New techniques for stabilizing, amending and revegetating mine waste

Including soil regeneration, erosion resistance and revegetation treatments in mined land remediation designs

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Overview: A primary goal of remediation is to remove or isolate hazardous materials. But subsequently, the site has to be stabilized for the indefinite future.

In California’s Mediterranean climate (cool, moist winters / hot dry summers) conventional erosion control practices and plants often do not stabilize the site long-term.

This can lead to chronic sediment production and increased saturation and leachate production, both of which influence mercury movement in the environment.
In California, winter rains fall on thin hillslope soils and seep downward to toe slopes, valley sediments or into groundwater. Annual grasses do not use all the available moisture, increasing subsurface water content. California subsoils are often moist through the summer. Moist sub-soils more rapidly re-saturate with fall rains.
Objectives for site sustainability:

1. geotechnically stable
2. hydrologically stable
   a. no surface erosion or sediment mobilization
   b. no subsurface saturation
3. sustainable plant cover and nutrient cycling

Rathburn Mercury Mine
Colusa County, CA
This site was steep but geotechnically stable, so the focus was on serpentine plant establishment and growth to reduce surface particulate losses in wind and water.

Excessive drainage made the surface droughty. Plants were propagated and installed using tall rooting columns leading to down to subsurface moisture.
A standard moil-point jackhammer bit was fitted in a steel casing sleeve and inserted to depth. Then the center bit is pulled out and amendments backfilled in the hole. Plants are propagated in cardboard planting sleeves with open bottoms so roots can follow the rooting column to moisture.
A ripper can lift, fracture and open compacted substrates on a larger scale. But it does not incorporate effectively. An agricultural vineyard tractor was used to minimize compaction and side-hill slippage and furrowing from the tracks.
Compacted substrates are opened up on an interval spacing that provides sheeting vs capture areas and that link adjacent fracture patterns.

Slopes are ripped at an angle to the slope to avoid water piping when saturated.
Composts, wood chips, lime, gypsum, biochar or microbial inocula can be loaded into the rip slot.
An previous revegetation treatment on acid mine waste from 1996 still shows plant growth patterns according to a 2 ft deep rip slot filled with lime and compost.

Leviathan Mine, Alpine County, CA
Treatment slots were ripped at an angle down-slope to 2 ft and then a second pass across slope to create a ridged planting bed (shown here). Seed was broadcast and mulched. Germination was good in the furrows.
But, the view looking downslope on the rip angle shows that the plants grew largest when directly over the deeper planting slot, not in the furrow over a non-ripped subsoil.
This pattern of down-slope trending rows of plant growth over the rip slots is still visible 20 years later.
Rainfall harvesting: Field treatments are often designed around available equipment. But establishing targets for soil hydrology can guide treatments and avoid necessary or ineffective effort.

Example targets:
+ no overland flow
+ capture of rainfall from 2 or 5 yr events
Envision the site during a potential failure event.

What are the design storms that a site should withstand?
What are the impacts of potential rain events on root zone hydrology?

Three events generating overland flow exported about 50% of the received water, reducing plant-available moisture by an estimated 10 – 20 % of annual rainfall.

<table>
<thead>
<tr>
<th>WATER YEAR</th>
<th>total annual precipitation</th>
<th>STORM DATE</th>
<th>1 hr (RFI yrs)</th>
<th>6 hr (RFI yrs)</th>
<th>24 hr (RFI yrs)</th>
<th>48 hr (RFI yrs)</th>
<th>96 hr (RFI yrs)</th>
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</thead>
<tbody>
<tr>
<td>2012-13</td>
<td>10.46”</td>
<td>Dec 1, 2012</td>
<td>0.34” (1+)</td>
<td>1.36” (2+)</td>
<td>1.73” (1-)</td>
<td>2.31” (1-)</td>
<td>4.41” (2+)</td>
</tr>
<tr>
<td>2013-14</td>
<td>11.64”</td>
<td>no runoff</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2014-15</td>
<td>19.57”</td>
<td>Dec 11, 2014</td>
<td>0.42” (2-)</td>
<td>1.90” (10+)</td>
<td>4.03” (10+)</td>
<td>4.61” (5+)</td>
<td>4.65” (2+)</td>
</tr>
<tr>
<td>2014-15</td>
<td>19.57”</td>
<td>Feb 6, 2015</td>
<td>0.41” (2-)</td>
<td>1.70” (5+)</td>
<td>3.13” (5-)</td>
<td>3.13” (2-)</td>
<td>3.13” (1-)</td>
</tr>
</tbody>
</table>

Set infiltration rate (intensity) and infiltration capacity (quantity) targets. Then characterize surface infiltration and subsurface percolation parameters. Use field-based measurements to build a soil hydrology model.
Following recharge of subsoil moisture from two winter flows, the perennial native grass creeping wild rye was still moist enough in late summer to squelch the flame front during the Rocky Fire. Aug 5, 2015.
Soils need to be able to rapidly infiltrate infrequent rain events to maintain perennial plant cover during dry seasons.

Soil root zone hydrologic characterization involves sampling for soil depth, texture, bulk density. Non-saturated conductivity is measured with a tension infiltrometer.

Then treatments are generated that maintain cover on the remediation site in target conditions.
Tension infiltrometer measures unsaturated conductivity.
Example of soil hydrology evaluation and treatment generation for a target rain event: Erosion from a 25 year Return Frequency Interval event of 5 day duration. Site is underlain by impermeable shale (right).
Hydrus 1D soil hydrology modeling software uses field measured hydraulic parameters to estimate soil moisture flow with time. Colored lines indicate water content at soil depths at different days since the start of a 25 yr 5 day storm event.
Of all the site field conditions and rainfall patterns, what treatment options will eliminate overland flow?

Effect of tillage depth on soil moisture during 25 yr 5 day target storm event:

- 5 ft loose fill over dense shale
- 3 ft fill
- 1.5 ft fill

![Graphs showing soil moisture depth variations for different tillage depths.](image)
Native reference soils showed no overland surface flows but a seepage interface at 18 inches depth collapsed surface soils along the road cut.
How can larger rooting ‘pockets’ for revegetation be stabilized on a steep slope?

Development of geotechnically stable deep planting pockets on steep, drastically disturbed site on serpentine geology following slope reconstruction in the mid-1990s.
Serpentine cut-slope to the right of drain, with compacted earth buttress to the left.
Parameterize substrates and design a treatment volume that retains sufficient soil moisture to grow perennial plants.
Initial flow is downward into the uncompacted surface layer (left) but after saturation above the compacted layer, flow runs laterally down-slope (right).
Red arrows indicate jackhammer fracture row locations to 24 or 36 inches depth.

Model computational mesh generated by Hydrus 2D. Surface 8” are uncompacted. Substrate parameterization and model development by Arek Fristensky.
Hydrus model output: Substrate pore pressure

Upper image: A thin black slippage plane promotes shallow slips.

Lower image: Rainfall was captured in the planting volume, but the positive pore pressure is over a horizontal bench.
Model output:
Substrate flow vectors
Geotechnical evaluation was completed prior to surface treatment.
Summary:
Using a combination of soils, botany and engineering approaches, degraded sites can be regenerated to be erosion resistant and sustainably revegetated.

Sediments and surface sorbed mercury mobilization is reduced when abandoned mine waste piles are erosionally stabilized.

Saturated substrates and anaerobic conditions can be reduced.

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Additional development needs:

Project format is needed that allows lower levels of activity for extended periods of time (5 yrs?) to cost-effectively stabilize low-impact sites using low intensity regeneration and revegetation approaches.

A surrogate soil organic matter amendment is needed to regenerate soil-like properties on raw substrate materials.

A series of well-characterized field sites is needed to convert results from technical and analytical approaches into effective, generally applicable ‘rules of thumb’ for routine, constructable field implementation.
Model output:
Substrate flow vectors