Leviathan Mine Revegetation Evaluation Report

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UC Davis
June 2015
Final Report

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EXECUTIVE SUMMARY

Several phases of revegetation work have occurred at Leviathan Mine. These previous revegetation efforts have regenerated plant cover in much of the regraded Pit Area, the east slope below Pond 2 North and South and the Delta Slope sites (Figure 1). The steeper north slope below Pond 2 North and South, however, remains insufficiently revegetated, with sparse vegetative cover, active downslope creep and occasional surface erosion events. Although the regarded Pit Area is generally vegetated, an increased density and extent of plant cover would further reduce erosion during intense storm events, especially from local bare areas of slope section toe slopes and untreated edges. Increased rooting depth would support increased plant density and growth that would also act to resist surface erosion during short-term but intense storm events. Improved plant rooting depth and density would also reduce percolation of soil moisture from rainfall and snow melt downward into the pit fill material beneath the rooting zone. The steeper slopes of Pond 2 North are not stable against wind or rain erosion currently and are not expected to regenerate a sustainable vegetative cover without being re-treated or re-graded to shallower slope angles.

Field demonstration plots and treatments were installed as part of this study in Fall of 2013. Evaluation of substrate conditions in these plots indicates that native plants in substrates injected with lime and compost amendment grow deeper roots and prolong their active growth through the summer until the onset of winter. Such responses are in contrast to the typical pattern of midsummer dry-down and inactivity seen in plants in untreated substrates. These improved growth responses were observed in existing, established plants and also in first-year growth of seeded grasses on newly established plots. These growth increases are considered significant because wildlands plants, as part of their long-term survival strategy, may be self-limiting in their short-term responses to improved environmental conditions and may not show an immediate response. In this study, increases were measured in both plant size and the length of active growth to the end of the summer season. These kinds of responses are expected to increase evapotranspiration and decrease the ambient substrate moisture content, providing a low-input management strategy.

The pilot scale injection system used on this project effectively delivered treatment materials to depth, but it did not provide an effective means for lateral distribution of treatment materials. This is likely due to the highly compacted, high clay content and deformable nature of the substrates. Subsurface substrates lateral to the point of injection of lime and amendment materials were observed to remain acidic and moist even in late summer when treatment effects should occur. It appeared to plastically deform rather than shatter and fracture. Larger scale and more intensive mechanical incorporation of lime to greater substrate depths (to three feet) is recommended. Constructible methods potentially include 1) bulk incorporation (mixing) of treatment materials with raw substrates during excavation and grading activities and 2) incorporation into existing, in-place substrates by ripping, slot injection or trenching that use larger, scalable construction methods rather than the pilot evaluation methods (injection holes) used in this study.

The plant species and ecotypes used in this study are well adapted to site conditions as demonstrated by their ability to germinate and establish from seed. This allows mechanized seed and mulch application, which is cost-effective for large or inaccessible sites. However, on the field plots, only the individual seeds that happened to germinate immediately over a treatment column survived through the first summer. This again indicates that a thorough and well mixed substrate treatment is needed to effectively revegetate these mine-site conditions, as opposed to smaller scale, localized, amended planting holes. Container-grown plants offer a somewhat different approach, since they are already actively growing. But, transplanting shock can reduce survivorship as they acclimate from propagation conditions to harsh field site conditions. The plant materials are recommended to be prepared with large root systems in proportion to the top growth. Further, treatment of the whole rooting volume rather than just a planting hole will help these plants establish and generate a vigorous revegetation cover on site. Given the documented ability of these plant species to grow on adequately treated substrates, a robust revegetation cover is recommended as a major component of stabilization, erosion control and surface water management of the Leviathan Mine site.

These field evaluations and observations lead to several recommendations for future revegetation project design and construction. These include shallow slope angles, subsoil decompaction and subsoil incorporation of lime and organics to facilitate greater plant growth and rooting depth. Appropriate plant species for sustained revegetation cover already occur on site. Increasing the density of these adapted species increases surface erosion protection. Increased rooting depth allows plants to extend active growth through the late summer to more extensively deplete subsurface moisture and reduce percolation of precipitation inputs during the following winter.

1.0 INTRODUCTION

Disturbed areas at Leviathan Mine have presented challenges for revegetation. Several previous phases of revegetation efforts offer clues for improved treatments going forward. The observed reduction of shrubs when in competition with grass (Butterfield, 1977) suggests that there is limited rooting depth and that water availability may be constraining growth. Small scale soil treatment that is limited to planting holes, as in forestry practices (Leiser, 1984), may need to be increased in intensity and scale for these acidic, highly altered, mine-impacted substrates.

Supplemental fertilization to conifers (Warden 1998) supported several years of improved growth but eventually growth returned to slower, pre-fertilization rates. Higher biodiversity or plant groupings (Wiese, 2003) showed initial improvements, but a treatment of shallow lime and compost incorporation reduced long term shrub cover and increased weed cover relative to the deep tilled plots with simpler planting palette. This again suggests rooting is limited by shallow amelioration of substrate conditions. Moderate ripping depth with lime incorporation directly into the rip slot increased plant growth (Claassen and Hogan, 1999), but plants remain clumped along these tillage passes, with limited expansion after over 15 years. This suggests that the whole substrate volume is not fully neutralized or decompacted. Shallow rooting and open inter-canopy spacing also suggests that plant rooting is still constrained by site conditions. Inadequate canopy density, rooting depth and water uptake through evapotranspiration potentially allows excess water from rainfall or snowmelt to flow overland and generate surface erosion or to percolate into the mined material beneath the rooting zone.

Under contract with the California Regional Water Quality Control Board, UC Davis commenced further study related to revegetation activities at the Leviathan Mine in 2013. The site was revisited and the long-term outcome of several previous revegetation projects were informally evaluated. Previous revegetation treatments have been generally successful but with a range of outcomes (Figures 1 - 4). Some of the low-intensity treatments turned out to be more viable than expected and some more intensive treatments were still showing long-term beneficial effects on plant growth. In some localized bare areas, substrates remained that were either not treated or that had substrate conditions too extreme to be adequately treated and revegetated by the average, generalized amendments used. Now, ten or more years after treatment, plants have equilibrated with the amended growth conditions and the effects on plant growth can be seen in a representative way without the short term, excessive growth that frequently occurs soon after treatment. Since degraded sites have often been observed to begin to decline after initial fertility and mechanical treatments dissipate, reevaluation after a longer time interval is also useful to gauge sustainability of the vegetation cover.

This study outlines tasks to evaluate current field growth conditions at Leviathan Mine, identifies adaptive management actions to avoid long-term deterioration of revegetation cover and provides updated guidelines for future revegetation work needed at the site. This study focused on three general locations that have undergone various revegetation treatments in the past – the regraded Pit Area, the north and east slopes below Pond 2 North and South, and the Delta Slope (Figure 1). The regraded Pit Area was revegetated in 2002 (Figure 2) with amendment and planting specifications developed from past revegetation research conducted at Leviathan Mine (Claassen and Hogan, 1999). The north and east slopes below Pond 2 North and South (Figure 3) were evaluated as examples of a revegetated slope (referred to Pond 2 East Slope throughout this document) and a generally untreated slope (referred to Pond 2 North Slope throughout this document). The Delta Slope is the most recent area that has received revegetation treatment work in 2005 (Figure 4) utilizing amendment and planting specifications that were slightly updated from past revegetation research conducted at Leviathan Mine (Claassen and Hogan, 1999). The information from this study will allow for preparation of maintenance work that, if needed, is less expensive when done proactively rather than after significant erosion has restarted and rebuilding of an eroded and degraded revegetation system is required. It characterizes current revegetation cover as well as recommendations for improved treatments. Since growth conditions are predicted to be more harsh in future climatic conditions than at present, the next few decades may be productively used to develop a more robust vegetative and erosion resistant cover on the site before conditions worsen. Slow, but low-input, management actions may allow reduced upfront costs compared to later, more intensive repairs on this erosion-sensitive site.

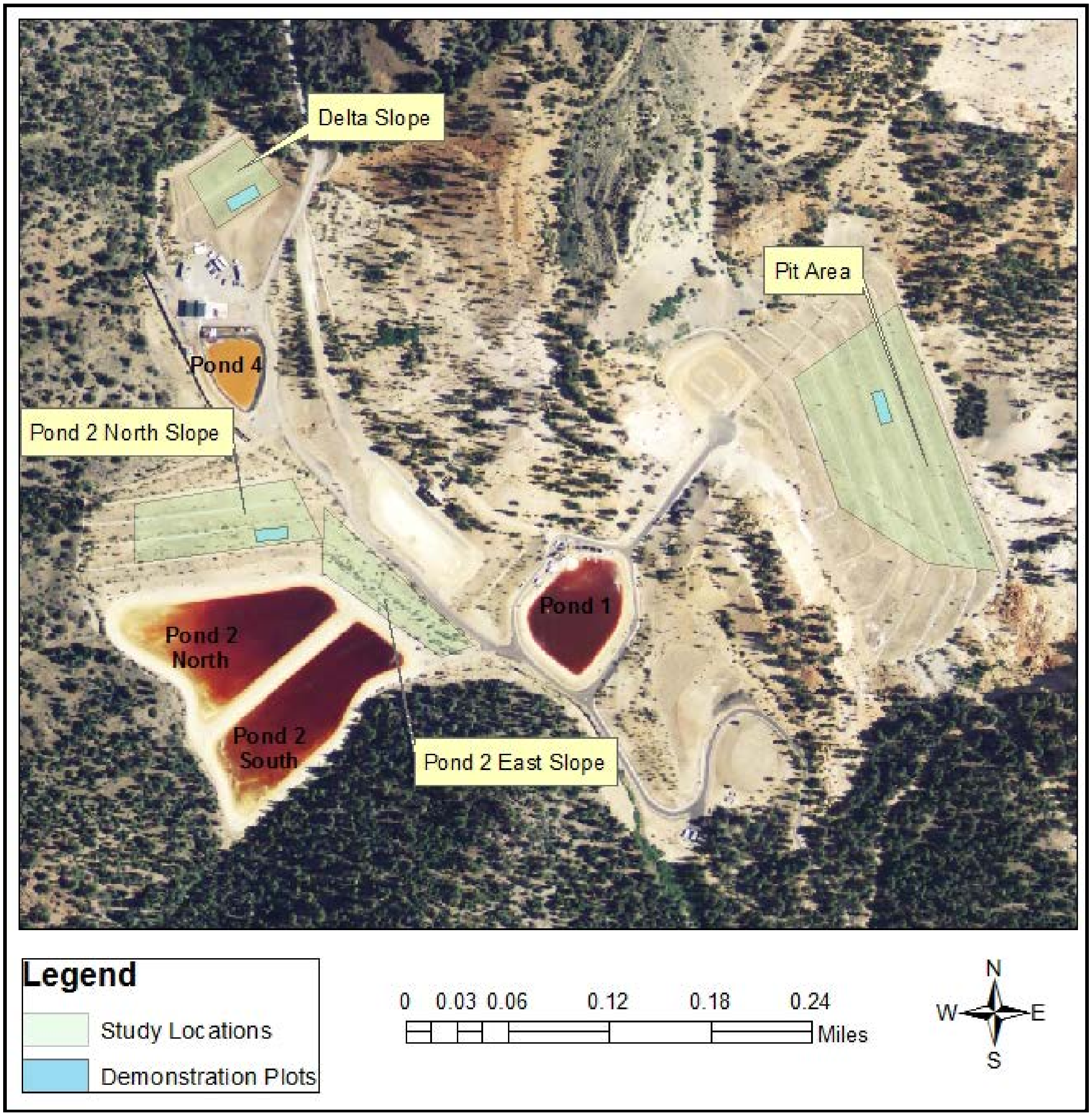

Figure 1. General study locations of the Pit Area, Pond 2 North Slope, Pond 2 East Slope, and the Delta Slope. Demonstration plots were established in 2013 and monitored through 2015.

Figure 2. Pit Area showing recent (2012) and historical condition (1997).

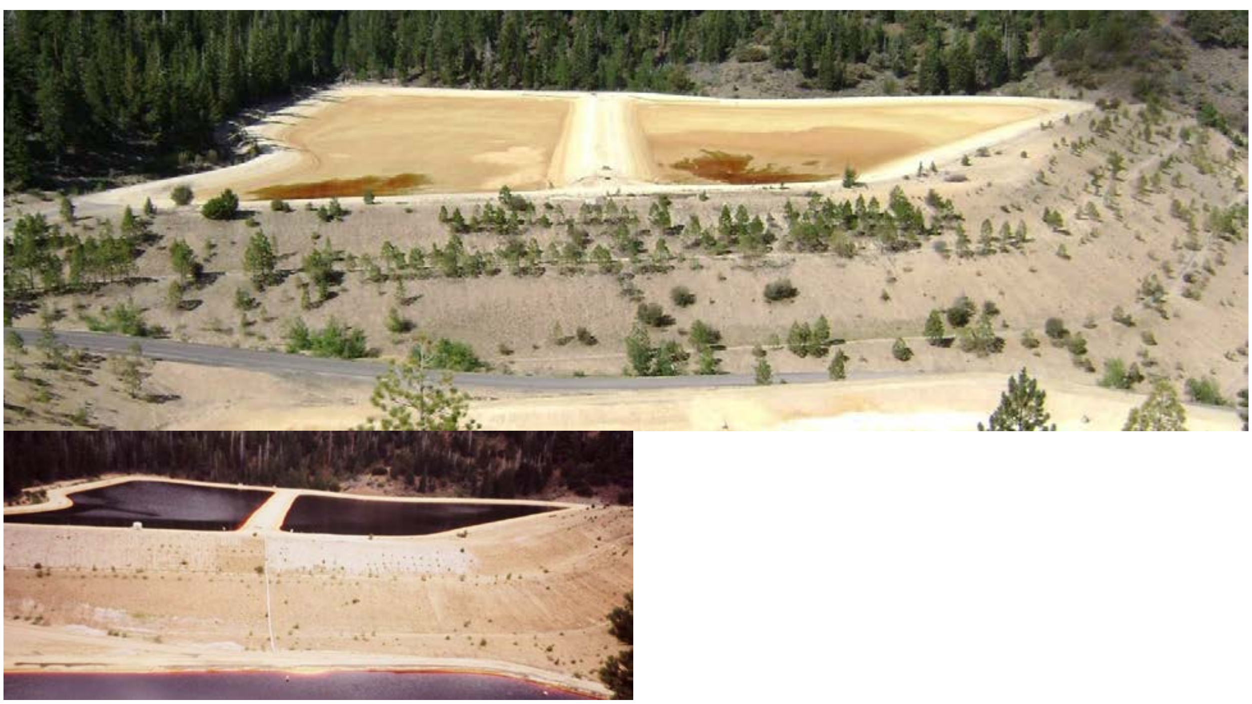
Figure 3. Pond 2 revegetation sites in 1999 (lower photo) and 2013 (upper photo). Pond 2 North Slope is the slope facing to the right of each image and Pond 2 East Slope is the slope facing the camera.

Figure 4. Delta Slope stabilization in 2005 (left) and in 2013 (right).

1.1 Goals for 2013-2015 Field Revegetation Evaluation Activities

Revegetation cover on treated areas of the site is generally observed to be widespread, but varying from fairly dense to very sparse. The goals of these field activities are to evaluate the status of existing revegetation cover resulting from different field activities through the last several decades and to update methods for establishment of sustainable, erosion resistant revegetation in future projects.

The above-mentioned goals are addressed through completion of the following specific tasks:

- Evaluate plant cover of Pit Area, Pond 2 Slopes and Delta Slope
- Evaluate existing substrate growth conditions
- Generate treatment recommendations using current and historical data
- Develop and install field demonstration plots
- Evaluate plot substrates for organic matter, nutrient release, infiltration
- Monitor plant performance and treatment response on revegetation plots
- Generate guidelines for future revegetation projects

2.0 SUBSTRATE EVALUATION

To evaluate current plant growth conditions, a variety of field measurements were made. These include line transects to document plant cover and for selection of test plot areas and tests for fertility, infiltration rates, penetrometer resistance and bulk density.

2.1 Evaluate Plant Cover of Pit Area, Pond 2 Slopes and Delta Slopes

Introduction:

Line transects were used to evaluate different sites within the Pit Area, Pond 2 Slopes, and the Delta Slope in order to establish overall vegetative cover and to select areas with contrasting vegetative cover for evaluation of substrate conditions.

Methods:

Total vegetation cover, along with rock or soil cover, was measured by line transects on previously revegetated sites on the Pit benches, Pond 2 East and the Delta Slope sites. Transect measurement methods and siting practices follow Elzinga et al., 1998. These sites are contrasted with the large Pond 2 North slope sites that were either untreated or sparsely treated and are currently less well vegetated. Each transect was 6 m long and was arranged at an angle to the slope of between 30 and 45 degrees below contour. This was done to reduce bias resulting a row / inter-row pattern of grass growth resulting from planting on contour tillage lines during the pit revegetation work. Point measurements were made along the transect line at 4 inch (10 cm) intervals, yielding 70 observations per transect. The number of transects varied with location, including 8 for well vegetated areas in the pit (Pit-veg), 8 for poorly vegetated areas in the pit (Pit-low), 6 for vegetated areas on the Pond 2 East slope (P2E-veg) and 6 for the relatively unvegetated Pond 2 North slope (P2N-low). Three transects were measured on the Delta Slope (DSlope-veg) as a cursory evaluation. Several areas of conifers were included in the initial data set. However, because of their large canopy area they were difficult to measure in an equivalent way to sites vegetated by forbs or grasses that have much smaller canopy areas. Transects with conifer cover were not used for comparisons between other sites. Statistical significance of vegetation cover from the different sites was evaluated by analysis of variance with mean separation by least significant difference (Statistica, StatSoft, Austin, TX).

Results:

First Year (2013) Transect Data:

Vegetation cover of the Pit-veg (treated) plots (46.8% total cover) is significantly higher than P2E-veg (38.6% total cover) (Figure 6). Empirical estimates of “greater than 25% revegetation cover” that were made before transects were measured are therefore considered conservative. The Pit-veg and P2E-veg areas are significantly higher in cover than the low-veg transects (Pit-low = 6.4% total cover, P2N-low = 11.4% total cover) ($p = 0.000$ for ‘veg’ vs ‘low’ sites; where ‘*p*’ is an estimate of the probability that the measured difference occurs by chance alone and does not represent an actual difference). The low-veg plots are indicated to not significantly differ from each other (p = 0.378). The low-veg had similar grass cover (4.1% vs 4.3%) while the P2N-low transects had 6.9% tree cover but none was measured in the Pit transects.

The total vegetation cover for the Delta Slope is 22.9% total cover, which is significantly lower than the Pit-veg (p =0.011) and P2N-low (p =0.085). The Delta Slope total veg cover does not significantly differ from the P2N-low (11.4%) (p = 0.116). This may be because only three replicate transects were measured on the Delta Slope data set. Increased transect numbers would be expected to increase the detection of numerically significant differences between these two contrasts.

Non-numerical observations were that the Pit vegetation in general was apparently able to resist down-slope erosion and soil creep, resulting in the formation of level terraces on the uphill side of grass clumps. While this is a positive sign of erosion resistance, the surface particles of the inter-plant or inter-row space is evidently moving by splash detachment or periodic surface erosion as a result of its lower vegetation cover. The inter-row area is well rooted, although not in the top several inches of the substrate and not uniformly deep. The inter-row area may become so dry that a uniform vegetative cover or a denser inter-row cover cannot regenerate. A large rain event during the measurement period showed the occurrence of widespread crusting and scattered small rills forming where water flow broke through the crust (Figure 5). This indicates a potential susceptibility for surface erosion under some rainfall conditions.

Figure 5. Example of crust and rilling in the Pit Area (up slope and downslope views) September, 2013.

The Pond 2 East slopes are steeper than the Pit or Delta Slope areas. In addition, the previous auger treatments were randomly arrayed across the slope. This treatment history improved plant growth in general, but made plant response variable and made it difficult to evaluate substrate conditions. Plants were relatively large and dense and surface erosion was limited. The Pond 2 North slopes also had no visible signs of water-caused erosion and sediment filled ditches in Fall 2014, although the surface substrate material from down-slope creep commonly accumulated against the up-hill side of scattered grass clumps, rocks and tree trunks. The Delta Slopes only showed erosion signs where overland flow from up-slope flat areas pooled and then drained down across the slopes. The Delta Slope area was much rockier than the other sites, so it had self-armored to a greater extent than the fluffy, more fine-grained Pond 2 or Pit substrates.

Conclusion of Vegetated Transect Evaluation:

Lime-treated substrates in the Pit Area generally had plant growth that was healthy and significantly greater than any other slope site (46.8% total cover). Treated and vegetated areas in the pit had much more cover than bare toe slope positions above each storm drain. Whether these are caused by deposition of ditch cleanout material, by lack of treatment during the original construction contract due to a limit on approach distance to the concrete-lined stormwater ditch or to long-term effects of acid subsurface seep flows is not known. The P2E-veg slopes had the next highest cover at 38.6% total cover. The Delta Slope had 22. 9 % total cover. The non-treated or sparsely treated P2N-low slope had 11.4 % total cover while the non-treated Pit-low areas had 6.4 % cover. Earlier vegetation treatments showed obvious effects to regenerate vegetation cover, but long term sustainability and regeneration was not as obvious. Such sustainability would be indicated by new vegetation seedlings filling inter-row spaces, numerous young recruits, and accumulation of a surface duff layer.

Second Year (2014) Transect Data:

Vegetation cover was remeasured on the transects that were established in 2013. Data show slight but non-significant increases in vegetation cover from 2013 to 2014 for Pit-veg and Pit-low and P2N-low areas (Figure 6). The Delta Slope vegetation cover showed a significant increase ($p = 0.027$) using a two tailed *t* test (Microsoft Excel Data Analysis ToolPak, 2013) between these two growing seasons. The growing seasons before and during this field work were dry. The years 2012, 2013, 2014, and 2015 were 63 %, 88 %, 93 % and 66 % of the 17 year average precipitation of 16.6 inches as measured at the Remote Automated Weather Station (RAWS) at Markleeville, CA (Figure 18).

Vegetation did not decline during the measurement interval of 2013 and 2014, showing no significant year-to-year trends except for the Delta Slope transects. The 2014 water year had rains later in the spring and was closer to average precipitation than 2013, which may contribute to the slight upward trends. The Delta Slope showed a significant increase in total plant cover and it appears that this could be because this area was treated more recently and plants were still filling the site’s potential for growth.

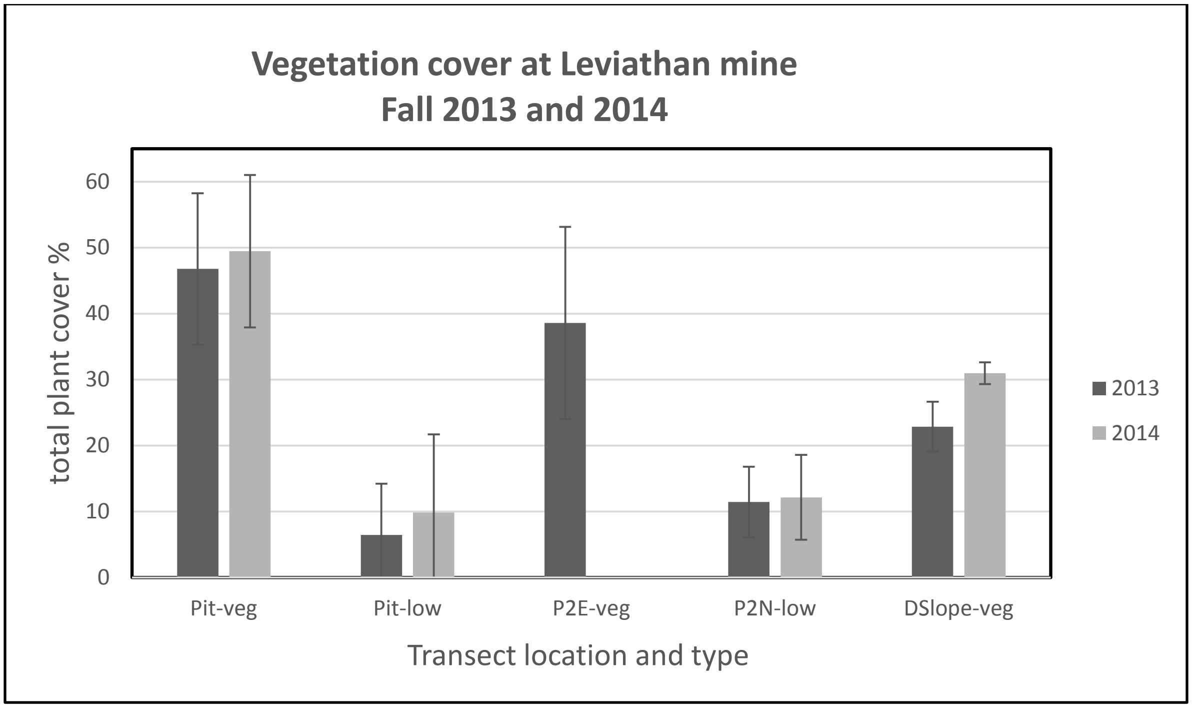

Figure 6. Comparison of vegetative cover of permanent transects at Leviathan Mine between 2013 and 2014. Only the Delta Slope plant cover changes were significantly different between years. The two sets of Pit transects were in vegetated slopes ('Pit-veg') or the lower or non-vegetated toe slope areas ('Pit-low') just above the storm drain. The Pond 2 East slope (P2E-veg) was generally well vegetated. The Pond 2 North slope (P2N-low) had very low vegetative cover. The Delta Slope transects (DSlope-veg) were vegetated.

2.2 Evaluate Existing Substrate Growth Conditions

Substrates were evaluated for plant-available nutrients, pH and salt levels. In addition, infiltration, penetrometer resistance and bulk density were measured in field conditions.

2.2.1. Substrate Growth Conditions – Nutrients

Introduction:

Mine impacted substrates often have very atypical combinations or levels of nutrient availability for plant growth. A general suite of nutrient tests can screen for growth limiting conditions. Even with adequate fertility, however, drought conditions can often limit plant growth on dry or shallow, non-irrigated sites in California. Therefore, following a review of substrate fertility conditions, substrate moisture characteristics are evaluated in more detail using infiltration and moisture retention tests and rooting depths.

Methods:

Soil fertility tests typically involve liquid extraction of a substrate sample using a variety of solutions appropriate for each nutrient and substrate chemistry. Following this extraction, analysis and interpretation are made for plant-available levels of fertility. Standard agricultural nutrient-availability tests are used but interpretation of test values is adapted for non-agricultural systems such as rangeland, forests or disturbed mined-land areas.

For this project, samples were collected from existing vegetated areas and contrasting areas with lower plant growth. Soils were collected from surface rooting zones (2 - 4 inches; 5 - 10 cm) and from deeper rooting areas (12 to 20 inches; 30 to 50 cm) according to the rooting depth observed. Soils were air dried and passed through a 2 mm sieve to obtain a fine-soil fraction. This was sent to a commercial lab (A&L Western Agricultural Labs, Modesto, CA) for the S3C ("Soil 3 Complete") suite of fertility tests that includes nutrient availability analyses, pH, buffering, salt content as electrical conductivity (EC) on a saturated paste and cation exchange capacity (CEC: the amount of negative charge on the mineral surfaces that can hold cation nutrients). Results are presented in Table 1.

2.3 Overall Summary of Nutrient Analysis

Plant growth on less well vegetated areas appears to be potentially constrained by low nitrogen, low potassium, and possibly low phosphorus levels. Phosphorus levels are difficult to judge on these substrates because arsenic is detected and counted as phosphorus in the fertility tests. However, plants can discriminate between arsenic and phosphorus, and phosphorus nutrient deficiency symptoms were not commonly observed on grasses growing on the site. Furthermore, lime sources provide more phosphorus than arsenic. These indirect indicators are taken to suggest that phosphorus is low but not limiting, at least on limed substrates.

2.3.1 Review of Individual Substrate Nutrient Availability and Potential Growth Limiting Conditions

Soil pH is typically higher in surface horizons that received lime application compared to subsurface horizons at 30 or 50 cm depth. Rooting in these deeper horizons was low or absent. Several surface horizon samples in the vegetated pit sites were greater than neutral (pH 7.3 – 7.5). This indicates residual lime remains unincorporated and non-reacted at the substrate surface. It appears that the lime material was inefficiently incorporated into the whole substrate rooting volume, leaving an excess on the surface. In contrast, the areas of the pit with low vegetation cover had surface horizons that had pH levels between 3.6 and 4.1. Aluminum 'toxicity' is generally expected to occur below 4.3 when aluminum atoms become monomeric and bind to root tip tissues, reducing or preventing growth extension and function. Substrates in the unvegetated plots had surface horizons with few roots or roots that were shriveled, laterally compressed and atypically thick and non-fibrous. The subsurface horizons in the unvegetated pit plots ranged from pH 2.6 to 3.3 and had very few to no roots. This represents a growth limiting condition.

Pond 2 East slope surface samples had pH levels from 5.9 to 6.7. This confirms that treatments were adequate for plant growth. Subsurface horizons were 3.8 to 4.3, suggesting pH-restricted rooting. Deeper application of lime would increase pH at depth, would increase plant available moisture and therefore plant cover. But, the auger-incorporated treatments that were done in the early 2000's were dense enough at least in the surface horizons to maintain plant growth.

Pond 2 North slope (bare) surface samples had pH levels that ranged from 3.6 to 4.3 with little differentiation in pH levels with horizon depth. This pH level appears to be approximately the baseline for these substrates as indicated by a number of deeper subsoil samples from different slopes. Any surface lime amendment applied to these slopes was not sufficient to significantly change pH levels. Plant growth, mainly of Idaho fescue and pines, was sparse and plants were not thriving.

One of the Delta Slope surface samples was at a pH of 6.5, which is expected from treatment history. The other was at 4.3, which may have been an atypical sample or rodent excavation of subsurface material to the sampled surface. Calcium levels were higher than the Pond 2 North slopes, showing that lime has been applied and partial amelioration of acidity occurred. Lime application neutralizes acidity and increases calcium levels, both of which contribute to plant survival and growth.

Most samples from all tested locations were well buffered at their existing pH (Table 1. buff pH column). This indicates that these materials have a significant tendency to resist neutralization after lime application and will tend to drift back toward their original pH. This pH buffering characteristic was not evaluated in this study.

In general, low substrate pH level strongly limits growth of fibrous roots in many areas to surface horizons of less than about 15 cm and restricts growth deeper than about 30 cm to a few, thicker non-fibrous roots. Few to no roots were observed as deep as 40 cm. The Pond 2 North slopes had no roots past 30 cm. Restricted rooting means that the abundant moisture contained in the subsurface horizons is not available for plant growth. Because moisture content of the subsurface horizons remains relatively high through the summer, they readily become re-saturated following rain or snow melt inputs the subsequent winter season. The residual retained pore water is then pushed downward deeper into the mined impacted materials compared to substrates that have been dewatered by evapotranspiration. If rainfall inputs exceed the rate of infiltration, overland flow occurs, mobilizing and transporting sediment.

Table 1. Preliminary soil tests for Pit Vegetated (PV) and non-vegetated Pit Bare areas (PB), Pond 2 East (E) and North (N) and the Delta Slope (DS). The values by the sample code are depths in cm. Abbreviations are listed below.

LM3 soil fertility tests			lab report # 13-268-050																							
A&L Western S3C																										
PIT VEGETATED (PV)																										
SAMP	LOC	%OM	ENR	Pbray	Pbicarb	pH	K ppm	Mg ppm	Ca ppm	Na ppm	buff pH	CEC	% K	% Mg	% Ca	% H	% Na	NO3 ppm	S ppm	Zn ppm	Mn ppm	Fe ppm	Cu ppm	B ppm	LIME	EC dS/m
P4V5	Pit-veg	4.7	125	112	192	7.3	423	576	8381	30		48	2.3	9.9	87.5	0	0.3	4.2	257	1.8	6	18	5.8	1	H	1
P4V30	Pit-veg	3.2	94	64	43	3.6	215	830	9038	19	4.8	210	0.3	3.2	21.5	75	0	1	6300	4.8	118	27	10.8	0.4	L	1.6
P5V5	Pit-veg	2.8	85	5	48	7.5	405	924	9276	10		55	1.9	13.8	84.2	0	0.1	0.4	324	1.2	4	5	3.4	0.7	H	0.5
P5V30	Pit-veg	2.2	74	46	66	6.2	308	881	6121	11	6.5	44	1.8	16.5	69.6	12	0.1	0.2	122	0.4	1	25	0.7	0.4	L	0.3
P5V45	Pit-veg	2.5	80	48	64	4.2	296	1158	8761	36	4.8	183	0.4	5.2	23.9	70.4	0.1	0.2	3999	0.7	53	31	2	0.3	L	0.7
average		3.1	92	55	83	5.8	329	874	8315.4	21	5.4	108	1.3	9.7	57.3	31.5	0.1	1.2	2200	1.8	37	21	4.5	0.6		0.8
PIT BARE (PB)																										
P4B5	Pit-low	1.2	54	46	46	4.1	257	1016	6516	14	4.8	160	0.4	5.2	20.3	74	0	2.6	817	1.4	59	18	3.2	0.3	L	0.8
P4B30	Pit-low	2.7	84	49	42	3.3	188	609	8520	17	4.8	192	0.2	2.6	22.1	75	0	0.3	5667	2.6	74	29	2.6	0.2	L	0.7
P7B5	Pit-low	2.1	73	31	25	3.6	168	529	3449	14	4.8	88	0.5	4.9	19.5	75	0.1	1.3	603	1.4	44	12	0.9	0.1	L	0.6
P7B25	Pit-low	2.6	81	36	31	3.2	141	429	2784	13	4.8	71	0.5	4.9	19.5	75	0.1	0.9	554	1.5	43	13	1	0.1	L	0.7
P7B40	Pit-low	3.2	93	38	28	2.6	28	608	8083	14	4.8	182	0	2.7	22.2	75	0	0.4	8049	4.1	87	26	4.9	0	L	2.5
average		2.4	77	40	34	3.4	157	638	5870.4	14	4.8	139	0.3	4.1	20.7	74.8	0.0	1.1	3138	2.2	61	20	2.5	0.1		1.1
Pond 2 E (E)																										
E2V5	P2Eveg	2.3	75	58	85	5.9	319	946	8802	7	6.1	63	1.3	12.3	69.4	17	0	1.2	356	2.1	5	10	3	0.4	L	0.3
E2V25	P2Eveg	2.1	71	35	29	3.8	209	368	1970	8	4.8	54	1	5.6	18.3	75	0.1	0.5	117	1.2	11	13	0.7	0.2	L	0.2
E3V5	P2Eveg	2.3	76	76	74	6.1	302	1034	5991	5	6.4	46	1.7	18.7	65.6	14	0	0.9	15	1.2	13	29	2.4	0.3	L	0.2
E3V25	P2Eveg	6.5	160	44	45	4.3	251	842	4138	13	4.8	83	0.8	8.3	24.8	66	0.1	0.7	91	0.6	28	24	0.8	0.2	L	0.2
E5V5	P2Eveg	1.3	56	31	73	6.7	346	886	7972	7		50	1.8	14.5	79.2	4.5	0.1	0.9	25	1	6	48	1.5	0.4	M	0.4
E5V25	P2Eveg	2.3	75	63	46	4.3	297	795	4288	7	4.8	85	0.9	7.7	25.3	66	0	0.3	75	1.2	23	12	0.3	0.2	L	0.2
average		2.9	88	50	53	5.0	281	785	4871.8	8	5.2	63	1.2	11.0	42.6	45.1	0.1	0.7	65	1.0	16	25	1.1	0.3		0.2
Pond 2 N (N)																										
N1B5	P2Nlow	1.9	67	49	49	4.3	226	687	5098	8	4.8	93	0.6	6.1	27.3	66	0	1.2	208	0.7	34	33	3	0.3	L	0.4
N1B30	P2Nlow	2.4	78	42	112	3.6	203	669	6494	10	4.8	154	0.3	3.6	21.1	75	0	0.5	3252	2.7	90	39	1.9	0.2	L	1.5
N1B50	P2Nlow	2.7	84	45	40	3.7	234	815	8153	13	4.8	192	0.3	3.5	21.2	75	0	0.4	5073	2.3	107	28	1.6	0.3	L	1.4
N6B5	P2Nlow	2.2	73	22	33	3.8	183	584	3271	9	4.8	87	0.5	5.5	18.9	75	0	0.4	360	1.2	35	14	0.6	0.2	L	0.5
N6B25	P2Nlow	1.7	65	53	51	4	244	785	4205	12	4.8	113	0.6	5.7	18.7	75	0	0.2	224	1	32	17	1.2	0.2	L	0.5
average		2.2	73	42	57	3.9	218	708	5444.2	11	4.8	128	0.5	4.9	21.4	73.2	0.0	0.5	1823	1.6	60	26	1.7	0.2		0.9
Delta Slope (DS)																										
DS15	DS	1.8	65	18	14	4.3	138	539	3872	8	4.8	71	0.5	6.2	27.2	66	0.1	0.3	294	0.4	38	23	1	0.2	L	0.5
DS125	DS	1.4	58	36	28	4.4	187	501	3848	7	4.8	63	0.8	6.6	30.6	62	0	0.5	178	0.8	41	33	4.2	0.3	L	0.3
DS35	DS	1.8	65	38	48	6.5	204	580	6349	7	6.6	40	1.3	11.9	79.2	7.5	0.1	0.2	36	0.5	3	11	1.8	0.3	M	0.2
DS325	DS	1.1	53	28	27	4.9	168	513	4606	8	5.3	49	0.9	8.5	46.5	44	0.1	0.3	283	0.3	16	31	2.6	0.2	L	0.4
average		1.5	60	30	29	5.0	174	533	4668.8	7	5.4	56	0.9	8.3	45.9	44.9	0.1	0.3	197	0.5	24	24	2.4	0.3		0.4
										average Ca at 5 cm depth					77.2											
										average Ca at 30 cm depth					21.7											

Abbreviations for Table 1: PxVx: Pit Veg; PxBx: Pit Bare; ExVx: Pond 2 East Veg; NxBx: Pond 2 North Bare; DSx: Delta Slope; SAMPL: sample; %OM: percent organic matter; ENR: estimated nitrogen release; Pbray: phosphorus bray extract; Pbicarb: phosphorus bicarbonate extract; pH: pH; K ppm: potassium, in parts per million; Mg ppm: magnesium parts per million; Ca ppm: calcium parts per million; Na ppm: sodium parts per million; buff pH: buffered pH; CEC: cation exchange capacity; % K : percent potassium on the exchange capacity; % Mg: percent magnesium on the exchange capacity; % Ca: percent calcium on the exchange capacity; % H: percent hydrogen on the exchange capacity: % Na: percent sodium on the exchange capacity: NO3 ppm: nitrate parts per million; S ppm: sulfur parts per million; Zn ppm: zinc parts per million; Mn ppm: manganese parts per million; Fe ppm: iron parts per million; Cu ppm: copper parts per million; B ppm; boron parts per million; LIME: excess lime capacity; EC dS/m: Electrical Conductivity deciSiemens per meter.

2.3.2 *Other Potentially Limiting Substrate Nutrient Characteristics*

2.3.2.1 *Calcium*

Surface horizons of the pit vegetated transects had average calcium levels on the soil nutrient exchange of 77% while the subsurface horizons had 22%. The Pit Bare areas (PB) and Pond 2 North (N) samples all resembled the subsurfaces from the vegetated Pit (Table 1, PV) samples with or about 21% of the exchange being filled with calcium. Delta Slope (DS) samples were intermediate, averaging 45%. At no time did a low calcium level coincide with high magnesium levels. This suggests that even though calcium was low, it was not masked by another nutrient cation.

These observed high calcium levels are interpreted to result from lime application, so treatment for acidity can also be expected to correct the low calcium levels of subsurface horizons. Calcium is known to strengthen plant roots against these strong acid conditions, but calcium levels on the exchange were lowest in the more acid subsoils where it would be needed most. Less vegetated areas all had similar lower calcium levels. All samples with calcium levels in the low 20% range had high hydrogen levels on the exchange, often at 75% saturation. Since soil acidity (hydrogen) is actually a positively charged water ion (H_3O), this means the plant root is looking for cation nutrients on the exchange, but is actually finding acidic, protonated water on three quarters of the sites. Whether application of calcium alone (probably as gypsum or calcium chloride) would improve plant growth was not tested. In spite of the elemental sulfur at the site and probably high sulfate levels, EC (salt) levels did not indicate saturation for gypsum, which would be indicated by EC levels of slightly over 2 dS/m.

2.3.2.2 *Nitrate Nitrogen*

Nitrate nitrogen in the substrate is generally low, ranging from 0.3 to 1.2 ppm nitrogen. There is a lack of soil organic matter to regenerate nitrogen levels, so when plant growth increases, as would occur after partial neutralization, nitrogen is expected to then become limiting. Pine trees showed a strong response to fertilization by increased internode length following a nutrient amendment trial (Warden, 1998). After several years, growth again declined. Evaluation of the amount and type of fertilizer that was applied in this study and the length of the observed growth increase would help guide development of a more long-term, sustainable amendment and would improve site management and maintenance responses.

2.3.2.3 *Potassium*

Potassium results also showed marginally deficient levels in substrates. Target levels for agricultural production are 1.5% of the cation exchange capacity. The Pit vegetated samples averaged 1.3% and the Pond 2 East averaged 1.2% of the cation exchange, both adequate levels for wildlands growth. Pit Bare/unvegetated substrates were 0.3 % and Pond 2 N were 0.5%, both indicating deficient supplies of potassium. Delta Slope samples were intermediate at 0.9%. The absolute level of potassiun was lowest on the Pit Bare samples, perhaps because of increased leaching from these toe slope positions. Because potassium is used in so many functions in the plant, these low levels may contribute to part of the low growth observed on some sites.

2.3.3 Non-Limiting Growth Characteristics

Remaining substrate nutrient characteristics are interpreted from these tests as being non-limiting to plant growth. These include phosphorus (potentially), potassium at some sites, magnesium, sulfur, micronutrients, cation exchange capacity and salt levels. Tests for phosphorus may be confounded by arsenic at the site. Lime amendments often have significant supplies of phosphorus, so amendment for acid neutralization will tend to indirectly increase plant available phosphorus.

2.4 Substrate Moisture Characteristics: Surface Infiltration

Introduction:

In order to avoid overland flow and surface erosion and to capture rainfall for summer growth, the substrate must have adequate surface infiltration. The infiltration rate of a substrate is the rate at which water permeates the substrate surface, while infiltration capacity is the volume of water the substrate can hold before saturation. The infiltration rate is particularly important during short term storm events, while the infiltration capacity is more important during longer-term rainy periods, multi-day storms or snow melt events that produce larger total volumes of water. Substrate infiltration should be interpreted relative to the rainfall patterns that the site experiences.

Infiltration methods also influence interpretation of site characteristics. The commonly used double ring infiltrometer and several other percolation test methods use a six inch (15 cm) positive head of water. This convention is representative of furrow irrigation or standing water in buried pipes and leach field systems. But in soils, the positive head of pressure has the effect of pushing water into the many pores and fractures that naturally occur. Since surface rainfall is not typically ponded to this depth in upland areas, this convention gives an unrealistically high substrate infiltration rate when evaluating rainfall infiltration. In the field, overland flow and surface erosion are observed to occur from storm events with rainfall rates that are lower than the measured level of substrate infiltration. Alternative methods of rainfall infiltration are used that do not have this positive head of pressure at the soil surface.

A drop-forming rainfall simulator (Battany and Grismer, 2000) provides a realistic combination of rain drop impact and controlled application of water to a substrate surface (Figure 7). This method has been used in the Tahoe Basin for measuring sediment generation and overland flow and sediment mobilization. The method was modified for this study to just give the threshold infiltration rate at saturation. But this method does not provide data at negative matric potentials and it is difficult to use to evaluate infiltration of subsurface horizons. For these characterizations, a tension infiltrometer (Soil Measurement Systems, Tucson, AZ) is used that can measure flow into a substrate at slightly negative pressure (tension, matric potential) (Figure 8). This field instrument is relevant because it measures hydraulic conductivity under unsaturated conditions such as occurs after a rain event ceases and the substrate drains down and the capacity to infiltrate a subsequent storm is restored.

Methods:

The rainfall simulator measurements are made by slowly increasing simulated precipitation rates until they are high enough that the substrate is barely saturated but does not yet create overland flow. The rate of the water flowing into the simulator is converted into units of cm per hour infiltration. The tension infiltrometer data are taken using an eight inch disc (20 cm diameter) that is faced with a very fine mesh covering that rests directly on the substrate surface without further disturbance. The disc is connected to a water reservoir that allows water to flow into the soil but under a controlled range of negative pressures. This allows the volume of flow to be measured in unsaturated conditions in undisturbed field soils. This avoids the artifacts of substrate preparation (sieving, rock removal, repacking to representative densities, alteration of pore sizes and flow paths) as occurs for tests made in laboratory conditions. Unsaturated conductivity is measured matric potentials of at - 20 cm through - 0 cm water head.

Results:

The field-measured infiltration from the rainfall simulator ranged from 1.0 to 3.7 inches per hour and averages 2.3 inches per hour (2.6 to 9.4 cm/hour; averaging 5.9 cm/hour). The high readings from one Pit sample substrate (Pit-low 3) are discounted because this area appears to have been more extensively overlaid with ditch cleaning fill and is not a wide spread condition in the Pit Area.

The interpretation of this data is that infiltration rates are high enough that they should not limit infiltration from intense storm events. Such storm events rarely exceed 2 - 3 inches per hour. For example, the Return Frequency Intensity prediction for a 60 minute interval of 2 inches per hour rain event is 500 years (Appendix 2a. NOAA Intensity Duration Frequency data tables for the Leviathan Mine location). However, a local storm that occurred in July 2013 generated surface flows and erosion at a much lower rate, as is discussed in the next section. For this reason, these areas were also evaluated with the tension infiltrometer.

Measurements by the tension infiltrometer method indicated similar high infiltration rates for the Pond 2 north and Delta Slope sites (2.40 to 3.09 inch/hour ; 6.1 to 7.8 cm/hour) (Table 2). But in the Pit Area, infiltration rates were much lower than measured with the simulator, approximately (0.39 to 0.46 inch/hour; 0.99 to 1.16 cm/hour). The various reasons for this difference are not resolved. However, this lower measured rate more closely matches field observations of surface erosion as discussed in the following section.

Figure 7. The drop-forming rainfall simulator evaluations on Pond 2 Slopes for measurement of saturated conductivity under rain-drop impact.

Figure 8. The tension infiltrometer used to measure saturated and unsaturated substrate hydraulic conductivity of different horizons in field conditions. In the photo, the infiltration disk is lying directly on the substrate under the orange hand level. The vertical stand pipe provides a reservoir that controls flow into the infiltration disk.

Table 2. Field-measured saturated conductivity results using rainfall simulator. Pond 2 North: P2N; Pond 2 East: P2E.

Field-measured saturated conductivity of LM substrates					
	Rainfall simulator				Tension infiltrometer
	infiltration	wet-up	infiltration	wet-up	infiltration
	rate	depth	rate	depth	rate
location	in / hr	inches	cm / hr	cm	cm / hr
Pit-veg 3	2.7	6.5	6.8	16.5	
Pit-low 3	5.2	16.0	13.2	40.6	
Pit-veg 4	3.1	12.5	8.0	31.8	1.16
Pit-low 4	2.3	9.0	6.0	22.9	0.99
P2E-veg 3	1.8	10.5	4.6	26.7	
P2E-veg 3	1.9	11.0	4.9	27.9	
P2N-low 1	1.3	10.5	3.4	26.7	7.26
P2N-low 2	1.8	11.0	4.5	27.9	6.10
P2N-low 3	3.7	12.0	9.3	30.5	
P2N-low 5	3.7	13.5	9.4	34.3	
P2N-low 6	1.0	11.0	2.6	27.9	
Delta Slope 1	2.0	6.0	5.1	15.2	7.84
	average	wet-up	average	wet-up	
	inches / hr	depth (in)	cm / hr	depth (cm)	
average of all samples	2.5	10.8	6.5	27.4	
average Pit-veg	2.9	9.5	7.4	24.1	
average Pit-low	3.8	12.5	9.6	31.8	
average Pond 2 East	1.9	10.8	4.8	27.3	
average Pond 2 North	2.3	11.6	5.8	29.5	
average Delta Slope	2.0	6.0	5.1	15.2	

Conclusion:

The rainfall simulator and the tension infiltrometer provide two methods for estimating surface infiltration rates that can be used to evaluate the resistance of the field site to surface erosion from different rain events. Their relationships to target rain events are discussed in the next section.

2.5 Substrate Growth Conditions: Target Storm Conditions

Introduction:

The amount of rainfall that occurs with different storm intensities and frequencies can be estimated using NOAA weather database (searchable under Precipitation Frequency Data Server - NOAA at http://hdsc.nws.noaa.gov/hdsc/pfds/orb/oh_pfds.html). This web site interpolates data from scattered, existing weather stations and historical records to provide point forecasts of rainfall intensity and occurrence frequency for user-selected locations. The probabilities of different hydrologic events are listed as Return Interval (RI) events such as 1, 5, or 25 year occurrences, along with the storm durations, such as 1, 6 or 24 hour storms (Appendix 2a and 2b).

Methods:

NOAA weather data were used to interpret the rainfall that was measured with the Atlantic Richfield weather station rain gauges located near Pond 4 at the north end of the Leviathan Mine site. Weather data were logged every 10 minutes. The measured rainfall from one or more consecutive 10 minute intervals was summed to get rainfall totals for different time durations during the overall event. These rainfall amounts for different storm durations were compared to the NOAA weather data table.

Results:

The infiltration rates measured with the rainfall simulator indicate a high capacity to infiltrate water in short, intense storms. Simulator infiltration rate was 1.9 to 3.8 inches per hour while the measured rainfall as a per-hour rate was only 1.02 inches per hour or less. This outcome does not match observations from the Pit Area. The July 25, 2013 storm event caused widespread development of many small rills that had cut through the surface crust and flowed for 5 to 20 feet down the slope face (Figure 5).

The tension infiltrometer estimate of surface infiltration rate was also high enough to avoid overland flow for the Pond 2 N and Delta Slope areas. But the tension infiltrometer estimates were much closer to the recorded field rainfall intensity on the Pit Area substrates. The tension infiltrometer indicated surface infiltration on the Pit Area substrates between 0.39 to 0.46 inch/hour (0.99 to 1.16 cm/hour) (Table 2). The recorded rain intensity, when converted to a per-hour rate, was 1.02 inch/hour for a 10 minute interval and 0.60 inch/horr over a 30 minute interval (Table 3). The tension infiltrometer data indicated that overland flow would start to occur in this type of storm on the Pit Area substrates.

According to NOAA weather databases (Table 3), this storm was not severe. The NOAA reference data indicate that a 1 hour Recurrence Interval (RI) storm rate is 0.42 inche/hour and a 2 yr RI storm is 0.52 inch/hour. These rainfall rates are close to those measured in the July 25 storms and suggest that the Pit Area remains susceptible to surface erosion and rilling even in relatively low intensity storms. This relatively low threshold for overland flow suggests that surface erosion occurs periodically, resulting in the stormwater drainage ditches receiving sediment. These sediment discharges can be expected to increase in higher intensity storms such as 10 or 25 year RI intervals compared to the July 25 storm that was less than 2 year Recurrence Interval event.

In contrast, surface flows were not observed on the Pond 2 slopes or the Delta Slope in this same event.

Table 3. Evaluation of selected 2013 summer precipitation events at Leviathan Mine in comparison to NOAA Precipitation Frequency forecast tables.

Table 3. Evaluation of summer precip events in comparison to NOAA Precipitation Frequency forecast tables									
http://hdsc.nws.noaa.gov/hdsc/pfds/orb/oh_pfds.html						http://dipper.nws.noaa.gov/hdsc/pfds/			
MET-1 weather station Leviathan Mine									
July 25, 2013 storm		Average	Peak						
Date	Time	Wind Spee	Wind Spee	Rainfall			Event duration		
		(mph)	(mph)	(inches)		10 min	15 min*	30 min	60 min
7/25/2013	15:30	3.83	10.88	0.00					0.00
7/25/2013	15:40	10.62	20.12	0.06				0.06	0.06
7/25/2013	15:50	3.41	13.06	0.17		0.17	0.17	0.17	0.17
7/25/2013	16:00	0.92	4.88	0.07			0.07	0.07	0.07
7/25/2013	16:10	2.62	6.06	0.02					0.02
7/25/2013	16:20	0.02	2.38	0.01					0.01
7/25/2013	16:30	1.44	4.94	0.00					0.00
maximum cumulative rainfall per event duration:						0.17	0.24*	0.30	0.33
exceeds what NOAA Recurrence Interval?						**<1**	**1 - 2**	**1**	**< 1**
NOAA 1 yr Recurrence Interval exceedence value (inches):						0.185	0.223	0.302	0.420
Equivalent measured RAINFALL rate in inches / hr:						1.02	0.96	0.60	0.33
Equivalent Recurrence Interval TARGET rate in inches / hr:						1.11	0.89	0.60	0.42
* NOAA table values not available in 20, 40 and 50 min intervals. The 20 min interval is interpreted as if all 20 minutes									
of ppt occurred within a 15 minute duration. This hypothetical value is then compared to NOAA 15 min data									
Duration data for each Recurrence Interval listed are averages. The averages with 90 % confidence interval ranges are:									
10 min: 0.185 (0.150-0.230) inches; 15 min: 0.223 (0.181-0.278); 30 min: 0.302 (0.245-0.376); 60 min:0.420 (0.341-0.523).									

Conclusion:

The field evaluation of infiltration using rainfall simulator is a useful tool to compare infiltration rates during dry seasons prior to rainy weather. But in this case it did not match the empirical field observations of surface rilling and erosion during the summer 2013 storms, estimated to be less than a 2 year RI event.

The tension infiltrometer measured similar high rates as the rainfall simulator at Pond 2 North and the Delta Slope sites. But it measured infiltration rates in the Pit Area substrates that were at or below the rate needed to infiltrate the July 2013 event. This field evaluation matched the observed start of overland flow, even if for a relatively short period of time.

In a separate event in early spring 2015, extensive surface rilling was observed on Pond 2 North (Figure 9) and on the north facing slope of the access road to the pit area. Perhaps a combination of rain on snow melt or a wind-driven rain on the steep, north facing slope generated these extensive rills. With erratic weather being a common occurrence, a solid vegetative cover and accumulated mulch of plant litter is recommended as a durable interface between weather inputs and the fine, unconsolidated substrates at the mine site.

Figure 9. Rills observed after winter season 2015 showing erosion at mid-slope and lower but not on the two mulched and planted demonstration plots on the Pond 2 North slope in the upper center of the photo.

As a technical note, these tests utilized water taken from wells. This water source is already partially saturated with cations and minerals. Rain water is essentially distilled water or has a very minimal mineral content. Application of distilled water to weakly aggregated soil structures can cause them to disperse into individual clay or silt sized particles. Once dispersed, they are easily washed into adjacent soil pores where they settle and plug the flow, reducing infiltration rates. This may have occurred during the intense July 2013 rain event that caused the rilling in the Pit Area (Figure 5). A weak surface crust was visible for several months after this event.

2.6 Substrate Growth Conditions: Penetration Resistance

Introduction:

Penetrometer resistance is a rapid, general field method to detect subsurface compaction. While the absolute resistance values of this hand held device are not precise indicators of either rooting or compaction, it is a useful field method to identify the thickness of surface, low-density surfaces that overlie compacted subsurface horizons.

Methods:

The handheld penetrometer used is a Field Scout Soil Compaction Tester 6120 (Spectrum Technologies Inc. Aurora, IL). Root limiting compaction is defined as substrates with penetration resistance between 250-300 pounds per square inch (PSI), or approximately 1500 to 2500 kilopascal (kPa). The depth at which resistance passed 250 PSI is used as a threshold of root-limiting compaction. Multiple probe insertions were used in any one area to determine if a high penetrometer reading indicated compacted substrate or only interception of a rock.

Results:

Substrates were generally observed to be relatively uncompacted in the surface horizons where the original compaction treatments had been disrupted by frost heave and shrink - swell movement from drying. Deeper horizons were still firmly compacted. General depths and resistance values are reported by location below.

<u>Pit Area</u>
Pit substrates in vegetated areas were generally 15 to 18 inches (38 - 45 cm) to compaction within the tillage rows and 6 to 9 inches (15 to 23 cm) to compaction between plant rows. At the depth where the deepest rooting ceased at approximately 16 inch (40 cm) depth, only 1 inch of penetration occurred before the 250 PSI compaction effort was reached. Areas that were bare did not have greater compaction at depth, but the compaction extended to within 4 to 6 inches (10 to 15 cm) of the surface.

<u>Pond 2 East (P2E-veg)</u>
The P2E-veg area was extensively treated in a random pattern of augered holes and lime and compost amendment in 1999. Exploratory soil pits in 2013 showed extensive variation over a few feet distance, ranging from 6 to 15 inch (15 to 40 cm) depth to compaction. Depths to 6 inches (15 cm) were most common. Because of this heterogeneity, the P2E site was not used further for substrate testing or demonstration plots.

<u>Pond 2 North (P2N-low)</u>
Depth to compaction ranged from 6 to 24 inches (15 to 60 cm) across 15 to 30 ft (5 to 10 m) distances. Typical depths to compaction in this area were 6 to 9 inches (15 to 23 cm).

<u>Delta Slope (DS)</u>
No readings were successfully obtained from this site because rocks were intercepted too frequently to get readings of the fine textured substrate matrix.

2.7 Substrate Growth Conditions: Bulk Density

Introduction:

Compaction and bulk density are common indicators of soil strength for built sites such as engineered fills, berms or trafficways. The ability of plants to root into substrates with higher levels of compaction or density is of concern since plant cover is a standard treatment for reducing surface erosion. The US Army Corps of Engineers (ERDC, Vicksburg, MS) has evaluated the relationship between bulk density and root growth (Goldsmith et al., 2001). A general conclusion is that root growth is limited between 1.3

and 1.6 gram/cm^3 although clay mineralogical structure also influences the critical bulk density that restricts root penetration.

As in all earthen structures, the slow disintegration of the as-built characteristics and the slow regeneration of soil structure starts as soon as construction is finished. Therefore, while these guidelines can help bridge between engineering objectives and natural soil processes, they do not definitively relate construction specifications with the actual ability of a plant root to access a volume of substrate.

In addition, the minerals found at Leviathan Mine may not show these typical relationships between strength and compaction or bulk density and drainage. Finely divided particles of volcanic geological material, especially in acidic conditions, weather to a type of short-range order oxy-hydroxide mineral that does not have the organizational structure of typical clays, with their plate-like, layer silicate structure. These short-range order materials can have relatively low bulk density levels but still limit root growth because there are few continuous pores such as form with more typical clay minerals. These minerals are problematic in many volcanic regions. Never-the-less, bulk density is a fundamental characteristic of built earth structures and it was included in the measurements gathered by this study. It was measured using a standard field method in an attempt to relate observed root growth patterns to standard engineering characteristics.

Method:

Bulk density was measured using the sand cone method (ASTM D1556), in which a cavity was excavated in an area with a level surface and the mass of the excavated material was measured after drying. In the same cavity, the mass of sand required to fill the cavity to the level surface was measured. The unpacked bulk density of the sand was used to relate the mass of sand to the volume of the hole. From these data the bulk density was calculated for the original soil in the excavated hole, in g/cm^3.

Results:

Bulk density data and depth to compaction varied across the site, but this trend did not appear to be closely related to rooting depth or to vegetation cover (Table 4). The mineralogy of the site contributes to a lower than expected bulk density, even for samples showing clear signs that roots are restricted to fractures and cannot enter the substrate matrix. In these cases, plant roots are observed to be squeezed (laterally appressed) in the narrow fractures between soil clods formed during construction. Density of some samples exceeded estimated limits to root growth on conventional substrates (>1.3 to 1.6 gram/cm^3). But in addition, the material was uniformly massive (unstructured), often saturated and potentially oxygen limiting and was moderately to extremely acidic. Many roots were observed that were growing thick and fleshy rather than thin and fibrous as is typical for the dominant grass type growing in the Pit Area.

Table 4. Bulk Density (sand cone method) of various sites and different substrate depths at the same location. Pit-veg and Pit-low are both in the regraded Pit Area. P2E-veg is the Pond 2 East vegetated area. P2N-low is the Pond 2 North low vegetation area.

plot location	depth (inches)	depth (cm)	bulk density (g/cm3)
Pit-veg 5	2	5	1.32
Pit-veg 5	12	30	1.24
Pit-veg 5	12	31	1.49
Pit-veg 5	18	45	1.37
Pit-low 7	2	5	1.24
Pit-low 7	6	15	1.13
Pit-low 7	10	25	1.03
Pit-low 7	16	40	1.36
P2E-veg 2	2	5	1.38
P2E-veg 2	10	25	1.04
P2E-veg 3	2	5	1.10
P2E-veg 3	10	25	1.63
P2E-veg 5	2	5	1.35
P2E-veg 5	10	25	1.45
P2N-low 2	2	5	1.33
P2N-low 2	2	5	1.13
P2N-low 6	2	5	1.25
P2N-low6	10	25	1.22

2.8 Survey of Rooting Depth

Introduction:

A number of soil pits were dug in vegetated and low-vegetated areas to determine plant rooting depth. Rooting depth was only verified by depth, not by root length or density.

Results:

Roots were observed to grow deeper in areas with greater vegetative cover and less deep on areas with low vegetation cover (Table 5). Very few roots were observed to grow below 16 inches (40 cm), even in the vegetated areas. This is a shallow rooting volume compared to potential rooting depths of over 79 inches (200 cm) measured for this grass species elsewhere (Appendix 3).

Table 5. Summary of observed rooting patterns for treated and untreated locations. Pit-veg and Pit-low are both in the regraded Pit Area. P2E-veg is the Pond 2 East vegetated area. P2N-low is the Pond 2 North low vegetation area.

Substrate Depth	Pit-veg (treated)	Pit-low (untreated)	P2E-veg (treated)	P2N-low (untreated)	Delta Slope veg (treated)
0-5 cm (0 - 2 in)	none; 'sandy'	none; + crust	none; gravelly	none; fines	none; rocky
10 -15 cm (4-6 in)	dense fibrous	few	dense fibrous	Few	common fibrous
15-30 cm (6-12 in)	dense fibrous	few	variable	Few	common fibrous
30-40 cm (12-16 in)	few coarse	rare	variable	Rare	few
40 + cm (16+ in)	few coarse	none observed	variable	none observed	rocky, depth not reached

2.9 Summary of Overall Substrate Evaluation

The overall observation from this field evaluation is that vegetation has established well in the treated areas of the Pit and Pond 2 East. Smaller, untreated areas still have bare substrates between plant clumps and in larger areas that were insufficiently treated or that remained untreated. Many areas above and below the concrete stormwater drainage ditches had bands of 10 or more feet of bare area with no plant cover. These areas frequently produce wind-blown sand sized particles and occasional surface erosion rilling. The lack of plant cover resulted in shallow subsurface horizons that were moist even in the late summer. Plants on the Delta Slope are smaller probably because the site is newer. But plants are evenly distributed and the rocky surface appears to be erosionally stable. Pond 2 North has sparse vegetation cover, little new vegetative recruitment and is actively sloughing.

The surface horizons of the Pit area where vegetation exists and the Pond 2 East and Delta Slope substrates all tend to be adequately limed but the subsurfaces remain acidic enough to limit root growth. In addition to the acidity, the subsoils also tended to have relatively low calcium availability. While not an outright nutrient limitation, low calcium may have a more pronounced negative effect when root tissues are also stressed with acidity, poor soil structure and other nutrient challenges. Other plant nutrients, including nitrogen, phosphorus and potassium also tend to be low.

Rooting appears to be limited by a combination of compaction and acid conditions. Poor rooting reduces the plant's ability to acquire moisture, resulting in growth reductions in mid to late summer. Low plant available moisture in the surface substrate may contribute to low recruitment of new plants from natural reseeding from existing plants, even as established plants continue to survive.

3.0 GENERATE TREATMENT RECOMMENDATIONS USING CURRENT AND HISTORICAL DATA

Introduction:

A brief overview of previous revegetation activities is summarized in Section 1.0 of this report. Outcomes from several of these efforts suggest that increased depth or intensity of substrate neutralization would increase plant growth. The field evaluation data gathered from 2013-2014 as part of this current study also suggest that deeper tillage and increased depth of substrate neutralization could increase plant growth and sustainability and reduce water percolation. Methods to incorporate these treatment elements are therefore the focus of the revegetation plot design and construction presented here.

3.1 Field Revegetation Plot Design and Construction

Introduction:

The primary objective of substrate treatments is to improve plant growth and cover. The limiting factor in these substrates is plant-available moisture, so the strategy to increase plant growth is to increase rooting volume. The plants that occur on site are otherwise adequate for climatic and seasonal conditions. Improvements are expected to involve deep subsurface decompaction and deep application of alkalinity, composted organics and fertility. Potential treatments must be geotechnically stable against liquefaction and lateral slippage on these slopes when saturated.

During a construction project, decompaction and deep incorporation of amendments can be accomplished with heavy equipment while steep slopes are being brought down by excavation or, conversely, while fill slopes are built up in compacted lifts. Some example methods for deep lime incorporation during construction are discussed in Revegetation Guidelines(Appendix 1) and Amendment of Existing Slope Materials During Construction (Appendix 4). For this study, due to various site restrictions such as steep slopes and lack of access, decompaction and incorporation of amendments were evaluated by alternative methods.

The equipment available for these types of remote, smaller, inaccessible sites is hand-held construction equipment powered by portable pumps or generators (Figure 10). These have been used to treat other small abandoned mine slopes and erosion scars for revegetation. Various components of the equipment are modified to treat deep horizons below the exposed surface to increase rooting and infiltration. While field methods continue to evolve, the current equipment uses a gasoline powered hydraulic pump and hose-fed hydraulic hammers and post pullers. The hammer uses a casing-sleeved moil point bits (blunt pyramidal chisel) to be able to penetrate rocky substrates where augers are difficult or impossible to operate. After insertion, the center bit is withdrawn, leaving an open casing-sleeved hole to depth for targeted, controlled application of treatment amendments. At the time of application, these fractured holes, backfilled with amendments, create a facilitated rooting channel. If substrate conditions are adequate (dry, rigid), the process of driving a bit through brittle geology creates a radial fracturing pattern that allows lateral movement of amendment materials and roots, effectively expanding the treatment and rooting volume.

Fig 10. Construction of the demonstration plot in the Pit Area using a hand-held hydraulic hammer and a casing-sleeved moil point bit. The bit extractor is at lower right.

Construction:

The target lime rate, developed during previous incubation work, is 20 ton/ac per foot of treated substrate (45 Mg/ha per 30 cm depth). This lime amendment was prorated for the volume of the holes and the hole spacing so that the substrate would be neutralized to the depth of the fracture hole to the different treatment depths up to 100 cm. The lime placed in the rooting column was sufficient to neutralize an area 24 cm away from the hole. The inter-hole distance was 50 cm. Sufficient lime was provided in the treatment to completely neutralize 72% of the whole plot volume to depth. Schematics of plot layouts are shown in Figures 11 and 12. Liming rates used for other sites in the future should be checked on a case-by-case basis because substrates and liming rates vary across the site.

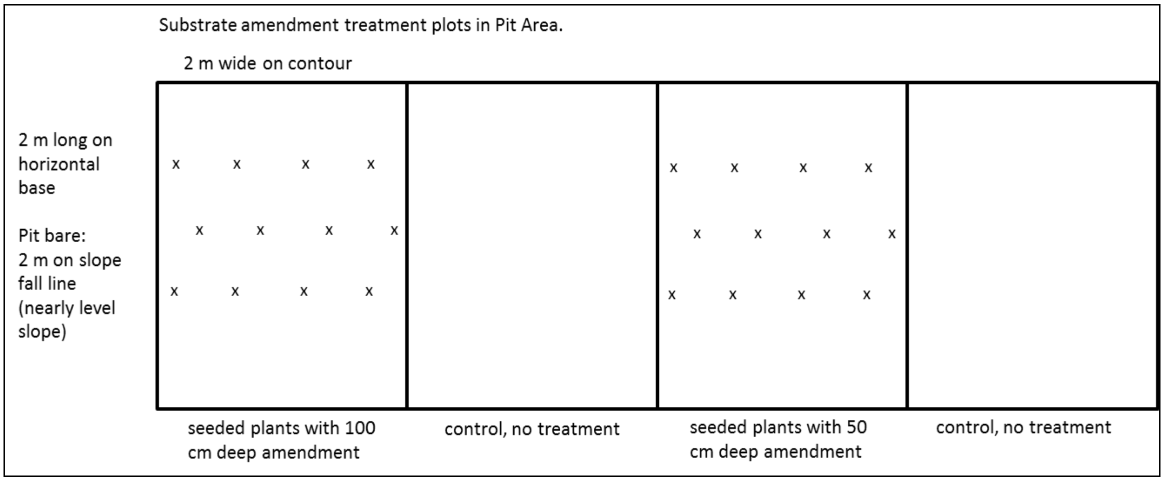

Figure 11. The pit plots were developed on flat areas and had a grid of rooting columns created that were all to the same depth in each plot (either 50 vs 100 cm). No fractured rooting columns were created in the control plots.

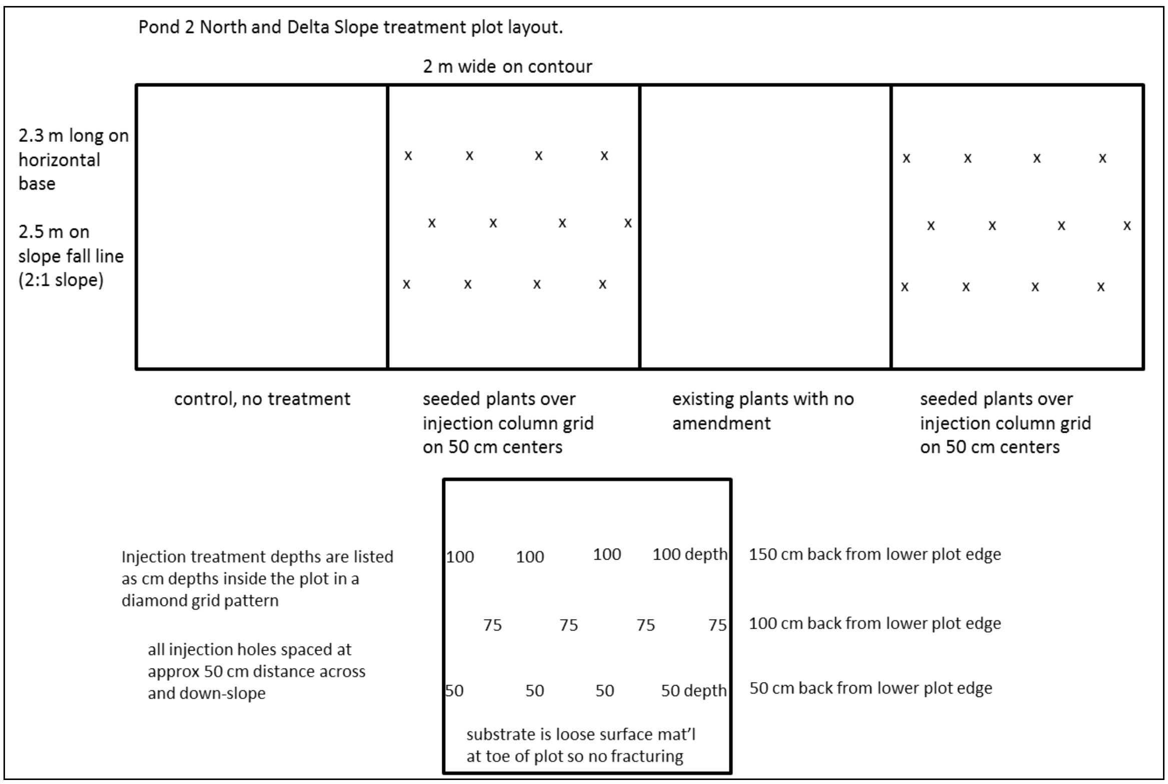

Figure 12. Steeper slopes at Pond 2 North and the Delta Slope sites called for the utilization of a fractured rooting volume on a nearly level base. For this reason, the depth of the fracturing increases with each row going up-slope. The bottoms of the fracture holes are approximately horizontal so that the volume can saturate but remains keyed to a level base. The depths of each of the three rows are listed in the figure.

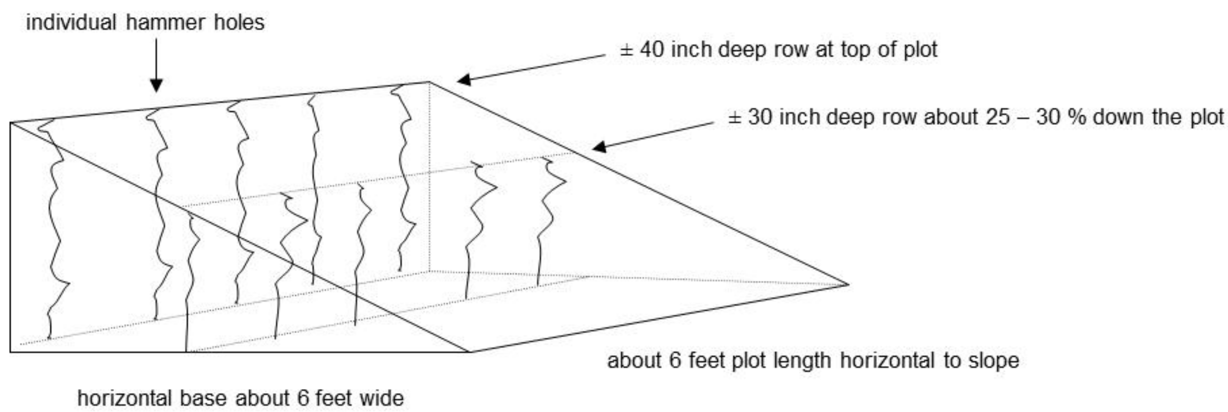

Figure 13. The wedge shaped graphic applies to the plots on Pond 2 N and the Delta Slope. For clarity, only two of the four rows of rooting columns that were constructed are shown.

The slope is typically fractured in a sequence from the lower rows on a plot (near the toe of the plot slope) back toward the upper rows. This sequence functions to 'crack' off slabs of the compacted substrate laterally outward from the slope, decreasing the overall density. A simplified schematic is shown in Figure 13. As the lime is consumed by neutralization of acidity, only about a third of the volume is left as gypsum (the carbonate is lost as water and carbon dioxide). This also reduces the density of a unit volume of substrate. In addition, the amended organics slowly decompose and create additional open pore space. It is important that a vigorous plant cover maintains dense growth of roots into these decompacted areas to retain the open pore structure against the settling and compressing effects of gravity.

The clay mineral types present appear to be susceptible to dispersion and packing. For this reason, incorporation of organic matter is important to keep the minerals from forming a uniform dense compacted layer. Compost was incorporated into these treatment demonstration plots at a rate equivalent to 10 % by volume within the rooting column. An equivalent amount of lime and compost was spread across the surface and incorporated to the top four inches (10 cm) in order to facilitate initial seed germination and establishment. The surface was then covered with wood chip mulch that covers the substrate and resists compaction and wind erosion.

3.1.1 Microbial Inoculants

Along with amelioration of pH and fertility as described elsewhere, regeneration of plant growth potential on highly altered substrates may require intentional regeneration of microbial activity for disease protection and nutrient cycling. Populations of microbial generalists and decomposers increase rapidly following addition of decomposable organic material. In these plots, composted plant materials and wood chips provided these decomposable organic materials.

Decomposer microbes are widely distributed and can migrate onto the site by wind, water flow or transport by animals or humans. Other microbial groups are much less likely to reach a site that has been recently exposed or made available through amelioration of limiting growth conditions. These types of microbes may have been intentionally brought to the site by inoculation treatments, as described below.

One of these groups potentially requiring intentional inoculation is the nitrogen fixing symbiont *Actinomycetes* which colonizes roots of antelope bitterbrush, ceanothus, mountain mahogany, and alder. In general, as field and substrate conditions become more extreme, it is more likely that some unique combination of microbial symbiont and plant ecotype are needed to function well under site conditions. For this reason, use of commercial or generalist inocula is expected to be less effective in the long-term than local materials. These microbes can be harvested from the rooting zones of similar plant species on similar substrates. In general, these field site inocula should be harvested during dormant seasons (late summer or mid-winter) and the soil should not be shredded, dried, or surface applied. For container plants, a pint to a quart (half to one liter) of live soil inoculum per plant container is a good target application rate.

Lupines and legumes utilize soil microbes from the *Rhizobium* or *Bradyrhizobium* groups. These microbes are commonly inoculated in greenhouse nurseries and form nodules, but the field performance is poorly known. Without additional characterization, soil from under local, existing stands of these plants can be used to bring these microbes into the project area.

Mycorrhizal fungi are beneficial fungal root colonists that improve phosphorus and trace element uptake in exchange for organics from the plant. They occur in two broad categories that greatly influence any inoculation strategy. Shrubs, forbs and grasses utilize a form called endo-mycorrhizae, or arbuscular mycorrhizae. Many different combinations of fungi and plant species can form, but the effectiveness of the resulting interaction varies greatly, from positive to neutral to a negative effect on growth. Given this complexity, a default approach is to locate similar stands in representative reference plant communities and, with as little damage as possible, harvest volumes of soil from the rooting zone (top foot) to bring bulk inocula into the planting area.

Creation of a field nursery can also be a cost-effective option to increase inocula if extra space and an extra season are available. With this strategy, a smaller area on an ameliorated site or on a moderately disturbed substrate, is inoculated with field collected materials as described previously. Next, a mix of faster growing, readily colonizing native species is planted. Grasses are valuable because of their extensive root systems and rapid growth. The substrate fertility and perhaps moisture is modestly improved so that growth is vigorous enough the first season to increase inoculum levels. Finally, the field nursery is harvested during the following dormant (dry) season for direct application to the revegetation area. Ideally, light construction equipment can be used rather than with shovels and buckets.

The other general type of mycorrhizal fungus is the group that colonizes on oak and conifer trees. These are called ecto-mycorrhizal fungi. Each of these fungal species is more closely associated with specific plant types and possibly substrate conditions. But luckily, these mycorrhizae reproduce by the familiar above ground “toadstools” or “mushrooms” and these structures are specially adapted to spread spores of each fungal type widely across the whole region. Although growth may be constrained the first year on uninoculated container plants, these fungi will soon reach distant sites and develop mycorrhizal colonizations on their own. Soils around many conifers in the Leviathan Creek corridor show dark brown fungal growths of *Pisolithus tinctoriu*s pushing up out of the ground that indicate that the roots below are beneficially colonized with an appropriate mycorrhizal fungus. No further effort to inoculate is needed for this general group, although container plants already inoculated in the potting stage may benefit during the initial transplanting period and first season.

3.1.2 Plant Plot Materials

A mixed seeding was broadcast on the amended treatment plots as shown in Table 6. The seeds were mixed with a carrier of rice hulls and spread by hand across approximately 500 sq ft of plot area. The total seeding rate was high in order to assure a dense, even stand across the plot surface. The recommended field rate is 50 to 75 lb Pure Live Seed per acre. The area was then covered with a 1 inch thick layer of wood chips equivalent to cubic yards per 130 cubic yards per acre.

A primary plant component observed growing in the Pit Area was Great basin wildrye or giant wildrye, (*Elymus cinereus* Scribn. & Merr). This species was seeding abundantly in the Pit Area, indicating that this accession was evidently tolerant of and thrived in the existing, previously amended mine substrate conditions. Seed was collected in the Fall of 2013 and used for this major component of the revegetation mix.

3.1.3 Plug Preparation

Seeds of Great basin wildrye (*Elymus cinereus*) are reported to be slow to germinate in fall rains. In contrast with the native squirreltail (*Elymus elymoides*) or the weedy invasive annual cheatgrass (*Bromus tectorum*), this plant behavior tends to shift the effective period of germination to the spring season. Because of this general strategy for spring germination, it was not known how robust the wildrye would be for fall planting.

As a fall-back strategy to test this keystone vegetative species, seeds were also germinated and grown in grass plugs to out-plant as a grid of test plants, in case the broadcast seeding failed to germinate. However, even though the winter was dry, seed germination was high. By spring, wildrye seedlings were extensively distributed across the plot treatment areas.

The plugs that were available were planted in early spring in a grid pattern along one edge of the plots. But the lack of spring rain caused them to desiccate and die before July. This illustrates the challenges of setting out larger, established plants into a harsh field environment. Seedlings start small but often are more acclimatized and survive longer.

Table 6. Seed mix used in Fall 2013 demonstration plots.

Comstock Seed
917 Highway 88
Gardnerville, NV 89460
(775) 265-0090

Order Date: 10/17/13
Order Number: 23305
Project Name: CLAUSSEN
Project Number: LEVIATHAN
Blend Name: Area 1

Sold To: CASH A-G

Species & Variety	Pure Seed %	Total Viable	Tested	Origin
BUCKWHEAT SULFUR	0.59	70	07/10/13	CA
NEEDLEGRASS WESTERN	0.60	94	09/19/13	CA - MONO
BROME CALIFORNIA CARINATUS	2.48	97	11/16/12	CA
BITTERBRUSH	2.46	95	09/18/13	CA
SAGEBRUSH BIG MOUNTAIN	0.37	78	09/18/13	NV
SAGEBRUSH LOUISIANA	0.76	73	08/19/13	NV
RICE HULLS	0.00	0	08/15/12	CA

Bulk Lbs: 12.10 PLS Lbs: 11.79

Other Crop: 0.00 Hard Seed: 0.00
Weed Seed: 0.00 Dormant: 2.91
Inert Matter: 92.74

Restricted:
Noxious:

3.1.4 Field Plant List

While the species listed previously were selected to test the demonstration plot treatments, a more complete variety of species has been used by other projects, including the previous field plantings at Leviathan Mine. These species are listed in Table 7. All seed shall be for native plants and from sources that are climatically representative of the mine site. More details are listed in Appendix 1 Revegetation Guidelines.

3.1.5 Plant Materials Application Methods

Use of hydroseed and hydromulch methods are cost-effective and can be applied on slopes that are too steep for access with seed spreading equipment. Use of container grown plants is more expensive but this method can rapidly add plant structure and diversity for species that are difficult to establish from seed. In either case, the substrate needs to be ameliorated deeply so that either container plants or germinated seedlings can root rapidly and extensively in order to become established and withstand their first late summer dry season.

Table 7. Field seed list and application rates:

Common Name	Latin Name	Vegetation Type	Seed	proportion
Grasses			**lb PLS/ac***	**(%)**
Basin wild rye	*Leymus cinereus*	perennial bunch grass	10	27.8
Western needlegrass	*Stipa occidentalis*	perennial bunch grass	5	13.9
Squirreltail	*Elymus elymoides*	perennial bunch grass	5	13.9
Blue wild rye	*Elymus glaucus*	perennial bunch grass	5	13.9
Idaho Fescue	*Festuca idahoensis*	perennial bunch grass	5	13.9
Shrubs				
Antelope bitterbrush	*Purshia tridentata*	evergreen shrub	1	2.8
Big sagebrush	*Artemisia tridentata*	evergreen shrub	1	2.8
Mountain mahogany	*Cercocarpus ledifolius*	evergreen shrub	1	2.8
Rubber rabbitbrush	*Ericameria nauseosus*	deciduous shrub	0.5	1.4
Yellow rabbitbrush	*Chrysothamnus viscidiflorus*	deciduous shrub	0.5	1.4
Forbs				
Showy Penstemon	*Penstemon speciousus*	perennial herb	0.50	1.4
Yarrow - white	*Achillea millefolium*	perennial herb	0.25	0.7
Sulfur buckwheat	*Eriogonum umbellatum*	perennial herb	0.25	0.7
Naked buckwheat	*Eriogonum nudum*	perennial herb	0.25	0.7
Anderson's, Tahoe or Silver-leaf Lupine	*Lupinus argenteus var Meionanthus*	perennial herb rhizobium inoculated	0.50	1.4
Spur Lupine	*Lupinus arbustus*	perennial herb rhizobium inoculated	0.25	0.7

Container plants and planting density:

Common Name	Latin Name	Vegetation Type	Plants/ac**
Mountain mahogany	*Cercocarpus ledifolius*	evergreen shrub inoculated for mycorrhizae and actinomycete at nursery	24
Whitethorn ceanothus	*Ceanothus cordulatus*	evergreen shrub inoculated for mycorrhizae and actinomycete at nursery	24
Wax Currant	*Ribes cereum var cereum*	decidious shrub	24
Jeffrey pine	*Pinus jeffreyi*	evergreen tree inoculated for mycorrhizae at nursery	48

* Minimum Pure Live Seed weights per acre. For convenient weighout sizes, the listed total is calculated for 36 lb PLS/ac. In the field, the total of all seeds shall be increased to equal 50 lb PLS per acre using the listed amounts as minimums.

**Minimum plants installed per acre, total container plants installed per acre is 120, approximately one per 19 square-feet.

4.0 EVALUATE PLOT SUBSTRATES FOR pH LEVEL, ORGANIC MATTER AND, NUTRIENT RELEASE

Introduction:

The effect of soil treatments on substrate acidity, fertility and plant growth were evaluated for the amended demonstration plots. The goals for vegetative growth were to attain adequate substrate pH and plant-available nutrient levels.

4.1 Soil Fertility

Surface substrates were sampled from 2 to 4 inches depth (5 to 10 cm) from vegetated treatment plots in the Pit Area and Pond 2 North (P2N). Control samples were also collected from existing vegetated areas of the Pit at each of the vegetated soil moisture probe profiles. Each sample was a mixture of four smaller field sub-samples and that were composited together to better represent average substrate conditions. Samples were sieved to < 2 mm and air dried. Analysis was done by A&L Western Agricultural Labs, Modesto CA using the S3C suite of nutrient tests (Table 8).

4.1.1 Interpretation of As-Built Soil Fertility

These tests represent the plant-available nutrients of the substrate in which germinating seedlings must establish. The nutrient concentrations do not need to be high. Nutrient levels that are in the low range for agricultural species are adequate for slower growing wildlands species.

Pre-project nutrient tests (Table 1) indicated that nitrogen, potassium, and possibly phosphorus were low to deficient. Amendment with compost and lime as part of the germination substrate for seeded revegetation raised each of these component elements in the demonstration plots (Table 8). The Organic Matter increased from 3.1% on the untreated to 4.2% on treated substrates. Approximately 10 % of this is organic, slow release nitrogen. The calculated Estimated Nitrogen Release (ENR) goes from 91 to 113 lb/ac available. The extractable nitrate remains low at 2.5 ppm, but this is acceptable since nitrate is a soluble, leachable form and is easily lost to percolation. The exchangeable potassium (K%) rises from 0.6% of the soil cation exchange to 2.0%. Target levels for agriculture are 1.5%, so this level is adequate. The potential exists that phosphorus levels are confounded with arsenic that occurs in the mine waste. The increase in plant available phosphorus following addition of the revegetation treatments, which do not contain additional arsenic, suggest that these measured levels actually represent plant-available phosphorus. Lime amendments contain phosphorus that is accessed in a general way by the ‘Pacid’ extract while organic materials in the compost are generally indicated by the ‘Pbicarb’ extraction.

Most critically, the revegetation amendment increases the pH from an average of 4.2 to 6.8, which is near neutral. This, more than amendment of any single element, allows the roots to grow through the amended matrix and attenuate the most growth limiting condition, which is plant-available moisture. In summary, these tests indicate that, after amendment, no other growth limiting requirements are limiting.

Table 8. Final as-built growth conditions, sampled April 2015. Locations include vegetated treatment plots in the Pit Area (Pit-veg North or South), the unamended control plots (Pit-low Cont), Pond 2 North vegetated plots (P2N-low East or West), the unamended control (P2N Cont). Three existing vegetated soils were sampled for a positive control and to characterize the Pit area substrates containing the vegetated moisture probe profiles (Probe-veg) or the untreated profiles (Probe-low). The average control (untreated) is calculated from Pit-low Cont, P2N Cont and Probe-low samples.

LM final sample collection veg plots and non-plots																	
15112047																	
sample	code	OM	ENR	Pacid	Pbicarb	pH	buffer	K	Ca	Mg	Na	CEC	K	Ca	Mg	Ca:Mg	Na
sample	descr	%	lb/ac	ppm	ppm		pH	ppm	ppm	ppm	ppm	cmol/kg	% exch	% exch	% exch	ratio	% exch
LF1	Pit-veg N	4.3	116.4	26.9	86.9	6.2	6.5	426.6	6321.0	1060.0	26.9	47.1	2.3	66.9	18.5	3.6	0.2
LF2	Pit-veg S	4.0	110.0	13.2	81.5	6.3	6.5	365.0	6365.0	1025.0	20.8	46.0	2.0	69.0	18.3	3.8	0.2
LF3	Pit-low Cont	3.5	100.0	12.5	47.4	4.3	4.8	265.2	5187.0	1008.0	20.8	102.8	0.7	25.2	8.1	3.1	0.1
LF4	P2N-low E	3.8	106.4	10.0	7.0	6.5	6.6	324.1	6263.0	757.1	19.6	41.5	2.0	75.3	15.0	5.0	0.2
LF5	P2N-low W	3.7	104.6	14.0	8.0	6.1	6.4	363.9	6382.0	792.8	17.2	45.8	2.0	69.6	14.2	4.9	0.2
LF6	P2N Cont	2.8	85.8	21.3	44.8	4.3	4.8	202.5	4507.0	516.5	11.5	80.3	0.6	28.0	5.3	5.3	0.1
LF7	Probe-veg1	5.8	145.2	30.3	106.3	7.7		363.4	5762.0	530.2	12.9	34.1	2.7	84.3	12.8	6.6	0.2
LF8	Probe-veg2	3.6	102.8	12.8	57.7	7.7		224.8	6484.0	382.1	6.9	36.1	1.6	89.6	8.7	10.3	0.1
LF9	Probe-veg3	3.9	107.8	89.8	96.4	7.1		281.9	7725.0	631.6	18.9	44.5	1.6	86.5	11.7	7.4	0.2
LF10	Probe-low	2.9	88.0	34.3	39.7	3.9	4.8	175.8	4314.0	527.2	11.5	105.4	0.4	20.4	4.1	5.0	0.0
average	treated	4.2	113.3	28.1	63.4	6.8	6.5	335.7	6471.7	739.8	17.6	42.2	2.0	77.3	14.2	5.9	0.2
average	control	3.1	91.3	22.7	44.0	4.2	4.8	214.5	4669.3	683.9	14.6	96.2	0.6	24.5	5.8	4.5	0.1

sample	code	NO3	S	Zn	Mn	Fe	Cu	B	Exch	EC	SAND	SILT	CLAY	TEXTURE
		ppm	ppm	ppm	ppm	ppm	ppm	ppm	Lime	dS/m	%	%	%	
LF1	Pit-veg N	1.7	596.8	4.2	72.3	20.6	16.9	1.0	L	0.9	33	24	43	clay
LF2	Pit-veg S	2.1	429.6	4.4	78.5	14.0	16.5	1.0	L	1.9	35	16	49	clay
LF3	Pit-low Cont	3.2	577.1	2.2	79.6	12.7	4.1	0.4	L	0.8	39	14	47	clay
LF4	P2N-low E	1.8	94.3	2.5	36.2	37.3	12.8	0.9	M	1.2	37	20	43	clay
LF5	P2N-low W	1.7	173.3	2.4	36.7	39.1	11.6	0.8	L	1.3	41	14	45	clay
LF6	P2N Cont	1.8	267.6	2.0	39.2	14.5	3.5	0.3	L	0.9	43	14	43	clay
LF7	Pit-vegprob1	3.9	61.0	5.1	10.6	14.0	3.1	1.2	H	0.9	43	22	35	clay loam
LF8	Pit-vegprob2	2.5	38.6	2.1	4.7	13.8	3.3	0.6	H	0.6	41	16	43	clay
LF9	Pit-vegprob3	3.3	723.1	2.1	14.6	21.5	12.5	0.9	H	1.6	37	24	39	clay loam
LF10	Pit-lowprobe	2.5	521.0	2.3	45.3	13.6	4.5	0.3	L	1.1	37	18	45	clay
average	treated	2.4	302.4	3.3	36.2	22.9	11.0	0.9		1.2	38.1	19.4	42.4	
average	control	2.5	455.2	2.2	54.7	13.6	4.0	0.3		0.9	39.7	15.3	45.0	

Abbreviations for Table 8: LF: Leviathan Final; N: north; S: south; E: east; W: west; SAMPL: sample; %OM: percent organic matter; ENR: estimated nitrogen release; Pbray: phosphorus bray extract; Pbicarb: phosphorus bicarbonate extract; pH: pH; K ppm: potassium, in parts per million; Mg ppm: magnesium parts per million; Ca ppm: calcium parts per million; Na ppm: sodium parts per million; buff pH: buffered pH; CEC: cation exchange capacity; % K : percent potassium on the exchange capacity; % Mg: percent magnesium on the exchange capacity; % Ca: percent calcium on the exchange capacity; % H: percent hydrogen on the exchange capacity: % Na: percent sodium on the exchange capacity: NO3 ppm: nitrate parts per million; S ppm: sulfur parts per million; Zn ppm: zinc parts per million; Mn ppm: manganese parts per million; Fe ppm: iron parts per million; Cu ppm: copper parts per million; B ppm; boron parts per million; LIME: excess lime capacity; EC dS/m: Electrical Conductivity deciSiemens per meter.

4.2 Carbon Stability

An erosion resistant, fertile soil has a mix of different types of organic matter that provide different functions. Most of what is measured as ‘soil organic matter’ in a natural soil is relatively inert, stabilized carbon (humic materials) that decompose very slowly, last for decades to centuries, strengthen soil aggregates, prevent crusting and store nutrients and moisture. A much smaller pool of organic matter typically is rapidly being added as dead plant materials and rapidly being decomposed by microbes in the process of cycling nutrients, resisting disease and start the initial stages of soil aggregation. The sizes and proportions of these different types of carbon pools and the stability of an organic matter addition is a useful way to interpret how amendment will affect regeneration of the whole functioning soil.

To evaluate the long-term carbon stability of the organics used for amendment of these plots, this study relied on a commercial incubation / respiration test from Soil Control Labs, Watsonville, CA. Incubations were run under two conditions. The first test is called ‘Optimal Respiration Rate,’ which uses ideal moisture conditions for maximum respiration under ambient organic matter substrate conditions that mimic decomposition under unamended field conditions. The second test is called ‘Biologically Available Carbon’ and is measured under conditions in which all other growth limiting nutrients are supplied except carbon, so that respiration is limited only by the quality of the substrate carbon source being tested.

Results:

The Leviathan Mine soil organic matter sampled from the Delta Slope plots is inherently stable as indicated by the reading of 1.7 mg CO_2-C/g of organic matter substrate per day (Table 9). This rate was the same whether incubated under optimal moisture conditions or whether supplemental nutrients were added. This level is interpreted to be approaching the transition between Very Stable and Stable. It indicates that this material has both decomposable materials and very stable components similar to a functioning soil.

A second sample was tested for incubation and CO_2 respiration using unincorporated organic compost material located from a pile along the road on the California side of Leviathan Mine road from a previous delivery. The question with this material (similar to that used in the Delta Slope samples above) is whether the organic stability from the active soil has changed compared to a similarly aged material with less biological activity as in the stockpile. This is indicated to be the case (Table 10). The material from the dried stockpile was much more stable and less biologically active. In addition, the biologically active soil was able to strip out much of the stabilized organic nitrogen from the original compost material (1.3% in the compost stockpile down to 0.39% in the soil sample) and has made that stabilized organic nitrogen biologically available. This indicates that these organic materials are functioning to provide long-term, slow release nitrogen for plant uptake and provide a long-term energy source for soil microbial activity.

Table 9. Existing soil organic matter stability from the Delta Slope treatment plots.

STABILITY			
Carbon Dioxide Evolution Rate		**Respiration Rate**	**Biological Available Carbon**
	Test Conditions:	(as received)	(carbon made the limiting factor)
	Pre-incubated:	3 day-20 deg.C	3 day-20 deg. C
	Incubation:	36 deg.C	36 deg.C
	Moisture adjustment:	saturated	saturated
	pH	Not adjusted	6.5 to 7.5
	Porosity	Not provided	#20 quartz sand
	Nutrients	Not provided	NPK+trace
	TMECC Method	05.08-B	05.08-F
RESULTS:	mg CO2-C/g OM/day	**1.7**	**1.7**
	mg CO2-C/g OC/day	2.2	2.2
	mg CO2-C/g TS/day	0.20	0.20
INTERPRETATION:	Very Stable	< 2	< 2
	Stable	2 to 4	2 to 4
	Moderately Unstable	4 to 8	4 to 8
	Unstable	8 to 20	8 to 20
	Very Unstable	> 20	> 20

RESPIRATION RATE
Optimizing moisture with pre-incubation to simulate maximum biological activity in a source pile.
BIOLOGICAL AVAILABLE CARBON
Optimizing all conditions (except carbon) makes rate of degradation limited by the available carbon in the compost. Purpose is to simulate condition of end use in an agriculture environment where nutrients, porosity, pH adj. and moisture are provided from the grower or receiving soil when optimizing conditions for plant growth.

	Units	Wet wt. Basis	Dry wt. Basis	TMECC Method
Total Nitrogen:	%	0.38	0.39	4.02-D
Organic Matter:	%	11.5	12.0	05.07-A
Organic Carbon:	%	8.7	9.1	4.01
Ash:	%	84.0	88.0	3.02
C/N Ratio	ratio	23.3	23.3	calc.
Moisture:	%	4.47	0	3.09

Table 10. Organic matter stability in field-aged compost material from existing stockpile.

STABILITY			
Carbon Dioxide Evolution Rate		**Respiration Rate**	**Biological Available Carbon**
	Test Conditions:	(as received)	(carbon made the limiting factor)
	Pre-incubated:	3 day-20 deg.C	3 day-20 deg. C
	Incubation:	36 deg.C	36 deg.C
	Moisture adjustment:	saturated	saturated
	pH	Not adjusted	6.5 to 7.5
	Porosity	Not provided	#20 quartz sand
	Nutrients	Not provided	NPK+trace
	TMECC Method	05.08-B	05.08-F
RESULTS:	mg CO2-C/g OM/day	**1.0**	**1.0**
	mg CO2-C/g OC/day	2.3	2.4
	mg CO2-C/g TS/day	0.40	0.41
INTERPRETATION:	Very Stable	< 2	< 2
	Stable	2 to 4	2 to 4
	Moderately Unstable	4 to 8	4 to 8
	Unstable	8 to 20	8 to 20
	Very Unstable	> 20	> 20

	Units	Wet wt. Basis	Dry wt. Basis	TMECC Method
Total Nitrogen:	%	1.2	1.3	4.02-D
Organic Matter:	%	34.3	39.3	05.07-A
Organic Carbon:	%	15	17	4.01
Ash:	%	53.0	60.7	3.02
C/N Ratio	ratio	13.1	13.1	calc.
Moisture:	%	12.7	0	3.09

Conclusions:

Organic matter is limiting soil function on the bare mined materials, but plant-based composts are able to function as a surrogate for natural soil organic matter.

5.0 MONITOR PLANT PERFORMANCE AND TREATMENT RESPONSE ON REVEGETATION PLOTS

Objectives:

To evaluate effectiveness of amendments on the treatment plot areas, the growth of germinating seedlings and established grass clumps and the effect of acid neutralization with depth were evaluated. These measurements are intended to indicate whether the expected plant response occurred or whether an additional limiting factor remained that constrained plant growth.

The following four plot treatment performance objectives are addressed:

- document plant growth on plots
- evaluate plot rooting depth
- measure pH patterns with substrate depth
- document growth of paired (treated and untreated) plants

5.1 Plant Growth on Field Demonstration Plots

Introduction:

Following evaluation of substrate fertility and infiltration contributing to growth conditions at Leviathan Mine, field plots were designed and installed that demonstrated the effect of deep rooting treatments on 1) canopy growth of seeded plants, 2) root depth, 3) pH levels and 4) canopy growth of existing plants.

Methods:

Each field plot was constructed with a grid of rooting column treatments on 20 inch (50 cm) centers that were installed to various depths and backfilled with lime and compost. To provide a uniform germination environment for the broadcast seeds, the surface to approximately 3 inches (8 cm) depth was mixed with lime and compost at the same rates as the treatment volumes to provide a germination medium for the broadcast seed. All plots received the same seed mix and rate, and were covered with one inch of wood chips.

The effect of rooting column treatment on seeded plant growth was evaluated using a 6 x 6 inch (15 x 15 cm) square ‘microquadrat’ centered directly over the treatment column location. Duplicate microquadrat locations for the non-treated (control) measurements were located equidistant between adjacent rooting column locations or as close as to this inter-treatment area as possible given the presence of large rocks on the plot. Plant response was measured using total leaf length of all plants and by summing the total cm of leaf length for each microquadrat. Most plants were grasses. Because of the different leaf shape of shrub germinants only grass leaf lengths were used. Means of total leaf length were compared using a simple two tailed *t* test, two sample, unequal variances (Microsoft Excel Data Analysis ToolPak) between contrasting treatment or control plots for each treatment depth. Significance values for *p* (student's *t* test) indicate probabilities of Type I error, which is the probability the difference in means observed here occurs by chance alone. Every treatment rooting column on the plot was measured, so no randomized subset was selected for sampling.

Results:

Visual evaluation (as shown in Figure 14) indicated that plant growth response only occurred within 10-15 cm of the treatment location, leaving over 30 cm of space between the treatment grid points. Plants in the inter-treatment area germinated and grew to an inch or two tall before becoming weak and thin. This pattern of low growth in the inter-treatment spaces is assumed to result from a lack of deeper rooting and access to moisture.

Total leaf length of the soil rooting column treatment was significantly greater than the untreated control on all Delta Slope plot treatments, Pond 2 North 100 and 50 cm treatments and both Pit plot depths (75 and 100 cm) (Table 11). The trend on the Pond 2 North 75 cm treatment was also positive (treatment plants were larger than control) but the difference is indicated to be non-significant (a 16 in 100 chance that this much difference may be observed by chance alone).

Overall, the general conclusion is that plants growing on or near the deep soil treatments are larger than on control areas, with total plant growth differences ranging from about 3 to 14 times greater.

Table 11. Plot microquadrat data comparing total leaf length means of the rooting treatment quadrat vs the non-treated area of the plot.

Pit Area Plots				Pond 2 North Plots			Delta Slope Plots		
	average leaf length		significant difference 100 vs 75 cm depth		average leaf length	significant difference treated vs control		average leaf length	significant difference treated vs control
100 cm plot	(cm)	*p* =	*p* =	**100 cm plot**	(cm)	*p* =	**100 cm plot**	(cm)	*p* =
treated	356.0	0.0093	0.324	treated	411.3	0.0047	treated	476.5	0.0070
control	83.8			control	140.3		control	95.3	
75 cm plot				**75 cm plot**			**75 cm plot**		
treated	264.75	0.0005		treated	201.8	0.1617	treated	414.0	0.0498
control	41.5		0.059	control	132.6		control	52.7	
				50 cm plot			**50 cm plot**		
				treated	280.6	0.0808	treated	472.0	0.0185
				control	102.8		control	33.3	

Conclusions:

The plants that germinated and grew within 3 inches (8 cm) of a rooting column treatment were significantly larger than those growing in the non-treated area, even though germination conditions, seed type and mulch treatment were the same. This was true for all treatment depths during this first year of growth. Differences in plant growth between treatment depths would have to be made in subsequent growth seasons.

5.2 Effect of Rooting Column Treatments on pH Neutralization

Introduction:

The purpose of deep injection of lime and compost is to fracture the compacted subsoil and to deliver soil fertility amendments to depth. Although the rooting column facilitates rapid root growth to depth, the total rootable volume needs to be expanded to provide an adequate volume of moisture extraction. To evaluate this, the soil pH was measured vertically down the rooting column treatment and also horizontally at distances away from the column to evaluate diffusion of the lime in the column out into the acid subsoil.

Methods:

To evaluate the effect of lime addition on neutralization, a soil profile from each plot was sampled in a depth x grid pattern with depth and distance from the rooting column fracture area (Figure 14). Substrate depths were 4, 12, 20, 28 inches (10, 30, 50 and 70 cm), or as deep as the plot was constructed. Soil samples were collected on the rooting column centerline at each depth and also at 2, 4, and 6 inches (5, 10 and 15 cm) to the left and right of the centerline. Approximately 3 tablespoons (3 cu in) (50 mL) of soil were collected by mixing four smaller samples together to get a composite sample for a more representative pH measurement. Distilled water was added to this volume in a 5:1 ratio, stirred and incubated for three days in loosely capped vials. Samples were re-stirred and the pH was measured with recalibration of the electrode between each of the different sites.

Results:

Substrate alkalinity with depth

Roots were observed to grow to full depth in all rooting column treatments. The pH levels of all columns at all treated depths was at neutral or above, as expected from the high lime addition rate (Figure 15, 16, and 17). The Pit pH levels (Pit sample, Figure 15) shows a pH of 3.8 at the bottom (70 cm) of the rooting column treatment that was injected only to 50 cm depth. This indicates that alkalinity did not diffuse downward from the column to deeper depths. The pH of the column that was injected past 70 cm remained near neutral (pH 7.4), showing the ability of the method to get alkalinity to the full treatment depth (data not shown).

None of the lateral distances away from the central rooting column showed appreciable increases in pH. This indicates that alkalinity is not diffusing outward from the column, although as the root extracts moisture, the acidified water is expected to be neutralized as it is diffused into the rooting column. This column is dosed with enough lime to neutralize the substrate nearly 10 inches (25 cm) outward from the column, so it has several years' worth of potential alkalinity in reserve.

While this injection method developed some radial cracking in the more dense plots in the Pit area, most of these substrates were too clayey and plastic to shatter. Rather, they appeared to smear and mold around the bit rather than splitting and fracturing. As a result, the treatment remained predominantly in the rooting column volume. The low rainfall that occurred during this season is also expected to reduce migration of alkalinity out of the treatment column into the adjacent soil.

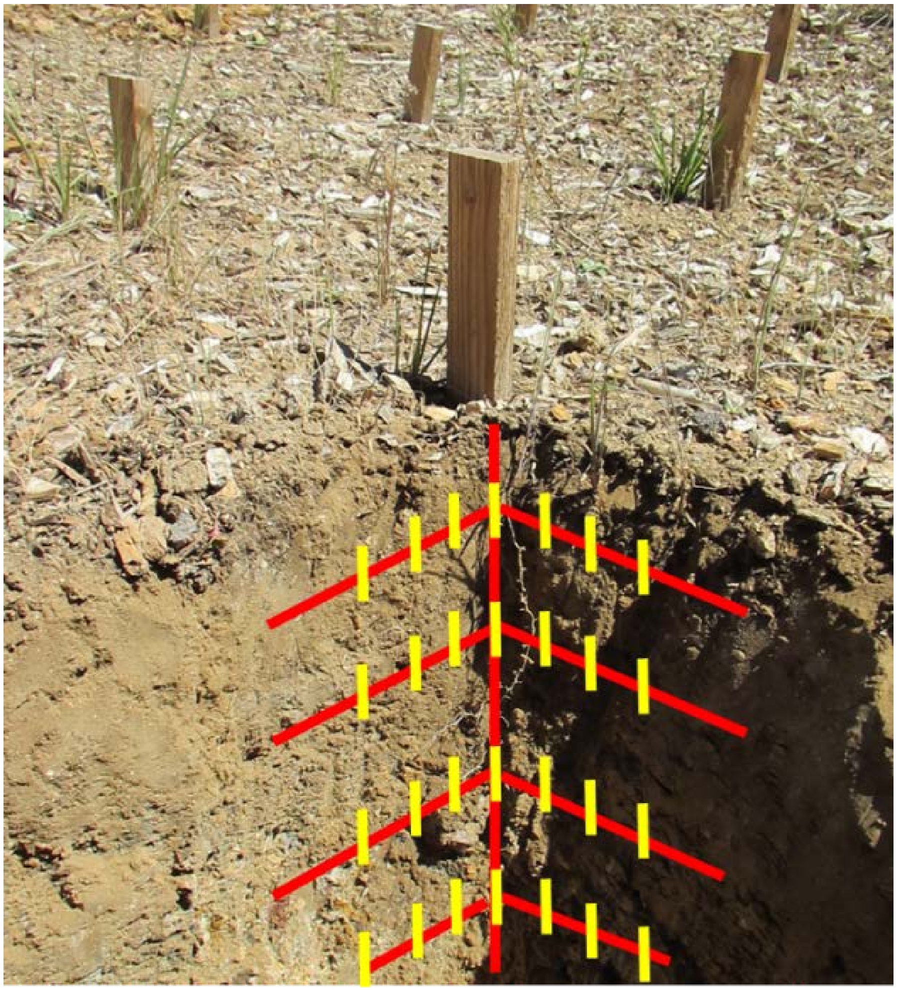

Figure 14. Treatment pH effect with depth. Samples were collected at each yellow vertical line. The rooting column treatment delivered alkalinity to the injection column but diffusion out into the unamended subsurface substrates was low and they remained critically acidic. Note that the largest plants grow immediately adjacent to the stake marking the rooting column treatment. Roots were observed to extend to the bottom of each excavated rooting column.

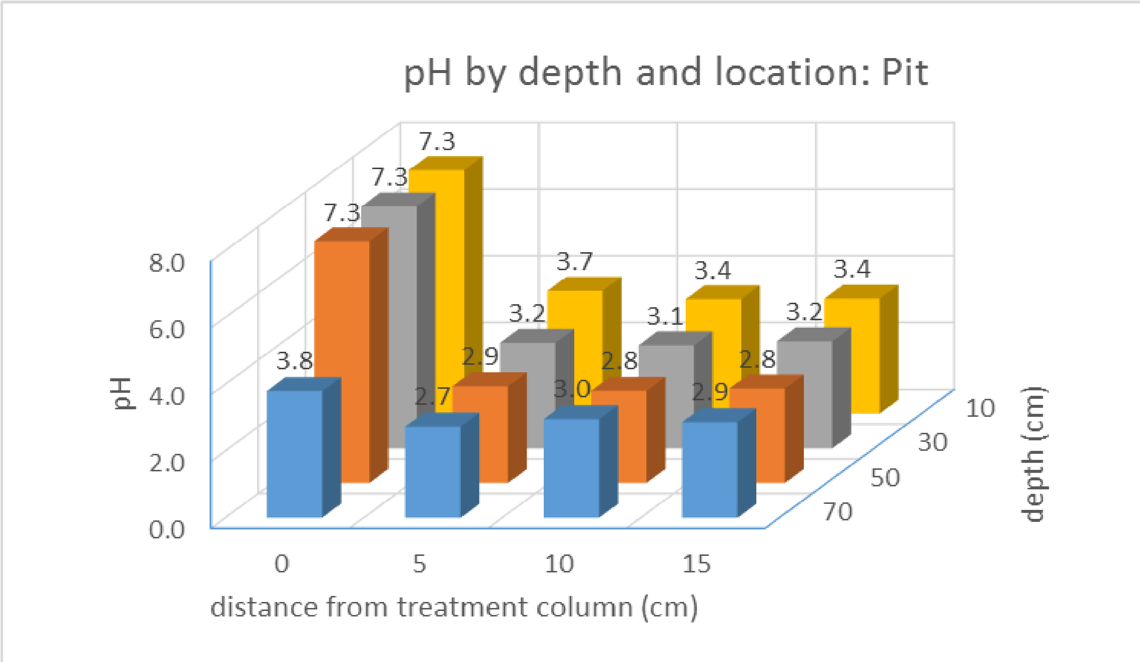

Figure 15. Distribution of pH levels from the Pit plot measured at the rooting column (left row) to 6 inches (15 cm) away (right column). The substrate surface samples are the back row at 4 inches (10 cm) and deeper horizons are indicated by rows at 12, 20, and 28 inch depths (30, 50, 70 cm).

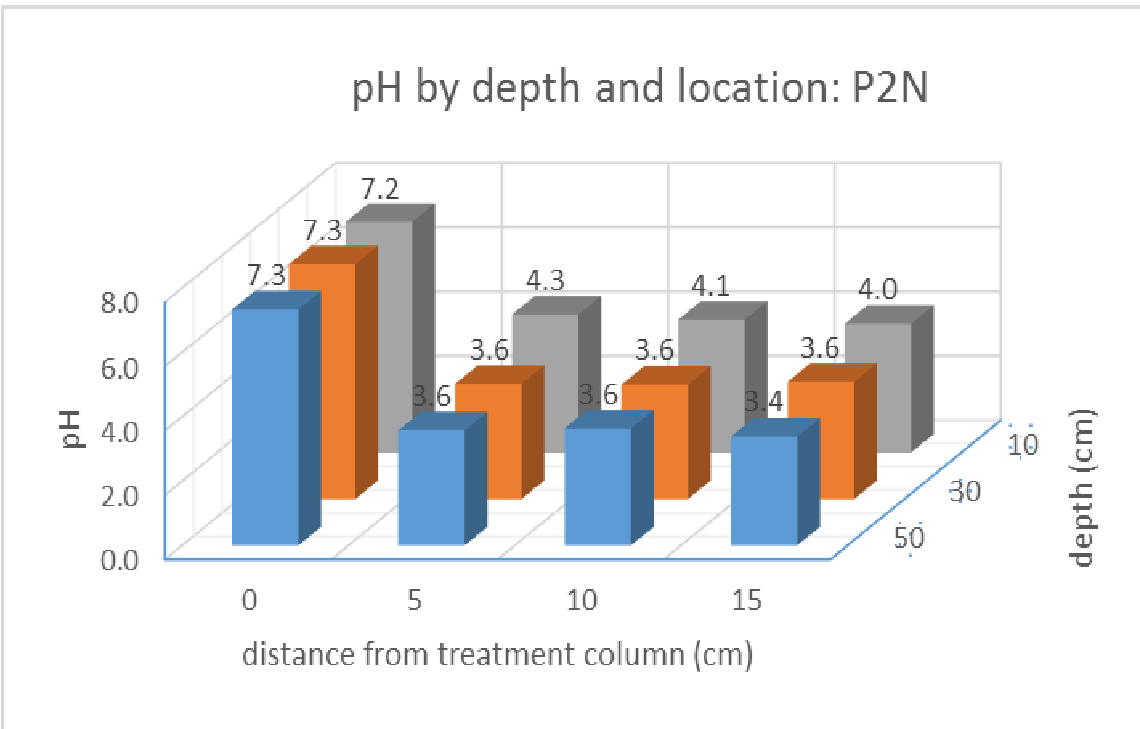

Figure 16. Distribution of pH levels at Pond 2 North measured at the rooting column (left row) to 6 inches (15 cm) away (right column). The substrate surface samples are the back row at 4 inches (10 cm) and deeper horizons are indicated by rows at 12 and 20 inch depths (30, 50 cm). Surface substrates and subsurface substrates away from the rooting column were not effectively neutralized by this treatment.

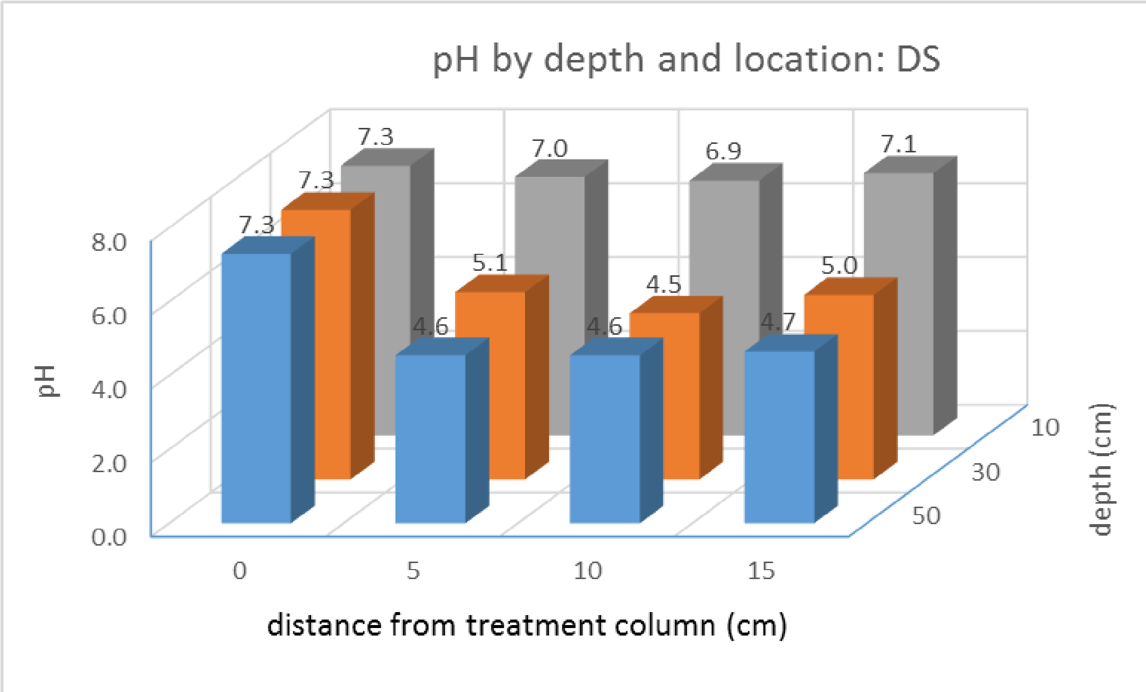

Figure 17. Substrate pH of the Delta Slope. Evaluation of the rooting columns indicated that the method was effective to increase deep rooting, but that the alkalinity did not spread out from the vertical column.

Conclusion:

The injection method may support increased plant growth for many years as the injected alkalinity is consumed by incoming acidic pore water. But, the rooting will probably not extend much out into the surrounding matrix based on pH measurements. This persistent state of compaction is a problem for rainfall infiltration during winter rains and moisture uptake during dry summer growth seasons. At sites accessible by heavy equipment, a larger-scale lime mixing or incorporation method is recommended as long as it still reaches three feet depth.

5.3 Pit Area Paired Plot Data Summary

Introduction:

Existing plants are widely scattered across the site. A comparative study of growth of closely occurring, similar sized ‘paired’ plants was designed to evaluate if these established plants respond to deep liming treatment and increase their growth, as was observed for the first year seeded grasses.

Methods:

Paired plants in the Pit area that were treated received 1 m deep lime and compost amendments injected into the slope about 15 cm above and below the edge of the plant crown. Lime amendment was sufficient to neutralize the substrate a distance of about 10 inches (25 cm) radially around the injection column. Compost was 10 % of the injection column volume. An existing plant with similar size and vitality growing nearby within 15 to 30 feet (5 to 10 m) was selected to represent a paired non-treated (control) plant. Because plant clusters were not exactly the same size, the area of the exposed basal crown was measured after clipping and the clipped biomass dry weight was pro-rated to a per-crown area basis. This crown basal area has only small year-to-year changes in size relative to the top growth of leaves, stems and culms, so this procedure standardized the absolute size of the plant relative to the changes in biomass production that were due to treatment effects.

Shoot biomass from grasses can be subdivided into recognizable tissues that can be grouped by age into three categories: 1) last year's growth, 2) current year's senesced (dead) growth and 3) leaves that were still actively growing at the time of harvest on Oct 10, 2014. The following statements relate to these normalized gram-per-crown area comparisons and biomass categories. Because these summary values are ratios of ratios (plant biomass contrasts as well as crown size contrasts), equal variance and independence could not be confirmed and therefore values are not statistically analyzed.

Results:

The previous year's growth of the selected plant pairs was compared to check if they had comparable pre-treatment growth. When normalized for the relatively unchanging area of the basal crown, the previous year's shoot growth was relatively similar between Treated and Control (untreated) plants (Table 12). The relatively small difference (5.2%) indicates that, previous to treatment, growth was similar between the selected plant pairs on a per-area basis. Following deep lime/compost amendment treatment in Fall, 2013, the biomass production of treated plants increased by 24.8% for the 2014 growing season, indicating a positive plant growth response to the deep rooting treatment. In addition, the weight of leaves that were still green and actively photosynthesizing at the end of the 2014 growing season increased nearly 200 % in treated plants compared to non-treated control plants.

This result indicates that not only did the rooting treatment facilitate additional biomass production, it also allowed the plants to extend their active growth period throughout the entire season. Typically, perennial grasses in this area go into summer dormancy whenever water becomes limiting due to drought or restricted rooting. While the longer period of growth is important for plant size, vigor, litter production and erosion control, the additional significance is that transpiration also continues throughout the entire season rather than decreasing with summer dormancy. The additional transpiration further decreases soil moisture, recharges the soil's reserve infiltration capacity and reduces the time the substrate is at or near saturation in the following rainy season. While the amount of soil moisture removed has not been calculated, this type of treatment can provide a low cost, relatively self-sustaining method of reducing seepage into and through the substrate at the mine site. The sizable increase in active, late season green biomass also indicates that the plant community as it exists on the site has not reached its maximum size, cover or ability to reduce internal percolation.

Deeper rooting volumes appear to have stronger limiting conditions than surface substrate characteristics.

Table 12. Comparison of biomass production of paired plant clusters following deep lime/compost amendment (g biomass per cm^2 crown area).

Treatment	Previous year's growth	Current year's growth	Active green growth
Pit Area Control avg g/cm^2, n = 4	0.164	0.217	0.037
Pit Area Treatment avg g/cm^2, n = 4	0.156	0.271	0.110
% change	-5.20 % decrease	+24.84 % increase	+199.33 % increase
Relative Growth Ratio	0.95 treatment / control	1.25 treatment / control	2.97 treatment / control

6.0 INTERPRETATION OF WEATHER RECORDS FROM ON-SITE STATIONS

Introduction:

Infiltration into a soil has two components: 1) surface infiltration rates and 2) surface infiltration capacity (depth of soil and amount of water it can hold). If the rainfall rate exceeds the soil infiltration rate, or if soils fill and saturate and rainfall continues, the excess water is sheeted off as overland flow. These characteristics should be interpreted relative to the types of weather that occurs on site. A NOAA weather data web site provides point forecasts for rainfall rates and volumes at different Recurrence Intervals and storm Durations. These can be compared to on-site weather events so that the 'severity' of the event can be interpreted relative to the impact the event had on the site and local drainages.

On-site weather data was acquired from the Atlantic Richfield weather station located near Pond 4 on the Leviathan Mine site. The more intense or longer duration storms were selected for comparison to the NOAA precipitation frequency data set to interpret the significance of the recorded events. This process is similar to that done for only the July 25, 2013 storm that was reviewed previously (Section 2.5) regarding infiltration measurements and surface flow in the Pit Area.

Methods:

Weather data from the Atlantic Richfield weather station for all of 2013 and 2014 were loaded into a spreadsheet. For each measured rain event, the cumulative rainfall for different successive 10 minute intervals was summed for time durations from 10 minutes to 2 hours. The maximum rainfall for different durations was compared to the NOAA precipitation frequency data tables to evaluate the Recurrence Interval (i.e. the 'severity') of the event (Appendix 2a and 2b).

Results:

6.1 Short Term, Intense Storm Events

The top five most intense 10 min duration events measured in the Atlantic Richfield station data in 2013 ranged from a high of 0.17 inch/10 min (July 25, 2013) down to 0.12 inch/10 min interval (June 28). The top 5 most intense 10 min events in 2014 ranged from a high of 0.11 inch/10 min (July 18) down to 0.07 inch/10 min (Aug 9). The NOAA Precipitation Frequency Data Server indicates that rainfall intensity for the Leviathan Mine location for a 10-minute duration with a 1 year average Recurrence Interval (RI) is 0.185 inches and a 10 minute 2 yr RI event is 0.229 inches. Therefore none of these recorded 10 minute interval storms appear to be intense or atypical and can be expected to occur several times per year on average.

Potentially, a shorter, more intense 5 minute event could have occurred within the 10 minute measuring interval that was long enough to ‘average out’ the shorter event. To interpret this scenario, the whole recorded rainfall amount for the 10 minute interval was compared with target rainfall for the next shorter interval, a 5 minute storm. The NOAA rainfall intensity table lists a 1 year 5 minute interval storm as 0.129 inches and a 2 year 5 minute interval as 0.160 inches. Hypothetically, if all the rain in the July 25 storm fell in 5 minutes it would have exceeded a 1 year event and was actually slightly more than a 2 year event (0.170 inch recorded vs 0.160 inch target amount). Even so, long-term erosional stability requires a site to withstand storms that occur on two year intervals. According to these data, no intense, short duration storms occurred at the site in 2013 or 2014 that would be expected to generate overland flow as a result of a very short intense rainfall.

6.2 Longer Term Storm Events

Cumulative rainfall over longer time intervals may, however, be sufficient to saturate near-surface horizons and divert additional rainfall from infiltration to overland flow. Using the available weather records, cumulative rainfall was calculated in rolling sums for intervals of 1 or 2 hours. The SMARA standard, for example is to be able to handle runoff from a 20 year 1 hour event without erosion. The NOAA weather tables report a 25 year RI, which is slightly more intense than a 20 year RI. The 25 year RI value will be used here.

The main 1 hour duration storms of the 2013 summer season were 0.45 inch/hour (June 28), 0.33 inch/hour (July 25), 0.20 inch/hour (Aug 6 and 0.15 inch/hour (Aug 20). When precipitation for these storm events was summed for 2 hour or longer, only the June 28 event had greater cumulative precipitation, totaling 0.57 inch/2 hour. No other increases in precipitation occurred when summing over longer intervals from 6 hours to 4 days.

The main 1 hour duration storms of the 2014 summer season were 0.29 inch/hour (Sept 27). 0.25 inch/hour (July 20), 0.24 inch/hour (July 18) and 0.13inch/hour (July 31).

When precipitation for these storm events was summed for 2 hours, the Sept 27 event increased to 0.48 inch/2 hour and the July 18 and 20 events increased to 0.31 inch/2 hour. No other increases in precipitation occurred when summing over longer intervals from 6 hours to 4 days.

The maximum recorded rainfall amounts for a 1 hour duration storm (0.45 inch/hour in 2013) is only slightly above the 0.420 inch/hour listed on the NOAA precipitation frequency estimate for a 1 year RI 1 hour event. No one hour storms reached this intensity in 2014. When a 2 hour interval was measured, the maximum cumulative amount in 2013 was 0.57 inch/2 hour (June 28) and in 2014 the maximum was 0.48 inch/2hour (Sept 27). For reference, the SMARA standard of a 20 year 1 hour storm is 1.02 inches, greater than twice those recorded during this work.

The greatest cumulative precipitation amounts recorded for a 2 hour interval (0.57 inch/2 hour on June 28, 2013 and 0.48 inch/2 hour on Sept 27, 2014) were at or below the NOAA target for a 1 year 2 hour duration storm of 0.572 inch/2 hour. No storms came close to the volume predicted for a 2 year return event of 2 hour duration (0.714 inch/2 hour). No longer duration storms occurred (for multiple hours or multiple days) that would saturate surface soils and generate overland flow.

In conclusion, these 2013 and 2014 precipitation events are typical of rainfall patterns that occur at 1 or 2 year Recurrence Intervals and have low intensities compared to greater than 5 year RI events.

The Lahontan Weather Station at Pond 1 also registered this event and records a maximum rainfall rate (using an event timer on a tipping bucket) (Table 13)

Table 13. Lahontan weather data showing maximum recorded rainfall rate as an equivalent rate per hour (inches).

Date	Time	Rain amount (inches)	Rain rate (inches per hr)
6/28/2013	1:00 PM	0	0
6/28/2013	2:00 PM	0	0
6/28/2013	3:00 PM	0.02	0.06
6/28/2013	4:00 PM	0.19	1.65
6/28/2013	5:00 PM	0.23	2.07
6/28/2013	6:00 PM	0	0
6/28/2013	7:00 PM	0	0

The second and third columns from right are maximum rain amount measured during the one hour interval and the calculated equivalent rate on a per-hour basis. According to the NOAA precipitation frequency estimate table (Appendix 2a and 2b) the highest rate recorded (0.23 inches) is equivalent to between a 5 and 10 year RI storm if it occurred in a 5 minute interval or 2 year RI event if it happened for a 10 minute interval, or a 1 year event if it occurred for a 15 minute interval. The equivalent period from the

Pond 4 weather station indicates a maximum of 0.16 per 10 min and 0.28 for a 20 minute interval. These are less than 1 year RI events that the site should handle easily.

6.3 Seasonal Weather Trends from Regional Weather Data (Markleeville RAWS)

The two seasons prior to establishment of the field plots received 63 and 88 % of average precipitation (using available 17 year data from Markleeville Remote Area Weather Station) (http://www.raws.dri.edu/). This suggests that soil moisture in the plot subsoils was not recently recharged. The first year of plant establishment (2014) received 93 % of average while the second year ending 2015 received 66 % of average (red lines of rainfall graph, Figure 18).

As can be seen from these data, only about a third of the years have precipitation near ‘average’ conditions. Two thirds are either much wetter or drier than average. For this reason, the field strategy should be to design for the upper or lower range of target conditions in which the project may potentially fail, rather than designing for an ‘average’ condition. For plant materials, the critical conditions are low-rainfall years in which moisture stress is highest. Plants must survive the one or more dry seasons if revegetation is to be sustainable. These target conditions could be selected to support plant growth in the drier 6 of the 17 years on this data record. This involves effective capture of rainfalls that do occur, and may be in occasional, more intense storm events. The moisture should be stored deep in the profile where it does not evaporate before being needed for use by the plants in late summer. Conversely, erosion control and percolation characteristics should be designed to function adequately in the wetter years. These functions would include erosion resistance either for intense storms and rain impact and flow protection on the surface (such as mulches or vegetation cover) or for multi-day events where saturation and overland flow are the main causes of erosion. Deep rooting volumes provide such increased infiltration capacity and reduce this source of erosion, as well as growing more vegetative cover and reducing subsurface moisture through evapotranspiration.

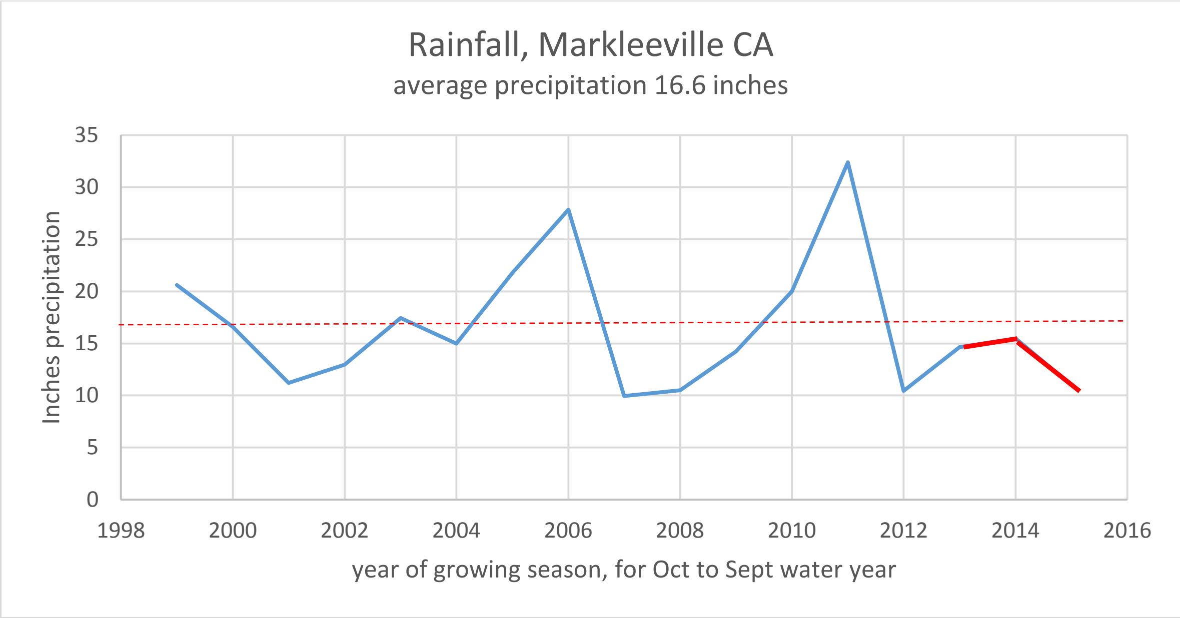

Figure 18. Variation in precipitation for water year, October 1 to Sept 30 and the 17 year average of 16.6 inches (dotted line). Date shown on graph is the year of the spring growing season. The vegetation evaluation period covers 2013, 2014 and 2015, shown in red on the graph.

6.4 Overall Plant Growth Conclusions

Conclusions:

1. Vegetation is steady in treated areas over this short measurement interval.
2. Sparsely vegetated areas tend to have acidic subsurface horizons.
3. With adequate substrate treatment, vegetation can be established from seed.
4. Plant roots are able to reach deeply into the amended substrate the first year to access moisture and to continue growth through the summer.
5. Established plants also respond the first season to deep lime placement.
6. Amended plants had three times the transpiration surface as control plants at the end of the following growing season.
7. General observations indicate that steeper slopes (Pond 2 North) were geotechnically stable but not erosionally stable. Downslope creep of soil materials currently buries established plants and exposes the down slope side of plant root crowns. Rapid drainage downslope created rills and sediment was deposited in the stormwater ditches during heavy rains. These slopes then dried and were left bare and exposed to wind scour or erosion, resulting in sediment being deposited in stormwater drainage ditches.

7.0 CONTINUOUS MONITORING OF SOIL MOISTURE CONDITIONS UNDER VEGETATED AND NON-VEGETATED PLOTS.

Introduction:

Soil moisture measurements utilize two characteristics to evaluate plant-available moisture for vegetative growth and cover. The amount of water per unit of soil is called the volumetric moisture content. This can be measured by comparing moist versus or air-dried soil weights. Or, the volumetric content can be monitored continuously by various volumetric soil moisture probes. This study used 10HS volumetric probes that were monitored with an EM50 data logger set to record on 15 minute intervals (Decagon Devices, www.decagon.com).

The other characteristic of soil moisture is the matric potential, which describes how tightly moisture is held in the soil. The smallest pores hold water so tightly that plants cannot extract it and they wilt. The field instrument to measure this characteristic is a matric potential sensor probe (MPS-6, Decagon Devices) (Figure 19). This pairing of volumetric and matric potential probes at different depths is intended allow tracking of both the amount and the availability of moisture for plant uptake or for percolation downward through the profile. As substrate moisture is depleted as the summer progresses, plants work harder to get remaining moisture. Plants use a variety of strategies to cope with this period of stress, including rooting more deeply, pulling harder on remaining moisture, osmotic adjustment and avoidance by going summer-dormant.

Methods:

Soil moisture was measured through the 2014-2015 winter season on three replicate profiles of vegetated and three non-vegetated areas of the mine that were co-located between the fourth and fifth contour stormwater drains in the pit (counting down from the top) on either side of the south vertical drain structure (Figure 20). A soil pit was dug into the root zones of representative existing Great basin wildrye (*Elymus cinereus*) clusters. Volumetric moisture content probes were installed at three horizons. Soil matric potential probes were installed only at the top and bottom horizons. Probes were installed in the vegetated replicates at 2, 12 and 28 inch (5, 30 and 70 cm) depths.

Probes were installed in the non-vegetated areas at about 2, 8 and 18 inches (5, 20 and 45 cm). No plant cover existed on the non-vegetated plots other than widely scattered small individuals of buckwheat (*Eriogonum* spp). The reason for selecting these plot locations is to characterize different infiltration conditions of these two contrasting areas of the pit. The upper soil moisture probes are placed in and represent the surface infiltration zone. The middle probe measures moisture in the bottom of the main rooting zone, located just above the compacted subsurface horizon. The lowest probe set was entirely within the dense, compacted subsoil and represents moisture beyond the depth of root extraction. Standard default calibration curves are used for all these presentations, so values do not represent absolute values of soil moisture. All differences should be compared internally within each individual data set.

Figure 19. Soil moisture volumetric probe (left) and matric potential probe (right).

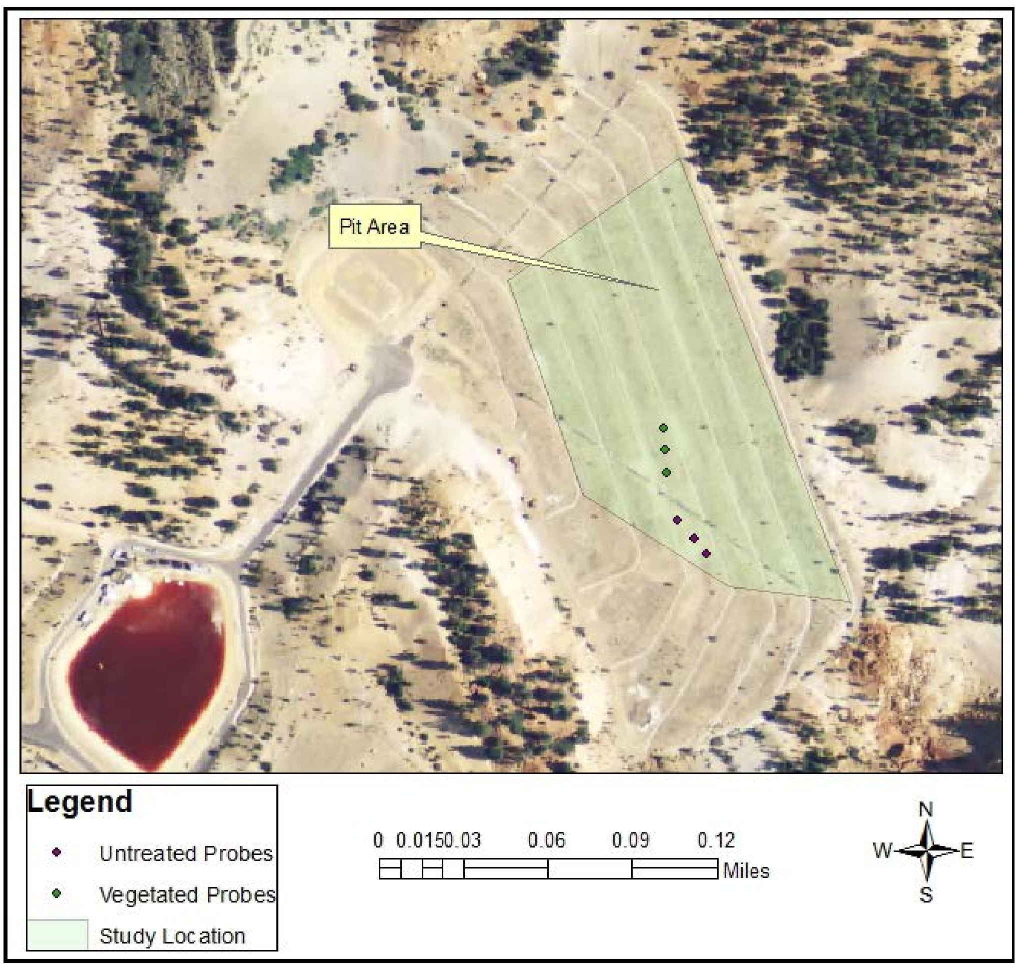

Figure 20. Locations of soil moisture probe sets on vegetated and non-vegetated (untreated) areas.

Results:

7.1 Soil Profile Volumetric Moisture Measurement - Pit Vegetated Plots

Soil volumetric moisture content of Pit vegetated plots is shown in Figure 21. Soil moisture is shown for the surface horizon at about 2 inch (5 cm) depth (Port 1; blue trace), the bottom of the uncompacted, rooted substrate at 12 inches (30 cm) (Port 2; brown trace) and for the non-rooted, compacted subsurface material that stays moist through the summer (Port 3; gray trace). This graphic shows that the surface (blue trace) is drier than the middle or lower horizons (brown and gray traces) unless after a rain event.

The moisture probes show the driest moisture content condition in November (19%), rising to near the maximum in February 2015 (about 50%). A rain event is recorded to occur on February 7, 8, and 9, 2015 (Markleeville RAWS), delivering a total of 2.23 inches of precipitation. This is not a severe storm (< 1 yr RI) but may have involved a rain-on-snow event since temperatures were only slightly above freezing. Subsequently, this horizon dries downward through the spring. The lowest horizon (Port 3, gray trace) is located at about 28 inches. It maintains a higher volumetric moisture content all year than the upper and middle horizons.

The surface moisture trace shows that this horizon retains over 30% of its volume in moisture comparing between late summer through the Feb storm (increasing from approximately 20% to 50%). This reduces overland flow and erosion. Evapotranspiration through the summer by plant uptake dewaters the profile and increases potential to infiltrate and retain much of the winter rain volume in surface horizons without percolation.

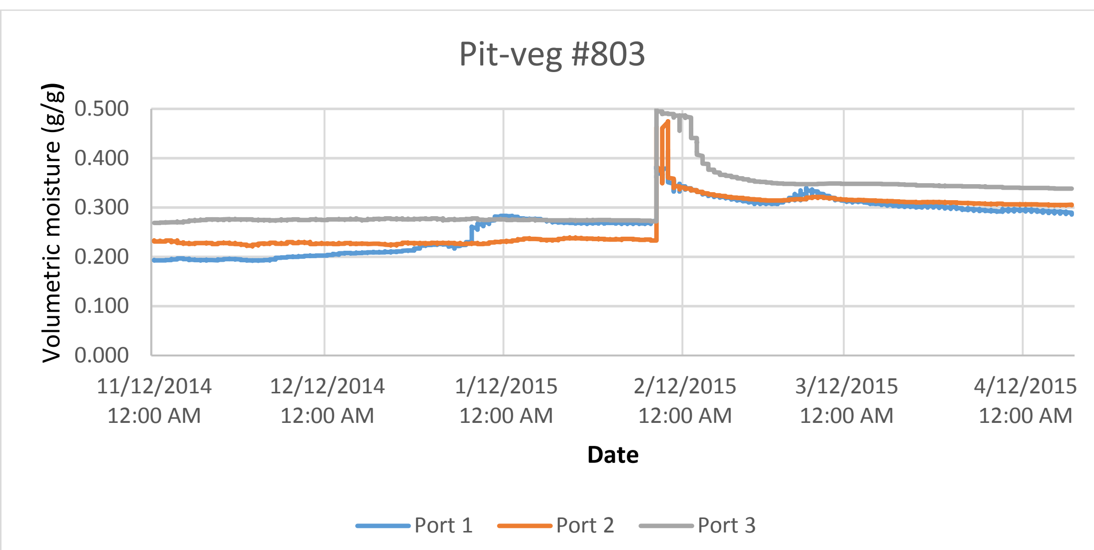

Figure 21. Pit-veg profile moisture status (logger #803). The Port 1 probe is buried within the decompacted surface at 2 inches (5 cm) depth, The Port 2 probe is buried at 1 ft (30 cm) at the bottom of the local rooting zone and the Port 3 probe is buried at 28 inches (70 cm) in compacted, non-rooted substrate that remains moist through the summer.

7.2 Soil Profile Volumetric Moisture Measurement – Non-Vegetated Plots

In contrast, the non-vegetated profiles were more moist compared to the vegetated profiles (Figure 22). The surface probe remained above 20% indicated volumetric moisture most of the time. The deepest probe (Port 3 gray) is several percentage points more moist than the comparable Pit-veg horizon. After the February storms, the surface probes show have less moisture content in the Pit-low veg than the Pit-veg because the non-vegetated plots sheet off rainfall as surface flow. The subsoils remain equally moist after winter wet-up but the mid-level probe (brown is several percent drier in the Pit-veg than the non- vegetated profile. The main difference to note is the difference in volumetric profile water content at the end of the summer on the left hand side of the graph. The upper two horizons of the vegetated plots are between 19 and 22% while the moisture in the nonvegetated surface horizons is indicated to be in the mid 20's. The upper two horizons in the vegetated plots also represent about a third deeper soil volumes, increasing the total volume of the difference in water content.

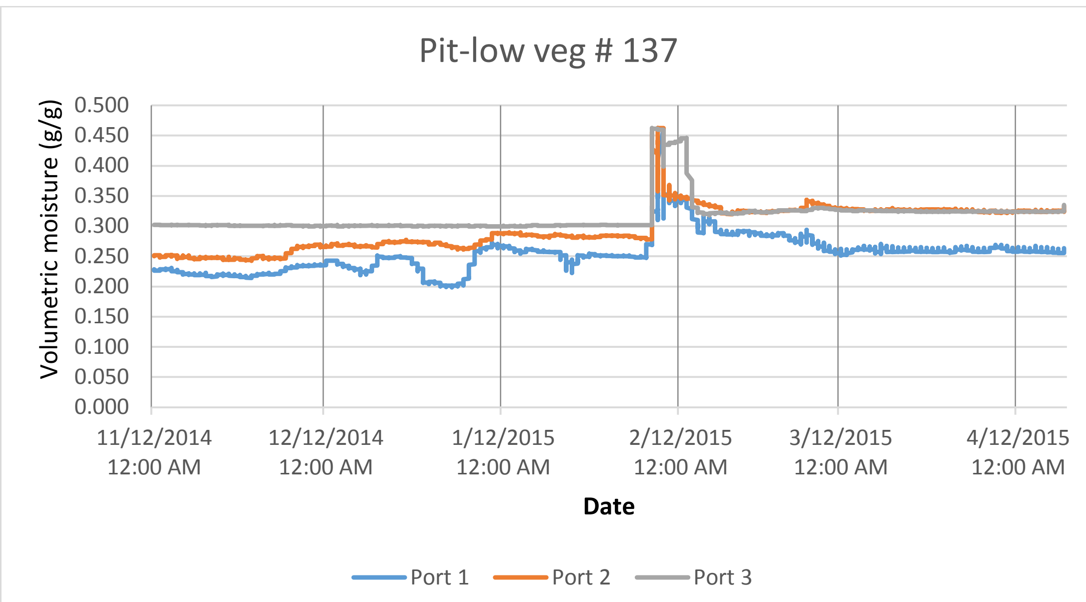

Figure 22. Pit-low veg profile moisture status (logger #137). The Port 1 probe is buried within the decompacted surface at 2 inches (5 cm) depth, Probe 2 is buried at 8 inches (20 cm) at the bottom of the local rooting zone and Probe 3 is buried at 18 inches (45 cm) in compacted, non-rooted substrate that remains moist through the summer.

7.3 Soil Matric Potential

The surface horizon of the Pit-vegetated plot is extensively dewatered during the late fall 2014, as indicated by the substrate's matric potential. Measured in negative pressure, the vertical axis shows that the vegetated plots decrease from moist condition (about -100 kPa) following installation in a saturated soil bedding down to approximately air-dry condition by December (Figure 23). Because this tracked the installation process, the surface soil is expected to have been air dried through late summer. In contrast, the Pit-low vegetated trace (brown line) remains near saturation throughout the year. Additional rainfall cannot infiltrate into the wet substrate, which rapidly saturates the soil and runs off as overland flow. All of the Pit-low vegetated plots had liquid water enter the data logger housing and the # 3 replicate was completely flooded, ruining the logger. Vegetated plots were completely dry.

7.4 Increased Utilization of Surface Substrate Moisture by Transfer Through Plant Roots.

An additional ecosystem service provided by a vigorous revegetation community is shown in the first section of the matric potential graph during the dry down to ambient late summer conditions. As the substrate that was moistened by the installation bedding process steadily dried out, the matric potential begins to develop periodic cycles between very dry (-10,000 kPa) to more moist levels that steadily decrease. This is the signature pattern of plant roots transferring moisture between damp subsurface horizons up to the drier surface horizons. Known as 'hydraulic lift' the plant roots recharge surface soil moisture during the night to near the surface plant roots where it is readily accessible during the hottest and most water stressed part of the day. Every downward spike is hypothesized to be an afternoon dry-down event and every less negative period is a night-time recharge event. A vigorous, well rooted substrate very actively removes water from the profile and makes the site more erosion resistant and less likely to percolate pore water downward through these acidic mine waste materials.

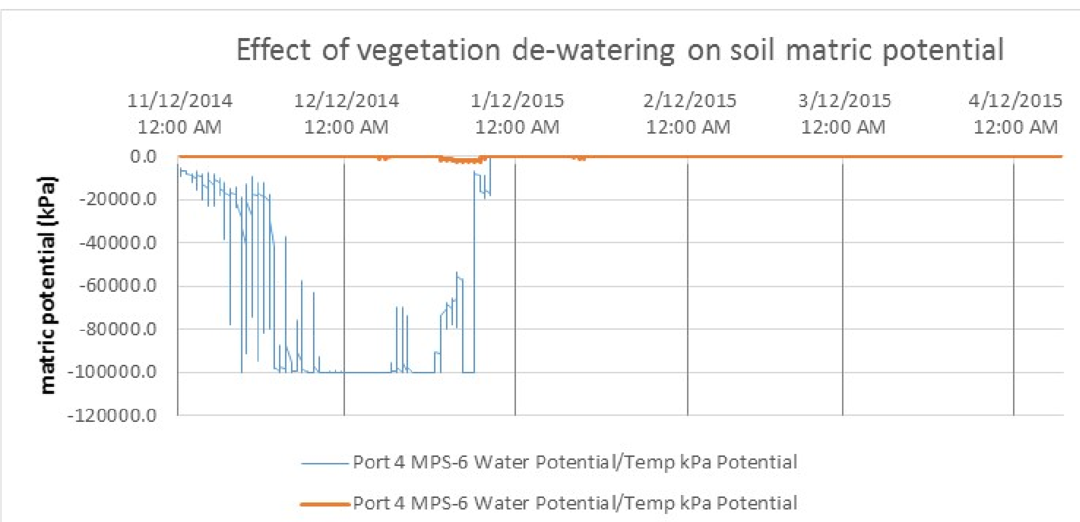

Figure 23. Surface moisture depletion in Pit-vegetated plots (in blue) compared to Pit-low vegetated plots (brown), which remains near 0 kPa moisture potential close to saturation. Oscillating blue line in late November shows dry-down potential with vegetated substrates. After storms in early January, both profiles are equally wet and the blue trace is hidden behind the brown line.

8.0 MODELED SUBSTRATE MOISTURE CONDITIONS USING FIELD DATA

Introduction:

Using accumulated field observations and field measurements, some general predictions can be made regarding the hydrologic behavior of surface substrates under example storm conditions. Hydrologic models were developed based on field measurements of substrate characteristics to represent the atypical site conditions existing at the site. The approach uses several different types of field characterization: a substrate moisture release curve to indicate moisture retention, tension infiltrometer values to represent saturated and unsaturated conductivity, bulk density measurements to indicate field compaction and a simulation program using field-measured parameters to integrate these conditions over time and under selected rainfall events.

Methods:

A substrate moisture release curve was measured for surface substrates composited from vegetated areas of the Pit Area near the soil moisture logging probes (Figure 24). Soils were dried and sieved to < 2 mm. Four replicate samples received a range of water additions. These samples were incubated for 4 days in tightly closed containers to allow the moisture to equilibrate throughout the sample. A WP4-T dewpoint potentiameter (Decagon Devices, Pullman WA) was used to measure the matric potential at this range of moisture contents.

Tension infiltrometer measurements were made in the field at multiple locations at multiple depths. These data were used in a software program (Van Genuchten et al., 1991) to generate fitting parameters to model hydrologic flow through unsaturated substrates. The fitting parameters were then loaded into Hydrus 1 D (PC-Progress.com) to model different substrate treatment and pre-storm moisture conditions and precipitation inputs. The field measured data represent a small number of field characterizations and should be used with caution. The data also relate to substrates that have been in-place for over a decade, so may not represent freshly excavated materials.

The substrates adjacent to the Pit Area revegetation plots were used to generate averaged rates of unsaturated conductivity (Pit Area section of Table 14). A review of the data indicated that previous treatment (tilled or not tilled) had a greater effect on conductivity than vegetated or non-vegetated condition. The models were parameterized to represent uncompacted surface substrates versus the deeper subsurface materials that are typically found below 15 to 18 inches deep (40 to 45 cm) in vegetated areas and 4 to 6 inches deep (10 to 15 cm) in non-vegetated areas. The models vary both the depth of these two layers and, independently, the intensity of the precipitation to show the effect of different storm scenarios on different substrate conditions.

Table 14. Field-measured hydraulic conductivity parameters used to generate model parameters for Hydrus 1D modeling. Θs is 'theta s', or the saturated gravimetric water content. Θr is 'theta r', or the residual gravimetric water content at wilting point at -1.5 MPa. Θair dry is 'theta air dry', or the gravimetric water content when air dried.

Summary of LM3 Ksat and unsaturated hydraulic conductivity values									
Infiltration (cm per hr) under saturated (0 cm) and unsaturated conditions (-3 cm and -10 cm matric potential)									
		Pit Area			Pond 2N			Delta Slope	
depth	0 cm	-3 cm	-10 cm	0 cm	-3 cm	-10 cm	0 cm	-3 cm	-10 cm
5 cm	1.099	0.781	0.475	3.713	4.010	1.574	8.020	4.159	0.297
30 + cm	1.016	0.336	0.297	2.079	2.638	0.692	9.208	3.119	1.188
Infiltration (inches per hour) under saturated (0 cm) and unsaturated conditions (-3 cm and -10 cm matric potential)									
		Pit Area			Pond 2N			Delta Slope	
depth	0 cm	-3 cm	-10 cm	0 cm	-3 cm	-10 cm	0 cm	-3 cm	-10 cm
5 cm	0.433	0.308	0.187	1.462	1.579	0.620	3.157	1.637	0.117
30 + cm	0.400	0.132	0.117	0.819	1.038	0.272	3.625	1.228	0.468
		Θs	Θr antec	Θr air dry					
	average pit	0.333	0.182	0.058					
	average P2N	0.377	0.112	0.008					
	average DS	0.418	0.088	0.022					

Interpretation of the Hydrus 1D model output:

The following narrative is a basic guideline for interpretation of the graphical outputs (Figures 25-28). All modeled scenarios are presented similarly and data for specific examples are discussed in more detail below.

In the Profile Information graphic, soil depth is shown on the left vertical "Y" axis in centimeters. Most model outputs show a movement of moisture downward into the modeled substrate profile with time. The substrate moisture at different points in time is shown by different colored lines. The end of the line (time period) is marked across the top or side of the output as hours of time since the simulation started. Typically there is a 1 hour equilibration period, then the storm event is modeled to start. A 1 hour duration event typically starts at 1 hour and stops at the trace marked 2 hour. If the modeled storm is a 24 hour duration event, then the soil moisture pattern occurring at the end of the event is indicated at the trace for 24 hours.

A more difficult aspect of reading the Profile Information output is to interpret the moisture status of the substrate at any given depth. Since pressure governs the movement of water through substrates, this output shows matric potential (negative pressure) as cm of water head across the lower horizontal X axis. If the cm of head (water pressure) were positive, this would be indicated by colored traces for different time intervals at the right of 0 cm (saturation) on the lower horizontal axis. The model is set up to sheet any of this water volume off as surface runoff. This represents upland conditions with no ponded water. Swales or infiltration basins would be set up to allow positive pressure from ponded water.

As the time point trace goes to the left, that substrate depth is indicated to be less and less wet. A trace at any given depth that is around -100 cm indicates a substrate that is at Field Capacity (was fully saturated several days earlier but has drained down by gravity). This would intuitively be a substrate that is no longer saturated but would still be ‘soggy’.

As the substrate dries down to what would be familiar as a damp garden soil, the matric potential would read around -1000 cm. Plants can readily extract this water that exists between Field Capacity and a drier soil. Eventually a soil becomes so dry that plants wilt before they can extract adequate moisture. This Wilting Point is set at -15000 cm water head for agricultural plants. Wildlands plants can reach twice this potential, although the rate of water uptake becomes very slow. Since Hydrus models are used here to evaluate inputs from rainfall events and infiltration and losses to percolation, all the matric potentials are in the very wet range, since that is where flows are dynamic and important to erosion processes. At the lower end of the range, moisture in the substrate pores can remain for years without moving, until another saturation event occurs and pushes more moisture down into or through the substrate horizon.

The first output, Figure 25, shows a rapid wet-up at 2 hour (green line moves far to the right) that indicates saturated conditions and runoff. The amount of rainfall lost to overland flow is shown in the middle Surface Run-Off graphic. This shows runoff flows starting at 20 or 25 minutes into the event and continuing until rain stops at 2 hour. The right graphic shows the amount of percolation below the modeled profile at 1 m as the total amount of moisture passing this depth. The units indicate that about 0.8 cm of water (8 mm or 5/16 inch) is passing out of the modelled profile.

The most gradual rainfall event of this set, Figure 28, clearly shows the movement of rain water moving downward through the substrate profile at different hourly time points (listed on the internal vertical axis). At 2 hours into this 24 hour modeled storm the wet-up front is at about 5 cm (2 inches depth). By 96 hours, the wetting front is indicated to be approaching the bottom of the 100 cm (39 inch) profile depth. By 168 hours, it is indicated to be percolating past this depth. No surface runoff occurs and percolation losses are indicated to be negligible. All graphics are set up to read the same way, but different rainfall inputs and substrate conditions result in very different patterns on the output that sometimes have to be studied carefully to be interpreted clearly.

Results:

8.1 Moisture Release Curve for Pit Area Substrate

Assuming that plants can extract moisture from substrates between -0.05 (Field Capacity) and -1.5 or -2.5 MPa (Wilting Point), depending on species and environmental conditions, the substrate moisture release curve (Figure 24) indicates that these substrates can release between 10.2 and 11.7 % of the substrate dry weight. This is termed ‘plant-available moisture.’ This range is typical for sandy substrates, but is very atypical for substrates with a clay texture particle size distribution, as is measured for these mine-impacted samples in Tables 1 and 6. The soil moisture release curve, when adjusted for rooting depth and rock content, can also be used to estimate the amount of moisture needed to grow vegetative cover as based on reference evaporation data for any future work involving tracking water use by plants to track profile dewatering from vegetative cover.

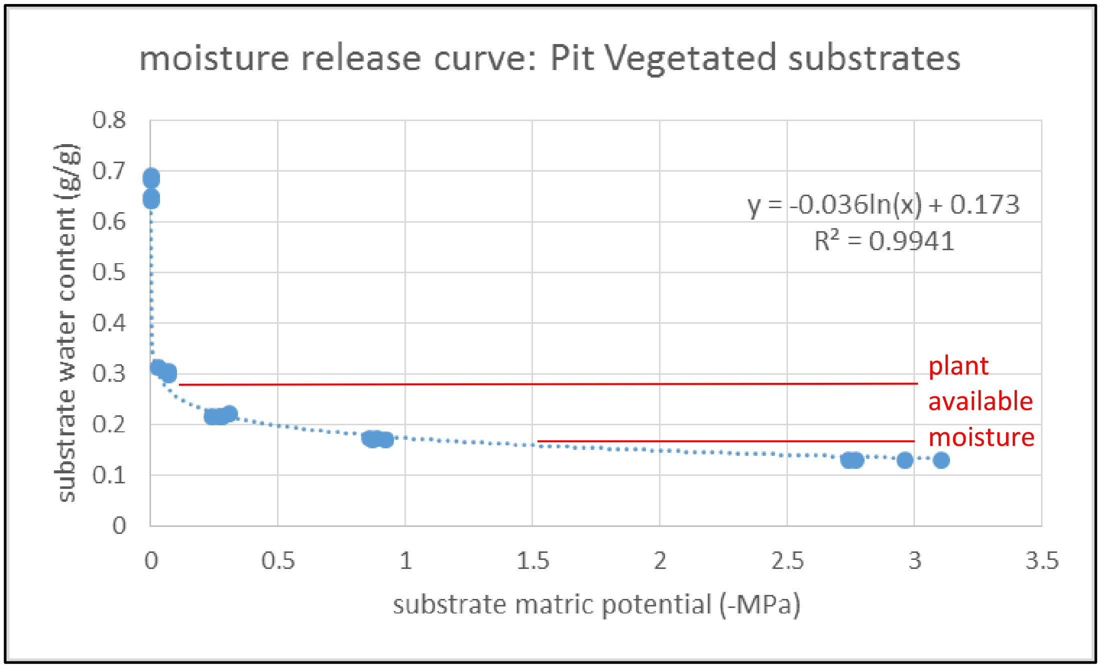

Figure 24. Substrate moisture release curve for vegetated pit substrates. Plants can extract moisture from about the cluster of points at 0.3 g/g moisture content down to about -1.5 MPa (to maybe -2.5 MPa, depending on species).

8.2 Modeled Hydrologic Response of Surface Substrates to Rain Events

Soil erosion during rain events is generated either by 1) runoff as a result of insufficient surface infiltration rates even when substrates are unsaturated or 2) by runoff generated after saturation of the surface horizons when additional rainfall inputs are forced to flow overland. Surface infiltration rates (the first condition) are influenced by compaction, plant cover, organic matter contents and soil aggregation. Infiltration capacity (the second condition) is influenced by how fast surface soils saturate, which depends on the depth, continuous pores structures and pore volume of a substrate, all of which are reduced by compaction.

The first scenarios modeled for the Leviathan Mine Pit Area represent a 5 inch (12.5 cm) uncompacted surface layer over a more compacted subsurface layer extending to 3 ft (1 m) and beyond (Figure 25). This is the untreated condition of the pit area before any tillage. A storm with a Return Interval of 25 years that lasts for 1 hour (i.e a 25 year 1 hour event) is modeled to occur on this substrate. The NOAA web site Precipitation Frequency Data Server table for Leviathan Mine (Appendix 2a) lists this storm as delivering 1.02 inches per hour (2.6 cm/hr).

Figure 25 (left) shows the movement of rainfall down into the substrate profile at different hourly time intervals. The first indicator to evaluate is whether any trace goes clear to the right or past the '0 cm' line. This indicates that the substrate has become saturated and overland flow will occur. This is shown to occur by the end of Hour 2, which is the end of the modeled storm event. The amount of erosion that occurs is graphed by time in Figure 25 (center). This graph shows saturation and overland flow starting about 20 - 25 minutes into the event that lasts from Hour 1 to Hour 2. A portion of the storm precipitation infiltrates into the substrate and percolates below the rooting zone (approximately 0.8 cm at the end of the model period, Figure 25 right). Because the model was initially started at Field Capacity, the surface profiles will eventually return to this same moisture content, defined as the moisture held in the substrate pores against the pull of gravity.

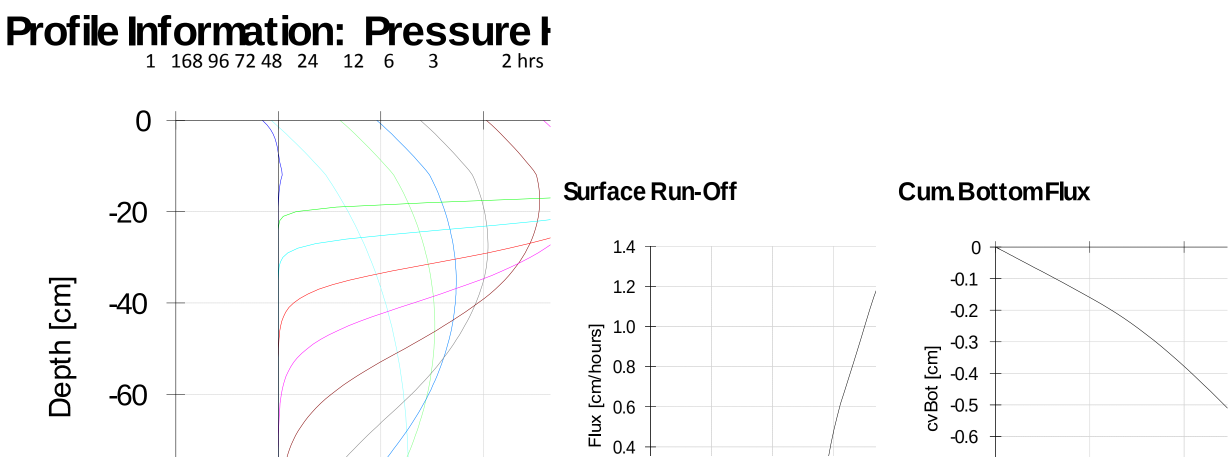

Figure 25. Modeled infiltration of a 25 year Return Interval storm of 1 hr duration delivering 1.02 inches (2.6 cm) per hour. Time intervals are listed on the top horizontal axis in hours. A bulge of rain water wets the substrate to saturation, but then the volume of water spreads downward through the substrate.

In contrast with the previous 25 year 1 hour storm, a 25 year 24 hour storm has a lower precipitation rate (0.2 inches per hour; 0.5 cm per hour) but higher total volume of water delivered (4.9 inches; 12 cm) (Figure 26 left). This storm scenario generates no surface runoff (Figure 26 center), but the volume delivered is large enough to fill the profile and start to push precipitation moisture downward below the 3 feett (1 m) modeled volume (Figure 26 right). Without additional root uptake, this moisture will continue downward below the rooting zone into the mined substrates. This percolation loss is indicated to exceed approximately 10 cm of the 12 cm storm input.

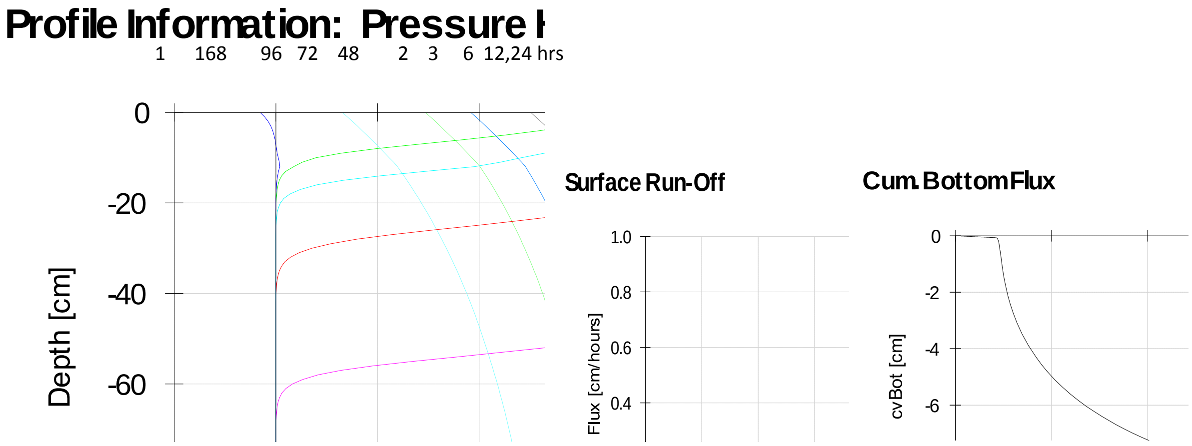

Figure 26. Modeled infiltration of a 25 yr Return Interval storm of 24 hours duration (left). No surface runoff occurs (center). More than 8 of the 12 cm of precipitation volume percolates below the rooted horizon (right).

The previous scenario represented a thin, 5 inch (12.5 cm) uncompacted surface horizon and showed losses of rainfall to percolation below the root zone. The following scenario models the effect of decompaction of the subsurface material to a depth of 18 inches (45 cm) (Figure 27), representing existing substrate treatments in the Pit Area. In this case surface erosion in a 25 year 1 hour storm is the same as before because the surface infiltration rate is the same (output not shown). Similarly, in the case of the 25 year 24 hour event, no surface erosion occurs because the storm is a long duration, low intensity event. This scenario evaluates whether a deeper substrate could be expected to infiltrate the longer storm and reduce percolation losses.

A 45 cm deep uncompacted profile produces no surface runoff (Figure 27 center) as expected, but the deep percolation is only slightly reduced (Figure 27, right).

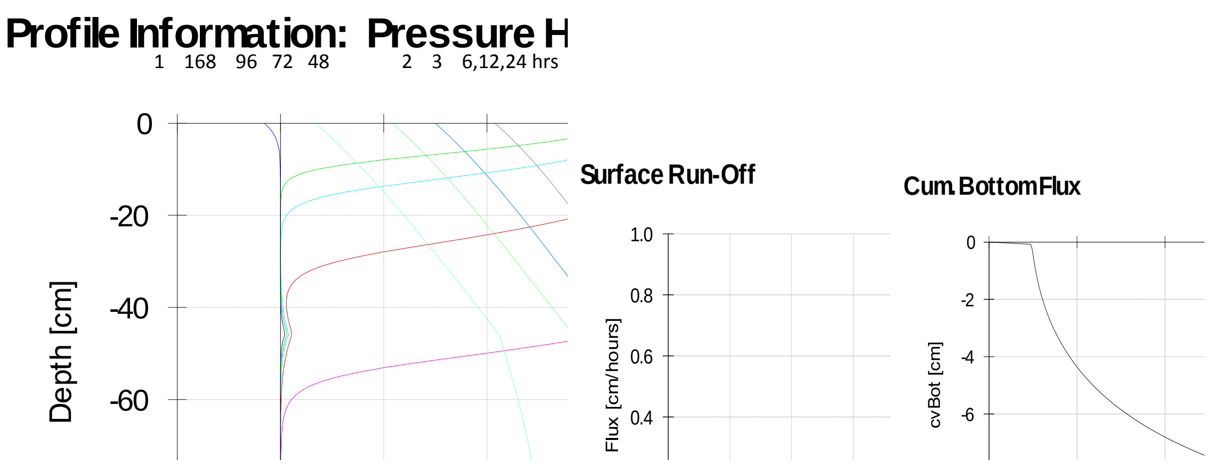

Figure 27. Modeled infiltration of a 25 yr Return Interval storm of 24 hours duration (left). No surface runoff occurs (center). More than 8 of the 12 cm of precipitation volume percolates below the rooted horizon (right).

Even though the rooting depth is 18 inches (45 cm) deep, the soil starts out relatively wet at Field Capacity (-100 cm). This represents the case when revegetation cover is not thick enough to dry the soil before the fall rains or when evergreen species are not dense enough to dewater the substrate during dry periods through the winter. This moist condition leaves relatively little capacity to soak up additional rainfall. This model condition of high antecedent moisture content is done to assure that the model represents worst case scenarios. With insufficient vegetation cover this condition will persist after wetter periods through the winter.

Several runs were also made to test how much drier soils would have to be to eliminate the percolation below the root zone and into the underlying mined substrates. The model indicates that percolation is reduced to negligible amounts if the antecedent moisture is between -500 and -1000 cm matric potential (Figure 28). This is still a relatively ‘moist’ soil. This condition could reasonably be expected to occur during less rainy intervals during the winter, assuming adequate revegetation cover. Figure 28 (right) shows Cumulative Bottom Flux as being less than 1 mm (values on left vertical axis) through the end of the 7 day model period. Details of evapotranspiration losses were not modeled as part of this project.

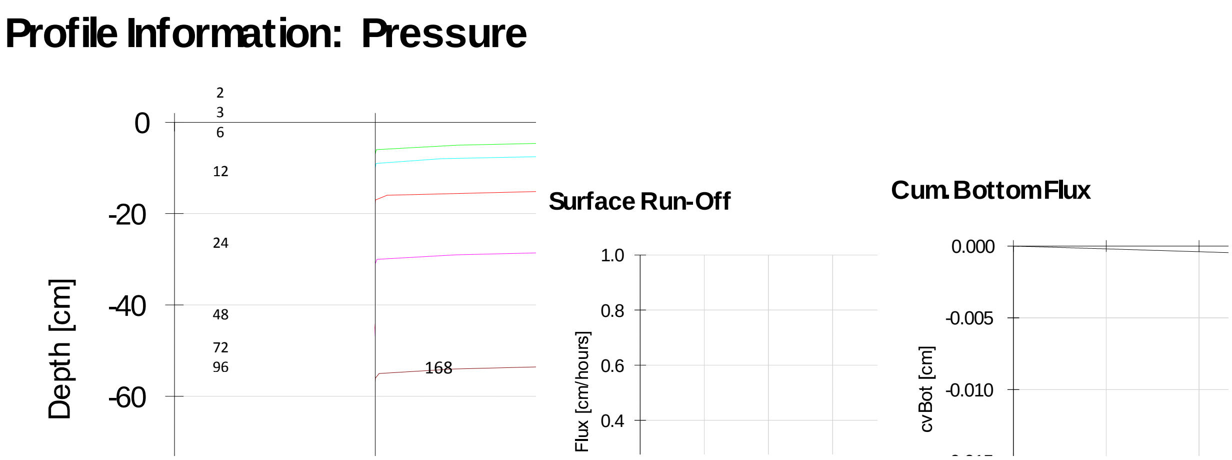

Figure 28. Modeled infiltration of a 25 yr Return Interval storm of 24 hours duration (left). No surface runoff occurs (center). Percolates below the rooted horizon (right) is reduced to less than 1 mm.

Conclusion:

These model simulations are generated with field-measured saturated and unsaturated hydraulic conductivity and moisture release curves measured on field collected substrates. Errors in their representation are expected to have more to do with adequately sampling the field condition rather than errors from using assumed or data-base averaged parameter values. These simulations suggest that even a moderately dewatered substrate (-1000 cm head, equivalent to -0.1 MPa or 1 bar matric potential, ‘garden soil’ moisture) has enough reserve infiltration capacity to retain a 25 yr 24 hr storm event without losing moisture to percolation below the rooting zone.

A full 3 feet (1 m) rooting depth would increase the probability through the winter that the substrate is ready to completely retain a subsequent rain event without percolation losses. Construction of an 18 inch rooting volume is obviously less costly than constructing a 3 ft rooting volume so the need for this level of substrate regeneration should be evaluated for various weather sequences and for different substrates at the site. A related issue with a substrate depth of 18 inches vs 3 feet (45 cm vs 1 m), however, is that the shallower depth may not provide sufficient moisture to maintain dense plant cover through the late summer dry season. A dense cover is needed in order to provide evapotranspiration function in mid-winter when it is most needed and is needed to keep enough groundcover in place to regenerate surface infiltration and to control the crusting that was observed in the Pit Area.

9.0 CONCLUSIONS AND REMAINING DATA GAPS

9.1 Overall Conclusions

These field revegetation evaluation activities documented the current revegetation cover on the site. Various tests and trials have also identified several substrate characteristics that, if ameliorated, would increase plant growth, erosion resistance and moisture removal from substrates. Surface erosion remains a periodic occurrence due to intense rains, high volume storm sequences, snow melt events, or wind. Surface erosion would be reduced if a self-sustaining, low maintenance, dense, revegetative plant cover was developed on site or increased on existing vegetated areas. A denser plant cover requires deeper rooting volume to attain moisture through the late summer dry period. Deeper rooting requires decompaction and neutralization of substrates to a depth of several feet. Because these substrates have atypical moisture release characteristics, the depth may vary with different mine waste materials across the site. This study evaluated three feet as a representation of a potential treatment depth. When a three foot depth was well rooted and dewatered, surface flows from substrate saturation were reduced and percolation of pore water from rain or snow melt below the rooting zone into the underlying substrates was reduced or eliminated. Surface erosion from short, intense rains depends on the process of regenerating water stable aggregates from dispersed substrate particles, which was not evaluated as part of this work. However, a denser plant canopy would cover the substrate surface with greater amounts of plant litter (dead leaves and twigs). A demonstration treatment of a wood chip mulch, along with seeded plant cover, reduced surface erosion on field plots compared to non-amended adjacent areas.

As a result of this field evaluation, the following general design elements are recommended for sustainable revegetation of the mined substrates:

1. Overall slope angles shallow enough to avoid sloughing, burial of plants, sediment creep and liquefaction when saturated.
2. Infiltration rate high enough to avoid overland flow and surface erosion in design storm conditions.

3. Infiltration capacity large enough to avoid saturation of surface substrates in design storm conditions.
4. Moisture retention large enough to avoid percolation below the rooting zone in a design rainfall year.
5. Rooting zone acidity neutralized sufficiently to allow sustained root growth and resist re-acidification.
6. Plant species that grow sufficiently to maintain ground cover, are relatively weed resistant and maintain their population density on site, resist surface erosion and dewater the surface substrate profile.

In order to attain these growth conditions and to provide adequate pore space for infiltration and root growth, substrates at surface positions must not be compacted. However, because substrates with lower compaction are susceptible to liquefaction, these volumes must reside on level surfaces that do not allow these materials to slide downhill. Potential construction methods are discussed in Appendix 1 Revegetation Guidelines. Finally, root growth cannot enter into these non-compacted materials if they still remain acidic. The process of regrading new slopes or revegetating existing slopes must include incorporation of adequate lime to neutralize the existing substrate to a depth of approximately three feet. More detailed modeling of water inputs and evaporative losses on different substrates at the Leviathan Mine or under different climatic scenarios may alter this tentative amendment and rooting depth.

9.2 Remaining Data Gaps

Leviathan Mine is a large and heterogeneous site with atypical mineralogy and growth conditions. Several additional components remain poorly understood. Information on these process would contribute to more efficient and cost-effective revegetation treatment:

1. The process of mineralogical transformation from ambient acid conditions to pH levels near neutral may create instability in the existing mineral components. This may generate a potential for re-acidification as the minerals transform to a new equilibrium in the neutralized substrate. Information on mineral composition and stability with large changes in pH should be evaluated for potential application to this site.
2. Compaction levels needed for geotechnical stability versus compaction levels that limit rooting are poorly understood. Interactions between these two objectives of geotechnical stability and rooting access may be possible.
3. Current organic materials available from Carson Valley (composts) or thinning projects (wood chips) are not well characterized for stability versus ability to decompose and support nutrient release and microbial activity. Rapid assessment methods for field materials such as forest thinning by-products is needed. The interaction of these organics with metal transport should also be characterized.
4. Long term plant response to soluble fertilizers is not well described. A cursory study was conducted regarding fertilizer application to the nutrient-stressed trees on the Leviathan mine site and showed a growth increase followed by a return to pre-treatment levels. This information needs to be evaluated and applied to future revegetation establishment and maintenance amendment practices.
5. The ability of plant cover to extract soil moisture for transpiration and to dewater the profile has been shown in a general way but not for different plant species, densities or weather conditions. Field tools are now available to couple field measurements with hydrologic models to characterize the effect of vegetative cover to remove subsurface moisture and therefore reduce percolation of precipitation into and through disturbed substrates on the mine.
6. Stable organic compounds function to aggregate substrate particles into less erosive materials and to resist crusting in natural soils. The ability to use organic amendments to improve infiltration on mine-impacted substrates and surface crust or seal formation is a significant need for management of the disturbed surfaces at the mine.

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Appendix 1: Leviathan Mine Site Revegetation Guidelines

Introduction

Revegetation cover and substrate growth conditions at the Leviathan Mine, Alpine County, California were measured as part of a revegetation evaluation project during the 2013-14 and 2014-15 growing seasons. The goal was to review the outcome of the last several decades of revegetation activity on this challenging and atypical site. Information from the evaluation is used to generate recommendations for future revegetation approaches and treatments to improve revegetation establishment. The particular areas of the mine that are addressed are the regraded Pit Area, the north and east slopes adjacent to Pond 2 North and South, and the Delta Slope.

These results suggest that plants in the revegetated areas of the Pit are well established but that surface erosion is still a risk during short-term but intense storms. In areas that have lower vegetation cover or are predominantly bare, the depth to compacted or acidic substrate is often shallow and limits rooting growth. Because of this shallow depth to compacted materials, moisture from longer duration storms or snow melt events can exceed the retention capacity of the surface horizon, resulting in saturation and overland flow. While the Pond 2 East slope appears to be stable with sustainable vegetation growth, the steeper Pond 2 North slope is sparsely vegetated and shows surface erosion. Downslope creep of soil materials buries plant crowns and exposes roots on their down-slope side. In contrast, the Delta Slope has higher vegetative cover and is predominantly stable and erosion free. These conditions are attributed to shallower slope angles and more intensive lime, compost, incorporation and planting treatments. The goal of these substrate grading and amendment recommendations is to revise existing revegetation methods on the site to more effectively regenerate a sustainable vegetation cover that is erosion resistant to most storm events and that increases evapotranspiration losses. To this end, the “Growth Media”, or surface substrate that is to be revegetated, is recommended to have the following design characteristics:

Main elements of substrate treatment for sustainable revegetation:

1. Slope angles shallow enough to prevent sloughing, burial of plants, sediment creep and liquefaction when saturated.
2. Infiltration rate high enough to prevent overland flow and surface erosion in design storm conditions.
3. Infiltration capacity sufficient to prevent saturation of surface substrates in design storm conditions.
4. Moisture retention sufficient to prevent percolation below the rooting zone in a design rainfall year and to support plant growth through the dry summer season.
5. Rooting zone acidity neutralized sufficiently to allow sustained root growth and prevent re-acidification.
6. Plant species that grow sufficiently to maintain ground cover, are relatively weed resistant and maintain their population density on site, resist surface erosion and dewater the substrate rooting profile.

The following guidelines for revegetation work are intended to supplement geotechncial plans and specifications.

Grading

All grading activities, including the construction of cut/fill slopes and installation of Growth Media are subject to the design requirements set forth by the Design Engineer, including measures necessary to mitigate potential slippage between differing materials (such as that which might occur if layers of differing materials are placed upon a sloped land area). Such measures may include horizontal keyways or other means to prevent the formation of a slip plane, as determined by the Design Engineer. In addition, the Design Engineer shall specify necessary measures to provide adequate geotechnical strength in underlying native materials to support Growth Media even when saturated.

Land areas to receive revegetation treatment are recommended to be graded to an inclination of less than 3:1 (Horizontal: Vertical), if the revegetation effort is intended to establish herbaceous cover or 2.5:1 if the revegetation effort is intended to establish conifer cover.

Growth Media

Growth Media should consist of well-mixed mine waste/overburden materials, lime and organic materials (as specified below) installed to a minimum depth of 3-feet (perpendicular distance below the finished grade plane and in a manner that does not limit root growth). Subject to the Resident Engineer's (RE) or designated representative's approval, Growth Media may be pre-mixed in bulk then applied to land areas, or alternatively, amendments could be applied to land areas and mixed in place with substrates to generate Growth Media.

For land application and mixing in place, amendments should be surface applied to 1-foot lifts of substrate at rates proportional to those provided below. The 1-foot lift of substrate with surface applied amendments should then be mixed by ripping to the full depth of the lift. Multiple cycles of lift, amendment and ripping passes may be required. Details of liming and fertility amendments are listed below. When the amended fill has been placed to the desired depth and grade, the surface should be track-walked when dry and friable (clods break but do not smear or deform) to firm the volume and remove larger pore spaces. Smaller-sized or wide-tracked equipment should be used to avoid additional compaction.

Acceptance of Growth Media by the RE or designated representative should be contingent upon Contractor's demonstration that Growth Media has been installed as required by the plans and technical or other specifications, including those for grading, materials, and compaction.

Revegetation Materials

Lime Amendments:

The target lime rate, developed during previous incubation work, is 20 ton calcium carbonate equivalent per acre per foot of treated substrate depth (45 Mg/ha per 30 cm depth). This is equivalent to approximately 60 tons per acre (calcium carbonate equivalent) to neutralize a three foot deep rooting volume.

Lime suitable for agricultural application is recommended for neutralization of acidity. Lime amendments should have a calcium carbonate equivalent greater than 90%. Lime particle size should be finely ground, with > 100 % by weight passing a #10 sieve (< 2 mm) and > 90 % by weight passing a # 50 sieve (< 0.3 mm). The Contractor should submit laboratory analysis of prospective material to the Resident Engineer for review and acceptance prior to delivery on site.

Site specific neutralization requirements for lime can be estimated using standard methods based on sulfide-containing minerals. Residual acidity and lime requirements for neutralization are also influenced by mineralogy and crystal size and the physical parameters that influence biological activity, especially oxidation of reduced sulfur compounds and production of acid. The long-term mineralogical transitions resulting from historically acid conditions to near-neutral pH levels following treatment were not evaluated as part of this study. Given these different sources of additional acidification and the primary goal of avoiding long-term re-acidification that would reduce revegetation cover, a more general empirical method is recommended to estimate the lime requirement for neutralization. Lime requirement and potential for buffering or re-acidification is recommended to be determined using aerated, long-term incubations with a gradient of lime additions and periodic monitoring of pH. Each general location, management unit, or substrate type at Leviathan Mine should be evaluated for site-specific neutralization requirements on a case-by-case basis.

Contractor’s submittal for the source of lime shall include documentation of the lime vendor’s participation in a program to prevent spread of invasive weeds and certification that the facility has received an adequate grade from the certifying agency. In addition, the lime vendor’s facility will be made available for inspection by the Resident Engineer or designated representative if requested.

Invasive plants of concern include but are not limited to:

- Diffuse Knapweed *Centaurea diffusa* Lam.
- Spotted Knapweed *Centaurea maculosa* Lam.
- Musk Thistle *Carduus natans* L.
- Yellow Starthistle *Centaurea solstitialis* L.
- Tall Whitetop *Lepidium latifolium* L.
- Bindweed *Convolvulus arvesisis*
- Dyer’s Woad *Isatis tinctoria*

Organic Materials:

Compost

Composted organic material must be derived from wood by-products, rice hulls, dairy waste or processed green waste that is screened to remove coarse materials > 3/8 inch and is thoroughly composted to eradicate all viable weed seed. The compost shall contain a minimum of 25 % organic carbon and a minimum of 1.2 % nitrogen. Green waste composts must conform to Federal Regulation 40 CFR, Part 503. Compost shall be certified weed free by producer test results from a certified soil laboratory or by the local County Agricultural Commissioner where the material originates. No biosolids or feedlot source materials are acceptable.

Composts are to be applied at a rate of 50 cubic yards/ac with lime application and incorporation. Spreading may occur by hand or by mechanical methods (blowing, spreading or rear-mounted box scraper) as long as the amendment is uniformly distributed across the slope face as determined by Lahontan staff or representatives.

Alternatively, prior to application, compost materials may be mixed with equal volumes of other woody materials as long as an equivalent volume of compost is applied to the slope.

Incorporated Woody Materials

Woody materials are needed for incorporation into the raw substrates to regenerate porosity and prevent settling and loss of infiltration (as in Cline, 2014). A total volume of 130 cubic yards per acre is recommended to be spread over the lime application (Caltrans Landscape Architecture Program, 2015) or with the compost application before incorporation. Woody materials include wood shreds, clean chipped construction debris or compost overs with particle size between 3/8 and 3 inches.

Fertilizer

Supplemental fertilizers shall be pelleted, polymer coated (not resin coated), slow-release formulations in order to get slow nutrient release rates on these harsh substrates. Nutrient content shall be 200 lb/ac of 24-4-8 (Nitrogen-Phosphorus-Potassium) such as Best Full Season or the equivalent. Deliver product in 50 pound bags.

Plant Materials Guidelines:

All seed shall be for native plants and from sources that are climatically representative of the mine site. Specially collected seed shall be gathered only for the listed species and shall be collected locally from an area within 500 feet higher or 500 feet lower than the Leviathan Mine elevation and from an area within 10 miles in a north or south direction and within 5 miles east or west of the mine site.

Once collected, seed shall be dried, cleaned, and stored in a cool, dry environment at a temperature that is specific to each species. Prior to seeding, the viability of the seed, purity of the collection, and the non-native seed content of each lot shall be analyzed to determine seeding rate.
All seed shall be identified with names conforming to *The Jepson Manual: vascular plants of California*, (Baldwin, et al., eds. 2012). Seeds shall include a signed certificate that lists the quantity and type of seed. Seed bags shall include:

Seed Tag Information:

- Name of seed (genus and species);
- Location of collection using GPS coordinates and/or USGS Topographic maps with quarter section, section, township and range;
- Elevation of collection;
- Quantity (weight);
- Name of supplier;
- Results of seed viability and purity analyses, non-native seed content, and date seed was tested.

Container plants shall be propagated in tall (10 - 12 inch tree pots) for direct planting on the slope. No plants shall be accepted that are root bound in their pots or that show signs of disease, as determined by the Resident Engineer or representatives.

Table 1. Field plant list and application rates for seeded species and container plants.

Seeded Species				
Common Name	**Latin Name**	**Vegetation Type**	**Seed**	**proportion**
Grasses			**lb PLS/ac***	**(%)**
Basin wild rye	Leymus cinereus	perennial bunch grass	10	27.8
Western needlegrass	Stipa occidentalis	perennial bunch grass	5	13.9
Squirreltail	Elymus elymoides	perennial bunch grass	5	13.9
Blue wild rye	Elymus glaucus	perennial bunch grass	5	13.9
Idaho Fescus	Festuca idahoensis	perennial bunch grass	5	13.9
Shrubs				
Antelope bitterbrush	Purshia tridentata	evergreen shrub	1	2.8
Big sagebrush	Artemisia tridentata	evergreen shrub	1	2.8
Mountain mahogany	Cercocarpus ledifolius	evergreen shrub	1	2.8
Rubber rabbitbrush	Ericameria nauseosus	deciduous shrub	0.5	1.4
Yellow rabbitbrush	Chrysothamnus viscidiflorus	deciduous shrub	0.5	1.4
Forbs				
Showy Penstemon	Penstemon speciousus	perennial herb	0.50	1.4
Yarrow - white	Achillea millefolium	perennial herb	0.25	0.7
Sulfur buckwheat	Eriogonum umbellatum	perennial herb	0.25	0.7
Naked buckwheat	Eriogonum nudum	perennial herb	0.25	0.7
Anderson’s, Tahoe or Silver-leaf Lupine	Lupinus argenteus	perennial herb rhizobium inoculated	0.50	1.4
Spur Lupine	Lupinus arbustus	perennial herb rhizobium inoculated	0.25	0.7

Container Plants			
Common Name	**Latin Name**	**Vegetation Type**	**Plants/ac****
Mountain mahogany	Cercocarpus ledifolius	evergreen shrub inoculated for mycorrhizae and actinomycete at nursery	24
Whitethorn ceanothus	Ceanothus cordulatus	evergreen shrub inoculated for mycorrhizae and actinomycete at nursery	24
Wax Currant	Ribes cereum var cereum	deciduous shrub	24
Jeffrey pine	Pinus jeffreyi	evergreen tree inoculated for mycorrhizae at nursery	48

* Minimum Pure Live Seed weights per acre. Using convenient weighout sizes, the listed total is calculated for 36 lb PLS/ac. In the field, the total of all seeds shall be increased to equal 50 lb PLS per acre using the listed amounts as minimums.

**Minimum plants installed per acre, total container plants installed per acre is 120, approximately one per 19 ft square.

Seed Application Process

Seed may be applied directly onto the substrate surface by 1) broadcast application by hand or mechanical mounted spreader or 2) by hydroseeding.

Broadcast application

Seed should be evenly spread across the area. Mechanical application should use sufficient volumes of rice hulls and seed to keep seeds from settling during application. Alternately, to avoid settling of different seed sizes during broadcasting, the larger seeds may be applied evenly across the slope, followed by a separate application of small seeds.

Hydroseed specifications

The hydroseeder should be equipped with gear-driven pump and a paddle agitator. Agitation by re-circulation from the pump is not recommended. Agitation should be sufficient to produce homogeneous slurry of seed, fertilizer, and tacking agent in the designated proportions. Water should be applied at a rate of 3,000 gallons per acre. Wood fiber that has been dyed with a non-toxic substance should be added as an aid for uniform application at a rate of 500 pounds per acre (High Sierra Resource Conservation and Development Council, 2005).

No seed should be added to the slurry until immediately prior to beginning of the seeding operation. The time allowed between placement of seed in the hydroseeder and emptying of the hydroseeder tank should not exceed 30 minutes. Legume seed should be documented to have an appropriate type and rate of inoculation (beneficial nitrogen fixation microbes). Legume seed should be placed in the mixing tank after all other ingredients have been included, as pellet inoculated legumes may have the coating washed off in the mixing tank.

Fertilizer of the specified formulation should be included at the specified rate.

If the hydroseed/hydromulch method is selected for applying seed, seed must be placed on the slope in a separate preliminary step followed by the second hydromulch application. A single application of seed and the full hydromulch application together will not be accepted.

Surface Mulch Application:

Mulch may be applied either 1) as an application of wood chips or shreds blown over the applied and raked seed (as recommended in previous section for chip mulch), or 2) as a separate hydromulch and tackifier application.

Wood chip mulch shall be applied after all slope construction and seeding is completed. A surface mulch application of chipped or shredded woody materials is recommended to be blown by pneumatic equipment or mechanically applied onto the soil surface at a rate equivalent to provide 1 to 1.5 inch covering, approximately 135 - 200 cubic yards of material per acre. Mulch material should be manufactured from recycled wood, shredded wood from forest thinning, clean construction debris from landfill diversion, or other clean wood chip material with a particle size range of 1/2 – 3 inches, and not less than 3/8 inch in width and 1/16 inch in thickness. The material must contain 85% by volume chips that conform to this size range. Wood chips produced from tree trimmings shall not contain leaves or small twigs.

A hydromulch application may be substituted for wood chips only on inaccessible slopes as determined by Lahontan staff or representatives. The hydromulching machine should be equipped with a gear-driven pump and a paddle agitator. Agitation by re-circulation from the pump is not recommended. Agitation should be sufficient to produce homogeneous slurry of tacking agent and mulch fiber. Tacking agent should be applied at a rate of 200 gallons of wet ingredients per acre or 80 pounds of dry ingredients per acre. Wood fiber mulch should be applied at a rate of 4,000 pounds per acre. Seed may only be applied in a separate preliminary hydroseed application before the main hydromulch application. Seed may not be applied with a single hydromulch application (Caltrans Landscape Architecture Program, 2015; High Sierra Resource Conservation and Development Council, 2005).

<u>Substrate Monitoring Requirements and Protocols</u>

Substrate pH

A survey of representative substrate pH levels shall be made at 2 and 4 years after application, with appropriate remedial responses based on lime requirements. After these two initial evaluations, pH shall be monitored at 9 and 14 years after the initial application. Substrate acidity shall be measured on ten individual samples per acre taken from the 3 to 6 inch depth. Average pH for each area shall not fall below 5.5. Smaller areas that show salt blooms, toe slope seep positions, dead plants, non-vegetated areas or surface patches of weathered gray pyrite may be sampled individually and not included in the per-acre averages. These areas should be spot treated on an individual basis with additional lime.

Soil fertility

Plants showing nutrient deficiency symptoms including yellow color of newly emerging leaves, purple-red coloration of leaves (unless frost damaged), or tip burning of leaves shall be amended with commercial slow release fertilizer.

Surface erosion

Surface flows of rainwater or snowmelt should be evaluated to determine if they resulted from surface crusting of the substrate or from saturation and overland flow of compacted or shallow soils. The severity of the event that caused the erosion should be evaluated to determine if this is a frequent recurrent event or a rare event that will not likely occur again soon. If so, the treatment selected needs to be effective decades or more later rather than just for the following season, such as a hydromulch or temporary erosion control blanket.

Areas with concentrated flow shall be reinforced to prevent sediment mobilization from these drainageways.

Potential Post Implementation Maintenance and Remedial Measures

Supplemental lime amendment

Areas showing low average pH values shall be surface amended according to the Mehlich buffer index (Mehlich, 1976) for agricultural soils to a level of pH 6.5. Appropriate amendments shall be spread across the surface and incorporated to a depth of at least 6 inches.

Soil fertility

Plants showing generalized nutrient deficiency shall be amended with 50 lb per acre (equivalent to 1.2 lb per 1000 sq ft) of a polymer coated slow release fertilizer such as Best Full Season 24-4-8 (Nitrogen-Phosphorus-Potassium) or the equivalent.

Surface erosion - spot treatment

Local areas with crusts can be broken up physically with hand or mechanical tillage through the incorporation of lime (1/8 inch application across the area) and wood chips (1 to 1.5 inch layer) that are incorporated to 6 inches depth. Grass straw cut from local clumps can be spread across the damaged area.

Shallow soil conditions should be ripped with a small tractor, excavator or trenches. Small areas can be treated by hand with a pick. During or after the mechanical tillage, incorporate lime (1/8 inch application across the area) and wood chips (1 to 1.5 inch layer) to a depth of 6 inches. Grass straw cut from local clumps can be spread across the damaged area.

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Appendix 2a: NOAA Weather Target Storm Precipitation Frequency Measured in Units of Inches

Target Storm Precipitation Frequency tables. Target storm event data from NOAA weather web site (*http://dipper.nws.noaa.gov/hdsc/pfds/*) in units of inches.

PDS-based precipitation frequency estimates with 90% confidence intervals (in inches)[1]

Duration	Average recurrence interval (years)									
	1	2	5	10	25	50	100	200	500	1000
5-min	0.129 (0.105-0.160)	0.160 (0.129-0.199)	0.206 (0.166-0.257)	0.248 (0.199-0.312)	0.313 (0.244-0.406)	0.370 (0.283-0.490)	0.436 (0.325-0.590)	0.511 (0.372-0.710)	0.629 (0.441-0.908)	0.735 (0.498-1.09)
10-min	0.185 (0.150-0.230)	0.229 (0.186-0.285)	0.295 (0.238-0.368)	0.355 (0.285-0.447)	0.449 (0.349-0.582)	0.531 (0.405-0.702)	0.625 (0.466-0.845)	0.733 (0.533-1.02)	0.902 (0.632-1.30)	1.05 (0.714-1.57)
15-min	0.223 (0.181-0.278)	0.277 (0.224-0.345)	0.356 (0.288-0.445)	0.429 (0.345-0.540)	0.543 (0.422-0.704)	0.642 (0.490-0.849)	0.755 (0.564-1.02)	0.887 (0.645-1.23)	1.09 (0.764-1.57)	1.27 (0.863-1.90)
30-min	0.302 (0.245-0.376)	0.374 (0.303-0.466)	0.482 (0.390-0.602)	0.581 (0.466-0.731)	0.734 (0.571-0.952)	0.868 (0.663-1.15)	1.02 (0.763-1.38)	1.20 (0.872-1.67)	1.48 (1.03-2.13)	1.72 (1.17-2.57)
60-min	0.420 (0.341-0.523)	0.521 (0.422-0.649)	0.671 (0.543-0.838)	0.808 (0.649-1.02)	1.02 (0.795-1.32)	1.21 (0.923-1.60)	1.42 (1.06-1.92)	1.67 (1.21-2.32)	2.05 (1.44-2.96)	2.40 (1.63-3.57)
2-hr	0.572 (0.465-0.712)	0.714 (0.579-0.889)	0.919 (0.743-1.15)	1.10 (0.884-1.39)	1.38 (1.07-1.78)	1.61 (1.23-2.13)	1.87 (1.39-2.53)	2.16 (1.57-2.99)	2.59 (1.81-3.74)	2.96 (2.01-4.42)
3-hr	0.693 (0.563-0.863)	0.864 (0.701-1.08)	1.11 (0.896-1.38)	1.32 (1.06-1.66)	1.64 (1.28-2.13)	1.91 (1.46-2.52)	2.19 (1.64-2.97)	2.52 (1.83-3.49)	2.99 (2.09-4.31)	3.39 (2.30-5.05)
6-hr	1.01 (0.817-1.25)	1.25 (1.02-1.56)	1.59 (1.29-1.99)	1.89 (1.52-2.38)	2.32 (1.80-3.01)	2.67 (2.04-3.53)	3.04 (2.27-4.12)	3.45 (2.51-4.79)	4.04 (2.83-5.83)	4.53 (3.07-6.75)
12-hr	1.47 (1.19-1.83)	1.83 (1.49-2.28)	2.33 (1.88-2.90)	2.75 (2.20-3.46)	3.34 (2.60-4.33)	3.82 (2.92-5.05)	4.33 (3.23-5.85)	4.87 (3.54-6.76)	5.63 (3.94-8.13)	6.25 (4.24-9.32)
24-hr	2.06 (1.87-2.32)	2.59 (2.34-2.92)	3.30 (2.97-3.73)	3.90 (3.48-4.45)	4.74 (4.07-5.62)	5.40 (4.54-6.56)	6.10 (4.98-7.62)	6.83 (5.41-8.81)	7.87 (5.94-10.6)	8.70 (6.32-12.2)
2-day	2.73 (2.47-3.08)	3.47 (3.13-3.91)	4.47 (4.03-5.05)	5.31 (4.74-6.07)	6.50 (5.59-7.71)	7.45 (6.25-9.05)	8.44 (6.89-10.5)	9.50 (7.52-12.3)	11.0 (8.30-14.9)	12.2 (8.87-17.1)
3-day	3.17 (2.87-3.57)	4.05 (3.66-4.57)	5.26 (4.74-5.95)	6.28 (5.61-7.18)	7.74 (6.65-9.18)	8.90 (7.47-10.8)	10.1 (8.28-12.7)	11.4 (9.06-14.8)	13.3 (10.1-18.0)	14.8 (10.8-20.8)
4-day	3.44 (3.11-3.87)	4.42 (3.99-4.99)	5.76 (5.19-6.52)	6.90 (6.16-7.88)	8.52 (7.32-10.1)	9.82 (8.24-11.9)	11.2 (9.14-14.0)	12.7 (10.0-16.3)	14.8 (11.1-19.9)	16.5 (12.0-23.1)
7-day	3.96 (3.58-4.46)	5.09 (4.60-5.74)	6.64 (5.98-7.51)	7.95 (7.10-9.09)	9.83 (8.45-11.7)	11.3 (9.53-13.8)	12.9 (10.6-16.2)	14.7 (11.6-18.9)	17.1 (12.9-23.1)	19.1 (13.9-26.8)
10-day	4.39 (3.98-4.95)	5.65 (5.11-6.38)	7.38 (6.65-8.35)	8.84 (7.89-10.1)	10.9 (9.39-13.0)	12.6 (10.6-15.3)	14.4 (11.7-17.9)	16.2 (12.9-20.9)	18.9 (14.3-25.6)	21.1 (15.3-29.7)
20-day	5.97 (5.41-6.73)	7.74 (7.00-8.73)	10.1 (9.12-11.5)	12.1 (10.8-13.8)	14.9 (12.8-17.7)	17.1 (14.4-20.8)	19.4 (15.8-24.2)	21.8 (17.3-28.1)	25.2 (19.1-34.1)	28.0 (20.3-39.3)
30-day	7.30 (6.61-8.23)	9.50 (8.59-10.7)	12.4 (11.2-14.0)	14.8 (13.2-16.9)	18.1 (15.6-21.5)	20.7 (17.4-25.2)	23.4 (19.1-29.2)	26.1 (20.7-33.7)	30.0 (22.7-40.5)	33.0 (24.0-46.4)
45-day	8.95 (8.11-10.1)	11.7 (10.5-13.1)	15.2 (13.7-17.2)	18.0 (16.1-20.6)	21.8 (18.8-25.9)	24.8 (20.8-30.1)	27.8 (22.7-34.7)	30.9 (24.4-39.8)	35.1 (26.5-47.4)	38.4 (27.9-53.9)
60-day	10.6 (9.60-11.9)	13.8 (12.4-15.5)	17.8 (16.0-20.1)	21.0 (18.8-24.0)	25.3 (21.8-30.1)	28.6 (24.0-34.7)	31.8 (26.0-39.8)	35.2 (27.8-45.4)	39.6 (29.9-53.5)	43.1 (31.3-60.5)

[1] Precipitation frequency (PF) estimates in this table are based on frequency analysis of partial duration series (PDS).
Numbers in parenthesis are PF estimates at lower and upper bounds of the 90% confidence interval. The probability that precipitation frequency estimates (for a given duration and average recurrence interval) will be greater than the upper bound (or less than the lower bound) is 5%. Estimates at upper bounds are not checked against probable maximum precipitation (PMP) estimates and may be higher than currently valid PMP values.
Please refer to NOAA Atlas 14 document for more information.

Appendix 2b: NOAA Weather Target Storm Precipitation Frequency Measured in Units of Millimeters

Target Storm Precipitation Frequency tables. Target storm event data from NOAA weather web site (*http://dipper.nws.noaa.gov/hdsc/pfds/)*) in units of millimeters.

PDS-based precipitation frequency estimates with 90% confidence intervals (in millimeters)[1]										
Duration	Average recurrence interval (years)									
	1	2	5	10	25	50	100	200	500	1000
5-min	3 (3-4)	4 (3-5)	5 (4-7)	6 (5-8)	8 (6-10)	9 (7-12)	11 (8-15)	13 (9-18)	16 (11-23)	19 (13-28)
10-min	5 (4-6)	6 (5-7)	7 (6-9)	9 (7-11)	11 (9-15)	13 (10-18)	16 (12-21)	19 (14-26)	23 (16-33)	27 (18-40)
15-min	6 (5-7)	7 (6-9)	9 (7-11)	11 (9-14)	14 (11-18)	16 (12-22)	19 (14-26)	23 (16-31)	28 (19-40)	32 (22-48)
30-min	8 (6-10)	9 (8-12)	12 (10-15)	15 (12-19)	19 (15-24)	22 (17-29)	26 (19-35)	30 (22-42)	37 (26-54)	44 (30-65)
60-min	11 (9-13)	13 (11-16)	17 (14-21)	21 (16-26)	26 (20-34)	31 (23-41)	36 (27-49)	42 (31-59)	52 (37-75)	61 (41-91)
2-hr	15 (12-18)	18 (15-23)	23 (19-29)	28 (22-35)	35 (27-45)	41 (31-54)	47 (35-64)	55 (40-76)	66 (46-95)	75 (51-112)
3-hr	18 (14-22)	22 (18-27)	28 (23-35)	34 (27-42)	42 (32-54)	48 (37-64)	56 (42-75)	64 (46-89)	76 (53-110)	86 (58-128)
6-hr	26 (21-32)	32 (26-40)	41 (33-51)	48 (39-60)	59 (46-76)	68 (52-90)	77 (58-105)	88 (64-122)	103 (72-148)	115 (78-171)
12-hr	37 (30-46)	47 (38-58)	59 (48-74)	70 (56-88)	85 (66-110)	97 (74-128)	110 (82-149)	124 (90-172)	143 (100-206)	159 (108-237)
24-hr	52 (47-59)	66 (59-74)	84 (76-95)	99 (88-113)	120 (103-143)	137 (115-167)	155 (126-193)	174 (137-224)	200 (151-270)	221 (161-310)
2-day	69 (63-78)	88 (80-99)	113 (102-128)	135 (120-154)	165 (142-196)	189 (159-230)	214 (175-268)	241 (191-311)	279 (211-377)	310 (225-435)
3-day	80 (73-91)	103 (93-116)	134 (120-151)	160 (143-182)	197 (169-233)	226 (190-275)	257 (210-322)	291 (230-375)	338 (255-457)	376 (274-529)
4-day	87 (79-98)	112 (101-127)	146 (132-166)	175 (156-200)	216 (186-257)	249 (209-303)	284 (232-355)	322 (255-415)	375 (283-507)	418 (304-587)
7-day	100 (91-113)	129 (117-146)	169 (152-191)	202 (180-231)	250 (215-296)	288 (242-350)	329 (269-411)	373 (295-480)	435 (328-587)	485 (353-682)
10-day	112 (101-126)	144 (130-162)	187 (169-212)	224 (201-257)	277 (238-329)	320 (268-389)	365 (298-456)	413 (327-532)	481 (363-650)	536 (390-753)
20-day	152 (137-171)	197 (178-222)	257 (232-291)	308 (275-351)	378 (325-449)	434 (365-528)	493 (402-615)	554 (439-715)	641 (484-866)	710 (516-997)
30-day	185 (168-209)	241 (218-272)	315 (284-357)	376 (336-430)	460 (396-546)	526 (441-639)	593 (485-741)	664 (525-856)	762 (575-1029)	839 (610-1179)
45-day	227 (206-256)	296 (268-334)	385 (347-436)	457 (408-522)	555 (477-658)	630 (529-765)	706 (576-882)	784 (621-1011)	891 (673-1204)	974 (708-1368)
60-day	269 (244-303)	349 (316-394)	452 (407-512)	534 (477-610)	643 (553-764)	726 (610-882)	809 (661-1010)	893 (707-1152)	1007 (760-1360)	1094 (795-1536)

[1] Precipitation frequency (PF) estimates in this table are based on frequency analysis of partial duration series (PDS).
Numbers in parenthesis are PF estimates at lower and upper bounds of the 90% confidence interval. The probability that precipitation frequency estimates (for a given duration and average recurrence interval) will be greater than the upper bound (or less than the lower bound) is 5%. Estimates at upper bounds are not checked against probable maximum precipitation (PMP) estimates and may be higher than currently valid PMP values.
Please refer to NOAA Atlas 14 document for more information.

Appendix 3: Plant Characteristics Notes

Appendix 3: Plant Characteristics Notes

The predominant species that has colonized in the regraded pit benches, from among all the seeded species is Basin wildrye, *Leymus cenerus*. Growth conditions for this species are interpreted from the USFS plant data base web site that indicates a root distribution that is 2 to 3 times deeper than measured in the Leviathan mine substrates even after amendment:

> Basin wildrye has an extensive soil-binding, fibrous root system [129]. Abbott and others [1] found that basin wildrye tends to root deeper in undisturbed soil (rooting depth of 39 inches or 100 cm) than in disturbed soil (rooting depth of 30 inches or 75 cm). Reynolds and Fraley [103], however, found that basin wildrye rooted to 79 inches (200 cm) in disturbed soils and to 63 inches (160 cm) in undisturbed soils. Basin wildrye reaches maximum lateral root spread of 39 inches (100 cm) [1,103] at approximately 16 inches (40 cm) deep [103]. http://www.fs.fed.us/database/feis/plants/graminoid/leycin/all.html, accessed Nov 5, 2013.
>
> Idaho fescue, the common plant on Pond 2N and somewhat on DS plots:
> Plants have a strong root system [124] that can extend 16 inches (40 cm) deep in a 4-inch (10 cm) diameter plant [306]. In well-drained soils, root biomass is greatest at 0.8- to 1.6-inch (2-4 cm) depths [296]. Goodwin and Doescher [111] found that in both disturbed and undisturbed sites, 40% of root biomass was contained in the upper 0.8 inch (2 cm) of soil, and 60% was in the upper 4 inches (10 cm) of soil. Idaho fescue roots are infected with vesicular-arbuscular mycorrhizae, which may give it a competitive advantage over non-mycorrhizal plants and/or allow it to thrive on nutrient-poor soils or extreme environmental conditions [112,134,176,198].
>
> A species with roots concentrated in upper soil layers (e.g., Idaho fescue) will experience a decline of water availability when compared with a deeper rooted species (e.g., bluebunch wheatgrass), thus affecting subsequent growth [84]. This may help explain why many studies show that Idaho fescue is more severely damaged by fire than bluebunch wheatgrass [2].
> http://www.fs.fed.us/database/feis/plants/graminoid/fesida/all.html\

The relatively shallow rooted habit of Idaho fescue may make it grow less densely on the Leviathan Mine substrates that dry extensively in the shallow surface horizons. Conversely, the mycorrhizal colonization may help it persist as one of the few herbaceous colonizers on the harshest north facing slopes.

Appendix 4: Amendment of Existing Slope Materials During Construction

Amendment of Existing Slope Materials During Construction

Deep, amended rooting volumes can be developed on slopes during the earthwork phase of a project as slopes are being built up during construction or as they are being brought down during excavation and slope reconfiguration.

Amendments can be incorporated in slopes being built up by adding lime and compost to each six to twelve inch lift and by ripping through the depth of the lift to mix it adequately. This cycle can be repeated through several successive lifts to develop a full rooting depth. Wide tracked equipment helps reduce compaction during earthwork.

Deep rooting volumes can be developed on steep slopes that are being brought down by creating an extra wide bench with an overly steep back wall. Bench widths and the height of the back wall, from 3 to 10 ft high, depend on the geometry of the slope. Loose material from excavation can be reserved, mixed with lime and compost and then pushed into the notch created by the flat bench and oversteepened back wall (Figure 4.1). The three objectives with these methods are: 1) utilize existing cut or fill material on-site as a growth media; 2) create rooting volume with amended substrate that are several feet deep for improved revegetation and erosion resistance and 3) to avoid unnecessary compaction by firming the amended fill material but not further compacting it. The uncompacted fill volume must rest on a horizontal bench with adequate geotechnical strength.

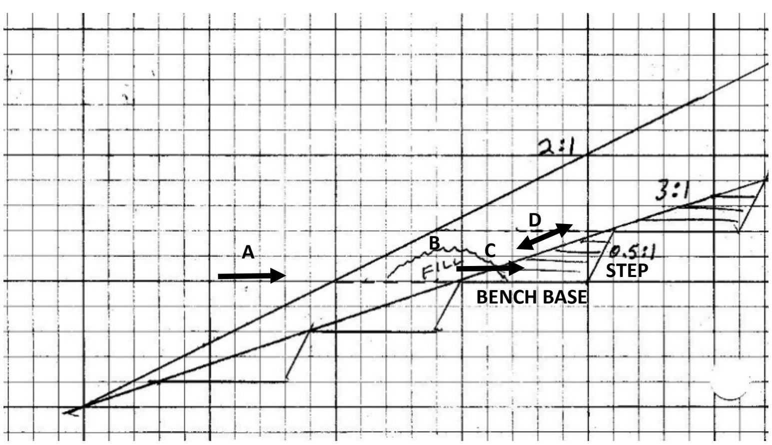

Figure 4.1. Schematic of grading sequence to reduce an existing 2:1 slope down to a 3:1 slope: 1) cut a wide horizontal bench in 2:1 slope (arrow A) with steep back wall (step) as the slope is being brought down; 2) reserve loose fill material and treat with lime and amendments (FILL pile B); 3) push amended fill into the notch of the bench in uncompacted lifts (arrow C); 4) grade 3:1 slope to uniform angle and trackwalk the uncompacted, treated fill (arrow D) to firm the amended rooting volume without additional compaction.

Appendix 5: Acid Neutralization Curves of Leviathan Mine Substrates with Varying Levels of Lime Addition

Acid Neutralization Curves of Leviathan Mine Substrates with Varying Levels of Lime Addition

Previous work at the mine site (Claassen and Hogan, 1999) included long-term incubations of several mine substrates and their neutralization response to different lime amendment rates. These graphics show pH response in 5:1 distilled water:substrate mixtures of substrate with lime equivalent to the megagram per hectare (Mg/ha) rate shown on each graph. These are field application rates equivalent for the top 30 cm (1 ft) of substrate depth assuming no rock content. These rates should be pro-rated upward for deeper treatment depths. One Mg/ha per 30 cm depth is equivalent to 0.446 ton/ac per 1 foot depth.

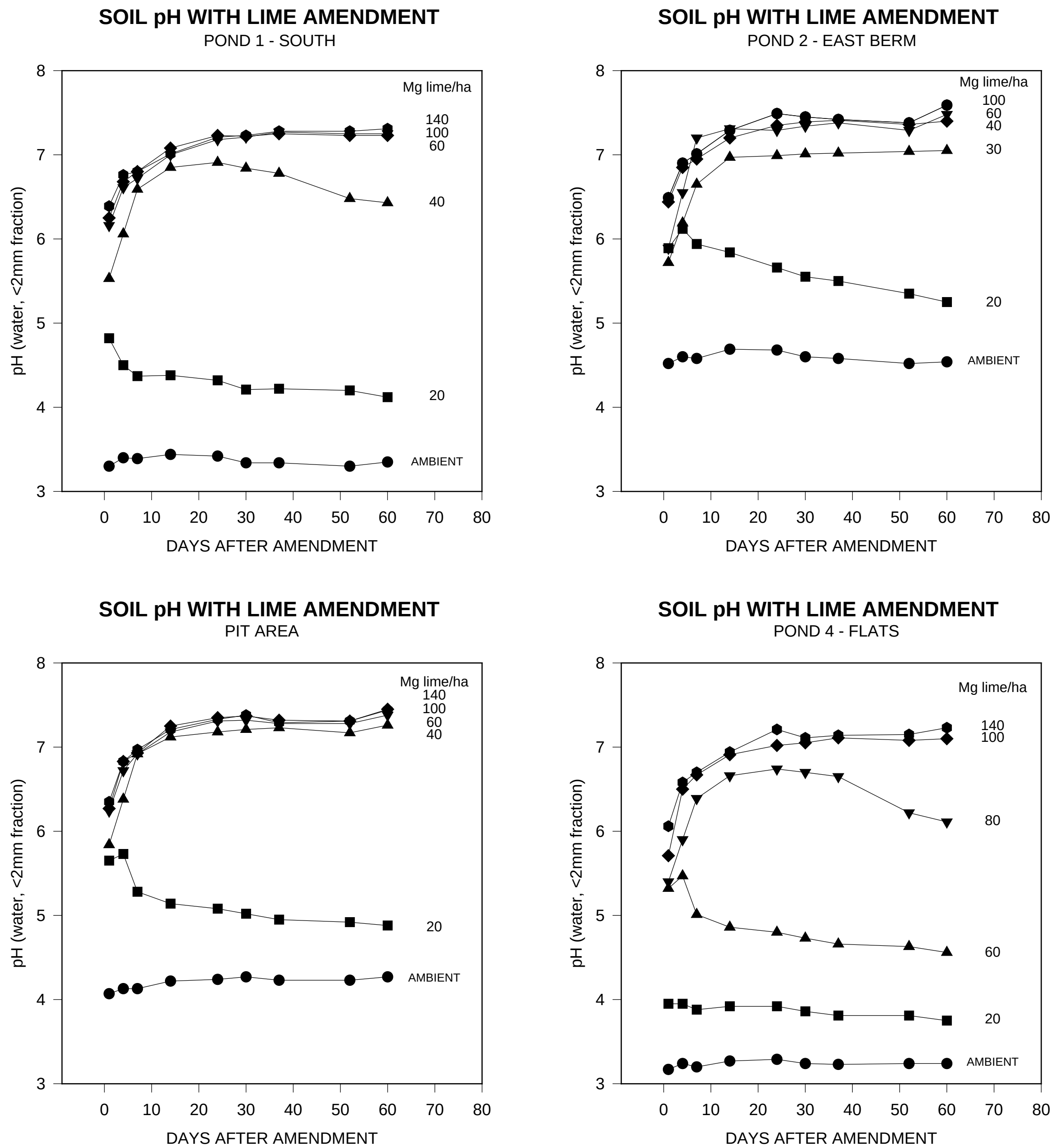

Figure 5.1. Soil pH with lime amendment: four surface soil sample locations within the Leviathan Creek corridor. Individual traces are labeled in metric tons (megagrams, Mg) calcium carbonate equivalent per ha to 30 cm depth.