

Enhancing Geomorphic Reclamation through 3D Soil Modeling

1

Insights from an Abandoned Uranium Mine in Wyoming

Challenge

Understand and quantify the distribution, quantity and quality of soil resources

2

Purpose

Provide designers with data for placement of hot material, fill and suitable growth media

Determine quality, quantity and location of suitable growth media

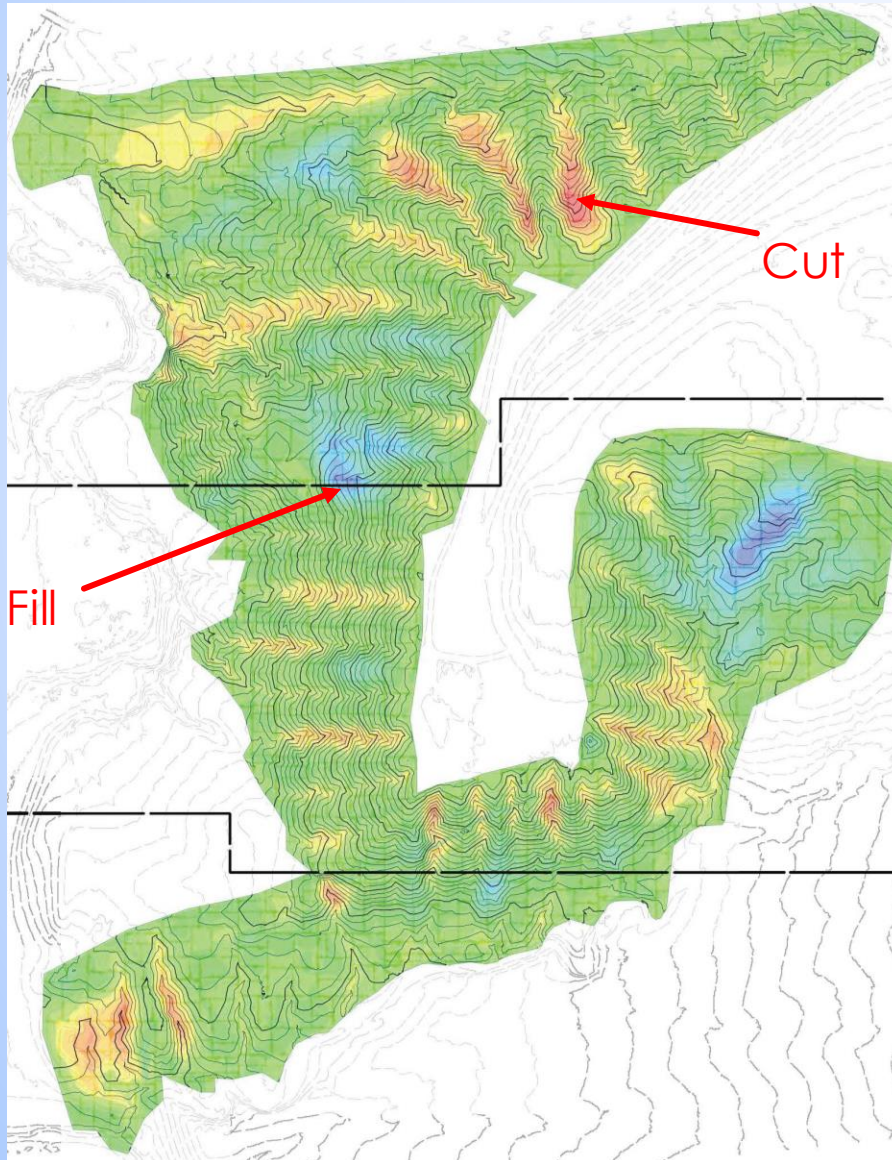
Select amendment types and rates

Method

CREATE A 3D SOIL MODEL

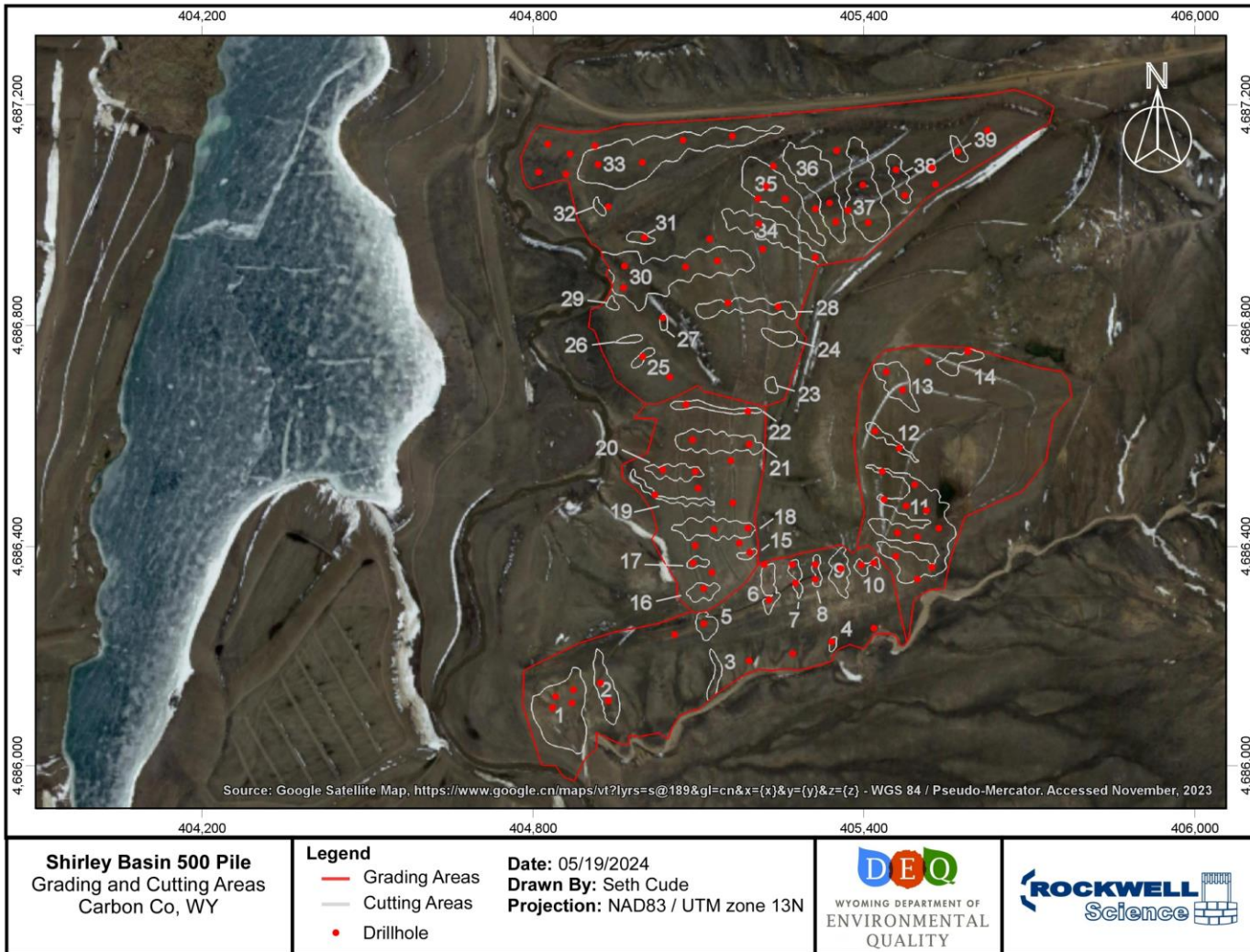
- Design a drillhole program
- Log soils
- Analyze soils
- Create a drillhole database
- Classify materials
- Model data
- Output classified volumes by area

Drillhole Program Design



- Make a preliminary geomorphic design
- Define cut and fill areas and depths
- Place drillholes to drill to the base of each cut

Drillhole Program Design



- 39 Cut areas
- 110 Drillholes
- Depth ranging from 10 to 45 feet
- 2,679 total feet drilled

Drillhole Program Design

► Lab analysis

Analyses	Units	Reporting Limit (RL)	Method
Neutralization Potential	t/kt	0.01	Modified Sobek
Acidification Potential	t/kt	0.01	Modified Sobek
Acid Base Potential	t/kt	0.01	Modified Sobek
Sulfur, Total	%	0.01	Modified Sobek
Sulfur, Hot Water Extractable	%	0.01	Modified Sobek
Sulfur, HCl Extractable	%	0.01	Modified Sobek
Sulfur, HNO ₃ Extractable	%	0.01	Modified Sobek
Sulfur, Residual	%	0.01	Modified Sobek
Texture	NA	NA	ASA15-5
pH, sat. paste	s.u.	0.01	ASA10-3
Conductivity, sat. paste	mmhos/cm	0.1	ASA10-3
Calcium	mg/L	1	SW6010B
Calcium, sat. paste	meq/L	0.05	SW6010B
Magnesium, sat. paste	meq/L	0.08	SW6010B
Sodium	mg/L	1	SW6010B
Sodium, sat. paste	meq/L	0.04	SW6010B
Sulfate	mg/L	1	E300.0
Sodium Adsorption Ratio (SAR)	unitless	0.1	USDA20b
Organic Matter	%	0.2	ASA29-3
Lime as CaCO ₃	%	0.01	USDA23c
Potassium	mg/kg	1	SW6010B
Phosphorus, Olsen	mg/kg-dry	1	ASA24-5

Analyses	Units	Reporting Limit (RL)	Method
Nitrate as N, KCL Extract	mg/kg	1	ASA33-8
Selenium, ABDTPA Extractable	mg/kg	0.1	SW6020
Arsenic, Total	mg/kg-dry	1	SW6020
Barium, Total	mg/kg-dry	1	SW6020
Cadmium, Total	mg/kg-dry	1	SW6020
Chromium, Total	mg/kg-dry	1	SW6020
Copper, Total	mg/kg-dry	1	SW6020
Lead, Total	mg/kg-dry	1	SW6020
Molybdenum, Total	mg/kg-dry	1	SW6020
Selenium, Total	mg/kg-dry	1	SW6020
Silver, Total	mg/kg-dry	1	SW6020
Zinc, Total	mg/kg-dry	2	SW6020

Analyze data

- Summary of 50 samples from the 500 pile

Analyte	Max	Min	Average
Acid/Base Potential (t/kt)	22	-67	7.82
pH (s.u.)	8.00	2.20	7.12
Conductivity (mmhos/cm)	16.40	0.30	2.67
Sodium Adsorption Ratio	5.70	0.20	1.32
Organic Matter (%)	1.20	0.20	0.50
Potassium (mg/kg)	191	38	112.78
Phosphorus, Olsen (mg/kg-dry)	7	1	2.30
Nitrate as N, KCL Extract (mg/kg-dry)	18	1	5.50
Lime as CaCO3 (%)	2.15	0.32	1.18
Selenium (mg/kg)	3	0	0.35

Drillhole Program Execution and Data Collection

- GPS locations of each collar
- Photographs and logs of entire soil core length
- Field analysis of pH and EC in from 0-2', 2-5' and in 5' increments to End of Hole
- Select samples for lab analysis

SOIL BORING AND MONITORING WELL CONSTRUCTION RECORD

Boring No.: 500p-40
Total Depth: 45
Sheet _____ of _____

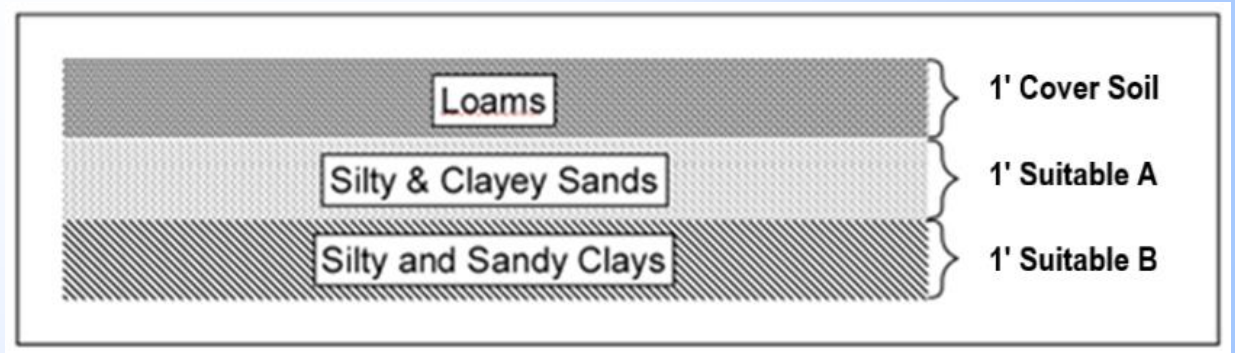
Project Name:	Contractor:	Drilling Method:
Project No.:	Location:	Sampling Method:
Client:	Start Date: 9/21/2023	Ground Elevation:
HEC Rep.:	End Date:	Air Monitoring (Y/N):
Notes: Background Radiation = 35 <u>micro R/hr</u> , Cameron logging 0'-20' and Brian logging 20'-45'. pH meter failing		Instrument(s):

Sample type, interval	% recovery	pH Reading	Radiometric Levels (μR/hr)	Depth (feet, BGS)	Soil group	Soil description / Comments
	90	-	36	2	Soil SiCL	0'-10" Sandy loam, roots present, light brown coloration 10"-1'4" Silty clay loam, orange brown
					SiC	1'4"-2' Silty clay, medium brown, dark black rock scattered
					SiC	2'-2'8" Silty clay, medium brown, black rock scattered
		2.47	36	4	SiC Clay silt	2'8"-3'8" Silty clay, medium brown, black streaks, light clay bands 3'8"-5' Clay mostly (70%), medium brown, light white clay, orange brown
	100	-	36	6	Clay CSand	5'-5'9" Clay, darker brown, low plasticity, some dark black rock 5'9"-6' Clayey sand, light brown color, black rock scattered
					Clay	6'-7'6" Brown/gray clay, low plasticity, dark rocks/streaks
				8	Clay	7'6"-8'4" Grayish/cyan, low plasticity, dry, dark rocks scattered
					Clay	8'4"-10' Darker gray, less cyan banding, low plasticity, slightly dense -dark rock scattered
	100	-	36	10	Clay	10'-12' Low plasticity clay, medium brown color, some small black rocks, slightly dense
				12	Silty-sandy clay	12'-12'4" Some sand/silt, mostly clay, sand light gray/brown, purple/red color 12'4"-12'6" Dark rock banding no other textures
				14	Sandy clay	12'6"-14' Sand light brown, gray clay, low plasticity, slightly damp, some black streaks/rocks
					Clay	14'-15' Gray clay, some dark brown streaks, low plasticity, scattered black rocks, some sand past 14'2"
	100	-	36	16	Clay	15'-16' Dark brown, some gray streaks, high plasticity, some dark rocks
					Sandy clay	16'-16'4" Dark brown clay, light gray sand
					Clayey sand	16'4"-16'8" Gray/blue sand with some fine clay

Amendment Considerations

- Determine potential amendments and rates
- Humic Acid : 750 lbs/acre
- Slow Release Organic Compost : 2 tons / acre
- Lime : Variable by layer. Mix of grain sizes
- Mycorrhizal Fungi : 100 lbs / ac
- Biochar : ???

Variable Amendments by layer



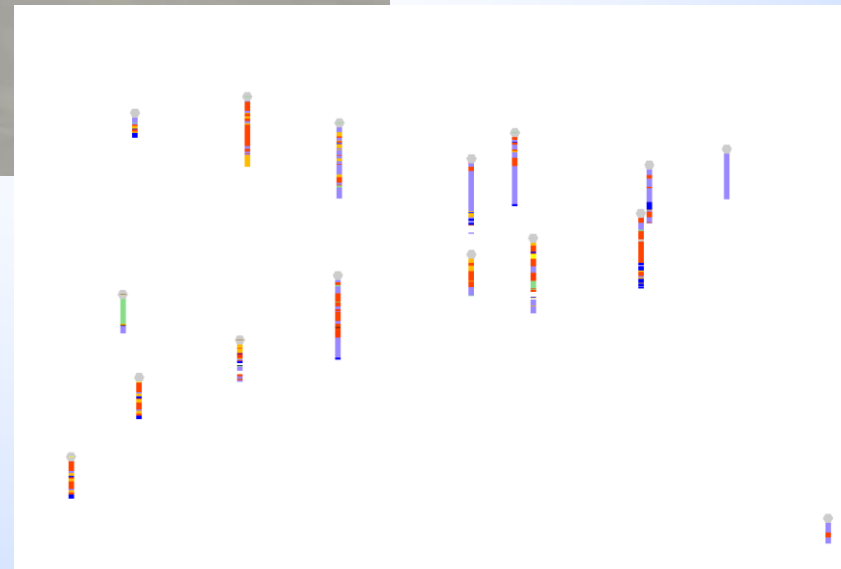
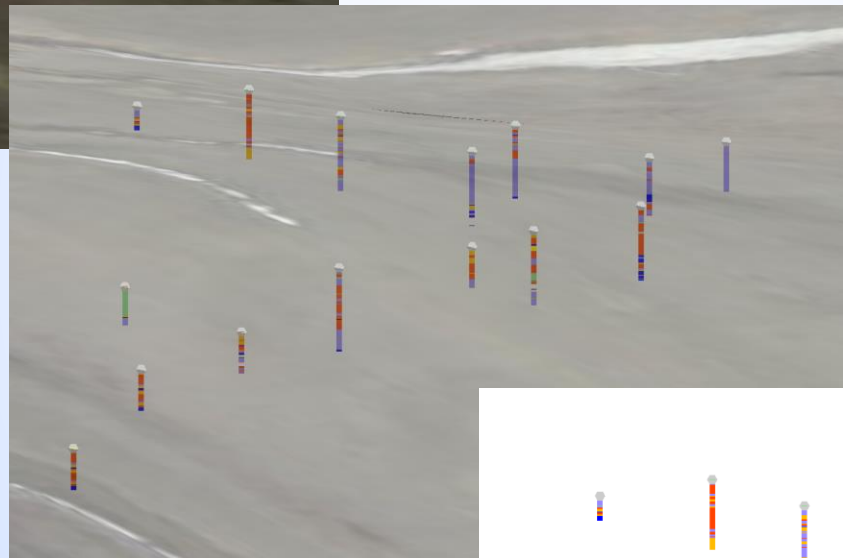
Create a Drillhole Database

DHID	From (ft)	To (ft)	Soil	Symbo	Color	Notes
500p_01	0.00	0.25	Clayey Silt	ML	lt gy	
500p_01	0.25	2.00	Sandy Clay	SC	lt gy	
500p_01	2.00	3.00	Clayey Sand	SC	lt gy	
500p_01	3.00	3.25	Clay	CL	rd bm	
500p_01	3.25	5.83	Clayey Sand	SC	lt gy	
500p_01	5.83	9.17	Clay	CL	bm to gy gm to dk gy	
500p_01	9.17	9.67	Sand	SP	off wh	Gravelly
500p_01	9.67	10.00	Clay	CL	gy	
500p_02	0.00	3.33	NR	NR		
500p_02	3.33	4.67	Sandy Clay	SC	gy	
500p_02	4.67	5.00	Sand	SP	org bm	
500p_02	5.00	6.00	Sandy Clay	SC	dk gy	occ blk
500p_02	6.00	10.00	Clay	CL	lt gy to gy to dk gy	occ sandy
500p_03	0.00	0.25	Topsoil	TS	lt bm	
500p_03	0.25	1.25	Sand	SW	tan	
500p_03	1.25	3.17	Clayey Sand	SC	tan	gravelly
500p_03	3.17	4.33	Clay	CL	bm	
500p_03	4.33	5.17	Sandy Clay	SC	bm	
500p_03	5.17	5.75	Sand	SP	tan	
500p_03	5.75	7.67	Sandy Clay	SC	tan	
500p_03	7.67	10.00	Clay	CL	bm to dk bm	occ sand
500p_04	0.00	0.25	Topsoil	TS	dk bm	
500p_04	0.25	1.00	Clayey Silt	ML	gy bm	
500p_04	1.00	2.00	Clayey Sand	SC	gy bm to bm	
500p_04	2.00	4.33	Clayey Silt	ML	bm	
500p_04	4.33	6.67	Silty Clay	ML	bm	
500p_04	6.67	9.17	Clay	CH	bm	
500p_04	9.17	10.00	Sand	SP	bm	
500p_05	0.00	0.50	Clayey Silt	ML	bm	

- Format data for 3D Input
- Compile all logs into one sheet
- Standardize data from loggers
- QA/QC
- 1,436 intervals logged

Import Drillhole Database into 3d

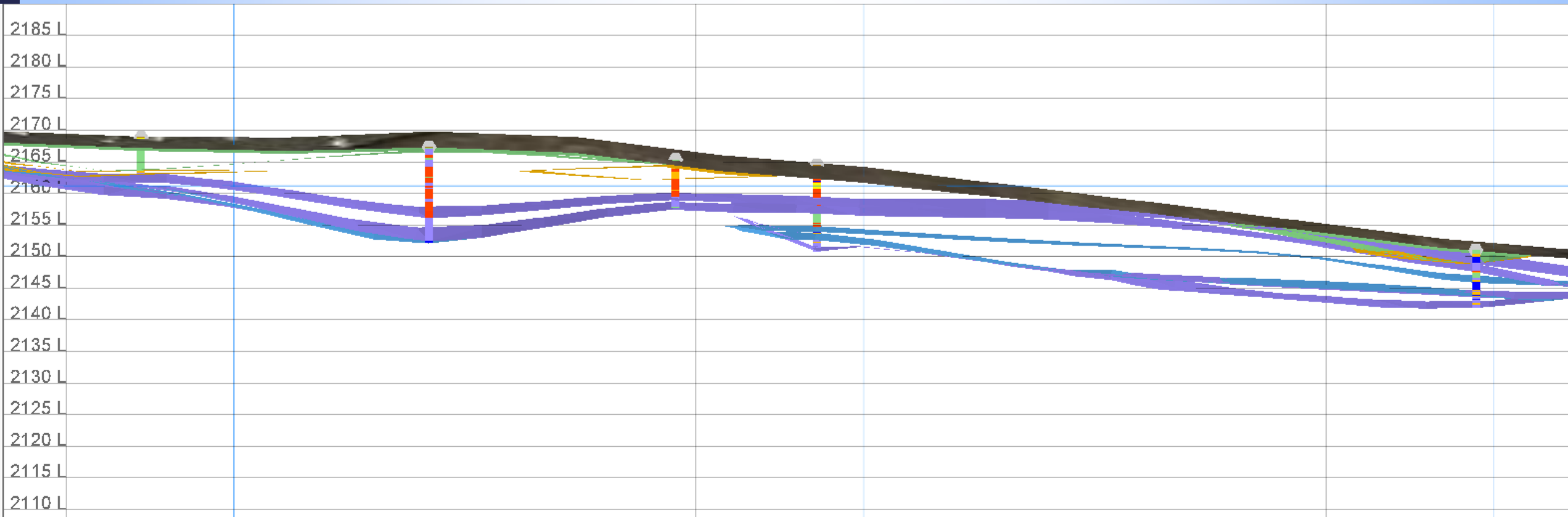
- Confirm proper coordinate system georeferencing
- Determine attributes of interest
- Create styles for visualization



	Clay
	Sandy Silty Clay
	Clayey Silt and Sand
	Clay Loams
	Sand
	Silty and gravelly S
	Silt and Loams
	Rock
	No Recovery

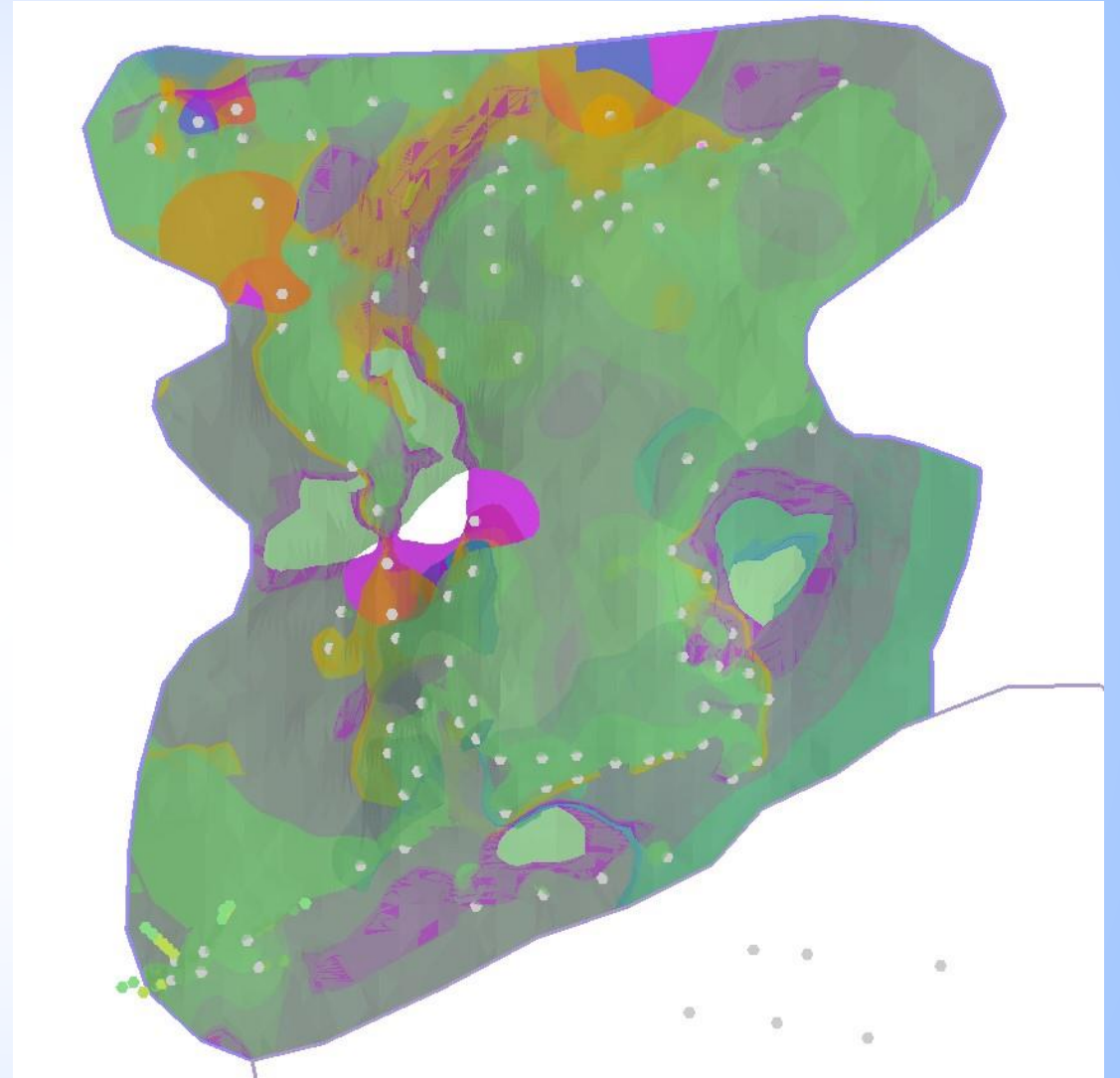
Interpret and Model Data

- ▶ Review data in 3D
- ▶ Review data in sections
- ▶ Determine correlation of data through space



Model data

- Create 3D correlations between data
- Create top and bottom surfaces for soil units
- Generate solids of soil units
- Review data to eliminate overlap
- Classify Material

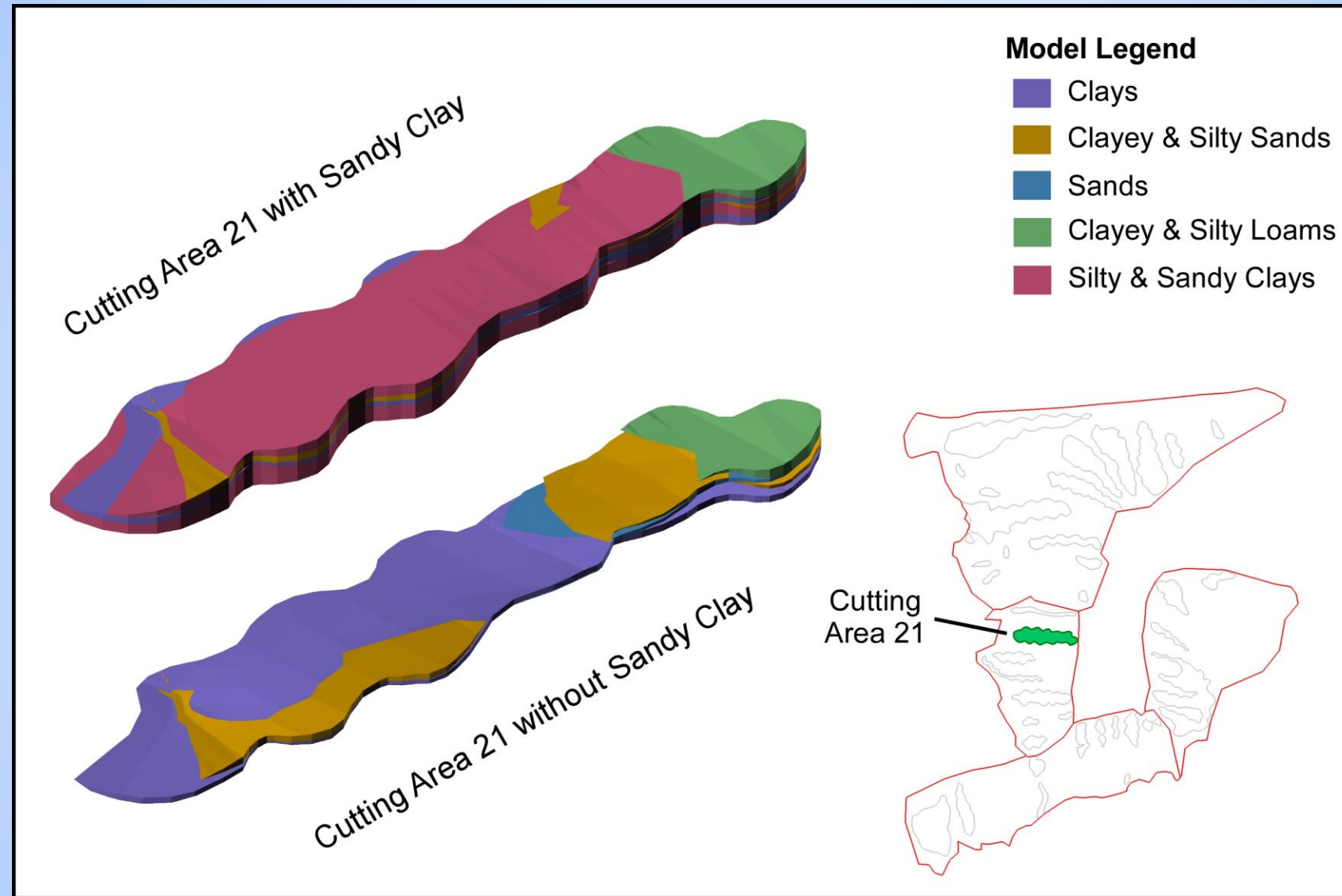


Classify material

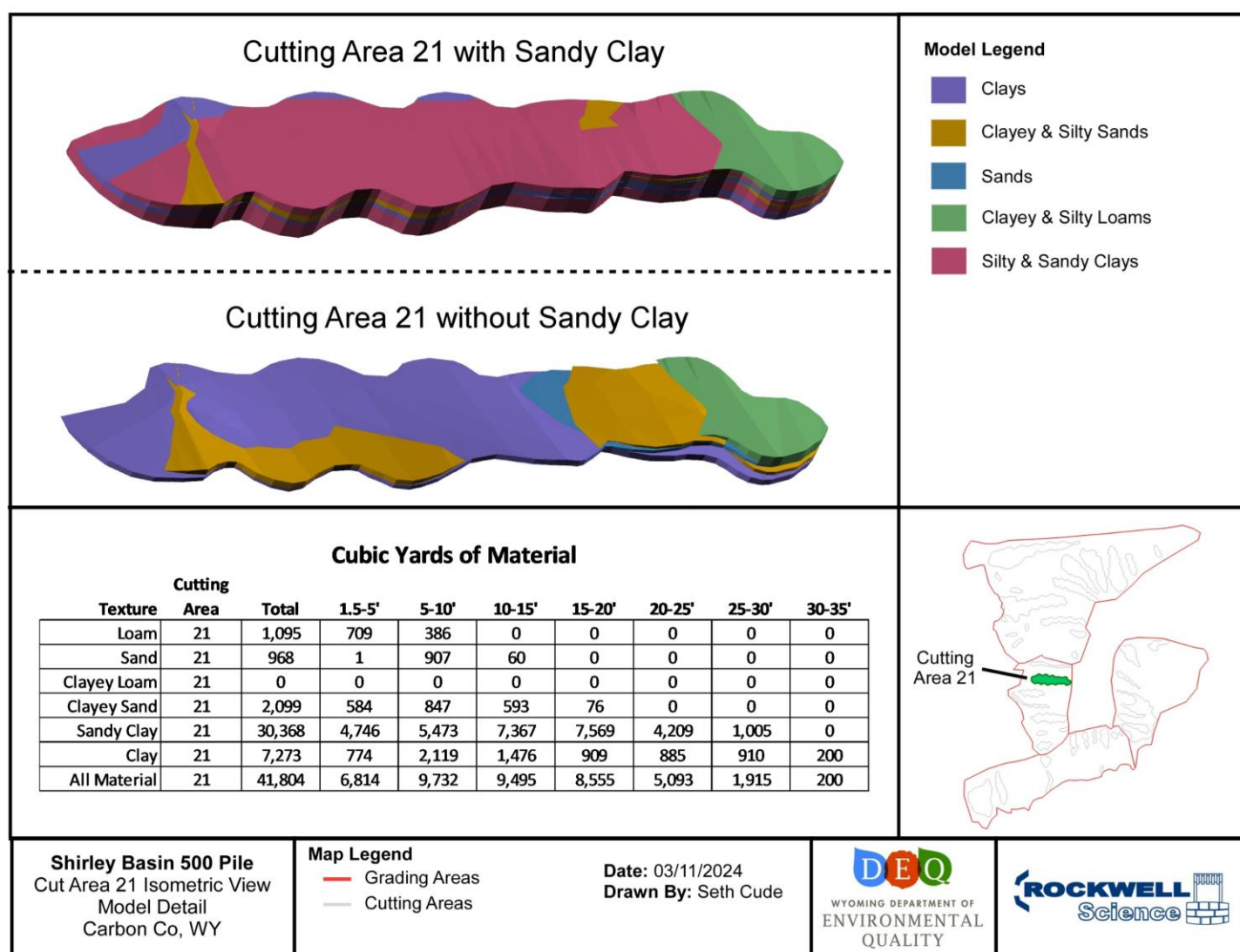
- Determine classification categories
 - Suitable Material - Coversoil
 - Suitable Material – Subsoil Suitable
 - Marginal Material - Fill
 - Unsuitable Material – Buried and isolated

Table I-4: Criteria to establish overburden suitability

Parameter	Suitable	Marginal	Unsuitable
pH	5.5-8.5	5.0-5.5	<5.0
EC (Conductivity) mmhos/cm	0-8	8-12	>12
Saturation Percentage	25-80	<25 >80	-
Texture	-	c,sic,s	-
SAR	0-10	10-12	>12
SAR (Clay)	0-10	10-15	>15
Selenium (ppm)	<0.3	0.3 - 0.8	-
Boron (ppm)	<5.0	-	>5.0 ppm
Nitrate/Nitrogen (ppm)	-	-	-
Molybdenum (ppm)	<1.0	>1.0	-
Acid/base pot. (CaCO ₃ equivalent)	>-5	-	<-5
Arsenic (ppm)	<2.0	>2.0	-
Organic Carbon (%)	<10	-	>10



Report data



Report data

► Volumes by depth and area

Estimated Volumes (cy) of Soil for Depths Below Ground Surface (ft)											
Texture	Area	Total	1.5-5'	5-10'	10-15'	15-20'	20-25'	25-30'	30-35'	35-40'	40-45'
Loam	30	8,409	5,269	2,967	173	0	0	0	0	0	0
Sandy	30	0	0	0	0	0	0	0	0	0	0
Clayey Loam	30	0	0	0	0	0	0	0	0	0	0
Clayey Sand	30	53,529	8,623	14,242	10,863	9,076	6,880	3,846	0	0	0
Sandy Clay	30	37,373	0	4,048	8,703	11,628	10,294	1,975	725	0	0
Clay	30	34,304	6,734	8,204	9,719	7,907	1,238	502	0	0	0
All Material	30	133,615	20,626	29,460	29,460	28,612	18,411	6,322	725	0	0

Estimated Volumes (cy) of Material for Depths Below Ground Surface (ft)												
Estimation	Classification	Area	Total	1.5-5'	5-10'	10-15'	15-20'	20-25'	25-30'	30-35'	35-40'	40-45'
Conservative	Unsuitable	30	20,626	20,626	0	0	0	0	0	0	0	0
Conservative	Unclassified	30	95,596	0	23,437	25,597	25,435	16,004	4,399	725	0	0
Conservative	Suitable	30	17,393	0	6,023	3,863	3,177	2,408	1,923	0	0	0
Conservative Total		30	133,615	20,626	29,460	29,460	28,612	18,411	6,322	725	0	0

Report data

- Report volumes
- Check volumes against design requirements
- Confirm sufficient material exists before construction
- Preconstruction decisions on alternatives

Results

CONSERVATIVE ESTIMATION

Estimated Volumes (cy)

Area	Unsuitable Material	Fill Material	Suitable Material
1	0	77,993	21,035
2	0	12,770	16,234
3	0	3,810	0
4	0	1,419	0
5	0	8,789	2,486
6	2,625	17,652	1,587
7	482	6,097	2,112
8	336	6,855	964
9	1,115	26,595	2,834
10	673	7,930	1,411
11	21,387	147,487	36,523
12	1,853	5,119	584
13	5,005	17,556	4,994
14	6,521	6,526	1,029
15	603	1,781	237
16	484	7,239	3,860
17	208	2,948	2,714
18	5,768	32,054	3,484
19	2,191	5,744	555
20	3,015	11,938	2,228

CONSERVATIVE ESTIMATION

Estimated Volumes (cy)

Area	Unsuitable Material	Fill Material	Suitable Material
21	9,246	31,673	885
22	3,133	4,646	188
23	954	6,225	0
24	3,956	12,898	254
25	0	3,494	2,422
26	0	4,098	568
27	170	1,595	424
28	8,265	12,562	1,587
29	3,205	0	0
30	20,626	95,596	17,393
31	4,321	362	0
32	1,942	17	0
33	0	75,680	12,414
34	0	48,581	15,534
35	11,060	67,456	43,098
36	0	86,811	31,097
37	0	77,885	54,945
38	8,191	2,503	1,821
39	1,170	2,939	50
Total	128,505	943,321	287,552

Sequencing and Optimizing

- ▶ Use volumes by area for construction
- ▶ Optimize direct haul
- ▶ Related to mine planning

THANK YOU!

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**KIROL APPLIED
ECOLOGICAL RESEARCH**

