Evaluation of Co-Product Bentonite Drilling Mud as a Soil Amendment

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Problem Statement

Oil and gas industry is rapidly expanding in West Virginia and neighboring Appalachian states (Fig. 1). This unprecedented increase in oil and gas production leads to a corresponding increase in the installation of gathering, transmission, and distribution pipelines. Horizontal directional drilling (HDD; Fig. 2) enables installation of underground pipeline without the need for open-cut trenches and disturbance of ecologically sensitive areas (streams, wetlands) and to avoid disrupting commerce on heavily used infrastructure (highways, airports, rail line). HDD operations uses large volumes of water-based sodium-bentonite slurry, resulting in generation of large amounts of spent mud in need of proper disposal. Federal and several states regulatory agencies recognized the spent mud as 'co-product' suitable for land applications. As HDD operators are attempting to contract with local farmers and landowners to apply the spent mud on their farmlands, the latter's seeking guidance from federal and state conservation agencies for best management practices for its use as a soil amendment. Yet, little is known about the effect of spent bentonite on soil quality and productivity. High salinity and elevated levels of sodium, and high levels of smectite clay minerals, as well as the potential of introduction of contaminants such as heavy metals can adversely affect soil physical, chemical, and hydrological properties. West Virginia State University is working with Pennsylvania and West Virginia NRCS to evaluate the spent material, its effect on soil quality, and to develop recommendation and best management practices for its use as a soil amendment.

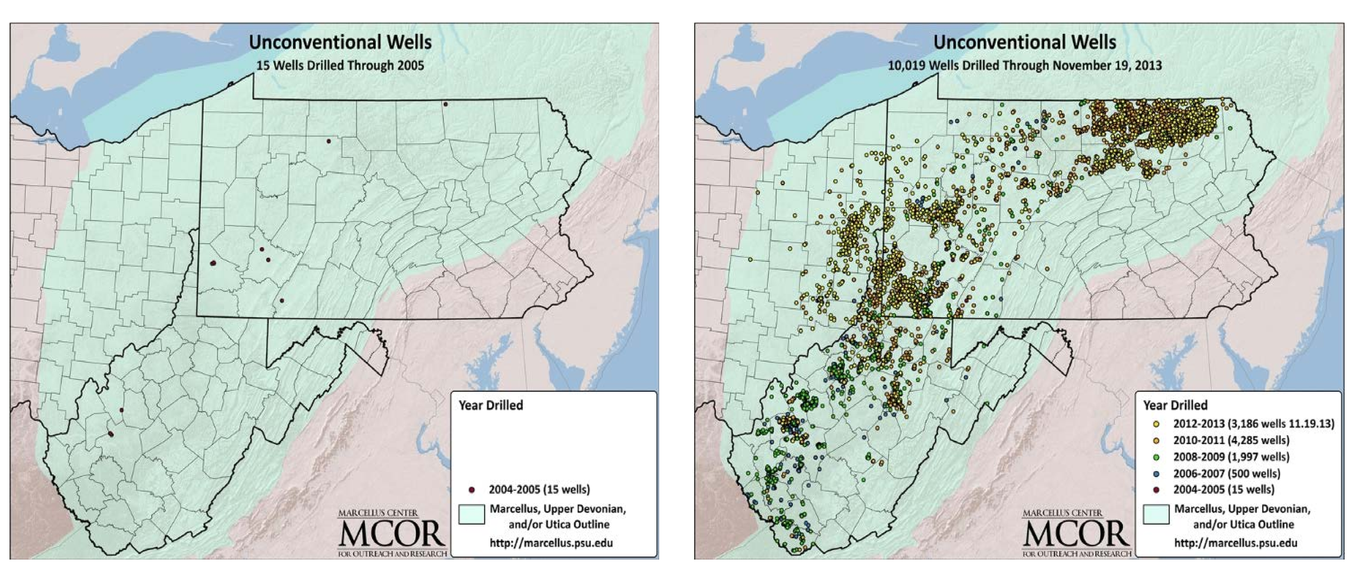

Figure 1. Increase in Shale wells drilled in Pennsylvania, Ohio, and West Virginia from 2004 to November 2013 (MCOR, http://www.marcellus.psu.edu/resources/maps.php)

Objectives and Approaches

Field and lab studies conducted to, i. characterize HDD mud properties, ii. asses the effect of spent HDD mud on soil quality and soil productivity, and iii. develop recommendations for the use of the mud as soil amendment. Mud was collected from 38 different HDD operators, locations, or stages. The mud was analyzed for properties of agronomic relevance such as pH, EC, metal content, water soluble ions, Mehlich-3 (M-3) and DTPA extractable elements, mineralogy, particle size distribution, solids content, etc. Field plots were established during the fall of 2014 at ten different locations, representing different soil types (Fig. 3). Identical treatments were established at each site, including 4 mud application rates equivalent to: 0 (control), 2.5, 5.0, and 10 Mg ha^{-1} (dry weight basis). Each treatment replicated 5 times, plots arranged in randomized complete block design. Spent HDD mud (from pullback stage) was used. Mud was applied using Turbo Turf HS-150 Hydro-seeding system followed by disking and seeding with a cover crop. Fields will be managed according to landowner plan at each site. The different sites will be tested annually for soil moisture and infiltration. Yield will be determined and plant and soil sample collected for lab analysis (e.g. nutrient content, organic matter content, CEC, pH, EC, ESP). Undisturbed core samples will be used to determine changes in saturated hydraulic conductivity, soil water content at field capacity and at saturation, bulk density, microbial activity, etc. Input from lab and field studies will be used to develop soil suitability rating and specific recommendations for use of spent HDD mud as a soil amendment.

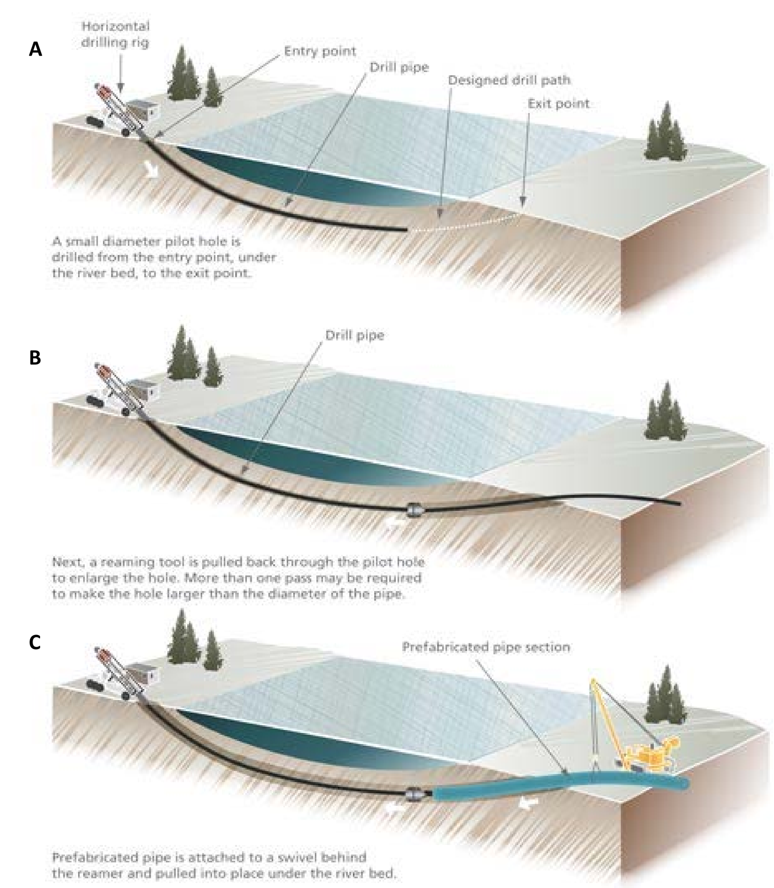

Figure 2. Stages of horizontal directional drilling: A. pilot hole – creating the borehole using small diameter steerable drill string; B. reaming – enlarging the borehole with a reamer, and C. pullback – pulling product pipe into borehole (https://www.neb-one.gc.ca/index-eng.html)

Table 1. Chloride, pH, and acid-extractable element content in bentonite and clean-mud at different HDD stages.

HDD Stage	pH	Cl⁻#	As	Cd	Cu	Co	Cr	Mo	Ni	Pb	Se	Zn
		µg g^{-1}										
Bentonite*	9.6 ± 0.6	6081 ± 140	ND**	ND	16 ± 20	25 ± 27	83 ± 60	ND	17 ± 15	35 ± 24	ND	75 ± 2
Pilot hole	8.8 ± 0.5	-ǂ	ND	ND	34 ± 4	39 ± 2	178 ± 10	ND	74 ± 8	32 ± 5	ND	102 ± 14
Reaming	8.9 ± 0.6	391 ± 84	ND	ND	34 ± 12	36 ± 8	145 ± 35	ND	57 ± 17	26 ± 6	ND	75 ± 18
Pullback	8.8 ± 0.3	44 ± 4.3	ND	ND	40 ± 14	42 ± 8	174 ± 32	ND	71 ± 13	26 ± 4	ND	92 ± 17
MDL***			21	1.1				3.2			30	
EPA limit##			41	39	1,500		1,200		420	300	36	2,800

* Bentonite powder; ** not detected; ***Method Detection Limit; ǂ not analyzed; in 1:10 soil : water extraction; from Clean Water Act title 40 CFR 503 Table 3.

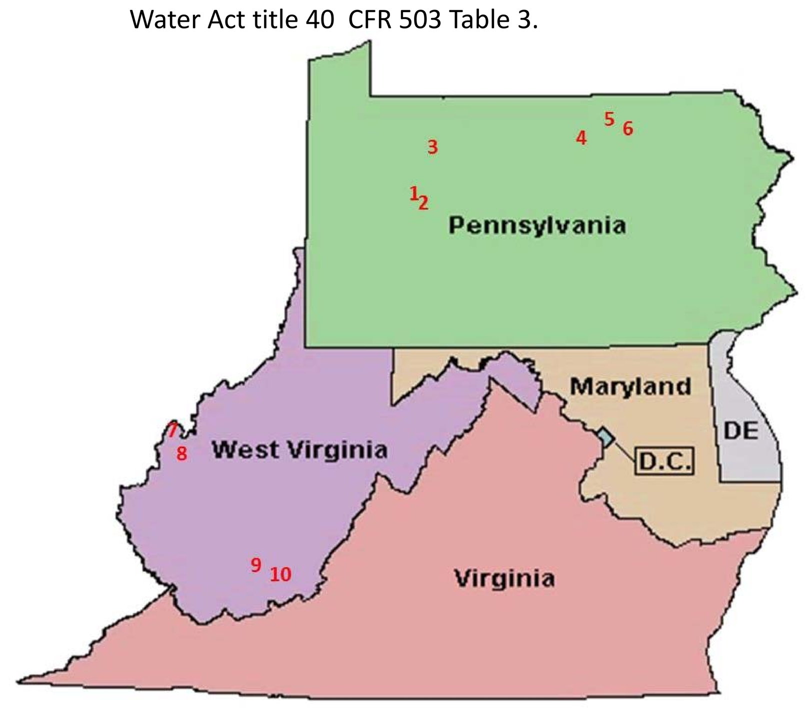

Figure 3. Experimental sites location and soil series: 1- Ernest; 2 - Gilpin; 3 - Sewell; 4 – mine site; 5 - Mardin; 6 - Wyoming; 7 – Lakin; 8 – Huntington; 9 – Kanawha; 10 – Cookport

Initial Results

While some elements behave rather conservatively during HDD operation (e.g. Al, Fe), the concentration of M-3 extractable-sodium decreased from 1.2% in the bentonite powder down to 767 ± 101 µg g^{-1} in the 'clean mud' and 530 ± 69 µg g^{-1} in the 'mud pit' during the pullback stage (Fig. 4). Similarly, water soluble Cl$^-$ decreased from 6,081 µ g^{-1} in the bentonite powder, to less than 400 µg g^{-1} during the reaming stage, down to 44 ± 2 µg g^{-1} in the pullback stage (all normalized to dry weight basis). Element concentration in 'clean mud' (i.e. mud collected after reclaiming of the mud; i.e. pass through ca. 0.075mm sieve membrane) was consistently higher than in mud pit (i.e. prior to reclaimer – including cuttings). This is likely due to a dilution effect by the larger, somewhat inert cuttings that are present in the mud pit but are removed as the mud is circled through the reclaimer, prior to being re-injected into the drilling pipe/string. While the spent mud was enriched in total content of several elements during HDD (Fig. 5) total concentration of toxic and heavy metals (As, Cd, Cu, Co, Cr, Mo, Ni, Pb, Se, Zn) were below detection limit or well below threshold concentration limits used by EPA for land application of 'Exceptional Quality' sewage sludge (Clean Water Act title 40 CFR 503 table 3; used as reference for allowable concentration in soil amended waste material; Table 1).

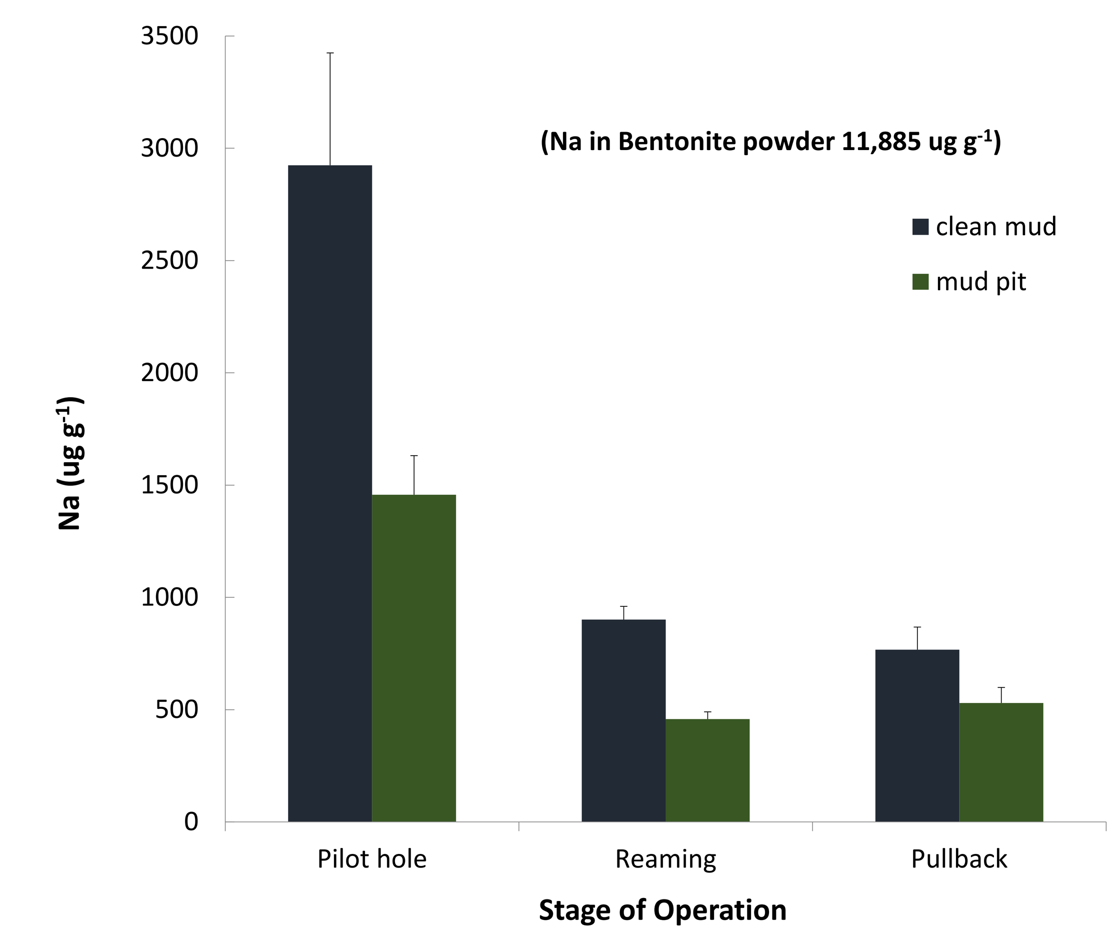

Figure 4. Changes in Mehlich-3 extractable sodium during HDD operation. 'Mud pit' - mud flow back, a mixture of cuttings and bentonite mud; 'clean mud' – mud collected after reclaiming of the bentonite mud (material ca <0.075mm). Pilot hole, reaming, and pullback are initial, middle, and final stages in HDD operations, all respectively.

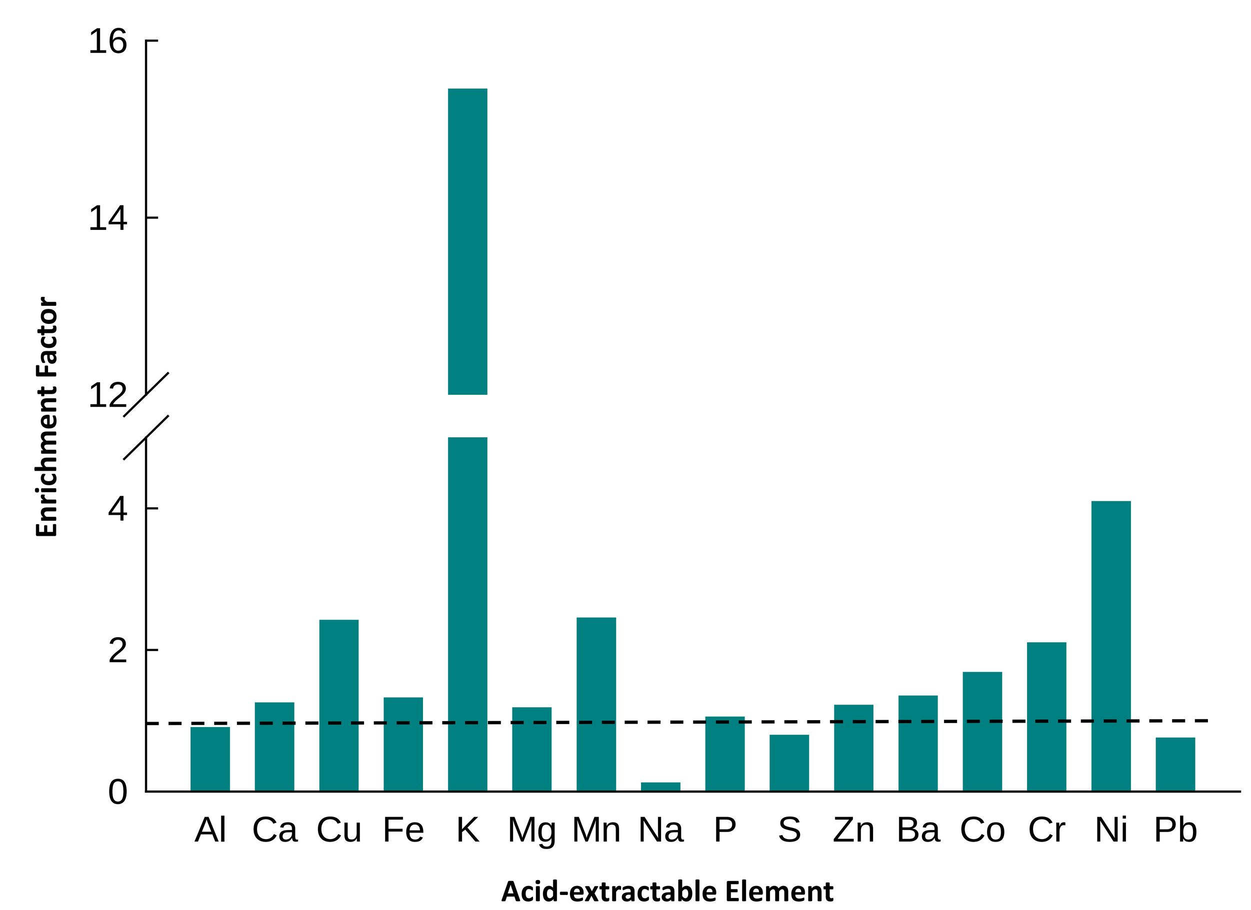

Figure 5. Total element enrichment factor during HDD operation taken as the ratio between the element content in the clean-mud at pullback stage divided by its content in bentonite powder (all normalized on dry-weight basis). The horizontal dissected line represents enrichment factor of 1 - values below the line represent element depletion whereas values above the line represent element enrichment.

Summary of Preliminary Findings

Initial findings suggest that inasmuch as Na-bentonite is used in HDD, both Na and Cl are depleted during the process to levels where salinity or sodicity are likely to be of minor concern. This is especially true when using the mud to amend soils in temperate zones (where precipitation exceeds evapotranspiration and further accumulation of Na or Cl is unlikely). Moreover, mud toxic material and heavy metal content is low and when enrichment occurs during HDD, concentrations remain well below accepted values for land application. Hence, spent mud effects on soil physical and hydrological properties is likely to be the primary limitation for its use as a soil amendment to Appalachian Region soils - to be further evaluated in field, lab, and greenhouse studies.