[January 2003. This paper was written in late 2000. The USGS has since announced The National Map, a program designed to create "...a seamless, continuously maintained set of public domain geographic base information that will serve as a foundation for integrating, sharing, and using other data easily and consistently." For more information, see The National Map Web site at www.nationalmap.usgs.gov]

THE U.S. GEOLOGICAL SURVEY'S REVISION PROGRAM FOR 7.5-MINUTE TOPOGRAPHIC MAPS

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ABSTRACT

From the mid-1940's through the late 1980's the 1:24,000-scale, 7.5-minute topographic quadrangle was the primary product of the U.S. Geological Survey's (USGS) National Mapping Program (NMP). This map series includes about 53,000 map sheets for the conterminous United States and is the only uniform map series that covers this area at such a large scale. The 7.5-minute mapping program lasted almost 50 years, from the mid-1940's until the early 1990's. Revision programs that date from the late 1960's have kept the median currentness date of the map series at 1979.

There are four main categories of map revision: minor, basic, complete, and single edition. Minor revision is done on maps that have few changes since the last revision; it includes boundary updates and corrections of previously reported errors. Basic revision updates features from digital orthophoto quadrangles (DOQ) and aerial photographs. Complete revision of all layers is seldom performed because of the high cost. Single-edition revisions are done by the U.S. Department of Agriculture Forest Service using procedures similar to basic revision. Contour update is an optional part of basic and single edition revision but is not often done because of the high cost.

These revision programs were not designed to do replacement mapping. Most map revision is done from remote and secondary data sources, including the following:

- Geometry is controlled and some feature content interpreted from DOQ's.
- Most feature content is interpreted by using stereophotographs from the National Aerial Photography Program.
- Boundary and name information is collected from Federal databases, other maps, and State and local agencies.

During the height of the 7.5-minute mapping program, a large part of the NMP budget was focused on graphic mapping. Because of funding increases in areas outside graphic map production and evolving customer priorities, the NMP today spends more of its data production resources on digital and image products, as well as more money on geographic research, data distribution, and customer assistance. Because of the expense of traditional topographic mapping, the NMP is investigating alternate data sources, procedures, and product designs for graphic maps.

INTRODUCTION

In 1989, the Mapping Science Committee of the National Research Council wrote that "...the primary product [of the U.S. Geological Survey (USGS) National Mapping Program (NMP)] is the 1:24,000, 7.5-minute topographic quadrangle series. This...is the only uniform map series that covers the entire area of the [continental] United States in considerable detail. The series will be completed in 1990...NMP's principal raison d'etre is changing to the equally challenging task of maintaining currency of these maps...A major ongoing revision effort, which the NMP is now pursuing, is required" (National Research Council, 1990, p. 8).

The USGS produces printed maps and digital map data for all States, possessions, and territories of the United States, and Antarctica. This paper discusses only the 1:24,000- and 1:25,000-scale topographic maps in the 48

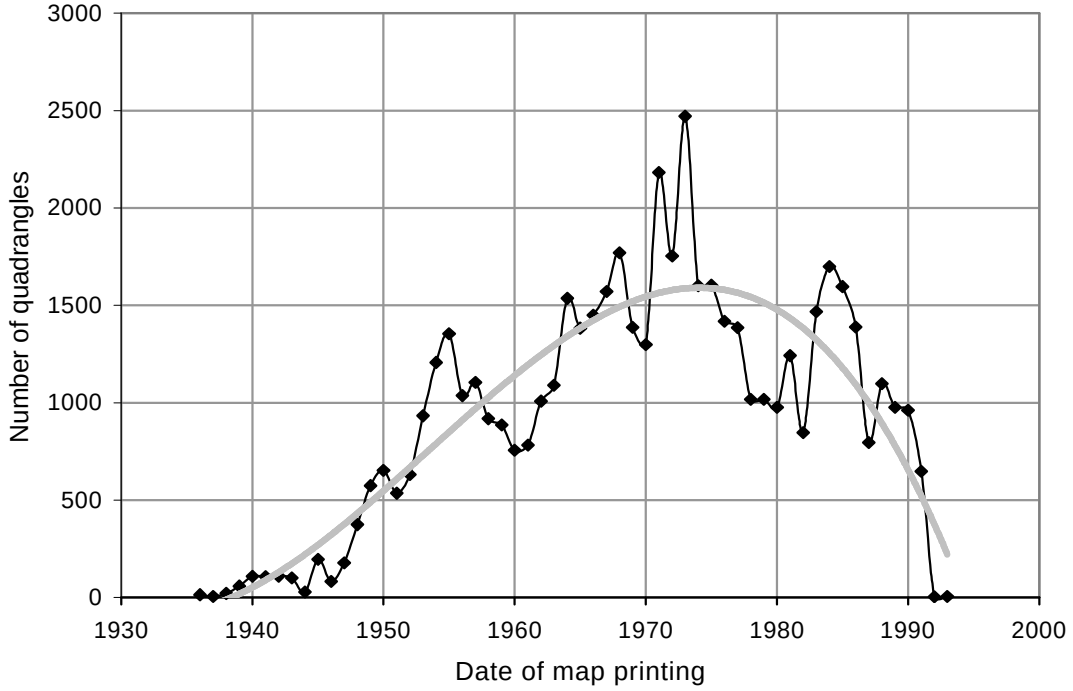


Figure 1. Original production of 7.5-minute quadrangles. Each data point is the number of quadrangles published in a particular year. Each cell is shown only once, the first time a map for the cell was made. The median date of printing is 1972. The smooth gray curve is a polynomial trendline.

The data for this and the other figures in this report are from National Mapping Program databases, including the map catalog (MAPCAT) and the assignment management system (AMS).

continental United States. There are 54,890 standard 7.5-minute and 7.5- by15-minute cells in this domain. Because the two cell sizes overlap, the number of map sheets has varied with time. At present, there are 53,336 map sheets that cover the continental United States. Both cell sizes and scales are referred to in this paper as "7.5-minute maps" or "7.5-minute quadrangles."

The 7.5-minute maps are more detailed versions of other quadrangle series that date back to the formation of the USGS in 1879 (Schwartz, 1980, p. 311). Although 7.5-minute maps were produced by the USGS as early as 1908, the effort to cover the country at this scale was a product of World War II technological advances and 1939 legislation creating a National Mapping Program (Bohme, 1989, p. 167). Initial coverage of 7.5-minute maps in the continental United States is summarized in figure 1. The program grew rapidly from 1945 through 1955, then more slowly, and peaked in 1973. In the early 1980's, it became evident that production rates were not sufficient to finish the series before the year 2000. Beginning in 1982, manuscript maps without final cartographic finishing were published (Bohme, 1989, p. 167). These were designated "provisional maps" (P-maps). A significant production increase in the mid-1980's resulted from the lower cost of provisional mapping (fig. 1). Most of the work on the 7.5-minute maps was finished by 1990, and the series was officially declared complete in 1992.

MAP REVISION PROGRAMS

7.5-minute maps have been revised almost from the beginning of the program, but revision numbers did not become significant until the mid-1960's (fig. 2). To speed up the revision of existing map sheets, an interim revision was introduced in 1967 (Bohme, 1989, p. 167). Commonly called photorevision, this remained the most common type of revision through the 1980's. The original map base was used as horizontal control, and new features were collected from stereophotographs without field verification. Contours usually were not revised. To show that the

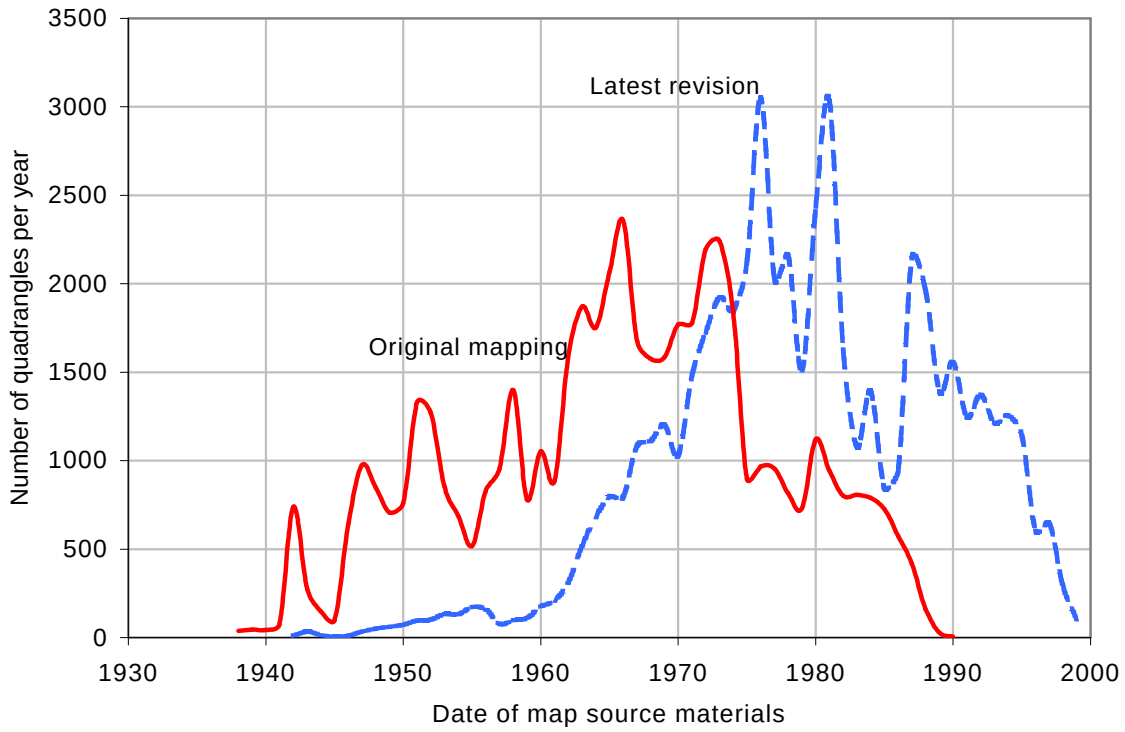


Figure 2. Currentness of revised maps compared to original maps. The solid line shows the date of source materials (date of aerial photography in most cases) for the data set in figure 1. The dashed line shows the date of source for the most recent revision of each cell. For example, 1981 is the source photography date for the most recent revision of about 3,000 quadrangles. The median currentness date for original mapping is 1966; the median for latest revisions is 1979. The data include minor revisions but not maps reprinted "as is" to replace low shelf stock.

revision did not meet new mapping standards for control and field verification, new photorevised features were printed on the maps in purple.

With the completion of the 7.5-minute mapping program in 1992, the USGS began formulating a graphic revision plan to keep primary series maps current. Decisions about revising 7.5-minute quadrangles are based on user requirements, available resources, and the preferences of funding cooperators. Accuracy assessments, evaluations of existing quadrangle materials, and error reports are also considered. For the last several years, the two primary drivers of the NMP revision program have been the following:

- Cooperative funding from other agencies. The USGS will divide revision costs equally with other State or Federal agencies.
- A list of 5,000 "high seller" maps. These maps are judged to be most in demand and are given priority for revision work. A percentage of these maps are revised each year with or without cooperative funding.

Other criteria, such as less formal input from other State and Federal agencies, are also considered. Revision decisions are also constrained by data availability, especially of recent aerial photography and digital orthophoto quadrangles (DOQ) for the quadrangle under consideration.

Age of the 7.5-Minute Series

Figure 2 shows the overall currentness of the 7.5-minute maps at the end of 1999. The median currentness date for the series as a whole is 1979, so the average 7.5-minute map is almost exactly 20 years old. The data in this figure

include all photorevisions and minor revisions but not maps reprinted "as is" to replace low shelf stock. Aerial photographs and other source materials used for map revision are usually 3 to 5 years old by the time the map is published, so most maps printed in 1999 appear in the years 1994 to 1996 in figure 2.

Figures 3 and 4 show the geographic distribution of the oldest and youngest maps. 9,270 maps have currentness dates of 1970 or earlier (fig. 3), and about the same number (9,420) are current as of 1990 or later (fig. 4). The remaining 34,650 quadrangles were made or revised between 1971 and 1989.

Many of the oldest maps are in relatively isolated areas with low populations and low land values. These areas may have experienced very little change since the maps were originally compiled.

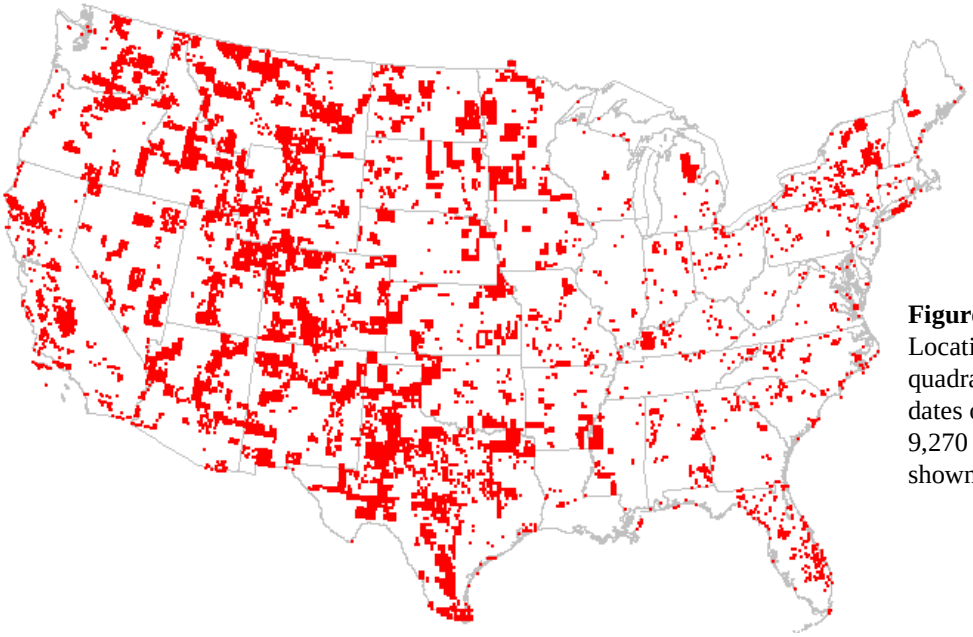


Figure 3. Oldest maps. Locations of the 7.5-minute quadrangles with currentness dates of 1970 and earlier. 9,270 quadrangles are shown.

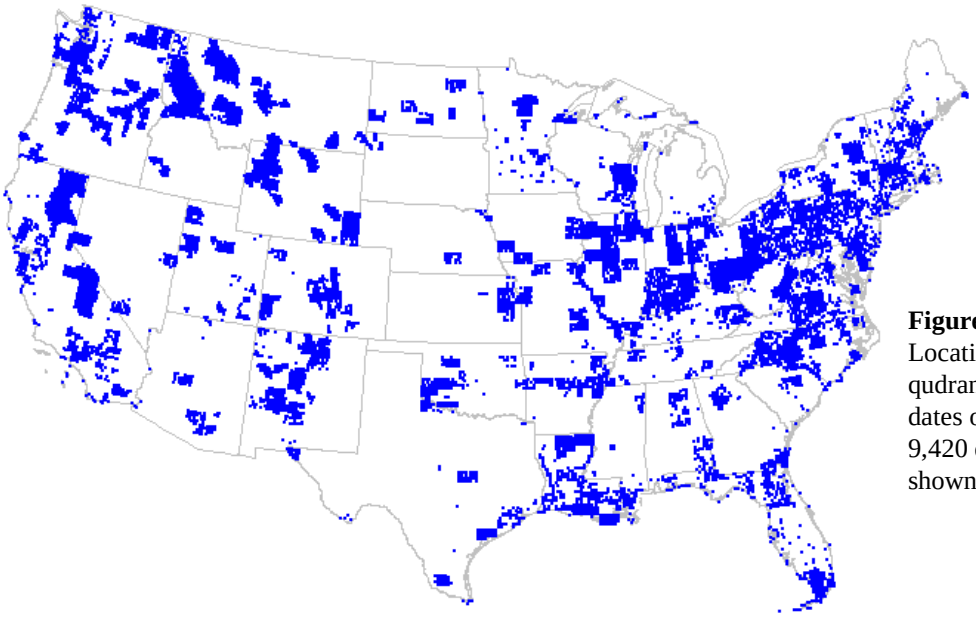


Figure 4. Newest maps. Locations of the 7.5-minute qudrangles with currentness dates of 1990 and later. 9,420 quadrangles are shown.

Types of Revision

There are currently four official types of map revision: minor revision, basic revision, complete revision, and single-edition revision. The first three are defined by USGS product standards, the fourth by an interagency agreement with the U.S. Department of Agriculture Forest Service (FS). Numbers of each type of revision produced from 1996 to 2000 are shown in figure 5.

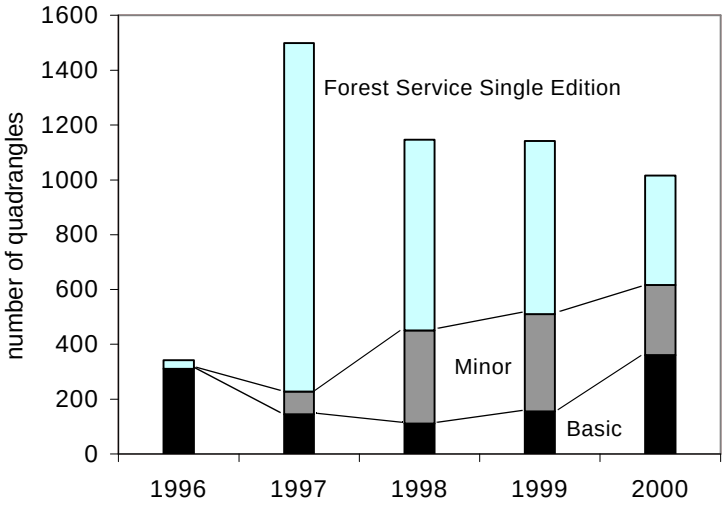
Minor Revision. Revision candidate quadrangles are compared to recent aerial photographs to determine how much change has occurred since the last map revision. If changes are small and few in number, the map may need only minor revision. Names and boundaries are updated using information from local sources and other maps. Corrections on file are made and the map collar is updated.

Basic Revision. Basic revision uses aerial photographs from the National Aerial Photography Program (NAPP) to update a subset of map features. DOQ's made from NAPP photographs are the primary data source. The DOQ's are used for horizontal position control and for feature interpretation. Stereopairs of the same NAPP photographs aid feature interpretation. In some cases, field checks may be performed by volunteers or by State cooperating agencies. Name, boundary, and collar updates are similar to minor revision. Basic revisions may or may not include contour updates.

Even though it depends almost entirely on remote sources, basic revision is not cheap. Basic revisions done with USGS Government labor in 1998 and 1999 required an average of 280 hours per quadrangle, or approximately $17,000. Although costs for contractor-produced revisions in 1999 were comparable, they are expected to decrease as contractors gain experience with USGS standards.

Complete Revision. Complete revision updates all standard feature content, including contours. Information is field checked. This is very expensive and is therefore rarely done. Only four USGS quadrangles were completely revised between 1995 and 2000. Complete revision of these four was possible because a State agency did the field verification work.

Single Edition. In 1993, the USGS and the FS signed an interagency agreement to begin a joint single-edition mapping program. The content of the maps includes features normally shown on USGS maps, with additional features required for the management of National Forest System land. Under the agreement, 7.5-minute quadrangles that contain National Forest land are revised by the FS but are printed and distributed by the USGS. There are about 10,000 7.5-minute single-edition map cells. Procedures for single-edition updates are controlled by the FS and are similar to USGS basic revision procedures. The interagency agreement allows the FS to update only the National Forest land on a quadrangle and leave the other areas of the map unrevised. In these cases, the



Forest Service	32	1,271	696	630	400
Minor		83	340	356	255
Basic contour			5	26	27
Basic	311	145	106	129	210
Total	343	1,499	1,146	1,141	1,200

Figure 5. Numbers and types of recent revisions. Basic revision and basic with contour revision are combined in the bar graph. The data show the year that production work was finished; source photography dates average about 3 years earlier.

remainder of the map is part of the USGS revision pool. The two organizations have different requirements and criteria for selecting maps for revision, so revision of forest and non-forest land is usually not concurrent.

Many of the blocks of newest maps in the western States shown in figure 4 are the result of single-edition revisions in National Forests.

Revision Numbers and Effect on Series Currentness

The map revision program is driven by high sellers and cooperative funding. Map revision is not implemented as a cyclic program that is guaranteed to keep all maps up to date.

Nevertheless, it is interesting to examine the effect of different production scenarios on series currentness. Figure 6 shows the results of a simple simulation run against the "most recent revision" dataset shown in figure 2. In the simulation, a fixed number of the oldest maps in the series were revised each year, starting in 2000. The simulation assumed 2-year-old source materials.

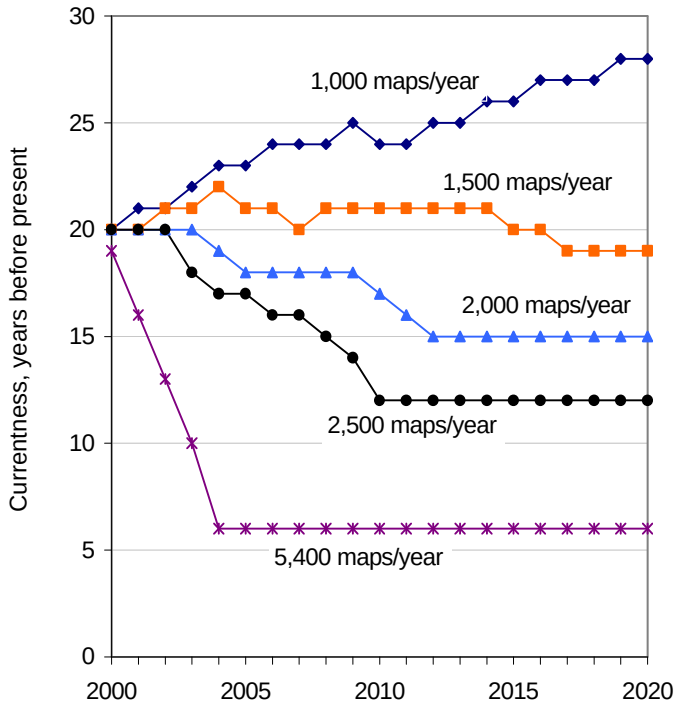


Figure 6. Improving currentness of the entire map series. A simple simulation that shows the effects of revising a fixed number of the oldest maps each year.

Figure 6 illustrates that if the 1,500 oldest maps are revised each year, the median age of the series remains near its present value of 20 years. If fewer than 1,500 maps are revised each year, the median age of the series increases. If more than 1,500 maps are revised each year, the age of the series decreases. Both the increase and decrease reach a limit that is a simple function of the number of maps revised per year and the age of the source materials.

Fewer than 1,500 maps are currently being revised each year (fig. 5), and revisions are not necessarily of the oldest maps. Therefore, it is safe to assume that the median age of the 7.5-minute map series is increasing.

Figure 6 illustrates the extreme difficulty of ever making the entire series "current." Even if the present map revision rate was increased five-fold, the median age of the series would still stabilize at about 6 years with the age of the maps evenly distributed between 2 and 12 years.

DATA SOURCES

The current USGS revision program was not designed to do replacement mapping. Most revision work is done using remote and secondary sources, including the original map, recent aerial photographs, information from other maps, and information from other Government agencies. Following are the major sources of data.

Aerial Photographs and Digital Orthophotos

DOQ's are the most critical input to basic revision. They are made using horizontal control that is usually independent of the topographic map, and the average USGS DOQ is positionally more accurate than the average topographic quadrangle. An objective of basic revision is, therefore, to make the revised map match the DOQ.

Major planimetric features, especially roads and buildings, can be collected directly from a DOQ in computer-aided drafting software systems.

DOQ's are made from NAPP photographs, and basic revision compilers also use stereopairs of the original photographs to assist with feature interpretation. The current NAPP plan calls for full coverage of the continental United States in 7 years (1997-2003). This schedule is subject to availability of funding, including State cooperative funding (USGS, 1996).

DOQ's made from the most recent photography do not always exist. The NAPP, the DOQ program, and the map revision program are not closely coupled; each has its own customer base and its own funding sources. Nonavailability of recent aerial photographs, a recent DOQ, or the control needed to make a DOQ can make it impossible to revise a particular map.

The photographs for the original 7.5-minute program usually had scales of 1:15,000 to 1:25,000. The NAPP photographs used for revision have an average scale of approximately 1:40,000. The smaller scale has some effects on the accuracy of the revision, especially on contour updates.

Other Government Agencies

The USGS depends on other agencies for some types of data, particularly boundaries. When a map is authorized for revision, requests for up-to-date boundary information are sent to Federal, State, and local government agencies. The elapsed time between requesting and receiving these data can be a significant factor in the total time required to revise a map.

State agencies participating in cooperative mapping projects may also elect to do field verification work to improve the accuracy and completeness of the map content.

Geographic Names Information System

The Geographic Names Information System (GNIS) database is the official repository of feature names for the United States. Names and feature locations are checked against the GNIS and changes are included on every topographic map revision.

Earth Science Corps

The USGS has a volunteer program that allows private citizens to contribute to the earth science mission of the agency. The Earth Science Corps is the field component of the volunteer program, and it includes an ongoing map annotation project where volunteers collect new information to be used in the National Mapping Program. As of October 1999, about 3,100 quadrangles had been assigned to 2,400 volunteers.

CONTOUR UPDATES

Elevation contour lines are the signature feature of USGS topographic maps. Much of the other information on a 7.5-minute map can be found on other types of maps, but until the recent development of airborne laser and radar ranging technologies, there were no other sources of elevation data with comparable coverage and accuracy.

USGS map revision programs have always assumed that topography is much more stable than planimetry. A new road or subdivision disturbs the land surface slightly, but rarely is the disturbance enough to warrant major revision of contour lines with 10-, 20-, or 40-foot intervals. The current map revision program is explicitly tied to DOQ's, and contours cannot be revised from these monoscopic images.

Basic revision follows these guidelines for revising contours:

- Contours are revised only as part of joint funding agreements; that is, only when another agency is willing to share the cost. Revising contours can increase the cost of a revision by 50 to 100 percent.
- The contour overlay is not completely recompiled but rather is updated in areas of significant topographic change. The original map base is used for vertical control.

- In areas of insignificant topographic change, "logical contouring" is used to preserve registration with other features. For example, contours are squared across new roads and routed around new ponds without stereorecompilation.

Contours are revised with NAPP stereophotographs, which are usually smaller scale than the photographs used to compile the original contours. Therefore, improving the accuracy of existing contours is usually not possible except in areas of very significant surface disturbance. This is consistent with the overall objectives of the revision program, which are to maintain the horizontal and vertical accuracy of the existing map.

Most basic revisions do not include contour updates (fig. 5), which means that the topography and planimetry on the revised graphic have different currentness dates. In some cases, this leads to glaring visual artifacts, such as contour lines in large water bodies or new islands with no topography.

HORIZONTAL ACCURACY

The USGS originally compiled topographic maps using procedures designed to meet the National Map Accuracy Standards (NMAS). Basic revision procedures were originally designed to retain the accuracy of the existing map but not necessarily to improve it. This objective has shifted in the last 2 years, and now the horizontal accuracy goals of basic revision are that the revised map should be at least as accurate as the previous version and that all features should match the DOQ to within at least 73 feet. Both goals are evaluated by statistically comparing the map to the DOQ.

The accuracy of old map bases can sometimes be improved by warping the base to fit newer control. When appropriate, the USGS incorportates such methods into revision processes (Moore, 1999).

DISCUSSION

Table 1 shows the Congressional appropriations for the NMP in fiscal year 2000. In addition to these appropriated funds, the total NMP budget included about $50 million from other agencies for jointly funded projects.

Table 2 summarizes production figures for some of the more important NMP data products in 1999, the most recent year for which these figures are available. Data production is funded partly by the Mapping Data Collection budget line item (Table 1) and partly by other Government agencies through Joint Funding Agreements (JFA). The exact dollar cost of the programs, as well as the proportions funded through JFA's, have not been published. However, some inferences about cost can be drawn from JFA prices and other known data production costs.

For example, it costs about $800 to make one DOQ quarter-quadrangle (a 3.75-minute cell), so the total 1999 DOQ production cost about $48 million. Up to half of this may have been paid by JFA partners.

Table 1: 2000 National Mapping Program Budget

Mapping Data Collection	56.3
Information Management and Delivery	34.2
Geographic Research	36.1
National Mapping Program Total	*126.7*

From the USGS Fiscal Year 2001 Budget Justification. Figures are in millions of dollars. These figures were compiled in mid-2000 and are therefore estimates of final expenditures for FY 2000. The Information Management and Geographic Research line items are not discussed in this paper.

The 1,141 topographic maps include 630 FS single edition revisions, 356 USGS minor revisions, and 155 USGS basic revisions (fig. 5). Minor revisions cost about $1,100 and basic revisions about $17,000 per quadrangle. The total cost of USGS map revision in 1999 was therefore about $3 million. As with DOQ's, up to half of this cost could have been paid by JFA partners.

These data illustrate that images are more important to today's NMP than topographic line maps. This is not particularly surprising; images are not only cheaper than line maps, they are easier to keep current. Image products therefore attract more cooperative funding, which is a major driver of NMP production decisions.

Traditional maps have two advantages over images: they show features that cannot be seen on images, and they present data with a greatly enhanced signal-to-noise ratio -- selected features are interpreted by the map producer and represented with clear symbols. But both of these advantages are very expensive. Correctly locating and classifying features such as survey markers, cemetaries, hiking trails, wells, and historical points of interest requires field work. Drawing contour lines, roads, and streams that are both accurate and visually appealing requires human craftsmanship (fig. 7).

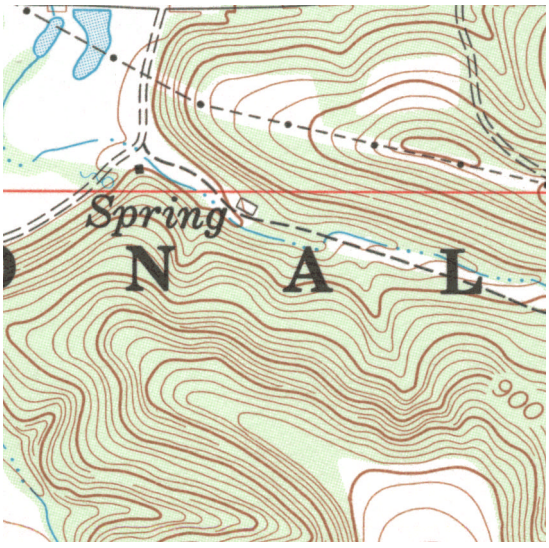
Table 2: Selected Core Data Base Production, 1999

National Hydrologic Dataset 1:100,000-scale cataloging units	1,800
National Elevation Dataset 7.5-minute quadrangles	4,400
Digital Ortho Imagery (DOQ) 3.75-minute quadrangles ("quarter quads")	60,100
Topographic Map Series 7.5-minute quadrangles	1,141
Satellite Land Remote Sensing Data Scenes processed	142,000

From the USGS Fiscal Year 2001 Budget Justification. Numbers of production units are not directly comparable for several reasons, including different product scales.

It is possible that the traditional topographic quadrangle is a product whose time has passed. Perhaps these maps were appropriate for the industrial age of the 19th and 20th centuries, but not for the information age of the 21st century. It may be that such maps cannot be made fast enough to meet modern users' expectations of "currentness." It is, for example, very difficult to imagine any combination of technical advances and budget conditions that would allow the 7.5-minute map series to be made to their original standards and also allow a large percentage to be kept current to within 5 years of the present.

Figure 7. Topographic map artwork. The image is a piece of a 7.5-minute topographic map in south central Missouri. This fragment covers about one quarter of one square mile, so approximately 12 million pieces this size are needed to cover the continental United States. The spring, cabin, power line, and four-wheel-drive road (single dashed line) probably cannot be seen on an aerial photograph, and so are on the map only because photointerpretation was done in the field. All linework was scribed by hand. Today linework is drawn on a computer screen with drafting software, but every new line must still be drawn by a person.



On the other hand, this might be true only if we insist on retaining the artistic appearance and elegant data integration of the traditional topographic quadrangle. Different products with comparable information content could be maintained more easily. Such products include combinations of images (orthophotographs, satellite imagery), gridded elevations, names from databases, and GIS vectors.

These types of image-based products, when compared to traditional topographic maps, would likely have these characteristics:

- Higher total information content, but less elegant presentation.
- More friendly to computer analysis, less friendly to human interpretation.
- More data overall because of the image base, but less consistency of content between maps because of using "best available" data sources for map linework.
- Could be kept more current at lower cost.

The USGS is investigating several alternative graphic products as potential replacements for the 7.5-minute map series. One proposal is to use a DOQ as a base, retain the 7.5-minute format with traditional collar and cartographic grids, and overprint selected linework and names on the DOQ. Key to this concept is taking the map linework from digital GIS databases created by other Government agencies, or even by commercial organizations. Using existing data would increase speed, reduce costs, and allow the map to use the best and most current sources. However, it also raises problems of data consistency and cartographic presentation. Few feature layers have been captured in nationwide databases, so content would vary by State and region. The scale and positional accuracy of GIS databases vary, so data from other sources may not register to each other or to the DOQ image base.

CONCLUSIONS

Up to 1,400 7.5-minute quadrangles per year are being revised. However, very few revisions include contour updates, new control, or field verification of content.

Map revision standards and procedures currently in place will be used for at least several more years. The USGS has no specific plans to return to a program of new 7.5-minute topographic mapping by collecting new control and doing new field verification. In order to revise a greater number of maps with available funding, topographic map revision will continue to be done with remote and secondary sources for the foreseeable future.

The USGS has active programs to improve the processes and lower the costs of topographic map revision. These programs focus on integrating data from external sources, and therefore may lead to changes in map content and symbol standards.

Traditional topographic maps are part scientific documents and part works of art. The artistic component -- shaping contour lines to be visually appealing, for example -- is very expensive in both time and money, and perhaps is no longer practical. Alternative products based on combinations of more modern data sources are being examined by the USGS as potential replacements for the 7.5-minute topographic map series.

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