# Completing the Land Resource Hierarchy

By Shawn W. Salley, H. Curtis Monger and Joel R. Brown

## On the Ground

- The Land Resource Hierarchy is a useful framework for organizing natural resource information and can provide both insight and explanation while maintaining consistency in terminology, concepts, and interpretations across scales is a challenge.
- While some scales of the Land Resource Hierarchy are well developed, with all land area assigned to quantitatively defined groups, other scales lack organizing concepts, relationships, and definitions that allow for testing and revision.
- Ecological sites and ecological site groups represent distinct scales in the Land Resource Hierarchy framework, so they should be based on appropriate quantitative variables that can be used to define and communicate their extent and behavior.

**Keywords:** landscape classification, land resource hierarchy, ecological site groups, ecological sites, generalized state-and-transition models, landscape ecology.

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Ecological sites are conceptual divisions of the landscape based on differences in potential vegetation and responses to disturbance. Because ecological sites represent one level within a multiple hierarchal framework,[1] they should be able to decompose into smaller units that reflect the characteristics of the larger spatial scales and agglomerate into larger units that encompass the variability of the parts. Ideally, moving both up and down scales should be intuitive and provide consistent interpretations for land management decisions relevant to desired outcomes at particular scales; however, work is still needed to construct consistent interpretations for management decisions from a landscape perspective.

The Natural Resources Conservation Service's (NRCS) Land Resource Hierarchy (LRH) is a hierarchal landscape classification used to guide agency program development and apply conservation practices to implement policy. Conceptually, the LRH scales from discrete points (such as vegetation patches) up to broad continental physiographic and bioclimatic zones; however, in practice many levels are incomplete, with some scales lacking spatial representation and other levels lacking robust concepts. Furthermore, organizing landscapes into distinct units (such as soil maps), has been useful for understanding how landscapes work, but classification alone has distracted from the ultimate objective: land management decisions to meet specific objectives.

As papers in this special issue illustrate, while ecological sites are a convenient way to break the landscape into pieces for inventory, monitoring, and evaluation, they may not tell the whole story about how to manage landscapes. In this article, we review the general aspects of classification, discuss theories of hierarchical groupings, and suggest steps forward to complete concepts of the LRH.

## Landscape Classification

To understand landscape classifications systems, it is important to understand our current view of ecosystems. Ecosystems are complex sets of interacting systems of organisms and their physical environments that operate from microsites to the biosphere and vary through time in composition, structure, and function.[2] Classification schemes attempt to stratify ecosystems into relevant units based on biological, physical, and human factors. These schemes identify geographical polygons at different levels of resolution that have similar capabilities and potentials for management with emphasis on land evaluation, classification, and mapping. Individual units of the LRH (expressed as detailed soil maps, ecological sites, and land resource units) are similarly stratified into a classification and integrated into a hierarchical structure.

Each scale in the hierarchy contains both mapped units and accompanying concepts. The map units are discrete and expressed at defined scales, while the accompanying concepts are grouped on the basis of similarities regardless of spatial relationships. Both can be expressed and viewed at multiple levels based on similarities and/or dissimilarities. In the case of detailed soil maps, map units may contain a single concept, but on arid lands they most often contain some combination of one or few major concepts (major components) and a handful of concepts as inclusions (minor components).

The framework of the National Cooperative Soil Survey[3] (NCSS) for mapping and describing soil is an appropriate illustration of the relationship between geography and concepts. Local conditions dictate the nature of soil map units, and these field-based units (or natural soil bodies) are recognized as different entities from classification units found within soil taxonomy.[4] In the classification system, soil series are conceptual, and there is seldom a direct relationship between the precise soil taxonomic unit (soil series) and the soil map unit. Even though a soil series name may be used in some soil map units, a soil series and a soil map unit are not the same entity.

## Ecological Sites, Soil Map Units, and Soil Classification

The precise and sometimes confounding distinctions between the physical map polygons and concepts that underlie them are typically not well understood beyond the NCSS community. Most importantly, natural soil bodies often have ranges in properties that overlap multiple taxonomic classes. Recognizing awkwardness in the conceptual link of map units is not new to soil scientists. Dr Marlin Cline, one of the early pioneers who helped bridge the gap between academic studies of soil classification with soil survey, wrote in 1977 that "at the lowest level of the system, we will have to acknowledge the differences between taxonomic soil series and mapping units that bear the same name and will probably have to rectify the confusion this causes."[5]

The application of ecological site information has suffered similar confusion regarding the incorrectly assumed direct link between ecological site concepts to soil map units. Ecological sites are correlated to specific components of the map units. Components are smaller map units of natural bodies of soils and miscellaneous units, such as bedrock outcrop, in a particular landscape. The direct link between ecological site and the soil component does allow for an ecological site to be discernable and fixed on the landscape; however, component level soil maps are rarely available, and often multiple ecological sites occur within the same map unit. As has been repeatedly stated, ecological sites have to be verified and to verify you have to dig a soil pit.

Just as a soil survey does not map soil taxonomic classes, ecological sites are not specifically mapped because both soil map units and ecological sites are based on conceptual landscape models and, most commonly, physical landforms. Thus, ecological sites are interpretations of soil surveys, map units, and soil properties. How those properties are grouped depends on the context of interpretations.

## Ecological Sites and Soil Survey within a Hierarchical Context

Continuing with the soil survey example, one of the first steps in an area survey is to develop a general map of landforms for the whole survey area. This allows surveyors to create a conceptual model of the area in order to view landscape relationships.[6] The process of developing and refining general soil concepts allows the surveyor to decompose a landscape into finer units while still retaining the landscape character, connections, and interactions. Landscape maps provide the context and constraints and thereby impose general limits on how more detailed soil units will be defined and ultimately mapped. After the natural soil bodies are surveyed, concepts developed, and the map unit components described, the landscape map is updated to reflect newer soil information.

The progression of using one scale to inform and improve upon another is an iterative process, and highlights two ways hierarchical systems are built. First is the top-down approach, wherein the whole is more than simply the sum of its parts because it explicitly includes interactions. This method begins with the whole and subdivides into smaller and smaller units based on similar units. The second is the bottom-up approach, with the inherent belief that information about the parts can explain the behavior of the whole. Bottom-up methods begin with all known objects and groups them based on similarities. Debate surrounding legitimacy of top-down versus bottom-up approaches has a long history[7] spanning disciplines of geography, soil science, and ecology, and we will certainly not be solving this debate in this article. It is important, however, to mention the two approaches within a discussion about hierarchical systems as the entire point is about finding relationships between the whole and the parts. A hierarchy is simply a system of superimposed constraints from higher levels on the individual components at any given lower level (Fig. 1) where higher-level behaviors are explained with lower-level information.

Resource managers and scientists realize that any ecological classification system is scale-dependent; however, rarely is there a single correct scale to study soil landscapes or ecological systems.[8] As scales change, relevant processes can change, often leading to seemingly unpredictable relationships across scales.[9] Within each focal level of the LRH there are constraints from the immediate scale higher in the spatial domain, and there are components that give specificity through mechanisms and initial conditions from the lower scale. Thus, fine-scale processes provide details necessary to *explain* the phenomena while broad-scale patterns *constrain* and, importantly, help predict behaviors.[10]

Although it may not be immediately apparent, both a top-down and bottom-up approach are applied when defining ecological sites. From the top-down, the landscape context comes from the soil-geomorphic system,[11] usually expressed as landscape components (i.e., slopes, fans, hills) providing limits to what an ecological site can include, both in terms of biophysical attributes and behaviors. From the bottom-up, the plant community attributes (vegetation structure, species composition, production) give ecological sites on-the-ground specificity, and understanding vegetation dynamics (response to disturbance) supply the necessary basis for describing ecological sites. The practical application of these complimentary approaches often results in excessive amounts of detail and makes seamless integration, which is required for successful land management decision-making, overly complex.

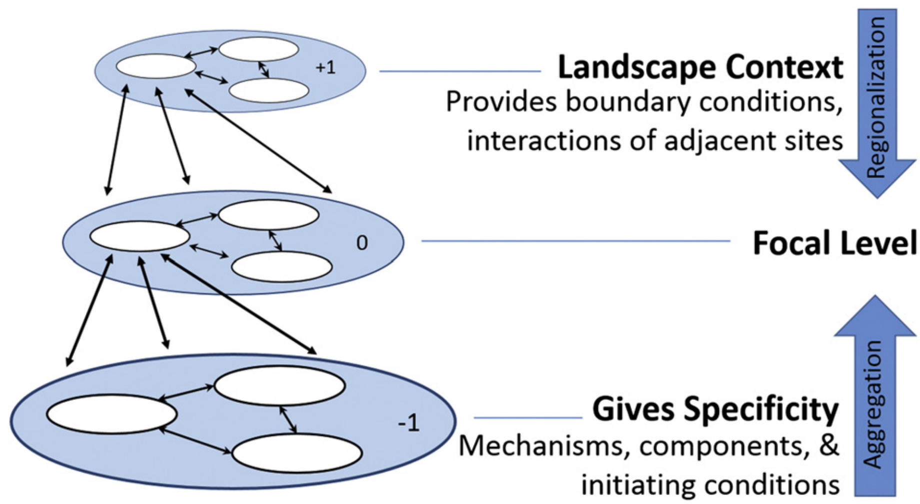


**Figure 1.** Scales of organization showing feedback and feedforwards from the immediate higher and lower scale in a hierarchical system. Adapted from Urban et al.[8] and O'Neill et al.[10]

In seeking an answer to the question of how much detail is needed, a single answer is often inappropriate and may even be misleading. Ecological Site Groups (ESGs) and their associated generalized state-and-transition models have potential to 1) inform and constrain individual ecological sites, and 2) provide a test for information from the levels below. ESGs have been proposed as an explicit scale in the hierarchy,[1] and other authors in this issue expand on use of generalized state-and-transition models as an appropriate scale to simplify interpretation and create spatial units that are easier units to manage in complex systems. As with any level in the hierarchy, the more explicit we can be about scale, process, and relationships, the more valuable the information.

## Resource Units in Space and Time

Controls on soil and ecosystem function vary across space and time. Disturbance regimes, biotic responses, and vegetation patterns are strongly linked to different scales.[12] The critical question in play at different levels is, "What controlling variables are the most important at that particular spatial and temporal scale?" The answer provides focus for research, management, monitoring, and communication.

We propose that the questions and answers for each scale in the hierarchy can be reduced to a limited suite of factors describing individual resource area units. For example, broad-scale units ($10^6$ km$^2$) can be defined by macroclimatic properties, which control daily and seasonal fluxes of energy and moisture: latitude (variability of soil energy), distance from the sea (continentality or oceanic influences), and elevation.[13] Then, only at mesoscale ($10^3$ km$^2$) and fine-scale (km$^2$) levels would landform properties (such as geology and topography) modify macroclimates by regulating the intensity of other key factors important to soil formation. We synthesize a general model in Fig. 2 that attempts to stratify these variables related to their appropriate scales in the LRH; although we recognize that the intensity of these variables can diverge drastically when fine scale drivers overwhelm larger scale processes. For example, weather extremes generally influence vegetation dynamics whereas only the climate averages are recorded in the soil. Another scaling example in arid and semi-arid environments is that run-on and run-off processes often become the dominant regulator of soils and landscapes.[14]

The reality of land management is that some decisions are critical and, once made, preclude others. In many cases, bad decisions made from the bottom-up lead to cascading decisions and effects that are ultimately disastrous.[15] For example, improper management of sensitive areas can initiate degradation processes that affect even relatively resilient landscapes via processes such as fire, erosion, or invasive species introduction. The best example in rangelands is probably the all-too-common poorly designed road. Conversely, a well-structured decision analysis supported by ecological site information can both identify which decisions should be made and when, and provide the necessary information to make those decisions.[16] The LRH provides the context for those decisions, and understanding the relationships is necessary to make good decisions.

## Land Resource Hierarchy Status

Of all the scales in the LRH, the only readily available spatial information includes Soil Survey Geographic Database (SSURGO), General Soil Map of the United States (STATSGO2), Major Land Resource Areas (MLRA), and the Land Resource Regions (LRR). Map unit concepts of natural soil bodies for the SSURGO and STATSGO2 databases are contained in tabular data available from Soil Data Mart[i], and the sum of soil taxonomic knowledge is available in USDA Soil Taxonomy.[4] Resource area concepts are contained in narrative form within the *Agricultural Handbook* #296,[17] and current ecological site concepts are

[i] Soil Data Mart is available at https://gdg.sc.egov.usda.gov/.

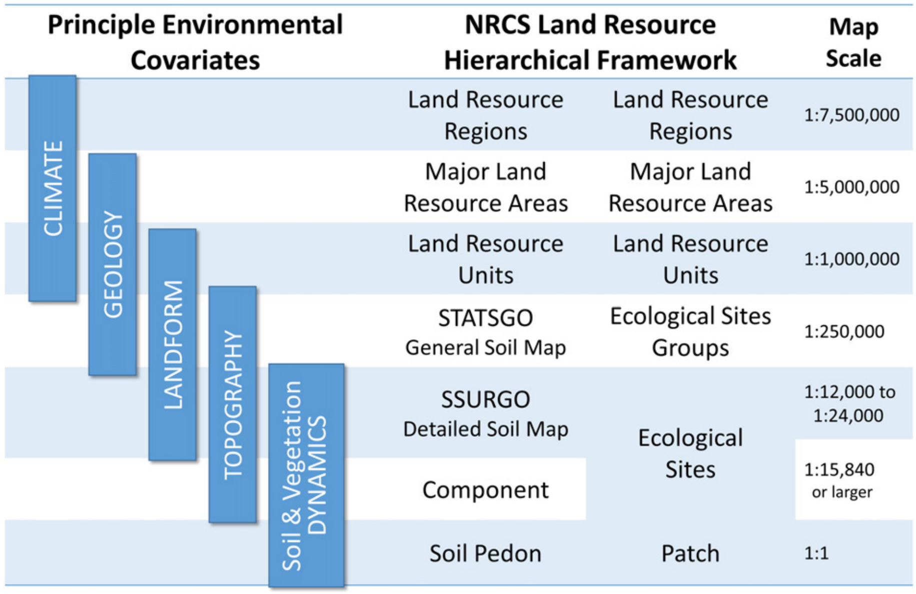


**Figure 2.** Proposed relationships between predictor variables and the NRCS Land Resource Hierarchy at specified map scales. Scales taken from Salley et al.[1]

also contained in narrative form within the Ecological Site Information System.[18]

The greatest limitation of the LRH is the lack of connectivity among scales in the hierarchy. Three important steps should be made to complete the LRH. First, each scale in the hierarchy must be well established and firmly set through cartographic standards and minimal size delineations. Second, respective scales should be defined based upon overriding environmental factors that control those set scales temporally and spatially. Finally, each mapped geographic unit in the LRH must include synthetic and quantitative "taxonomy" defining each component.

A recent amendment to the *Soil Survey Handbook - Part 649* has standardized resource area definitions through implementation of cartographic standards and minimal size delineations.[19] Cartographic standards exist in most soil maps where adjustments are made regarding the standards of purity based upon the level of precision required by the survey objectives.[6] The use of mapping standards also smooths azonal units (inliers and outliers) occurring at spatial levels smaller than the intended scale of the mapped unit. The expectation is that individual map unit concepts reflect the range and variability of resources in each map unit while maintaining constancy across the entire study area. However, work is still needed to develop policy regarding better quantitative concepts of resource area units.

Advances in the art and science of landscape classification systems over the last 50 years have taught us much in order to have a scientifically defensible and consistent resource hierarchy. Work is still needed to design consistent interpretations for land management and conservation decisions while moving both up and down scales of the resource hierarchy. Implementation of ecological sites for conservation decision making—specifically landscape scale management units—continues to be the greatest impediment for widespread implementation of ecological sites concepts.

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