The following article is a continuation of the story of Turtle (Indorante, 1986), a fictional field soil scientist in the later stage of an enjoyable career (Fig. 1). New technologies like GIS, multi-spectral imagery, high-resolution elevation data, etc. have emerged, while new colleagues have entered into Turtle’s life. The new techniques and data fit right in with the tasks required of field soil scientists. However, new ways of thinking are required to utilize the new tools effectively. The latest chapters of this pedological tale explore these new technologies with a few new colleagues Turtle has gained.

In Part III of the series, Turtle was advised by Eagle and Bear to carry on the study of the spatial component of soil mapping using the current tools of the geographic disciplines. Some of the more important topics discussed by the curious earth scientists follows.

On Soil Maps

**Eagle (E):** What is a soil map?

**Turtle & Bear (T&B):** At the most basic level, a “good” soil map groups soils geographically that are similar and separates soils geographically that are different.

**All:** What could be improved?

**All:** Soil map accuracy and precision could be improved by applying digital tools to a traditionally analog process, within the context of understanding the soil-landscape relationships.

**E:** Expand on that.

**B:** As Hudson (1992) stated, it is the predictable pattern of soil occurrence that has allowed us to map large acreages with minimal observations of the soil itself. The process of consistently identifying similar landform segments is what has and remains to be the most difficult step in producing a good soil map using analog techniques. For example, the ability to identify areas that have concave profile curvatures in lower side slope positions with slopes less than 5% is a straightforward proposition using GIS/RS software. In addition, the results would be repeatable and easily expressed to end users in the form of rules, e.g., this soil occurs where profile curvatures are less than A, with a relative position between B and C on slopes less than D. We were confident in providing qualitative descriptions in the pre-GIS/RS days but were never confident that we could say that a particular setting as described was mapped with accuracy and precision within a soil survey project, let alone across soil survey projects.

**Fig. 1.** Turtle and Bear reviewing their latest GIS/RS soil mapping efforts.

**T:** There is no question that if the present day data, software, and skills were available during my early days of mapping, I would have made better soil maps. I would also have been sure there was consistency among my crew. That is not a knock on the work we all did. We produced the best product possible given the tools available at the time. We had hand probes, sharp shooters, clinometers, USGS topos, and stereo paired aerial photos. We used the clinometers, topo maps, stereo pairs, and our walking feet for topographic control. We thought we had it made! The present day tools are more like a surgeon’s scalpel, while the older tools were more like a stone ax.

**E:** If Dukuchaev, Glinka, Hilgard, Marbut, or any of the early pedologists had GIS/RS tools in their day, I absolutely think they would have used them. I think the early soil surveyors that mapped a county over the course of one field season would have used these tools too.

**On Legacy Soil Mapping and Slope Classes**

**E:** Why is slope class a criterion for mapping soils?
various parts of the United States (Indorante et al., 1996). The history and
with the goal of understanding soil land-
T:
T&B: Well, it is important to remember
that the maps in a soil survey report are
not soil type maps but are soil manage-
ment maps. Map units are intended to
delineate uniform management areas,
not uniform soil areas. Slope gradi-
ent is an important potential limiting
factor, and in the past, there wasn't much
information related to things like slope
gradient. It was not that long ago that
USGS completed the 1:24,000 scale topo-
graphic quadrangle map series for the
continental states. We remember when
the 1-inch-to-the-mile topographic maps
were common. Having a slope class
phase was important as a matter of char-
acterizing the landscape for the USDA as
part of the soil survey program. At the
same time, soil scientists were gaining
a better understanding of the relations-
ships between soil distribution and slope
characteristics (e.g., soil landscape). In
the 1950s, 1960s, and 1970s, regional soil
landscape projects were carried out in
various parts of the United States (Nettle-
ton and Lynn, 2008a, 2008b; Fenton 2010),
with the goal of understanding soil land-
scape relationships to improve the speed,
utility, and accuracy of soil survey. These
regional studies were critical in the birth
and acceleration of modern soil survey (Indorante et al., 1996). The history and
impact of these studies is recorded in the
legacy soil maps, soil classification, and
soil surveys in the areas of the respective
studies, as well as in refereed scientific
literature.
T: Historically, a soil map with slope
classes provided a huge amount of
information that was desired for char-
acterizing soil and land resources for
the nation. This information was not
available anywhere else as a synthe-
sized product. In addition, slope class
became very important as USDA pro-
grams began to put conservation
requirements on some agricultural pro-
ducers starting in the mid-1980s. Over
time, it was discovered that slope was
a very strong predictor of soil distri-
bution. The soil-forming glasses that
Dr. Owl prescribed helped me focus on
soil–landscape relationships that helped
segment the landscape, grouping simi-
lar soils and separating dissimilar soils
geographically. Dr. Owl emphasized the
importance put on the proper use of the
genetic glasses with flip-down taxonomic
glasses. Use the pedogenic glasses first,
and then use the flip-down taxonomic
glasses—flipping back and forth between
the glasses helped to make a good soil
map.
On Digital Soil Mapping
and Slope Classes
E: That explains why it was done in the
past, but what about present day, con-
sidering the increased availability of
high-resolution elevation data derived
from LiDAR? Wearing glasses to map
soils seems so yesterday.
T: All of the new GIS/RS tools are just
modern technology versions of the orig-
inal pedogenic glasses prescribed by
Owl, optometrist in the town of Even.
The “earth” glasses that let us see GIS/RS
data are a much more powerful prescrip-
tion, but like any prescription, they can
be used properly or abused.
E: What do you mean by used or abused?
T: Take the slope (topographic) factor in
the pedogenic glasses prescription. My
glasses were able to identify landscape,
landform, and landform component level
units. The current GIS/RS data layers (e.g.,
LiDAR) are very detailed, and it is possi-
ble to focus too closely on the micro-scale
topographic variability at the expense of
viewing the connectivity and contin-
uity and cross-scale relationships of
natural landscapes (Roecker and Thomp-
son, 2010). There is a distinct possibility
that the “hole mappers” of traditional
soil survey could now morph into “pixel
mappers” of the current era of digital soil
survey.
E: So it is possible to have too strong a
prescription?
T: For now, yes. I think that Bear has
something to say on this subject.
B: It is a given that slope gradient is a
factor in soil genesis. It helps us group
similar landscapes and landforms, which
in turn, helps us separate and group soils
accordingly. All soil series have slope
parameters as a range in characteristics,
with some series confined to the low or
high end of the slope spectrum and others
spanning a wide range of slopes.
After our many talks with you Eagle, we
think it would be preferable to dispense
with slope phase and just map the soil
series or class. When we develop slope
maps from high-resolution DEM and
compare them to our legacy polygon
slope classes, we are often discouraged.
We can see many areas defined by the
slope class maps that are outside of the
slope classes defined by soil polygons. It
has been common to see discrepancies
occupying 40 to 50% of the area when we
have compared SSURGO slope classes to
slope classes derived from high-resolu-
tion DEM. At first, we thought the data
were suspect, but we can’t recall many
cases where the LiDAR was wrong and we
were correct. We think the improved
data will allow us to shift to a higher
level of precision for slope estimation,
improving mapping consistency.
A soil scientist is no match for accurately
determining and mapping slope grad-
ient when compared with LiDAR. Once
upon a time, we soil scientists could feel
pretty good about our abilities to define
delineate slope classes with our stereo
photo pairs and clinometers when com-
pared with a 30-m DEM. We can no
longer make that claim when deal-
ing with LiDAR, and the more we think
about it, the more convinced we are that
slope phases just complicate the soil map.
On Polygon Data
E: Are the slope class phases the problem
or is it the map unit polygon data model?
T&B: A little of both, since they are related.
The map unit polygon data model was
the only option available in the past
and has proven to be quite useful. We
have discussed the imprecise nature of
As for the slope classes, soil scientists were often asked to generalize slope classes, thereby compromising the task of mapping a natural landform segment. Given the increased availability of high-resolution DEM, it would be possible to dispense with slope class phase altogether. An end user could group slopes any way they see fit using DEM and combine them with a raster soil map. In fact, a new raster-based system could be developed that uses raster versions of all variables related to particular interpretation and output cell-based ratings or interpretations.

E: That is a big change, but I think I can see this...

T&B: Yes it is, but data and software available today provides a tremendous opportunity that was not available in the past. Legacy or current soil surveys were developed as a data synthesizer, since there were no other sources available. Now that new tools are available that perform the job better, the need to synthesize things like slope class equally for all map unit polygons is less important and may not be appropriate to include in legacy soil geographic databases.

E: There would need to be an educational effort in how to use a soil map that may be more detailed compared with a map unit polygon map. There are different scales of precision and levels of confidence for each variable used in an interpretation or rating. The system of fuzzy logic currently used for soil interpretations provides a nice framework for continuing something like a completely raster-based system. New terms will also need to be developed and defined to enhance communication among soil scientists and soil survey users.

T&B: That could work well. As you said, this would be a big change from the current system, but it should be a change that provides great benefits to the user. Furthermore, there is already some evidence that users are ready for raster soil maps (Grunwald et al., 2011).

On Raster Data and Soil Maps

E: We have discussed the raster data model for some time. Would it work?

T&B: The raster data model seems to be the next logical step. Large amounts data in standard formats are becoming available in raster form like imagery, elevation, LiDAR vegetation derivatives (canopy height, biomass, and vegetative density), electromagnetic induction, gamma spectrometry, and climate, to name a few. The use of data like these for mapping soil classes and properties is well documented (McBratney, et.al, 2003). Keeping the output data in the same format as the input makes sense. Raster soil survey products have been reviewed favorably (Grunwald, et.al. 2011). We have a 100-plus year history using the polygon model and a vast infrastructure designed to support it, so it will take a period of time to transition from our current polygon model to a raster model, especially when considering the associated database.

E: Speaking of the attribute database, how valuable is a perfect database if the geographic representation of soils on the ground is flawed?

T&B: Both are required to have the best product possible. With regard to data management, there is a tendency to treat the spatial and tabular data as separate entities. A large emphasis has been placed on the tabular, and rightly so, but the spatial has often been ignored or neglected.

E: I always chuckle at the old soil mapping analogy, “would you rather map soils on the back side or the front side of an aerial photo?” Does that apply in the present day?

T&B: That analogy is timeless. Aerial photography and stereo-photography, in particular, revolutionized soil mapping. Much can be inferred from an aerial photo, and it was an indispensable tool that helped us inventory much of the USA. Given the tools available today, spatial data processed with GIS/RS can be considered the “front side” of a symbolic aerial photo while a plain orthophoto occupies the “back side.” That statement is a little extreme, but the capability to synthesize, categorize, and classify these various raster datasets for the purpose of mapping soils should not be underestimated.

T&B: These GIS/RS-based tools could help us convey soil–landform relationships to soil scientists more effectively than oral tradition and on-job training.

E: You mean arm waving only goes so far?

T&B: Right, when you can describe something qualitatively in the office and show it in the field, it is effective. When the qualitative is defined quantitatively, mapped in the office, downloaded to a device, and taken to the field, it becomes even more effective.

E: Don’t forget the inverse operation: collecting georeferenced data in the field and coupling it with data in the office to help quantify the setting of soils.
T: Good point. The ability to collect, define, and “project” one’s understanding of the soil-forming environment is something we could not conveniently do in the past. The software today is more suited to that task than blackboards or whiteboards.

On GIS/RS and Fieldwork

E: Will these powerful tools and data without geopolitical limits eliminate field work?

T: No. In the past, we would sit over a stereoscope to map our lines. That time can now be spent developing relationships with our data and documenting soil distribution using GIS/RS.

B: The stereoscope was only effective when the user above the scope had an understanding of soil–landscape relationships. GIS/RS is the same way. When GIS/RS is coupled with a knowledgeable soil scientist, it can be thought of as a smart stereoscope. An understanding of soil–landscape relationships is required to make effective use of GIS/RS.

E: You make GIS/RS sound too good to be true.

T&B: We don’t mean to, and we are aware that there is no silver bullet. We have both mapped in areas that are unpredictable, and using these techniques may be more time consuming than doing things the traditional way.

B: There have also been situations where the soil–landscape relationships may be able to be determined and mapped via GIS/RS, but their extent is so small that by the time you figure out the soil–landscape relationships, it is effectively mapped.

T: Some of the GIS/RS work I see just looks like a pretty map. Is it really useful?

B&E: There is no question we can produce eye-pleasing maps with GIS/RS. But, which is the “pretty map”—one produced under a stereoscope that has been redrafted two or three times to produce “cartographically” pretty polygons on its way to becoming legacy SSURGO, or a map with quantitatively defined extents and settings produced using GIS/RS? Neither procedure advocates more or less field work. Both procedures require the same understanding of soil–landscape relationships. The difference is the GIS/RS procedure can be explained, defined, and reproduced by others. The polygon map can be explained but falls short when it comes to definition and reproduction. If we assume a common understanding of soil–landscape relationships, the tasks becomes determining the most effective means to “project” that knowledge spatially. GIS/RS is the tool designed to facilitate this task. Not using GIS/RS is akin to playing darts while one’s eyes are blindfolded.

On Accuracy and Confidence of New Soil Inventory Techniques

T&B: What about measures of accuracy and confidence with these new techniques?

E: What metrics are available for the present SSURGO?

T&B: Nothing stated in the tradition of accuracy assessments or confusion matrices exists for SSURGO. The reason for that, in our experience, is the practice did not exist for much of the time period when the soil survey was taking place. In addition, there is an assumption in most soil surveys that every delineation was visited and the named soil was observed within the confines of the polygon. Some soil survey reports presented information summarizing map unit composition based on transect data (Doolittle, et al, 1989; Linsemier, 1980). There are many examples in the literature related to assessing the variability and accuracy of conventional soil maps (Amos and Whiteside, 1975; Brown, 1988; Wilding and Drees, 1983; Edmonds and Lentner, 1986; Mausbach and Wilding, 1991). The component table provides data related to map unit composition, and there are ranges provided for the physical and chemical properties.

E: I suppose that gets at the issue a bit, but these new techniques typically have the development of an accuracy assessment assumed as part of the process (Malone et al., 2013; Nauman and Thompson, 2014). It is a more straightforward way of reporting the information than SSURGO.

T&B: Our procedures have been in place for a long time, but there is no reason accuracy assessments could not be incorporated in the future products.

E: Regarding the ranges of physical and chemical properties, I’ve always wondered what a representative value (RV) is, how it is determined, and if everyone across the USA uses the same criteria to make that determination.

T&B: Very good question. The RV is not defined statistically. As a result, it may not be consistently defined or applied across the country.

E: What if these were defined statistically so that the data could be populated and interpreted consistently?

T&B: Indeed, if we have enough data, we use something like the mean and two standard deviations for the RV, low and high values. When we don’t have enough data, we have to rely on our best professional judgment and expert knowledge. We are open to suggestions.

E: I like your option when you have enough data but only if the data are normally distributed. Another option could be as simple as selecting the median as the RV and the low and high ranges as a quantile, like 20 and 80%. It would sure make it easier to interpret for users like me.

T&B: It would definitely make it easier for us to explain to users too.

E: Get back to me when that gets resolved.
T&B: Well, we do edit our tabular data quite a bit, so maybe we can get that implemented.

**On the Blending of Old and New Techniques**

T: It is too bad all of these neat tools are coming at a time when the inventory is nearly complete.

B&E: Well, do you throw your knife away when it gets dull, or do you sharpen it again?

T: That is true; refining the product we have created sounds good.

B&E: It is always a challenge to improve an existing product. The existing product will be a huge knowledge base for new maps. Given the choice, a violinist would rather fix a Stradivarius than buy a brand new violin. When you think about it, there is no data set in the world that can match the NRCS soil survey for the extent of coverage, level of detail, or intensity of observation. There is an excellent foundation to build upon. This quote by R.S. Smith, Director of the Illinois Soil Survey, on 27 Sept. 1928 is as appropriate now as it was back then: “I hope the answer to your question is clearly indicated in what I have written. It is that the soil survey will never be completed because I cannot conceive of the time when knowledge of soils will be complete. Our expectation is that our successors will build on what has been done, as we are building on the work of our predecessors” (Smith and Wascher, History of Illinois Soil Survey, Department of Agronomy, University of Illinois at Urbana-Champaign, unpublished, 1967).

T: How would it work?

B&E: Like any new endeavor, the first step is to think a bit, plan a bit, do a few trials, evaluate the results, and then repeat. It will take a few years to work out the details, but there are examples of methods being developed that incorporate legacy maps as inputs for the DSM process (Nauman and Thompson, 2014; Nauman et al., 2012). Once that is done, a reasonable protocol could be implemented for others to follow. We believe harnessing these new tools for evaluating the soil–landscape will help to improve our understanding of soil systems.

T: Who wants to map and refine from the office?

B&E: We all want to get out more often. There will always need to be time devoted to field work to build and verify the work done on the computer. These tools offer the potential to make our field work more targeted and efficient. However, there is no way these tools preclude field work. A soil scientist is required to make it all come together. One example of such work is what is being called disaggregation. The result of a disaggregated soil map is a more refined representation of the soil–landform relationships (Nauman and Thompson, 2014; Nauman et al., 2012).

T: Maybe we will be able to spatially represent what we currently just list in the component table.

B: That would be the good goal.

**On Soil Series and Soil Mapping**

E: Since we are talking about refining, I will be a little provocative and ask a somewhat loaded question. When I look at the plethora of soil series and read the Official Series Description, I would ask you to explain, “What are the differences between the hypothetical James, Seamus, Giacomo, Jacob, Hagop, and Jaime soil series?”

T&B: We thought this was going to be a friendly discussion! The ability to split on minutia may exceed our ability to explain why it is important to do so or if the splits are functional pedogenic breaks that make sense and are predictably identified on the landscape. Brevik and Hartemink (2013) show the growth of soil series over time (Fig. 2). No doubt, mapping in new landscapes during the acceleration of the soil survey added to the numbers, but at some point, it may be helpful to see if these series are actually unique, or if some could be aggregated, deactivated, combined, etc.

**The Quest Continues**

Adopting and using GIS/RS, GPS, and data to better understand the distribution, pattern, genesis, and behavior of soils has enhanced the endeavor for Turtle and Bear. The technology required a learning curve, but it did not get in the way of the process. The many methods available for data mining and classification will ensure the need to stay abreast of new techniques and continued exploration of their respective strengths and weak-
nesses for use in soil survey operations. The pedogenic glasses that Dr. Owl prescribed Turtle 28 years ago to help make soil maps are still useful, but the more modern and powerful tools from Eagle and Dr. Owl help Turtle do a better, more consistent job.

Oh, and one more thing. A pair of reading glasses from Dr. Owl (Fig. 3) in the town of Even can still come in very handy when reading Chapter 5 of Soil Taxonomy—Application of Soil Taxonomy to Soil Surveys (Soil Survey Staff, 1999). The traditional “hole mappers” and the more recent “pixel mappers” are likely to become “whole mappers,” after a good read.

Fig. 3. Dr. Owl, the optometrist, in his office in the town of Even Numbers (Indorante, 1992).

References