2023 FECM/NETL SPRING R&D PROJECT REVIEW MEETING – 4/18/2023

An Autonomous Robotic Inspection System for Coal Ash and Tailings Storage Facilities (FE0032177)

University Training and Research for Fossil Energy and Carbon Management – UCR

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Co-PI: Ihsan “Berk” Tulu (Mining Engineering)

WestVirginiaUniversity.

Benjamin M. Statler College of Engineering and Mineral Resources

Team

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  - Department of Mechanical and Aerospace Engineering – WVU
  - Specialist in Robotics
- **Ihsan “Berk” Tulu** – Co-PI
  - Department of Mining Engineering – WVU
  - Specialist in Geomechanics/Mine Safety and Health
- **Paulo Galvão Simplício** – PhD student
  - Mechanical Engineering
- **Mustafa Can Suner** – PhD student
  - Mining Engineering

Coal Ash and Tailing Dams

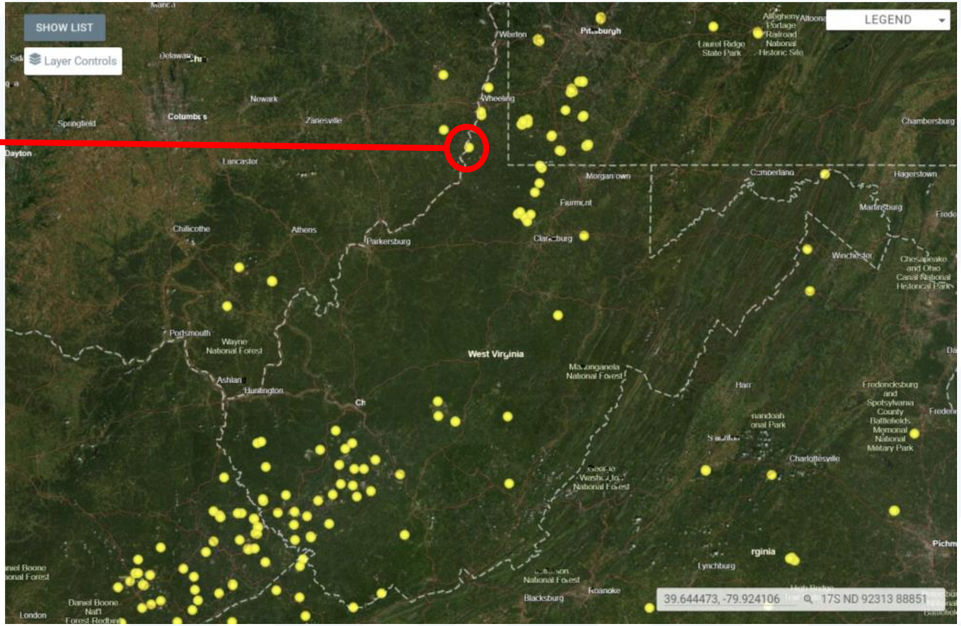
- **Tailings dams, impoundments**, **slurry ponds,** or **ash ponds** are facilities that store waste by-products from coal mine and coal-fired power plants.
- The US has more than 700 coal ash ponds.
- In WV only, at least 52 impoundments[1] are classified as high hazard level
  - failure may result in loss of life, significant economic losses, and/or environmental damage.
- Ash ponds contain contaminants like mercury, cadmium, and arsenic.

Brushy Fork impoundment, WV
31,000,000 m^3 of coal waste
Image: https://appvoices.org/

[1] https://nid.usace.army.mil/

Map of dams in Northern and Central Appalachia

Conner Run Refuse Impoundment, Wheeling, WV



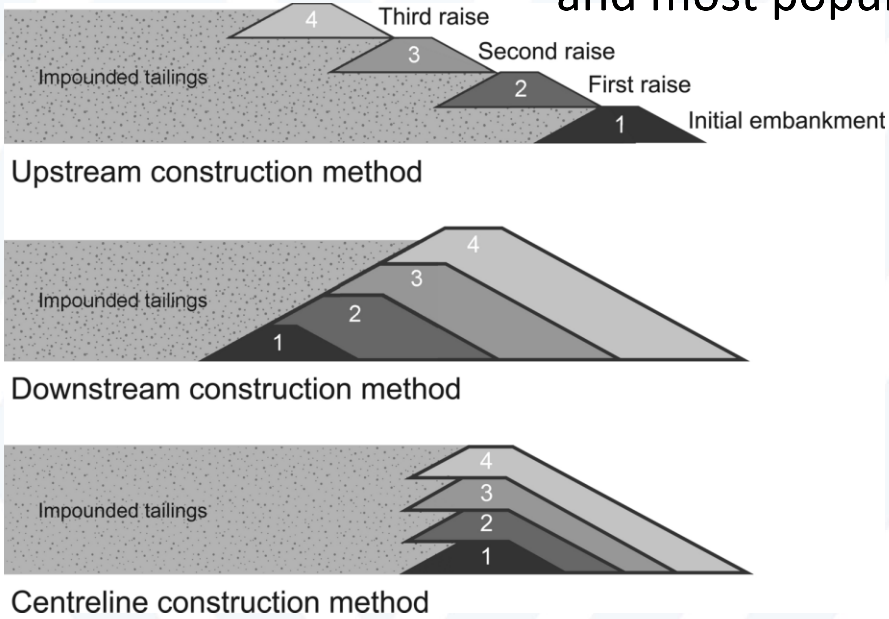
Source: US Army Corps of Engineers, National Inventory of Dams, Geographic Information System (GIS). https://nid.usace.army.mil/

Impound Construction

- Impounds are often embankment dam structures incrementally raised with the same waste they store.

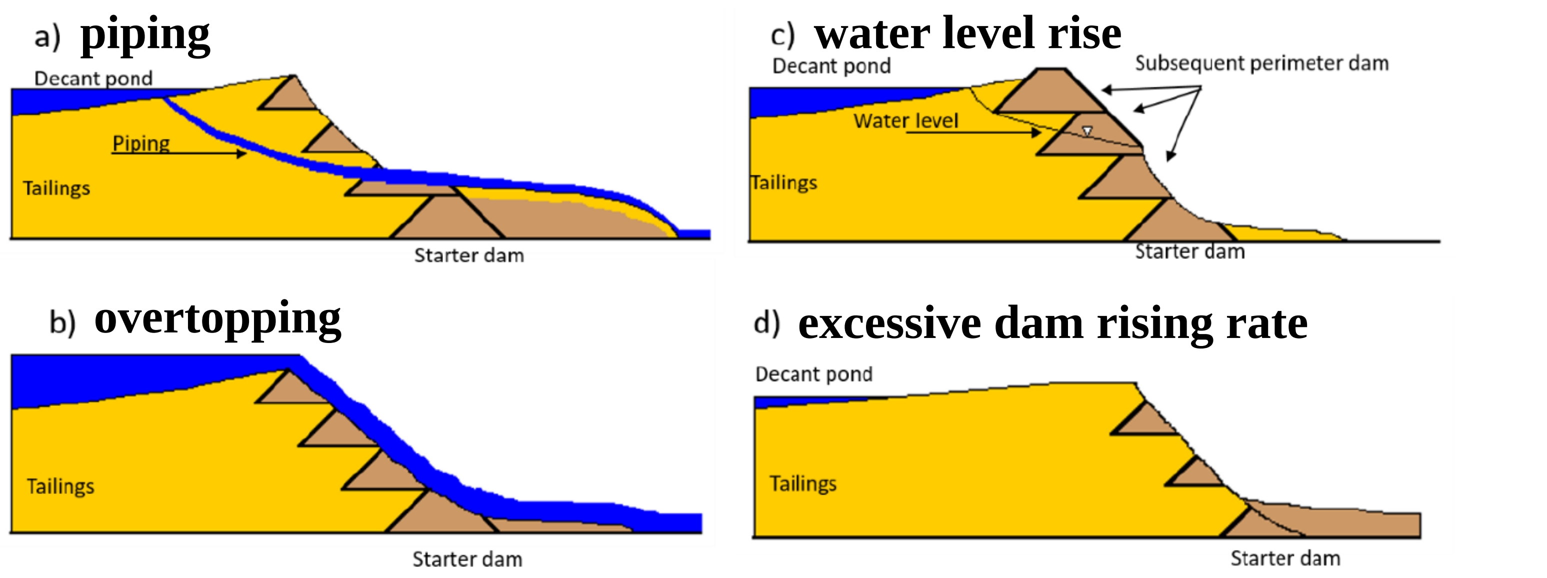
Lowest initial cost and most popular.

MSHA Handbook Series, Dam Inspection and Plan Review Handbook, Number PH21-V-6, January 2021



Lumbroso, D., Collell, M.R., Petkovsek, G. *et al.* DAMSAT: An Eye in the Sky for Monitoring Tailings Dams. *Mine Water Environ* **40**, 113–127 (2021).

Impound Liquefaction (Failure)



Pacheco, R. L. R. (2019). Static liquefaction in tailings dam and flow failure. *Madrid, SP*.

Impound Liquefaction

- Iron mining tailing dam, Brumadinho, Brazil, Jan. 2019
- 11.7 million m^3 of tailings were released
- 363 people died or are missing

https://www.youtube.com/watch?v=NK6EDKOys5E

Closer accidents

Dan River Steam Station, North Carolina, USA

Jan. 2014 - About 74,000 tons of coal ash and 27 million gallons of contaminated water flown through drainage pipe into Dan River.

https://www.nytimes.com/2014/03/01/us/coal-ash-spill-reveals-transformation-of-north-carolina-agency.html

Closer accidents

Dec. 2008 – A retention wall failed. The wave of coal ash and mud toppled power lines, covered roads and ruptured a gas line. It damaged 12 homes, and one person had to be rescued, though no one was seriously hurt.

Image: https://www.nrdc.org/

Closer accidents

Feb. 1972 - collapse of tailings dam after heavy rain; the tailings traveled 27 km downstream, 125 people lost their lives, 500 homes were destroyed. Property and highway damage exceeded $65 million.

Image: https://www.herald-dispatch.com/

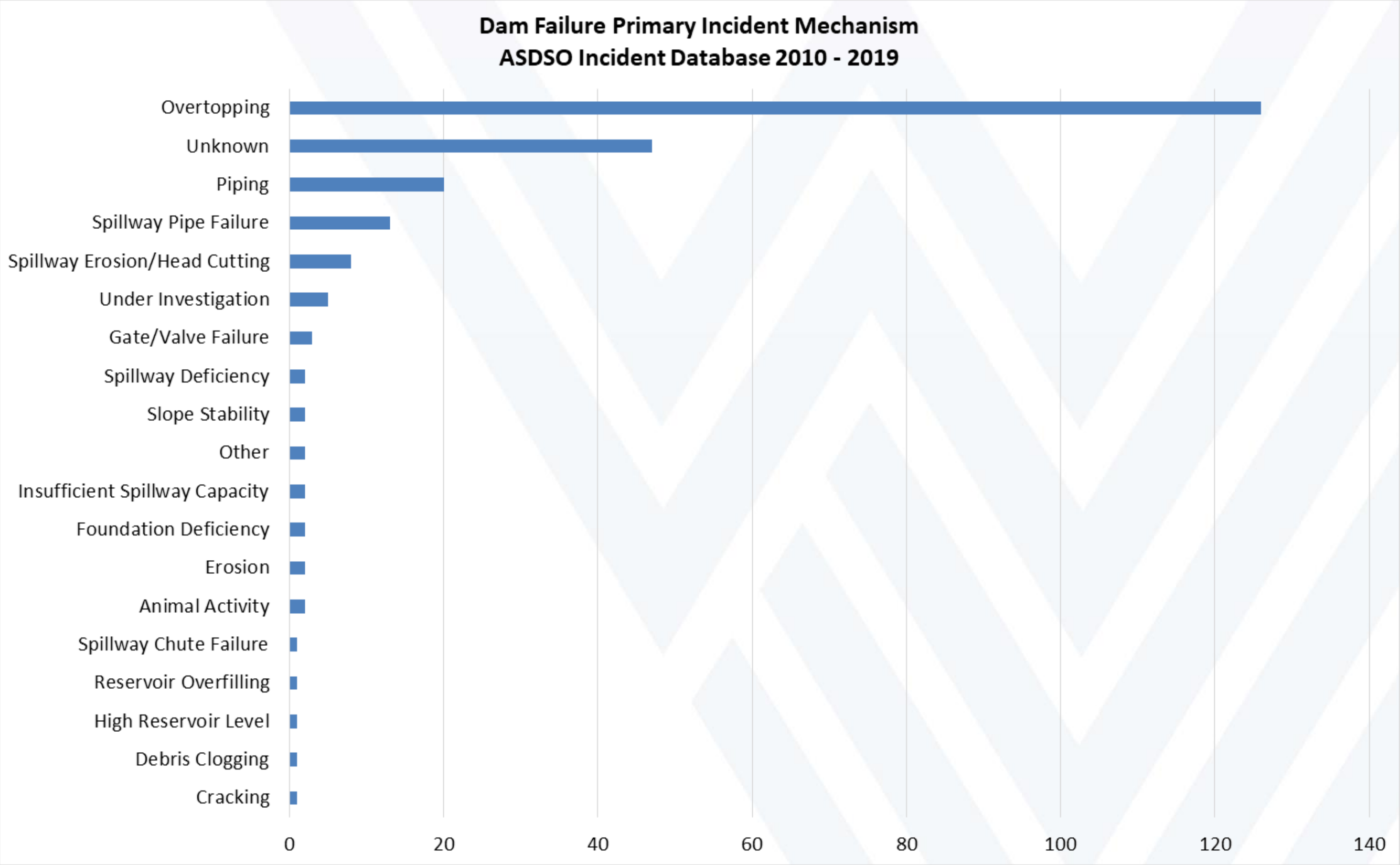
Main causes of accidents

- Clogged drains;
- Obstructed spillways;
- Settlement of the dam crest;
- Settlement and slope instability;
- Inadequate Maintenance
  - excess of vegetation, erosion, animal burrows;
- Cracking;
- Sink holes in the dam;
- Seepage.

Result in Overtopping (34% of accidents)

May result in Piping

https://damsafety.org/dam-failures



https://damsafety.org/dam-failures

Prevention: Inspection!

MSHA Dam Inspection Frequency

Condition	Inspection Frequency	Inspector
All dams associated with underground mines.	Once each quarter	Mine S&H Inspector
All dams associated with surface mines.	Once every 6 months	Mine S&H Inspector
All high hazard potential dams.	At least once each quarter	Impoundment Specialist/Inspector
All significant hazard potential dams.	At least every 6 months	Impoundment Specialist/Inspector
Critical construction activities at high and significant hazard potential dams. +	As needed *	Impoundment Specialist/Inspector
Unusual event (weather or seismic).	As needed **	Mine S&H Inspector or Impoundment Specialist/Inspector

MSHA Handbook Series, Dam Inspection and Plan Review Handbook, Number PH21-V-6, January 2021

Inspection

Common Inspection Frequencies for High or Significant Hazard Potential Dams

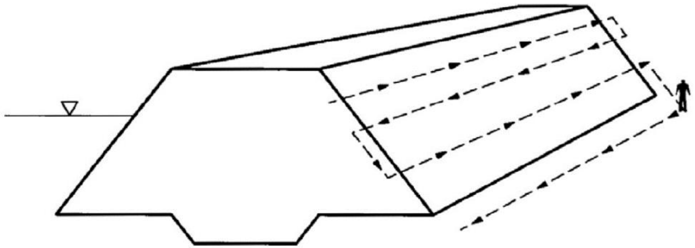
Inspection and Monitoring Category	Inspection and Monitoring Frequency
Construction inspections	Daily – Weekly
Informal inspections during operation	Daily
Normal inspections during operation	Every 7 days
Formal inspections during operation	Yearly
Extreme weather or first filling	As needed per occurrence
Seismic event	As needed, and see table below

MSHA Handbook Series, Dam Inspection and Plan Review Handbook, Number PH21-V-6, January 2021

Abandoned dams

- The long-term stability of the embankment and any seepage containment system is critical.
- To be considered abandoned, tailings dams need to be modified to ensure it is not capable of impounding water above the tailings.
- Inspection at its normal frequency should continue until the site is abandoned according to the design plan.

Suggested inspection (MSHA)

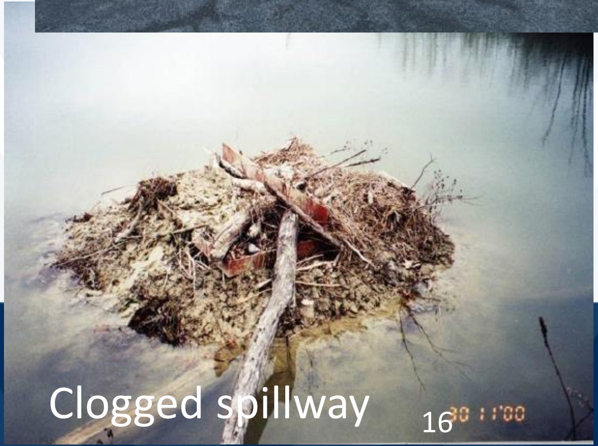


Seepage on downstream slope

Sinkhole in pool area

Crack on the crest

Cracks on embankment slope



Clogged spillway

MSHA Handbook Series, Dam Inspection and Plan Review Handbook, Number PH21-V-6, January 2021

This project

MSHA recommended inspection equipment

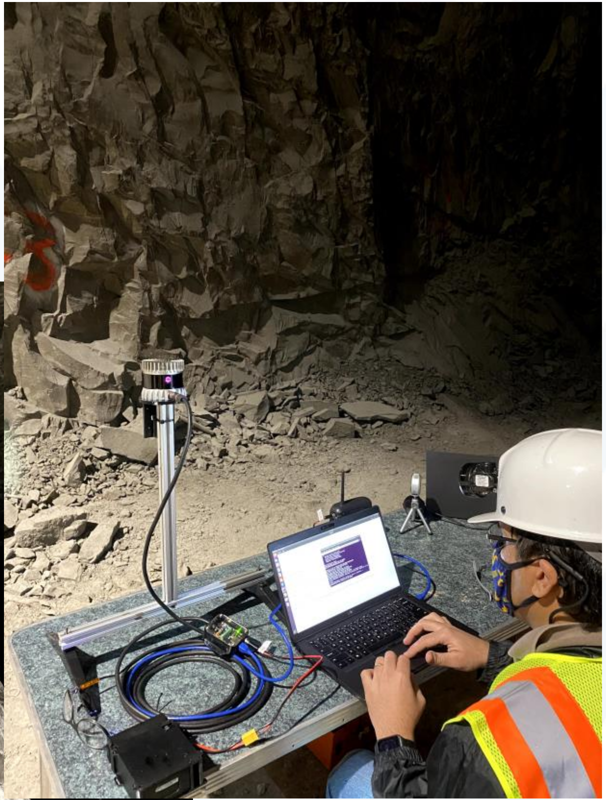
- Note pad / Inspection form
- Weir and pipe flow charts
- Camera and extra batteries
- Calculator
- Global Positioning Unit (GPS)
- Measuring tape and 6-foot ruler
- Range finder or Abney level
- Water level indicator
- Survey ribbon
- Graduated bucket or container of known volume
- Clear container for checking clarity of flow
- Watch or timer
- Binoculars
- Handheld spotlight

Our proposed equipment

Objectives

- Develop a robotic drone, equipped with several complementary sensors, that will autonomously inspect several structures of a storage facility;
- Create AI-based hazard detection algorithms that will use multispectral and georeferenced images (i.e., thermal and visual) and 3D Point Clouds to detect hazards in the storage facility structure.

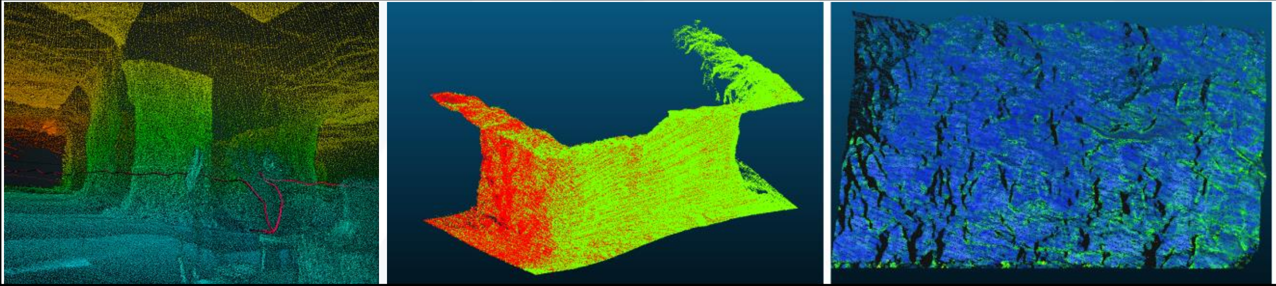
Previous work



Previous work

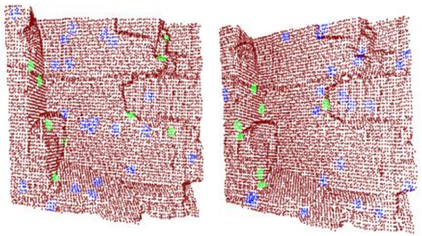
Robotic Inspection

Robotic System Output

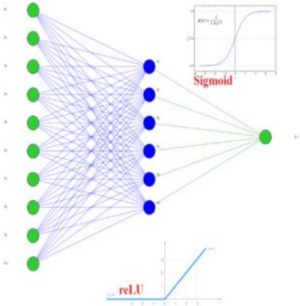


Sampling and Neural Network Training of the Data

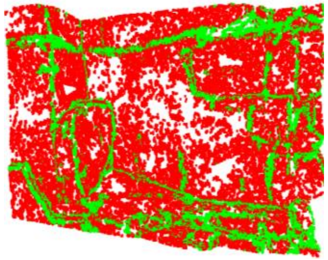
3D Point Cloud Sampling



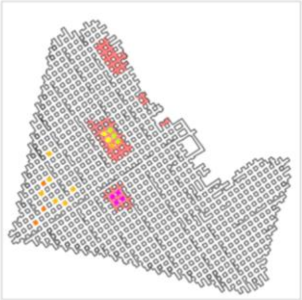
Simple Structure of Neural Network



Classified Discontinuities



Hazard Mapping

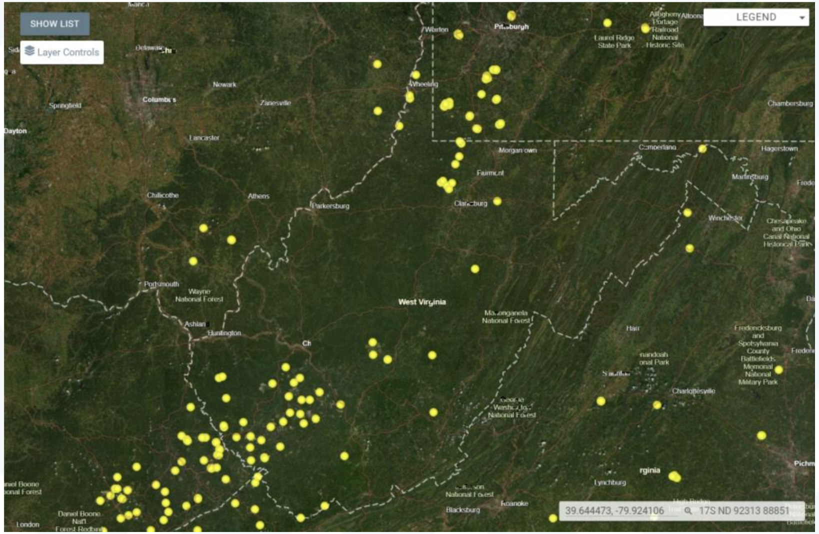


This project: Technical Approach

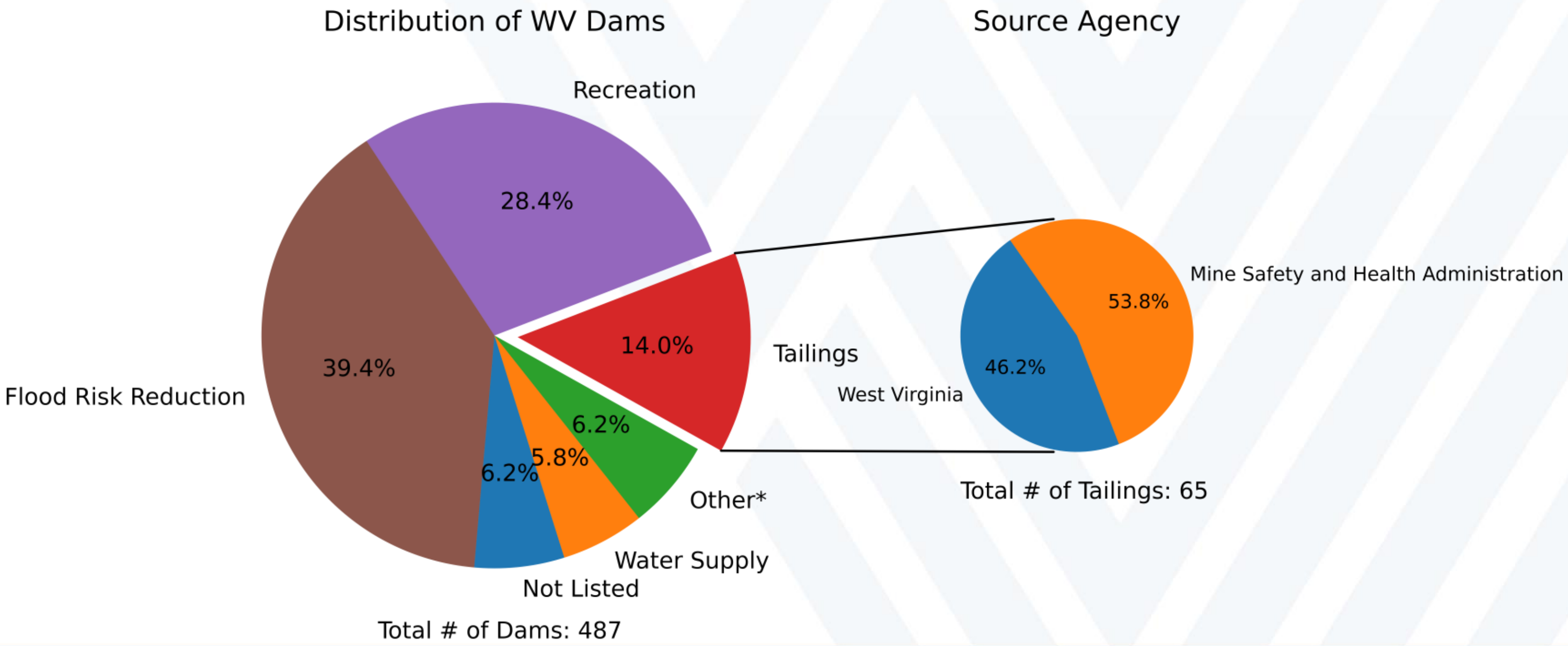
- Task 1.0 – Project Management and Planning
- Task 2.0 – Configuration assessment of coal refuse facilities and programming of autonomous inspection logics
  - 2.1 Preliminary facility configuration assessment
  - 2.2 Detailed assessment of inspection structures and locations
  - 2.3 Development of autonomous inspection logics
- Task 3.0 – Drone assembly and programming
  - 3.1 – Drone assembly
  - 3.2 – Inspection of open-channel spillways and principal spillway inlets/outlets
  - 3.3 – 3D mapping of dam’s crest and slopes
  - 3.4 – Detection of leaking due to seepage through embankment slope and foundation
- Task 4.0 – Development of hazard detection software and user interface
  - 4.1 – Hazard detection
  - 4.2 – User Interface application

2.1 – Preliminary facility configuration assessment

- Database with some characteristics of coal waste facilities in WV and neighboring states.
- Source: US Army Corps of Engineers, National Inventory of Dams (NID)



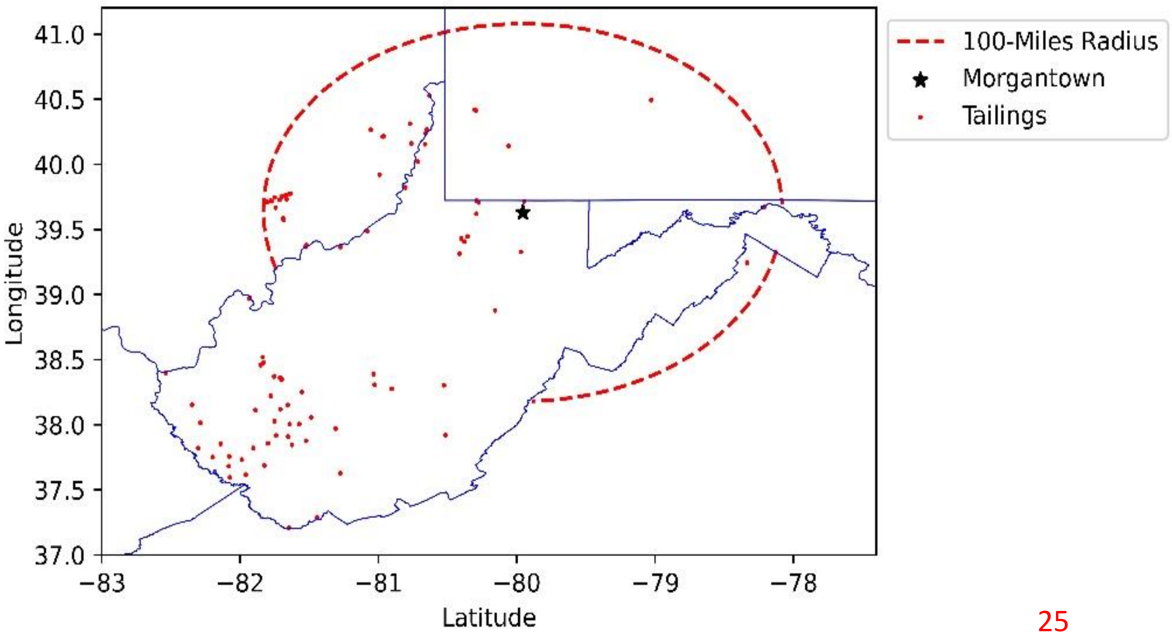
Dams in WV



Distribution of WV Dams
Source Agency
Recreation
28.4%
39.4%
Flood Risk Reduction
14.0%
Tailings
6.2%
5.8%
6.2%
Other*
Water Supply
Not Listed
Total # of Dams: 487
Mine Safety and Health Administration
53.8%
46.2%
West Virginia
Total # of Tailings: 65

Characteristics of the database

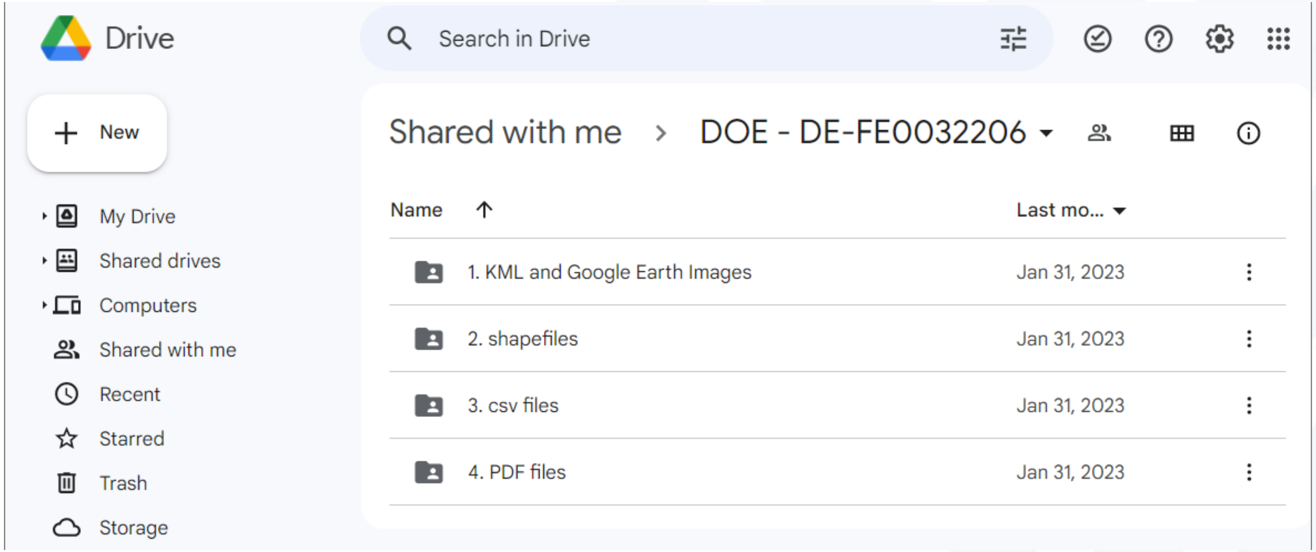
- Tailing dams in WV and 100 miles radius from Morgantown
  - 65 from WV
  - 29 from OH
  - 4 from PA
  - 1 from VA



Characteristics of the database

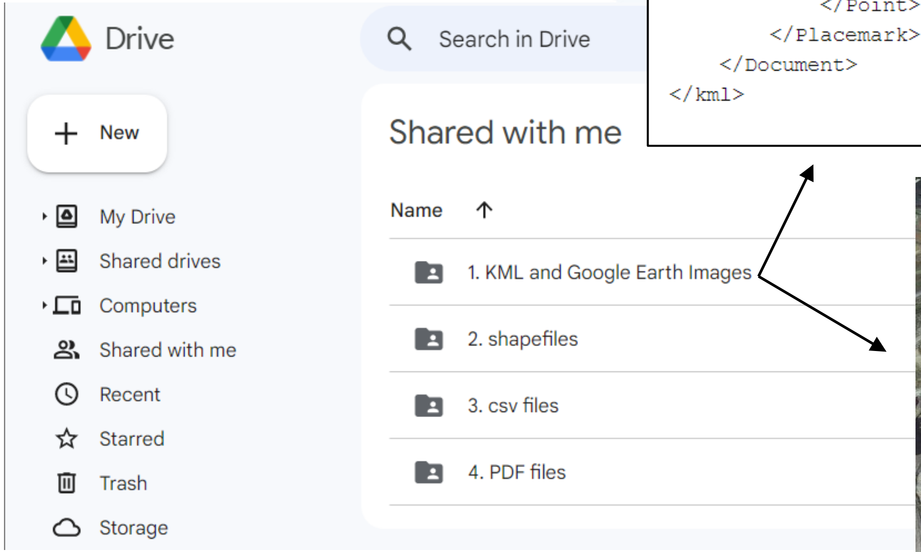
- The database consists of
  1. Keyhole Markup Language (KML)
     - used to visualize storage facilities and their NID data on Google Earth
  2. shapefile with NID (National Inventory of Dams) data of the facilities
  3. csv files with NID data of the facilities
  4. pdf and drawing files with the imported google image
     - will be used for detailed analysis.

Characteristics of the database



Characteris

```xml
<?xml version="1.0" encoding="UTF-8"?>
<kml xmlns="http://www.opengis.net/kml/2.2" xmlns:gx="http://www.google.com/kml/ext/2.2">
    <Document id="1367">
        <Placemark id="1369">
            <name>Moccasin Hollow Impoundment</name>
            <Point id="1368">
                <coordinates>-81.48611111,38.056400000000004,0.0</coordinates>
            </Point>
        </Placemark>
    </Document>
</kml>
```



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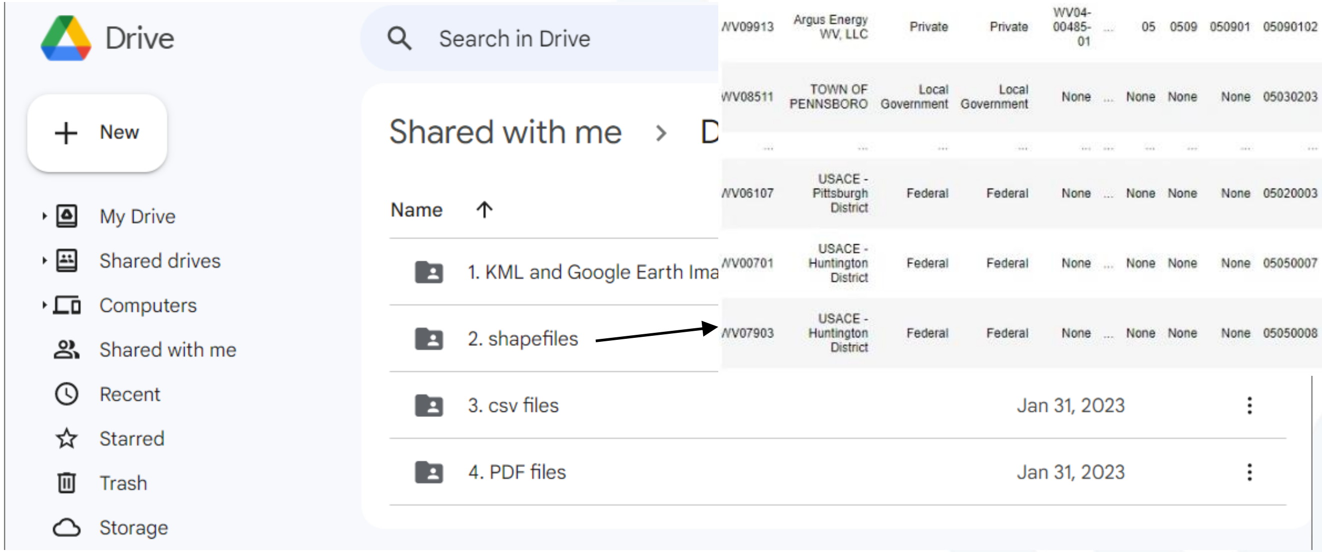

federalI	ownerNam	ownerTyp	primaryO	stateFed	...	huc2	huc4	huc6	huc8	zipcode	nation	stateKey	femaRegi	femaComm	geometry
WV03520	WV BAPTIST CONVENTION	Private	Private	None	...	None	None	None	05030202	25271	USA	WV	5	Jackson County, West Virginia	POINT (-81.75778 38.79833)
WV01702	WV DOH	State	State	None	...	None	None	None	05030201	26456	USA	WV	5	Doddridge County, West Virginia	POINT (-80.74322 39.29048)
WV05120	WHEELING CREEK WATERSHED COMMISSION	Local Government	Local Government	None	...	None	None	None	05030106	26033	USA	WV	None	Marshall County, West Virginia	POINT (-80.52500 39.95167)
WV09913	Argus Energy WV, LLC	Private	Private	WV04-00485-01	...	05	0509	050901	05090102	25511	USA	WV	5	Wayne County, West Virginia	POINT (-82.28722 38.01389)
WV08511	TOWN OF PENNSBORO	Local Government	Local Government	None	...	None	None	None	05030203	26415	USA	WV	5	Ritchie County, West Virginia	POINT (-80.92556 39.28139)
...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
WV06107	USACE - Pittsburgh District	Federal	Federal	None	...	None	None	None	05020003	26501	USA	WV	2	Monongalia County, West Virginia	POINT (-80.00998 39.58247)
WV00701	USACE - Huntington District	Federal	Federal	None	...	None	None	None	05050007	26601	USA	WV	None	Braxton County, West Virginia	POINT (-80.69294 38.66160)
WV07903	USACE - Huntington District	Federal	Federal	None	...	None	None	None	05050008	25168	USA	WV	5	Putnam County, West Virginia	POINT (-81.91307 38.52659)

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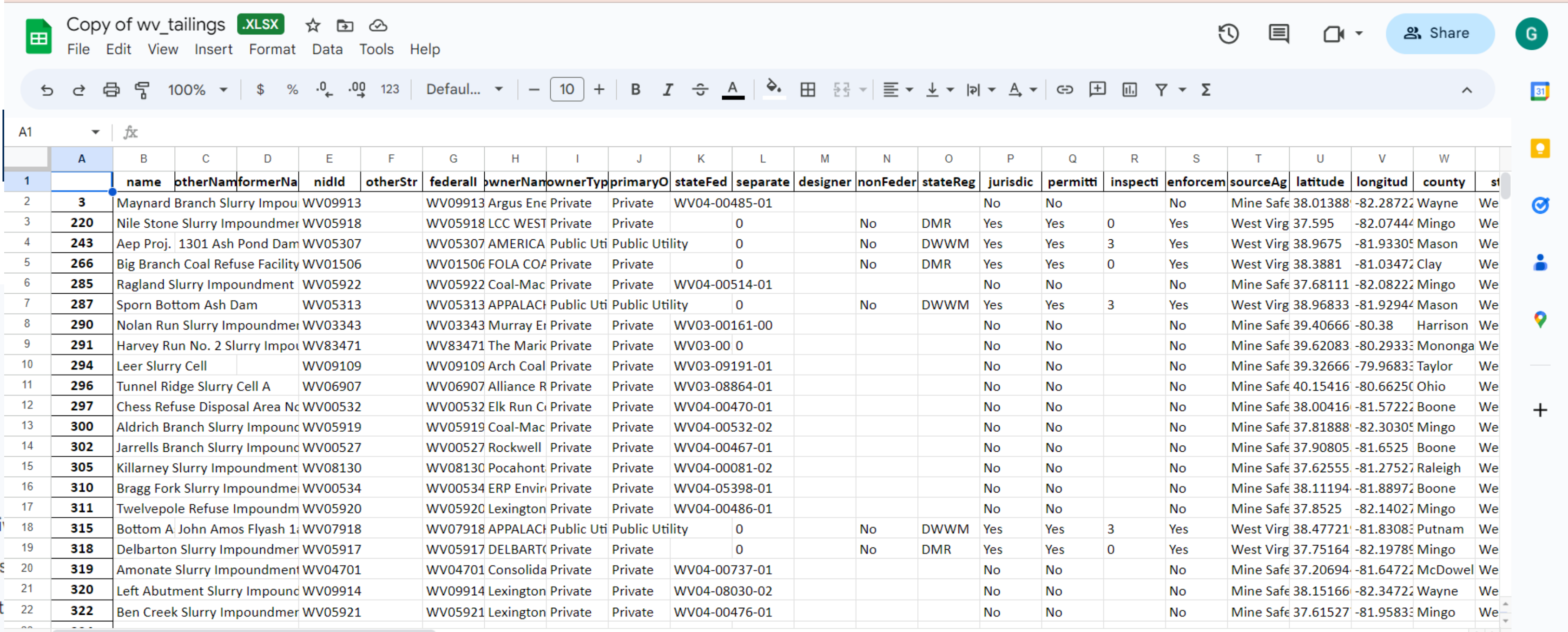
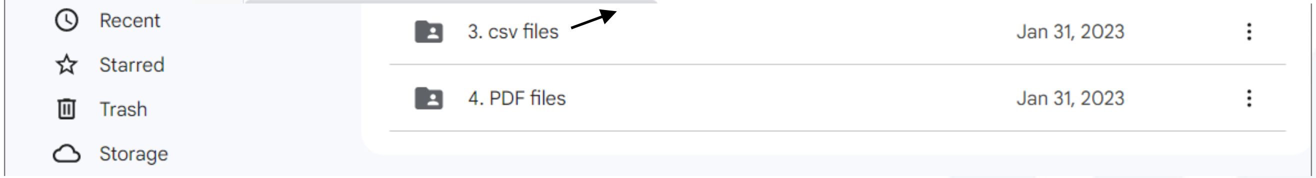
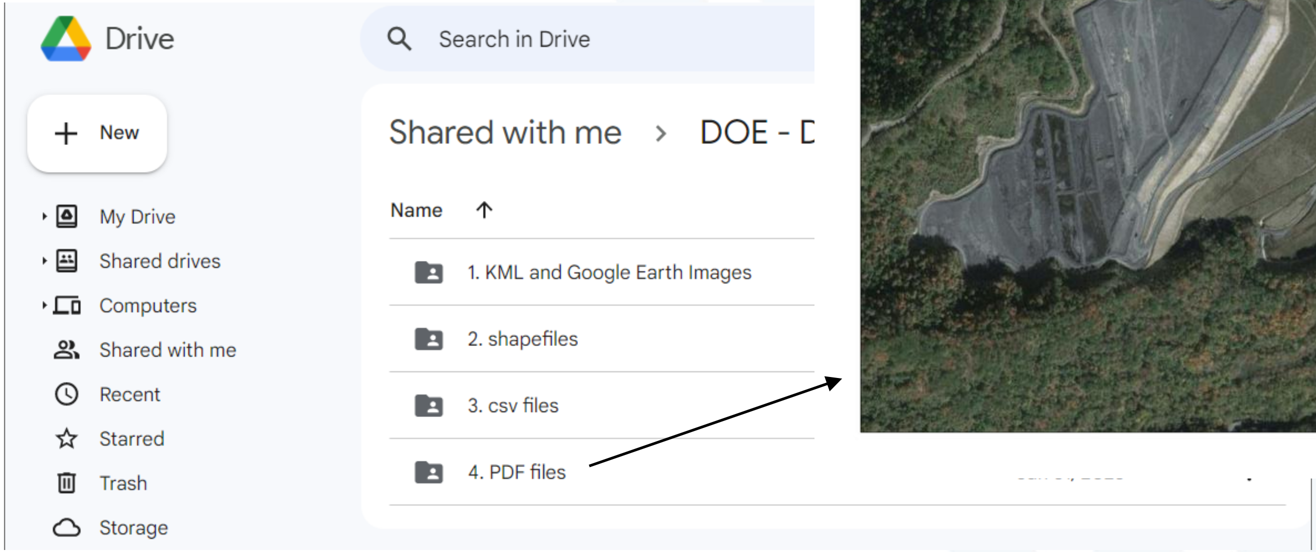


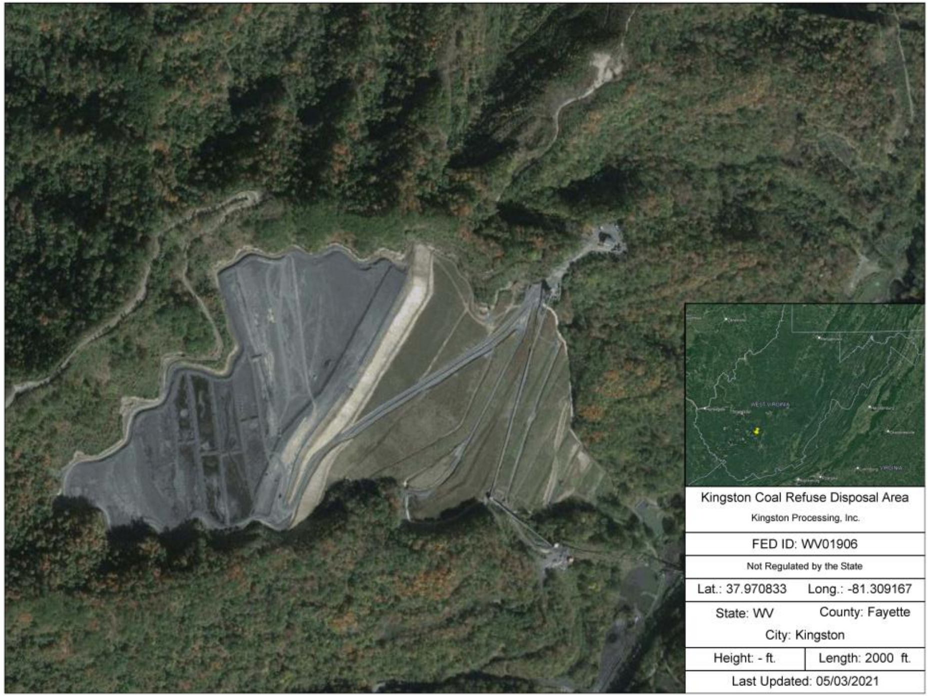
Copy of wv_tailings .XLSX

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X
1		name	otherNam	formerNa	nidId	otherStr	federalI	ownerNam	ownerTyp	primaryO	stateFed	separate	designer	nonFeder	stateReg	jurisdic	permitti	inspecti	enforcem	sourceAg	latitude	longitud	county	st
2	3	Maynard Branch Slurry Impou			WV09913		WV09913	Argus Ene	Private	Private	WV04-00485-01					No	No		No	Mine Safe	38.01388	-82.28722	Wayne	We
3	220	Nile Stone Slurry Impoundmer			WV05918		WV05918	LCC WEST	Private	Private		0		No	DMR	Yes	Yes	0	Yes	West Virg	37.595	-82.07444	Mingo	We
4	243	Aep Proj. 1301 Ash Pond Dam			WV05307		WV05307	AMERICA	Public Uti	Public Utility		0		No	DWWM	Yes	Yes	3	Yes	West Virg	38.9675	-81.93305	Mason	We
5	266	Big Branch Coal Refuse Facility			WV01506		WV01506	FOLA COA	Private	Private		0		No	DMR	Yes	Yes	0	Yes	West Virg	38.3881	-81.03472	Clay	We
6	285	Ragland Slurry Impoundment			WV05922		WV05922	Coal-Mac	Private	Private	WV04-00514-01					No	No		No	Mine Safe	37.68111	-82.08222	Mingo	We
7	287	Sporn Bottom Ash Dam			WV05313		WV05313	APPALACH	Public Uti	Public Utility		0		No	DWWM	Yes	Yes	3	Yes	West Virg	38.96833	-81.92944	Mason	We
8	290	Nolan Run Slurry Impoundmer			WV03343		WV03343	Murray Er	Private	Private	WV03-00161-00					No	No		No	Mine Safe	39.40666	-80.38	Harrison	We
9	291	Harvey Run No. 2 Slurry Impou			WV83471		WV83471	The Maric	Private	Private	WV03-00	0				No	No		No	Mine Safe	39.62083	-80.29333	Monongа	We
10	294	Leer Slurry Cell			WV09109		WV09109	Arch Coal	Private	Private	WV03-09191-01					No	No		No	Mine Safe	39.32666	-79.96833	Taylor	We
11	296	Tunnel Ridge Slurry Cell A			WV06907		WV06907	Alliance R	Private	Private	WV03-08864-01					No	No		No	Mine Safe	40.15416	-80.66250	Ohio	We
12	297	Chess Refuse Disposal Area Nc			WV00532		WV00532	Elk Run Cc	Private	Private	WV04-00470-01					No	No		No	Mine Safe	38.00416	-81.57222	Boone	We
13	300	Aldrich Branch Slurry Impounc			WV05919		WV05919	Coal-Mac	Private	Private	WV04-00532-02					No	No		No	Mine Safe	37.81888	-82.30305	Mingo	We
14	302	Jarrells Branch Slurry Impounc			WV00527		WV00527	Rockwell	Private	Private	WV04-00467-01					No	No		No	Mine Safe	37.90805	-81.6525	Boone	We
15	305	Killarney Slurry Impoundment			WV08130		WV08130	Pocahont	Private	Private	WV04-00081-02					No	No		No	Mine Safe	37.62555	-81.27527	Raleigh	We
16	310	Bragg Fork Slurry Impoundme			WV00534		WV00534	ERP Envir	Private	Private	WV04-05398-01					No	No		No	Mine Safe	38.11194	-81.88972	Boone	We
17	311	Twelvepole Refuse Impoundm			WV05920		WV05920	Lexington	Private	Private	WV04-00486-01					No	No		No	Mine Safe	37.8525	-82.14027	Mingo	We
18	315	Bottom A John Amos Flyash 1			WV07918		WV07918	APPALACH	Public Uti	Public Utility		0		No	DWWM	Yes	Yes	3	Yes	West Virg	38.47721	-81.83083	Putnam	We
19	318	Delbarton Slurry Impoundmer			WV05917		WV05917	DELBARTO	Private	Private		0		No	DMR	Yes	Yes	0	Yes	West Virg	37.75164	-82.19789	Mingo	We
20	319	Amonate Slurry Impoundment			WV04701		WV04701	Consolida	Private	Private	WV04-00737-01					No	No		No	Mine Safe	37.20694	-81.64722	McDowel	We
21	320	Left Abutment Slurry Impounc			WV09914		WV09914	Lexington	Private	Private	WV04-08030-02					No	No		No	Mine Safe	38.15166	-82.34722	Wayne	We
22	322	Ben Creek Slurry Impoundmer			WV05921		WV05921	Lexington	Private	Private	WV04-00476-01					No	No		No	Mine Safe	37.61527	-81.95833	Mingo	We



Characteristic





WestVirginiaUniversity

Preliminary analysis

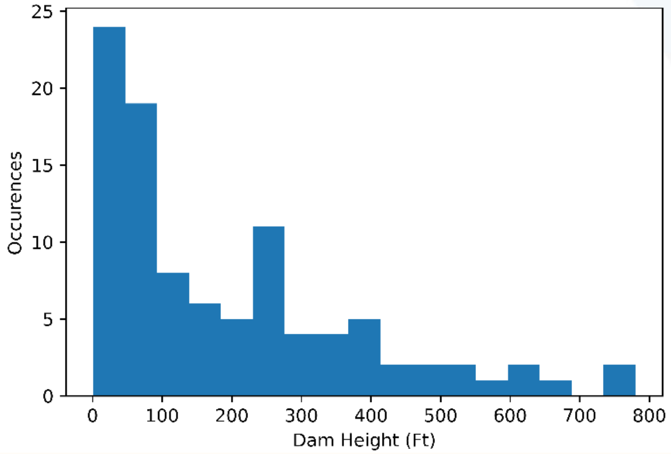
- Hazard levels (Tailing Dams in WV)
  - 52 – **High**
    - Failure would likely result in loss of human life, extensive property damage to homes and other structures, or cause flooding of major highways such as State roads or interstates
  - 8 – **Significant**
    - Failure could possibly result in loss of life or increase flood risks to roads and buildings, with no more than 2 houses impacted and less than six lives in jeopardy
  - 1 – **Low**
    - Failure is unlikely to result in loss of life and only minor increases to existing flood levels at roads and buildings is expected.
  - 4 – **Undetermined**

Preliminary analysis

- some of the facilities in the database were reclaimed and are not active.

Preliminary analysis

- parameters relevant to the project objectives: dam height, dam length, hydraulic height, structural height, and surface area.

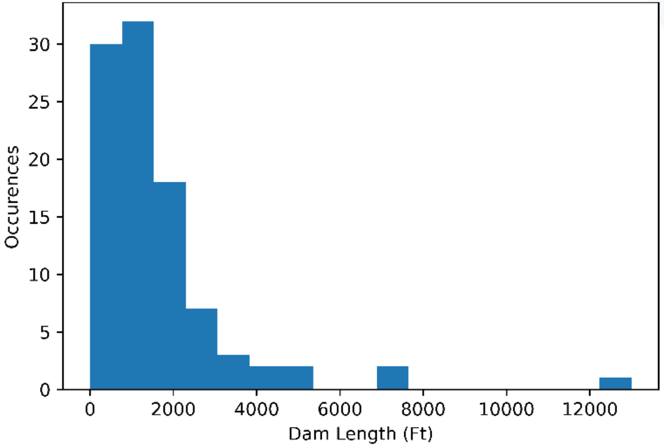


Dam Height: *vertical distance between the lowest point on the crest of the dam and the lowest point in the original streambed*

Mean height: 193 ft (59m)
Max height: 780 ft (238 m)

Preliminary analysis

- parameters relevant to the project objectives: dam height, dam length, hydraulic height, structural height, and surface area.

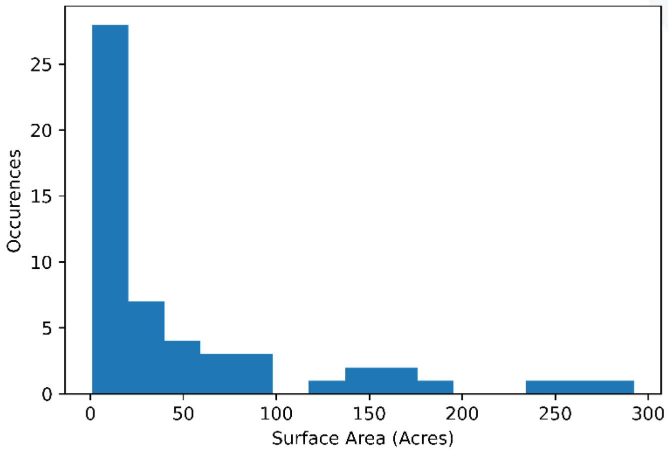


Dam Length: *length along the top of the dam*

Mean Length: 1,624 ft (0.3 miles)
Maximum Length: 13,000 ft (2.5 miles)

Preliminary analysis

- parameters relevant to the project objectives: dam height, dam length, hydraulic height, structural height, and surface area.



Surface Area: *Surface area, in acres, of the impoundment at its normal retention level*

Mean Area: 53 acres
Maximum Area: 292 acres

Next steps…

2.2 – Detailed Assessment of inspection structures and locations

- field survey of some coal waste facilities in WV
- use of drones, hand-held devices and cameras.

Nest steps…

2.3 – Autonomous inspection logics

- Development of drone inspection logics according to *MSHA Dam Inspection and Plan Review Manual,* and consultation with a MSHA inspector and facility operators
- Determination inspection parameters of each critical structural component
  - flight path
  - flight distance to the structure
  - type of sensor and monitoring data

3.1 – Drone assembly

- Purchase, assembly, test, and initial programing of the drone.
- Ground control station (laptop)
  - Robot Operating System (ROS)
  - Data collection and storage
  - Motion planning and execution

Drone selection - criteria

- Required
  - Made in USA (to comply with DOE FOA)
  - Remote ID (to comply with FAA)
  - Programable by a computer with SDK (necessary for automation)
  - RGB Image (required for Dam inspection)
  - Thermal Image (required for Seepage detection)
  - Lidar (required for 3D Mapping)
- Desirable
  - NDAA & TAA compliant (to facilitate use by governmental agencies)
  - RTK (for precise positioning)
  - Easy operation (to facilitate transfer of technology)
  - Affordable (to facilitate transfer of technology)

WestVirginiaUniversity

FAA - Federal Aviation Administration
NDAA - National Defense Authorization Act
TAA - Trade Agreements Act

Drone selection

Model	Company	Country	SDK Control	SDK Payload	RGB Resolution	Gimbal	Thermal	RTK	Payload (for LIDAR)	Price
M300 RTK	DJI	China	Yes	Yes	20 MB Zoom	Yes	Payload H20T	Yes	2.7 kg	$29,500
M210 RTK	DJI	China	Yes	Yes	12 MP	Yes	Payload XT2 FLIR	Yes	1.4 kg	$15,100
Anafi USA	Parrot	France	Ground SDK	Yes	21 MP	Yes	Included	No	00 kg	$7,000
Anafi USA GOV	Parrot	USA	Ground SDK	Yes	21 MP	Yes	Included	No	00 kg	$14,000
Anafi AI	Parrot	France	Yes	Yes	48 MP	Yes	No	No	00 kg	$ 4,500
Anafi Thermal	Parrot	France	Ground SDK	No	21 MP	Yes	Included	No	00 kg	$3,500
Siras	Teledyne Flir	USA	No	No	16 MP	Yes	Included	No	00 kg	$9,695
X2D - Thermal	Skydio	USA	No	No	12.3 MP	Yes	Included	No	00 kg	$10,999
Astro Map	Freefly	USA	MAVSDK	No	61 MP	Yes	No	Yes	1.5 kg	$24,109
Alta X	Freefly	USA	MAVSDK	Wiris Payload	RGB Payload	Yes	No	Yes	15.87 kg	$24,220
Commander 2	Draganflyer	Canada	No	No	RGB Payload	Yes	Payload Thermal	Yes	1.0 kg	$17,107
EVO II DUAL 640T V2	Autel	USA/China	Mobile SDK	Mobile SDK	48 MP	Yes	Included	Optional	150 g	$4,800
EVO II RTK V2	Autel	USA/China	Mobile SDK	Mobile SDK	48 MP	Yes	Included	Yes	150 g	$4,800
EVO II 640T V3	Autel	USA/China	Mobile SDK	Mobile SDK	50 MP	Yes	Included	Optional	150 g	$5,999
EVO II 640T RTK	Autel	USA/China	Mobile SDK	Mobile SDK	50 MP	Yes	Included	No	150 g	$7,699
EVO Max 4T	Autel	USA/China	Mobile SDK	Mobile SDK	50 MP	Yes	Included	Optional	150 g	$8,999
Accent X/X8	CamFlite	USA	No	No	RGB Payload	Yes	No	Yes	4.5 kg	$26,673
H520E-RTK	Yuneec	China	No	No	20 MP	Yes	Payload CGORTX	Yes	??	$16,300

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ANAFI USA GOV drone

- Required
  - ✓ Made in USA (to comply with DOE FOA)
  - ✓ Remote ID (to comply with FAA)
  - ✓ Programable by a computer with SDK (necessary for automation)
  - ✓ RGB Image (required for Dam inspection)
  - ✓ Thermal Image (required for Seepage detection)
  - ✗ Lidar (required for 3D Mapping)
- Desirable
  - ✓ NDAA & TAA compliant (to facilitate use by governmental agencies)
  - ✗ RTK (for precise positioning)
  - ✓ Easy operation (to facilitate transfer of technology)
  - ✓ Affordable (to facilitate transfer of technology)

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FAA - Federal Aviation Administration
NDAA - National Defense Authorization Act
TAA - Trade Agreements Act

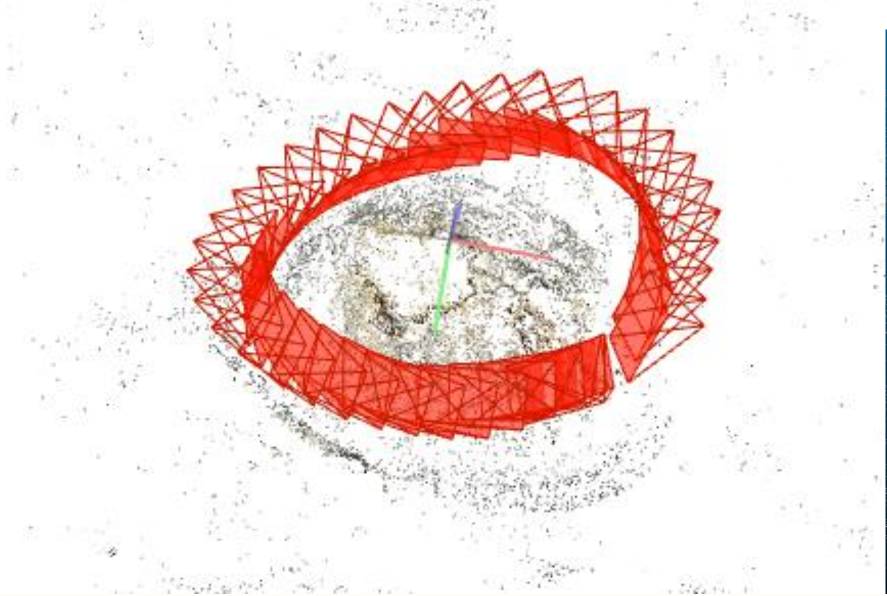
Do we need Lidar and RTK?

https://youtu.be/2cBsiPxzV44

Lidar - Light Detection and Ranging (creates 3D point clouds)
RTK - Real-time kinematic positioning (increase positioning accuracy)

Do we need Lidar and RTK?

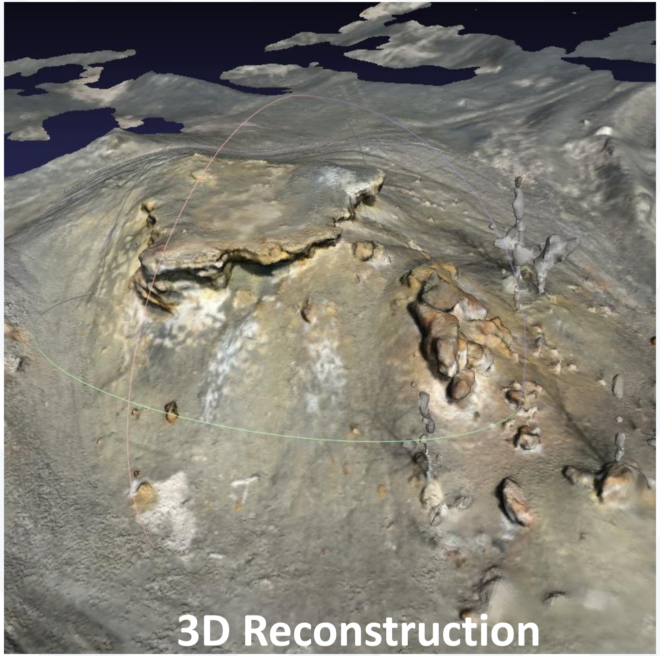
Results from COLMAP[1] free software



[1]Schönberger, J. L., Zheng, E., Frahm, J. M., & Pollefeys, M. (2016). Pixelwise view selection for unstructured multi-view stereo. In *Computer Vision–ECCV 2016: 14th European Conference, Amsterdam, The Netherlands, October 11-14, 2016, Proceedings, Part III 14* (pp. 501-518). Springer International Publishing.

Do we need Lidar and RTK?

Original image

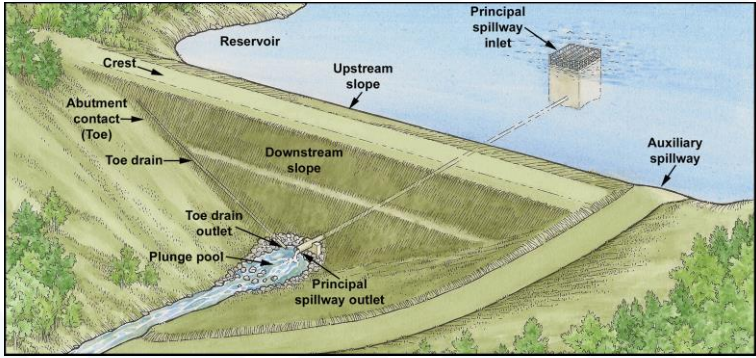


3D Reconstruction

Next steps…

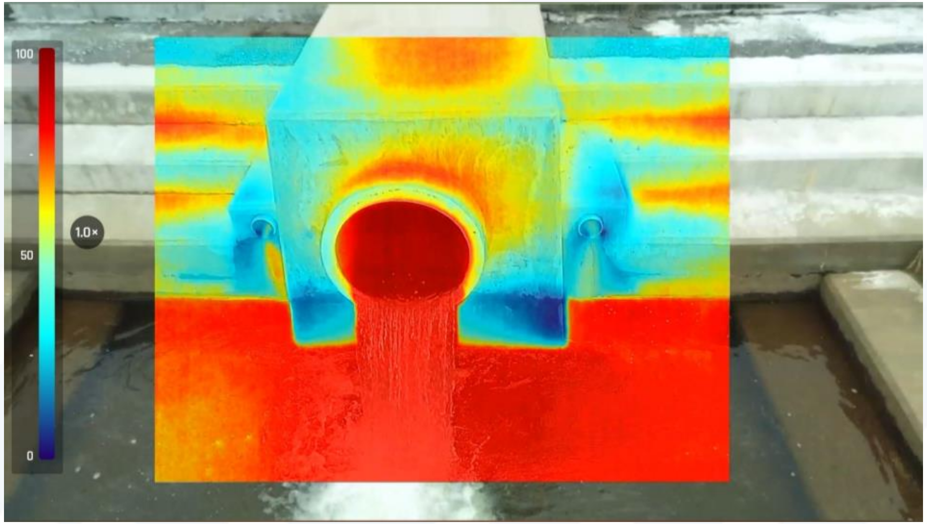
3.2 – Inspection of spillways

- development of software to autonomously inspection open-channel spillways and principal spillway inlets/outlets with the drone.
- Structure position using GPS.
- Object detection using computer vision and AI.

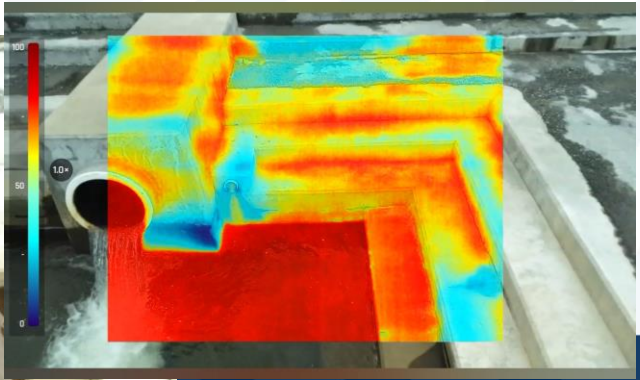


https://dnr.nebraska.gov/dam-safety/common-problems-dams
https://www.ars.usda.gov/

Initial data



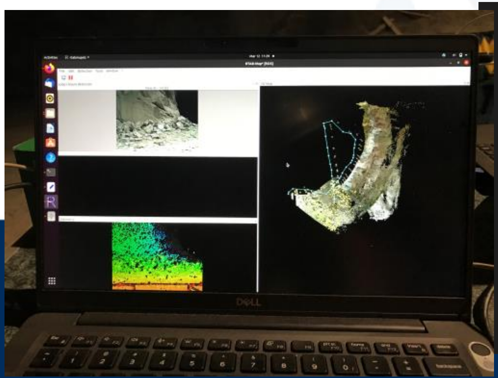
principal spillway outlets



Next steps…

3.3 – 3D mapping of dams

- development of a software that creates tri-dimensional maps of coal waste facilities with a drone
- Focus on crest and slope
- Investigations on required resolution, optimal coverage, etc.



https://skytographerz.com/

Next steps…

3.4 – Seepage detection

- development of software to detect leaking and infiltration in the embankment slope and foundation of coal waste facilities using the drone.
- Computer vision based on thermal images.
- Investigation of the best weather, season, time of day, distance to the structure, etc.

Next steps…

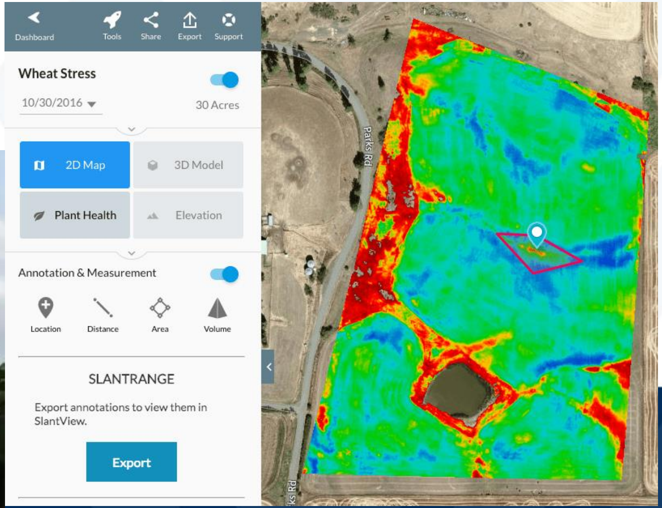
4.1 – Hazard detection

- development of algorithms for hazard detection in coal waste facilities using data collected by the drone
- AI-based software
  - Comparison of time-lapse data (images, LIDAR point clouds)
    - Erosion and crack
    - Excess of vegetation
    - Animal activity, etc

Next steps…

4.2 – User interface

- development of a user interface to facilitate drone control and hazard detection



https://www.dronedeploy.com/

Timeline

Task #	Task name	Year 1				Year 2				Year 3			
		Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
1.0	**Project Management and Planning**												
2.0	**Configuration assessment of coal refuse facilities and programming of autonomous inspection logics**												
2.1	Preliminary facility configuration assessment												
2.2	Detailed assessment of inspection structures and locations												
2.3	Development of autonomous inspection logics												
3.0	**Drone assembly and programming**												
3.1	Drone assembly												
3.2	Inspection of open-channel spillways and principal spillway inlets/outlets												
3.3	3D mapping of dam's crest and slopes												
3.4	Detection of leaking due to seepage through embankment slope and foundation												
4.0	**Development of hazard detection software and user interface**												
4.1	Hazard detection												
4.2	User Interface application												

Project Benefits

- At least 4 students trained in multidisciplinary technology
  - 2 PhD students
  - At least 2 undergraduate students (to be hired)
  - Recruitment focused on underrepresented groups
- Efficient methodology/technology for coal storage facility inspection
  - Reduced time of inspection
  - Increase in inspection frequency
  - Automatic logging and archiving

Project Benefits

- More efficient inspection may help prevent accidents
  - Social impact
  - Environmental impact
- Technology transfer
  - TRL 5 expected at the end of the project (Technology validated in relevant environment)
  - Stakeholders feedback and use

Acknowledgments

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Thank you!

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