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Improving Hydric Soil Identification in Areas Containing Problematic Red Parent Materials: a Nationwide Collaborative Mapping Approach

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Abstract

Hydric soil identification utilizes diagnostic morphologic features, including iron transformations, resulting from anaerobic conditions. However, soils derived from some red parent materials (RPM) fail to develop characteristic hydric soils morphologies, confounding hydric soil and wetland delineation. Laboratory and field methods addressing resistant RPM soils exist, but application remains limited by uncertainty regarding problematic RPM distribution. In response, a collaborative effort (>50 participants) documented problematic RPM distribution across the contiguous United States. Specifically, >1100 samples from >450 locations underwent laboratory analysis using the Color Change Propensity Index to identify problematic RPM soils. Geospatial analysis linked verified problematic soils with associated geologic units and soil series, generating maps of RPM distribution. Potential problematic RPM was identified in the Northeast and Mid-Atlantic, Great Lakes, South-central, and Desert Southwest-Western Mountains (problematic RPM regions herein), encompassing diverse groups of soils and parent materials. Despite the observed variability in soil characteristics, results suggest that problematic RPM was consistently derived from sedimentary, hematite-rich red bed formations developed where deposition of terrestrial sediments occurred in near-shore, marginal-marine environments. Understanding problematic RPM soils distribution promotes the appropriate application of existing hydric soil field indicators, including F21 – Red Parent Material, thus improving approaches to hydric soil identification and wetland management.

Keywords Hydric soil · Red parent material · Wetland delineation · Sedimentary red beds

Introduction

Hydric Soil Morphology and Problematic Hydric Soils

The United States Army Corps of Engineers (USACE) wetland delineation manual and associated regional supplements provide technical guidance and procedures for identifying and delineating wetlands (Environmental Laboratory 1987; Wakeley 2002). Accordingly, identification and delineation of wetlands utilizes a three-factor approach encompassing indicators of wetland hydrology (e.g., near surface, seasonally high water tables), hydrophytic vegetation (water-loving plants), and hydric soils. In general, each of these factors are identified using readily applicable field indicators (Environmnetal Laboratory 1987; Berkowitz 2011a; USACE 2012; Tiner 2016).

Hydric soils are defined as "soils that have formed under conditions of saturation, flooding, or ponding long enough during the growing season to develop anaerobic conditions in the upper part" (Federal Register 1994). These periods of saturation, when combined with soil-microbial activity and the depletion of oxygen, promote biogeochemical processes that result in morphological features particularly useful for wetland identification during both wet and dry periods (Craft 2000; USDA-NRCS 2017). Common hydric soil morphologic features include: 1) the accumulation of organic matter from reduced rates of microbial decomposition under anaerobic conditions; and 2) the reduction and dissolution of ferric iron

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followed by subsequent translocation and depletion of ferrous iron phases (Reddy and DeLaune 2008). In particular, these iron reaction processes result in the formation of redoximorphic features that account for the prevalence of low chroma, Fe-depleted matrix colors associated with many mineral wetland soils (Vasilas and Berkowitz 2016; Rabenhorst 2011). The characteristic morphologies associated with prolonged saturation and aerobic conditions form the basis of field indicators of hydric soils, providing rapid and reliable approaches to identifying hydric soils utilized as part of wetland delineation procedures (USDA-NRCS 2017; Berkowitz 2011b).

In some cases, however, wetland areas exhibit the presence of hydrophytic vegetation and wetland hydrology, yet lack typical hydric soil morphological features due to natural conditions (Environmental Laboratory 1987). These soils are called "problematic hydric soils" (Vepraskas and Sprecher 1997; Robinette et al. 2011). Common examples of problematic hydric soils include: soils with low iron and/or organic matter contents that preclude the formation of redoximorphic features, high alkalinity soils that inhibit iron transformations, and recently deposited soil materials that simply have not been in place long enough to develop characteristic hydromorphic properties (USACE 2012; Tiner 2016). Additionally, some problematic soils result from factors related to parent material characteristics. For example, soils derived from dark parent materials (e.g. black coal deposits) mask morphological patterns associated with soil wetness (Stolt et al. 2001; U.S. Army Corps of Engineers 2012). These problematic soils led to the development and use of several field indicators of hydric soils specifically addressing a particular phenomenon or landscape position (e.g., F19 - Piedmont Flood Plain Soils; S11 – High Chroma Sands; Berkowitz and Sallee 2011; USDA-NRCS 2017).

Problematic Red Parent Material Soils

It has long been recognized that soils derived from certain red-colored parent materials (RPM) fail to develop soil morphologies (i.e., Fe-depleted matrix colors) characteristic of most wetlands, even where prolonged soil saturation and anaerobic conditions occur (Mokma and Sprecher 1994). Wetland delineation practitioners identified RPM as one of the most common problematic soil situations, accounting for up to 20% of the difficult soil scenarios reported in a national dataset examining wetland evaluation procedures across the United States (Berkowitz 2011b). Guidance was developed as early as 1996 to aid in the identification of wetlands in soils derived from RPM, with additional strategies described in recently published regional supplements to the USACE wetland delineation manual (USACE 2012).

Previous and on-going research suggests that these problematic RPM soils exhibit resistance to color change due to mineralogical characteristics inherited from their parent materials (USDA-NRCS 2017), and therefore occur in association with particular geological formations. For example, Niroomand and Tedrow (1990) demonstrated that soils derived from red shales resisted color changes under both field and laboratory conditions compared with soils derived from the other formations within the same area of New Jersey. Red soils from stratigraphically-related formations in Maryland and Connecticut also lacked prominent redoximorphic features despite highly-reducing conditions observed during field studies (Elless et al. 1996; Rabenhorst 2011; Ford 2014). Similar findings were reported across a range of formation types and geographic locations including soil hydrosequences derived from red-colored lacustrine deposits in Michigan (Mokma and Sprecher 1994), clayey alluvial deposits derived from red beds in Louisiana (Rabenhorst and Parikh 2000), and glacio-lacustrine sediments in Minnesota and Wisconsin (Petersen et al. 1967; Wheeler et al. 1999).

While these case studies demonstrate that some red soils are problematic, the majority of red soils or soils derived from red-colored parent material readily form hydromorphic features under anaerobic conditions (Rabenhorst and Parikh 2000). For example, red soils derived from metabasaltic rocks high in ferromagnetic elements and soils derived from red-colored fluviodeltaic sands displayed no resistance to color change despite the presence of red colors indicative of parent materials with high iron content (Sirkin 1986; Schwertmann 1993). Further, red soils derived from metamorphic and paracrystalline rocks associated with the Congaree River floodplains in North and South Carolina also do not exhibit a resistance to color change, despite the predominance of colors often 5YR or redder (USDA-NRCS 2017).

To explore the issue of color change resistance in red soils, Rabenhorst and Parikh (2000) developed a laboratory approach that distinguishes between red soils that were problematic (i.e. resistant to color change) and those that displayed color change propensity. In their study, red soils (both suspected problematic RPM and non-problematic RPM) were collected and treated with a sodium dithionite reducing agent in various treatments of differing periods of time and temperatures. Following treatments, digital colorimeter measurements documented shifts in Munsell color components (hue, value, chroma). Based on observed color changes, an equation quantifying the inherent capacity of the soils to form redoximorphic features (i.e. change color) under reducing conditions was developed; entitled the Color Change Propensity Index (CCPI). The CCPI groups soils into three categories: 1) non-problematic RPM soils displaying no color change resistance (CCPI values >40); 2) problematic RPM soils that resisted color change under reducing conditions (CCPI <30); and 3) an intermediate range with CCPI values in which soils displayed limited color change resistance representing a group of potentially problematic RPM (CCPI = 30–40). The CCPI provided a procedure for quantitatively identifying problematic RPM, contributing to the development of a field indicator of hydric soils to help improve wetland delineation approaches in areas containing RPM.

Development of F21 Red Parent Material

In order to address hydric soil delineation challenges associated with problematic RPM soils, a field indicator of hydric soils was developed for use in areas containing RPM (F21 - Red Parent Material). The F21 - Red Parent Material hydric soil field indicator requires (USDA-NRCS 2017):

A layer derived from red parent materials that is at least 10 cm (4 in.) thick, starting at a depth ≤ 25 cm (10 in.) from the soil surface with a [Munsell] hue of 7.5YR or redder. The matrix has a value and chroma greater than 2 and less than or equal to 4. The layer must contain 10% or more depletions and/or distinct or prominent concentrations occurring a soft masses or pore linings. Redox depletions should differ in color by having:

a. a minimum difference of one value higher and one chroma lower than the matrix, or
b. value of 4 or more and chroma of 2 or less.

The F21 - Red Parent Material hydric soil field indicator is approved for use in portions of the mid-Atlantic, New England, and Appalachian mountains including Major Land Resource Area (MLRA) 127 of Land Resource Region (LRR) N, MLRA 145 of LRR R, and MLRAs 147 and 148 of LRR S. Notably, the indicator has also been approved for testing across the United States in all soils derived from RPM (USDA-NRCS 2017). As a result, the F21 – RPM indicator can be applied in any soil identified as containing problematic RPM. To that end the F21 - Red Parent Material hydric soil field indicator user notes incorporate the CCPI concept, limiting application to soils in which problematic RPM (i.e., CCPI <30) has been documented using laboratory testing. Additionally, current guidance highlights examples of derivative problematic RPM soils (e.g., residuum in the Piedmont Province Triassic lowlands, Paleozoic red beds of the Appalachian Mountains) promoting application within those areas.

Despite the advances in laboratory techniques and field indicator development related to problematic RPM, several obstacles continue to restrain utilization of F21 - Red Parent Material. First, field practitioners report limited experience and comfort differentiating between problematic RPM and other red soils. Second, prior to the current study, CCPI analysis was utilized on a case by case basis, precluding development large scale problematic RPM mapping. As a result, current guidance lacks a comprehensive list of confirmed problematic RPM locations throughout the country. For these reasons, field staff report a general reluctance to utilize F21 - Red Parent Material when making wetland determinations despite the persistence of problems related to RPM (Berkowitz 2011b).

In response, the USACE and the Pedology Research Laboratory at The University of Maryland, in cooperation with the United States Department of Agriculture – Natural Resources Conservation Service (USDA-NRCS) and Kellogg Soil Survey Laboratory (KSSL), began a nationwide soil mapping project to identify areas containing problematic RPM in support of the application of F21 - Red Parent Material. Study objectives include: 1) evaluating soils suspected to be associated with problematic RPM using CCPI analysis across a wide variety of soil and geologic settings, 2) correlating CCPI results with soil/geologic map units using spatial datasets, and 3) developing national and regional guidance maps for recommended application of F21 - Red Parent Material to improve hydric soil (and therefore wetland) identification across the country. Select examples of the geologic origin of problematic RPM are also provided within each section along with guidance on the application of study results. A comprehensive report on the geology and soils related to problematic RPM is provided in Mack (2018).

Methods

A national effort was coordinated between soil and wetland scientists from federal agencies, state/local agencies, universities, and the private sector. Letters of invitation were sent to all USDA-NRCS MLRA regional offices and USACE district offices to solicit participation among scientists and/or field personnel familiar with the RPM phenomenon to participate in the project. A cooperative arrangement was also established with KSSL permitting access to archived soil samples and associated data. The project was further promoted at conferences organized by the Soil Science Society of America and the National Cooperative Soil Survey. These efforts resulted in the collection and/or volunteer submission of >1100 soil samples from the contiguous United States over a 1.5 year period. Supplemental figures identify soil sampling and archival locations used to develop guidance maps.

All submitted soil samples were derived from geologic formations and/or parent material(s) potentially associated with problematic RPM. As a result, CCPI soils analysis could be correlated with geological data in the mapping phases of the project. Sampling included all red soils suspected of problematic RPM, irrespective of the presence of wetland conditions or field indicators of hydric soils (including F21 – Red Parent Material). This approach utilized the local knowledge of field professionals to obtain a broad representation of soils, as well as attempting to capture all possible inclusions of hydric soils that can occur in soil map units dominated by well drained soils to map the entire possible extent of problematic RPM. Based on the reports of potential RPM soils and their parent materials from participating scientists, additional soils were requested for analyses from the KSSL.

Project participants provided a 500 cm^3 sample from each horizon to a depth of 1 m to reflect properties of the entire soil profile and/or the soil's parent materials to the extent possible. Basic soil descriptions, containing horizon names, depths, colors, field textures, and the presence, contrast, and abundance of any redoximorphic features, were requested to accompany samples as described in Vasilas and Berkowitz (2016). Finally, site location (GPS coordinate), soil series, and any geological context (e.g., formation name, time period, rock type, etc.) were also requested.

All CCPI analyses followed methods outlined in Rabenhorst and Parikh (2000). Soils were dried, crushed, and sieved using a 2 mm (#10) sieve. Two to three horizons (one from the surface, subsurface, and deeper subsurface) from each profile underwent CCPI analyses. Soil colors were measured using a Konica-Minolta digital colorimeter, with Munsell hue, value, and chroma recorded to the 0.1 unit. Soil color was measured on each sample under three different conditions: 1) after saturation with citrate buffer solution; 2) after treatment with citrate buffer solution and sodium dithionite at room temperature (25 °C) for 1 h; and 3) after treatment with citrate buffer solution and sodium dithionite at 80 °C for 4 h. Based on measured color data, a CCPI value was calculated for each sample to document if the soil was problematic RPM, non-problematic, or potentially problematic as described above. The mean CCPI value for all horizons samples was used to assign a single designation to each sample location. Some soils in which problematic RPM was positively identified (24 of >450 pedons) displayed CCPI results that differed by horizon; utilizing the mean value for each pedon may represent a potential limitation of this approach. Statistical testing evaluating difference in CCPI values between problematic, non-problematic, and potentially problematic RPM soils utilized one-way analysis of variance (ANOVA; $\alpha = 0.05$) following testing for normality (Shapiro Wilk test) and homogeneity of variance (Levene's test; SPSS IBM, Inc. Version 20).

Following CCPI analysis, problematic RPM samples were linked with associated soil series and/or geologic formations using USDA-NRCS Official Series Descriptions (OSDs), Block Diagrams, Series Extent Maps, other available resources, as well as local knowledge from project participants. Specifically, a list of soil series associated with problematic RPM was generated using the following criteria: series with direct CCPI verification, published literature documenting problematic RPM, the OSD indicated geographic association with a CCPI verified series, or the soil series was derived from a USDA-NRCS Block Diagram composed of CCPI verified materials. Notably, feedback from experienced soil scientists familiar with the local distribution of problematic RPM was utilized to further refine the series list. Following the generation of the problematic RPM soil series lists, series names were joined to both the USDA-NRCS Digital Gridded U.S. General Soil Map (gSTATSGO2) and Gridded Soil Survey Geographic (gSSURGO) map units as found in the component tables for the map unit records using ArcGIS 10.4 software.

Additionally, parent materials and geological units associated with problematic RPM soil series were identified for mapping. Similar to the soil series approach described above, submitted samples were linked with geological units (as members, formations, groups, etc.) verified as containing problematic RPM, or those lithologically-associated with verified problematic RPM units. A geological unit was added to the list when: the geological unit was the parent material of a soil series identified as problematic RPM using CCPI, previously published literature identified the geological unit as problematic RPM, the geological unit was identified in the OSD of a verified soil series using CCPI data, the geological unit was associated with a verified problematic RPM series using USDA-NRCS Block Diagram, or the geological unit was mapped and was substantially overlain by a problematic RPM soil map unit in both USDA-NRCS gSTATSGO and gSSURGO databases. The USGS Mineral Science Program's Integrated Geologic map database for the United States was also utilized to define geologic features. Geologic units identified as problematic RPM were mapped predominantly by formation name within the US Geological Survey's (USGS) "Preliminary Integrated Geologic Map Databases for the United States" using ArcGIS 10.4 software.

Individual soils map units were identified as problematic RPM if the map unit contained ≥5 % of a problematic RPM soil series, or corresponding geologic unit datasets suggested the presence of problematic RPM parent materials. As a result, national scale problematic RPM guidance maps represent the composite of both soils and geological information supported by CCPI analyses. Regional maps were also generated based on the locations of RPM occurrence across USDA-NRCS LRRs and MLRAs and USACE regional supplements. Draft problematic RPM maps were sent to affected USDA-NRCS MLRA offices and USACE district offices to solicit comment and feedback from field personnel familiar with local soil conditions. Following editing and comment response based upon user feedback, final guidance maps were generated for recommended application of field indicator F21 - Red Parent Material.

Results and Discussion

National Overview

More than 1100 individual soil samples, collected from >450 geographic locations within the contiguous United States, were analyzed for CCPI to investigate the spatial distribution of problematic RPM. Within the dataset, 51% of soils were characterized by CCPI values consistent with problematic RPM properties (i.e., color change resistance; CCPI <30), 19% displayed some resistance to color change (i.e., potential problematic RPM; CCPI 30–40), and 30% consisted of soils were identified as non-problematic RPM (CCPI >40). Where present, problematic RPM soils displayed mean CCPI (± standard deviation) of 19 ± 6.1, significantly lower ($p < 0.001$) than non-problematic soils (CCPI = 66 ± 35), and potentially problematic (CCPI = 36 ± 4.0) soils ($p < 0.001$) examined. Similar statistical differences were found in each problematic RPM region discussed below. As a result, approximately 745 soil series and associations linked with 270 geologic formations displayed CCPI values consistent with potential problematic RPM conditions. Problematic RPM soils were associated with a wide variety of parent materials, with residual (31%), alluvial (28%), and till (23%) sources most commonly observed. A variety of colluvial, lacustrine, erosional deposits and mixed parent materials also exhibited problematic RPM properties. Notably, despite the wide variety of parent materials observed, all samples identified as problematic RPM soils across the national dataset were associated with parent materials derived from red bed formations, as well as glacial, alluvial, and colluvial transported materials derived from red bed formations. Red beds include detrital, siliciclastic sedimentary rocks or sequences (e.g., conglomerates, sandstones, siltstones, shales) in which ≥60% of the total stratum displays red pigments resulting from ferric oxides, predominantly hematite. For more information on the characteristics, origins, or classification of red beds, see Krynine (1949); Van Houten (1973); Turner (1980); and Bigham et al. (1993).

Four problematic RPM regions have been identified where F21 - Red Parent Material application is recommended based on the occurrence of problematic RPM across various USACE regional supplement areas and USDA-NRCS LRRs (Fig. 1): Northeast and Mid-Atlantic, Great Lakes, South-Central, Desert Southwest and Western Mountains. The following section provides detailed maps and describes CCPI results within each of these four problematic RPM regions, yielding insight into the soil series and geologic formations identified, and problematic RPM locations within USACE regional supplements, USDA-NRCS LRRs and MLRAs. Tables provide lists of geologic features and soil series linked with problematic RPM. Guidance for the application of study results to identify hydric soils in areas containing problematic RPM is also discussed. Supplementary maps are also provided, displaying sampling locations within each region (Figs. S1-S5).

Northeast and Mid-Atlantic

Over 100 sample locations were analyzed for CCPI from the Northeast and Mid-Atlantic problematic RPM region confirming problematic RPM in two USACE regional supplement areas, five LRRs, and 14 MLRAs (Table 1; Fig. 2).

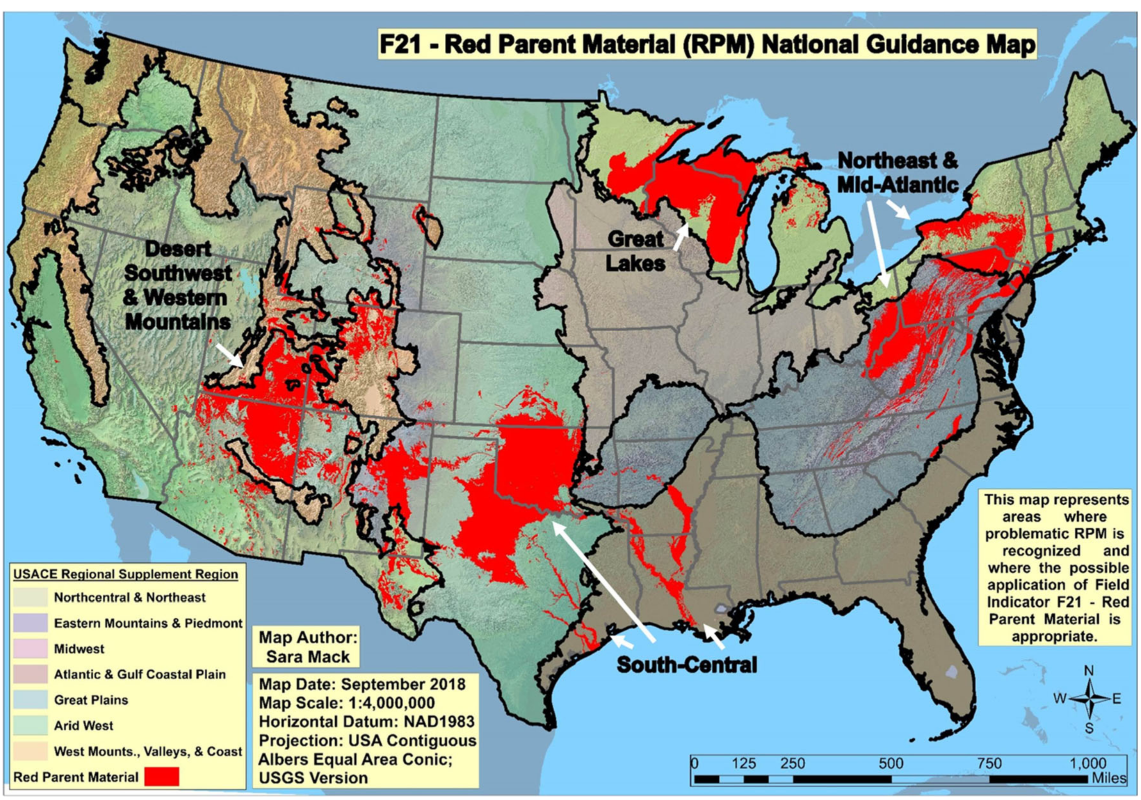

Fig. 1 National guidance map for recommended application of the F21 - Red Parent Material hydric soil field indicator in the United States. Red areas indicate locations with soils and geological formations where problematic RPM potentially occur

Table 1 USACE regional supplement areas, LRRs, and MLRAs within the Northeast and Mid-Atlantic RPM region where application of the F21 - Red Parent Material field indicator is recommended

USACE region	Land Resource region (LRR)	Major Land Resource Area (MLRA)
Northcentral and Northeast	L – Lake States Fruit, Truck Stop, and Dairy region	101 – Ontario-Erie and Finger Lakes
	R – Northeastern Forage and Forest Region	140 – Glaciated Allegheny Plateau
		142 – St. Lawrence-Champlain Plain
		144A – New England and Eastern New York Upland
		145 – Connecticut Valley
Eastern Mountains and Piedmont	N – East and Central Farming and Forest Region	124 – Western Allegheny Plateau
		125 – Cumberland Plateau
		126 – Central Allegheny Plateau
		127 – Eastern Appalachian Ridges and Valleys
		128 – Southern Appalachian Ridges and Valleys
		130A – Northern Blue Ridge
	P – South Atlantic and Gulf Slope Cash Crops, Forest, and Livestock Region	136 – Southern Piedmont
	S – Northern Atlantic Slope Diversified Farming Region	147 – Northern Appalachian Ridges and Valleys
		148 – Northern Piedmont

Within the Northeast and Mid-Atlantic 76 locations contained problematic RPM (mean CCPI ± standard deviation = 20 ± 5.9), 19 locations were non-problematic (CCPI = 50 ± 11) and 18 exhibited potential color change resistance (CCPI = 35 ± 4.2). Parent materials displaying problematic RPM were derived from till (31%), alluvium (26%), residuum (24%), with colluvial and mixed deposits also present. The Northeast and Mid-Atlantic encompasses considerable topographic, climatic, and geologic diversity, with problematic RPM stretching across portions of thirteen U.S. states.

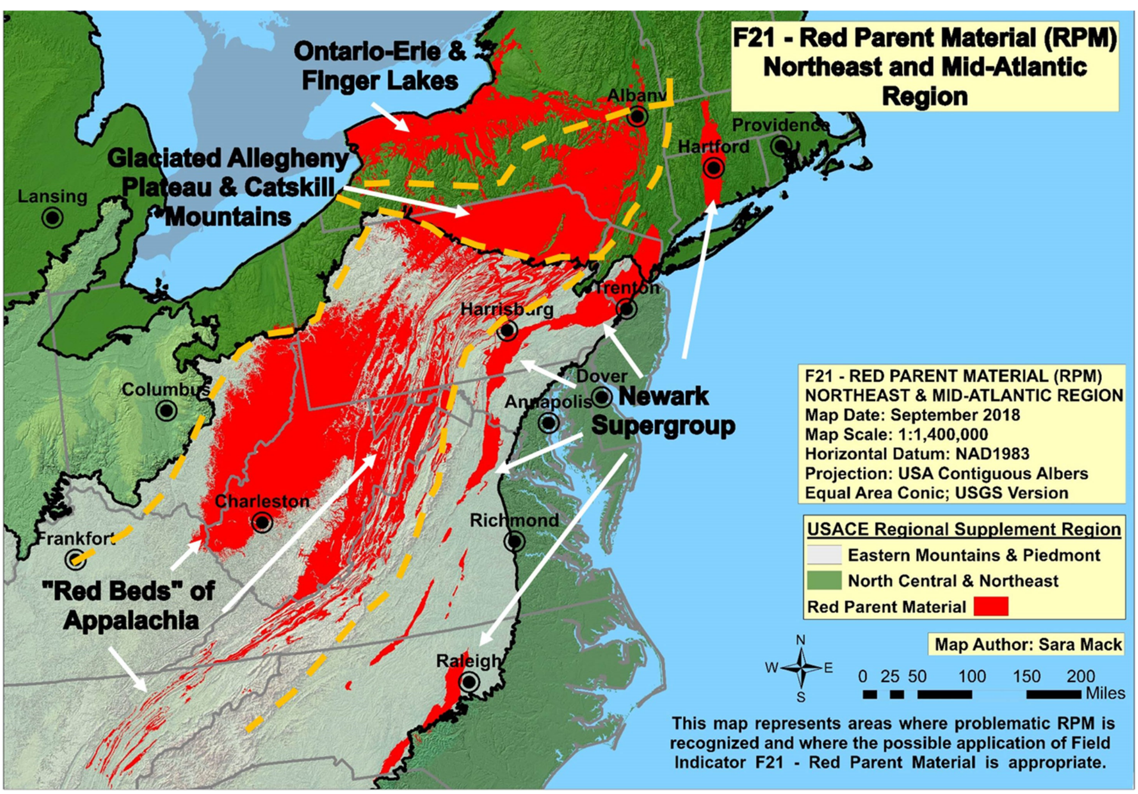

Fig. 2 Guidance map for recommended application of the F21 - Red Parent Material field indicator in the Northeast and Mid-Atlantic RPM region. Red areas indicate locations with soils and geological formations where problematic RPM potentially occur

Generally, the geology of the problematic RPM region is differentiated between northern (USACE Northcentral and Northeast regional supplement area) and southern (USACE Eastern Mountains and Piedmont regional supplement area) portions by the southernmost extent of Pleistocene glaciations (Mack 2018; USDA-NRCS 2006). Within the Northeast and Mid-Atlantic problematic RPM region, four distinctive groups (Fig. 2) of soils and parent materials have been identified including soils derived from: 1) Paleozoic-aged, sedimentary red beds of Appalachia; 2) glacial deposits of the Glaciated Allegheny Plateau and Catskill Mountains; 3) till and (glacio)lacustrine deposits of the Ontario-Erie Plain and Finger Lakes; and 4) sedimentary rocks of the Newark Supergroup. These areas are characterized by residual and glacial soils derived from dark, red shales, siltstones, and sandstones laid down in passive continental margins during the formation of the current Appalachian mountain system (i.e. the Paleozoic "Red Beds" of Appalachia; the Glaciated Allegheny Plateau and Catskill Mountains; and the Ontario-Erie Plain and Finger Lakes) and in low lying basins formed during the breakup of supercontinent Pangea (i.e. the Newark Supergroup). Specific soil series and geologic formations associated with each portion of the Northeast and Mid-Atlantic problematic RPM region are provided in Tables 2, 3, 4 and 5.

Great Lakes

A total of 218 soil samples from 78 sites were analyzed for CCPI from the Great Lakes problematic RPM region. Fifty-six locations contained problematic RPM (mean CCPI ± standard deviation = 21 ± 6.3), 7 locations were non-problematic (CCPI = 47 ± 5.3) and 15 exhibited potential color change resistance (CCPI = 35 ± 6.6). Soil materials in the Great Lakes problematic RPM region are most commonly derived from Pleistocene-aged, glacial deposits (>67%) that stretch across portions of three U.S. states that include portions of the Northcentral and Northeast regional supplement area and two LRRs (Table 6).

In general, the Great Lakes RPM region is characterized by dark red, Wisconsinan-aged glacial deposits distributed by the advance and retreat of glacial lobes of the Laurentide ice sheet. These glacial deposits originated from red sedimentary rocks of the Superior Basin and some possible Paleozoic/Mesozoic rocks of the Michigan basin. A full reporting of the Great Lakes geologic origin is beyond the scope of the current manuscript, which focuses on linking problematic RPM distribution with soil series data to improve approaches to hydric soil identification in red soils. However, a comprehensive discussion of geologic features associated with the Great Lakes problematic RPM region is provided in Mack (2018). To

Table 2 Geological formations and soil series identified as potential problematic RPM that are associated with the Paleozoic red beds of Appalachia

Geological Formation(s)		Soil Series	
Bloomsburg Formation	Foreknobs Formation	Albrights	Meckesville
Bloomsburg Red Beds	Glenshaw Formation	Alcoa	Moshannon
Bluefield Formation	Greenbriar Formation	Allenwood	Neubert
Bluestone Formation	Greenbriar Group	Basher	Peabody
Casselman Formation	Greene Formation	Belpre	Pipestem
Catskill Formation	Hampshire Formation	Birdsboro	Raritan
Beaverdam Run Member	Hinton Formation	Calvin	Red Hills
Berry Run Member	Holston Formation	Cateache	Senecaville
Clarks Ferry Member	Huntley Mountain Formation	Coghill	Sensabaugh
Duncannon Member	Juniata Formation	Corryton	Steekee
Irish Valley Member	Maccrady Shale	Craigsville	Summitville
Long Run Member	Maccrady Formation	Gallia	Tellico
Packerton Member	Mauch Chunk Formation	Hackers	Ungers
Poplar Gap Member	Mauch Chunk Group	Hustontown	Upshur
Sawmill Run Member	McKenzie Formation	Leck Kill	Vandalia
Sherman Creek Member	Monongahela Formation	Lehew	Vandergrift
Towamensing Member	Monongahela Group	Linden	Vincent
Walcksville Member	Pennington Formation	Kedron	Watson
Chemung Formation	Pennington Group	Klinesville	Woodsfield
Clinton Group	Rose Hill Formation	Madsheep	
Conemaugh Formation	Slide Mountain Formation		
Conemaugh Group	Washington Formation		
Dunkard Group	Waynesburg Formation		

Table 3 Geological formations and soil series identified as potential problematic RPM that are associated with the Glaciated Allegheny Plateau and the Catskill Mountains area

Geological Formation(s)	Soil Series	
Catskill Formation	Bash	Monguap
Beaverdam Run Member	Barbour	Morris
Berry Run Member	Basher	Norchip
Clarks Ferry Member	Cadosia	Norwich
Duncannon Member	Cheshire	Onteora
Irish Valley Member	Elka	Oquaga
Long Run Member	Halcott	Suny
Packerton Member	Hawksnest	Tor
Poplar Gap Member	Gretor	Trestle
Sawmill Run Member	Lackawanna	Tunkhannock
Sherman Creek Member	Lewbeach	Vly
Towamensing Member	Linden	Wellsboro
Walcksville Member	Maplecrest	Willowemoc
Slide Mountain Formation	Menlo	Wyoming

facilitate identification of problematic RPM, Fig. 3 as well as Tables 7, 8 and 9 link areas of verified problematic RPM soils with underlying geologic formations and soil series.

Areas containing problematic RPM are differentiated across the landscape based on their association with distinct tongues or lobes created during advances and retreats of the Laurentide ice sheets (Lusardi 1997). As a result, problematic RPM soils deposited by these glacial fronts, occur on a wide variety of glacial landforms (moraines, drumlins, outwash plains, lake beds). Three distinctive groups of problematic RPM soils and parent materials were identified in the Great Lakes, including soils derived from red glacial deposits associated with: the Superior Lobe; the Kewaunee formation; and the northern portion of the Michigan Basin (Fig. 3). A number of subordinate lobes further subdivide the area, with multiple episodes of glaciation complicating the geologic history of the area, with each glacial advance and retreat introducing new mixtures of materials including potentially problematic RPM across the landscape. As a result, the extent of potential problematic RPM in the Great Lakes (Fig. 3) must be linked with other factors prior to the identification of hydric soils (and wetlands). See the application discussion below for details on the recommended use of problematic RPM maps for additional guidance. Further, many areas exhibit problematic RPM at depths below a mantle of recently deposited soil materials that may or may not contain materials resistant to color change. The authors observed this during several field site visits in which the problematic RPM (and field indicator F21 – RPM) was encountered at depths ≥20 cm below the soil surface. Accumulations of organic materials (i.e. histic epipedons) or other non-problematic soils that rapidly develop redoximorphic features may also overlay problematic RPM deposits. In these cases, other field indicators of hydric soils may be useful in delineating hydric soils and associated wetland features.

Table 4 Geological formations and soil series identified as potential problematic RPM as associated with the Ontario-Erie Plain and Finger Lakes area

Geological Formation(s)	Soil Series	
Clinton Group	Alton	Lockport
Lockport Group	Appleton	Odessa
Medina Group	Barre	Ontario
Queenston Formation/Shale	Cayuga	Ovid
Rondout Formation	Cazenovia	Romulus
Salina Group	Churchville	Schoharie
Camillus Formation	Hilton	
Syracuse Formation	Lairdsville	
Vernon Formation	Lakemont	

South-Central

A total of 300 soil samples from 148 sites underwent CCPI from the South-Central problematic RPM region, resulting in identification of problematic RPM in 28 MLRAs across eight LRRs. Of those samples, 27% exhibited problematic RPM characteristics (CCPI = 26 ± 4.9), 29% displayed some color change resistance (CCPI = 36 ± 4.6), and 43% were non-problematic (CCPI = 58 ± 19). Where present, problematic RPM mostly occurred in soils derived from alluvial and residual parent materials.

Problematic RPM predominantly occurred within the USACE Great Plains and Atlantic and Gulf Coast Plain regional supplement areas, with small areas also found in the Midwest and the Eastern Mountains and Piedmont areas (Fig. 4; Table 10). Problematic RPM occurred across parts of central Texas, Oklahoma, and southern Kansas. Additionally, major rivers and tributary networks rivers transported problematic RPM materials into the alluvial valleys of Arkansas and Louisiana. The South Central problematic RPM region is characterized mostly by residual and alluvial soils derived from Permian-aged bedrock of the Great Plains (i.e. the Central Red Bed Plains), and recent alluvial deposits of the Red, Brazos, and other rivers in southern parts of the Coastal Plain physiographic province (i.e. Central Red Bed Plains Alluvium). Problematic RPMs in the South-Central group vary west to east as conditions shift from the drier, bedrock-controlled portions of the Great Plains to the wetter, thick alluvial deposits overlying the Coastal Plain.

Problematic RPM in the Great Plains typically occurs as Permian-aged, red bed formations found on gently rolling plains and prairies dissected by current and ancient stream terraces in the north, and more eroded plateau areas with

Table 5 Geological formations and soil series identified as potential problematic RPM that are associated with basins of the Newark Supergroup

Basin(s)	Geological Formation(s)	Soil Series	
Harford, Deerfield, Northfield	East Berlin Formation	Bash	Ludlow
	Mount Toby Formation	Berlin	Manchester
	New Haven Arkose	Branford	Menlo
	Portland Arkose	Brownsburg	Penwood
	Shuttle Meadow Formation	Cheshire	Watchaug
	Sugarloaf Formation	Ellington	Wethersfield
	Turner Falls Sandstone	Harford	Wilbraham
		Holyoke	Yalesville
Newark	Boonton Formation	Abbottstown	Knauers
	Brunswick Formation	Arendtsville	Lamington
	Feltville Formation	Athol	Lansdale
	Hammer Creek Formation	Bermudian	Landsdowne
	Lockatong Formation	Birdsboro	Lawrenceville
	Passaic Formation	Boonton	Lewisberry
	Raritan Formation	Bowmansville	Lucketts
	Stockton Formation	Brecknock	Morven
	Towaco Formation	Bucks	Nixon
Gettysburg	Gettyburg Conglomerate	Buckingham	Norton
	Gettysburg Formation	Chalfont	Pascask
	Heidlersburg Member	Croton	Penn
	Gettysburg Shale	Doylestown	Quakertown
	Hammer Creek Conglomerate	Dunellen	Raritan
	Hammer Creek Formation	Exway	Readington
	New Oxford Conglomerate	Greenbelt	Reaville
	New Oxford Formation	Haledon	Rowland
		Joanna	Springwood
		Klinesville	
Culpeper, Barboursville, Scottsville	Newark Supergroup – conglomerates, sandstones, siltstones, shales, mudstones	Aden	Leedsville
		Albano	Manassas
		Arcola	Nestoria
		Ashburn	Oatlands
		Brentsville	Ott
		Calverton	Panorama
		Catlett	Rapidan
		Clover	Sudley
		Dulles	Sycoline
		Kelly	Totier
Crowburg, Wadesboro, Ellerbe, Sanford, Durham, Davie County, Dan River, Danville, Scottsburg, Randolph, Roanoke Creek, Briery Creek, Farmville	Chatham Group	Ayersville	Meadows
	Cow Branch Formation	Belews Lake	Mooshaunee
	Cumnock Formation	Brickhaven	Peakin
	Dan River Group	Carbonton	Pinkston
	Pekin Formation	Claycreek	Pinoka
	Pine Hall Formation	Creedmoor	Polkton
	Sanford Formation	Easthamlet	Sheva
	Stoneville Formation	Granville	Spray
		Hallison	Stoneville
		Hasbrouck	Straightstone
		Hornsboro	Wadesboro
		Lackstown	Warminster
		Leaksville	White Store
		Mayodan	Wolftrap

deeply entrenched streams and rivers in the south. The RPM soils in these areas are often shallow, overlying the red-colored bedrock. In the Atlantic Gulf Coast Plain, RPM soils are derived from red-colored alluvial deposits of major river systems that drain the Permian red beds described above. These alluvial soils occur on terraces, floodplains, lowlands, and deltas along major river systems. Minor RPM areas are also possible in small portions of the USACE Midwest and Eastern Mountains regional supplement areas, where RPM is associated with river systems transporting problematic RPM materials.

Although problematic RPM and their associated soils are extensive in the portions of the South Central United States, much of the area exhibits an ustic soil moisture regime, limiting the extent of hydric soils. Nevertheless, Permian red beds provide the source rocks of RPM soils stretching across several states through alluvial transport. As a result, the F21 –

Table 6 USACE regional supplement areas, LRRs, and MLRAs within the Great Lakes RPM region where application of the F21 - Red Parent Material hydric soil field indicator is recommended

USACE region	Land Resource Region (LRR)	Major Land Resource Area (MLRA)
Northcentral and Northeast	K – Northern Lake States Forest and Forage Region	57 – Northern Minnesota Gray Drift
		88 - Northern Minnesota Glacial Lake Basins
		89 – Wisconsin Central Sands
		90A – Wisconsin and Minnesota Thin Loess and Till, Northern Part
		90B - Wisconsin and Minnesota Thin Loess and Till, Southern Part
		91A – Central Minnesota Sandy Outwash
		91B – Wisconsin and Minnesota Sandy Outwash
		92 – Superior Lake Plain
		93A – Superior Stony and Rocky Loamy Plains and Hills, Western Part
		93B - Superior Stony and Rocky Loamy Plains and Hills, Eastern Part
		94A – Northern Michigan and Wisconsin Sandy Drift
		94B – Michigan Eastern Upper Peninsula Sandy Drift
		94C – Michigan Northern Lower Peninsula Sandy Drift
		94D –Northern Highland Sandy Drift
		95A – Northeastern Wisconsin Drift Plain
		95B – Southern Wisconsin and Northern Illinois Drift Plain
	L – Lake States Fruit, Truck Crop, and Dairy Region	96 – Western Michigan Fruit Belt
		98 – Southern Michigan and Northern Indiana Drift Plain
		99 – Erie-Huron Lake Plain

Red Parent Material may be useful in identifying hydric soils in landscape positions where water accumulates and wetlands are likely to occur as well as in aquic portions of southeastern Texas and Louisiana where wetlands are more common (U.S. Army Corps of Engineers 2010a). To facilitate identification of problematic RPM in a field setting, Tables 11 and 12 link areas of verified problematic RPM soils with underlying geologic formations and soil series.

Desert Southwest and Western Mountains

A total of 237 soil samples from 97 sites underwent analysis for CCPI from the Desert Southwest and Western Mountains problematic RPM region. Residual deposits accounted for the majority of parent materials associated with problematic RPM soils (>55%), with alluvial deposits (30%) and mixed source materials also present. Problematic RPM soil CCPI results were significantly lower (CCPI = 19 ± 5.6) than potential (CCPI = 34 ± 2.9; $p < 0.001$) and non-problematic soils (CCPI = 49 ± 10; $p < 0.001$). As a result, problematic RPM has been identified for recommended use of the F21 – Red Parent Material hydric soil field indicator in 26 MLRAs of five LRRs. These mostly occur within the USACE Arid West and the Western Mountains, Valleys, and Coast regional supplement areas, with minor areas also occurring in portions of the Great Plains regional supplement area (Table 13; Fig. 5).

The Desert Southwest and Western Mountains problematic RPM region encompasses portions of Arizona, Colorado, New Mexico, Texas, South Dakota, Utah, and Wyoming. The problematic RPM in this region occurs across six vastly different physiographic provinces: the Colorado Plateaus, Middle (Central) Rocky Mountains, Southern Rocky Mountains, Wyoming Basin, Basin and Range (Mexican Highland and Sacramento sections), and portions of the Great Plains (Black Hills, Pecos Valley, and Edwards Plateau sections). Soils within the Desert Southwest and Western Mountains problematic RPM region are characterized by residual, colluvial, and alluvial soils derived from dark, red Paleozoic and Mesozoic-aged rocks uplifted and preserved in the regions mountain ranges (i.e. the Middle and Southern Rockies, Black Hills, Arizona and New Mexico Mountains, Wasatch and Uinta Mountains) and the various plateaus, canyons, and gorges (i.e. the Colorado Plateau and Pecos River Valley) associated with those features. Despite the variability in soils observed in area, the terrestrial red beds that produced problematic RPM soils share similar geological origin related to the erosion and deposition of the Ancestral Rocky Mountains (Table 14; Branson 1927; Reeside 1929; Baker et al. 1947; Pipiringos 1968; Lucas et al. 1993; Lucas and Anderson 1998).

The following groups of problematic RPM and their associated soils where the F21 – Red Parent Material field indicator may be applied include: 1) portions of the Western Mountains, Valleys and Coasts regional supplement area and surrounding foothills; 2) the Colorado Plateaus physiographic province (i.e., the Four Corners region); and 3) the Pecos River Valley (Mack 2018). Problematic RPM associated with the Western Mountains, Valleys, and Coast regional supplement area and surrounding foothills (U.S. Army Corps of Engineers 2010b) includes portions of the central and southern Rockies, the Black Hills, the Arizona and New Mexico mountains, and the Wasatch and Uinta mountains (Fig. 5). As noted elsewhere, understanding where red bed formations and

Table 7 Geological formations and soil series identified as potential problematic RPM associated with the Superior Lobe

Geological Formation(s)	Soil Series			
Bayfield Group	Adolph	Ellsburg	Matchwood	Poskin
Chequamegon Sandstone	Ahmeek	Escanaba	McQuade	Richford
Devil's Island Sandstone	Aldenlake	Fayal	Mecan	Robago
Orienta Sandstone				
Chippewa Lobe Till	Algonquin	Fence	Mesaba	Rockland
Copper Falls Formation	Allendale	Finland	Michigamme	Rockmarsh
Fond du Lac Formation	Amery	Flak	Milaca	Ronneby
Hinckley Sandstone	Amnicon	Flink	Millward	Rosholt
Jacobsville Formation	Anigon	Flintsteel	Misery	Rudyard
Jacobsville Sandstone	Annalake	Forbay	Mishwabic	Sanborg
Keweenaw Bay Lobe Till	Anton	Freeon	Miskoaki	Santiago
Langlade Lobe Till	Arcadian	Freer	Montreal	Schaat
Lincoln Formation	Arnheim	Froberg	Mooseline	Creek
Michigamme Lobe Till	Ashwabay	Gaastra	Moquah	Schisler
Miller Creek Formation	Augustana	Garlic	Mora	Schweitzer
Ontonagon Lobe Till	Automba	Gay	Morganlake	Scoba
Oronto Group	Baden	Giese	Munising	Sconsin
Copper Head Conglomerate	Badriver	Glendenning	Negwegon	Sedgewick
Freda Sandstone	Barto	Gogebic	Nemadji	Shag
Nonesuch Shale	Bergland	Gratiot	Net	Skanee
River Falls Formation	Big Iron	Greenstone	Newood	Spear
Superior Lobe Till	Bigisland	Gull Point	Newot	Sporley
Trade River Formation	Borea	Haugen	Nonesuch	Springport
Wisconsin Valley Lobe Till	Brennyville	Haybrook	Normanna	Springstead
	Brill	Hegberg	Ocqueoc	St. Francis
	Bushville	Hellwig	Odanah	Sturgeon
	Canosia	Herbster	Ogilvie	Superior
	Carp Lake	Hermantown	Oldman	Tipler
	Cebana	Hibbing	Omega	Toimi
	Chequamegon	Hulligan	Ontonagon	Trap Falls
	Chetek	Jewett	Oronto	Trimountain
	Chippewa	Karlin	Ossmer	Tula
	Harbor	Kellogg	Otterholt	Turpela
	Clemens	Keweenaw	Paavola	Twig
	Copper	Kingsley	Padus	Wabeno
	Harbor	Lac La Belle	Padwood	Wahbegon
	Cornucopia	Langola	Palmers	Waiska
	Cress	Lerch	Parent	Wakefield
	Cromwell	Loggerhead	Payseor	Watab
	Culver	Magnor	Pearl	Watton
	Dairyland	Mahtowa	Pelkie	Worchester
	Dechamps	Majestic	Pemene	Wormet
	Denomie	Makwa	Pence	Worwood
	Dinham	Manido	Pesabic	Yalmer
	Duluth	Manistee	Peshekee	
	Dusler	Manitowish	Pickford	
	Eaglebay		Porkies	
	Eldes		Portwing	

associated soil series (Table 15, 16 and 17) are located will help identify hydric soils derived from problematic RPM soils in these areas. While problematic RPM and their associated soils are extensive, the expanse of ustic and aridic soil moisture regimes likely limits the extent of hydric soils. However, the F21 – Red Parent Material may be useful in identifying hydric soils where water accumulates and wetlands are likely to occur across the landscape including riverine, depressional, and groundwater discharge landscape positions.

Interestingly, the Permian red beds of the Pecos River Valley are lithologically correlated with strata confirmed in the South-Central problematic RPM region discussed previously, while the Mesozoic red beds are lithologically correlated to those that occur in the Colorado Plateaus and Rocky Mountain systems. Like the red beds of the Central Red Beds Plains, the rock sequences known to contain red beds also grade into sequences dominated by gray, marine-carbonate rocks that are not recognized as problematic RPM. A variety of river systems drain areas characterized by problematic RPM. Therefore, alluvial deposits may be comprised of (or contain) problematic RPM soils. Furthermore, the headwater of the Pecos, Canadian and Cimarron rivers flow across

Table 8 Geological formations and soil series identified as potential problematic RPM that are associated with the Kewaunee formation

Geological Formation(s)	Soil Series		
Bayfield Group	Angelica	Moquah	Tipler
Chequamegon Sandstone	Banat	Mosel	Wabeno
Devil's Island Sandstone	Bonduel	Moshawquit	Waymor
Orienta Sandstone	Borth	Nadeau	Winneconne
Fond du Lac Formation	Briggsville	Omena	Worchester
Green Bay Lobe Till	Cress	Omro	Wormet
Hinckley Sandstone	Cunard	Onaway	Wyocena
Holy Hill Formation	Elderon	Oshkosh	Zittau
Horicon Member	Emmert	Ossineke	Zurich
Liberty Grove Member	Escanaba	Pearl	
Kewaunee Formation	Fairport	Pecore	
Branch River Member	Fence	Peebles	
Chilton Member	Frechette	Pelkie	
Florence Member	Gaastra	Pemene	
Glenmore Member	Hortonville	Perote	
Kirby Lake Member	Kaukauna	Peshekee	
Middle Inlet Member	Kennan	Peshtigo	
Ozaukee Member	Keshena	Poy	
Silver Cliff Member	Kewaunee	Poygan	
Two Rivers Member	Keweenaw	Rabe	
Valders Member	Kiva	Richford	
Jacobsville Formation	Kolberg	Rosholt	
Jacobsville Sandstone	Longrie	Shawano	
Oronto Group	Manawa	Solona	
Copper Head Conglomerate	Manistee	Stambaugh	
Freda Sandstone	Mecan	Symco	
Nonesuch Shale	Montello	Tilleda	

Table 9 Geological formations and soil series identified as potential problematic RPM that are associated with the Michigan Basin

Geological Formation(s)	Soil Series	
Bayfield Group	Algonquin	Morganlake
Chequamegon Sandstone	Allendale	Nadeau
Devil's Island Sandstone	Angelica	Negwegon
Orienta Sandstone	Annalake	Nunica
Fond du Lac Formation	Bergland	Ocqueoc
Hinckley Sandstone	Biscuit	Oldman
Ionia Formation	Bonduel	Omena
Jacobsville Formation	Cunard	Onaway
Jacobsville Sandstone	Engadine	Ontonagon
Jurassic Red Beds	Fairport	Ossineke
Oronto Group	Fence	Pelkie
Copper Head Conglomerate	Fibre	Pickford
Freda Sandstone	Gaastra	Poy
Nonesuch Shale	Gay	Rudyard
Queenston Formation	Graveraet	Solona
Salina Group	Karlin	Sporley
	Kellogg	Springport
	Kiva	Superior
	Longrie	Waiska
	Manistee	

red beds identified as problematic RPM in the Upper Pecos River Valley providing alluvial source materials for problematic RPM soils as they proceed east and south (Mack 2018).

Application of F21 – Red Parent Material for Hydric Soil and Wetland Delineation

The RPM guidance maps, supplemental information on associated geologic features, and soil series lists are designed to aid practitioners in overcoming obstacles in accurately identifying hydric soils derived from problematic RPM. Maps and tables link soil series, geological formations, and parent materials containing problematic RPM with USACE regional supplement areas, LRRs, and MLRAs, allowing users to rapidly identify potential problematic RPM soils through a variety of pathways. For example, problematic RPM can be identified based upon information regarding either soil survey data, soil series identification or geologic formation information within a given location (e.g., USACE Atlantic Gulf Coastal Plain region; LRR T; MLRA 152A).

Notably, the guidance maps developed encompass all areas potentially containing problematic RPM, including both wetland and upland areas. The provided tables are not limited to soils which appear on the hydric soils list or soil series with poorly and very poorly drained designations. As a result, identification of hydric soils requires both the presence of problematic RPM as determined by the maps, geologies, and soil series lists herein, and the conditions outlined in the F21 – Red Parent Material hydric soil field indicator. Further, for an area to be identified as a wetland, areas exhibiting problematic RPM must also display indicators of wetland hydrology and hydrophytic vegetation as required by the procedures outlined in the USACE wetland delineation manual and associated regional supplements. Based on the findings in the current study, a proposal will be made to the National Technical Committee for Hydric Soils to revise the guidance for F21-Red Parent Material application. The revisions will apply the technical criteria of the hydric soil indicator as written, but require *either* the application of CCPI data *or* the occurrence of potential problematic RPM soils within one of the problematic RPM regions described herein. This approach will promote the proper application of the F21 – Red Parent Material hydric soil field indicator without requiring laboratory data collection for individual project areas. Additional site specific

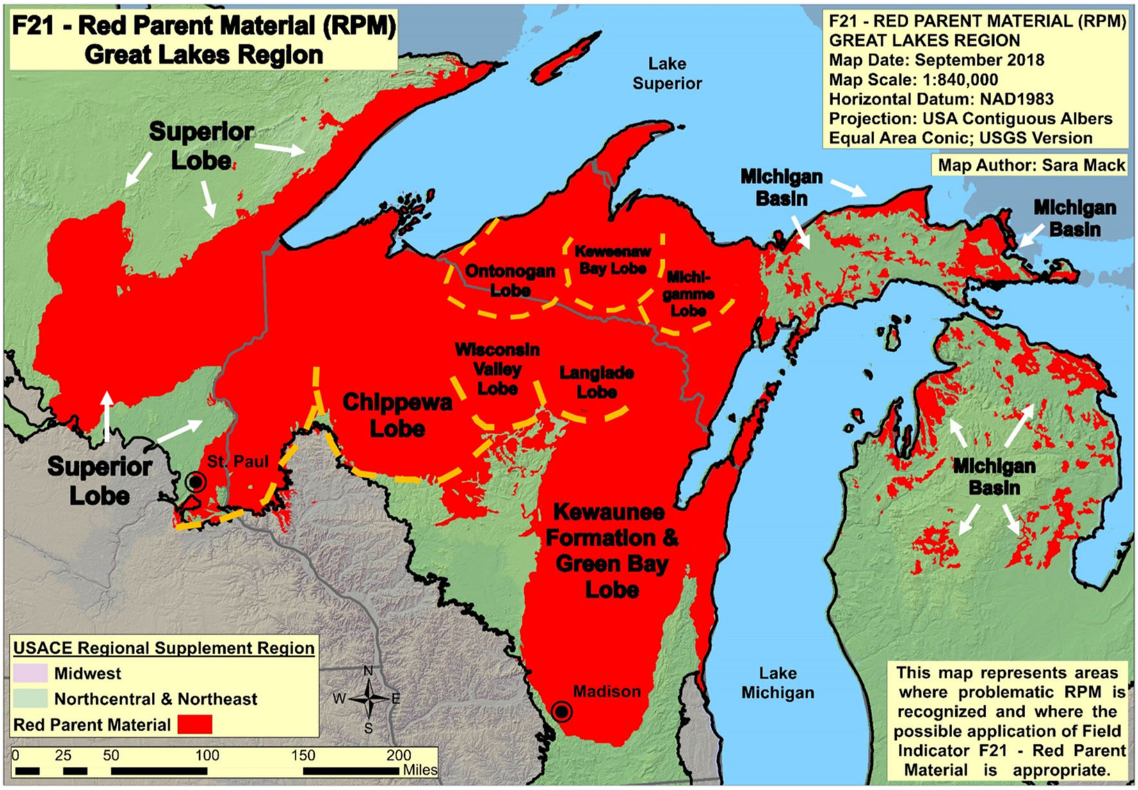

Fig. 3 Guidance map for recommended application of the F21 - Red Parent Material field indicator in the Great Lakes RPM region. Red areas indicate locations with soils and geological formations where problematic RPM are possible

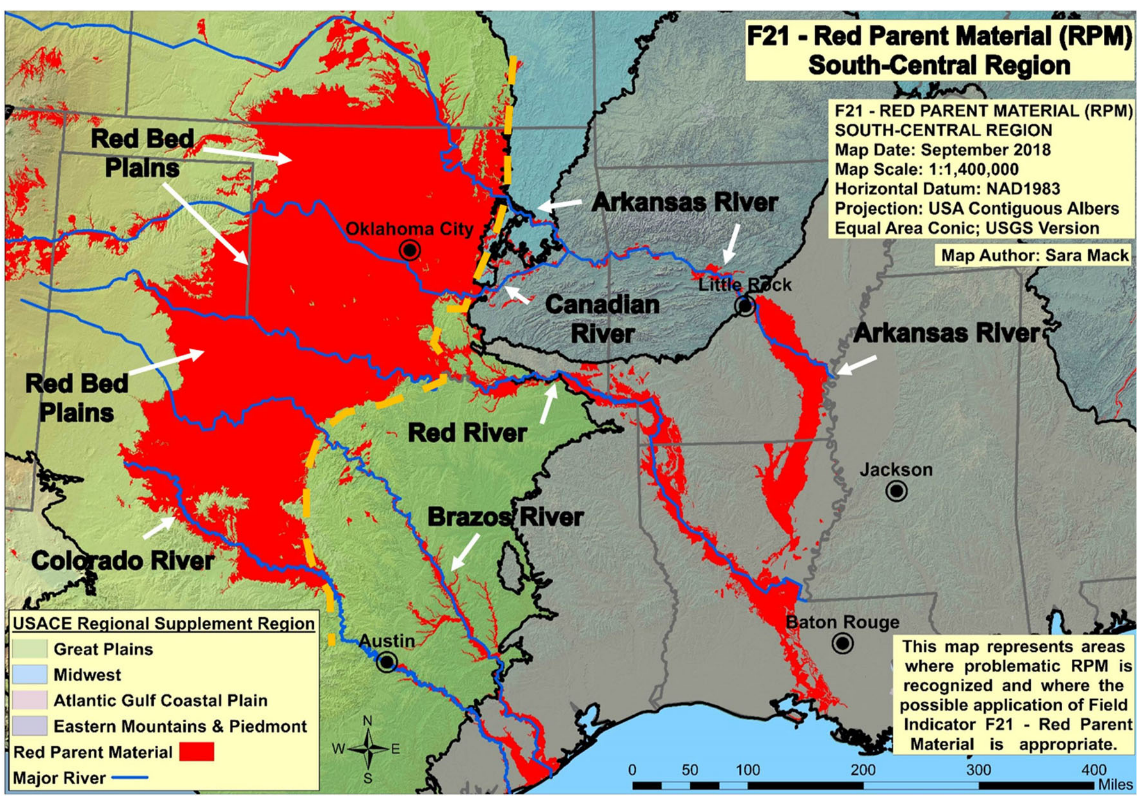

Fig. 4 Guidance map for recommended application of the F21 - Red Parent Material field indicator in the South-Central RPM region. Red areas indicate locations with soils and geological formations where problematic RPM are possible

Table 10 USACE regional supplement areas, LRRs, and MLRAs within the South-Central RPM region where application of the F21 - Red Parent Material hydric soil field indicator is recommended

USACE region	Land Resource Region (LRR)	Major Land Resource Area (MLRA)
Great Plains and Midwest	H – Central Great Plains Winter Wheat and Range Region	78A – Rolling Limestone Prairie
		78B – Central Rolling Red Plains,
		78C – Central Rolling Red Plains,
		80A – Central Rolling Red Prairies
		80B - Texas North-Central Prairies
	I – Southwest Plateaus and Plains Range and Cotton Region	81B – Edwards Plateau, Central Part
		81C – Edwards Plateau, Eastern Part
		82A – Texas Central Basin
	J – Southwestern Prairies Cotton and Forage Region	82B – Wichita Mountains
		84A – North Cross Timbers
		84B – West Cross Timbers
		84C – East Cross Timbers
		85 – Grand Prairie
		86A&B – Texas Blackland Prairie
		87A&B – Texas Claypan Area
	M – Central Feed Grains and Livestock Region	112 – Cherokee Prairies
Eastern Mountains and Piedmont	N – East and Central Farming and Forest Region	118A – Arkansas Valley and Ridges, Eastern Part
		118B – Arkansas Valley and Ridges, Western Part
Atlantic and Gulf Coast Plain	O – Mississippi Delta Cotton and Feed Grains Region	131A – Southern Mississippi River Alluvium
		131B – Arkansas River Alluvium
		131C – Red River Alluvium
Atlantic and Gulf Coast Plain	P – South Atlantic and Gulf Slope Cash Crops, Forest,	133B – Western Coastal Plain
		134 – Southern Mississippi Valley Loess
	and Livestock Region	135B – Cretaceous Western Coastal Plain
	T – Atlantic and Gulf Coast Lowland Forest and Crop Region	150A - Gulf Coast Prairies
		150B – Gulf Coast Saline Prairies

Table 11 Geological formations and soil series identified as potential problematic RPM within the Central Red Bed Plains

Geological Formation(s)		Soil Series			
Admiral Formation	Marlow Formation	Altus	Foard	Lugert	Roark
Archer City Formation	Doe Creek Lentil	Arnett	Frankirk	Lutie	Ruella
Bear Mountain Formation	Verden Sandstone Lentil	Ashport	Gaddy	Madge	Rups
		Aspermont	Gageby	Mangum	Sagerton
Big Basin Formation	Moran Formation	Aydelotte	Gracemont	Masham	Selman
Bison Formation	Nippewalla Group	Beckman	Gracemore	McKnight	Shrewder
Blaine Formation	Nocona Formation	Bethany	Grainola	McLain	Southside
Elm Fork Member	Petrolia Formation	Binger	Grandfield	Milan	Spikebox
Van Vacter Member	Post Oak Conglomerate	Bukreek	Grant	Miles	St. Paul
Cedar Hill Sandstone	Post Oak Formation	Burford	Hardeman	Miller	Stamford
Chickasha Formation	Post Oak Sandstone	Burson	Harrah	Minco	Stoneburg
Clear Fork Formation	Pueblo Formation	Callahan	Hayfork	Mulhall	Teller
Clear Fork Group	Purcell Sandstone	Canadian	Heman	Nash	Tillman
Cloud Chief Formation	Quartermaster Formation	Carey	Hinkle	Nashville	Tilvern
Dockum Group	Rush Springs Formation	Chickasha	Hollister	Newalla	Tipton
Dog Creek Shale	Weatherford Gypsum Bed	Clairemont	Huska	Nipsum	Treadway
Doxey Formation		Clearfork	Ironmound	Noble	Vernon
Doxey Shale	Salt Plains Formation	Cobb	Jamash	Norge	Vinson
Duncan Sandstone	San Angelo Formation	Colorado	Jaywi	Oakley	Wakita
El Reno Group	San Angelo Sandstone	Cordell	Jester	Obaro	Waurika
Elk City Sandstone	Santa Anna Branch Shale	Cornick	Jolly	Oscar	Westola
Elm Creek Formation	Sumner Group	Cosh	Kamay	Ozark	Westill
Fairmont Shale	Talpa Formation	Darsil	Kingco	Paducah	Westview
Flowerpot Shale	Valera Formation	Darnell	Kingfisher	Pawhuska	Wetbeth
Garber Sandstone	Waggoner Ranch Formation	Decobb	Kirkland	Piedmont	Weymouth
Grape Creek Formation		Deepwood	Knoco	Pond Creek	Wheatwood
Guadalupian Series	Wellington Formation	Dill	Konawa	Port	Wichita
Hennessey Group	Whitehorse Formation	Dodson	La Casa	Pulaski	Winters
Jagger Bend Formation	Whitehorse Group	Drummond	Lawrie	Quanah	Wisby
Kingman Formation	Wichita Group	Duke	Lawton	Quinlan	Woodward
Kingman Siltstone	Wolfcampian Series	Enterprise	Lebron	Reinach	Yahola
Leuders Formation		Easpur	Lela	Renfrow	Yomont
		Ezell	Littleaxe	Renthin	Zaneis
		Farry	Lovedale	Retrop	Zellmont

Table 12 Geological formations and soil series identified as potential problematic RPM associated with alluvial deposits dissecting the Central Red Bed Plains

Geological Formation(s)	Soil Series				
Arkansas River Alluvium	Addielou	Dougherty	Keo	Muldrow	Severn
Canadian River Alluvium	Armistead	Forbing	Kiomatia	Necessity	Ships
Cimarron River Alluvium	Bastrop	Gaddy	Konawa	Norwood	Solier
Red River Alluvium	Belk	Gallion	Larton	Okay	Sonnier
	Billyhaw	Garton	Latanier	Oklared	Sterlington
	Bistineau	Glenwild	Lebeau	Perry	Stidham
	Bossier	Goodwill	Lela	Portland	Ustibuck
	Buxin	Gore	Liddieville	Porum	Wabbaseka
	Caplis	Hebert	McGehee	Redlake	Waskom
	Caspiana	Hicota	McKamie	Redport	Weswood
	Choska	Idabel	Mer Rouge	Rilla	Whakana
	Coushatta	Idee	Miller	Rodessa	Yahola
	Dardanelle	Kamie	Moreland	Roebuck	Yorktown
	Desha	Karma	Morse	Roxana	
Brazos River Alluvium	Apalo	Clemville	Highbank	Oklared	Sumpf
Colorado River Alluvium	Aquilla	Coarsewood	Hornsby	Paluxy	Surfside
	Asa	Colorado	Kopperl	Pledger	Velasco
	Bastrop	Decordova	Mangum	Rabbs	Westola
	Belk	Gad	Miles	Roetex	Wheatwood
	Bergstrom	Gaddy	Miller	Sagerton	Weswood
	Brazoria	Gageby	Minwells	Ships	Winters
	Churnabog	Gause	Mohat	Smithville	Yahola
	Clearfork	Gholson	Norwood		

CCPI data can be collected if problematic RPM soil occurs outside of the current guidance maps, further expanding the available dataset.

The following steps are recommended when users encounter soils containing potential problematic RPM: 1) Determine if the soil occurs in association with a series or geologic

Table 13 USACE regional supplement areas, LRRs, and MLRAs within the Desert Southwest and Western Mountains RPM region where application of the F21 - Red Parent Material hydric soil field indicator is recommended

USACE region	Land Resource Region (LRR)	Major Land Resource Area (MLRA)
Arid West	D – Western and Irrigated Region	32 – Northern Intermountain Basins
		34A – Cool Central Desertic Basins and Plateaus
		34B – Warm Central Desertic Basins and Plateaus
		35 – Colorado Plateau
		36 – Southwest Plateaus, Mesas, and Foothills
		38 – Mogollon Transition
		41 – Southeastern Arizona Basin and Range*
		42 – Southern Desertic Basins, Plains, and Mountains
Great Plains	G – Western Great Plains and Irrigated Region	61 – Black Hills Foot Slopes
		70A – Canadian River Plains and Valleys
		70B – Upper Pecos River Valley
		70C – Central New Mexico Highlands*
		70D – Southern Desert Foothills*
	H – Central Great Plains Winter Wheat and Range Region	77A - Southern High Plains, Northern Part*
		77B – Southern High Plains, Northwestern Part*
		77E – Southern High Plains, Breaks*
		77D – Southern High Plains, Southwestern Part*
	I – Southwest Plateaus and Plains Range and Cotton Region	81A – Edwards Plateau, Western Part*
		81D – Southern Edwards Plateau*
Western Mountains, Valleys, and Coast	D – Western and Irrigated Region	39 – Arizona and New Mexico Mountains
	E – Rocky Mountain Range and Forest Region	43B – Central Rocky Mountains
		47 – Wasatch and Uinta Mountains
		48A – Southern Rocky Mountains*
		48B – Southern Rocky Mountain Parks
		49 – Southern Rocky Mountain Foothills*
	G – Western Great Plains and Irrigated Region	62 – Black Hills

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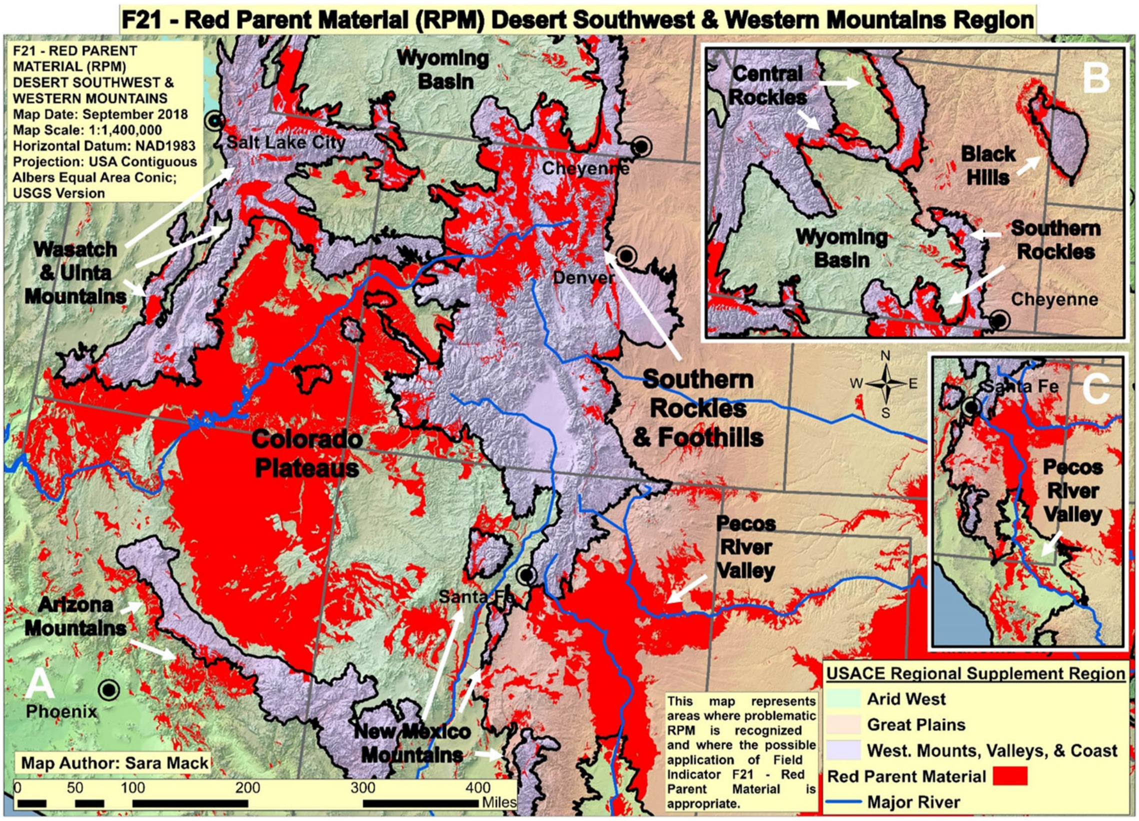

Fig. 5 Guidance map for recommended application of the F21- Red Parent Material field indicator in the Desert Southwest and Western Mountains RPM region. Red areas indicate locations with soils and geological formations where problematic RPM are possible

Table 14 Geological formations identified as potential problematic RPM within the Desert Southwest and Western Mountains RPM region

Geological Formation(s)		
Abo Formation	Curtis Formation	Morrison Formation
Ankareh Formation	Dinwoody Formation	Naco Group
Arapien Formation	Dockum Formation	Navajo Sandstone
Arcturus Formation	Dockum Group	Nugget Sandstone
Artesa Sequence	Dolores Formation	Park City Formation
Artesia Group	Eagle Valley Formation	Pitoikam Formation
Graysburg Formation	Entrada Formation	Purgatoire Formation
Seven Rivers Formation	Entrada Sandstone	Quartermaster Formation
Tansill Formation	Fountain Formation	
Queen Formation		
Yates Formation	Gardner Canyon Formation	Ralston Creek Formation
Bull Canyon Formation	Glen Canyon Formation	
Burro Canyon Formation	Glen Canyon Group	Recreation Red Beds
Bursum Formation	Glen Canyon Sandstone	Rudolfo Red Beds
Carmel Formation	Goose Egg Formation	San Rafael Group
Casper Formation	Grand Canyon Supergroup	Satanka Shale
Chinle Group	Nankoweap Formation	State Bridge Formation
Chinle Formation	Guadalupian Series	
Garita Creek Formation	Gypsum Spring Formation	Spearfish Formation
Redonda Formation	Ingleside Formation	Summerville Formation
Rock Point Formation	Hermit Formation	
Santa Rosa Formation	Hermit Shale	Sundance Formation
Shinarump Conglomerate Member	Jelm Formation	Supai Group
Chugwater Formation	Junction Creek Sandstone	Thaynes Formation
Chugwater Group	Kayenta Formation	Wanakah Formation
Chupadera Formation	Lykins Formation	Wingate Sandstone
Cutler Group	Lyons Formation	Woodside Formation
Cedar Mesa Sandstone	Lyons Sandstone	Woodside Shale
Cutler Formation	Maroon Formation	Vampire Formation
Organ Rock Formation	Mahogany Formation	Yeso Formation
Organ Rock Shale	Moenkopi Formation	Yeso Group
	Moenave Formation	Zuni Sandstone

Table 15 Soil series identified as potential problematic RPM that are associated with the Western Mountains, Valleys, and Coast regional supplement and surrounding foothills

Soil Series				
Almy	Gypnevee	Perrypark	Sandark	Tilford
Barnum	Gystrum	Pimsby	Schooner	Tinytown
Bernal	Lamphier	Plome	Scout	Tours
Boyett	Lonetree	Podo	Sinkson	Vale
Chaseville	Miracle	Red Spur	Sixmile	White House
Cheesman	Monticello	Redbank	Southfork	Wycolo
Connerton	Nevee	Redridge	Spearfish	Yahmore
Contention	Neville	Redtom	Swint	
Fortwingate	Nuffel	Rekrop	Tampico	
Garber	Palma	Rizno	Thermopolis	
Gove	Peralta	Rule	Tieside	

feature identified in the maps and tables provided herein. These map and table resources define areas in which application of hydric soil indicator F21 is recommended. This can be accomplished by evaluating the study location using on-site data collection, Web Soil Survey, maps of geologic features, and the comprehensive descriptions of soil-geologic features in problematic RPM regions provided in Mack (2018). 2) Determine if the soil meets the criteria described in hydric soil indicator F21 – Red Parent Material. If the soil meets the requirements of F21 –Red Parent Material and occurs within a verified problematic RPM region, the presence of a hydric soil is confirmed. Alternatively, if the soil occurs outside of the guidance map boundaries, CCPI analysis can verify the presence of problematic RPM. 3) Determine if the location displays indicators of wetland hydrology and hydrophytic vegetation as described in the USACE wetland delineation manual and associated regional supplements. If the requirements of vegetation, and hydrology are documented in conjunction with 1) and 2) above, the presence of a wetland is confirmed.

Despite the collaborative, comprehensive approach utilized within the national mapping project, several important data

Table 17 Soil series identified as potential problematic RPM that are associated with Pecos River Valley

Soil Series					
Alama	Glenrio	La Lande	Los Tanos	Quay	San Jon
Bernal	Hagerman	Lacita	Montoya	Redona	Tucumcari
Berwolf	Hassell	Lacoca	Newkirk	Regnier	Tuloso
Conchas	Ima	Largo	Palma	Ribera	Walkon

limitations need to be considered when using RPM guidance maps and tables. Some limitations result from the broad scale of the mapping effort and inherent variability associated with soils and geologic source materials. To date, more than 24,000 soil series have been established nationwide (Rabenhorst 2016), which precludes the possible evaluation of CCPI for each soil series to verify their status as problematic RPM (or not). As a result, it is possible that problematic RPM may exist in other locations and additional CCPI analysis may be needed to confirm the presence of problematic RPM in those areas. Soil series in the potential problematic RPM range (CCPI of 30–40) were also included in RPM guidance maps if the soil series met criteria (provided above) that were utilized to generate lists of potential RPM soil series during the mapping phases of the project. This was done to avoid exclusion of potential problematic RPM associated with materials that displayed some degree of color change resistance. Additionally, RPM guidance maps were generated using the U.S. General Soil Map (STATSGO2) Database, which is designed for mapping purposes on regional, multi-state scales (1:250,000). Thus, map units identified as problematic RPM are intended to reflect areas where problematic RPM may be present, and onsite verification is required prior to application of the F21 – Red Parent Material hydric soil field indicator. Also, areas included in the RPM guidance maps required 5 % or more of a map unit component to contain a soil series identified as potential problematic RPM as defined in the U.S. General Soil Map (STATSGO2) Database. As previously noted, the approach intentionally did not consider other

Table 16 Soil series identified as potential problematic RPM that are associated with the Colorado Plateaus

Soil Series					
Acree	Epikom	Mack	Monue	Remorris	Tours
Aneth	Fortwingate	Mellenthin	Naplene	Ribera	Wetherill
Arches	Gladel	Mespun	Nuffel	Rizno	Whitecanyon
Arntz	Grassytrail	Mido	Padilla	Robroost	Winkel
Barx	Hadden	Milok	Palma	Sandark	Yahmore
Begay	Hagerman	Mivida	Parkelei	Simel	
Blackston	Hassell	Moenkopie	Penzance	Strych	
Brinkerhoff	Hillburn	Mokaac	Plome	Suwanee	
Burnswick	Jocity	Monogram	Redbank	Tintero	
Caval	Leanto	Monticello	Regracic	Tobler	

factors relevant to hydric soils (or wetlands) such as drainage class or slope, but sought to encompass all areas where problematic RPM was likely to occur. Similar limitations are related to the geologic datasets and mapping, including discontinuity between states boundaries regarding geologic mapping conventions and other factors.

Future work should focus on refining national RPM guidance maps based upon application of the hydric soil field indicator F21 - Red Parent Material by wetland practitioners and soil scientists. Increased consultation and collaboration with wetland, soil, and geological scientists should also be pursued in areas where problematic RPM has been identified to further correlate soils and geological datasets with problematic RPM at/across state boundaries. This is especially true for areas in the South-Central and Desert Southwest and Western Mountains problematic RPM regions where sample submission was limited compared to other areas. Further research could also incorporate datasets specifically relevant to wetlands to align the maps presented herein with the occurrence of hydric soils developed in problematic RPM. For example, evaluation of the problematic RPM maps using hydric soils lists, drainage class designation, U.S. Fish and Wildlife Service's National Wetlands Inventory data, and other tools may prove useful at various spatial scales. Also, utilization of higher resolution soils and geological datasets (where available) could further refine results.

Conclusions

Hydric soil field indicator, F21 - Red Parent Material, has been approved for nationwide testing in soils derived from problematic RPM soils that are resistant to redox-induced color changes. The maps and tables provided allow for rapid and defensible application of hydric soil field indicator F21 – Red Parent Material across the United States, whereas the spatial occurrence and extent of problematic RPM soils was previously unknown. As a result, four problematic RPM regions (Northeast and Mid-Atlantic, Great Lakes, South-Central, and Desert Southwest and Western Mountains) were identified for the application of the F21– Red Parent Material hydric soil field indicator. Within each of these problematic RPM regions, diverse groups of soils and parent materials exhibited problematic RPM characteristics, however all problematic RPM areas occurred in association with sedimentary, hematite-rich "red bed" formations, and the recently deposited (alluvial, colluvial, and glacial) materials derived from them. The problematic RPM maps, tables, and supplemental guidance link soil series, geologic formations, and parent materials containing problematic RPM, allowing users to rapidly identify potential RPM soils through a variety of pathways. Based on these findings, revisions to the F21 – Red Parent Material will be proposed recommending e*ither* the application of CCPI data *or* the occurrence of potential problematic RPM soils within one of the problematic RPM regions described herein prior to the use of the indicator. The collaborative effort among universities, agency staff, soil archives, and field practitioners provided for a national scale mapping effort, improving approaches to hydric soil identification and accurate wetland delineation across a large and diverse geographic area.

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