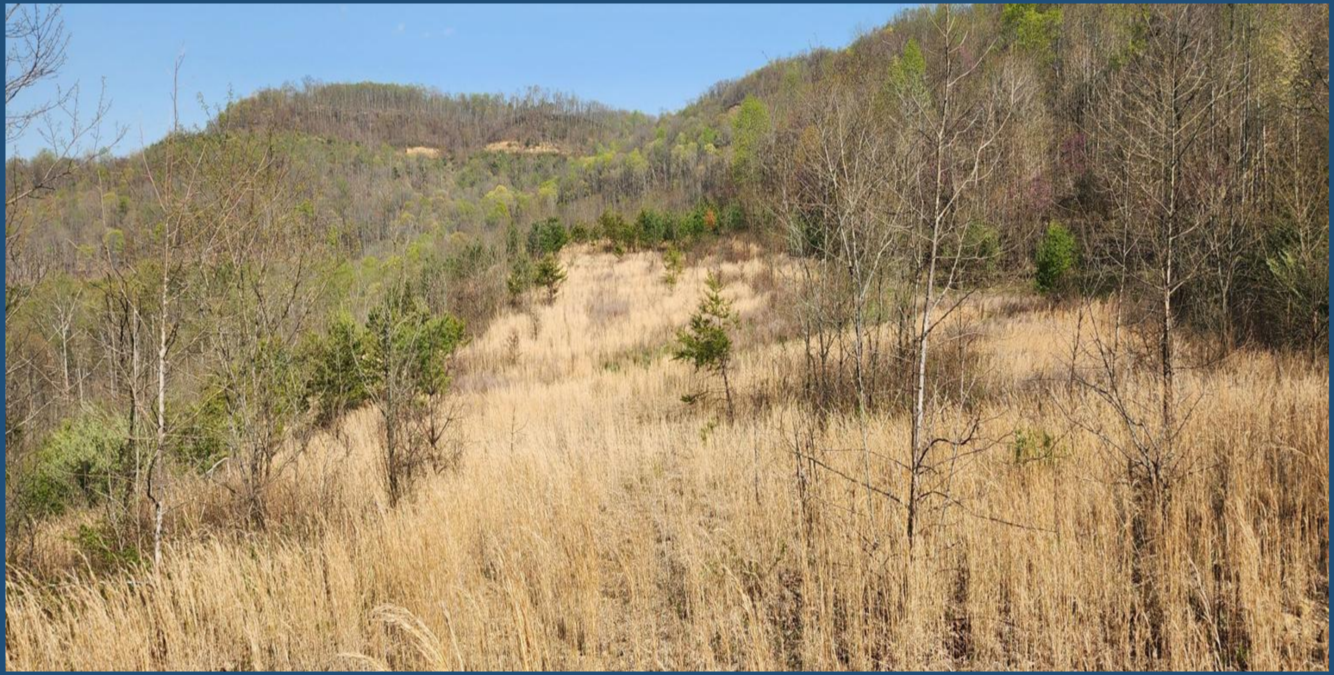
Impacts at the Landscape Level: Fire Spread - Methods

Based on a wildfire that occurred in the area in 2024: do these flat, grassy benches act as a fire break?

Topography and fuels data (1993) from USDA-Landfire: Fire dates from NASA-FIRMS.

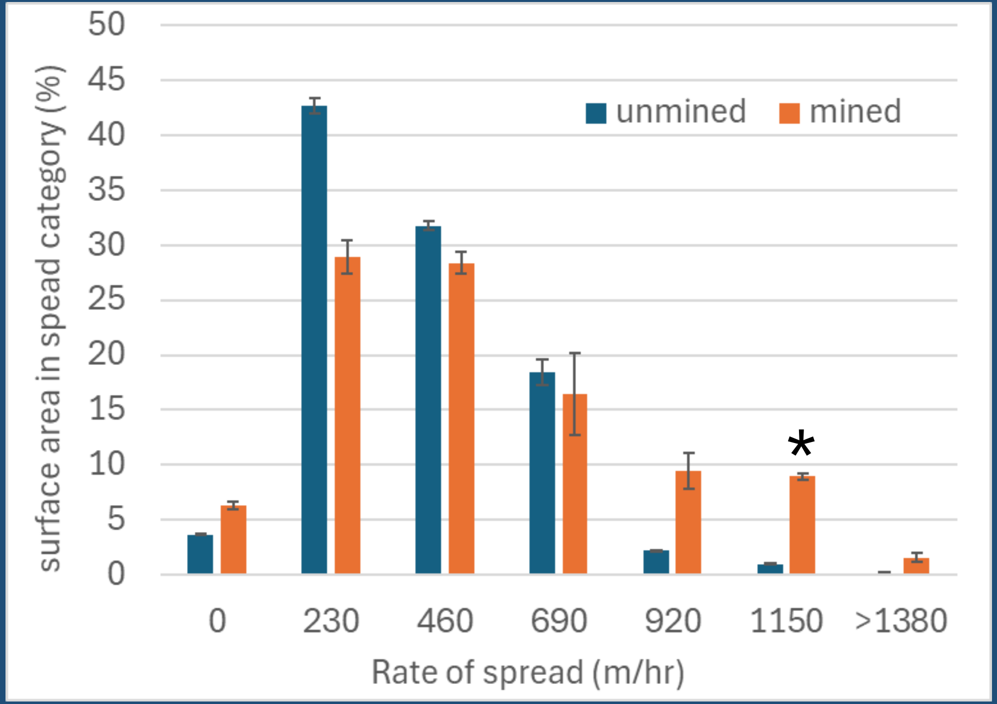
Weather and fuel moisture from NCSU archives.

FlamMap6 used to determine rate of fire spread based on the above for four wind directions (N, S, E, and W). Distribution of mined and unmined areas in rate of spead categories tested using chi-squared.

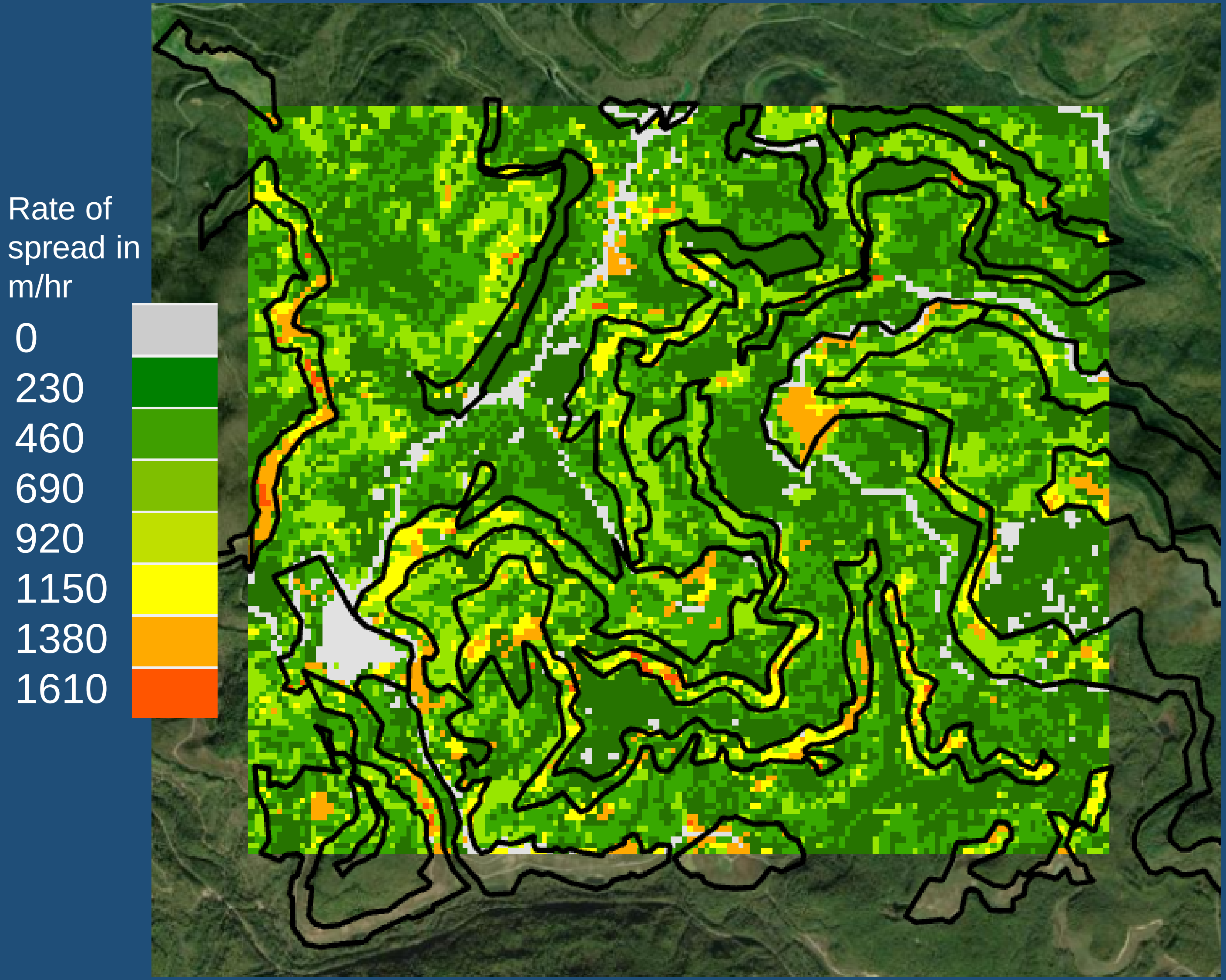


Results: Rate of spread

- Rate of spread differs between mined and unmined areas, mainly due to larger proportions of mined land with grasses that had a high ROS.



Rate of spread with north wind



Impacts at the Landscape Level: Fire Spread

Fire size after a 6-hour burn was determined.

Model run using random ignition points. Points within 5 m of the mined-unmined boundary or located on roads were eliminated.

30 points on mined and 30 on unmined areas were used for each wind direction (N, S, E, and W).

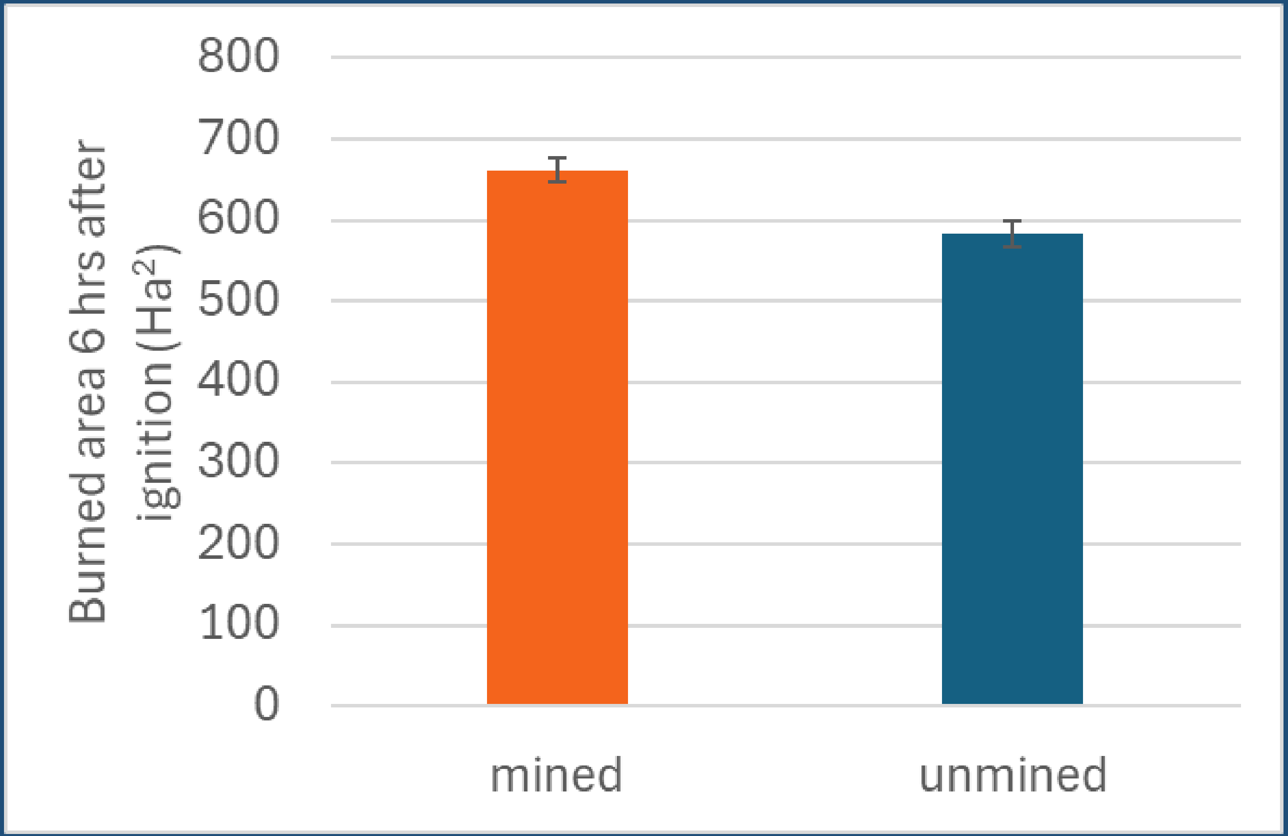
Size of fires that began on mined areas was compared with those that started on unmined areas.

Results: fire size

- Under conditions conducive to wildfire, after 6 hours of burning, fires that began on mined areas were significantly ($P<0.001$) larger if the point of ignition was on a reclaimed mine if no attempts are made to contain it.

- Fires are more likely to begin on a mine due to ease of access, more recreational use, and fine fuels that ignite more easily.

- However, access and water availability from sediment ponds could potentially improve the efficiency of firefighting efforts.

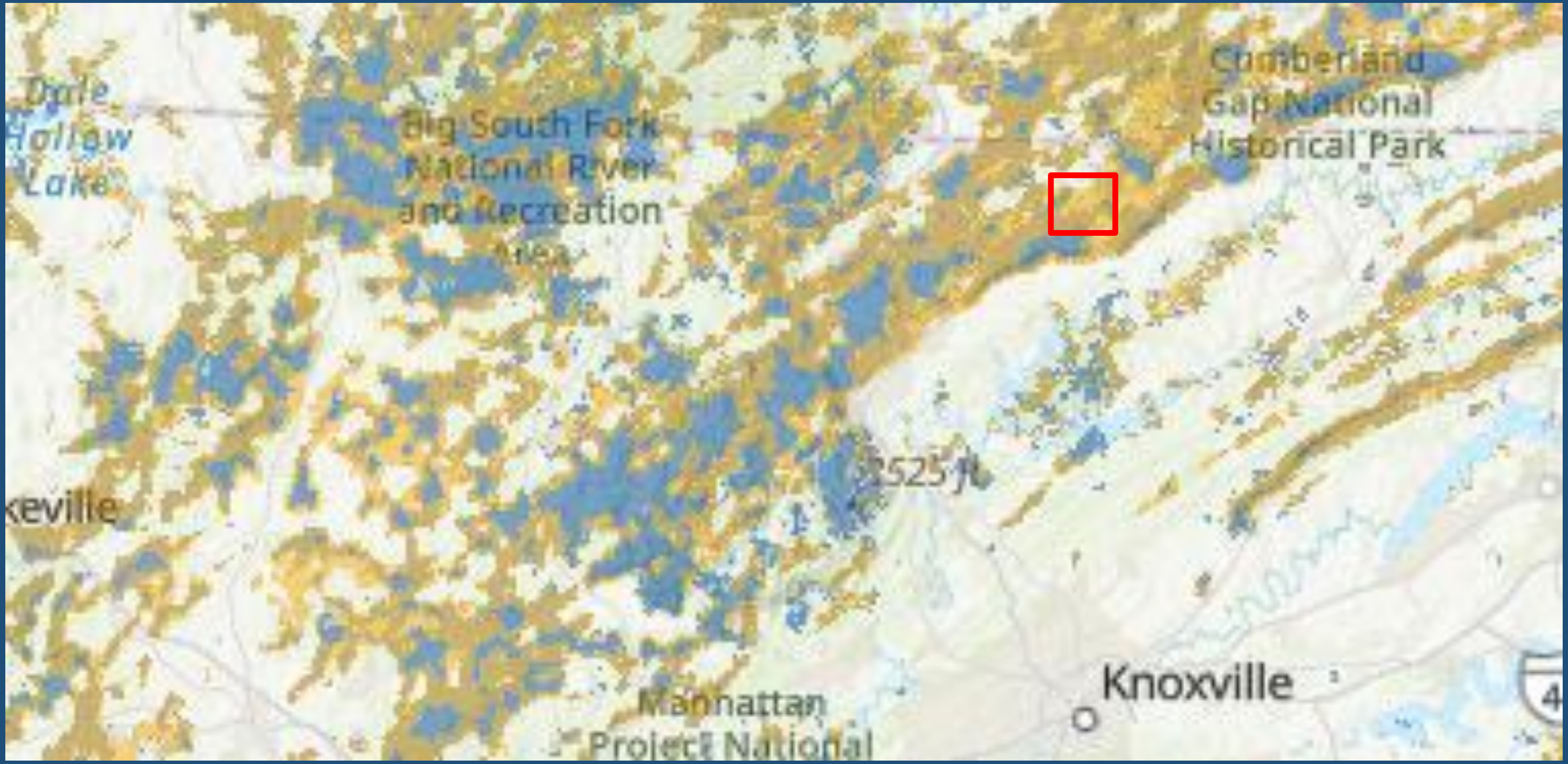


Impacts at the Landscape Level: Wildlife and Biodiversity

A literature review and qualitative methods were used as a preliminary assessment of wildlife and biodiversity impacts.

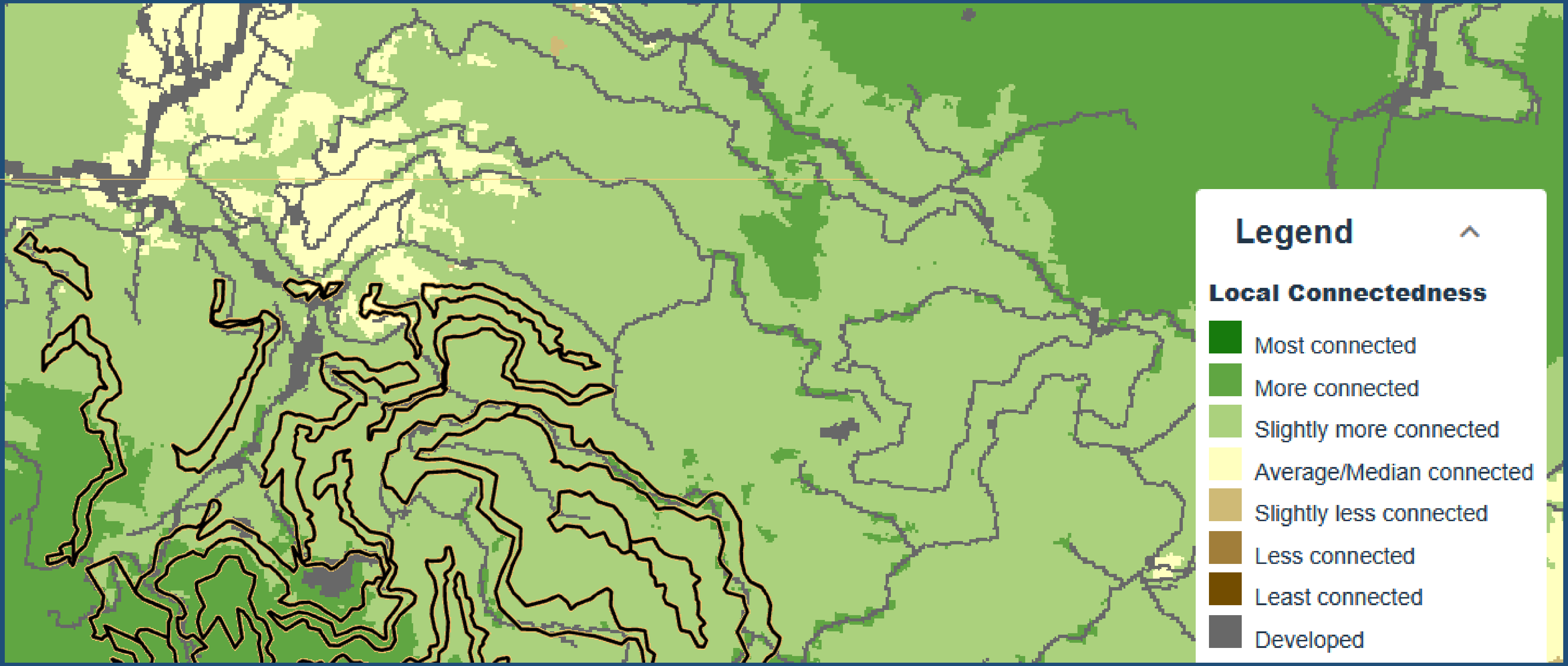
- Wildlife corridors and barriers to animal movement and gene flow

- Biodiversity indicators



Biological movement

Reclaimed mines are not a barrier to migration, and increasing local connectedness are a priority



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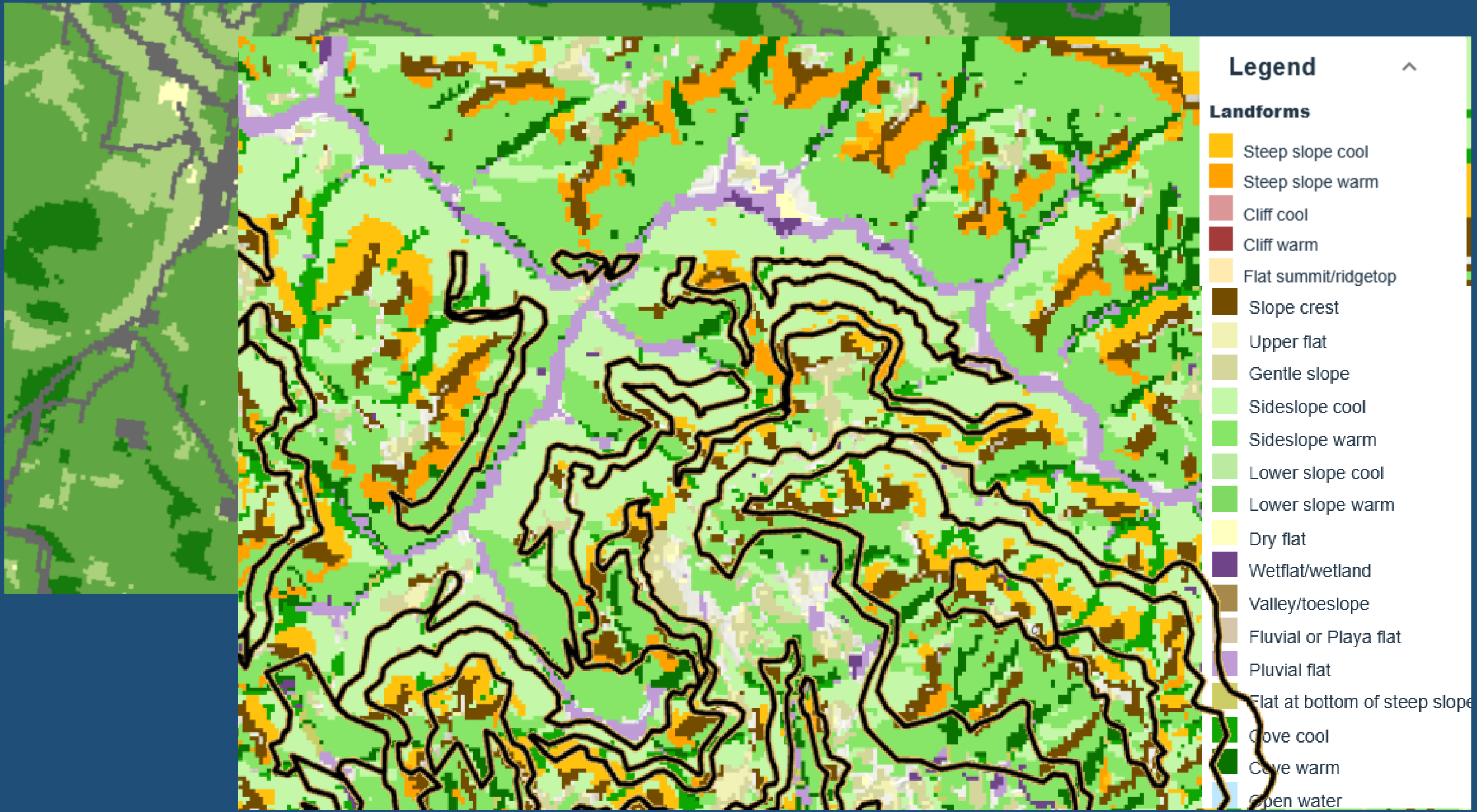
Biodiversity

Mining and reclamation can increase diversity of the physical environment, increasing biodiversity at the landscape scale.



Discussion
Project-Level and Landscape-Level Ecological Restoration

- The distinction between the **project level** (site-specific) and the **landscape level** (regional/systemic) is very important from a long-term success point of view.

- **At the Project Level, the** focus is on **tactical execution** within a specific boundary (e.g., a 50-hA wetland, a specific stretch of river, or a local forest patch).

- **Thus, it can engage in detailed** "ecological engineering, including using control soil composition, removing specific invasive species, and planting precise seed mixes.

- **Field Feedback is often** visible within a few seasons on rates of seedlings or the return of a specific bird species.

- However, it does come with the isolation or "Island Risk". A perfectly restored project-level site may fail if the surrounding landscape is degraded. For example, a small restored prairie might be overrun by invasive seeds blown in from neighboring unmanaged fields.

Project-Level and Landscape-Level Ecological Restoration (contd.)

- Landscape-level restoration requires “systems engineering” and therefore must consider **connectivity of processes within the landscape and their interactions.** It must consider how project-level sites interact across a mosaic of different land uses (farms, suburbs, protected parks).

- **Emphasis is on achieving Ecological Resilience and the goal is** to restore "flows"—the movement of genes, water, and wildlife. Therefore, **biological corridors** may need to be created that connect multiple separate project-level forests.

- **It emphasizes “Process over Pattern”. For example, instead of creating agricultural land, the goal may be to control many** natural flooding cycles, that maintain the ecosystem over hundreds of kilometers.

- In planning a restoration project, always assess: *"What is the matrix surrounding my site?"* If the site is a 'sink' for regional pollution or seeds, your project-level efforts will require much higher maintenance than if they were part of a healthy landscape-level plan

Concluding Remarks

- Should we always try to replace the original ecosystem?
- What ecosystem services are needed at the landscape level?
- Some ecosystem services will likely be reduced by mining, can this be offset by increasing ecosystem services at the landscape level for a net ES gain?
- Consider fire spread, and the potential use of prescribed fire

Questions?

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