**Powder River Basin Transportation & Infrastructure**

*Monitoring Land Disturbances Caused by Coal Mining in the Powder River Basin Using Remote Sensing*

**Project Team**

***Project Team:***

Gina Cova (Project Lead)

Andrew Bake

Claudia Herbert

Hayley Pippin

***Advisors & Mentors:***

Dr. Juan Torres-Pérez (Bay Area Environmental Research Institute, NASA Ames Research Center)

Dr. Kenton Ross (NASA Langley Research Center)

John Dilger (Spatial Informatics Group, LLC)

**Project Overview**

***Project Synopsis:*** The Powder River Basin of Wyoming is home to 41 percent of the coal production in the United States, but mining operations threaten surrounding ecosystems. The Powder River Basin Transportation & Infrastructure Team partnered with the Powder River Basin Resource Council and the Western Organization of Resource Councils to build a Coal Mining Assessment Tool (CMAT) that monitors land disturbances from coal mining using NASA Earth observations. The tool has the capability to assess changes in vegetation, water extent, and land cover in the Powder River Basin from 1985 to 2018 to aid end users in understanding and monitoring mining impacts and reclamation efforts in the area.

***Abstract:***

Coal mines in the Powder River Basin of Wyoming account for approximately 41 percent of coal production in the United States, causing significant land disturbances. Without proper reclamation practices, orphan mines create barren, unstable lands unlikely to recover. Where mines have been successfully reclaimed, human and natural communities have benefited from reconnected hydrology, functioning ecosystems, and economic opportunities, but the financial decline of the coal industry has raised concerns about the stability of long-term reclamation efforts. The Powder River Basin Transportation & Infrastructure Team partnered with the Powder River Basin Resource Council and the Western Organization of Resource Councils to create a Coal Mining Assessment Tool (CMAT) in Google Earth Engine to monitor the impacts and reclamation efforts of coal mines in the basin. The tool incorporates Earth observations from Landsat 5 Thematic Mapper (TM), Landsat 7 Enhanced Thematic Mapper Plus (ETM+), and Landsat 8 Operational Land Imager (OLI), and utilizes the LandTrendr change detection algorithm to assess land disturbance. CMAT outputs include land disturbance maps and charts showing how land cover, Normalized Difference Vegetation Index (NDVI), Normalized Difference Water Index (NDWI), and tasseled cap transformations have changed from 1985 to 2018. In a case study of three neighboring mines, results showed that the mine nationally recognized for its reclamation practices recovered land up to 78 percent faster than its neighbors. The ability to visualize and assess how coal mining and reclamation has progressed over the study period will allow partners to better understand and advocate for regional reclamation practices.

***Keywords:***

Google Earth Engine, Landsat, reclamation, Coal Mining Assessment Tool, Wyoming, change detection, tasseled cap, LandTrendr

***National Application Area Addressed:*** Transportation & Infrastructure

***Study Location:*** Powder River Basin, WY

***Study Period:*** 1985 to 2018 (June to August)

***Community Concerns:***

* Coal mining in Wyoming uses open-pit mines, or surface mines, that require removing large amounts of topsoil to access the coal resources below, thus disturbing the soil ecosystem.
* Land disturbances from coal mining adversely impact environmental and human health. Conservation officials in Wyoming monitor and enforce environmental regulations aimed at limiting these impacts.
* Contemporaneous reclamation restoring disturbed land to its pre-mining state is a legally required part of a coal mine life cycle. The decline in the national demand for coal has strained financial resources for the reclamation process, leaving reclamation efforts vulnerable to remaining unfinished.
* The Powder River Basin Resource Council (PRBRC) and Western Organization of Resource Councils (WORC) are interested in monitoring reclamation efforts to track progress over time and better inform future land conservation efforts and mining reclamation strategies.

***Project Objectives:***

* Classify reclamation and land disturbance throughout the Powder River Basin
* Analyze the extent and distribution of water and vegetation change over time around Powder River Basin coal mines
* Provide CMAT to the PRBRC and WORC, allowing these organizations to monitor land reclamation efforts into the future and review the success of previous reclamation efforts
* Provide partners with output data from CMAT that can be used as inputs for broader analyses on energy extraction

**Partner Overview**

***Partner Organizations:***

|  |  |  |  |
| --- | --- | --- | --- |
| **Organization** | **POC (Name, Position/Title)** | **Partner Type** | **Boundary Org?** |
| **Powder River Basin Resource Council** | Shannon Anderson, Staff Attorney | End User | Yes |
| **Western Organization of Resource Councils** | Dan Cohn, Regional Organizer | End User | Yes |
| **Clemson University, Energy-Economy-Environment Systems Analysis Group** | Dr. Mik Carbajales-Dale, Director  | Collaborator | Yes |
| **SkyTruth** | Christian Thomas, Geospatial Engineer | Collaborator | Yes |

***Decision-Making Practices & Policies:***

The Powder River Basin Resource Council (PRBRC) is a regional non-governmental organization that advocates for sustainable natural resource practices and policies via community organizing and connections with scientific, policy, and legal experts. The PRBRC provides input on legal decisions surrounding extraction policy and audits the status and completion of reclamation activities, litigating against agencies that fail to meet environmental standards. The PRBRC is a member organization of the Western Organization of Resource Councils (WORC), a regional network of grassroots community organizations representing seven western states and tribal reservations advocating for environmental and economic sustainability. Both the PRBRC and WORC are concerned with the failure of regulators to enforce contemporaneous reclamation with coal mining and do not currently use NASA Earth observations to monitor coal mining-related land disturbances and reclamation practices.

***Project Benefit to End User:***

The CMAT tool relies on Landsat 5 Thematic Mapper (TM), Landsat 7 Enhanced Thematic Mapper Plus (ETM+), and Landsat 8 Operational Land Imager (OLI) Earth observations to create intuitive and interactive maps of landscape changes associated with coal mining. The user-friendly interface will empower the PRBRC, WORC, and their members to actively monitor and track regional mining land disturbance and reclamation progress over time. Identifying high amounts of mining land disturbances coupled with lax reclamation processes will allow the PRBRC and WORC to pressure mine operators to uphold their regulatory obligation of contemporaneous reclamation. Contemporaneous reclamation during active mining is critical for financing reclamation but is unlikely to occur without increased regulatory pressure. CMAT will allow the PRBRC and the WORC to independently verify mining disturbances and reclamation activity to locate mines with high mining-to-reclamation ratios for better protection of natural resources for current and future generations.

**Earth Observations & End Products Overview**

***Earth Observations:***

|  |  |  |
| --- | --- | --- |
| **Platform & Sensor** | **Parameters** | **Use** |
| **Landsat 5 TM** | Normalized Difference Vegetation Index (NDVI), Normalized Difference Water Index (NDWI), tasseled cap transformation, surface reflectance | Landsat 5 TM data were used to calculate NDVI, NDWI, and tasseled cap transformations for the land associated with twelve coal mining facilities in the Powder River Basin region of Wyoming at a 30 m2 resolution between 1985 and 2011. These scenes were also used to develop a pixel-change time series analysis using LandTrendr in Google Earth Engine. |
| **Landsat 7 ETM+** | NDVI, NDWI, tasseled cap transformation, surface reflectance | Landsat 7 ETM+ data were used to calculate NDVI, NDWI, and tasseled cap transformations for the land associated with twelve coal mining facilities in the Powder River Basin region of Wyoming at a 30 m2 resolution for the year 2012. These scenes were also used to develop a pixel-change time series analysis using LandTrendr in Google Earth Engine. |
| **Landsat 8 OLI** | NDVI, NDWI, tasseled cap transformation, surface reflectance | Landsat 8 OLI data were used to calculate NDVI, NDWI, and tasseled cap transformations for the land associated with twelve coal mining facilities in the Powder River Basin region of Wyoming at a 30 m2 resolution between 2013 and 2018. These scenes were also used to develop a pixel-change time series analysis using LandTrendr in Google Earth Engine. |

***Ancillary Datasets:***

* CHIRPS Pentad: Climate Hazards Group Infrared Precipitation with Station Date – Used for tracking changes in precipitation over the study area
* Energy Information Administration Production Data – Coal production data from Wyoming between 1984 to 2017 used for correlative tests
* United States Geological Survey (USGS) National Land Cover Database (NLCD) Gap Analysis – Used to determine the vegetation types and land cover of the Powder River Basin region
* United States Geological Survey (USGS) Gap Analysis Project Protected US Areas – Used to identify mine locations that are on publicly managed lands
* Wyoming Game and Fish Department sage-grouse core area and habitat mines data – Used to identify habitat areas of the endangered species that are in close proximity to surface mining
* Wyoming State Geological Survey (WSGS) Coal Maps – Used to establish active coal mining facility boundaries in the Powder River Basin region of Wyoming

***Software & Scripting:***

* Esri ArcGIS Pro – Map generation
* Google Earth Engine API – Construction of a web-based tool for monitoring land disturbances and reclamation efforts of the land associated with coal mining facilities
* R 3.6.1 – Data manipulation and analysis

***End Products:***

|  |  |  |  |
| --- | --- | --- | --- |
| **End Products** | **Earth Observations Used**  | **Partner Benefit & Use** | **Software Release Category** |
| **Land Disturbance Maps and Time Series Graphs** | Landsat 5 TM Landsat 7 ETM+Landsat 8 OLI | This product allows the partner to visualize where land disturbances have persisted over time to identify how and where mines have caused disturbance and are successfully completing reclamation. | I |
| **Water and Vegetation Maps and Time Series Graphs** | Landsat 5 TMLandsat 7 ETM+Landsat 8 OLI | Using NDVI, NDWI, and a tasseled cap transformation, these maps and graphs displayed changes in vegetation and water extent in mined areas from 1985 to 2018 in order to help the partner assess reclamation efforts in the region. | I |
| **Coal Mining Assessment Tool (CMAT)** | Landsat 5 TMLandsat 7 ETM+Landsat 8 OLI | This Google Earth Engine tool combines NDVI, NDWI, an image difference analysis, and tasseled cap transformations to analyze and visualize land disturbances and mining reclamation efforts for future partner use. | III |
| **CMAT Google Earth Engine Video Tutorial** | N/A | This video tutorial explains how to navigate the CMAT graphical user interface so that it can be used by partners for future monitoring. | N/A |

**Project Handoff Package**

***Transition Plan:*** Using NASA Large File Transfer, we sent all Handoff Package items, except CMAT, to Shannon Anderson, Dan Cohn, Dr. Mik Carbajales-Dale, and Christian Thomas at the end of the project term. We conducted a video conference in week 10 of the term with our partners and collaborators to explain our analyses, maps, and CMAT, which will be released after going through the NASA Software Release Process.

***Software Release Plan:*** The aforementioned video conference was held to provide the partners with an overview of CMAT prior to its release and to discuss deliverables, the tool, and overall findings before the end of the project term. Because CMAT was not immediately available to the partners at the end of the term, we also included a video tutorial in the Handoff Package for the partners to reference in the future. Our Software Release Package also included a README file detailing script application. Additionally, CMAT incorporates a graphical user interface to maintain accessibility across a range of audiences with varying levels of scripting experience.

***Team POC:*** Gina Cova, grosacova@gmail.com

***Software Release POC:*** Hayley Pippin, habpippin@berkeley.edu

***Partner POCs:*** Shannon Anderson, sanderson@powderriverbasin.org

 Dan Cohn, dcohn@worc.org
 Dr. Mik Carbajales-Dale, madale@clemson.edu
 Christian Thomas, christian@skytruth.org

***Handoff Package:***

* Poster
* Technical Paper
* Land Disturbance Maps and Time Series Graphs
* Water and Vegetation Maps and Time Series Graphs
* CMAT Google Earth Engine Video Tutorial

**References**

Alden, M. G. (2009). *Remote sensing techniques for monitoring coal surface mining and reclamation in the Powder River Basin* (Unpublished master's thesis). Retrieved from http://rave.ohiolink.edu/etdc/view?acc\_num=ohiou1257279388

Karan, S. K., Samadder, S. R., & Maiti, S. K. (2016). Assessment of the capability of remote sensing and GIS techniques for monitoring reclamation success in coal mine degraded lands. *Journal of Environmental Management*, *182*, 272-283. https://doi.org/10.1016/j.jenvman.2016.07.070

Kennedy, R. E., Yang, Z., Gorelick, N., Braaten, J., Cavalcante, L., Cohen, W. B., & Healey, S. (2018). Implementation of the LandTrendr Algorithm on Google Earth Engine. *Remote Sensing*, *10*(5), 691. https://doi.org/10.3390/rs10050691

Pei, W., Yao, S., Knight, J. F., Dong, S., Pelletier, K., Rampi, L. P., … Klassen, J. (2017). Mapping and detection of land use change in a coal mining area using object-based image analysis. *Environmental Earth Science*, *76*(125). https://doi.org/10.1007/s12665-017-6444-9

Powder River Basin Resource Council. (2018). *Reclaim Wyoming: Prioritize coal mine reclamation*. Sheridan, WY: Hesid Brandow. https://www.powderriverbasin.org/wp-content/uploads/2018/07/Coal-Mine-Reclamation-Web-Final.pdf