# Simple Guidelines for Deciding When Soil Variability Does – and Doesn't – Matter for Rangeland Management and Restoration

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## Abstract

"Rangelands in most parts of the world are relatively homogenous and can be managed uniformly at the landscape scale" or "rangelands are extremely diverse and require different approaches even at the landscape scale." Both statements are made frequently by rangelands scientists and managers. Both are correct. Whether or not it is worthwhile to consider soil variability when planning management and restoration at the landscape scale depends on objectives, location, and the management or restoration strategies under consideration. Together these factors determine whether outcomes are likely to be different at different locations in the landscape, and whether those outcomes can be significantly improved by varying management across the landscape. In this paper we present simple guidelines for deciding whether soil variability should be taken into account when planning management and restoration projects. We conclude by providing a few suggestions on how to decide whether existing soil maps are adequate where soil information is required, and suggestions for how to quickly field-check soil map accuracy.

## Introduction

Some rangelands are relatively homogenous. There are also some management systems and restoration practices that can be successfully applied uniformly across diverse landscapes and regions. In an ideal world every scientist could claim global relevance for their research results, and every purveyor of a silver bullet solution to increasing productivity on degraded rangelands could honestly sell a "one simple trick" package throughout the world.

Most rangeland and other natural resource scientists and managers recognize that this world does not exist – that variability in soils, topography, climate and topography interact to create mosaics of different potential responses. Sometimes these differences are significant across distances as short as tens of meters. But the pressures of publishing or making a living from consulting, together with time limitations, often lead us to overlook critical differences in land potential – differences that determine whether a grazing system or brush control method will increase production and limit soil erosion, have no impact, or even result in greater degradation. For example, we recently found that two widely-applied brush control techniques actually *increased* wind erosion to 11 to 58 times the rates measured in adjacent controls on the same soils over a two-year period (Karban et al. In Review). Two other recent studies found that the effectiveness of small (1m) structures in limiting erosion (Rachal et al. 2015) and promoting grass establishment (Peters et al. 2020) varied widely across three soils all located in a single basin in New Mexico, USA. Conversely, in relatively flat landscapes with uniform soils and no significant rainfall or temperature gradients, responses to management and restoration treatments can remain consistent across thousands of square kilometers. Furthermore, there are some management principles, such as destocking early in drought, that nearly always apply nearly everywhere. Even this principle, however, may have exceptions, such as when overgrazing during drought contributes to a desired state change.

The objective of this paper is to present some simple guidelines for deciding when soil and topographic variability, in particular, do and do not need to be considered when planning rangeland management and restoration. As a contribution to the proceedings of a conference, we hope that this paper will stimulate further discussion, and would welcome feedback as we continue to refine these simple guidelines into a broader framework and decision support tools for accessing and applying soil information.

## Methods

The guidelines described below were developed over the course of more than two decades of research, leading rangeland health assessment and monitoring workshops, and developing monitoring and ecological site systems in the United States and throughout the world. Several landscapes and regions were particularly helpful in highlighting the incredible variability in the importance of soil and topographic variability. First and foremost is the Jornada Experimental Range and the contiguous Chihuahuan Desert Rangeland Research Center, located just north of the US-Mexican border (Figure 1). They include within their borders relatively large areas of uniformly sandy soils as well as alluvial fans covered by soils that vary widely in both texture and parent material over distances of tens to hundreds of meters. It also includes areas where wind-deposited sand overlies finer-textured sediments at depths of just a few centimeters to tens of meters. Time, too, has played a factor, as it partially determines the depth and level of development of calcic and petrocalcic layers that can both restrict root growth, and modify soil water holding capacity, contributing to vastly different patterns of shrub establishment and production in former grasslands (Browning et al. 2012).

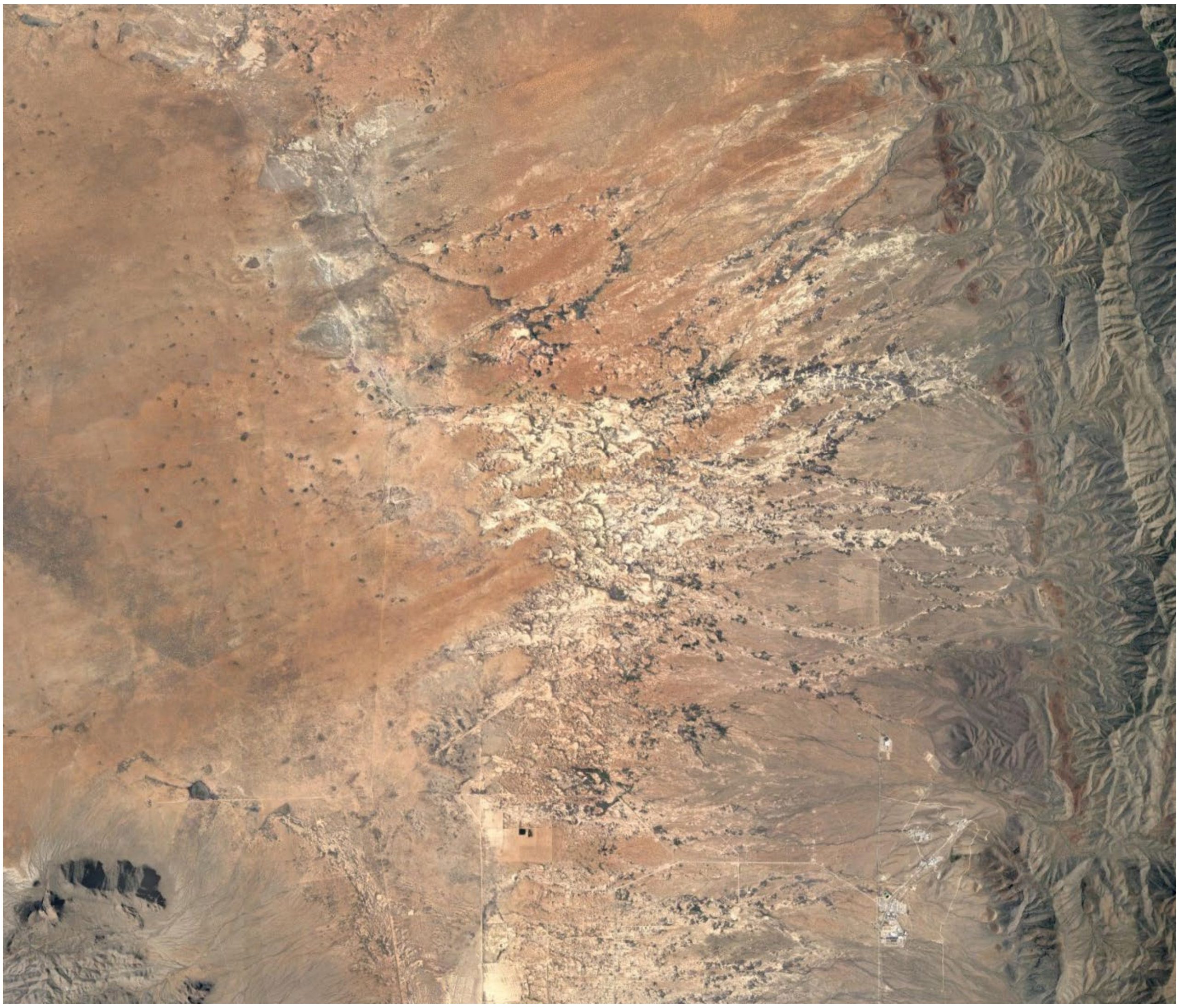

**Figure 1**. Google Earth image of an approximately 700km$^2$ area in southern New Mexico, USA including a relatively uniform area of sandy soils in the upper left that has responded to management and a complex mosaic throughout the rest of the image.

Other areas of particular note in the US include the Colorado Plateau, the Basin and Range and the Snake River Plain. Internationally, vast rangelands in Mongolia where response to grazing impacts are relatively consistent across large areas contrast with the Laikipia region of Kenya, where an incredible diversity of soils and topography contributes to a complex mosaic of both potential vegetation and response to both grazing and restoration practices.

## Results

Based on our work in these and other landscapes, we suggest the benefit of considering soil variability when planning rangeland management and restoration can be determined by systematically and iteratively addressing five questions. We emphasize the importance of *iteratively* addressing the first four questions in order to confidently answer the fifth: an early, and brief, review of all of the questions often highlights where additional information and analysis is required. Bayesian Network models can be used to structure this process, providing a rigorous statistical framework for prioritizing information that will provide the highest return on the investment required to obtain the information (Whitney et al. 2018).

***1. Is there significant soil variability?***

Is there significant variability in topography and the soil properties that are likely to influence the response of the land to a treatment? The relative importance of different properties varies globally, but there are a few that are nearly always important, including slope, landscape position, texture at different depths, and fertility. Slope and landscape position are often determined using digital elevation models or DEM's. While these can be useful, relatively fine-scale changes in slop and slope shape may not be detected. We suggest walking the land, where possible, or at least taking a virtual walk across the land with satellite imagery to see if there appear to be sharp breaks that are not reflected in the DEM.

For soil texture, review both traditional soil maps, such as the global Harmonized World Soil Database, and new digital soil maps, such as SoilGrids and, in Africa, the new ISDA soil map. The two types of maps are used differently. For the traditional soil maps, compare the different types of soils that are included in a map unit. How many are there? How different are they? A difference of one texture class at one depth is unlikely to influence most outcomes, but a two-texture class difference at multiple depths can result in more than a two-fold difference in the soil's plant-available water holding capacity. With the digital soil maps, simply look at the pattern of predicted texture classes within the area.

Differences in fertility are more difficult to discern because they are much more dynamic. Nitrogen, in particular, declines rapidly under most forms of soil degradation. Basic differences, and particularly those (like phosphorous availability) that are related to pH can often be predicted based on the soil classification (taxonomy) included in traditional soil maps. Soil pH and nutrient content is also predicted by the digital soil maps.

It is critically important to remember that both types of soil maps are simply predictions, and that the accuracy and precision of these predictions varies widely across the world, and even within a region. Unusual soils are often not reflected in either type of soil map. As for topography, its best to walk the landscape, ideally with a good shovel (Herrick et al. 2008) and an app, such as LandPKS, that provides direct access to soil map information.

***2. Is ignoring the variability likely to increase degradation in some part of the landscape?***

This is the most important question of all, and the one that is most often ignored. When planning management and restoration, our inclination is to think big. We tend to think broadly of the landscape, and focus on the dominant landform. One of the most obvious examples of the failure of this approach is overgrazing of riparian zones in a large pasture as livestock tend to concentrate on the higher quality forage, and access to water, near the stream. Less obvious, however, are smaller areas of shallow, highly erodible soils. These often occur on and near ridges where livestock concentrate to avoid ticks and flies. Because the soils are shallow, they may not support the same vegetation as the rest of the landscape, so vegetation removal treatments followed by seeding may not only fail, but increase short- and long-term soil erosion.

***3. Would considering soil variability significantly improve the management or restoration outcome?***

The goal of increasing net benefits is perhaps the most obvious, and often the most difficult. To efficiently address this question, pick the one soil type or part of the treatment area that you believe is *most* likely to respond differently, and determine if that difference is significant, then look at the next area. If after the first few you have concluded that there is unlikely to be a benefit to adjusting management based on soil variability, there is likely no need to spend time completing the analysis for the remaining soils.

***4. Does this variability occur at a scale at which the management or restoration action can be modified?***

A perceived inability to manage for soil variability is the most common excuse for not considering it. And yet tools and strategies for adjusting management, and especially restoration, at even sub-hectare scales are becoming increasingly available. These include GPS collars for livestock, drones to systems that deliver herbicide to individual shrubs. Traditional pastoralists can provide even more effective control over livestock distribution, and manual brush control methods are inherently suited for managing variability while minimizing soil surface disturbance on highly erodible soils.

***5. Is there a positive return on investment in mapping and managing for soil variability?***

This final, question depends on the responses to the first four, and on the costs of creating and implementing a spatially explicit plan. Here again, rough and accurate estimates are more valuable than precise costs for specific activities. The book "Consider a Spherical Cow" (Harte 1988) provides useful, light-hearted guidance that is not (despite the title) bovine-specific. A more sophisticated approach is to use "value of information analysis", a technique used in decision science (Howard, 2015). This analysis would determine whether the benefits of additional soil information would outweigh the costs of obtaining it. Soil information is likely to have high value when there is large uncertainty in soil attributes that are likely to impact outcomes. Where there is large uncertainty, any source of information that helps to narrow uncertainty will have high value (e.g., Hubbard, 2014; Luedeling & Shepherd, 2016).

## Discussion

The questions listed above appear straightforward and seemed almost painfully obvious while writing this paper. Answering them is clearly much more complex. But our conclusion is that the most important recommendation is that the questions at least be explicitly and systematically considered before initiating a management or restoration action.

Each of these guidelines can, of course, be expanded almost infinitely. The process for applying them could also be quite quantitative and complex with the use of geospatial analysis tools informed by remote sensing and field observations and measurements. However, we suggest that even a cursory, qualitative consideration of the guidelines can save considerable time unnecessarily spent acquiring and analyzing soil information or, conversely, flag the importance of "digging deeper" before committing resources to a new project.

The rationale behind the approach described here is similar to, and draws from, those applied by Stringham and others (2016) to the development of "Disturbance Response Groups", and by Bestelmeyer and others (2016) to "Ecological Site Groups". These groups can be used as a starting point for determining if additional analysis is required. For example, if (a) all of the soils mapped or observed in an area have been assigned to the same Group, and (b) the management system or restoration treatment and their effects on key processes were considered (implicitly or explicitly) in the development of the Group.

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