

# Mine Soil Reconstruction Protocols to Improve Internal Drainage and Plant Growth in Reclaimed Coastal Plain Mine Soils in Virginia

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# Topics for Today

- **Brief review of research on reclamation of mined prime farmland in Virginia, including biosolids utilization protocols.**
- **Common soil/landform limitations and our integrated soil reconstruction approach utilizing deep tillage + biosolids.**
- **Use of nested wells/piezometers to interpret local mine soil drainage regimes.**
- **Describe results for our 3 yr research at the Moss Neck sand & gravel mine in Caroline County.**

**Large-Scale application of Philadelphia biosolids @ 30 DT/Ac (67 Mg/ha) + woodchips on rocky spoils in Wise County, VA in 1989.**



**Based on Sopper et al. at Penn State University in 1970's and 1980's. Typical loading rates in PA and MD are/were 60 DT/Ac (135 Mg/ha)**

**Powell River Project area 10 years after application with biosolids.**

**Five years of monitoring found no impact on P-runoff or N-Leaching to surface- or groundwater.**



**First monitored Coastal Plain biosolids application study. Land application of municipal biosolids to large experimental plots at Shirley Plantation (Charles City) in 1996 on reclaimed former prime farmland soils.**



**Wheat response to biosolids on unmined control plots at Shirley Plantation one year after application.**



Downgradient GW  
Wells showed no effects

Sampling from zero-tension  
lysimeter @ 1 m. Net  
nitrate-N losses were  $< 5\%$   
of total-N applied at rates  $\leq$   
35 DT/acre (78 Mg/ha)

7 26 '97

# Application to Coastal Plain Sites

- Mid 1990's, mining entities and landowners interested in potential for biosolids application on Coastal Plain sites. Most were originally Prime Farmlands.
- Initial loading rate studies at Shirley Plantation and other locations with extensive water quality monitoring indicated that a “one-time flush” of nitrate-N ( $> 10$  mg/L) from the rooting zone occurred the first winter, but did not affect local groundwater.
- Integrated results led to an agreed-upon cap at 35 DT/Ac (78 Mg/ha) for class B materials and 50 DT/ac (112 Mg/ha) if high C residues added to generate bulk C:N  $\geq 30: 1$  or better

**Active mineral sands mine (Iluka Resources, Dinwiddie/Sussex/Greenville Co). Over 3000 acres of land have been disturbed with ~ 600 left for final revegetation. Over 2/3 of disturbed area was NRCS prime farmland.**



**Typical prime farmland landscape in Dinwiddie County.**

**This area has been extensively mined and disturbed for Ti  
“mineral sands” and zircon.**





**A horizon; topsoil**

**B horizon; subsoil**

**Deep rooting to > 30"**

- ▶ **Highly productive soil profile in mineral sands mining are. This field was the top peanut producer in VA several times in the 1980s.**
  - ▶ **Low BD**
  - ▶ **Well-structured subsoil that allows rooting to 36+"**
  - ▶ **Uniform response to management**

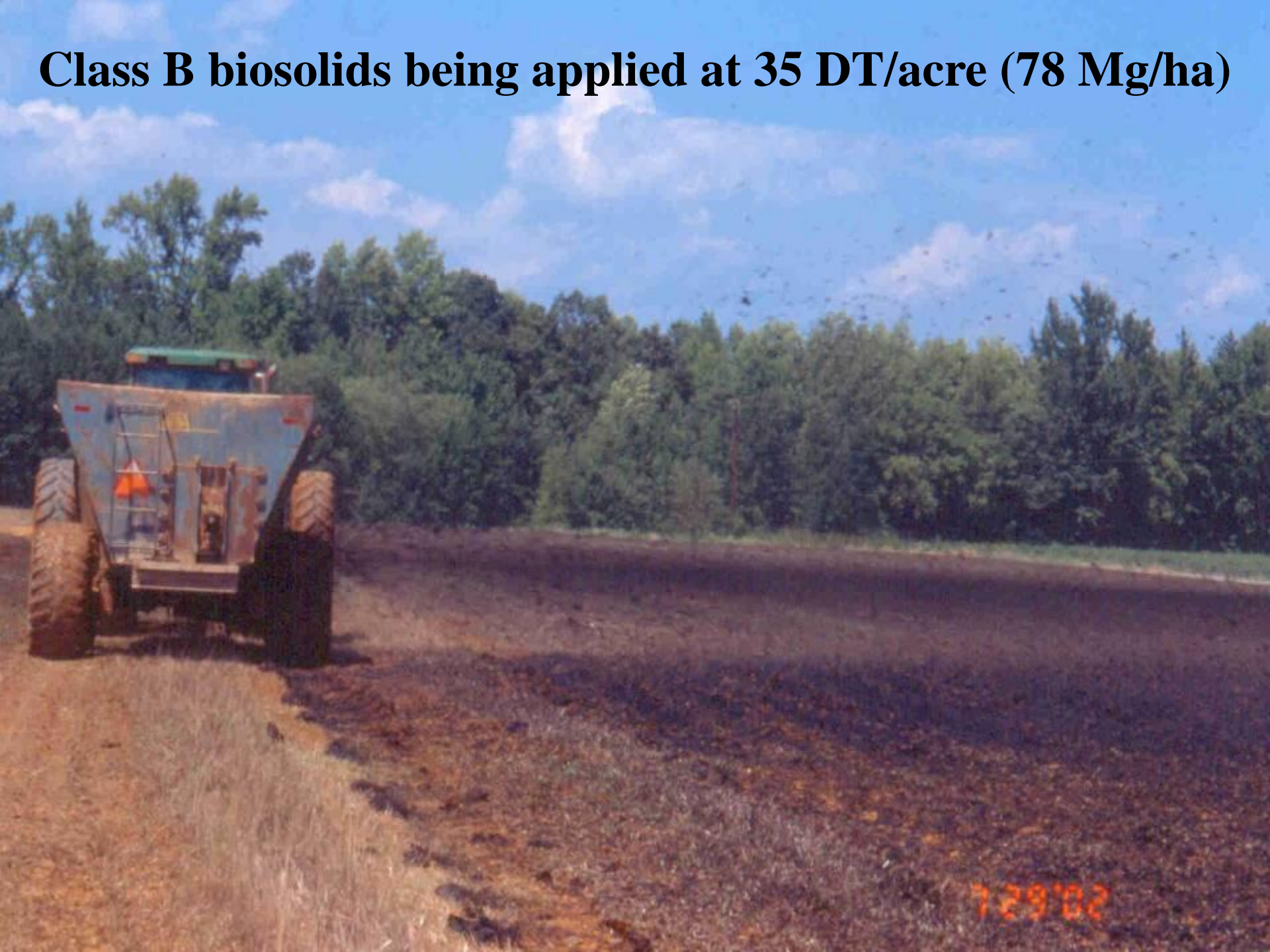
# Long-term (1989 to 2025) Results at Iluka

- ▶ Heavy soil compaction, strong stratification and low plant-available P are the dominant factors limiting return of these soils to intensive agricultural productivity levels.
- ▶ Post-mine landscapes were left generally flat until ~2015 when we emphasized geomorphic reconstruction practices to limit compaction, make subsoils more uniform and improve surface drainage and internal permeability.
- ▶ Our 10-year replicated and intensively managed rowcrop experiment (corn/wheat/soybeans) indicated that with deep ripping and frequent P fertilization or biosolids, average post-mine productivity was ~75% prime farmland - could equal or exceed county average yields for all soil types.



- ▶ **Ripping of subsoil before complete application of topsoil for final reclamation.**
- ▶ **Note: subsoil was “too dry” at this time for ideal effect and the operation was “throwing chunks”.**

**Class B biosolids being applied at 35 DT/acre (78 Mg/ha)**



## 2005 Corn Yields (bu/ac)

**Topsoil/Lime/NPK 61 c\***

**Tails + Biosolids: 174 a**

**Tails + Lime + NPK: 136 b**

**Unmined adjacent: 224**

**County Average: 98**

**(2000 – 2005)**

*Adjacent prime farmland –  
Orangeburg Soil with same  
management as plot area.*



13.7.2005

*\*Yields within experiment followed by  
different letters were different at  $p > 0.01$*

**Fully reclaimed area (biosolids at 35 DT/ac (78 Mg/ha)) supporting vigorous three-year old mixed grass/legume forage stand. Forage/hay crops are less sensitive to subsoil compaction than rowcrops and improve surface soil quality over time once established & maintained.**



# Biosolids Rate Policy for Mined Lands in VA

- ▶ **Mid-2000's, Virginia DEQ/DCR and Virginia Tech concurred that higher than agronomic rates of biosolids could be utilized on mined land with minimal risk to soil/water quality with the following restrictions:**
  - ▶ **Class B may be applied at up to 35 DT/Ac (78 Mg/ha) with seasonal restrictions, setbacks (10 m), and time/access limits (e.g. 30 days for grazing on pasture) and incorporation within 24 hours.**
  - ▶ **Class A/EQ materials not rate restricted, but still need agency approval and are limited to similar rates.**



**Ripper/tillage trial (2017-2023). Here the ripper is running shanks between previous rips - doubles the rips/area. Run at ideal moisture (just drier than FC) and only minimal subsoil is being pulled up.**



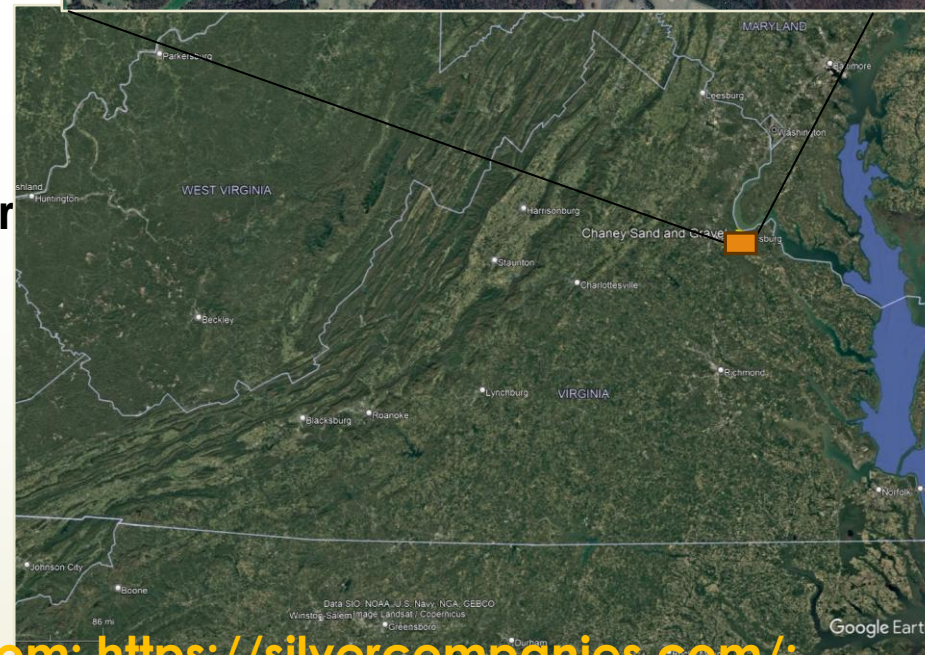
- ▶ Profile in 1X rip plot from Iluka ripping/tillage study in 2017.
- ▶ Most profiles (n = 16) did not show such visible evidence of ripping, but the rips could be detected with a knife as being “looser” and roots were concentrated down the rips.

- Multiple mine soil pit studies found that deep ripping often does not reduce overall BD but does create preferential rooting and water movement zones.
- Pine tree rooting study showed roots would grow in “fans” along ripper traces



# Chaney Sand and Gravel

- ▶ Chaney Enterprises active mine operator on Moss Neck Lodge property.
- ▶ Moss Neck Lodge is an upscale lodging and function facility on the higher river terrace overlooking active mining operation.
- ▶ Facility and surrounding farming operations owned and managed by the Silver Companies.
- ▶ Active farming operations focus on high-quality hay production (equine) – target post-mine land use.



<https://thelodgeatmossneck.com/>; <https://silvercompanies.com/>;  
<https://www.chaneyenterprises.com/>

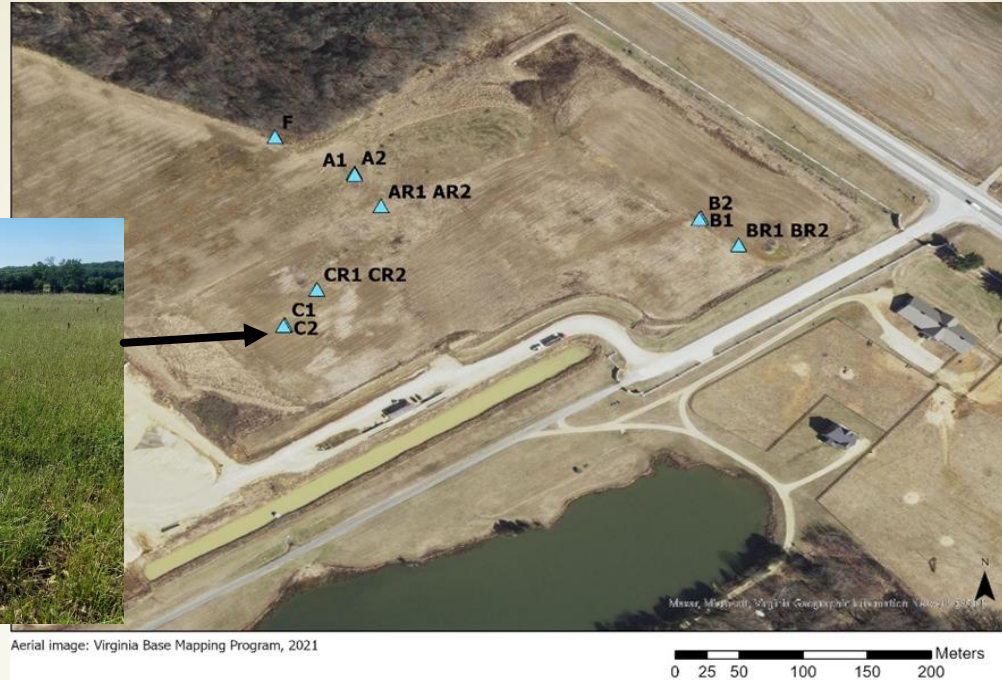


- Initially reclaimed (~2019) area in June 2020. Mostly weeds, including wetland species (sedges etc.) in “low flat spots”. Overall flat with limited gently convex sloping zones.
- Up to 12” (30 cm) of topsoil returned and pH/fertility were not limiting (based on soil testing).
- Soil highly compacted to 60” (1.5 m). Initial orchardgrass establishment failed. Excessive spring/fall surface wetness was identified by the farm operator as a significant limitation.

# Prescribed Geomorphic Reconstruction Approach

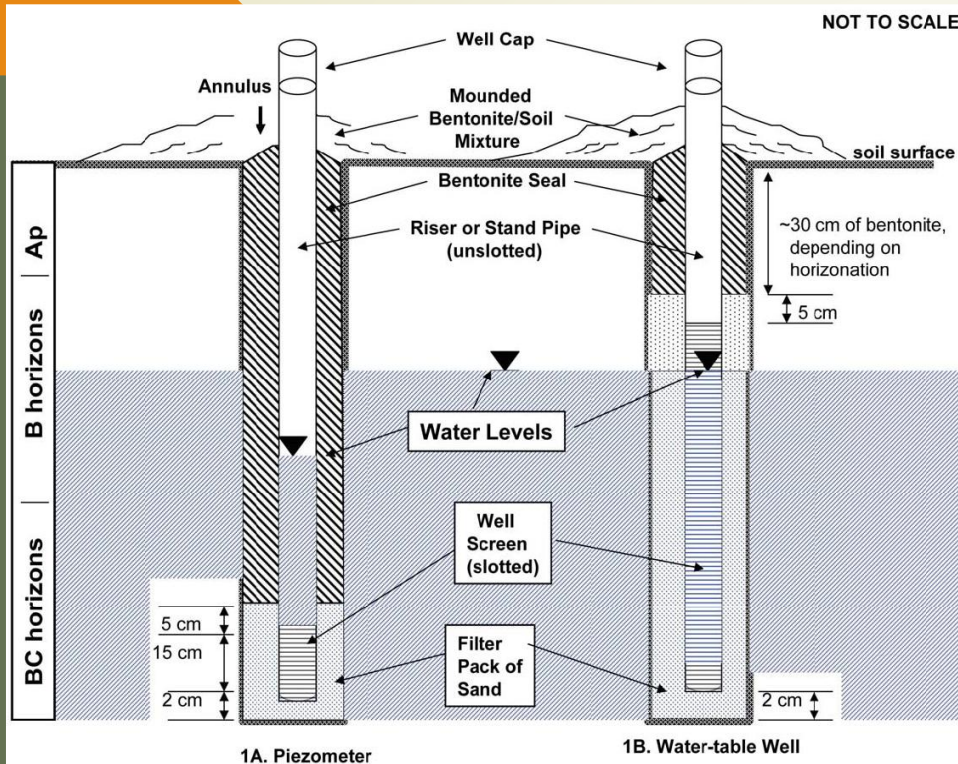
- **Regrade subsoil to reflect local natural gently sloping convex landforms with appropriate concave drainage conveyances**
- **Reapply salvaged topsoil**
- **Deep rip topsoil + subsoil with shank ripper (36"; 90 cm) in two directions. Time deep ripping to avoid very wet or dry subsoils (easier said than done!)**
- **Apply and incorporate biosolids**
- **Seed to appropriate fall or spring seed mix immediately after final biosolids+tillage operations**
- **Follow-up with spot remediation for deep rills or gullies and/or to re-rip wet spots (concave areas)**

# VT x Chaney S&G Timeline- Area 1



- **First site visit in Oct 2020**
- **Reclaim area 1 ~15 ha area**
  - **Initial nested wells (18")/piezometers (60") installed May 2021.**
  - **Field ripped August 2021, 50 m buffer around wells.**
  - **Class A/EQ biosolids pellets (20 DT/ac (45 Mg/ha) in Sept 2021 with "semi-incorporation".**
  - **Nested wells/piezometers installed in ripped area October 2021. Routine soil sampling, etc.**

# Paired Shallow Well vs. Deep Piezometer Interpretation



**Piezometers installed to 60" (1.5 m) with 12" of open screen at bottom**

**Shallow wells installed to 18" (45 cm) with 12" of open screen**

- ▶ Falling potential head vs. depth indicates a downward local gradient (e.g. groundwater recharge)
- ▶ Rising potential head vs. depth indicates an upward local gradient (e.g. groundwater discharge)
- ▶ Similar temporal response of both (shallow well + deep piezometer) to rainfall events indicates that both are "connected" and part of the same surficial hydrologic regime
- ▶ Lack of "connection" between surface and deep rainfall response indicates that the surface is isolated from the underlying groundwater and is "perching" a saturated zone over a compacted subsoil layer



- ▶ Initial deep ripping attempt in Reclaim Area 1 in August 2021. Ripping delayed until several rain events moistened subsoil.
- ▶ Compaction (not pH x fertility) is by far and away the most common limiting soil property on mined lands, ROW's, urbanized areas and solar farms.



- ▶ Reclaim Area 1 one week after final drilling (orchardgrass, 20 lbs/acre) on 9/27/21.
- ▶ Note patchy emergence and common weeds.
- ▶ Synagro and the farm manager observed quick germination after a 2.5" soaking 2-day rain...then quick dieback after 4d > 85° F.
- ▶ Surface soil samples taken in mid-October indicated saturated paste SC of 1.8 to 3.0 mS/cm.
- ▶ Overseeded with annual rye in late October



- Incorporation of the pelletized Class A/EQ product only to ~2 inches across site. Many pellets “migrated” after rain and concentrated via sheet flow in drill lines and low spots.
- *Basically, we cooked the emerging orchardgrass and allowed weedy species from the topsoil to dominate.*



- ▶ **Middle of Reclaim Area 1 looking S in Feb 2022. Most vegetation was annual ryegrass with some cereal rye.**



- ▶ **Flat poorly drained highly compacted area In Reclaim Area 1 in Feb 2022. Not deep-ripped in Aug 2021 due to wetness/rutting.**
- ▶ **Drainage was improved in the wet area during Area 2 reclaim in 2023.**

# Reclaim Area 1 in Feb 2022



**Well F inside woods line**

**Wells A1 and A2**

**Wells AR1 and AR2**



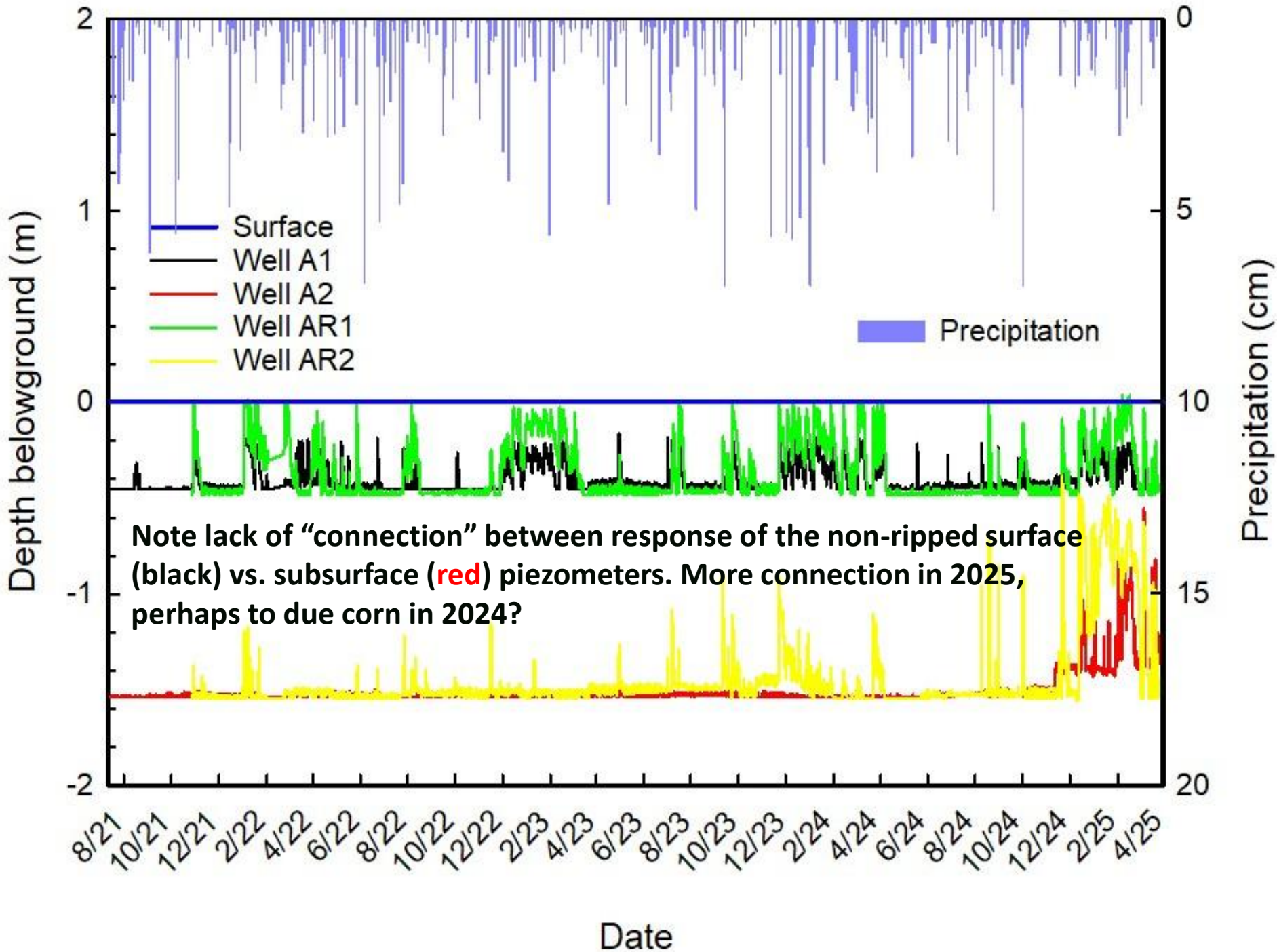
Aerial image: Virginia Base Mapping Program, 2021  
0 25 50 100 150 200 Meters

**Reclaim Area 1 in early April 2022. Annual ryegrass stand appeared to be suitable for a late spring cutting of hay but tissue samples were high in nitrate (1.18%) and the stand was left “as is” to mature over the summer to be reseeded in 2023/2024.**



**Corn on original older level landform, Sept. 2024. Good early establishment, growth, and weed control. Yield low but influenced by mid-summer drought.**





# VT x Chaney S&G Timeline – Area 2



- Reclaim area 2 ~ 20 ha area
  - Regrading work through March 2023
  - Paired wells/piezometers installed in May 2023.
  - Ripped Oct 2023 (no ripped comparison wells/piezometers)
  - Class B applied and incorporated at 25 DT/ac (56 Mg/ha) in late October 2023.
  - Seeded into mixed forage cover in mid-November 2023.

Newly reconstructed landforms in Reclaim Area 2 with variable slope shapes (interspersed slightly concave surface drains, gently convex landforms) in late March 2023. Topsoil has been returned, but not deep-ripped yet.



Wells H1  
and H2

**Area uphill from well G in late Sept. 2023 after initial ripping. The topsoil stockpile used here was not screened leading to some problems. Weedy vegetation.**





Sep 21, 2023, 9:30 AM

- Influence of excess logs on shank ripping efficiency, shear pins, etc.
- Ripping was completed by mid-October with 2 x passes 90° to each other.

**Well location E in mid-October 2023 after growth of topsoil seedbank, etc. Smartweed > 5 feet tall in many locations. Surrounding area mowed, ripped and prepped for biosolids application.**





**View across site following ripping and biosolids incorporation to at least 4" on 10/20/23. Drill seeding occurred one week later.**

**One month after seeding.....  
Cold/wet.....Very nervous**



**Finally seeing some germination! View of newly revegetated site in January 2024.**



**View of stand looking North in mid-April 2024. Oats (cover), MaxQ tall fescue, orchardgrass, and crimson clover. Forage nitrate levels acceptable (0.31%) for this stand at this stage. Well location D in middle of image.**



D





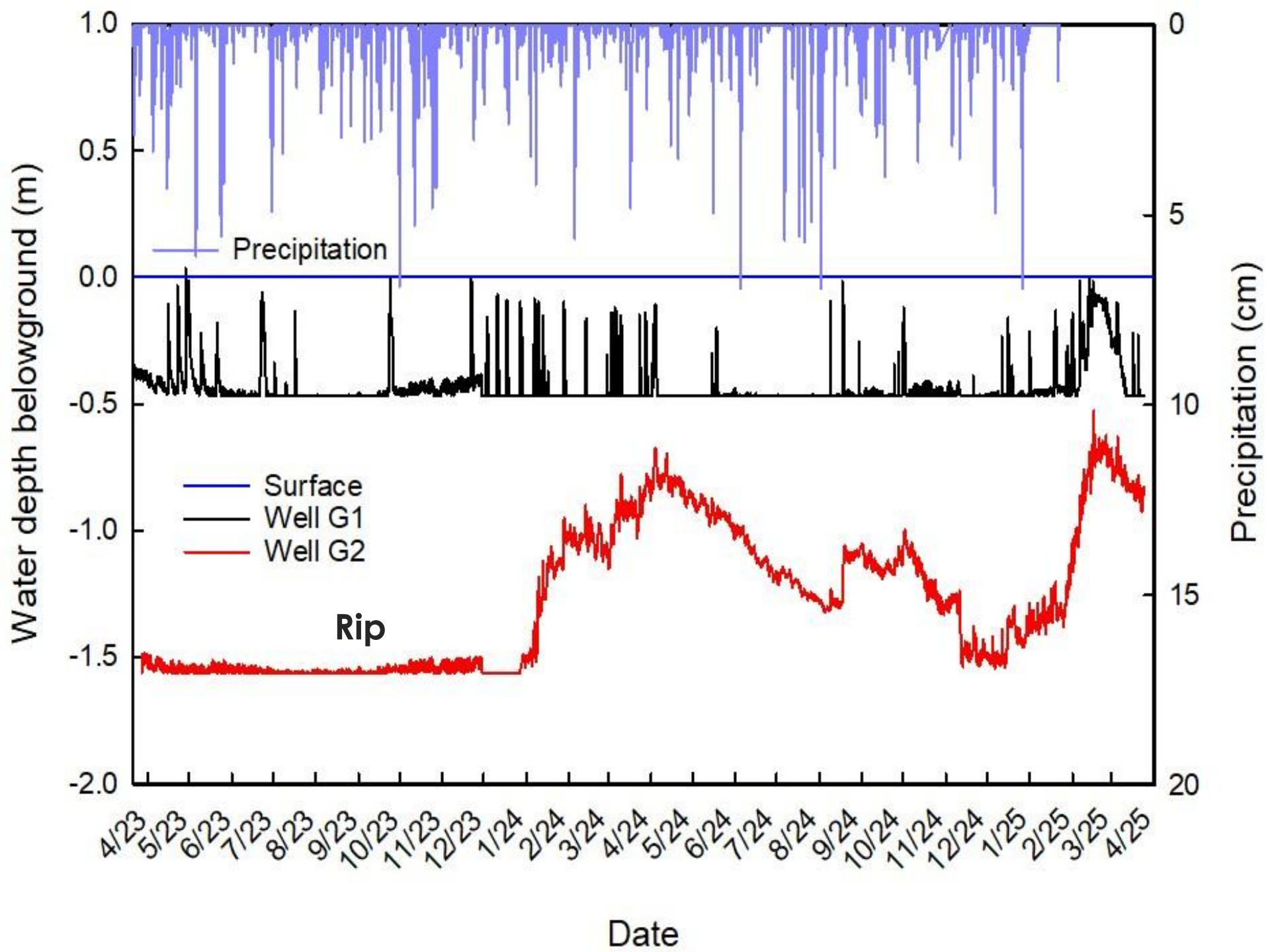
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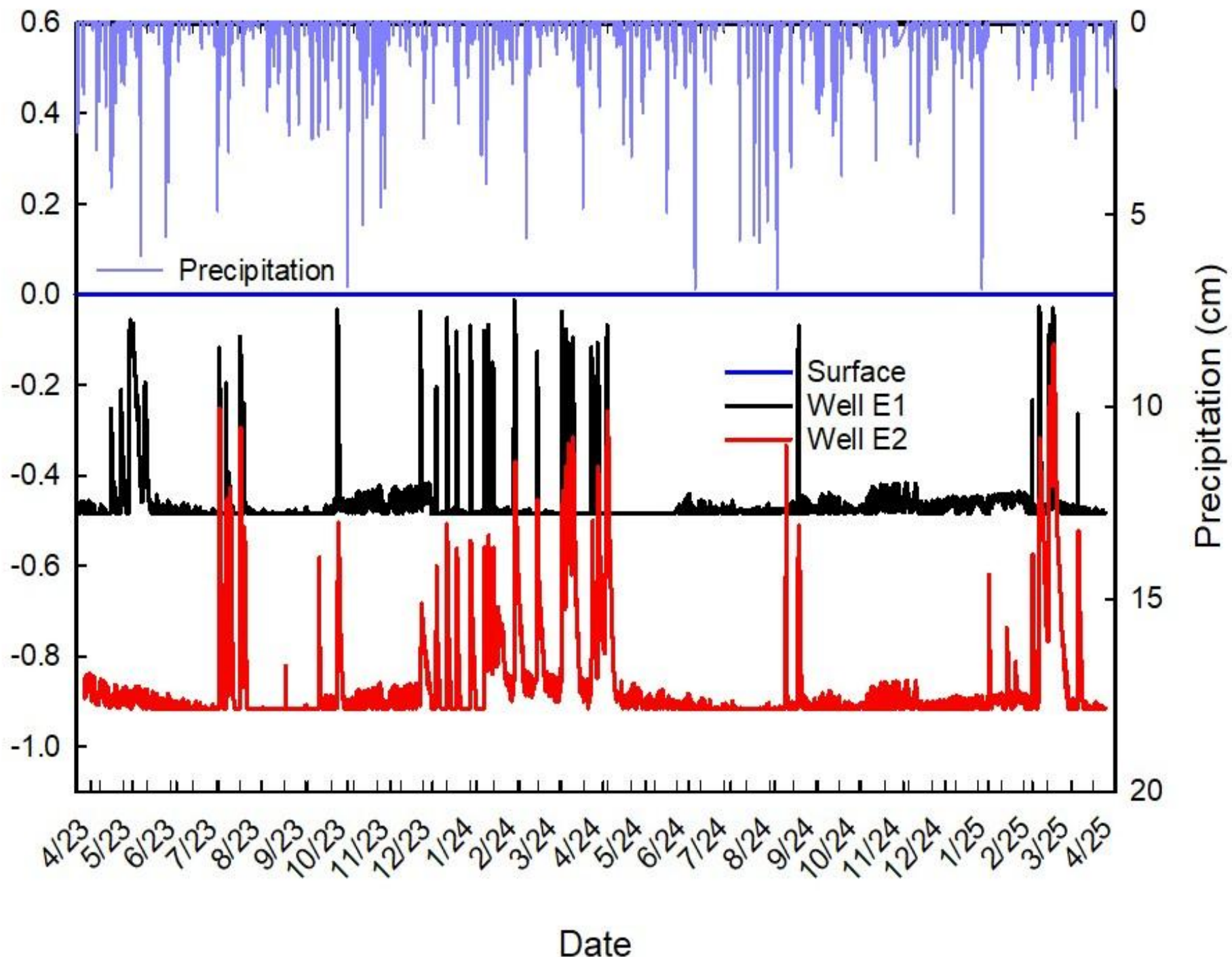
- ▶ **Late May 2024 vegetation on gentle slope near well E.**
- ▶ **Spring oats matured; good mix of fescue and orchardgrass. This area was released from bond (at landowner's request) in the fall of 2024 based on the stand quality.**

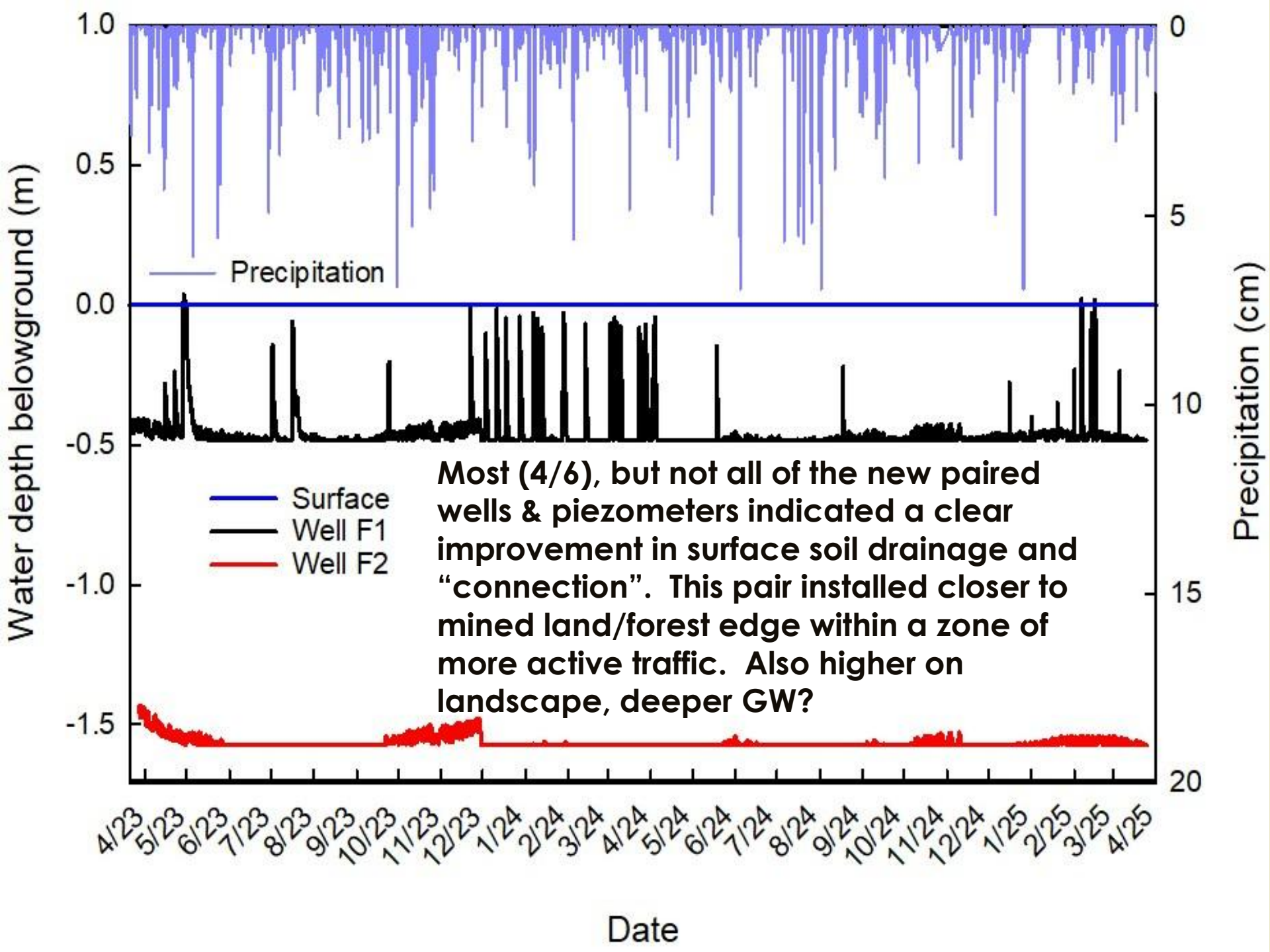
**View of Reclaim Area 2 in Spring of 2025. Tall fescue/clover stand was relatively weed free and well-established.**





Water depth belowground (m)





# Summary Points

- ▶ **The primary key to successful reclamation of S & G mines is the development of final landforms that are dominantly gently convex, with appropriate concave drainage conveyances.**
  - ▶ **Avoid large flat areas, long linear side slopes, and isolated upland areas that cannot readily drain.**
- ▶ **Surface and subsoil compaction is the major productivity limiting factor in mine soils and needs remediation before (or during) final amendment and seeding.**
- ▶ **We continue to recommend the utilization of biosolids at appropriate rates ( $\leq 35$  DT/Ac; 78 Mg/ha) on mining sites with deep incorporation to enhance organic matter & aggregation, N+P fertility, etc.**

# Summary Points

- **Deep ripping protocols combined with incorporation of biosolids into the topsoil, can greatly improve infiltration, limit runoff, and return soil hydrology to a more “connected system” with underlying groundwater.**
- **While not monitored specifically at this site, we have not noted any water quality degradation (turbidity, algae, etc.) in the large pond that was downhill from the reclaim areas.**
- **Removal/return of topsoil to mining sites is unquestionably a “best practice” but also generates complications including (a) additional compaction/smearing, (b) weed pressures, and (c) surface crusting if not quickly revegetated.**
- **Deep ripping is most effective with moderate soil moisture and this doesn’t always work well with typical mine closure plans.**

# Lessons Learned

- ▶ Integrating final mine closure and revegetation regulatory objectives with quick conversion to productive agriculture was “complicated” at this site. In particular, the long time gap between topsoil return and final permanent seeding led to significant weed issues
- ▶ Return of prime farmlands to 100% pre-mining productivity is not a reasonable expectation. 75 to 85% productivity is achievable, but only where we take care of basic landform/compaction issues
- ▶ Subsoil grading, topsoil return, ripping, soil amendments and final seeding must be carefully coordinated and timed. The weather will seldom cooperate....
- ▶ Without that correct timing/coordination you can count on weeds, surface soil wetness, and numerous other factors to greatly complicate your plans!



# Thank you!

## **Funding:**

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