Changes in Spoil Electrical Conductivity (EC) and Sodium Adsorption Ratio (SAR) Following Irrigation at a Mine Site in Northwestern New Mexico

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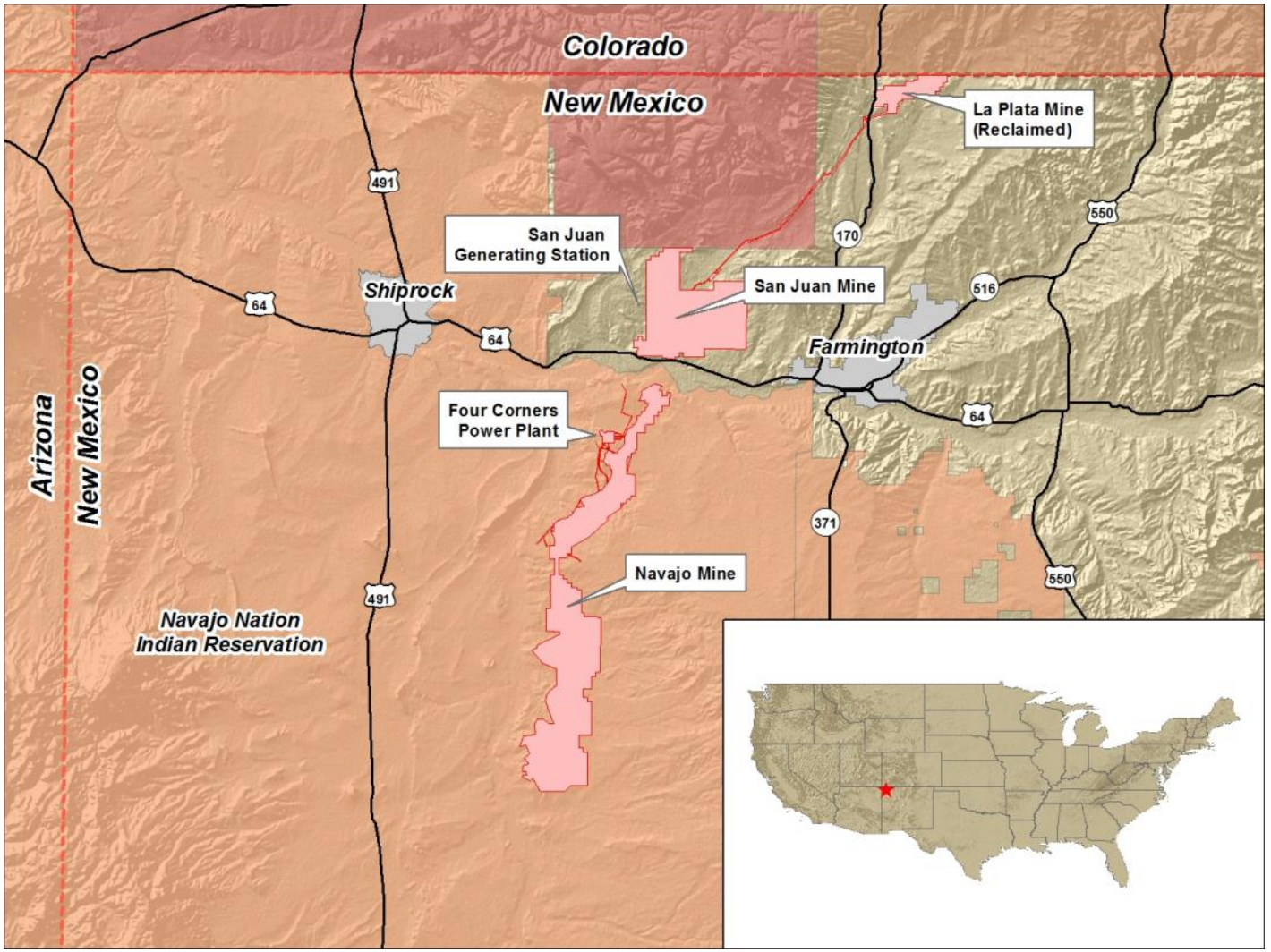
Study Location



Climate

Navajo Mine Climate

- 15 cm annual precipitation
- 140 cm net evaporation
- 33.5^{o}C average maximum temperature in July
- -9.0^{o}C average minimum temperature in January

Reclamation

Evaluation of Spoil Material

- Regraded spoil is sampled and analyzed
- Navajo Mine SMCRA permit outlines criteria for spoil suitability
- Spoil that is unsuitable is mitigated by burial or removal
- Suitable spoil is covered with topsoil, seeded, and irrigated for two seasons

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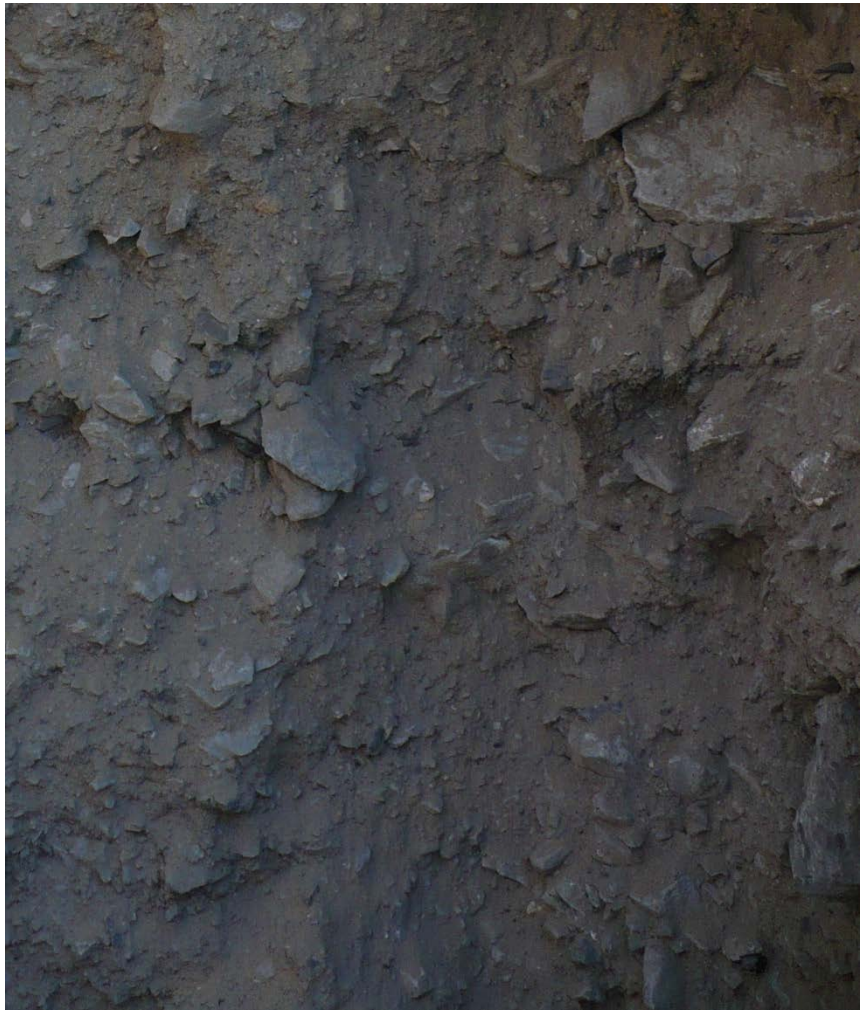
Spoil Suitability Criteria

- pH: >5 and <9
- Acid-Base Account:
  > -5 t CaCO3/1000 t
- Texture: <50% Clay
- Saturation: <85% OR <100% only if EC>4 mmhos/cm
- Selenium–Total: <2.5 ppm
- Selenium– Soluble: <0.26 ppm
- **SAR: <18 OR**
  <40 only if: EC>4 mmhos/cm
- **EC: <16 mmhos/cm**



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Irrigation Year 1

- Irrigation applied May to mid-October
- Germination cycle consists of four 2.9 cm applications over 13 days
- Support cycle consists of 1.4 cm applications repeated every 11 to 13 days

Irrigation Year 2

- Generally a one time application of 1.4 cm in April or May
- Supplemental applications as necessary

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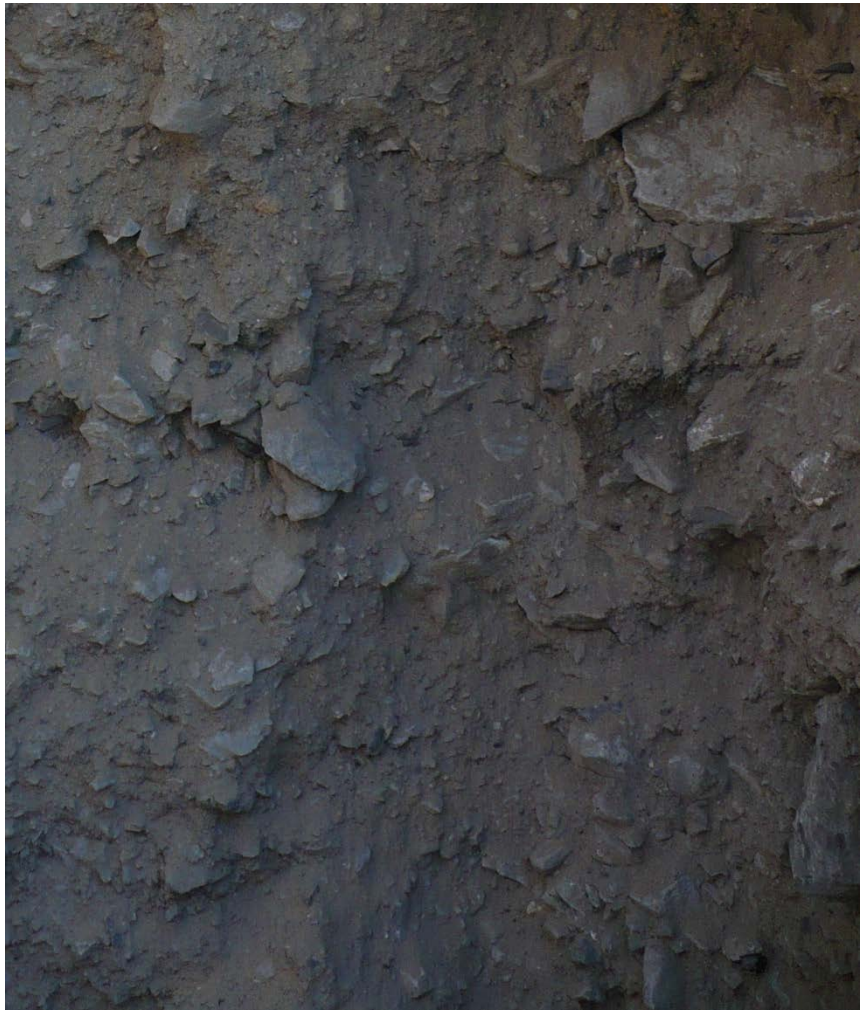
Spoil Weathering

- Several local studies indicated that spoil weathering during the irrigation treatments improved the suitability of the spoil for plant growth
- Through weathering processes, soluble salts would be redistributed and result in SAR and EC values more suitable for plant growth

Study

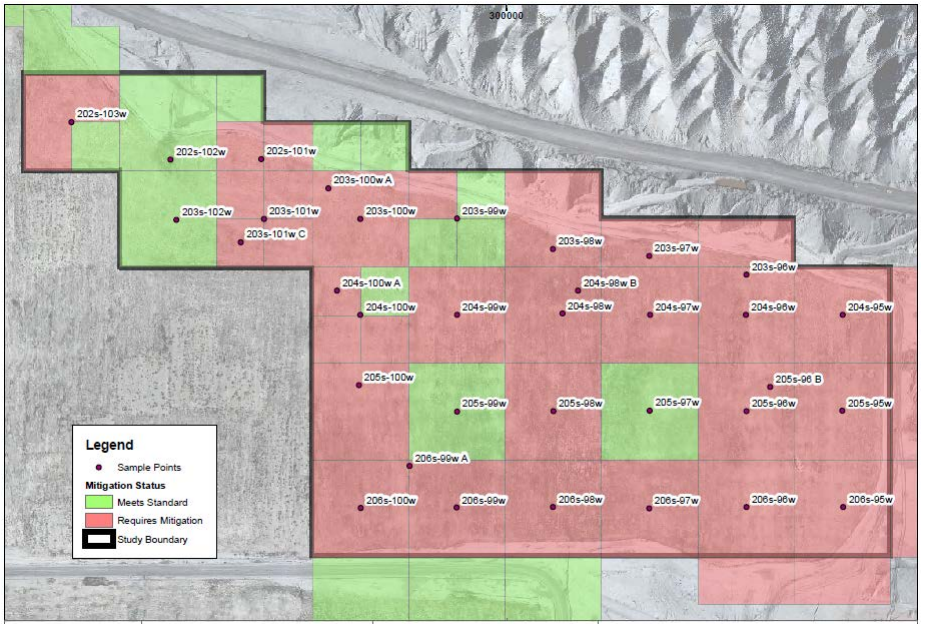
Hypothesis

- The application of irrigation, coupled with natural precipitation, would promote weathering and significantly alter spoil EC and/or SAR, thereby creating a more favorable EC/SAR relationship in the top 15 cm of the spoil profile.
- If this hypothesis is correct, it would indicate that unsuitable spoil can become suitable through weathering processes.



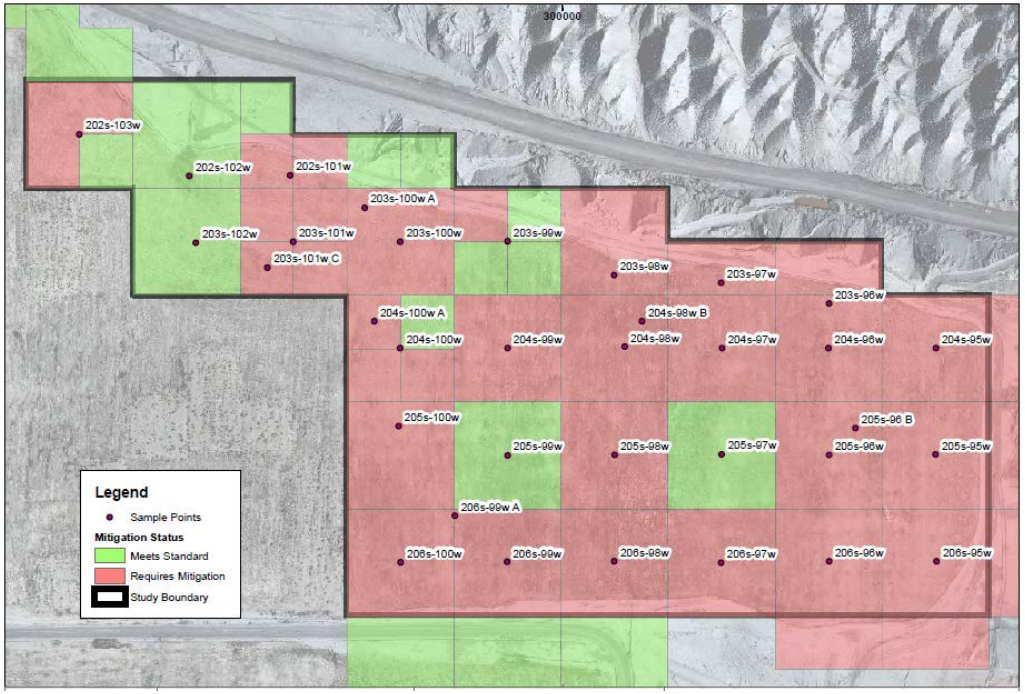
Study Site

- In 2005, spoil material was placed in the Dixon area at Navajo Mine
- The spoil material was sampled in 2006 to determine suitability
- The majority of samples from 0 – 30 cm did not meet the suitability guidelines, primarily due to EC and SAR values
- A 68 acre plot was demarcated for the study and an average of 27 cm of topsoil was placed on the plot



Methods

- In February 2006, spoil samples were collected from 79 locations in the study area
- A subset of 28 sample locations was selected for the study, with 6 more later added for a total of 34 sampling sites in the study
- The 34 sites were sampled between Oct. 23 and Nov. 6, 2006



Methods

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Sample Depths Included:

- 0 – 10 cm above topsoil/spoil interface
- 0 – 5 cm below interface
- 5 – 10 cm below interface
- 10 – 15 cm below interface
- 15 – 30 cm below interface
- 30 – 60 cm below interface
- 60 – 90 cm below interface

Methods

- Sample pits were excavated with a backhoe
- Topsoil/Spoil samples were obtained sequentially from bottom to top of pit to avoid potential for mixing

Methods

Topsoil/Spoil Samples were sent to a commercial lab and analyzed for:

- pH
- EC
- Sodium Adsorption Ratio (SAR)
- Saturation Percentage
- Texture (sand, silt, clay %)
- Cations (Calcium, Magnesium, Sodium)
- Anions (Sulfate, Bicarbonate)

Methods

- Two soil/spoil moisture monitoring access tubes were installed at each sample site prior to backfilling
- Soil/spoil moisture measured with neutron probe

Methods

Final Sampling

- Final sampling occurred in September 2008
- Topsoil/spoil moisture samples collected and moisture content determined gravimetrically
- Topsoil/spoil samples collected 50 cm from previous pit's north wall
- Archived fall 2006 samples were re-analyzed at the same time as fall 2008 samples to ensure consistency in analysis methodologies

Methods

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Final Sampling

- Depth of spoil structure
- Depth of rooting

Methods

Data Analysis

- Paired t-tests were performed that compared each laboratory analysis parameter in fall 2006 and fall 2008 for the sampled layers
- The statistical significance level was set at $p<0.10$

Results

February 2006 Sampling

Parameter	Sample Depth	
	0 - 30 cm	30 - 120 cm
Navajo Mine Root Zone Suitability Guidelines	Unsuitable	
EC · SAR	12	12
EC · Saturation %	0	1
EC · SAR · Saturation %	7	8
Total	19 (68%)	21 (75%)

Results

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10 - 0 cm Topsoil Layer

Parameter	Fall 2006	Fall 2008	Change	p-value
pH	7.8	7.8	No Change	0.59
EC dS/m	2.5	3.8	Increase	<0.01
Alkalinity meq/L	2.1	2.3	Increase	0.08
Sulfate meq/L	19.4	38.1	Increase	<0.01
SAR	9.4	11.8	Increase	<0.01
Ca meq/L	8.7	13.8	Increase	<0.01
Mg meq/L	1.4	2.4	Increase	<0.01
Na meq/L	18.7	29.7	Increase	<0.01

Results

0 - 15 cm Spoil Layer

Parameter	Fall 2006	Fall 2008	Change	p-value
pH	7.6	7.7	Increase	<0.01
EC dS/m	7.5	7.9	No Change	0.23
Alkalinity meq/L	3.5	2.6	Decrease	<0.01
Sulfate meq/L	79.0	87.5	Increase	0.04
SAR	30.7	27.3	Decrease	<0.01
Ca meq/L	10.9	13.9	Increase	<0.01
Mg meq/L	3.6	4.4	Increase	<0.01
Na meq/L	76.4	79.0	No Change	0.51

Results

0 - 15 cm Spoil Layer

Sampling Period	Navajo Mine Root Zone Suitability Guidelines		
Fall 2006			Unsuitable
	Saturation %		1
	EC · SAR		1
		Total	2
			(6%)
Fall 2008			
	Saturation %		0
	EC · SAR		0
		Total	0
			(0%)

Results

15 - 30 cm Spoil Layer

Parameter	Fall 2006	Fall 2008	Change	p-value
pH	7.7	7.7	No Change	0.57
EC dS/m	7.5	9.7	Increase	<0.01
Alkalinity meq/L	3.5	2.8	Decrease	<0.01
Sulfate meq/L	80.8	107.5	Increase	<0.01
SAR	31.1	31.6	No Change	0.59
Ca meq/L	11.0	16.0	Increase	<0.01
Mg meq/L	3.9	6.0	Increase	<0.01
Na meq/L	76.1	100.3	Increase	<0.01

Results

0 - 30 cm Spoil Layer

Parameter	Fall 2006	Fall 2008	Change[1]	p-value
pH	7.6	7.7	Increase	0.06
EC dS/m	7.5	8.8	Increase	<0.01
Alkalinity meq/L	3.5	2.7	Decrease	<0.01
Sulfate meq/L	79.9	97.5	Increase	<0.01
SAR	30.9	29.4	Decrease	0.06
Ca meq/L	11.0	15.0	Increase	<0.01
Mg meq/L	3.7	5.2	Increase	<0.01
Na meq/L	76.2	89.6	Increase	<0.01

Results

0 - 30 cm Spoil Layer

Sampling Period	Navajo Mine Root Zone Suitability Guidelines	0 - 30 cm
Fall 2006		Unsuitable
	SAR	1
	Saturation %	1
	SAR · Saturation %	0
	EC · SAR	2
	Total	4
		(12%)
Fall 2008		
	SAR	0
	Saturation %	1
	SAR · Saturation %	0
	EC · SAR	0
	Total	1
		(3%)

Results

30 - 60 cm Spoil Layer

Parameter	Fall 2006	Fall 2008	Change	p-value
pH	7.7	7.7	No Change	0.31
EC dS/m	7.6	8.6	Increase	0.01
Alkalinity meq/L	3.1	3.1	No Change	0.80
Sulfate meq/L	81.9	94.7	Increase	0.01
SAR	30.1	31.1	No Change	0.29
Ca meq/L	11.7	14.4	Increase	<0.01
Mg meq/L	4.0	5.5	Increase	<0.01
Na meq/L	76.5	88.9	Increase	0.01

Results

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60 - 90 cm Spoil Layer

Parameter	Fall 2006	Fall 2008	Change	p-value
pH	7.7	7.6	Decrease	0.08
EC dS/m	7.4	8.0	Increase	0.07
Alkalinity meq/L	3.4	3.4	No Change	0.91
Sulfate meq/L	80.2	88.5	Increase	0.03
SAR	28.7	29.4	No Change	0.53
Ca meq/L	12.4	13.9	Increase	0.06
Mg meq/L	4.3	5.3	Increase	<0.01
Na meq/L	73.9	80.8	Increase	0.05

Results

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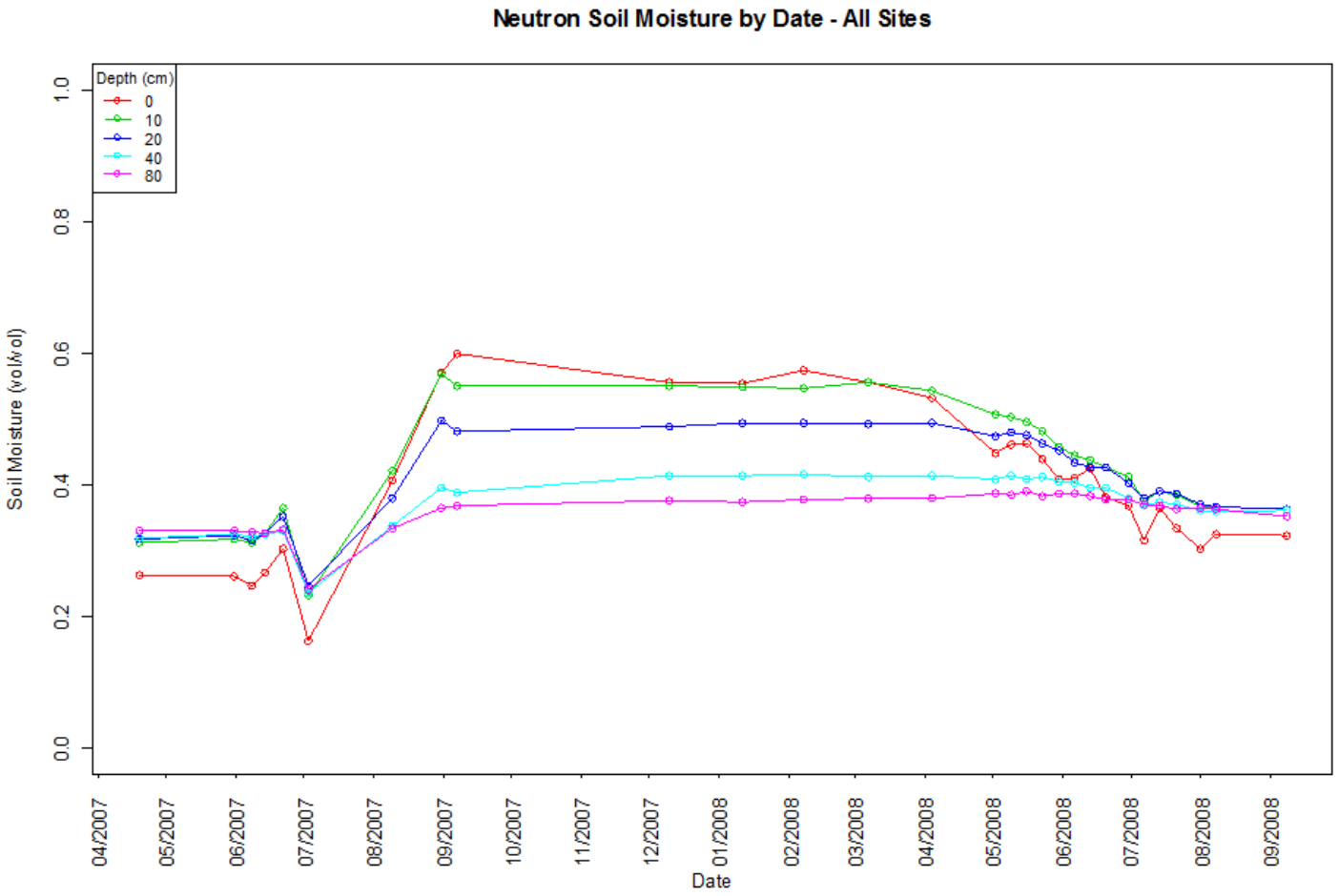
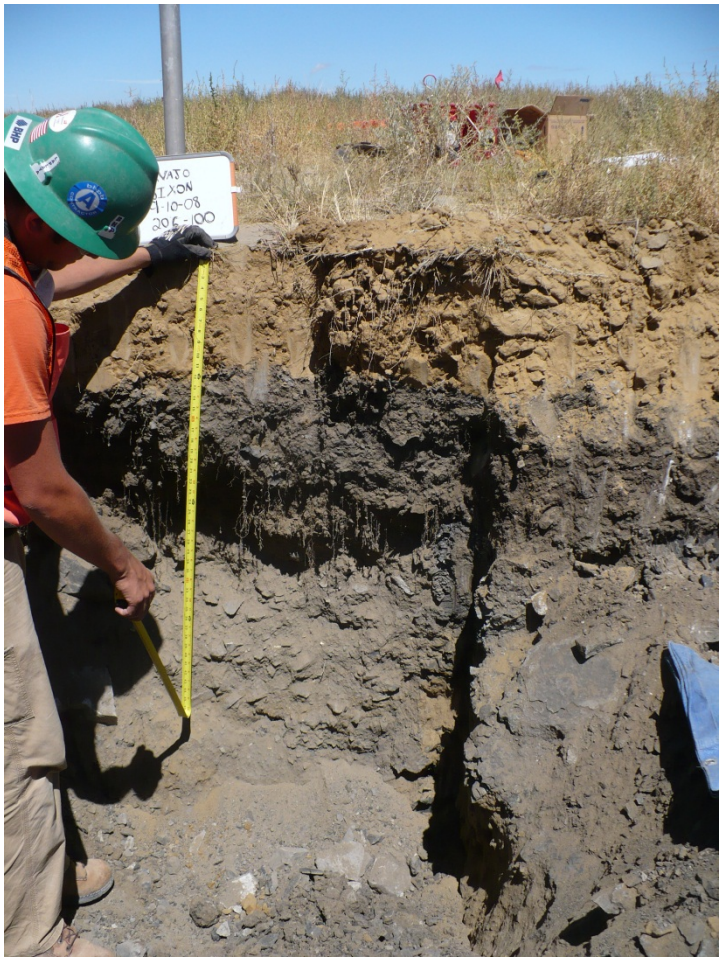
Topsoil/Spoil Moisture



Results

Spoil Structure and Rooting



Site	Depth of Topsoil (cm)	Depth of Structure (cm)	Depth of Rooting (cm)
Mean	27.0	78.3	99.1
SD	9.0	37.8	36.3

Results

Conclusions

- The spoil at Navajo Mine experienced chemical changes resulting in increased suitability
- Moisture data indicate that water was able to infiltrate into and percolate through the soil/spoil profile
- Spoil structure and root development extended into the spoil profile
- Cumulatively, the chemical analyses and observations of spoil structure and root development support the conclusion that over time, the spoil material at Navajo Mine became more favorable for reclamation.

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