# PERFORMANCE OF MAP SYMBOL AND LABEL DESIGN WITH FORMAT AND DISPLAY RESOLUTION OPTIONS THROUGH SCALE FOR *THE NATIONAL MAP*

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KEY WORDS: Map Design, Topographic Mapping, Multiscale, Multiresolution, *The National Map*

ABSTRACT:

Symbol and label design for U.S. topographic mapping using data from *The National Map* has been progressing, partly in support of research by Buttenfield and Stanislawski on hydrographic generalization, and is sponsored by CEGIS, the USGS Center of Excellence for Geospatial Information Science. The work also seeks to make the best use of GIS for map design that requires no hand-work to make custom adjustments for readable displays. Users of electronic topographic map products may use U.S. topographic maps in multiple media, so the robustness of the designs will be tested across varied landscape regimes and through scale. Maps from hydrographic subbasins in Missouri, West Virginia, Florida-Georgia, Colorado, Utah, Texas, and urban areas of Saint Louis, and Atlanta are evaluated at six scales from 1:24,000 to 1:1,000,000. Map segments for the evaluation are selected to cover a wide sampling of symbol combinations and labeling challenges. Maps are examined on-screen in ArcGIS (MXD) and as a PDF export on-screen. Onscreen views are examined at 96 ppi, common for Windows desktop computer screens, and 130 ppi, representing the higher resolution that laptop computer screens offer. The goal of the work is to systematically refine the map symbols and labels so the resulting map performs well in all of these forms through all scales.

## 1. INTRODUCTION

Three types of evaluations are being conducted for proposed topographic map solutions for *The National Map,* which replaces existing paper topographic map series for the United States. Validation of hydrographic generalizations, by comparing against 1:100,000 Medium Resolution NHD (National Hydrography Dataset; nhd.usgs.gov), and metric evaluation of channel length, network local density, catchment areas, and upstream drainage are progressing (for example, Stanislawski, 2009; Stanislawski et al., 2009, 2010; Buttenfield et al., 2010). Procedures for contextual evaluation are described in this paper and complement the work of Buttenfield and Stanislawski. They involve visual examination and critique of the map design, with generalized hydrography embedded, for map series across a range of scales.

Draft designs for topographic mapping are being prepared from data served by *The National Map* program (viewer .nationalmap.gov/viewer), suited to multiple resolutions—onscreen 91 ppi (desktop), 120 ppi (laptop), print 400 ppi—and to multiple formats (PDF, ArcMap, cached tiles for web display, paper). Preliminary work and continued progress on this multiscale topographic mapping project by the authors is posted at ScaleMaster.org (see also Brewer and Buttenfield, 2007, 2010; Brewer and Akella, 2008) and disseminated through CEGIS, the USGS Center of Excellence for Geospatial Information Science, at carto-research.er.usgs.gov/ generalization (or from cegis.usgs .gov).

Interest in topographic map design has been championed by

Kent in recent years, with his evaluation of European series and general discussions of map aesthetics (Kent, 2009a, 2009b; Kent and Vujakovic, 2009). Forrest and Kinninment (2001) and Collier et al. (1998, 2003) also make in-depth examinations of topographic mapping with an emphasis on Great Britain. The challenge of improving automated mapping at national mapping agencies by evaluating generalization tools and results has been advanced by Stoter (2005) and Stoter et al. (2009).

Topographic maps are not road maps, and Kent (2009a) makes the point that consumer navigation websites do not replace topographic mapping. Consistent with this perspective, we work hard to not use a wide color-contrast range on road categories for the topographic design. Color hues are used systematically in the map designs. For example, blues and greens for physical features such as hydrography and forest; red, orange, yellow for human features such as settlements and roads; and purple for administrative boundaries. We also leave a portion of hues unused so they are available for update and overlay of operational information. For example, magenta could be used for additions such as emergency response planning, since no magenta symbols are used. Given the limitations of this proceedings paper format, we direct readers to numerous map examples in papers and presentations posted at ScaleMaster.org to see progress on the designs, such as Brewer et al. (2010).

Color contrast issues with existing designs include the problem that red roads and brown contours are hard to distinguish in the uncontrolled viewing conditions common for maps disseminated to the public, so we use gray contours. All colors

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in the design are lighter than black labels, requiring only a few halos on labels. For example, blue hydro labels have a light blue halo, contour numbers have a light greenish-brown halo,

| UDA class breaks | | Blues | Line weights in points | | | | |
|---|---|---|---|---|---|---|---|
| **Dry regimes** | **Humid regimes** | **Blues** | **24~50K** High Res NHD | **50~215K** 50K LoD | **215~320K** | **320~500K** | **500K~1M** |
| | | | | | *Need new LoD?* | | |
| *Perennial flowlines* | | | | | | | |
| min-20 | min-2 | pale | 0.38 | 0.38 | 0.38 | No symbol | No symbol |
| 20-50 | 2-5 | light | 0.75 | 0.75 | 0.75 | | |
| 50-100 | 5-10 | light | 1.13 | 1.13 | 1.13 | | |
| 100-300 | 10-30 | med | 1.50 | 1.50 | | 0.63 | 0.50 |
| 300-3000 | 30-300 | med | 1.88 | 1.88 | 1.50 | 0.88 | 0.63 |
| 3000-max | 300-max | dark | 2.25 | 2.25 | 1.88 | 1.13 | 0.75 |
| *Intermittent flowlines* | | | | | | | |
| min-20 | min-2 | pale | 0.38 | No symbol | No symbol | No symbol | No symbol |
| 20-50 | 2-5 | light | 0.75 | 0.38 | | | |
| 50-100 | 5-10 | light | 1.13 | 0.75 | 0.38 | | |
| 100-1000 | 10-100 | med | | 1.13 | 0.75 | | |
| 1000-max | 100-max | dark | 1.50 | 1.50 | 1.13 | | |

Table 1. Multiscale symbols for hydrography flowlines. Line weights are multiples of 0.75 points (and halves of 0.75) to optimize cached web tile appearance (mappingcenter.esri.com).

and populated place labels have a white drop shadow. Other labels are intended to remain readable when overprinted on map symbols. We use contrasting outlines on point symbols separate from each other, and the background, as they overlap with scale change.

Table 1 lists example detail on the crucial group of layers for this project, hydrographic flowlines. Color, line weight, and elimination decisions for up-stream drainage area (UDA) and perennial/intermittent classes are detailed through scale.

Practical considerations in design work are implemented for ease of sharing files and fidelity with *The National Map*. We do no custom edits on *The National Map* data (no data clean up) to improve the look of the map designs. We use simple geometric symbols so there are no missing fonts or pictures in exports. We also use regular Windows fonts for robust export and file sharing among collaborators. We pay a lot of attention to Symbol Levels and Maplex weightings in ArcMap (Esri ArcInfo 9.3.1). In structuring map projects, we use many group layers to easily turn off categories while evaluating appearance. All rasters and layers with transparency are at the bottom of the Table of Contents in ArcMap so export of layers above those retain editable vectors and type (layers below all convert to raster on export). We use no over/under passing on bridges and ramps—again, these are not road maps and other consumer navigation services provide that level of detail.

## 2. METHODS

### 2.1 Selecting the Map Sample Sites

The eight NHD subbasins used for this study were selected by colleagues at the USGS (detailed in previous reports, such as Brewer et al. 2009). In contrast, much smaller sites at which screen captures would be taken were selected for visual evaluation. Each site was outlined by a five-inch by five-inch box (12.7 cm square) at three of the scales of capture, 1:24,000, 1:100,000, and 1:250,000. Each box nested in the smaller scale boxes. The sites were selected from USGS paper topographic maps at these scales.

Two main criteria were used in site selection. First, richness of map content was sought. Not every map symbol was required to be present in each site; indeed, this would be impossible. Instead, over the eight subbasins, sites were selected that collectively contained all of the content for which symbols and labels had been designed. Second, sites that contained complex or varied hydrography were sought to illustrate the quality of generalized Level of Detail databases (LoDs) prepared from NHD by Buttenfield and Stanislawski (e.g., Buttenfield et al., 2010). These LoDs were suited to the scale range of 1:50,000 to approximately 1:200,000, but they were extended out to 1:1,000,000 to see where in the range the next smaller-scale LoD would be needed.

To ensure that the correct scale was seen on screen (the same size as on the paper maps), 5x5 boxes were drawn on the paper map. The geographic coordinates of the box corners were calculated by measuring their distance from longitude and latitude lines on the maps and converting this distance to degrees. The coordinates were then projected to a polygon feature class and displayed in register with the other subbasin content in ArcMap. Boxes were measured with digital and physical rulers on screen to ensure that the box retained the same dimensions on screen as on the paper maps at 1:24,000, 1:100,000, and 1:250,000.

Three additional scales were included in the experiment: 1:50,000, 1:500,000, and 1:1,000,000. However, new 5x5 boxes were not constructed at these scales. Rather, to ensure the correct scale on screen, the corresponding box from a larger scale was kept in the image and measured to the appropriate size. For example, at a scale of 1:50,000, the 1:24,000-scale box measured 2.40 inches (6.1 cm).

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## 2.2 Organizing Map Changes Through Scale

A ScaleMaster diagram visually depicts decisions about changes in display and geometry for map content over a specific range of scales (Brewer et al., 2009). A ScaleMaster was developed for this project by viewing the map content in ArcMap at multiple scales. When a layer's symbology became illegible or cluttered, we noted the problems and the scale at which they occurred. With this information, we made decisions in concert to correct these issues for the full design. This was an iterative process, with new problems arising and adjustments made repeatedly as we examined portions of the eight subbasins at numerous scales between 1:20,000 and 1:1,000,000.

There were four types of decisions made concerning map content and symbols (Table 2; Roth et al., 2008). First, *symbol* design or *label* styles and rules would change. For example, a symbol or label could become smaller with a reduction in scale. Second, map *content* would change, such as filtering the data using a threshold value. Finally, the *geometry* of the content would change, such as simplification of a boundary or substitution of the generalized hydrography LoD in place of the high-resolution NHD data. Figure 1 shows the decisions made for this project and the scales at which they occurred. Figure 2 shows the key summarizing these decisions. The ScaleMaster groups data layers by the following themes: hydrography, physical, transportation, cultural, and administrative boundaries. These themes echo the full set for *The National Map*: elevation, land use/land cover, boundaries, transportation, structures, hydrography, geographic names, and orthoimagery (Sugarbaker et al., 2009; nationalmap.gov).

As with the ScaleMaster, layers in the ArcMap project were grouped thematically and then by their scale range. Visibility ranges were set as properties for layer groups. Thus, we were able to seamlessly navigate between scales without the burden of turning layers on or off to examine map design decisions.

## 2.3 Evaluating the Design at Scale and Resolution

The designs were captured at the six scales previously mentioned in each of the eight subbasins. They were captured onscreen within ArcMap (from the MXD) and Adobe Acrobat (from the PDF), which use different drawing engines. Map samples were captured on both a laptop (with 120-ppi resolution) and desktop (with 91-ppi resolution).

Map patches that are 5 inches (12.7 cm) on each side are being examined:
  - by 3 raters (2 so far),
  - at 6 scales,
  - for 9 subbasins (8 so far; New Haven, Connecticut, will be added for a coastal and urban landscape),
  - at 2 resolutions,
  - in 3 file formats (2 so far; web cache preview to be added).
As of August 2010, 196 evaluations had been completed (2 x 6 x 8 x 2 x 2), and 972 combinations are planned for a complete evaluation at this stage of map design (3 x 6 x 9 x 2 x 3).

Before working at scale in ArcMap, the exact horizontal and vertical dimensions of the computer screen in mm were set in the Advanced Settings utility for every screen on which we worked (at C:\Program Files\ArcGIS\Utilities\AdvancedArc MapSettings.exe on our computers for ArcInfo 9.3.1). If screen

size is not specified, the scale listed in the ArcMap view will be only approximate in relation to the displayed map scale.

To collect map samples, a screen capture of the sites that included a measured box were taken in Layout View. Additional adjustments to scale were sometimes needed given slight differences in datum and projection between the paper maps and our displays. The screen capture was then pasted into Adobe Photoshop CS4, where it was cropped to a fixed height and width of 5.1 inches (13 cm). For Adobe-rendered captures, a PDF of the map document with a resolution of 400 ppi was exported from ArcMap from Layout View. The PDF was then opened in Adobe Acrobat Pro 9, where the viewing percentage was adjusted to ensure the correct size of the box and a screen capture was taken. This capture was then pasted into Photoshop and cropped. Images in Photoshop were saved with no resampling as TIFF files. The TIFF format was chosen because it preserved the image pixel-by-pixel without lossy compression (unlike JPEG). Ratings were made from an organized set of 192 images examined onscreen in an "Actual Pixels" View in series using Photoshop.

Table 3 lists the types of problems with the map design that we are looking for on each 5x5 sample. Labels, points, lines, areas, and terrain are each examined for appearance and generalization problems. More holistic evaluations of appearance and vertical integration are also prompted. Ratings for the sample set take approximately 40 hours and is paid work for one undergraduate and one graduate student schooled in cartographic design, plus a cartography professor, for a total of three raters.

## 3. CONCLUSIONS

Preliminary results for the map design evaluations will be presented at the AutoCarto 2010 conference, and slides from the presentation posted at ScaleMaster.org. This paper establishes the background and methods for the evaluations. As a mid-way conclusion, we emphasize that we needed to be vigilant at every stage of map design and map sample production to retain the specific scale desired. Images required size adjustments to retain equal scales in ArcMap, Acrobat, and Photoshop (and to the printer). We wanted all maps to be the scale claimed and to not have pixels resampled at any stage to further degrade (or enhance) the map symbols and labels. This caused unexpected confusion and impressed on us that scale has become only an approximate naming for displays. Images change size with viewing tools in unpredictable ways. Our five-inch (12.7 cm) map samples were anywhere between 3.5 and 7 inches (about 9 to 18 cm) in size before we adjusted or corrected our tools to force the desired scale. Very few map users will make these adjustments, so we must design for quality map appearance through a range of scales and resolutions.

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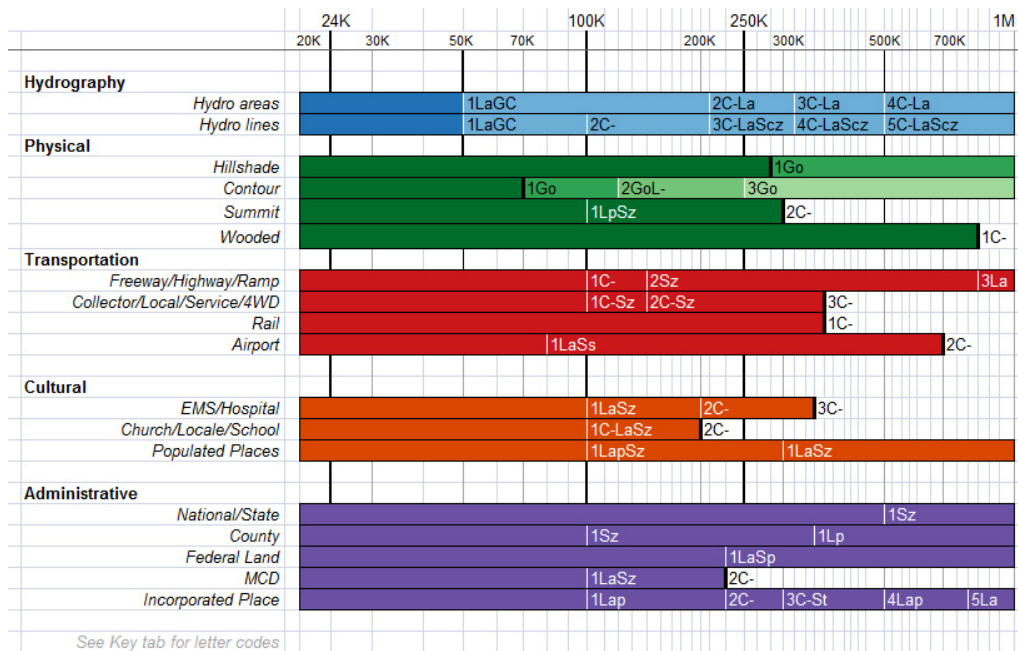
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Figure 2. ScaleMaster diagram describing multiscale topographic map design changes from 1:20,000 to 1:1,000,000

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| Data Themes | Operation Order for Content, Generalization, and Style Changes Through Scale | | | | |
|---|---|---|---|---|---|
| **Hydrography** | 1 | 2 | 3 | 4 | 5 |
| *Hydro areas* | **La**, reduce label font size; **GC**, High Res. hydro replaced by 50K LoD | **C-**, filter small waterbodies; La, reduce label font size | **C-**, filter small waterbodies; **La**, reduce label font size | **C-**, filter small waterbodies; **La**, reduce label font size | |
| *Hydro lines* | **La**, reduce label font size; **GC**, High Res. hydro replaced by 50K LoD | **C-**, eliminate diffs | **C-**, filter small waterbodies; **La**, reduce label font size; **Sc**, lighten line color; **Sz**, reduce line weight | **C-**, filter small waterbodies; **La**, reduce label font size; **Sc**, lighten line color; **Sz**, reduce line weight | **C-**, filter small and medium flowlines and centerlines; **La**, reduce label size; **Sc**, lighten line color; **Sz**, reduce line weight |
| **Physical** | 1 | 2 | 3 | 4 | 5 |
| *Hillshade* | **Go**, smooth DEM at r=15 | | | | |
| *Contour* | **Go**, smooth DEM at r=15 | **Go**, smooth DEM at r=30 | **Go**, for mountainous environments, smooth DEM at r=50 | | |
| *Summit* | **Lp**, change label position to centered on point; **Sz**, remove point | **C-**, remove layer | | | |
| *Wooded* | **C-**, remove layer | | | | |
| **Transportation** | 1 | 2 | 3 | 4 | |
| *Freeway/Highway/Ramp* | **C-**, eliminate Ramps | **Sz**, reduce line weight | **La**, reduce shield size | | |
| *Collector/Local/Service/4WD* | **C-**, eliminate Service and 4WD | **C-**, eliminate Local; **Sz**, reduce line weight | **C-**, remove layer | | |
| *Rail* | **C-**, remove layer | | | | |
| *Airport* | **La**, reduce label font size; **Ss**, change symbol | **C-**, remove layer | | | |
| **Cultural** | 1 | 2 | 3 | 4 | |
| *EMS/Hospital* | **La**, reduce label font size; **Sz**, reduce point size | **C-**, in urban environments, remove layer | **C-**, in rural environments, remove layer | | |
| *Church/Locale/School* | **C-**, eliminate Church and School (and in urban environments, Locales); **La**, reduce label font size; **Sz**, reduce point size | **C-**, remove layer | | | |
| *Populated Places* | **La**, reduce label font size; **Lp**, change label position to best location around point; **Sz**, reduce populated place point size for both incorporated places and populated places | **La**, reduce label font size; **Sz**, reduce populated place point size for both incorporated places and populated places | | | |
| **Administrative** | 1 | 2 | 3 | 4 | |
| *National/State* | **Sz**, reduce line weight | | | | |
| *County* | **Sz**, reduce line weight | **Lp**, change label placement to centered in polygon | | | |
| *Federal Land* | **La**, reduce label font size and use dictionary-based abbreviate ; **Sp**, change polygon outline pattern to solid | | | | |
| *Minor Civil Division* | **La**, reduce label font size; **Sz**, reduce line weight | **C-**, remove layer | | | |
| *Incorporated Place* | **La**, reduce label font size and change style; **Lp**, change label position to best placement around point (using points from the populated places data) | **C-**, eliminate dashed line | **C-**, filter small incorporated places by area; **St**, reduce transparency | **La**, reduce label font size and change style; **Lp**, change label placement to best position outside of polygon | **La**, reduce label font size and change style |

**Symbols**

| | |
|---|---|
| Adjust Color | **Sc** * |
| Enhance | **Se** |
| Adjust Pattern | **Sp** |
| Rotate | **So** |
| Adjust Shape | **Ss** * |
| Adjust Size | **Sz** * |
| Adjust Transparency | **St** * |
| Typify | **Sf** |

**Labels**

| | |
|---|---|
| Add Labels | **L+** |
| Eliminate Labels | **L-** * |
| Adjust Appearance | **La** * |
| Adjust Position | **Lp** * |

**Content**

| | |
|---|---|
| Add Features | **C+** |
| Eliminate Features | **C-** * |
| Reclassify Features | **Cc** |
| Reorder Features | **Co** |

**Geometry**

| | |
|---|---|
| Aggregate | **Gg** |
| Collapse | **Gc** |
| Displace | **Gd** |
| Exaggerate | **Gx** |
| Merge | **Gm** |
| Simplify | **Gs** |
| Smooth | **Go** * |

**GC** – replace with generalized dataset *

Table 2. Inventory of display and geometry changes used for multiscale mapping. Asterisks (*) note operations used in the current ScaleMaster (Figures 1 and 2).

(Adapted from Roth et al., 2008)

Figure 2. Key to ScaleMaster diagram (Figure 1) describing types of map design change through scale.

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**A - Label appearance and readability**
    Too small or large
    Letter forms corrupted (at angle)
    Too light or dark
    Styling poor (too narrow, italic, bold, letter spaced)
    Individual characters unaligned (uneven)
    Letter form is jagged (due to rendering)
    Different case would better suit feature (change to lower case)
    Leading too close or far within a label
    Poor font choice
    Poor abbreviation

**B - Label positioning and generalization**
    Interference from other features below label
    Too close to other labels
    Difficult to understand location of named feature (too many symbols or no symbol)
    Label along boundary of area that's too small (or centered on area that's too big)
    Poor curve or angle to label (or curve/angle needed for horizontal label)
    Multiline label needed (or too many lines in one label)
    Too many features of one type are labeled
    Hierarchy of labels would better suit feature type
    Categories of labels would better suit feature type

**C - Point symbol appearance**
    Point appearance too similar to other point symbols
    Point too big (or too small)
    Poor shape
    Poor multilayer point combination (e.g., outline, shape within shape)
    Poor color
    Interference from other features above or below label
    Poor symbol-level drawing (point should be above or below another feature type)
    Point form is jagged (due to rendering)

**D - Point generalization**
    Too many point features
    Hierarchy of point symbols would better suit feature type
    Categories of point symbols would better suit feature type

**E - Line symbol appearance**
    Line appearance too similar to other line symbols
    Line too wide (or too narrow)
    Line form is jagged (due to rendering)
    Poor pattern choice (e.g., dash)
    Poor multilayer pattern combination (e.g., dash, centerline, line casing)
    Poor color(s)
    Interference from other features above or below line
    Poor symbol-level drawing (line should be above or below another feature type)

**F - Line generalization**
    Too many line features (cluttered)
    Lines too short to suit scale
    Line shapes too complex (or too simple)
    Hierarchy of line symbols would better suit feature type
    Categories of line symbols would better suit feature type

**G - Area symbol appearance**
    Area appearance too similar to other area symbols
    Poor pattern choice (e.g., hatch, dots)
    Poor multilayer pattern combination (e.g., color and speckle)
    Poor color(s)
    Area casing is jagged (due to rendering)
    Interference from other features above or below area
    Poor symbol-level drawing (area should be above or below another feature type)
    Area form is jagged (due to rendering)

**H - Area generalization**
    Areas too small to suit scale (outline closes in on area fill)
    Too many area features (cluttered)
    Area shapes too complex (or too simple or unrealistic)
    Gaps between areas too thin
    Hierarchy of area symbols would better suit feature type
    More categories of area symbols would better suit feature type
    Category or hierarchy of symbols is not clear

**I - Terrain appearance**
    Hillshade or contour color too light or too dark
    Contour lines too wide or too thin
    Hillshade colors not logically positioned (e.g., one color both sides of a valley bottom)
    Hillshade or contours should be omitted or included

**J - Terrain generalization**
    Hillshade too jagged or terraced
    Contours too few or too close
    Contours too jagged or loopy
    Contours too complex in shape
    Contours not well nested up slope

**K - Vertical integration between layers**
    Boundaries misregistered (e.g., county and state line do not align)
    Flowlines not in valleys within terrain
    Water bodies not in flat areas of terrain
    Suspect road routings in relation to ridges and valleys
    Boundaries miss road or water features that likely guide position
    Points in middle of major roads
    Land features located in water and water features on land

**L - Overall appearance of map**
    Too dark, too light
    Too cluttered, too jumbled
    Too wiggly or angular
    Too many labels
    Wrong proportion of label types
    Wrong proportion of feature types (e.g., an urban area with many physical and few cultural features)
    Terrain form is overbearing or too subtle to be seen

Table 3. Quality rating criteria for multiscale topographic map designs (August 2010)

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