

## USDA Forest Service TEUI-Geospatial Toolkit: An Operational Ecosystem Inventory Application

Haans Fisk<sup>1</sup>, Robert Benton<sup>2</sup>, Corey Unger<sup>3</sup>, Timothy King<sup>4</sup> and Sharie Williamson<sup>5</sup>

<sup>1</sup>USDA Forest Service, Remote Sensing Applications Center, 2222 W. 2300 South, Salt Lake City, Utah 84119, [hfisk@fs.fed.us](mailto:hfisk@fs.fed.us)

<sup>2</sup>USDA Forest Service, Remote Sensing Applications Center, 2222 West 2300 South, Salt Lake City, Utah 84119, [robertbenton@fs.fed.us](mailto:robertbenton@fs.fed.us)

<sup>3</sup>Utah Geology Survey, 1594 W. North Temple, Salt Lake City, Utah, 84114, [coryeunger@utah.gov](mailto:coryeunger@utah.gov)

<sup>4</sup>Gray & Pape, Inc., 1318 Main Street, Cincinnati, Ohio, 45202, [tking@graypape.com](mailto:tking@graypape.com)

<sup>5</sup>USDA Forest Service, Geospatial Technology Center, 2222 West 2300 South, Salt Lake City, Utah 84119, [smwilliamson@fs.fed.us](mailto:smwilliamson@fs.fed.us)

### Abstract

The TEUI-Geospatial Toolkit (Toolkit) is an operational ecological inventory application used by the USDA Forest Service and other land management agencies. This resource mapping tool complements traditional inventory methods by streamlining the collection and analysis of inventory information in a digital environment.

The Toolkit is based on the Forest Service Terrestrial Ecological Unit Inventory Technical Guide, which complies with the National Cooperative Soil Survey (NCSS) standards. It is intended for resource specialists with a strong background in terrestrial mapping and basic geographic information system (GIS) skills. This Environmental Systems Research Institute, Inc. (ESRI) ArcGIS™ mapping tool guides the user through the TEUI mapping process and helps stratify landscapes and analyze environmental characteristics with geospatial data. Products derived with this operational mapping application comply with corporate data standards and are stored in corporate database systems.

Design, development and operational support are performed by the Forest Service Remote Sensing Application Center (RSAC). RSAC provides technical assistance to field units and increases application awareness at various meetings, workshops, and conferences. Staying connected with the TEUI soil mapping community establishes an essential feedback loop for gathering new ideas and enhancing application functionality. This paper provides an overview of the current application and highlights specific mapping and data analysis functionality. It also identifies specific benefits that are realized through geospatial technologies as the Toolkit is implemented in the pre-map phase of a TEUI project.

### 1 Introduction

Terrestrial Ecological Unit Inventory (TEUI) is the land survey system used by the Forest Service for classifying and mapping ecological types. Ecological types are defined by abiotic and biotic environmental factors that incorporate combinations of climate, physiography, geology, soil, and vegetation. The purpose of TEUI is to classify

ecosystem types and map land areas that have similar management capabilities (Cleland et al. 1997).

The TEUI Technical Guide (Winthers et al., 2005) provides methods and procedures for inventorying lands administered by the agency. TEUI products include maps, spatial and tabular databases, map unit descriptions, ecological-type descriptions and interpretations. These data are stored and managed by the Forest Service Natural Resource Information System Terrestrial Module (NRIS-Terra). This information provides basic land-unit information for land planners to assess ecosystem capabilities, determine sustainable production levels, and make informed and practical management decisions. For example, it supports ecological and watershed assessments, burned-area emergency rehabilitation (BAER), range-allotment updates, forest-plan revisions, and project-level planning and analysis.

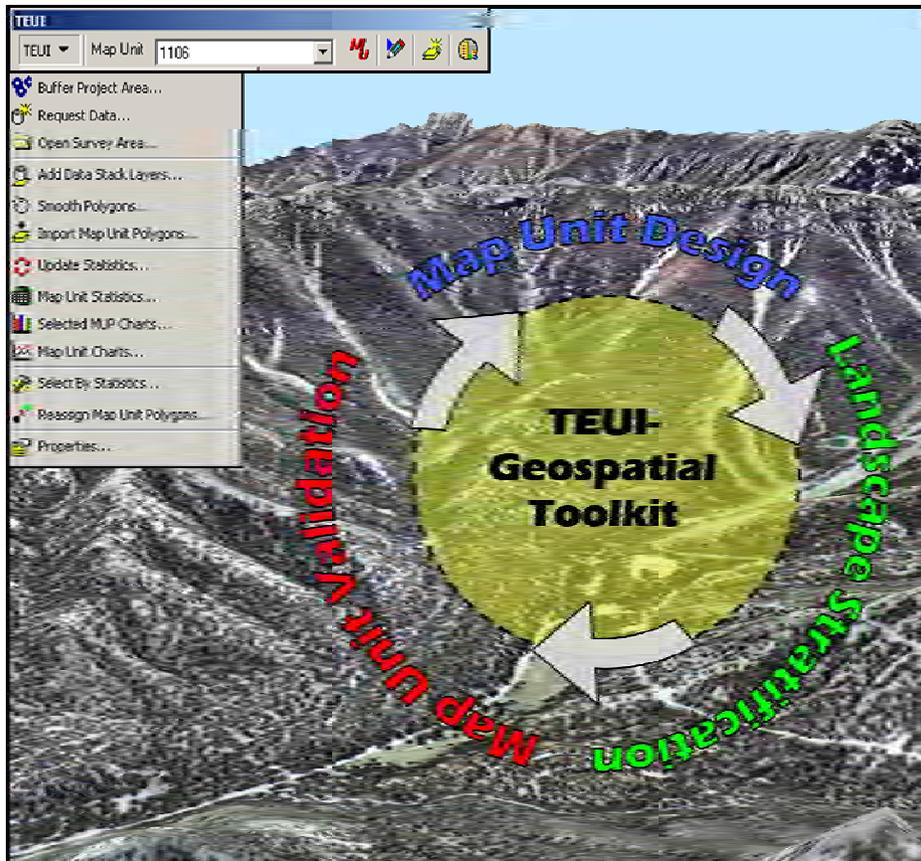
Traditional TEUI or Soil Resource Inventory (SRI) methods rely heavily on interpretation of aerial photography using a stereoscope (USDA Soil Conservation Service 1993). Although this platform has been used for decades, there are drawbacks when applying it across large survey areas. Assembling and preparing hundreds of photographs is time consuming and cumbersome. Characterizing land unit areas and consistently applying map unit delineation criteria may reflect the ability and bias of the individual photo interpreter which compromises the value of the TEUI products. Moreover, once the landscape delineations have been created on hard-copy photographs, additional effort is necessary to transfer line work into a GIS.

As of 2007, 55 million acres of NFS land lacked modern TEUI or SRI, and an additional 18 million acres, although mapped, did not meet standards of the National Cooperative Soil Survey (NCSS). Given the high cost of traditional TEUI surveys (\$2 to \$3 an acre); the Forest Service is leveraging new technology to complete ecological-unit inventory faster and more economically (Fallon *et al.*, 1994; Lane and Fisk, 2002). Remote sensing, geospatial technologies and raw computing power have dramatically improved over the last few years affecting our ability to visualize entire landscapes and stratify repeating patterns more consistently and efficiently. In searching for less expensive ways to conduct TEUI, the Forest Service designed and developed the TEUI-Geospatial Toolkit application to streamline the mapping process and provide resource management a cost-effective alternative to traditional methods.

## **2 TEUI-Geospatial Toolkit**

The TEUI-Geospatial Toolkit (Toolkit) implements the mapping standards prescribed in the TEUI Technical Guide and directly supports field units. The application is designed for resource specialists with a strong background in terrestrial mapping and intermediate GIS skills. The results of research and available geospatial technology are integrated into this digital mapping application as push-button solutions that simplify complex data processing procedures. Thus, end-users can accomplish their tasks more efficiently and increase overall workforce productivity. Built as an ESRI ArcMap extension, the Toolkit

gives non-technical resource specialists the ability to access geospatial data, visualize landscapes, design and delineate ecological map units, validate map criteria, and generate field maps (Figure 1). Resulting output products comply with Forest Service GIS Data Dictionary standards and can be transferred to NRIS-Terra.



**Figure 1.** The TEUI-Geospatial Toolkit implements the mapping protocols provided by the USFS *TEUI Technical Guide*. Standard mapping elements of map-unit design, landscape stratification, and map-unit validation are integrated through an iterative workflow.

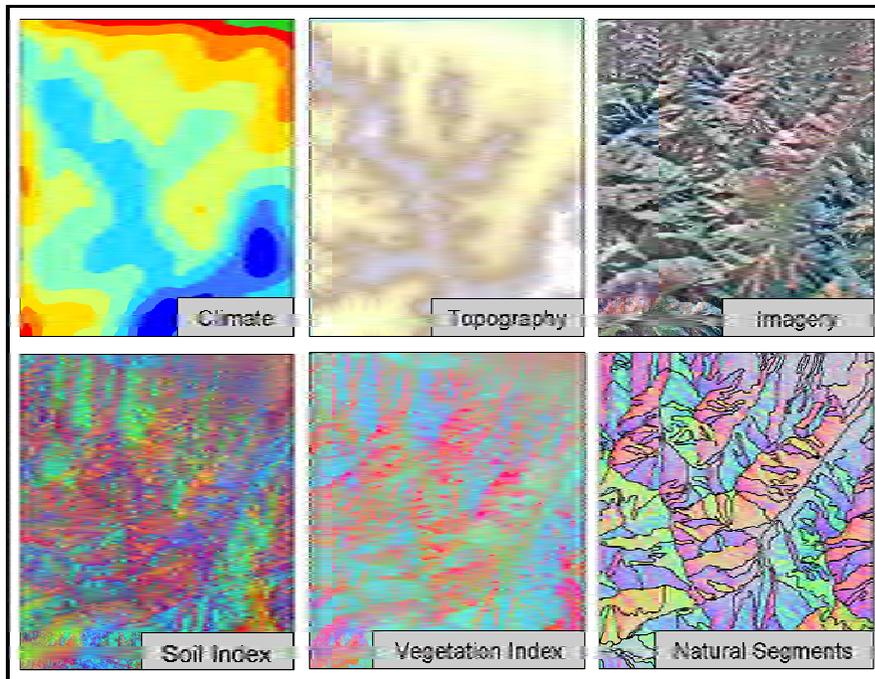
### 2.1 Geospatial Data Acquisition

The Toolkit provides a solution for creating consistent and continuous geospatial data layers and delivering standard products to resource specialists<sup>1</sup>. The standard TEUI geospatial data package (TEUI GDP) contains 32 raster (pixel-based) and 16 vector (point, line and polygon) layers, which provide a foundation for conducting TEUI in a digital environment (Figure 2).

Raster data include topographic, climate, and spectral indices, as well as multi-spectral and multi-resolution backdrop imagery. Vector layers include USFS cartographic feature

<sup>1</sup> It is not required that one request data via the data provisioning system in order to take advantage of the Toolkit application.

files, standard USGS 7.5-minute and 3.75-minute quadrangles and natural segments<sup>2</sup>. To access these standard products, the requestor simply submits a survey area (polygon file) to the TEUI Data Coordinator, who in turn generates the TEUI GDP, compresses it, and returns it to the requestor.



**Figure 2.** The TEUI GDP provides a foundation for conducting resource inventory in a digital environment. Shown above are samples of analytic, vector and backdrop layers in the TEUI GDP.

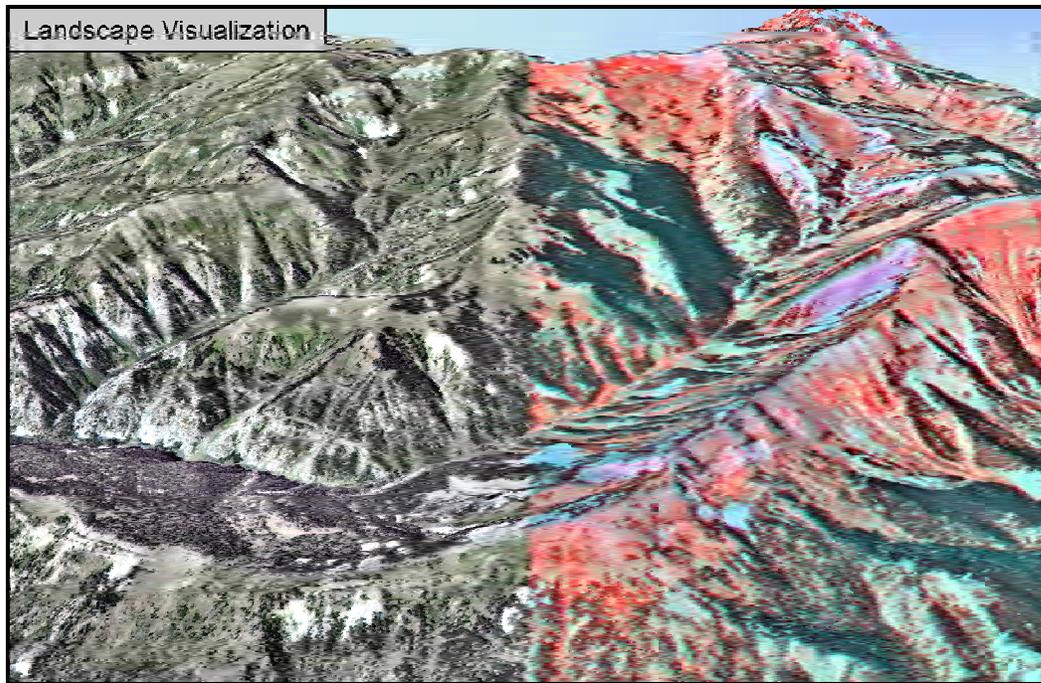
## 2.2 Map Unit Design

Map unit design involves assessing and conceptualizing repeating landscape patterns. As defined in the TEUI Technical Guide (Winthers et al., 2005), map unit design is the “process establishing the relationship between classifications and the products depicting them.” It further states that classification is the “grouping of similar types according to criteria considered significant for this purpose. The rules for classification must be clarified before identifying the types within the classification standard. The classification methods should be clear, precise, quantitative (where possible), and based on objective criteria so that the outcome would be the same whoever performs the definition (or description).”

The Toolkit offers resource scientists three interactive capabilities to develop and capture preliminary map unit concepts: viewing landscapes at multiple scales, viewing landscapes in 3-D and defining map unit properties. Viewing the landscape at multiple scales and in 3-D allows users to develop mapping criteria, identify individual

<sup>2</sup> Natural segments are custom polygon layers that divide the landscape into relatively homogeneous polygons, based on topographic and spectral imagery.

components, and establish a strategy for delineating ecological resources (Figure 3). Once map unit criteria are identified, map unit characteristics are documented using the *Define Map Unit* utility. This interface stores and organizes key information such as map unit symbol, map unit name, as well as lengthier map unit descriptions.

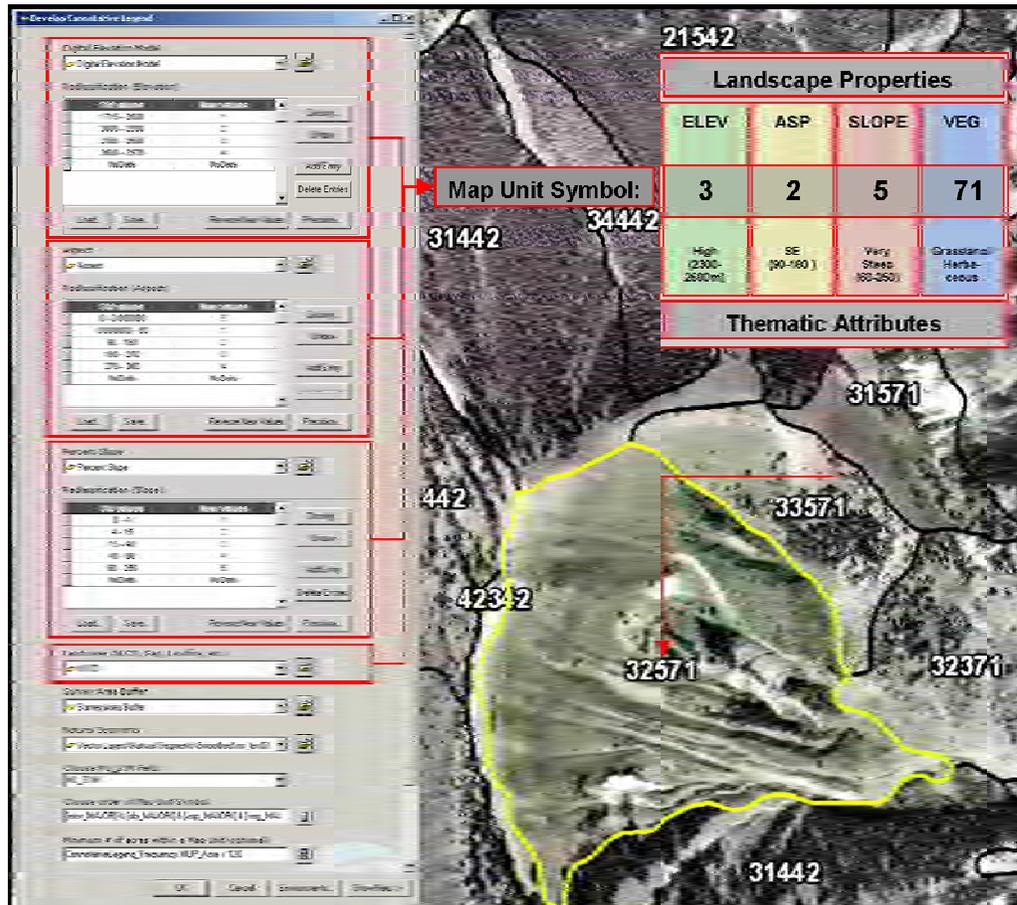


**Figure 3.** The Toolkit uses ArcScene interactive visualization capabilities to display landscapes using a variety of data at multiple scales (a blended ETMDOQ merge). These capabilities enable resource specialists to see landscape patterns and develop mapping criteria. Shown above is a 3-meter ETMDOQ merge draped over a 10-meter DEM surface: *Left* – natural color composite (RGB – band3, band2, band 1); *Right* – false color infrared composite (RGB – band4, band5, band 3).

### 2.3 Landscape Stratification

Landscape stratification is the process of dividing a survey area into repeating ecological landscape units with similar abiotic and biotic soil forming properties. The Toolkit provides two ways to accelerate and enhance the stratification process: 1) digitizing polygons directly into GIS and 2) attributing those polygons with appropriate map unit symbols. Polygons that segment the survey area can be generated through basic heads-up digitizing with the aid of backdrop imagery that provides spatial and contextual reference. The resulting polygons are an expression of the map unit design (classification scheme). Also, map unit polygons can be imported from existing data layers using the *Import Map Unit Polygons* utility and refined using standard ArcMap™ editing utilities to reflect map unit concepts. Using this method, polygon attributes are documented manually. Alternatively, the *Connotative Legend* tool may be used. This tool uses polygons as zones for calculating statistics (zonal majority) for selected layers (e.g., slope, aspect, elevation). The concatenated statistics are used to label each polygon (Figure 4). This compact label is a symbol that repeats over the landscape giving the

resource specialist an appreciation for the representation of the specific map unit across the study area.



**Figure 4.** The connotative legend feature helps organize landscape properties and applies user-defined criteria to predict spatial landscape patterns. The backdrop is ETMDOQ merge imagery (3, 2, 1).

#### 2.4 Map Unit Validation

Map unit validation is the process of evaluating these polygons and assessing the homogeneity of the characterization criteria. This process is part of a cycle in which a) outliers in the classification are identified; b) adjustments to the classification scheme or landscape stratification are implemented; and c) the effects of the adjustments are observed and reevaluated. The resource specialist iterates through this cycle until s/he is satisfied that all polygons adhere to the classification scheme.

The Toolkit provides three features to help evaluate map units: computing tabular statistics, analyzing unit properties, and comparing contrasting map units. Together, these features provide a quantitative assessment of how closely the landscape delineation corresponds to ideal concept underpinning the classification scheme.

Unique to the Toolkit are its analytical charting utilities that allow users to generate, display and summarize a variety of statistical measures used to delineate terrestrial ecological units (Figure 5). These interactive charts provide a new way to integrate environmental raster data into the validation process and better understand the relationships between spatial and tabular data. Overall these utilities help specialists consistently stratify landscapes, quantify landscape properties, and improve the resulting map products.

### *2.5 Map Generation*

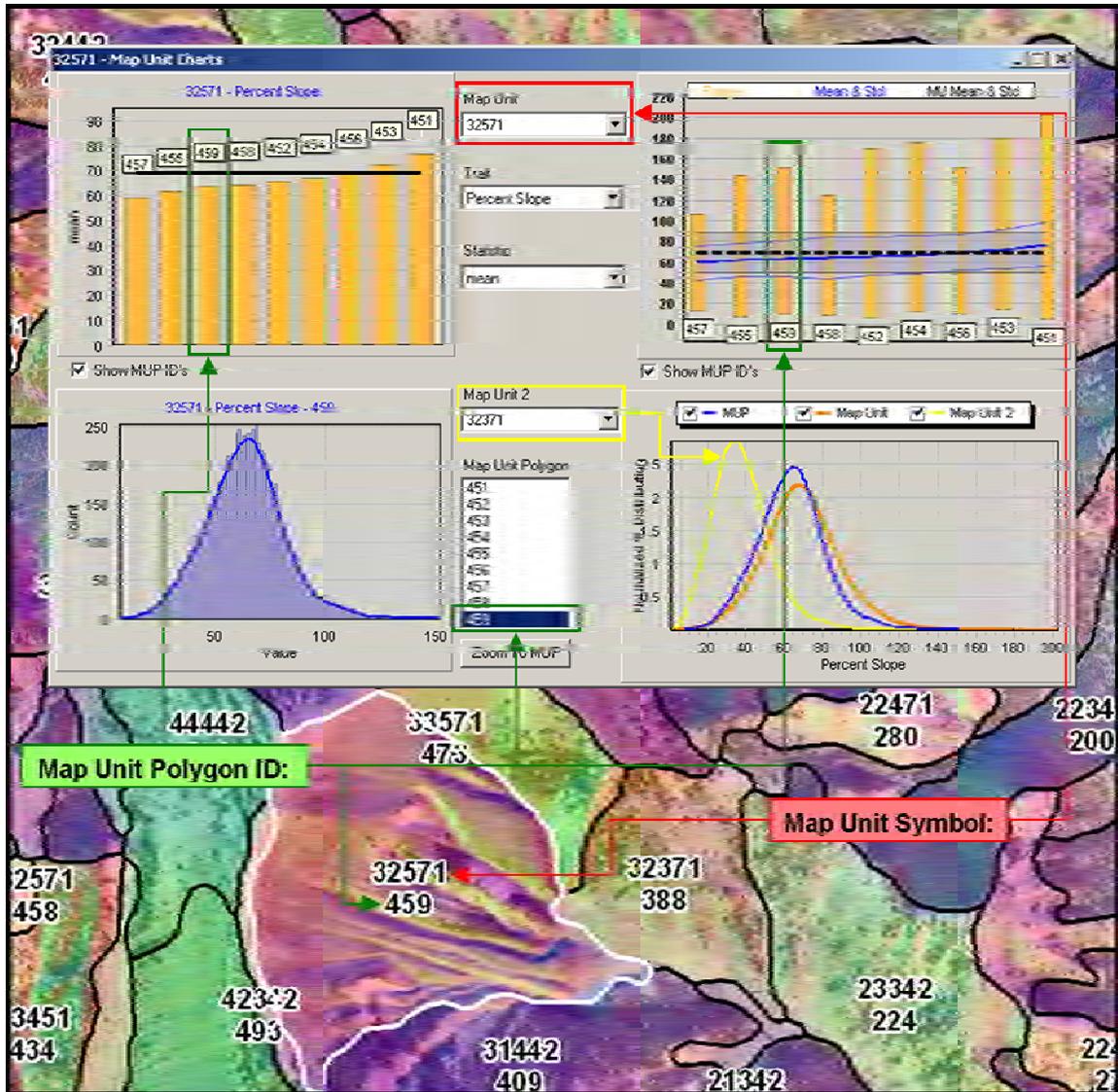
Hard-copy field maps are important tools for collecting field documentation and validating map unit delineation. The Toolkit streamlines the process for generating field maps and provides four standard map templates that simplify and increase the efficiency of map production. Map templates provide the capability to create maps at scales of 1:9,000, 1:12,000, 1:24,000 and a variable scaled map that includes the extent of the study area.

Map layers are automatically symbolized, but can be updated to reflect project specific conditions. Users can also specify an assortment of backdrop imagery and vector layers, as well as include map unit boundaries and representative field sample locations. These maps can be printed as hardcopy or exported to other electronic formats such as PDF. The map template technology is based on Map Books, an ESRI application.

## **3 Discussion**

Since the TEUI-Geospatial Toolkit application is founded on a GIS, a number of advantages are available immediately to the resource specialist. First, the GIS can enforce standards assuring the needs of both the project and the organization are met. Second, attribution is assured. In this way, the value of the corporate database will increase with each project undertaken. Third, integrity rules are explicit within the geodatabase greatly increasing the utility of the data to researchers and other third-party stakeholders.

In a typical TEUI project, the methods described above are sequenced to define a workflow. The most obvious characteristic of the workflow is the iterative or cyclic pattern in which the methods are used for various phases of the project. For example, the sequence of *Map Unit Design* → *Landscape Stratification* → *Map Unit Validation* applies equally well whether in the pre-mapping phase or in the data reduction phase following a field season. What needs to be recognized is that nothing material has changed regarding the workflow as compared to undertakings that do not use the Toolkit. The application simply brings technology to bear on certain activities within the workflow thereby improving the efficiency and effectiveness of the resource specialist charged with completing the project.



**Figure 5.** The analytical charting tools help validate delineation and characterization criteria as well as assess overall map consistency. In the background of the above graphic, preliminary map units are overlaid on a blended ETMDOQ merge and fully illuminated hillshade. In the foreground, the Map Unit Chart shows: Map Unit Chart for map unit 32571 (comprised of nine polygons, 451 through 459 - only 459 visible in display - focused on the trait, percent slope. Features a) the distribution of values for polygon 459 (lower left) and b) population mean of values in polygon 459 against all other polygons in the map unit (upper left). The upper right-hand chart features a number of population statistics for all polygons in this map unit. This chart includes: a) the range of values (orange bar), b) the population mean for a given polygon (dark blue line), c) standard deviation of values about the population mean for a given polygon (light blue shaded area), d) the population mean for the map unit (dotted black line) and e) standard deviation of values about the population mean for the map unit (light gray shaded area). Finally, the chart at the lower right features the distribution of population values for a) the selected map unit polygon (dark blue line), b) the map unit to which the selected polygon belongs (orange line) and c) another map unit, in this case 32371.

The Toolkit provides a convenient link to ESRI's ArcScene™ application<sup>3</sup> that supports and enhances initial reconnaissance efforts of pre-mapping. The *Navigate* and *Flyover* tools provide insight regarding the logistics facing the field teams. By draping assorted backdrop imagery (e.g., multispectral Landsat ETM or high-resolution NAIP) over a digital elevation model (DEM), the resource specialist can have a virtual tour of those areas that may present hazards or challenges to a ground crew. If these areas must be visited, adequate provision can be made to support the team and ensure its safety. Alternatively, it may be that landscape delineation revealed that such areas are well represented in areas that present fewer challenges to access. Under such a situation, the priority to visit difficult terrain can be lowered and perhaps avoided altogether.

In the pre-mapping phase of the project, it is expected that the soil scientist will define some preliminary delineation. S/he has a number of options for creating the initial set of polygons – a) digitize polygons from scratch, b) import existing line work, or c) make use of the generated natural segments. Without regard to the method chosen, one of the benefits of using a GIS is immediately apparent. Landscape delineations can be visually inspected and assessed right at the workstation. For example, by draping the preliminary polygons over high resolution backdrop imagery, the soil scientist can observe whether image patterns align with soil delineations. A great degree of alignment suggests that the classification scheme used to delineate the landscape is also expressed by other measures that serve as proxies for soils. The degree to which there is disagreement or conflict between the preliminary polygons and other soil proxies can cause the resource specialist to reflect on the tentative classification scheme and consider changes that may bring about better alignment. This refinement can be completed in a GIS environment in a fraction of the time it would take to replicate the process using traditional aerial photography.

Finally, the prospect exists to develop more than one classification scheme and associated delineations during the part of the season that is not suitable for field work. When the field conditions improve, early field samples can quickly reveal which of the classifications is likely to best represent the ground conditions. Should sampling requirements differ significantly between the schemes, field teams could be deployed with greater efficiency resulting in a savings in both salary and travel expense.

## 5 Conclusions

The Forest Service needs soil or basic terrestrial resource information to practice sustainable resource management. The TEUI-Geospatial Toolkit supports resource management by integrating geospatial technology with Forest Service TEUI protocols and is used by the USFS and its partners as a cost-effective and credible alternative for consistently collecting natural-resource information. It bridges an important technology gap that exists for many resource specialists and streamlines their workflow by enabling them to access geospatial data, design ecological map units, delineate landscape patterns,

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<sup>3</sup> ArcScene is licensed separately from ArcMap. In order to access ArcScene functionality, a license must be secured.

analyze map unit properties and generate standard field maps. Products derived using the Toolkit comply with corporate information-system standards.

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