

Multi-resolution Multi-scale Topographic Map Design: Toward a New Look for *The National Map*

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ABSTRACT: The pilot study reported here examined the effects on map readability of the interaction of scale change, symbol design, and media resolution. Existing USGS topographic map design was examined in two media (paper prints and computer screen displays) through a range of large scales, with the smallest at 1:24,000. Symbol and label clarity for nine study sites were examined with PDF and ArcMap screen rendering at two onscreen resolutions, 81 and 132 pixels per inch. Generally, maps must be enlarged more at coarse resolution for clarity and PDF views required less enlargement than ArcMap views.

KEYWORDS: topographic maps, map design, USGS, multi-scale maps, screen resolution

Introduction

Success of *The National Map* (TNM) effort lead by USGS relies on readability of maps that present federal geospatial data for the public domain. This work advances topographic map design for two media (paper prints and 81 to 132 pixel-per-inch screens) through scale. Good symbols for well-generalized features at all scales are the keys to readable maps. The study examines the effects on map readability of the interaction of scale change, symbol design, and media resolution using a set of nine study sites prepared in GIS with existing USGS topographic map design specifications.

Background

The overall look and aesthetics of a map and how it is understood by the user have long been a primary focus in cartography, and these concerns extend to online map display. There are a wide variety of sources that provide guidelines for the design of static paper maps, but similar guidelines are sparse for digital media (Lobben and Patton, 2003). The majority of the literature in this area focuses on interactive aspects of map displays (interface design, animation, rollovers, sound, etc.) and their potential for map use, in contrast to investigating thresholds for basic design issues, such as color use, line weights, symbol sizes, and label fonts, styles, and sizes for map elements.

Technical restrictions cause screen presentations suffer to deform graphic elements (Lechthaler and Stadler, 2007). Some of the constraints for design of quality on-screen maps are limited screen resolution, conflicts between screen resolution and minimum dimensions, symbolization, and layer overlay (Oberholzer and Hurni, 2000). Given these limitations, it is important that screen-adapted map graphics (Lechthaler and Stadler) be identified as such, because design specifications for printed maps do not translate well to the digital environment. Because the mapmaker does not know the quality of users' viewing devices for digitally distributed maps, a good starting point is to design for "minimum display standards" (Lobben and Patton, 2003, p. 53).

A map appearance that is aesthetically pleasing is more likely to have higher user acceptance (Harrower, 1997; Lechthaler and Stadler, 2007). In order to achieve this for digital formats, Lechthaler and Stadler make a variety of recommendations, including attention to suitable

graphic density, map resolution adapted to screen resolutions used for presentation, and use of differentiable symbols. They also conclude that the symbols and labels suited to on-screen display will be about four times larger than the symbols for the same map printed at high resolution on paper.

The study reported in this paper also builds on past work examining the interaction of symbol design and feature generalization, funded by ESRI and in collaboration with Barbara Buttenfield (Brewer and Buttenfield, 2007; Brewer et al., 2007; see also ScaleMaster report on ESRI Mapping Center). The research background for the multiscale aspect of our work is well summarized in Mackaness et al. (2007) which presents current research from around the world on multi-representation databases (MRDB) and generalization operators. European national mapping agencies (NMAs) are making progress on integrating topographic data across boundaries and through scales, and much of the research reported in the Mackaness volume is based on European MRDB progress. Buttenfield and Brewer have developed a conceptual tool called ScaleMaster for cataloging design changes and database changes across a wide range of map scales, 1:5,000 to 1:1,000,000 (this ranges from approximate square-inch city blocks to a square-inch for an entire city). Their work presents an approach more suited to the U.S. NMA context with data developed at different scales (rather than working from extremely detailed databases to map the whole country, the approach for many NMAs in Europe).

USGS provides excellent pre-designed maps through the National Atlas for scales smaller than topographic mapping <nationalatlas.gov/printable.html>. Of many online mapping resources, *The National Map* (TNM; <nationalmap.gov>) provides an early viewer for USGS layers <mviewogc.cr.usgs.gov/viewer.htm>; GOS <gos2.geodata.gov>, Map Locator tools <store.usgs.gov>, and commercial efforts such as Topozone <www.topozone.com> provide access to DRGs of existing topographic maps and ortho imagery. USGS staff at Reston and the Rocky Mountain Mapping Center have developed prototype graphic products for new topographic mapping. This project also grows from USGS interest in directing research toward electronic topographic mapping solutions based on the NRC report (National Research Council, 2007) which encouraged the creation of the Center of Excellence for Geospatial Information Science (CEGIS) <cegis.usgs.gov>.

Topo maps at 1:24,000 for the U.S. are on average over 20 years old. For example, the State College, Pennsylvania, sheet's most recent photo updates are from 1987. A portion of this map is shown below (Figure 1). In comparison to consumer navigation mapping with online tools (the same area in Google and MapQuest are shown in Figures 2), new land development is missing from the topo.

The mapping that competes with TNM looks great, given their competent map designs, but they have a limited range of uses (Figure 2). The emphasis of these consumer mapping tools is on human detail, point locations, and route planning. Readable maps are served by these tools regardless of the scale increment requested. Mashups of spatially referenced data with Google basemaps, however, are rapidly changing the usage distinction from TNM services. The success of the *The National Map* program led by USGS relies on readability of their maps that present the important geospatial data resources prepared by the federal government for the public domain (copyright free).

This research is a step toward redesign of U.S. topographic mapping to produce on-demand attractive and effective large-scale mapping for the entire country that supports:

- multiple map uses (recreation, rescue, scientific analysis, planning),
- multiple media (coarse on-screen, high resolution print),
- multiple delivery formats (paper, PDF, interactive),
- at multiple scales (local detail to regional views),
- with integration of geospatial data from local data producers (cities, counties, tribes, environmental agencies),
- to suit all U.S. landscapes (from high relief mountains to urban floodplains).

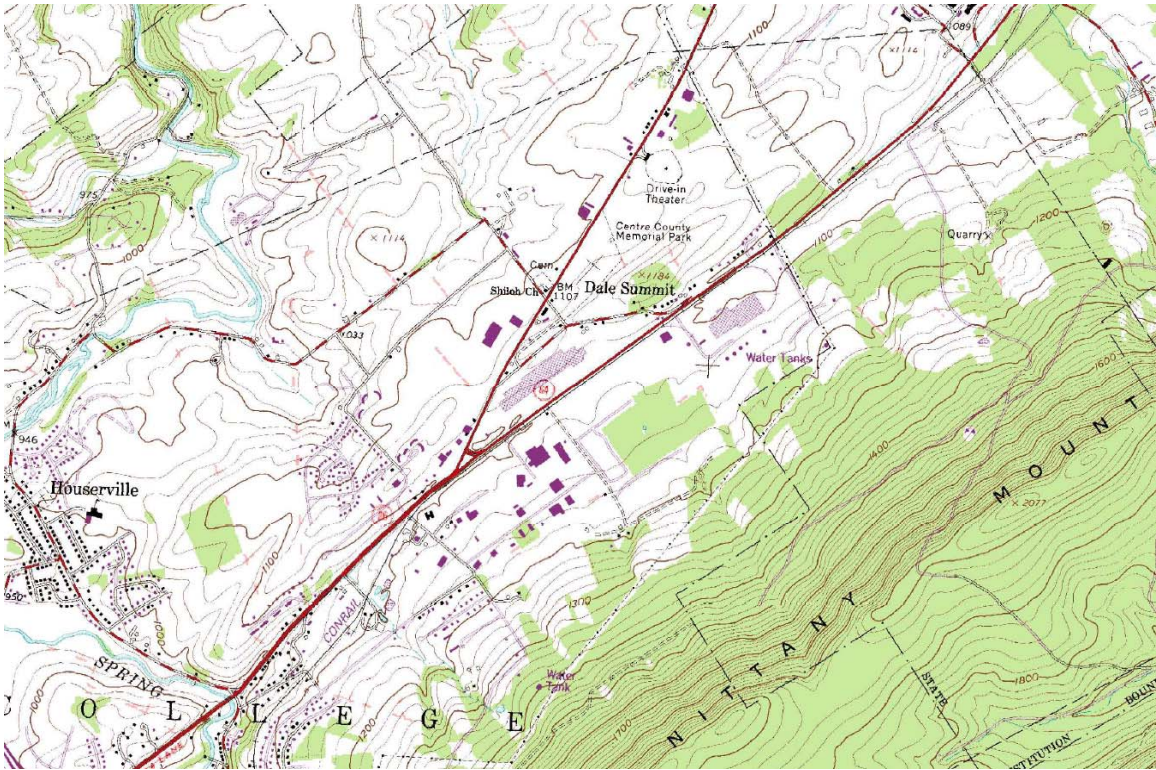
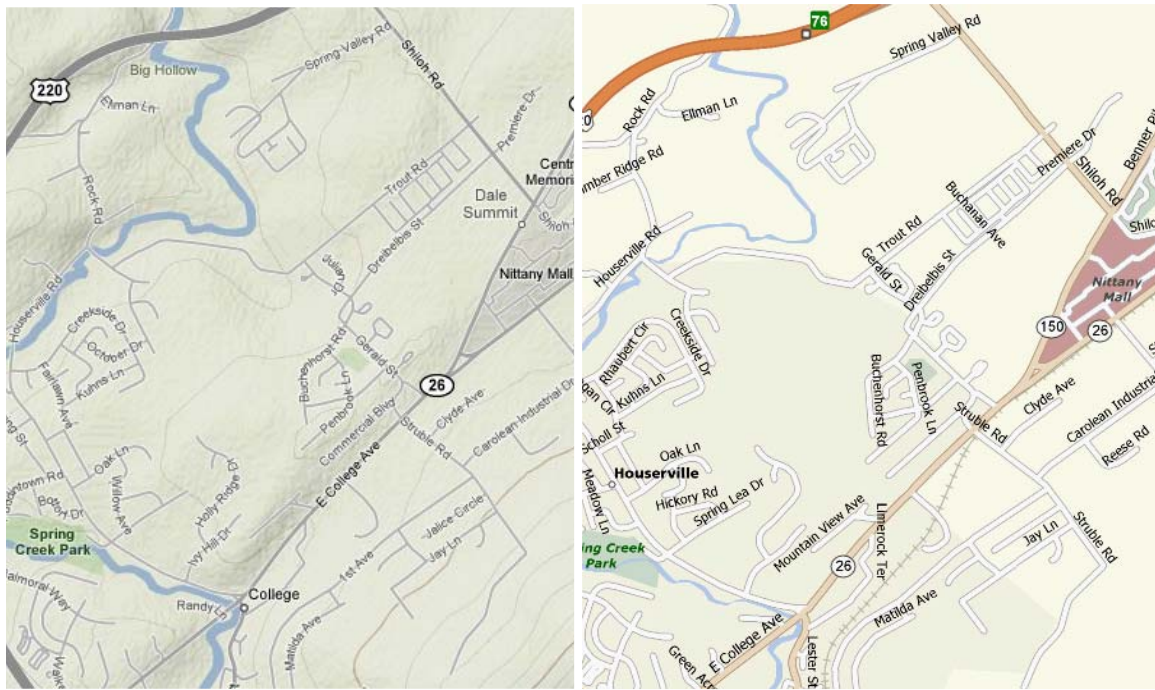


Figure 1: 1987 USGS 1:24,000 topographic mapping for a portion of State College, PA (not to scale).



a)

b)

Figure 2: The competition for TNM. Examples are from (a) Google Maps, Terrain option <maps.google.com>, and (b) MapQuest <www.mapquest.com/maps>.

For topographic data services, many U.S. map users currently rely on raster scans of topographic maps which were designed as paper prints, or they access more limited vector data presented in bold colors and coarse sizes in online viewing tools.

At the same time the country works to build seamless up-to-date digital geospatial data, the public needs a way to look at it—a new topo map design for *The National Map*. Though Google's addition of generalized terrain and contours ('Terrain' option; Figure 2a) further encroaches on the roles of topographic mapping, they guard their product from reproduction, so it is not a viable base for flexible dissemination of research results. For example, Google map terms and conditions make it clear that these data are not copyright-free resources, unlike USGS data:

You may not delete or in any manner alter the copyright, trademark, or other proprietary rights notices appearing in map information, including photographic imagery. Geocoding data for map content in Google Maps is provided under license by Navteq North America LLC ("NAVTEQ") and/or Tele Atlas North America, Inc. ("TANA") and/or other third parties, and subject to copyright protection and other intellectual property rights owned by or licensed to NAVTEQ, TANA and/or such other third parties. The use of this material is subject to the terms of a license agreement. You may be held liable for any unauthorized copying or disclosure of this material, and by using Google Maps you agree to make NAVTEQ and TANA third party beneficiaries of this agreement (from www.google.com/intl/en_us/help/terms_maps.html).

The current inability of university and government researchers to use consumer basemaps for publication and research dissemination is a very important distinction and a key driver for continuing to serve a competent national map. *The National Map* remains the basis of an important national resource.

Objectives

An overall goal of the research—for which this project serves as pilot study—is to create and evaluate new designs for *The National Map* that perform well through resolution and scale change. This goal includes working toward coherence in the look of maps through all scales to allow readers ready interpretation of all topo maps presented within the viewers they use and from their printers. This study approaches that problem by working from the existing 1:24K topo designs to select the scale at which topo design still functions when viewed at coarse resolutions of 81 to 132 ppi (pixels per inch) when viewed onscreen using Adobe Reader for PDF files and and ESRI's ArcMap dataview for MXD files.

Within the context of addressing the problem of map readability with scale change and resolution change (Figure 3), the study objective is to minimize the number of symbol combinations that serve multiple media resolutions. The hypothesis underlying the work is that designs intended for smaller-scale high-resolution displays serve well for larger-scale coarse-resolution—redesign is not needed for each media/viewer capability.

The utility of reaching this goal is sketched in Figure 4. Map designs that function well for high-resolution print displays are noted along the upper axis of the figure, with existing topo designs at scales of 24K (i.e., 1:24,000), 100K, and 250K. Angled lines linking the axes show these designs at larger scales for onscreen viewing, with symbols and labels proportionately enlarged to correspond to the larger scales. For example, the 24K print design is sketched as functioning well at 8K at coarse resolution, and perhaps the 250K design functions well at 210K, less of an enlargement because simpler symbols may be chosen at smaller scales for print.

The utility of systematizing this relationship between resolutions is that designs for all scales and resolutions may be interpolated. For example, the purple line midway along the axes in Figure 4 suggests that an intermediate print design at 170K then serves coarser onscreen display at 100K. These are hypothetical results that offer an example of the overall goals of the research. This relationship may be shown to be unsatisfactory through testing, but it offers a big-picture perspective on coherent topo design through scale and resolution.

Solve these problems together:

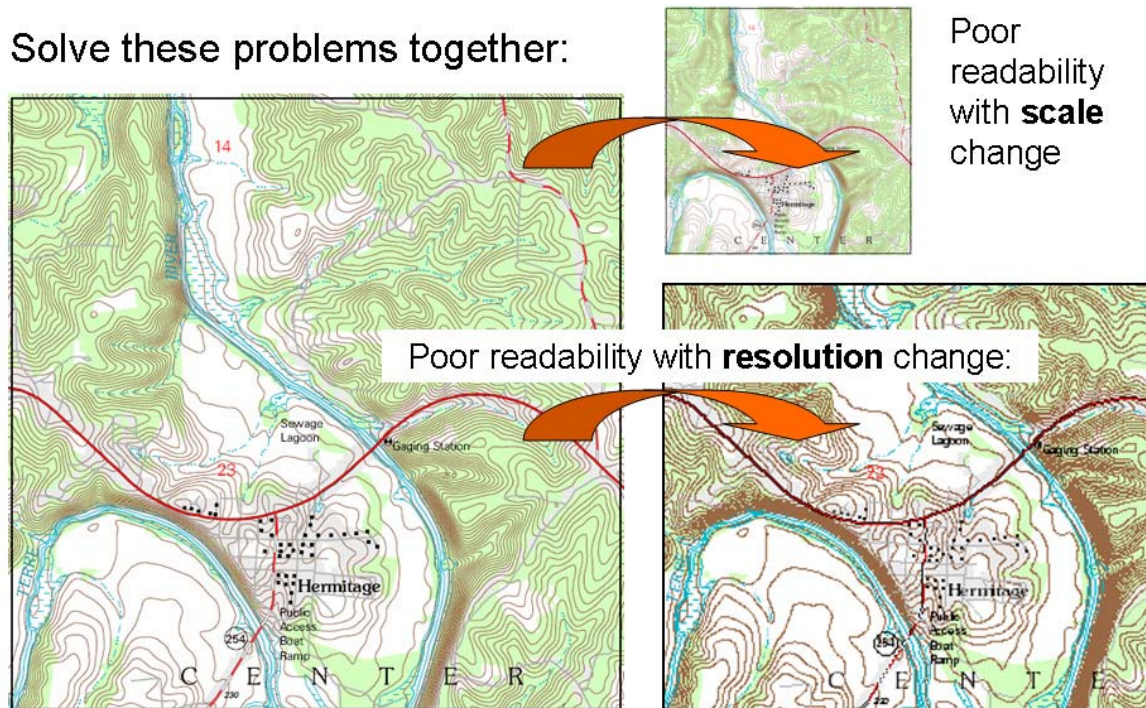


Figure 3: The overall goal of the project (for which the results reported here are a pilot study) is to solve two interrelated problems: poor readability of maps with scale change and with resolution change.

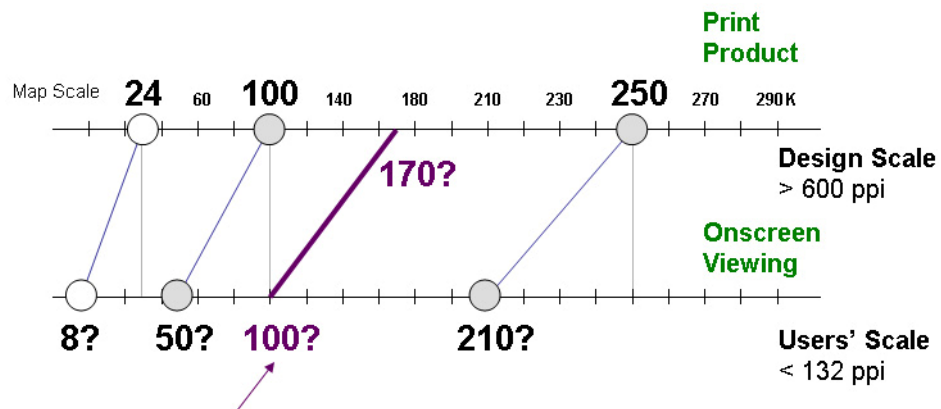


Figure 4: Hypothetical results are sketched, showing a potential relationship between high-resolution print designs and lower-resolution onscreen designs through scale.

Method

In order to determine what topo design changes need to take place for *The National Map*, current (USGS) lithographically printed topographic map specifications were recreated in the digital environment. The design specifications provided by the USGS give a detailed description of how symbols were manually created including symbol colors, sizes, and patterns, as well as typographic choices along with other map sheet production details. This study focuses on symbol design for a subset of features currently available to the public on *The National Map*: transportation, hydrography, boundaries, land use and land cover classes, points of interest, contour lines, and naming. Labels and structures were added manually to sample sites for the pilot study.

The maps used in this study are from three areas in the United States: Portland, Oregon; Upper Suwannee subbasin spanning the Florida-Georgia boundary; and Pomme de Terre subbasin in Missouri. These three study areas were chosen because they vary physiographically and range from dense urban to rural swamp. Portland is a dense urban area, Upper Suwannee is rural and flat, and Pomme de Terre is rural and hilly. Testing the existing topo designs in these three areas is a start at examining how they function through varied physiographic regions of the U.S. with a substantial variety of USGS symbols seen in context. Symbols and fonts function differently in conjunction with surrounding symbol groups in the digital environment and, therefore, applying symbol sets to varied landscape regions is a necessary step in evaluating current USGS lithographically printed designs. These are three of the nine study areas planned for the larger project.

Using the geoprocessing capabilities of ArcGIS 9.2, raw national map data were transformed into more usable forms for cartographic design purposes. The major geoprocessing tasks were dissolving the roads layer to join most small disconnected features, converting raster layers (such as National Land Cover Database (NLCD)) to generalized polygon features, and smoothing and creating contours from DEMs. Figure 5 shows one of the study topo maps designed to existing specs using GIS data compared to a scan of the existing topo sheet. The goal was not to recreate the existing map but to use the TNM data to produce a map consistent with USGS topo print design.

Paper USGS 1:24K topo maps were also purchased for each basin, ranging in age from 1961 to 1993, which served as an important reference for evaluating draft products against existing representations. Though this sounds like it might hold the larger project back from design change, the collection allows checks on DEM processing and suitable place name frequency for example. (The paper maps also show the symbol sizes, textures, and colors in much truer renditions than online DRGs.) Full sets of Souvenir and Univers fonts were also purchased for reproducing the look of USGS topographic maps.

Existing topographic map designs were recreated in ArcGIS using *USGS Topographic Mapping Specifications* for printed maps at scales of 24K as a guide. For the pilot study reported here, 'Part 6' specifications were used (Figure 6 shows example USGS specifications), but continued research will be based on the more current 'Part 5,' <nationalmap.gov/gio/standards/>.

Testing with traditional designs is not a recommendation to stay with existing topo specifications—testing them provides systematic evidence for design changes needed. The tests are conducted with existing topographic map designs to see what aspects fail. These failures provide information on symbols and labels styles that need adjustment. This testing also allows a direct and accurate response to hesitancy about changing from the traditional design with the transition to onscreen map products.

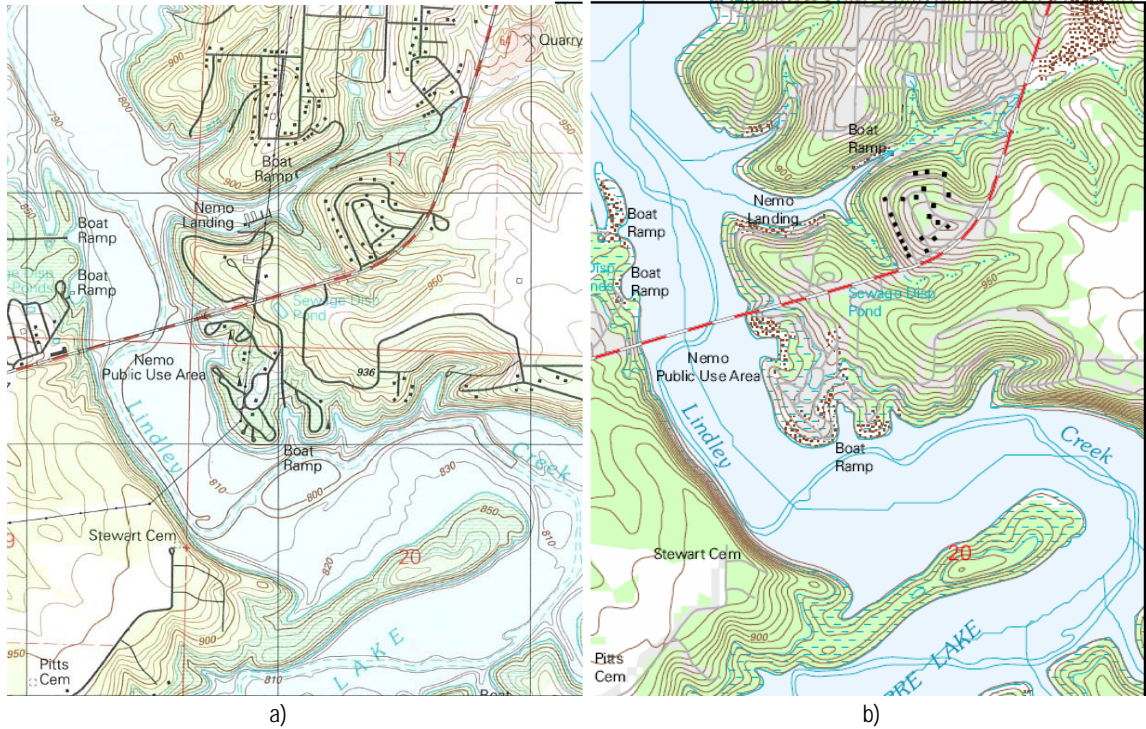


Figure 5: Comparison of a portion of (a) litho-printed 1:24K USGS paper topographic map and (b) a GIS-rendered map produced with TNM data. This location is part of site 1 in the Pomme de Terre (MO) subbasin, shown in Figure 8 below (not shown to scale).

Once the design phase was complete, the next step in the process was to evaluate the USGS topographic map design as rendered by ArcMap 9.2 and Adobe PDF files at screen resolutions of 81 and 132ppi. These resolutions are the minimum and maximum in the study's laptop and straddle the standard 96 ppi for Windows desktop computers (see discussion at blogs.msdn.com/fontblog/archive/2005/11/08/490490.aspx). PDF display was tested because the tactical plan for TNM (Zulick, 2008) calls for use of GeoPDF formats for map distribution to the public. ArcGIS was chosen as a common commercial-off-the-shelf application used for mapping national map data by more advanced TNM users.

ROADS-HIGHWAYS





- 100 Class 1—Primary highway, hard surface, four or more lanes..... 
Overall width to scale with minimum .02". Line weight .003". See symbol 512 for red fill.
- 101 Class 1—Primary highway, hard surface, two or three lanes..... 
Overall width to scale with minimum .02". Line weight .003". See symbol 513 for red fill. Label if 3 lanes.
- 102 Class 2—Secondary highway, hard surface, four or more lanes. 
Overall width to scale with minimum .02". Line weight .003". See symbol 514 for red fill.
- 103 Class 2—Secondary highway, hard surface, two or three lanes. 
Overall width to scale with minimum .02". Line weight .003". See symbol 515 for red fill. Label if 3 lanes.

Figure 6: Example portion of specifications from USGS *Part 6 Publication Symbols* used for the pilot study.

For practical file sizes for each of the three study areas, three sites within the extent of the prepared GIS data were chosen, producing a sample of nine 5x5-inch maps (Figures 7, 8, and 9). Each site was five-inches square at 1:24K, and this consistency proved to be important for confirming scale accuracy in varied display situations (combinations of viewing format and screen resolution settings).



Figure 7: Three sample sites from Portland (OR), an urban landscape.
(maps not shown to scale in Figures 7, 8, and 9).

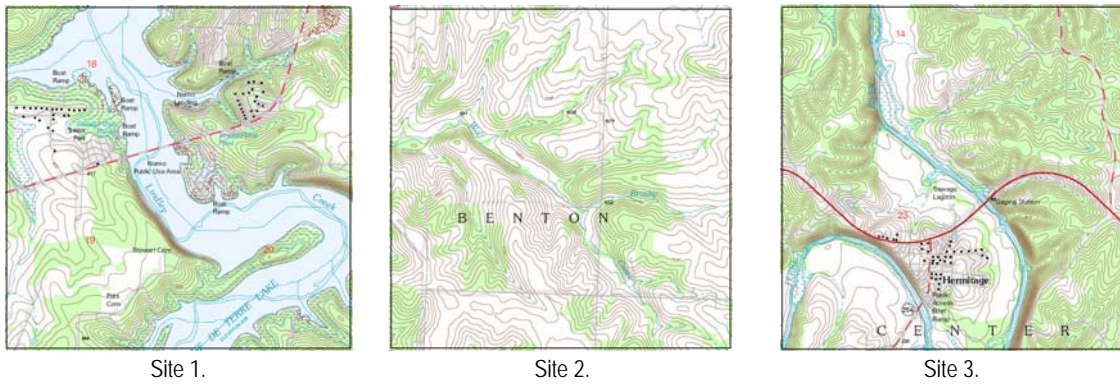


Figure 8: Three sample sites from the Pomme de Terre (MO) subbasin, a humid and hilly landscape

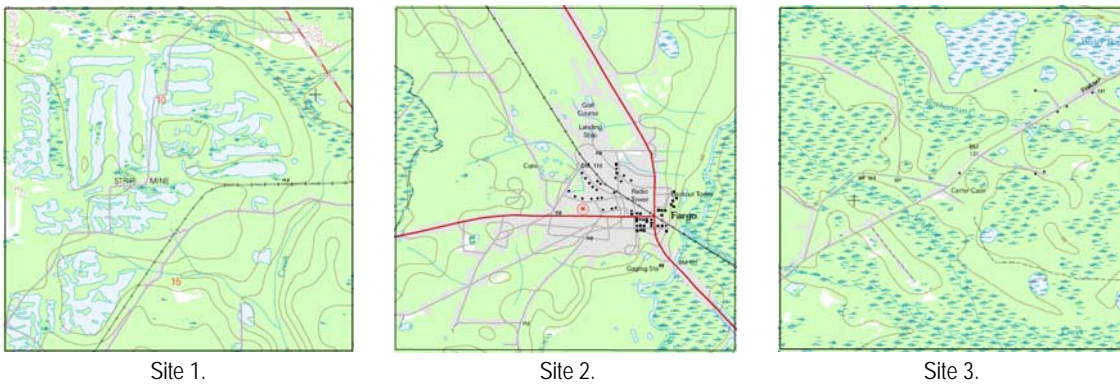


Figure 9: Three sample sites from the Upper Suwannee (FL-GA) subbasin, a humid and flat landscape.

These nine sites were each individually evaluated in four different situations: MXDs in ESRI ArcMap 9.2 at 81 and 132ppi, and PDFs in Adobe Reader 7.0 at 81 and 132 ppi. The evaluation consisted of the two authors examining each site at a given resolution through multiple scales. First, the design was examined at its intended scale of 24K. From this initial evaluation, features that were not readable were determined and the map scale adjusted until all of the features became clear. Scale adjustments were made incrementally in both ArcMap and Adobe Reader, with scale increments of 1000 in ArcMap and 10-percent zoom increments for the PDF. Intermediate scales at which individual features became readable were also determined. For example, large to medium text may be readable at 24K on screen, but the smaller labels were not readable at this scale. Likewise, small text may be readable at a larger scale, but other features such as dashed lines or thin road casings may still be rendered unreadable. To better see the next-most difficult features, the designs were evaluated at progressively larger scales. Once all features were readable, the largest scale to which evaluations progressed was noted as the ‘best’ onscreen viewing scale for the USGS design (Table 1).

This pilot evaluations provided a look into several factors that influence the readability of the current USGS design as well as progress on understanding which symbols must be modified to accomplish the goal of a quality map view for both onscreen and print display.

Preliminary Results

Onscreen map views were evaluated in ESRI ArcMap and Adobe Reader by the two authors and are based on judgments of the readability of many details of the symbols and labels. More complete evaluation of the usability of the map and evaluation of the maps by a larger sample of map users are both appropriate next steps for this sort of research. For this proceedings paper, however, initial pilot results are reported as designs, data, computer screens, and resolutions are still being decided upon for the longer-term project.

The types of failures seen in the evaluation when converting traditional topographic design to coarse resolution onscreen viewing include:

- line symbols blur and adjacent lines merge
- line weights not distinguishable (e.g., index vs. intermediate contours)
- line casings disappear
- line dashes and ticks blur, break, or shift position
- spacing becomes irregular in pattern fills
- pattern fills with small shapes lose definition and bleed together
- labels become illegible when placed on pattern fills
- labels become illegible at small point sizes
- areal features, such as structures, lose angular form

Table 1 provides a summary of the ‘best’ scale for each combination of site/view/resolution. For example, Pomme de Terre site 3 (sixth data row) is completely readable at 8K for ArcMap and 9K for the PDF view at a coarse resolution of 81 ppi. Figure 10 shows the bitmap (BMP) of the screen rendered at 81 ppi by ArcMap; Figure 10a shows a portion of this site at 24K and Figure 10b shows it at 8K where failings in clarity are resolved. At a higher resolution of 132 ppi, the ArcMap view was enlarged to 13K and the PDF view was enlarged to 18K to produce clear 24K symbols and labels. The bottom two rows of Table 1 show summary numbers, the maximum readable scale and the median of readable scales based on data in the body of the table. The median numbers are graphed along scale axes in Figure 11, and similar axes were also presented in Figure 4.

Both resolutions require enlargement from 1:24K for clarity, unless the range of geographic features on the map are very simple. Generally, coarser resolution requires greater enlargement to

retain clarity than finer onscreen resolution. Similarly, onscreen anti-aliasing and other refinements of a PDF viewer allows for less enlargement for map clarity in most cases than the screen rendering capabilities for ArcMap files. These are preliminary results providing an initial indication of the scale relationships among resolutions for an existing topo print design.

Table 1: Summary of 'best' scale judgments for nine sites at two resolutions (81 and 132 ppi) and in two formats (ArcMap and PDF). Scale numbers in the table indicate thousands for the denominator of the representative fraction (e.g., "14" represents a scale of 1:14,000).

<i>Map samples</i>	<i>Resolution: View:</i>	<i>81 ppi</i>		<i>132 ppi</i>	
		<i>ArcMap</i>	<i>PDF</i>	<i>ArcMap</i>	<i>PDF</i>
Portland (OR)	site 1	1:8K	14	13	19
	site 2	7	7	10	10
	site 3	7	8	8	13
Pomme de Terre (MO)	site 1	8	8	13	13
	site 2	8	7	11	11
	site 3	8	9	14	18
Upper Suwannee (FL-GA)	site 1	8	17	13	15
	site 2	8	9	14	18
	site 3	13	16	19	24
max readable scale		7	7	8	10
median of readable scales		8	9	13	15

Concluding Comments

The next research steps are to prepare a wider range of study sites that span a full range of landscapes—mountainous, hilly, flat, urban—and across dry and humid regimes. More detail in characterizing the types of symbol and label failures will be recorded and decisions about appropriate summary measures are intended. The preliminary data presented here are a start on systematizing the relationship among resolutions across a fuller range of scales.

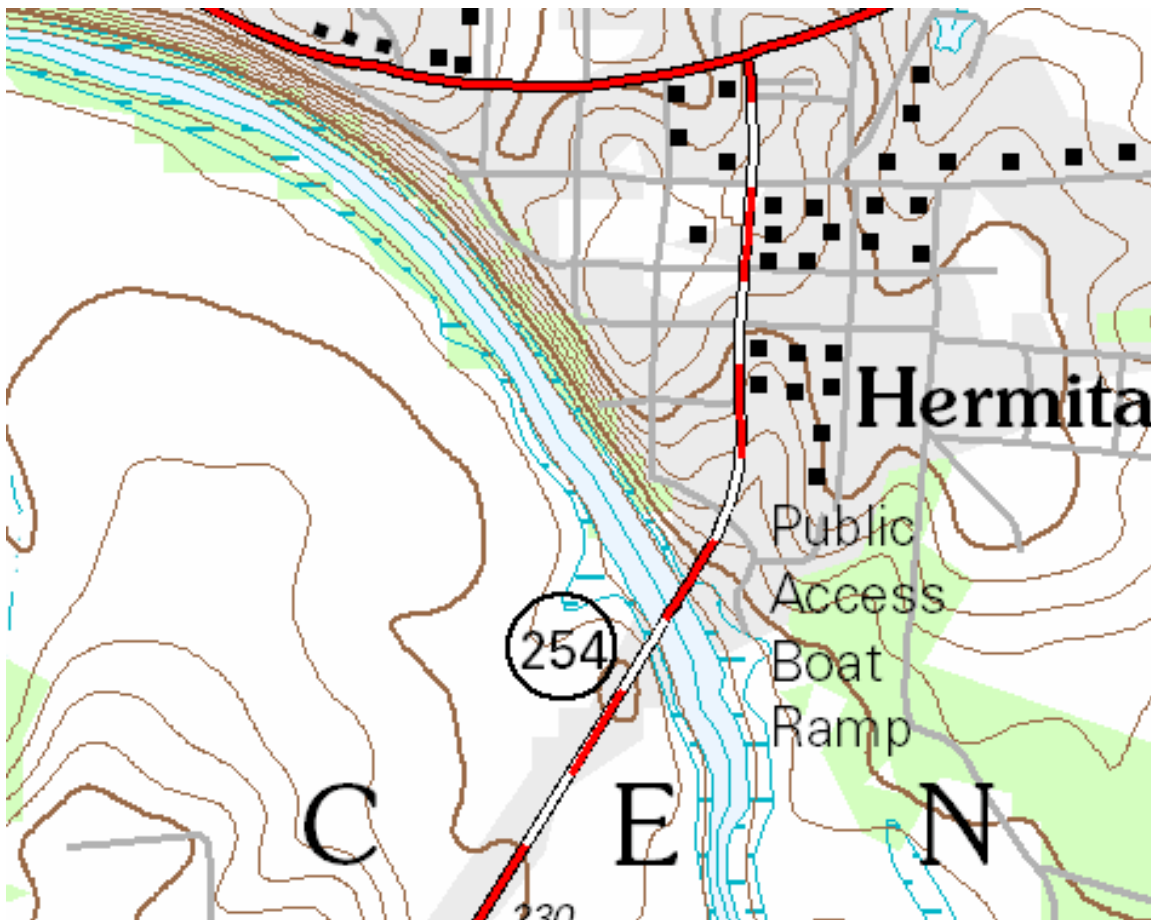
Readable and attractive maps are basic to public use of federal spatial data resources, and readable base maps underpin examination of spatial scientific results of USGS disciplines' research. Access to TNM information content is key to its success (NRC, 2007). Coherence in the look of maps across all scales allows users to interpret all maps presented within viewers they use and from their own printers. This coherence may be produced by minimizing the number of symbol combinations that serve users' varied media resolutions and choices of map scales. The larger goal of the pilot study reported upon is to create and evaluate new TNM designs that perform well through both resolution and scale.

Acknowledgements

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a)



b)

Figure 10: Figure a is a portion of Pomme de Terre site 3 (see Figure 8) captured onscreen when viewed using ArcMap at 81 ppi (the coarsest resolution tested in the pilot). The increased scale needed for readability of the 1:24K symbols/labels is 1:8K (Figure b). In ArcMap, a Reference Scale of 1:24K is set, yielding symbols/labels three times larger when the map is viewed at 1:8K (e.g., 24K line weights of 0.25 points is 0.75 point wide at 1:8K).

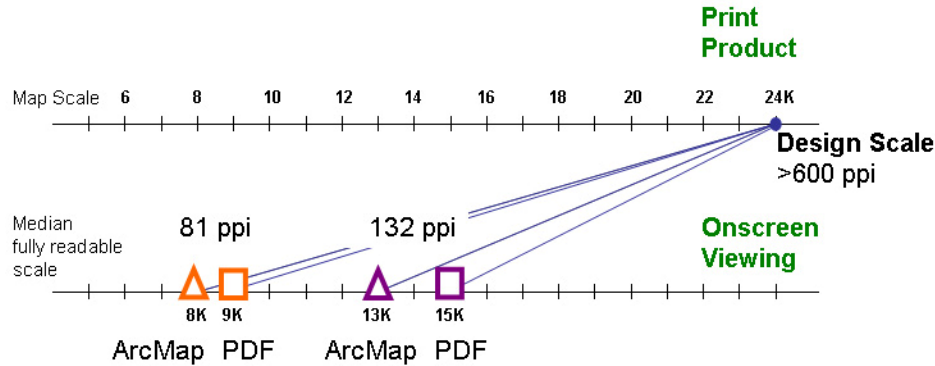


Figure 11: Median readable scales for nine sites with an existing USGS 1:24K top design at two resolutions (81 ppi in orange and 132 ppi in purple) and for two viewers, ArcMap (triangles) and PDF (rectangles). These data are listed in the last row of Table 1.

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