CO-310

CHOOSING BETWEEN GEOMETRY CHANGE AND DISPLAY CHANGE FOR MULTISCALE MAPPING: THE ROLE OF ELIMINATION IN DESIGN

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ABSTRACT

The paper discusses a conceptual tool for recording display and geometry changes for mapping across a range of scales, called ScaleMaster. Examples of design outcomes from a continuing project with data from The National Map by USGS show how ScaleMaster can support decisions about which type of design choice to make. Sequences of display and geometry changes are applied to hydrography, terrain, transportation, settlement, and administrative boundary data to differentiate choices for each data theme. The importance of decisions about elimination (including select, remove, filter, prune, refine, thin, omit) to design for scale change are emphasized.

INTRODUCTION

Multiscale mapping requires decisions on how to reduce the detail of a map but still provide useful landscape information to the map user, whether they want a general reference map or a basemap to underpin their operational data. The ScaleMaster project is an ongoing effort, which began seven years ago, to explore the feasibility of annotating systematic changes of symbol design across changes in mapping scale (Brewer and Buttenfield 2007). As it developed, ScaleMaster roles have expanded to include not only changes to a map display, but changes to content and geometry through various generalization and geoprocessing operations. Our work with ScaleMaster diagrams (e.g., Brewer et al. 2010) has required us to be explicit about map design changes that produce readable topographic maps through a wide range in scales [1:20,000 (20K) to 1:1,000,000 (1M)] by recording those changes in sequence and by theme along a continuum of target scales. A particular ScaleMaster diagram is one of a variety of possible solutions to this many-variable problem, and the basic categories of design change we record at present include geometry, content, symbols, and labels.

At target scales where the appearance of a map's symbology begins to falter, diverse options are available to improve it. For example, when terrain form becomes hard to read at smaller scales, the mapmaker might create generalized contours by smoothing the DEM and regenerating the lines (change geometry). Alternatively, the mapmaker might replace contours with hillshading (content), make the contour symbols lighter or thinner (symbols), and/or change the contour label rules (labels). Varied combinations of these types of choices provide a variety of solutions to the map design problem for the target smaller scale.

A group of the design decisions remove features from a map as scales get smaller. These are variously called select, eliminate, omit, filter, prune, refine, and thin. These operations are the least consistently treated approaches in the generalization literature, perhaps because they ambiguously involve geoprocessing and/or display change aspects of design, depending on how the geospatial data are modeled. The mapmaker does not need to alter feature geometry to eliminate a class of features from a map or to exclude features below a set threshold (for example, below a size threshold). For example, elimination or pruning decisions may remove minor road classes, streams with low drainage volumes, small waterbodies, regional airports of lesser importance, or unincorporated towns. Some of these choices often require suitable database enrichment and the requisite geoprocessing to implement. Taking the example of the regional airports, if the runways are stored as line or polygon features, enrichment might involve removing regional airports containing only one runway. Likewise, data on numbers of landings at each airport from the FAA might be used to filter out airports with low traffic volumes or assign them smaller labels. For the streams example, enrichment has involved estimating catchment size or upstream drainage area (Stanislawski et al. 2007, Stanislawski 2009). Another type of enrichment for stream channels delineates a centerline or primary stream channel (Tarver et al. 2011).

OVERVIEW OF CHANGES

The design workload differs for display change and geometry change. In many (but not all) cases, display change requires less work and less specialized computation than does geometry change. Display change mandates creation of new data files less often than does geometry change, except for creating label annotations or latent polygons for labeling features with indeterminate boundaries. To explore the full range of possibilities for working with symbol change in multiscale map design, we have been developing strategies to prepare multiscale topographic map designs with minimal geometric change, following earlier work (Brewer and Buttenfield 2010). We do a lot of careful elimination, using size and other thresholds. We also render features with thinner lines, smaller points, and in lighter colors, often without cased outlines, as scale decreases.

An intermediate ScaleMaster (Figure 1) prepared in July, 2010, for on-screen topographic maps, using data from The National Map for the United States, demonstrates that design decisions range fairly evenly among the categories. Out of a total of 73 design changes, 25 were label changes, 20 were symbol changes, and 22 were content changes (plus four content-changes to Level of Detail databases produced in support of computationally intensive processing steps). Content removal accounts for more than 30 percent of the design decisions made for this multiscale mapping project. The predominance of content removal is partly due to focused attention on hydrography; as a consequence few geometry changes have been applied to other themes for the topographic mapping project. Our heavy reliance on removal of features does however produce reasonably acceptable mapping through a wide range in scales (for example, Figures 7, 8, 9).

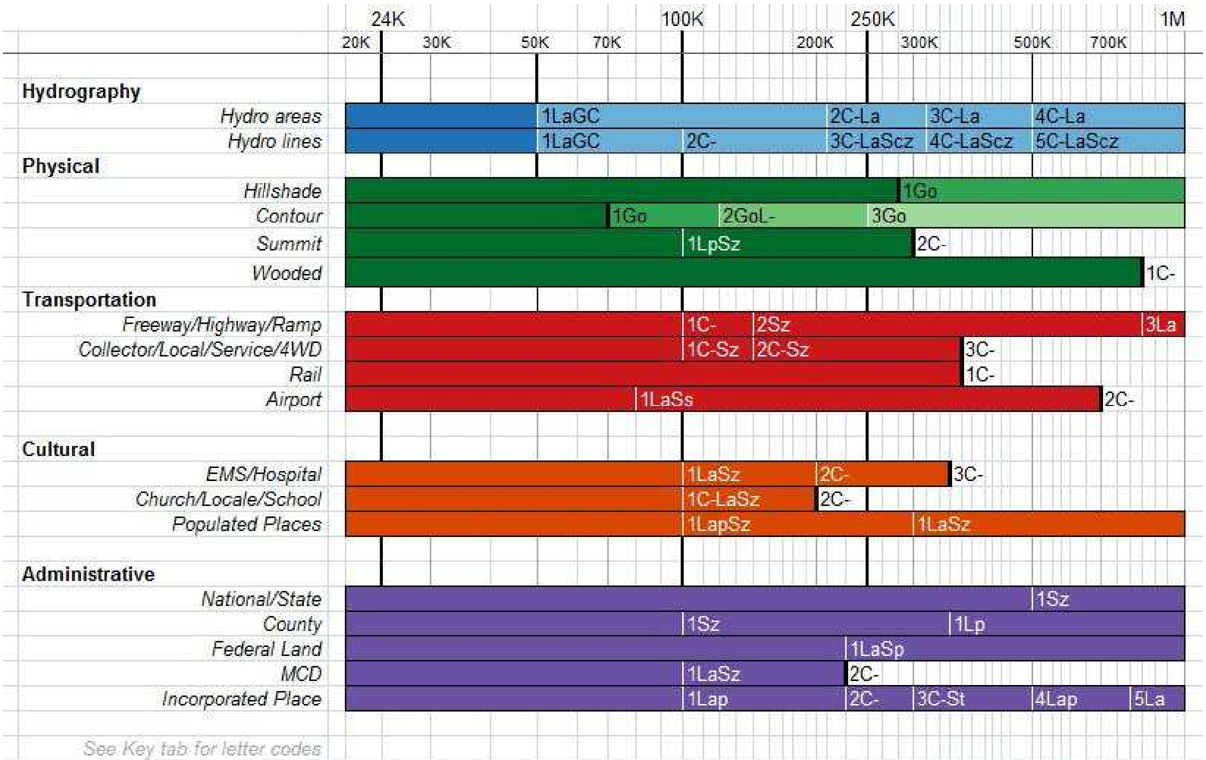

Figure 1. ScaleMaster diagram (original file is posted as item 19 at ScaleMaster.org).

The two lists below summarize the changes in geometry and design that accumulate to create maps at 1:100,000 (100K) and 1:500,000 (500K) from data compiled for mapping at 1:24,000 (24K). Changes that involve removal of features are bold and marked by asterisks. In designing for scale change from 24K up to 100K, five of 24 changes (21 percent) eliminate features or layers (items 2, 7, 11, 13, 18). Eight additional elimination changes accumulate with the next jump, up to 500K (33 percent of the 24 additional changes listed; items 26, 29, 33, 35, 36, 37, 45, 46).

Changes that accumulate from 24K up to 100K (compare Figure 2 to 6):

Hydrography

1. reduce label font sizes for waterbodies and flowlines
2.* **filter** small waterbodies
3. aggregate waterbodies
4. simplify waterbody outlines
5. collapse area rivers to centerlines
6. simplify flowlines

7.* **prune** flowline segments with smallest upstream drainage areas

Terrain/Physical

8. simplify hillshade using smoothed DEM
9. simplify contour lines using smoothed DEM
10. increase contour interval
11.* **remove** point symbol for summits
12. change label position to center on point for summits

Transportation

13.* **eliminate** highway ramps, service roads and 4WD roads
14. reduce airport label font size
15. change airport symbol to smaller pictogram

Cultural/Populated Places

16. reduce label font size for emergency services locations
17. reduce symbol size for emergency services locations
18.* **eliminate** locale points (in urban areas), churches, and schools
19. reduce label font size for locales retained in rural areas and populated place points.
20. reduce point symbol size for locales retained in rural areas and populated place points.
21. change label position rule for populated place points

Administrative Boundaries

22. reduce line weight for county and minor civil division boundaries
23. change symbol style for incorporated places
24. reduce label font size for minor civil division and incorporated place

Additional changes that accumulate from 100K to 500K (compare Figure 6 to 8):

Hydrography

25. reduce label font sizes for waterbodies and flowlines
26.* **filter** small waterbodies.
27. lighten flowline color
28. reduce line weight
29.* **prune** flowlines and centerlines with small and medium upstream drainage areas

Terrain/Physical

30. simplify hillshade using further smoothing on DEM
31. simplify contour lines using further smoothing on DEM
32. increase contour interval
33.* **remove** summits layer

Transportation

34. reduce line weight for freeways and highways
35.* **eliminate** collector and local road categories
36.* **remove** railroads layer

Cultural/Populated Places

37. * **remove** emergency service, locale, church, and school point layers
38. reduce label font size for populated place points.
39. reduce point symbol size for populated place points.

Administrative Boundaries

40. reduce line weight for state and country boundaries
41. change label placement rules for counties and incorporated places
42. reduce label font size for federal lands and incorporated places
43. use dictionary-based abbreviate for federal lands
44. change polygon outline pattern for federal lands and incorporated places
45.* **remove** minor civil division layer
46.* **filter** small incorporated places

47. reduce transparency of incorporated place polygons
48. change label style for incorporated places

We summarize some of the particular strategies we use in development of electronic topographic maps using The National Map data from the United States Geological Survey (USGS) for the scale range of 20K to 1M. Figures 2 to 9 show example maps for subbasin areas at 24K, 50K, 100K, 250K, 500K, and 1M. Figure 2 also shows an example of the ArcGIS Table of Contents with visibility ranges set to swap in appropriate symbols and labels dynamically as scales are requested. An multi-representation database (MRDB) would seem a less laborious way to structure this project, but we report on what we can do now with COTS tools. The sections that follow summarize approaches to multiscale design we have taken by theme.

TRANSPORTATION THROUGH SCALE

Road symbols include six line styles at large scales. The least important roads (service, 4WD, ramps) are removed first (at 100K), then local roads are removed at 150K, and major road lines are made thinner and simpler in style at the smallest scales. Roads are not simplified or otherwise generalized in geometric form at this stage of design development, but we see a need for additional levels of collector roads to retain a network that is refined from the local roads but is more dense than the current collector/highway/freeway set. Railway lines remain the same for a wide scale range until they are omitted at small scales. Airports shift from a circle symbol covering a large area to a small airplane icon as scale is reduced.

CULTURAL FEATURES AND ADMINISTRATIVE AREAS THROUGH SCALE

We use the obvious strategy of having small point feature symbols, such as schools and hospitals, get smaller as scale decreases. Incorporated places start as areas at large scales and then are shown with a point symbol that also controls label placement (instead of labeling the areas) at smaller scales. Other small point locations and labels (such as parks at points) are omitted with scale reduction.

Administrative features are split into lines placed above hydrography and areas placed below hydrography. This interleaving ensures that water areas are not colored by administrative fills (such as the transparent green for national forest areas) but administrative boundary lines are visible within water areas or on top of water lines at larger scales. Lines are reduced in prominence at smaller scales and shift to placement below hydrography. Administrative areas such as incorporated places and reserves (such as national forests, state parks, BLM lands, and reservations) are transparent fills that overlay terrain shading and wooded land cover areas. The reddish incorporated areas and reserves are light (70% transparent) and distinguished from each other with a dotted line to mitigate problems with distinguishing the pale red and green intermingled with the yellow and brown of the terrain shading (an impossible color set for some colorblind map readers). Lines and labels redundantly differentiate the categories.

Light green for wooded areas is at the bottom of this stack (not transparent), while swamp/marsh area fill in the hydro group layer is transparent (50%) and is the first of a series of transparent or raster layers positioned at the bottom of the Table of Contents. This lower portion of the layer stack (swamp to wooded) converts to raster in a desirable way, creating a manageable PDF with vector lines and labels above this rasterized group. Contour lines are sandwiched into this stack below the terrain shading to be visually integrated into the map and to convert the most laborious drawing task to a raster image as well.

At this stage in design development, the polygons for administrative areas are not generalized but rather represented without outlines, or with very light outlines, at smaller scales so that excessive detail is removed with a visual merge.

HYDROGRAPHY AND TERRAIN THROUGH SCALE

Hydrography is perhaps the most sensitive to the need for generalization through scale. Currently, modest amounts of simplification are applied to flowlines and waterbodies, and the resulting deterioration in vertical integration with terrain form (shading and contours) is not particularly troublesome (improving consistency and completeness of hydrography data is a major challenge, so this is a relatively minor problem in the wider context). The very light character of the terrain shading is one aspect that helps ease integration as flowlines become simpler. In addition, we smoothed the DEM in three stages to produce a set of progressively smoother contours and corresponding terrain shading, so the landform becomes simpler to suit the smaller scales in three ways: simpler contour lines, simpler terrain shading, and simpler flowlines and water areas. Vertical integration is poor in some locations, but these features become more and more background elements as roads and places become more prominent with smaller scales. Hydrography is tapered using upstream drainage area (UDA), so small headwater streams are thinner and lighter than reaches that serve larger areas. Small reaches may be more prone to vertical integration problems because they run through narrower channels, and thus their small and light representation makes these sorts of problems less distracting within the design. Likewise, displacement would be desirable as roads overlay rivers at smaller scales, but the current lack of this sort of tool means that hydrography is pushed more to a background feature and just not visible where roads visually dominate many valleys.

Eliminating area features using size thresholds is also a common strategy for these maps, so small ponds and lakes are removed as scale is reduced. Stream names are removed for small UDA flowlines to get labels on more significant streams. After names go, low UDA flowlines are systematically removed in a topologically consistent manner using pruning tools developed by Larry Stanislawski at USGS. Replacing wide river areas with centerlines as scale is reduced works well (giving the appearance of a collapse operation), though handling braided or multichannel rivers remains an unsolved problem for us. These generalization solutions are implemented by creating Level of Detail (LoD) databases designed to cover a range of scales. To date, Dr. Barabara Buttenfield's parallel CEGIS research project is preparing a complete set of LoDs, and we currently have nearly a dozen hydrographic LoDs drafted to cover the scale range of 1:50,000 to approximately 1:200,000 for our sample areas.

LABELS THROUGH SCALE

Labels become smaller as map scale is reduced, but this doesn't provide much flexibility because we are designing for on-screen viewing and the coarse resolution of even high-resolution laptop screens is much coarser than the printed page (for example, 130ppi versus 600ppi). So we do much label elimination, using Maplex at Best settings to place as many labels with reasonable positioning as possible while retaining dynamic label placement functionality. To generalize labels, we use a dictionary function to replace frequently used and somewhat lengthy words with abbreviations, such as "County Road" with "CR", "River" with "R", "Mountain" with "Mt". This strategy frees map area for additional labels at smaller scales. Road shields function similarly, so "Interstate Highway 99" is replaced by just "99" within a small shape. Though this is an obvious option, it's not easy to do because The National Map data does not contain a number-only column separate from a road-type column that would set the shield type, so these attribute fields need to be constructed through data processing and used in concert. Labels are often removed from the map before a symbol for a feature is removed. For example, local roads are not labeled at the smallest scales they appear. This is not always the case, though: summit names are retained at smaller scales, after their symbol is removed. By embedding the symbol for the smallest point features, such as churches, into the leader line function (rather than symbolizing a point layer), we are able to remove points that are not labeled and reduce clutter (The St. Louis city data has a church at almost every block while they are infrequent but important landmarks in rural areas, so this can become an important strategy).

Hierarchies of importance for all sorts of features would improve the mapping and labeling, but these are not available in a consistent form for the whole country for many features. We are working on developing hierarchies for the more obvious feature types for which data are available, such as a populated place hierarchy using population data and airports based on air traffic volumes. We also weed some point names by not labeling or symbolizing all features listed parenthetically as "historical" in GNIS name (though these historical features remain in the database should a user want to see them).

CLOSING THOUGHTS

These topographic maps look acceptable but additional work can refine these design solutions or extend the range of usable mapping scales. The maps are designed using GIS data, which are largely compiled from 24K mapping and require enrichment and additional structure for efficient mapping at the broad range of proposed scales. The database information carries different content than did the paper topographic maps that served the U.S. for over 100 years, although much of the U.S. data were derived from them and further updated. Because design decisions will differ for different datasets compiled by different national mapping agencies for various generalized or specialized applications, a unique ScaleMaster must be created for each instance. Creation will however highlight many stylistic choices which are the hallmark of any map design or mapping organization.

Many challenges lie ahead, such as extending currently stored point labels to associated physical features, and designing feature densities and typifications that properly accentuate natural terrain conditions through scale changes, along with the design enhancements described above. But with good minds on the problems of display change and geometry change, we are optimistic about continued improvement and production of successful multiscale topographic maps disseminated to the U.S. public.

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MAP FIGURES

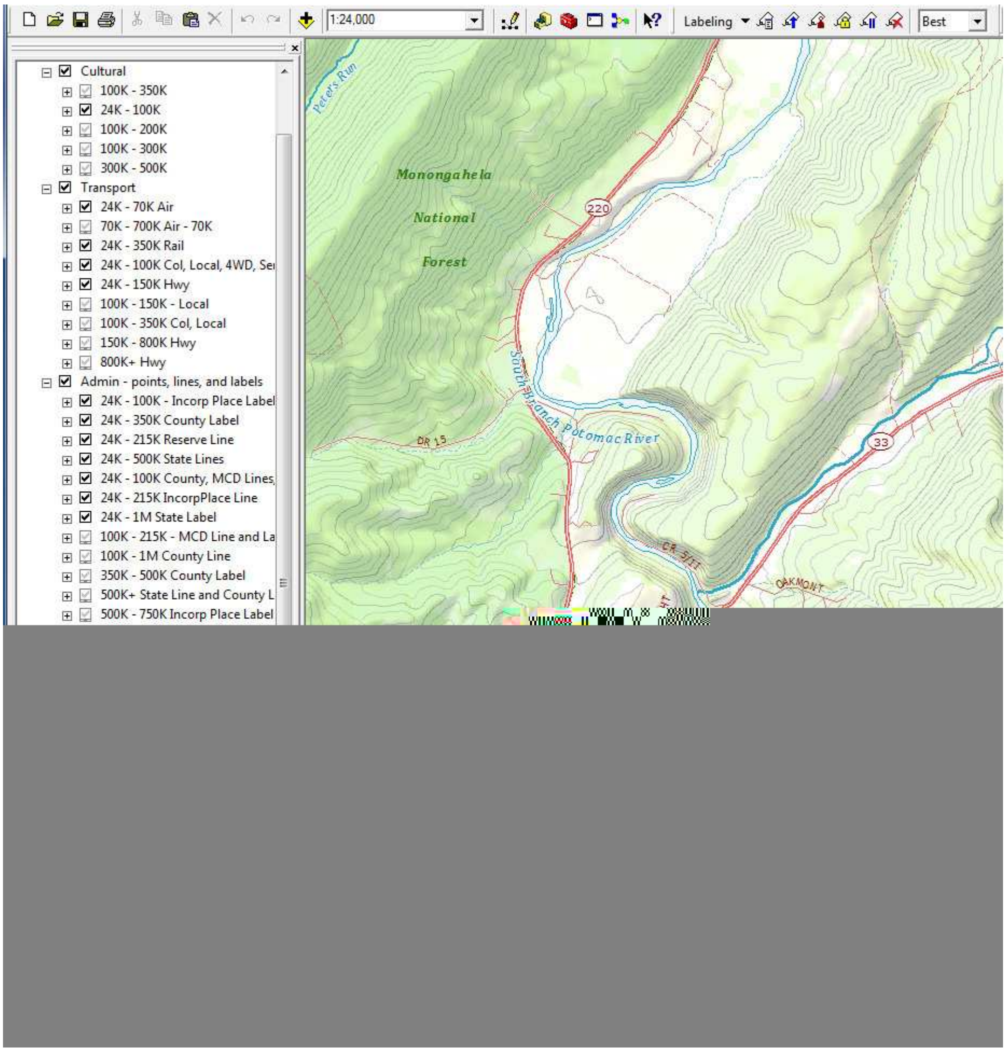

Figure 2. West Virginia subbasin (02070001) at 1:24,000 on screen (reduced size in figure) with ArcInfo Table of Contents at left showing visibility ranges (black checks mark layers set to visible at 1:24,000).

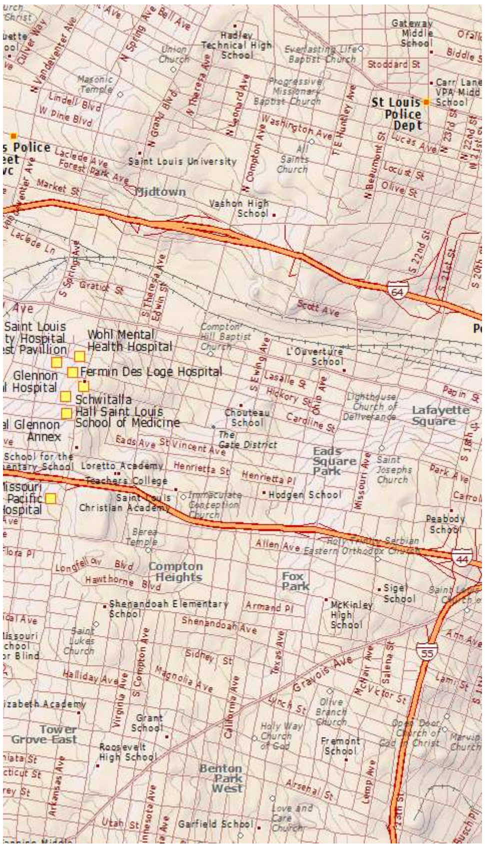

Figure 3. St Louis, Missouri, subbasin (07140101) at 1:24,000 on screen (reduced size in figure)

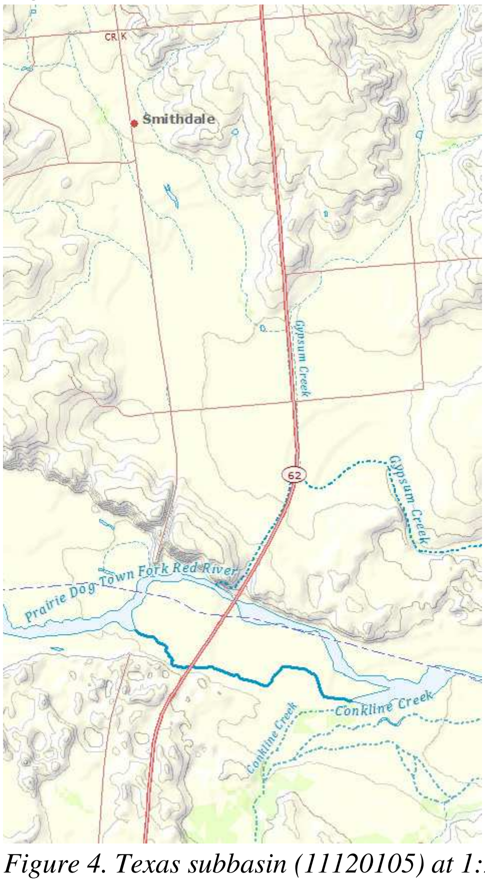

Figure 4. Texas subbasin (11120105) at 1:24,000 on screen (reduced size in figure)

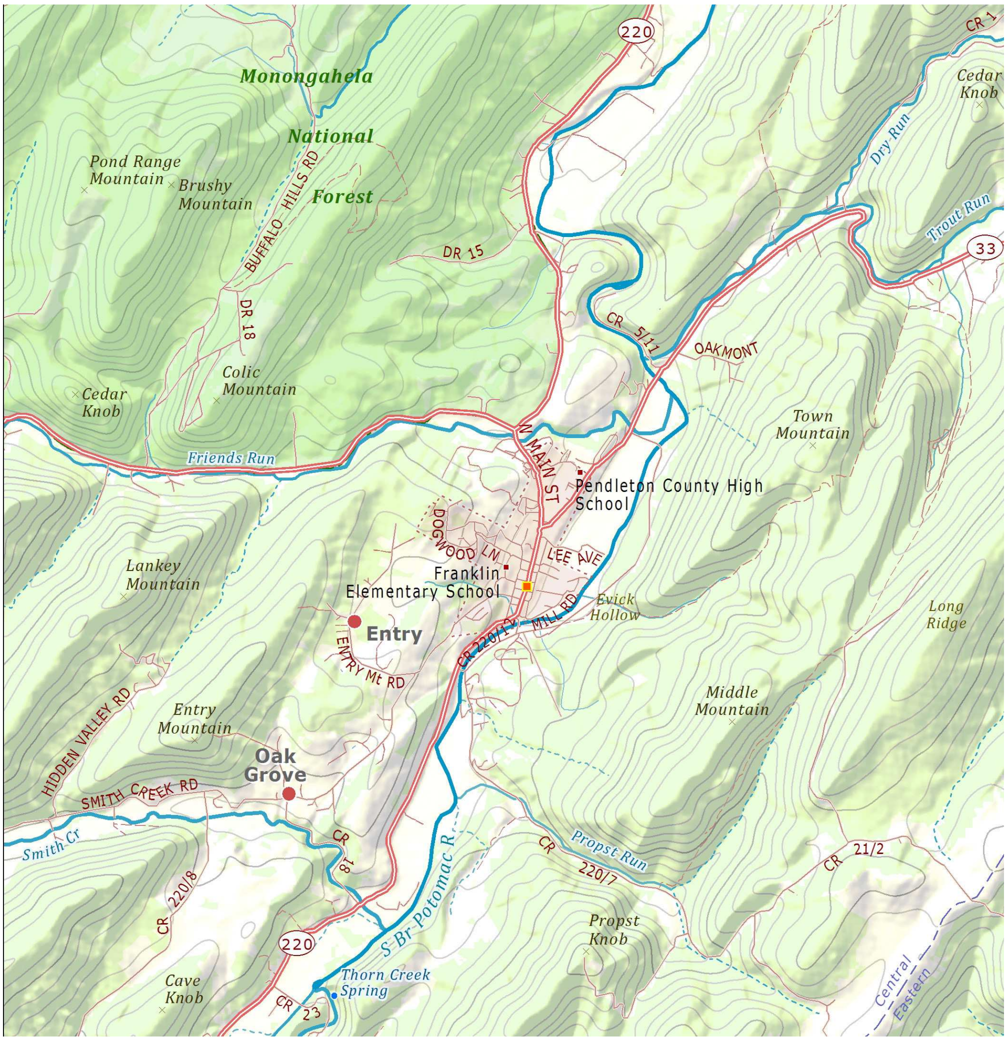

Figure 5. West Virginia subbasin at 1:50,000 on screen (reduced size in figure).

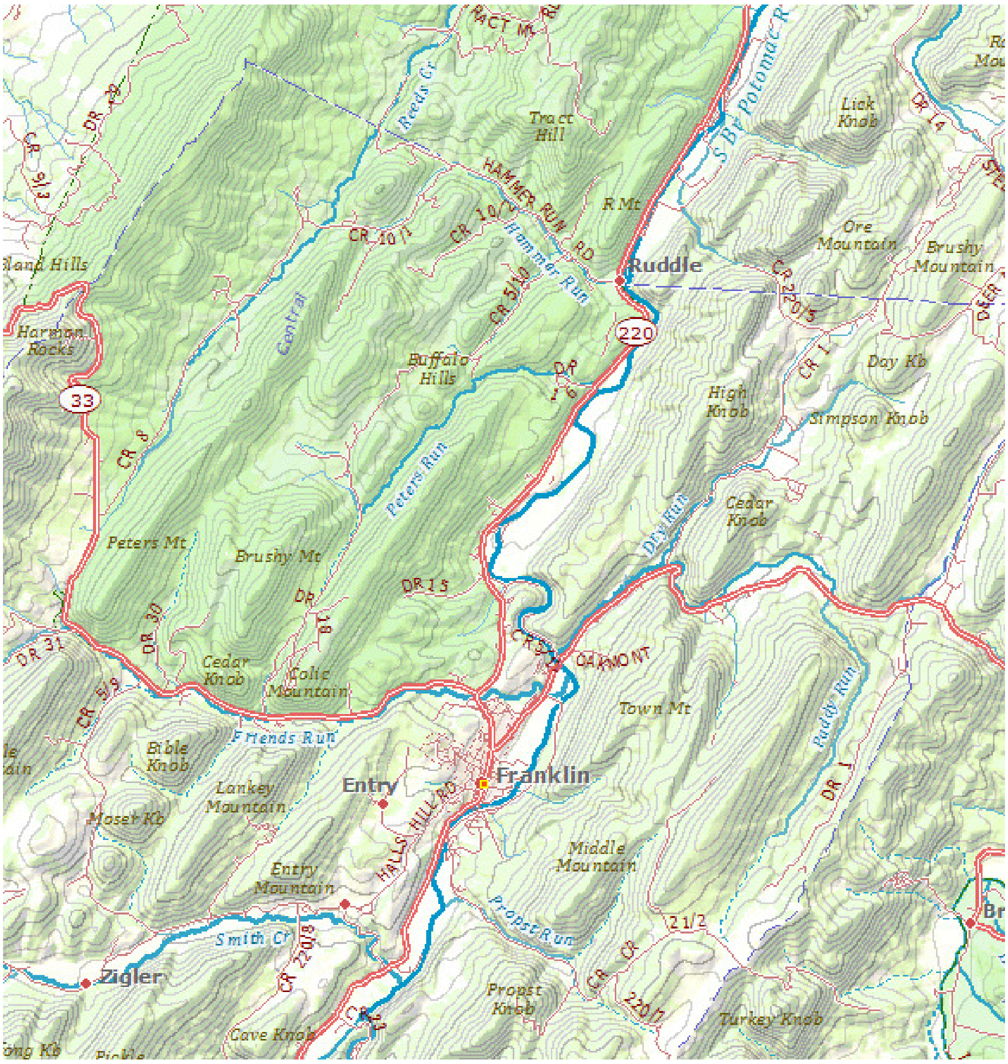

Figure 6. West Virginia subbasin at 1:100,000 on screen (reduced size in figure).

Figure 7. West Virginia subbasin at 1:250,000 on screen (reduced size in figure).

Figure 8. West Virginia subbasin at 1:500,000 on screen (reduced size in figure).

Figure 9. West Virginia subbasin at 1:1,000,000 on screen (reduced size in figure).