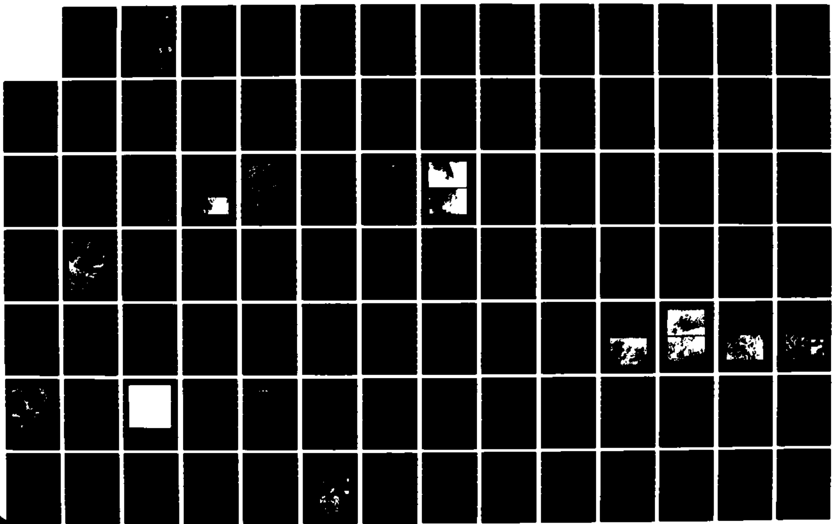
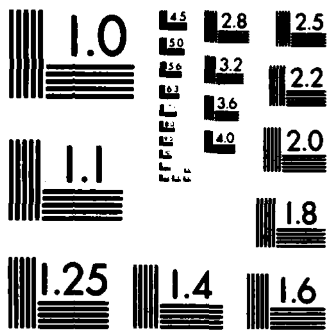
AD-A151 061 MAP DESIGN FOR COMPUTER PROCESSING: LITERATURE REVIEW AND DMA PRODUCT CRITIQUE(U) NAVAL OCEAN RESEARCH AND DEVELOPMENT ACTIVITY NSTL STATION MS G LANGRAN JAN 85 1/2

UNCLASSIFIED NORDA-72 F/G 8/2 NL





MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

(10)

AD-A151 061

Naval Ocean Research and Development Activity

NSTL, Mississippi 39529 NORDA Report 72 December 1984

Map Design for Computer Processing: Literature Review and DMA Product Critique

Final Report

Sponsored by Defense Mapping Agency HQ/STT

Gail Langran

Mapping, Charting, and Geodesy Division
Ocean Science Directorate

85 02 19 104

Foreword

As Navy's lead laboratory for Mapping, Charting and Geodesy, NORDA continues to maintain R&D capabilities and interest for improving map and chart designs for new production techniques and distribution procedures, including electronic charting concepts.

This report identifies mapping and charting techniques currently used by DMA that should be discontinued or updated so conversion to digital production processes is not hampered by traditional but unwieldy practices. A prototype product line, suggested in the report, capitalizes on the computer's fortes (computation and data processing), minimizes subjective and nondiscrete processes, and responds to current user requirements. An optimized product line will yield economy and speed so resources can be devoted to making products current and accurate.

R. P. Onorati, Captain, USN
Commanding Officer, NORDA

Executive summary

A comprehensive review of DMA's standard map and chart products is necessary before DMA converts to digital production. Tradition has prevented product designs from evolving with changing technology. With digital production imminent, some current designs become prohibitively expensive because they rely on subjective or artistic decisions, or because they use nondiscrete processes unsuited to digital methods. To avoid extraordinary expense and delay in procurement, installation, and use of digital equipment, such designs should be replaced by graphic formats that are better suited to computer processing.

This study identifies current DMA practices that will resist automation and suggests alternatives. Content and appearance of DMA products have been evaluated following a survey of available research literature. User requirements surveys, performance tests, and psychophysical studies have been applied to a critique of DMA's product line.

Recommendations are made for extensive changes to current DMA product designs that will

- replace intuitive, subjective, and nondiscrete design practices suited to human intelligence with techniques that exploit the computational powers of the computer;
- promote hierarchical derivation of products from a digital data base;
- remove unnecessary features from current products, reducing clutter and expense;
- standardize type, symbols, and terminology used by aeronautical, topographic, and hydrographic departments to maximize efficiency;
- ease DMA's transition to a fully digital production environment.

Additionally, new and interesting cartographic techniques that could be of future interest to DMA are discussed. Prototype maps from as early as the 1930s are reviewed—valuable cartographic techniques have been available for years, but become practical only with computer processing. No original research was conducted in this study. Instead, the present state of research applicable to digital mapping was surveyed. Most techniques recommended in this report require virtually no additional research and can be immediately implemented at minimal cost to yield greater efficiency, quicker response, and better communication of geographic information to mapreaders.

The maps and charts produced by DMA can communicate information more effectively, and they can be more responsive to user requirements. Changes to product design will avert problems and extraordinary expense in procuring, implementing, and using digital production equipment. Design modifications suggested in this report include simplifying symbols, using alternate methods of relief representation, eliminating contour lines on small scale maps, eliminating bathymetry and underground features from aeronautical charts, reducing the size of DMA's largest charts to fit current digital equipment, adjusting formats slightly to facilitate digital mosaicking, and reducing the amount of type on maps by relying more heavily on point and area symbols. A landscape format with bleeding edges is recommended for the 1:50,000 topographic map. A 1:100,000 ground/air product is proposed.

Section I reviews research concerning graphic techniques. Section II discusses ways to portray features on maps, and users' requirements for features. Section III describes techniques that are uniquely suited to digital production, as well as problems in computer mapping that can be minimized by careful planning and design modification. Section IV applies the discussion and conclusions to a critique of DMA's standard products. Conclusions, summarized in Section V, include suggestions to promote efficiency for DMA action and a program of recommended research to answer questions raised by the current study.

Acknowledgments

This work was sponsored by DMA under program element 63701B; its subtask title was "Analysis of Map/Chart Information." Special credit goes to Lt. Col. Tom Baybrook, the DMA Program Manager, for comments, suggestions, and ideas. Dr. Don Durham, head of NORDA's Mapping, Charting and Geodesy Division and Dr. Charles Walker, head of NORDA's Pattern Analysis Branch, provided valuable advice and support. The NORDA Project Manager was LCDR Vic Hultstrand. Gail Langran was the principal investigator.

Contents

Illustrations

Tables

Map Design for Computer Processing: Literature Review and DMA Product Critique

Introduction

As computer techniques for map processing become available and inexpensive, it is increasingly surprising that standard map designs have not evolved to exploit benefits offered by the computer. Instead, map designers have insisted upon uncompromising adherence to traditional products, despite imprecise instructions that depend on artistic judgments difficult to automate; and despite attractive alternatives that capitalize on the computational and data processing abilities of computers.

A comprehensive review of DMA's standard map and chart products will make conversion to digital production easier. Tradition has prevented product designs from evolving with changing technology. With digital production imminent, some current designs become prohibitively expensive because they rely on subjective or artistic decisions, or because they are nondiscrete processes unsuited to digital methods. To avoid extraordinary expense and delay in procurement, installation, and use of digital equipment, such designs should be replaced by new graphic formats that are suited to computer processing.

A study of map design has a large body of research from which to draw. The past 30 years in cartography has been a period of extraordinary interest in map design and its impact upon transmitting geographic information. The growing volume of research in cartographic communication has been credited to the realization that for the first time in man's history "the ability to gather and reproduce data has far outstripped our ability to present it" (Robinson, 1952). It can be said today that we have more objective information regarding what makes a map a good map than ever before.

It has been predicted that the design of government-produced map series is unlikely to change in the 1980s regardless of any gain in knowledge. According to Taylor (1983b),

> Imaginative design and new approaches to cartography as a medium for effective communication are unlikely to come from the topographic map producers. This would require a conceptual shift of some magnitude of which there is at present little evidence. Change is also hindered by the economics of map production. Millions of dollars have been invested in equipment and personnel to produce the standard topographic map. Sheer economic inertia makes any substantial change in this area most unlikely.

This prediction ignores a strong economic incentive to modify current product specifications to take advantage of substantial cost savings in both the development and the production stages. Cartographic reproduction methods have influenced map design throughout history. Each new printing technique has altered the appearance of maps without apparent detriment to mapreaders.*

PURPOSE OF REPORT

It is the purpose of this report to:

- summarize the practical applications of research in cartographic communication;
- summarize what is known of user requirements;
- ease DMA's transition to digital map and chart production by modifying product designs, omitting current practices that are unreasonably difficult to perform automatically relative to their importance, and substituting techniques that exploit the computational powers of the computer;
- comment on new and interesting cartographic techniques made practical when the computer is ensconced in the production line;
- recommend a program of research to assist DMA in designing a product series that will maximize efficiency upon transition from analog to digital methods.

This study identifies current DMA practices that will resist automation and suggests alternatives. Content and appearance of DMA products have been evaluated following a survey of available research literature. User requirements surveys, performance tests, and psychophysical

*American mapmakers have been criticized for having a retrospective attitude toward map design that causes them to cling to design standards set by the restrictions of wax-engraving despite the widespread use of offset lithography since the 1940s (Woodward, 1975 and 1983).

studies have been applied to a critique of DMA's product line. No original research was conducted in this study. Instead, the present state of research applicable to digital mapping was reviewed.

Recommendations are made for extensive changes to current DMA product designs that will:

- replace intuitive, subjective, and nondiscrete design practices suited to human intelligence with techniques that exploit the computational powers of the computer;
- promote hierarchical derivation of products from a digital data base;
- remove unnecessary features from current products, reducing clutter and expense;
- standardize type, symbols, and terminology used by aeronautical, topographic, and hydrographic departments to maximize efficiency;
- ease DMA's transition to a fully digital production environment.

Additionally, new and interesting cartographic techniques that could be of future interest to DMA are discussed. Prototype maps from as early as the 1930s are reviewed—valuable cartographic techniques have been available for years, but become practical only with computer processing. Most techniques recommended in this report require virtually no additional research and can be immediately implemented at minimal cost to yield greater efficiency, quicker response, and better communication of geographic information to mapreaders.

ORGANIZATION OF REPORT

Sections One and Two review research concerning graphic techniques and contains chapters on symbology, type, color, clutter, and product format (scale and size).

Section Three deals with the portrayal of features on maps and charts. Techniques and requirements are discussed for depicting terrain features, vegetation, hydrographic features, cultural features, navigation aids, grids, and boundaries. Arrangement and composition of marginal information are also discussed.

Section Four describes techniques that are uniquely suited to a digital production environment, as well as limitations of digital production that must be compensated for. It includes chapters that discuss symbol design for digitally produced maps, describe alternate means of representing terrain, examine the impact of digital production on type processing, outline automated generalization techniques; discuss ways to maximize efficiency in DMA's multiproduct environment, and examine the demands and possibilities of softcopy media and electronic chart displays.

Section Five applies the material discussed in the previous three sections to a critique of DMA's standard products. City Graphics, the 1:50,000 topographic map, the family of aeronautical charts, and hydrographic charts are examined in turn. The design of each is evaluated in terms of how effectively it conveys the information required of its users, and how easily it will be to produce using digital techniques. Alternate techniques are suggested when current designs require extensive intuitive or subjective judgments, exorbitant amounts of storage, or unnecessary amounts of computation.

Section Six presents conclusions reached during this study. General strategies for improving DMA products and preparing DMA for a digital era are outlined. Areas in which further research is needed are indicated and a program of research is outlined to further DMA's move toward an effective product line processed efficiently by digital means.

INTRODUCTION TO RESEARCH STRATEGIES

A summary of research methods and a commentary on test design for map evaluation provide a basis for future research designs as well as a means by which to evaluate the results of the studies reviewed in this report. Of necessity, this report focuses on research that uses maps as test stimuli in task-based analyses. Yet to follow the progression of human factors research from basic psychophysics, to task-based perceptual studies, to studies of the cognition of usable geographic information is to arrive at an appreciation of the level of effort involved. Many disciplines have cooperated in the hopes of reaching a better understanding of the mechanisms by which humans read graphics. Only through such knowledge can we improve our ability to accurately convey geographic information to a mapreader.

Research strategies can be distinguished in terms of their questions and their approaches. Research questions are only briefly examined in this chapter as an introduction to the studies surveyed for this report. The approach used to answer a research question is a major issue in evaluating the validity of research and is examined at some length.

Approaches to the study of map and chart design generally fall into two broad categories: subjective assessment and empirical, task-based analysis. Subjective assessment polls the users of maps as to needs, likes, and behavior. Empirical research, in an attempt to objectively measure the effect of map components upon performance, evaluates the results of tests in which subjects perform basic mapreading tasks. A discussion of research questions and the two types of research methods form the remainder of this chapter.

RESEARCH QUESTIONS

The questions that human factors research has undertaken to answer are briefly surveyed in this section. The question asked by a researcher must dictate the research method he uses.

User habits are a major topic of research. By which features do mapreaders orient themselves? How and where are the maps used? What training improves the ability to read maps? And (with a grain of salt) how do mapreaders feel about the maps that they are using? These types of questions are generally answered using a subjective technique, such as a questionnaire survey or interviews with users. Equipped with knowledge of a target user group's habits, the map designer can determine map content and map design. Unfortunately, studies that focus on opinions, habits, capabilities, and limitations of mapreaders often recommend action beyond the control of a cartographer: to teach mapreading more intensively or with a different emphasis in order to have a more consistently knowledgeable user group; or to provide better conditions for mapreading.

The effect of map design on transmitting information to a mapreader is a common concern. Color, line weights, clutter, and symbol strategies are graphic variables that can have a distinct effect upon mapreading. Since there is generally a tradeoff between speed and accuracy, an overriding requirement for either is an important consideration. For example, the purpose of contour lines in relief portrayal is to provide accurate information about the terrain. If subjects perform poorly in a test of speed using contour lines, it is not a major concern. It is, however, of interest if it is found that the speed of reading contour lines can be increased without jeopardizing the accuracy of interpretation. Map design questions are most appropriately answered by performance tests. Tests must be designed to answer the specific question asked, be it comparison of speed, accuracy, or differentiation.

The most appropriate contents for a given map or map series is a research question that must be revived and reviewed continually as field conditions, field equipment, and field techniques evolve. This type of question has been successfully answered using both questionnaire surveys and performance tests.

The remainder of this chapter discusses methods that have been employed in studying map design.

SUBJECTIVE ASSESSMENT

User requirements analysis

User requirements define the capabilities of map users, the features that must appear on a map, and the relative importance of features shown. A ranked hierarchy of features to appear on a chart enables a cartographer to emphasize the most important data.

Requirements are gleaned from a user group by one of two survey techniques: product review, in which a chart or group of charts is subjectively evaluated, compared, or ranked; or "visualization," where users imagine themselves in situations requiring map use.

A questionnaire survey is the most direct way to approach users. Most users are highly aware of their requirements and provide detailed direction to researchers in this area, making user surveys an invaluable tool for analyzing user requirements and for formulating guidelines for map design. For example, a survey of aircrew provided the following valuable information: despite enforcement of red-light legibility in the specification of aeronautical charts, a vast majority of airmen surveyed did not use red lighting; the survey group frequently used none of the lighting alternatives provided in the cockpit (including standard-issue flashlights), preferring instead to use privately owned flashlights for night flights (Taylor, 1977). Such individuality of human preference is a major obstacle to deriving concise, meaningful results from a study.

Visualizing a task helped military officers to define their map requirements. By imagining themselves in an operational environment facing specific problems, subjects were able to verbalize requirements that would not be anticipated in a strict laboratory setting. As they framed solutions to operational problems, researchers helped them to describe their data needs. Such data needs ranged from potential enemy hiding places to trafficability (Landee et al., 1979).

Subjective design assessments

User surveys can be and have been used to assess the actual design of maps and charts. Design preferences stated in surveys, however, must be carefully interpreted. There is no scientifically proven link between mapreader preference and mapreader performance, especially in the case of map appearance (Wheaton et al., 1967; McGrath and Osterhoff, 1969; Hill, 1974; Granda, 1978; and Farrell and Potash, 1979). One study found preference judgments to be entirely irrelevant of performance under daytime conditions; under nighttime conditions some significant correlation existed between preference and performance (Hill, 1974a).

The key to this lack of correlation between user preference and user performance can be linked to the susceptibility of most mapreaders to an attractive or familiar product, which is generally perceived to be more effective than it really is unless past experience has pointed out shortcomings. Respondents tend to criticize an unfamiliar product more harshly than a familiar product and look for defects in prototypes, perhaps because they perceive that this is the purpose of the survey. This reaction makes existing maps test more favorably by comparison (Lakin, 1972).

Careful test design has helped to overcome this bias toward the familiar or attractive. Taylor (1974) avoided user bias by having users critique a set of unfamiliar charts that encompassed the major qualities of a familiar chart. It was felt that because the familiar chart was also popular, other charts would suffer by comparison. As a further safeguard, a group of new pilots was tested who, while being quite familiar with flight procedures, were as yet unfamiliar with the standard issue chart and were, presumably, unbiased.

User surveys highlight a truism: given a choice of several ways by which to perform a task, some users prefer one method, others choose a different one, and resistance to change can be very high. Any attempt to satisfy all mapreaders is doomed to failure from the start, and encouraging a proliferation of highly individual means of mapreading can only perpetuate clutter on charts. If cartographers bow to this resistance to change, insights provided by the scientific study of geographic information transmission will not be incorporated into cartographic practice. While it is unrealistic and perhaps dangerous to attempt to force mapreaders to adopt unfamiliar methods of accomplishing complex mapreading tasks, minority requirements must be carefully scrutinized before they are honored. By forcing respondents to rank information as "essential," "desirable," and "unnecessary" (or otherwise on a continuum), user requirements can be separated from user preference.

PERFORMANCE TESTING

Performance tests empirically analyze the effect of design variables upon the transfer of information from cartographer to map to mapreader. These tests are most often used for objectively evaluating the effect of graphic components upon the ability of the mapreader to perceive (extract information) and to cognize (assimilate the information into knowledge) mapped information.

Constraints upon empirical tests

It is easy to dismiss the volume of perceptual studies to date: some tests have been poorly designed, frequently subjects have been too few, and it is difficult to apply the findings of these studies to cartography—in many cases, test stimuli were abstract arrangements of symbols that had little in common with maps. The individuality of mapreaders in all ways defies quantification. Even if an average mapreader response were established, mapreaders who are not average must be considered.

Yet the research is of value; when it is surveyed, distinct traits and perceptual trends can be distilled which, if analyzed, will lead to the design of better maps that efficiently convey a more accurate depiction of geographic reality to mapreaders. As summarized by Monmonier (1980), precision in mapreading cannot be expected—humans are variable, so are printing presses. Edge growth from printing processes and perceived irradiation are difficult to predict and to control. Understanding the limitations of cartographic communication may be the greatest contribution to be made by studies of perception and cognition in mapreading.

Pitfalls in empirical test design force careful planning. Preston (1936b) found that when asked to make relative judgments, subjects do not like to repeat the same judgment on consecutive calls. Potash (1977) warns of the interrelatedness of map symbols: changing one symbol on a map is likely to cause one or more of the other symbolic methods to change as well. Thus, to test the effect of supplementing contour lines with layer tints by comparing subjects using both layer tints and contour lines against subjects using only contour lines ignores the fact that when tints are not used to depict elevation, they are generally employed to depict vegetation. Two tests, then, and two symbol sets are required:

- extracting relief information using elevation tints and contour lines (vegetation shown by iconic symbols) versus extracting relief information using only contour lines (vegetation shown by tints);
- extracting vegetation information using iconic symbols (relief shown by elevation tints and contour lines) versus extracting vegetation information using vegetation tints (relief shown by contour lines).

Only by accounting for the full range of information displayed on a map can the impact of different methods of portrayal be analyzed.

Test designs

Performance test designs range from simple laboratory tests of speed or accuracy in mapreading, to complex field tests of the skills reliant upon quick, accurate cognition of geographic information. The remainder of this section will describe and comment upon some representative test designs.

Eye movements of subjects searching a display for an assigned target provide insight into the cues that guide eye movement from one symbol to another. This also illustrates the strategies people use when asked to familiarize themselves with a mapped area. Different mechanisms are used for recording eye movements. One is described by Dobson (1977):

> A scene viewed by a person, if it is sufficiently bright, is reflected (or forms a bright spot) on the cornea of the eye. Because the cornea forms an eccentric bulge on the eyeball, the angle of reflection changes as the eyeball rotates and the bright spot appears to move. When movements of the head and the display are prohibited, the reflection can be used to determine where the subject is fixating on the display, since the reflection systematically varies as the eye scans.

Central to the design of an empirical test is the determination of tasks to be performed by test subjects. Mapreading involves many types of tasks on both a micro- and a macroscale. At the most basic level, search, counting, and identifying have been used in task-based performance tests. On a higher level, landscape identification tasks (such as locating geomorphic features, matching terrain profiles, and determining the steeper of two slopes) are useful in analyzing relief portrayal. In general, the results of higher level or multiple task performance are more difficult to analyze due to the number of contributing variables. Christner and Ray (1961) used factor analysis to extract the underlying components of four tasks: count, verify, compare, and locate. They found that recognition, search, and memory were used in varying degrees in all four tasks.

McCann (1982) lists the tasks most frequently used in experiments on mapreading:

- symbol identification;
- symbol matching;
- symbol code intepretation;
- recognition of areal patterns formed by point symbols;
- search;
- count, verify, compare, and locate;
- route planning;
- map memorization;
- low level air navigation;
- tactical military planning and combat operations.

McCann observes that while these tasks encompass a broad range of complexity, the more complex tasks involve less complex components.

Board (1978) divides mapreading tasks into three categories, each comprised of simple task elements:

- navigation—search, identify and locate position on map, orient map, search for optimum route on map, search for landmarks en route, recognize landmarks en route, search for destination, identify destination, and verify;
- measurement—search, identify, count, compare, contrast, estimate, interpolate, and measure;
- visualization—search, identify, describe, compare/recognize, contrast, discriminate/distinguish, delimit, verify, generalize, prefer, and like.

Cole (1981) warns of the need to distinguish between tasks that require recognition and tasks that require recall when designing performance tests. Castner (1979) calls attention to factors in the mapreading process that affect test results and over which the map designer has little control: the level of experience of the mapreader; and the amount of time the mapreader allocates to each component of the task being performed.

Most empirical test results are analyzed statistically. A technique that can be used either in conjunction with statistical analysis or alone is to analyze the comments of users when performing a task. This technique is called "verbalizing" (Thorndyke and Stasz, 1979).

Gaming helped a research team to test the effect of reducing the level of detailed information shown on a map display. The impact of a reduced-detail design upon the quality and speed of decisions was evaluated by simulating a tactical operation. Subject scores were based on combat effectiveness. Thus, perception, behavior, requirements, and cognition were evaluated in a single study (Granda, 1976). In a similar study focusing on a different question, gaming was incorporated with other techniques to test the effectiveness of a map display. Symbols were varied while subjects played a reconnaissance game. Subject ability to select a route was instrumental in evaluating symbol effectiveness, since route selection requires not only perception of distance but use of mapped information in decisionmaking (Landis et al., 1967).

Orienteering teams can be used to test a prototype map against a traditional map. Several groups equipped with differently designed maps of the same area race to traverse an area. Both speed and accuracy of mapreading are of major import to win an orienteering match. With controls in effect, the relative virtues of the maps employed could be analyzed (Norway Computing Center, in prep.).

A MODEL TEST DESIGN

A study that empirically measured photomap reading performance (Wheaton et al., 1967) serves as an example of a well-designed performance test. The study had two related goals: to select a preferred photomap format based on military map user performance; and to determine the impact of design variations upon performance.

Tasks representing a variety of military map uses were chosen to be performed both in field and in laboratory ("command post") settings to take advantage of the realism provided by the field, and the precise control provided by the laboratory. In both test settings, the map-reading tasks were performed under subdued lighting, since many operational situations offer poor illumination, and because studies in perception have indicated that reduced lighting magnifies mapreading difficulties (e.g., differentiating hues, figure-ground discrimination, and distinguishing detail).

There was concern during the design stage of the test that identical photomaps could produce different results, depending upon the type of mapped terrain. To control the possibility of terrain/design interactions, each prototype format was tested on two geographic areas that were topographically diverse.

Test subjects were military personnel from two stations with a range of mapreading expertise. Since the two geographic areas represented on the test maps corresponded with the two geographic areas of the military bases, the test was controlled for subject familiarity with the test site—subjects could be rated on their performance in an area with which they were familiar and also in an area that was strange to them.

Performance measures were developed to permit adequate sampling of map use behavior. In field performance, subjects were tested on their ability to correlate their physical surroundings with the information provided by the photomaps. The tasks used were positional location, direct orientation, and route following. Laboratory tests were designed to measure the ability of the subjects to detect and identify a set of natural and man-made features marked on the maps. The speed and quality of tactical decisions were also measured.

Experimental maps were unique in the following ways: production technique, contour line density, type of river and road enhancement, color of the background image, and level of annotation density employed. The effect of each of these variables on the interpretability of the map was to be tested. The feasibility of a large scale factorial study design was analyzed and the strategy rejected as being too expensive—432 photomaps and over 4000 subjects would be required. Instead, the study was conducted in phases that permitted sequential screening of photomaps in terms of the main variables. The purpose of this strategy was to identify the superior photomaps during each phase and to include only these "superior" maps in subsequent testing.

This test is well-designed due to its organized approach to compensating for the complex interrelation of variables present in mapreading. It is exceptional in the number of controls utilized over possible irrelevent variables such as terrain familiarity, type of mapped terrain, and level of mapreader experience.

SUMMARY OF RESEARCH

Both subjective and objective techniques have been used successfully to investigate human factors involved in mapreading. Subjective methods, which include questionnaire surveys and interviews, are most successful in analyzing user requirements. Objective empirical methods for map design evaluation abound; only some of this type of research is applicable to cartography, but that which is applicable provides valuable input to map designers.

Graphic Elements

1. Symbology

Symbols are abstractions of reality. Information is encoded by varying shape, size, pattern, and color. Point, line, and area are the most common classes of symbols. A point symbol generally shows feature position only without linking the horizontal or vertical dimensions of the feature to that of the symbol. A line symbol represents both feature position and linear extent. An area symbol indicates feature position and its extent on a horizontal plane (Potash, 1977).

When evaluating symbols for digital production three criteria should be applied.

- How effectively do the symbols communicate information?
- Do the symbols take full advantage of the benefits provided by the computer, or are they unnecessarily difficult to produce by automated means?
- Do the organization and the form of the symbols optimize automated recapture of mapped data through scanning, recognition, and feature-to-symbol relation?

The first criterion is examined in this chapter. Research is reviewed that evaluates the variables influencing communication via symbols. The next two criteria are discussed in Chapter 14—Computer Production of Symbols. Problems occurring when symbols are displayed in softcopy are discussed in Chapter 19—Softcopy Display and Electronic Charts.

PERCEPTUAL RESEARCH

Despite a large volume of psychophysical experimentation on symbol perception, there are problems in extrapolating the symbols on a white background) in timing the performance of tasks that are only skeletally mapreading. A high percentage of the work has been with point symbols, and a large proportion of the work with point symbols has examined the perception of geometric symbols used in thematic maps (graduated circles, squares, and triangles) and volumetric point symbols (spheres and cubes) seldom used on non-thematic maps.* A systematic research structure for evaluating the effect of individual symbols has been proposed by Morrison (1976) and is illustrated in Table 1.

Interest in radar displays led to investigating the mechanisms used by humans when searching a display for a target symbol, in the hope that the knowledge can be exploited to create radar displays that are more efficiently searched. Some research questions are: how does the size of the target, or its color, or its shape affect performance? Which symbols become illegible most quickly when resolution of the display is degraded? Which background characteristics relate to performance? Performance is generally defined by either speed or accuracy of identification, or by a combination of the two measures. Williams and Falzon (1963b) found speed and accuracy of symbol identification to be correlated.

Because search has been defined as a sequence of visual fixations stopping finally at a target (Williams, 1971) there is a question of how the subject determines the order of the fixation sequence. Evidently, clues from both extrafoveal and from foveal vision play a role. Thus, researchers are led to examine the discriminability of symbols in both peripheral and foveal vision.

STANDARD SYMBOL SETS

There are standardized conventions within any given map series for map symbols. These standards must be analyzed before considering alternate symbols, since minimum change is preferable. Standardization of symbols on all maps is an arguably important goal. Principles emerging from a study of the literature (Board, 1973) are:

- insofar as possible, existing symbols should be kept;
- symbols already used to represent one thing should not be used to show another;
- in the case of point symbols, iconic forms where association is expressed in symbol form or color are best when there will be no size scaling;

*It is agreed that areal estimation of graduated point symbols is nonlinear (Flannery, 1971; Cox, 1976; Crawford, 1973; Kang-Tsung, 1977) and that the value of volumetric point symbols is estimated as if they were areal point symbols (Ekman et al., 1961; Ekman and Junge, 1961).

Table 1. Systematic research structure by which to evaluate symbols (Morrison, 1976).

	MAP READING TASKS			
dimension	detection	discrimination	recognition	estimation
Size				
Shape				
Hue				
Value				
Intensity				
Orientation				
Arrangement				
Texture				

- more abstract point symbol forms whose chief merits are their simplicity are best when continuous size scaling is required.

International standardization of map symbology is conceivable. Certain cartographic elements are already understood worldwide, among them: the graticule, isolines, representation of river courses and dimensions, shaded relief, geological symbols, and particular symbols for minor landforms. Yet Arnberger (1974) feels such international standardization is undesirable at the present time because:

- Scientific tests are not yet available. Without them the standardization of symbols would be premature.
- Automation offers cartography new prospects for all aspects of production, and the formation of symbols must be allowed to adapt to this new processing.

Techniques and devices exist for constructing and, to some extent, for automatically recognizing DMA's current symbol set; this makes computing the relative cost-effectiveness of new symbols somewhat complex. Standardization encourages familiarity with symbol forms and meaning, which in turn improves mapreader performance. If new symbols based on innovative perceptual research were to be introduced, overall mapreader performance could initially be degraded because of unfamiliarity with the new forms. It follows that some conventions are so well-established that they will provide the basis for standardization without being validated by empirical research (Board, 1973; see also the discussion following the papers on the subject of "Map and Color," *International Yearbook of Cartography* 7 (1967): 97-99).

SYMBOLIZATION STRATEGIES

Symbols may be either iconic (resembling in some way the feature they represent) or arbitrary (chosen for ease of production, optimum discriminability, or availability). Wood (1968) lists three ways to establish iconicity:

- imitation (also called image-related pictographs by Modley, 1972)—such as shaded relief, a swamp shown by tufts of grass;
- contiguity (or concept-related, Modley, 1972)—such as oil derricks for oil fields, anchors for anchorages, pickax for mining activity, railroad, and church symbols;
- synesthesia, the association of two senses (for example, red or orange is used for a hot desert).

The majority of shape codes used on qualitative maps are iconic; since a complete legend is not included on the map, mapreaders can, through iconicity, surmise the meaning of a symbol. Color codes are both arbitrary (graded layer tints) and iconic (blue for water, green for vegetation). Iconic color coding is a subtle endeavor; in a study of visual metaphor, Gombrich (1963) warns that red has no absolute meaning—it stands for "danger" and "stop" as well as for political parties of revolution.

Coded information is contained in one or all of the color, shape, texture, and size attributes of a symbol. A means of practical symbol design based on current theoretical thinking is described and implemented by Morrison (1982). Dimensions of the feature to be symbolized are matched to coding dimensions of the symbol. Thus, in the case of settlement characteristics, population would be coded in one dimension, most logically size; administrative importance is coded in a different dimension--shape, color, or texture. Using this strategy a maximum of four attributes can be coded in a single symbol. Human perception limits the number of attributes that can be understood by the mapreader.

Research concerning symbol attributes--shape, color, and size--is discussed in the remainder of this chapter.

SHAPE

A great deal of effort has been expended on determining which shapes are most easily and accurately identified. Researchers have studied eye movements, speed of search, and accuracy of identification to empirically track the identification process. Yet this research may be entirely inapplicable to cartographic problems. Iconic point symbols (in which the symbol resembles the feature it represents) rather than arbitrary symbols chosen for optimum recognizability are generally used on maps, a practice supported by theory, since iconic shape coding with its rational associations is easily learned, remembered, and used (Barmack and Sinaiko, 1966; Honigfield, 1964; Meister and Sullivan, 1969; and Van Cott and Kincade, 1972). Unfortunately (since iconic symbols tend to use shape to establish iconicity) shape has proven to be one of the more difficult criterion by which to identify symbols in a random distribution (Williams and Falzon, 1963b).

Although research efforts indicate that some shapes are more distinctive than others, absolute rules of construction have not been produced. Some general requirements for constructing recognizable shapes follow (Bowen et al., 1960):

- simplicity;
- symmetry;
- continuous contour (and often long perimeter);
- relatively large enclosed area;
- either sharply angular or simple curved forms;
- familiarity, especially in the sense of having a familiar name or meaning.

Yoeli and Loon (1972) found filled symbols to be more discriminable than open symbols, a quality that can be added to the list above.

If iconicity is a desirable trait for a symbol, the question arises whether the symbols used on maps are sufficiently iconic. Berry (1961) had subjects design symbols for 20 map features and found that less than 50% of the respondents created symbols similar to standard topographic symbols for 20 of the 30 features. Patton and Crawford (1977) found that although hypsometric maps using spectrally ordered colors for layer tints do accurately convey elevation, they also imply vegetation type, amount of rainfall, and temperature to children. Evidently, colors are more broadly iconic than desired.

COLOR

After extensive review of color coding research Christ (1975) summarized known attributes of color coding, as below.

- If the color of a target is unique for that target and is known in advance, color aids both identification and searching.
- Accuracy of identification is better for colors than for size, brightness, geometric, and nonalphanumeric shape codes; accuracy of identifying alphanumeric shape codes is higher than color codes.
- Locating and counting are performed more quickly with color coded symbols than with size, brightness, or shape (including alphabetic) code symbols.
- When colors are added to an achromatic display, accuracy in identifying achromatic target features decreases relative to a fully monochromatic or fully achromatic display.
- When color provides a natural representation of the real world, search time can decrease.
- When color is used redundantly, search time increases as the number of nontargets with the same color as the target increases.
- When color is used redundantly, search time increases if the subject does not know the color of the target.
- It appears that memory of a target color fades less rapidly than memory of target size, orientation, and shape.
- When brightness contrast is low, color contrast can improve visual acuity appreciably, but acuity is increased much more by increasing brightness contrast.
- Orientation is not a factor in color coding.
- Color does not distort shape.
- Red is best for distance viewing; orange is more easily seen in peripheral vision; yellow-greens are best for tasks demanding high acuity.

Dobson (1983a) warns against absolute faith in the recommendations listed above, since a vast majority of the contributing studies did not use map-like stimuli. Indeed, examining the effect of color coding point symbols on maps or on map-like displays is a neglected research area.

Constraints on color coding include: red-light legibility, a requirement that Taylor (1975a) recommended be dropped because few airmen were found to use red lighting; color blindness of mapreaders;* combinations of colors that alter original or intended hue; and different color perception depending on the method of generation (e.g., additive or subtractive).

While it is important to be aware of the effect of color upon the perception of symbols by the mapreader, in actuality the choice of color must be balanced against the importance of a symbol relative to the purpose of the map. Ideally, all data on the map is maximally legible; in practice, a cluttered map would result.

POINT SYMBOL SIZE

Berry (1961) examined the relationship of size to other symbol coding attributes. Size judgments were found to be relatively unaffected by most factors, as below.

- Size judgments are essentially the same between solid and outline symbols.
- Size judgments are essentially the same between solid and patterned symbols.
- Symbols drawn to appear three-dimensional are judged the same as if they are two-dimensional.
- Size judgment is only slightly affected by color.
- The relationship between actual and perceived size is nonlinear.

LINE SYMBOL WIDTH

Wright (1967) tested the ability of subjects to perceive line weight differences for solid line symbols on a map. He discovered three variables affecting the ability of the reader to discriminate among line widths.

- The ratio between the difference in line widths and the width of the wider line.
- The pattern of lines. Widths in rectilinear patterns were more difficult to distinguish than widths in irregular patterns.
- The number of categories of line width. The more categories, the more difficult was discrimination.

SUMMARY

This chapter has discussed the findings of objective research into symbolic communication. Symbols in cartography are generally iconic, since iconicity promotes learning and recall. Although a great deal of research has been expended on shape encoding, for cartographic purposes color is a more useful tool. Color coding aids search, identification, locating, counting, and memory, being more useful than size or shape in all these counts. Size judgment is not particularly variable with color or pattern, but perception of relative sizes is nonlinear; thus, symbol sizes must be carefully selected if size encodes a hierarchy of importance.

2. Type

Type, more than any other aspect of cartographic design, has evolved along with the capabilities of current technology throughout history. Printer's metal type replaced hand lettering despite protests that the inflexible spacing of metal type was rigid and unattractive (Crocker, 1964). With the introduction of photographic typesetting, the practice of separately proportioning each point size within a type style was replaced by typefaces in which a single face was enlarged and reduced, regardless of the disapproval of those who felt the practice produced inferior type and lowered the quality of charts. There is, however, no scientific evidence that any of these concessions to time and money degraded the communication of geographic information.

The literature dealing with typography for maps and charts was, until the 1960s, comprised of affirmations of tradition, artistry, and personal preference. Some scientific analysis of typographic conventions had been performed for linear but not for spatial applications (Burt, 1959; Zachrisson, 1965; Marchbanks and Levin, 1965). Saito (1962) examined the literature of psychophysics and designed guidelines for map typography by using psychophysical rules as predictive guidelines for legibility and perceptibility of map type. Gardiner (1964) applied the recommendations from linear typographic research to extrapolate typographic requirements for cartography. The works of Saito and Gardiner were the first attempts to approach cartographic typography in a scientific manner. Neither Saito nor Gardiner, however, tested their hypotheses extensively.

Thus, the work of Bartz (1969a, 1969b, 1970a, and 1970b), which established and exercised a methodology to analyze cartographic type parameters, came as an important step. Bartz observed that the function of type on a map is multifaceted and includes symbolic/analogic meaning not found in running text. To this point, type had been tested by assessing its legibility; now "searchability,"

*An estimated 6% of all healthy males have reduced sensitivity to color, and 0.003% are fully color blind.

too, was an issue. From this observation came the technique of measuring the amount of time required to search for assigned names as a means of assessing the most efficient map annotation methods. Assessing the search task is the most widely accepted means to date of evaluating typographic parameters.

TYPE STYLE

Perhaps the single most important finding of typographic research is that font variations on a map have no significant effect upon the performance of mapreaders. The popular belief that nominal differences in features can be encoded by the mapmaker (and more important, decoded by the mapreader) via variations in type fonts is entirely unsubstantiated by any research to date, and in fact has been contraindicated (Bartz, 1970a; Foster and Kirkland, 1971; Amachree et al., 1977; Phillips et al., 1978). Research indicates that unless a mapreader has the correct expectation concerning the typeface in which a name will appear on the map, search time is actually increased when more than one typeface is used. Surprisingly, even the use of Roman and italic coding have not been found to be effective (Phillips et al., 1978).

The relative legibility of various fonts has been the subject of several studies. It has been found that sans-serif lettering is equally legible and is generally preferred to serif lettering (Amachree et al., 1977; Bartz, 1970a; Taylor, 1976a; and Phillips et al., 1978) despite findings that in running text serifs improve readability (Burt, 1959).

A poll of mapreader preference between the Gill Sans-Serif and the Times Roman (serif) typefaces showed that respondees generally preferred the Gill Sans-Serif. Map noise and clutter were simulated with a patterned background on several of the test maps. The questionnaire survey asked how easily various test maps were read. At medium sizes of type there was only a slight preference for sans-serif typefaces. As lettering size was reduced, however, the sans-serif lettering was increasingly preferred. Perhaps significant was the fact that the Times Roman lettering used in the study has notably less inked area than the Gill Sans-Serif. There was a marked decrease in user preference for maps with mixed typefaces (Amachree et al., 1977).

Neither serifs, a light face, a bold face, nor a four-point variation in type size had a significant effect in a test of search times for names upon a simulated map. Typeface variations proved to have an adverse effect on search speed unless the subject had been provided the correct expectation of the typeface in which the name would appear (Bartz, 1970a). Since the average mapreader pays virtually no attention to typefaces and thus has no expectation as to typeface, variations in type can be assumed to be generally unhelpful and arguably distracting to mapreaders.

Records of subject eye movements when searching displays for simple symbols (squares, circles, triangles, crosses, and semicircles) of different color and size shed light upon this seeming lack of response by mapreaders to typeface coding. Subjects search the study area with a series of rapid eye fixations which fall near or on the symbols being searched. In a test when the color of the target was known, over half the eye fixations fell on symbols of the correct color. When the size of the target was known this tendency weakened slightly. When the shape of the target was known the frequency of fixating stimuli of the correct shape was insignificant (Williams, 1967). Information coming from peripheral vision guides the decision on where the eye will move when searching an area, suggesting that color codes are most easily distinguished via peripheral vision, size codes are slightly more difficult, and shape codes are the most difficult of all to use.

This concept led to the hypothesis that subjects who know the size or color of a name should be faster in finding it simply because they need to make fewer fixations with their eyes. An experiment was designed to test whether typeface has a similar beneficial effect on search times. Being a shape code, the expectation was that it would not be as effective a means of coding. Results showed that increasing type size improved performance. Case was also found to be important in improving performance: names set in lower case with an initial capital were almost 10% faster to find than names set fully in capitals, even though mixed case names were somewhat smaller. There was no significant difference in search times for names set in Times Roman over Univers (Phillips et al., 1977).

A set of typographic guidelines and recommendations was put forth based on research performed collectively and separately by Phillips, Noyes, and Audley over a 4-year period (Phillips et al., 1978). The recommendations follow.

- Legibility of type must be considered in relation to the legibility of the map as a whole. The designer should ask himself: are the names among the most important features on the map, or are they of relatively minor importance?
- The size of type should be determined by the importance of individual names, and the importance of names in general for the map in question. Eight-point type is easier to search for and is more accurately copied than 6-point type.

- Names set in lower case with an initial capital are easier to search for than names set entirely in capitals of the same point size. As lower case names also occupy less space of a map, they are strongly recommended.
- Bold type is no more legible than normal weight type and should be avoided, as it has a cluttering effect on maps.
- The choice of typeface appears to have little effect on legibility.
- Under the rare circumstances when it is especially important that names are copied correctly and at the same time names are likely to be very difficult to pronounce, capitals are preferred to mixed upper and lower case.
- Type should be placed in as clear a space as possible. It is particularly important that the space to the left of the initial letter be uncluttered either by other type or by symbols of a similar size and weight. Clutter in this position significantly increases the time taken to find a name.
- Typographic coding by color or by point size can considerably reduce the time taken to find a name if the mapreader knows what size or color to expect. Type coding using type style is not effective in reducing search time. Irrelevant coding may actually increase search time.

Phillips et al. (1978) summarized their cumulative findings by comparing the process of finding a name on a map to that of the police finding a culprit known to be bald with a scar on his left knee. The police can see at once whether a suspect is bald, just as the mapreader can immediately eliminate all objects in the field of vision that are clearly not type and thus need no further eye fixation. The more labor-intensive matter of moving the eyes to a candidate name is comparable to the time-consuming process of requesting that suspects raise their left pantleg.

Balodis (1981) tested the hypothesis that the readability of a map is not affected if conventional lettering styles of reasonable sizes and weights are used. The typefaces selected for the test map were Univers Medium, Univers Medium Italic, Times New Roman, and Times New Roman Italic in 7-, 9-, and 11-point sizes. Six test maps were prepared and test subjects were timed in their search for target names. The results showed that neither the use of mixed lower and upper case letters, nor the presence or absence of serifs, nor italics affected search times significantly. Balodis concluded that the effects of typographic differences on maps had eluded the test setup and are more complex than originally supposed.

Robinson et al. (1971) argue that serif type provides better visibility and legibility. This notion is based on work with a computer simulation of human visual processing in which strongly serifed letterforms did not exhibit the visual decay of sans-serif letters when processed by line detectors. The test was slightly flawed by the extremely exaggerated serifs on the characters used (generated by an IBM Selectric typewriter). Additionally, this test was conducted in the abstract, with no reference to cartographic context and its accompanying interaction with (and interference from) other map features.

In summary, sans-serif typefaces are generally preferred by users. Although performance has not been proven to be significantly better using sans-serif type, neither has it proven to be significantly worse. Eliminating serifs could help reduce map clutter. Font variations do not improve mapreader performance and may be detrimental, since coding of this type is effective only when it is expected by and meaningful to users.

TYPE SIZE

When changes were made to standard typefaces to optimize the legibility of type for moving map displays, the main method undertaken was to increase letter size, weight, and density. After testing type legibility on the projected map, type readability context could be gleaned from surrounding characters. A larger type size is needed for a spot elevation, since each numeral must be separately distinguishable. A placename, with phonetics and familiarity to give clues to recognition, can be set in a smaller type size (Taylor, 1976a). By this same reasoning, generics can be displayed in very small sizes without losing legibility.

A caveat was placed upon this method by Phillips et al. (1978), who support the use of larger type but caution against the use of bold type. Tests showed that bold type cluttered maps without proving itself more legible than type of normal weight, as pointed out under the previous heading.

The minimum type size for a map is generally agreed to be 6 points and, in extreme cases, 4 points (Robinson, 1950; Saito, 1962). In a study currently in progress, however, type as small as 2 points was found to be readable on maps when spacing was increased (Hinckley, in prep.). Soar (1955) found the most visible combination of height and width to be a ratio of 10 height/7.5 width and the most visible combination of stroke width and height to be 1 width/10 height. Shortridge (1979) has worked to establish size intervals that provide a sense of visual hierarchy.

TYPE COLOR

Type normally appears on a map in three colors: black for cultural features, brown for hypsographic features, and blue for hydrographic features. This practice is a well-known convention, making it a meaningful code to most users. Thus, the element of expectation is present and the practice can be assumed to be effective, based upon the following evidence.

In a test of color coded versus all black type on maps, Foster and Kirkland (1971) demonstrated that a map on which hydrographic features were printed in blue took longer for a mapreader to scan when no indication was given to the subject as to the color coding. When the same map was searched with instructions that names printed in blue on the list of target names would also appear in blue on the map, search times improved significantly. The finding that expectation increases the speed of search on a map is supported by the findings of Bartz (1970a), in which correct expectation of typeface improved performance.

POSITION OF TYPE

Optimum positions for names relative to their features have not been definitively established by performance tests. There are a number of "rules of thumb" upon which, although not backed by scientific method, most cartographers would agree (e.g., those of Imhof, 1975 and Keates, 1956). This type of rule, however, will not be discussed in this report since the focus is intended to be on scientifically substantiated rules of cartography.

Terminology for label positions has been set as follows. Straight, horizontal lettering means the configuration of alphanumerics is essentially parallel to the base of the map (Fig. 1a). Straight, gridded lettering means the baseline of lettering is adjusted to the map graticule (Fig. 1b). Straight, enclosed lettering implies an alignment of alphanumerics with the frame of the map regardless of the curvature of the graticule (Fig. 1c). Sinuous lettering connotes alphanumeric arrangements that follow the sinuosity of any particular feature (river, road, mountain range, etc.) (Fig. 1d) (Balodis, 1983).

In an experiment designed to discover whether search times differ significantly between straight and sinuous lettering, Balodis (1983) assembled eight different test maps whose names, typefaces, and sizes were selected to make

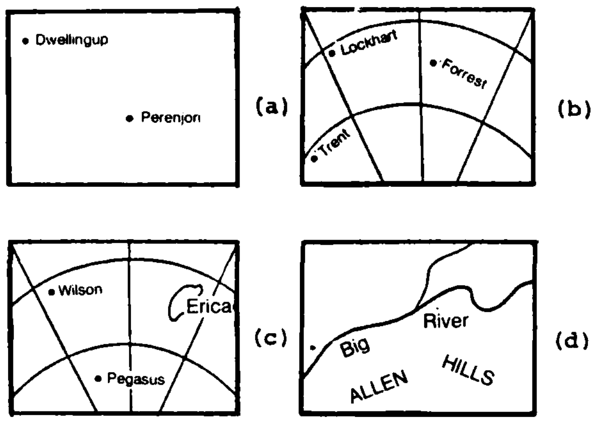


Figure 1. Label positions. From M. Balodis, "Positioning of Typography on Maps," Proceedings of the ACSM Fall Technical Meeting, September 1983.

them resemble encyclopedia atlas maps. Four maps were prepared with straight, horizontal lettering, four with sinuous lettering. After testing the search time of 50 subjects, the investigation found no evidence to support the assumption that straight lettering is more effective than sinuous lettering. This finding is contradicted by Foster and Kirkland (1971), who found that names placed horizontally and straight in a line are more easily found than curved names or non-horizontally placed names. It is also contradicted by the theory of figure-ground, discussed in Chapter 4—Clutter.

A hierarchy of preferred positions for labels relative to point symbols was produced by an experiment using the search task (Saito, 1962). The top four recommended positions in the hierarchy are: below and to the right, below and to the left, centered above, and centered below the point. The worst positions are on a line with the point symbol either to the right or to the left, since the symbol interferes with recognizing the names during search (see also Phillips et al., 1978).

Differentiation between land and water on black and white maps was improved by placing all land names upon land (Head, 1972). The importance of coastline shape to pilots and navigators makes this a significant observation.

Areas of scattered settlement in sparsely-developed areas, or "dispersed settlements," present difficult and subjective labeling decisions. A settlement is generally treated by cartographers as a point feature centered at the densest concentration of buildings, although many rural settlements are only loosely defined areally and economically. The difficulty is not solely cartographic: it can be toponymically and geodetically difficult to arrive at coordinates for a dispersed settlement. It has been proposed that such settlements be labeled as area features. Names that are solely names of post offices or other specific facilities should include the proper generic term in order not to be misinterpreted as the downtown area of a settlement (Rayburn, 1968).

SUMMARY

The research on type summarized in this chapter strongly indicates that variations in typeface are not helpful to mapreaders, and in fact may decrease the speed of searching for a name on the map. The number of typefaces used on a given map or chart can be reduced to two families for cost savings and to benefit users. Users generally prefer sans-serif typefaces. Color coded type is an effective aid when searching for a name, provided the mapreader knows the color in which the name will appear.

3. Color

Color is integral to all aspects of map design. The applications of color to type, symbology, clutter, and softcopy display are discussed in their respective chapters in this report. This chapter discusses fundamentals of human color perception.

There are 125 Just Noticeable Differences (JND) of hue; in certain hues as many as 200 JNDs of brightness and saturation can be detected (Evans, 1951). Fewer JNDs are detectable in yellow than in blue. The number of JNDs of brightness and saturation depends also upon the shape, size, location, texture, and environment of the colored object. Fifteen JNDs of hue are differentiable by most people.

However, as observed by Castner and Robinson (1969), JND is not a useful measure in cartography because differences must be immediately obvious if the map is to be used efficiently. They offer the Least Practical Difference (LPD) as an alternative. LPD is the difference observable by a chosen percentage of mapreaders—usually 70% or more.

Compilations of findings that impact color perception are discussed next. Following these compilations is a discussion of considerations for choosing color on maps and charts.

VARIABLE EFFECTS ON COLOR PERCEPTION

The following effects on color perception were noted by Wood (1968).

- The effect of contrast on brightness alone: a gray ring appears light if seen on a dark background, or dark if seen against a light background.
- The effect of the size of an area on the hue: as an area becomes larger, brightness and saturation increase. A small area can render similar hues (like blue and green) impossible to distinguish.
- The effect of contrast on saturation: two identical yellow rings look different when surrounded by a pale buff ring or by a gray ring.
- The effect of contrast on hues: the perceived hue of an object is affected by the hue of its surroundings.
- In some complex patterns, changes occur among colors in small juxtaposed areas that make them appear more alike rather than more contrasting. Small areas interwoven with fine black lines usually appear to be darker than the same areas interwoven with fine white lines. An identical gray area appears yellowish if interlaced with yellow lines and bluish if interlaced with blue lines.

PHYSIOLOGICAL ASPECTS OF HUE

Robinson (1967) lists the following physiological aspects of hue.

- Man is not extremely sensitive to hues. The smaller the colored area, the more difficult it is to distinguish a hue.
- Man is more sensitive to some hues than to others. Man is most sensitive to red, followed in order by green, yellow, blue, and purple.
- When passing through a transparent medium such as the eye, light is refracted in inverse relation to its wavelength. Thus, red is refracted the least and blue the most. This is the cause of red sometimes appearing closer and blue farther when side by side.
- Fine detail is more distinct when colored by some hues than by others. Monochromatic light is superior to polychromatic light (which combines many wavelengths). Brown, a polychromatic hue, is not as efficient for line work as is green. Among the monochromatic hues, yellow provides the best definition and blue the worst. For this reason, blue is a poor choice for defining coastlines, and yellow is often recommended as a background color.

PHYSIOLOGICAL ASPECTS OF VALUE

Robinson (1967) has noted these physiological aspects of value.

- Man is not sensitive to value differences. The average untrained eye can distinguish from six to eight value steps. Fewer steps are distinguishable in hues with narrow value ranges, such as yellow. Sensitivity to value appears to be greater in the middle range than near the extremes. Thus, greater value differences should be used near the dark and near the light ends of the value scale.
- A high value appears closer than a low value. There is also a contrast effect that causes a high value to appear lighter when it is adjacent to a low value, which correspondingly appears even darker. This effect is offset when the values are separated by a white or a black line.
- The greater the contrast in values, the greater is the definition of detail.

PHYSIOLOGICAL ASPECTS OF INTENSITY

Robinson (1967) describes the following physiological aspects of intensity.

- Man is perhaps even less sensitive to variations in intensity than to variations in either hue or value. The more extreme is the value, the poorer is discrimination of differences in intensity. Man's ability to discriminate among differences in intensity deteriorates at the extremes of the visible spectrum.
- The larger the colored area, the more intense will a hue appear.

TOPICS IN COLOR STUDY

A great deal of research has tried to determine a scale of gray tones perceived to be of equal contrast (Cuff, 1973; Jenks and Knos, 1961; Kimerling, 1975; Williams, 1958). It appears that these findings cannot be extrapolated to color tones.

An interesting aspect of color selection for worldwide map and chart series is the differences in linguistic and cultural treatment of color. Different languages and cultures divide the color spectrum in different ways. Some color terms used in English cannot be translated to other languages. Of eleven basic colors (black, white, red, green, yellow, blue, brown, purple, pink, orange, and gray) neither blue nor orange have equivalents in Vietnamese; Urdu does not have pink, orange, or gray; Tzeltel has only the first five colors on the list; and Ibibio only the first four (Berlin and Kay, 1969; Segall, Campbell, and Herskovits, 1973). Common terms do not always apply to the same areas of the spectrum.

There is a philosophical breach over whether color should be used iconically or strictly as coding medium. Iconic coloration results in a map that resembles the mapped area—green for vegetation, blue for water, white for mountain peaks, brown or yellow for desert. Symbol colors might be chosen for their associative value—red for danger or importance and black for railroads and buildings. Color used solely as a coding medium is selected to achieve objectives based on the physiological interaction of the color with the human eye (darker is more, lighter is less; red is near, blue is distant; orange, more easily perceived peripherally, is used for targets).

Most maps use color in a mixture of the two ways. Indeed, certain colors have been in use for given features for so long that they have become iconic in the sense of being immediately related to the feature class. An example is brown hypsography. Iconic colors are at the same time preferred—few would suggest representing water in any color but blue—and unfortunate—blue poorly defines the shape of hydrographic features, despite their stated importance to airmen.

SUMMARY

Guidelines on color perception can help cartographers to select color for maps and charts. Applications of color to particular aspects of cartography are discussed in the appropriate chapters of this report.

Graphic Format

4. Clutter

Clutter is an expensive addition to a chart. It is costly at both the stage of production and at the stage of usage. The deleterious effect of clutter on the page to the search for target information has been repeatedly demonstrated by researchers.

Promisel (1964) measured search performance as a function of the number of targets and found that the time taken to complete the task increased with the number of competing targets. Andrews and Ringle (1964) tested the certitude and accuracy of responses to questions on symbol arrangements. The data indicated that as the number of displayed symbols increased the average certitude and accuracy of the response decreased. French (1954) found that increasing background noise caused difficulty in recognizing a target pattern. Increasing the complexity of the target pattern improved recognition accuracy but also increased the time required for recognition. Dobson (1980) related an increase in information density to a substantial increase in confusion on the part of test subjects attempting to match symbols upon test graphics. Mackworth (1965) determined that an observed decrease in ability to identify symbols when information density was increased was caused by

- reduction in the field of view,
- degradation of foveally sensed information processing,
- a reduction in the usefulness of peripheral vision.

Maintaining current charts is more difficult with the added burden of clutter, since the extraneous information, too, must be revised. Because the task of updating increases due to better data acquisition methods, the less detailed the chart, the less there is to be altered (Magee, 1968).

Users of charts dislike clutter. A lower density of information is preferable on any chart used for navigation because users need space on the paper to mark their position fixes, times, and tracks (Magee, 1968). Since hydrographic charts have relatively low densities of information, there is no serious lack of such space. On aeronautical charts, however, the situation is critical. A survey group composed of pilots and navigators expressed a general preference for chart series designed to minimize the visual clutter of cultural information (Taylor, 1974a).

Low resolution maps resulting from projection, scanning, or transmission require a close examination of clutter, since clutter can make the difference between the legibility or illegibility of information on the page. The growing use of electronic devices for chart display has brought new interest in reducing the amount of detail.

Three major factors contribute to clutter:

- a category of features not required by the mapreading audience;
- noisy symbolic representation, needlessly redundant symbolization, a very high ratio of figure to ground, or colorful heterogeneity;
- disaggregation of information beyond the needs of the mapreader.

In the following sections each of the above contributors to clutter will be examined and remedies will be suggested.

REDUCTION OF CONTENT

The most obvious and the best method of reducing clutter is to eliminate any features that are not essential to the stated and approved purpose of the map. The evident risk of following this course is eliminating a feature that later proves to be crucial.

An analysis of user requirements must precede any major map revision to expose all possible criteria for selecting the level of detail with which geographic data are displayed on the chart. Findings suggest that information must be ranked by the users on a continuum that includes "unnecessary," "often used," and "essential." Respondees are instructed to mark an item "essential" only if it is absolutely required. No item considered to be "essential" is removed from the map. This action guards against two hazards of editing map content. First, data that are vital yet infrequently used, or data used in only a single crucial operation, cannot be eliminated by a "majority rule." Second, redundant information that is "often used" by a minority of respondees can be eliminated, forcing the minority to adopt the mapreading methods of the majority.

A list of features seldom used during visual night flight at low altitude was derived from a survey of airmen. Examples of features and symbology felt to be expendable are listed.

- Contour values (leave spots heights)
- Grid and grid annotations
- Small roads
- Woods
- Names of rivers
- Names of moors and mountain ranges
- Electronic navigation aids
- Magnetic information

Small settlements are used during night flights and must appear on the map. Their names, however, could be eliminated. The airmen surveyed were in favor of stricter qualifications for major roads; the heavy symbol was felt to clutter the map, and worse, was misleading if the road was not highly visible from the air (Taylor, 1977).

The content requirements of aircrews were further defined when a group of pilots and navigators evaluated a collection of charts at scales of 1:250,000 and 1:500,000 (Taylor, 1974a). The aircrews were divided more or less evenly between the two scales but generally preferred the amount of detail shown on the 1:500,000 charts. But, while 1:500,000 charts were felt to have complete information content, the 1:250,000 scale provides an extra degree of geodetic accuracy that can be important. This observation led Taylor to suggest that an ideal chart for low altitude/high speed users would be a 1:250,000 scale chart with information content determined by 1:500,000 scale selection criteria, providing a decluttered map with both the geodetic accuracy and the content matched to user requirements.

Two reduced clutter aeronautical charts were demonstrated by Taylor and are shown in Figures 2 and 3. The first is an experimental black chart for softcopy display. The second is a Radar Significant JOG, a standard JOG modified to expedite radar-to-map matching.

When an experimental 1:250,000 scale topographic map was produced for projected map display (Taylor, 1976a) three out of four of the major revisions reduced content to reduce clutter. Modifications made to a standard JOG to improve its readability when projected included removing hillshading to reduce the visual complexity of the map; removing minor placenames, which are difficult to read on a projected map; removing district boundaries, which were felt to be unnecessary to the intended use of the map; and changing the first height interval tint to white, lightening the overall map ground. Symbols were streamlined by removing fine detail, ineffective at low resolution (Fig. 4).

The effect of reducing map detail was tested in a tactical simulation where one group used a topographic map of reduced detail displayed on a CRT. Previous tests suggested that the level of detail in standard Army maps was excessive for many tactical tasks. When the map was tested to determine whether the reduction of detail caused a corresponding reduction in the efficiency of decisionmaking, no significant difference was found in performance or speed among those tested in a simulated tactical operation. Further, although some users of the reduced detail maps had subjectively judged their maps to be inadequate, their scores

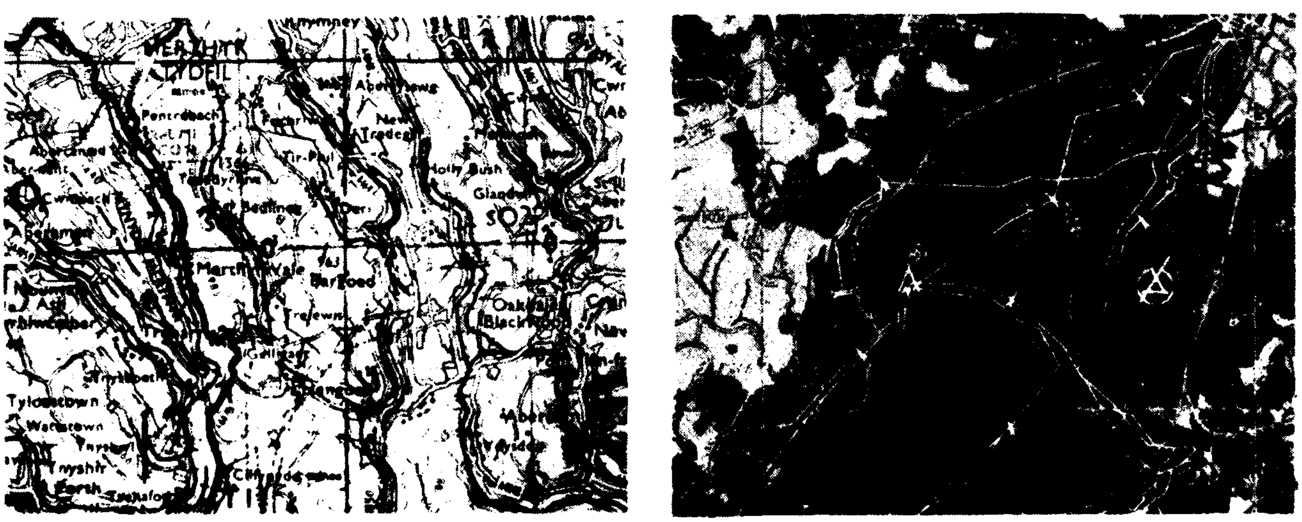


Figure 2. Black map to control brightness (Taylor, 1975).

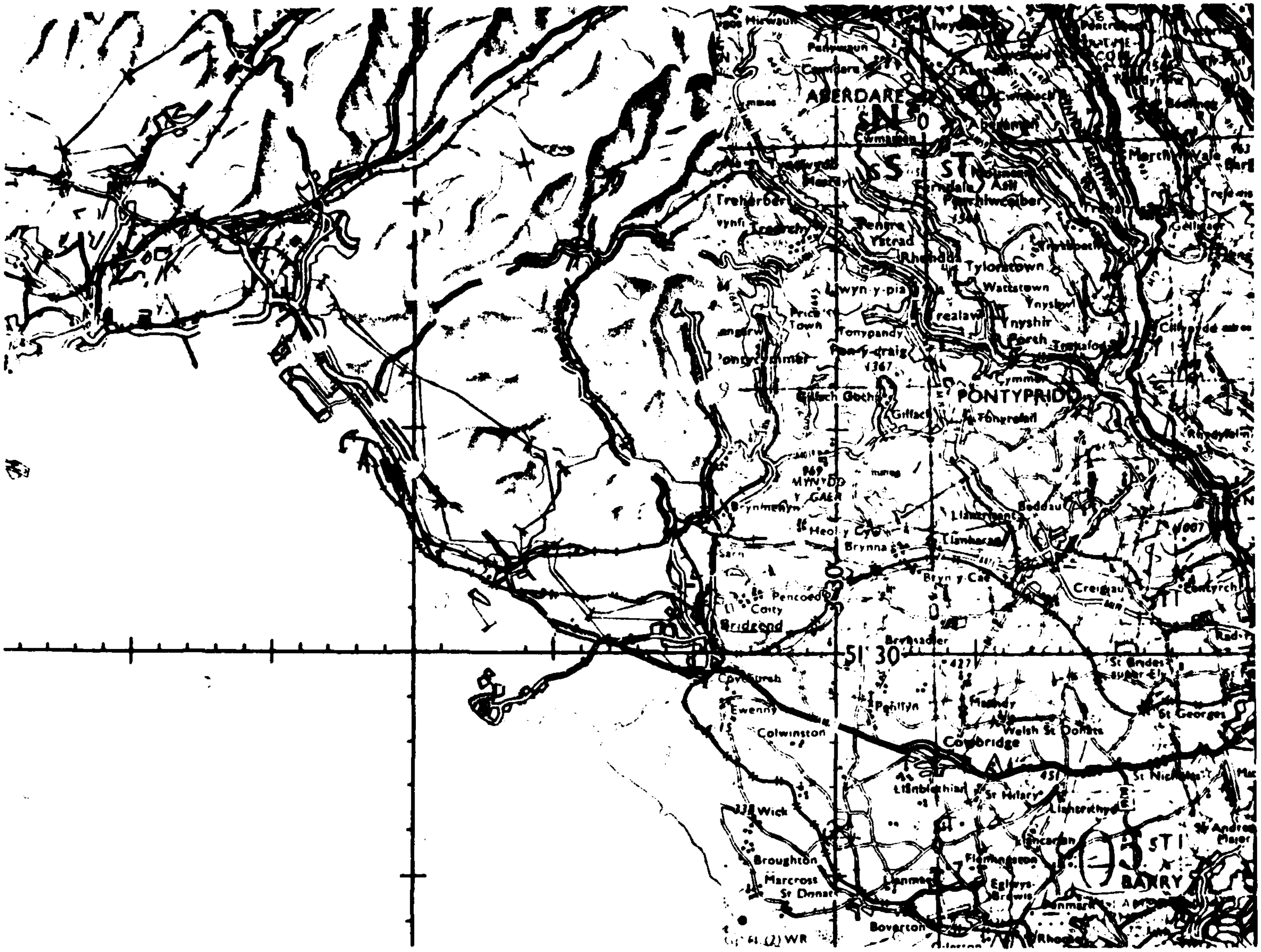


Figure 3. Radar Significant JOG (Taylor, 1975).

were not significantly different from those who felt that the reduced detail maps were adequate (Granda, 1976).

In sum, clutter can be reduced by eliminating detailed information from a chart following an analysis of user requirements. Some information may be found to be extraneous; in other cases, although an item is extraneous the majority of the time, it may be vital in unusual (but not unexpected) situations and so must be depicted on the map. The survey of user requirements must be designed so that such cases are detected. When editing is performed with care, there is no proven reduction in the efficacy of the chart.

NOISY SYMBOLIZATION

A map's content is not questioned when clutter is reduced by symbol redesign. At issue is the prominence of symbols in relation to the importance of their features.

Excessive color and excessive color contrast lead to the appearance of clutter. Such clutter can be alleviated by changing hues or saturations to reduce heterogeneity. Taylor and Belyavin (1980) admonish against maximizing color differences to promote rapid distinction among symbols. Such an effort will produce a map that appears chaotic and disorganized.

A set of prototype maps produced by the U.S. Geological Survey (USGS) illustrate how effective use of color and simplification of symbols can reduce clutter on a map. Figure 5 shows a portion of the standard Monterey quadrangle alongside a prototype design of the same area (Figs. 7 and 8 in later chapters picture related prototypes). Of special interest on the Monterey prototype are screened type, reduced prominence for vegetation, and simplified symbols (note airport and road symbols). Depth curves are blue; some hydrographic information has been omitted.

The most flagrant clutter on DMA products is from type. This clutter will be difficult to eradicate; placenames are selected by toponymists whose decisions are made somewhat independently of the need to reduce clutter. Yet the fundamental unimportance of placenames to airmen was demonstrated by McGrath et al. (1964). In testing the geographic orientation of pilots on simulated flights, no significant difference in performance was discovered between pilots using a standard Sectional Aeronautical Chart and those using a Sectional Aeronautical Chart from which all placenames—towns, rivers, and bodies of water—had been removed.

Generic labels comprise an unwarranted amount of type on DMA products. Both a symbol and a generic label are frequently used in concert (example: "anchorage" by an anchorage symbol; "light" by a lighthouse symbol). At other times a generic label is used in lieu of an areal symbol (example: "sand," "rocks"), which affords sand and rocks an undue amount of prominence. These practices should be discontinued.

Perception has been defined as the ability to distinguish a figure from its background. Merriam (1971) states that using graphic techniques to emphasize common elements on a map makes it easier for the reader to see and reconstitute patterns. Use of the figure-ground relationship, i.e., prioritizing mapped information and encoding the most important as a figure against the ground, enhances the legibility and "searchability" of the map. This separation of classes of features into one or more visual planes creates a logical appearance of organization and reduces map noise.

By establishing figure-ground on a map, features chosen to dominate the map due to importance are raised to a level perceived by a mapreader to be higher than its surroundings. This effect is achieved through the conscious arrangement of color, pattern, and shape. The lowest plane is coded in recessive colors (blue, gray, and pastels) while the highest plane uses colors (black, red, and orange) that appear closer and more distinct. Texture is used in the highest plane, since it appears to protrude; little or no line work is used on the lower plane to add to the effect of distance. If lettering is on the highest plane the shape of the words is detached from the lower planes by using straight, horizontal lines that interrupt the plane below. If the lettering is curved and oriented to the shapes of features it tends to fuse with the landscape and recede to the lower plane (Arnheim, 1976).

Laws of organization that help to predict which of two possible shapes will be seen are suggested by the accumulated research of Gestalt psychologists. These are summarized as follows by Wood (1968).

- Area—if a closed region is small it is more likely to be seen as a figure.
- Proximity—dots or objects that are close together tend to be seen as groups. Half-tone printing screens illustrate this principle.
- Closedness—areas with closed contours tend to be seen as figures more than those with open contours.
- Symmetry—the more symmetrical a closed region, the more it tends to be seen as a figure.
- Good continuation—minimizing changes or interruptions in straight or smoothly curving lines or contours emphasizes the figure-ground relationship.

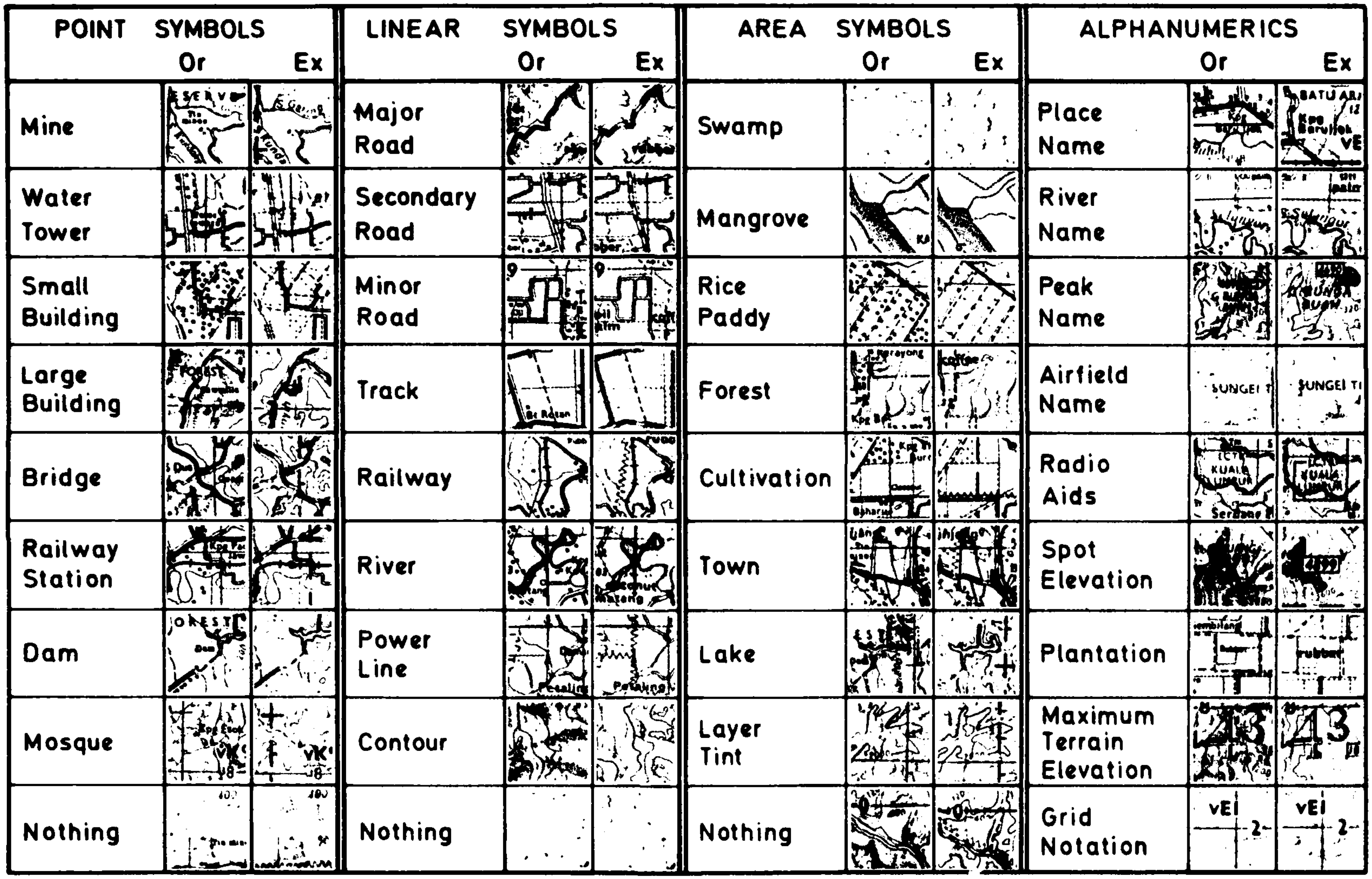


Figure 4. Experimental symbol set. Or=original map; Ex=experimental map. (Taylor, 1976.)

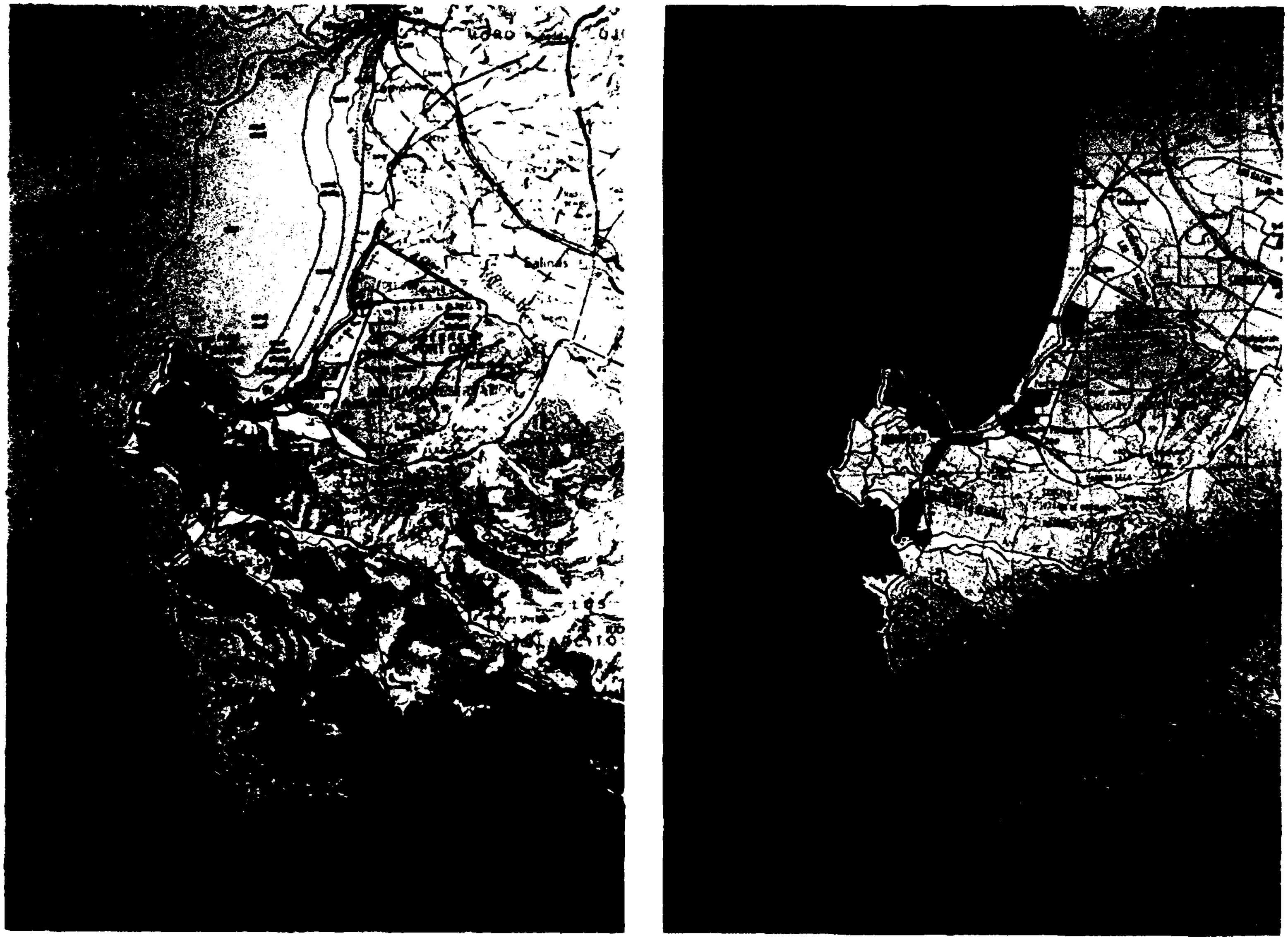


Figure 5. Clutter on conventional USGS and prototype map of Monterey, California 1:250,000.

Wood (1968) applies the theory by constructing a hypothetical map with four separate planes as follows:*

- The sea, the least important plane, is pale blue. Blue is one of the Gestalt "soft" or "film" colors that gives the illusion of recession through chromatic aberration in the eye.
- Land and associated features are placed closer to the viewer by selecting an areal tint of a "harder" color, such as green or yellow. If hill names are to be added they should be labeled in very lightweight letters, their thinness maintaining an impression of distance.
- Cultural features on a third visual plane move yet closer to the viewer by choosing a color such as red, and selecting bolder type and symbols to contrast with the second plane.
- Political features, most important on this hypothetical map, are delineated in black and labeled in heavy type.

Dornbach (1975) refuted the efficacy of the figure-ground technique. He stated that although there is an undeniable physiological effect of warm colors appearing to advance while cool colors appear to recede, when the colors become part of a display the eye-brain combination no longer perceives a focal length difference, making the theory ineffective in practice.

AGGREGATING INFORMATION

Rather than struggling to balance a given number of symbols within an inflexible amount of space, basic information can be compressed to a higher fact-to-symbol ratio to represent more data on the map without more clutter. Preliminary findings show that as compression is increased, search time, too, increases slightly offset by an improvement in the quality of decisions based on the data (Landis et al., 1979.

For example, if school symbols, church symbols, and house symbols are used by mapreaders only to ascertain the importance of a town, this fact can be more compactly represented by a simpler symbol code. By the same reasoning, if trafficability estimates are the sole purpose for encoding vegetation and soil, bivariate coding can depict trafficability by soil moisture or other factor. Vegetation and elevation data could perhaps be aggregated to produce a new layer tint strategy, since vegetation type is often dependent upon elevation, slope, and aspect.

*An application of the figure-ground technique to city mapping (Bartholomew and Kinniburgh, 1973) is described in Chapter 20—City Maps.

Hypsography is depicted redundantly on most charts. For example, DMA's Tactical Pilotage Chart shows hypsography via layer tints, contour lines, shaded relief, Maximum Elevation Figures, and spot elevations. Although each technique serves to portray either elevation or relief to maximize either speed or accuracy of interpretation, other more concise means of relief portrayal are available. Slope maps offer one solution. Several alternate ways to encode terrain information are suggested in Section III, Chapter 15—Alternative terrain representation.

Aggregation is most practical in electronic maps and charts where the mapreader has access to the data base should he/she require disaggregated information. If user needs are fully understood, however, aggregation is suitable for hardcopy use.

SUMMARY

Cluttered maps can be decluttered by reducing the contents of the map based upon knowledge of user requirements; by ensuring that the symbols used are in line with the importance of the features they represent through enforcement of Gestalt principles; and by aggregating information for a more concise symbolic representation that better serves the user.

5. Scale and Size

To users of maps and charts, scale and size are too interrelated to be discussed separately. This tradeoff was one of the major dilemmas mentioned by an aircrew evaluating aeronautical chart formats. On the one hand, a large scale (1:250,000) chart provides the level of geodetic accuracy desired by many navigators; yet the large amount of paper required to cover an area at this scale is clumsy to handle in the cockpit (Taylor, 1974a). From the perspective of the user, this tradeoff between accuracy and ease of handling is the predominant consideration in selecting map and chart format. Since scale dictates space available, the resolution at which features must appear in order to be useful is also important.

The map producer must consider the constraints of production hardware. Equipment should be optimized, such as by maximizing the image area per printing press plate or by process printing. Digital production hardware presents new constraints and outdates previous methods of optimization.

To set a product format, it is essential to consider the activities it will support and the equipment upon which it will be produced. Even more interesting is to design a product series that will provide an appropriate product format for each intended user. DMA is tasked with such a problem: it is made more complex by the diversity of users, by a coming new era in production equipment, and by DMA's responsibility for global coverage. Global coverage, in particular, introduces problems: inadequate data for some areas, projection changes with latitude, and designing overlap between products without wasting image space.

PRODUCT SIZE

Equipment constraints

Off-the-shelf digital production equipment does not easily handle DMA's larger charts. Although the exact dimensions of DMA's digital production model are to be determined, it is safe to say that none of the equipment currently on the market will accommodate the large format of DMA's aeronautical charts, or many of its hydrographic charts and City Graphics. The largest of DMA's charts are 1083 mm x 1511 mm (42-5/8 x 59-1/2 inches). Interactive graphics workstations are available in a size large enough to accommodate these dimensions, but at an appreciably higher cost than workstations with smaller worktables. The largest color scanners accept pages of only 40 x 40 inches. Currently, charts are cut in half to be scanned, an inconvenience at best. The alternatives are either to procure special hardware or to reduce chart sizes.

Topographic map size allows four sheets to be printed at one time. Optimizing sheet size in this way, based on the size of the printing press, is wise. Chapter 18—Recommendations for multiproduct operations discusses the need to derive each successively smaller scale chart from related larger scale charts to optimize generalization processes and to assure consistent content reduction. A set of "nested" chart sizes to allow efficient series-to-series derivation is recommended. A second criterion for setting chart size should be maximizing the image area on the output hardware.

User requirements

The USGS has experimented with the traditional portrait format (height greater than width) of the topographic map. A landscape format (width greater than height) using the metric scale was tried on the San Juan prototype. It was greeted with enthusiasm by the users surveyed. Comments indicated that the landscape format was more comfortable to use when seated, eliminating neck-craning; and it was easier to hold while standing because it did not buckle and fold (Gilman, 1982). This experimental format was dubbed the 45 x 60 cm (north-south to east-west) format. A set of 45 x 60 cm metric map formats is listed in Table 2.

In addition to easier handling, a landscape format is already used by DMA's aeronautical charts. Derivation of a small scale product by mosaicking the corresponding

Table 2. 45 x 60 cm format (from Gilman, 1983).

Suggested Grid Interval			Suggested Format Size		
Map Scale	Ground Interval	Map Interval	Height	Width	Recommended Series Name
1:100	5 m	5 cm	45 cm	60 cm	45 x 60 m
1:500	25 m	5 cm	45 cm	60 cm	225 x 300 m
1:1,000	50 m	5 cm	45 cm	60 cm	450 x 600 m
1:5,000	250 m	5 cm	45 cm	60 cm	2-1/4 x 3 m
1:10,000	500 m	5 cm	45 cm	60 cm	4-1/2 x 6 m
1:20,000	1 km	5 cm	45 cm	60 cm	9 x 12 km
1:50,000	2.5 km	5 cm	45 cm	60 cm	22-1/2 x 30 km
1:100,000	5 km	5 cm	45 cm	60 cm	45 x 60 km
1:200,000	10 km	5 cm	45 cm	60 cm	90 x 120 km
1:500,000	25 km	5 cm	45 cm	60 cm	225 x 300 km
1:1,000,000	50 km	5 cm	45 cm	60 cm	450 x 600 km
Related formats					
1:24,000	1 km	4.2 cm	45.8 cm	58.3 cm	11 x 14 km
1:25,000	1 km	4 cm	44 cm	60 cm	11 x 15 km
1:250,000	10 km	4 cm	44 cm	6 cm	110 x 150 km

large scale products will be far simpler if there is an integer n-to-1 correlation between products. By changing DMA's topographic format from portrait to landscape, only minor changes need be made to the formats of DMA's aeronautical products to achieve this desired n-to-1 fit.

Aeronautical charts are oversized to allow aircrew to cut a strip from the chart covering the line of flight for an intended mission. This practice can be continued even if the size is reduced. Hydrographic charts vary in size and scale to provide optimum coverage. A maximum size in this case is unlikely to cause any problems.

A working group of the German Hydrographic Institute recommended standardizing to only two sizes of hydrographic charts: the larger with a neat line size matching that of the International Chart (630 mm x 980 mm, 24-4/5 x 38-3/5 inches) and the smaller being one-half the size of the larger. This standardization was meant to make storage and handling of the charts easier. Within these two sizes, scale can be adjusted on a continuum as is the current practice.

PRODUCT SCALE

Scales of the DMA standard products reviewed in this study are 1:50,000 (topographic); 1:250,000; 1:500,000; 1:1,000,000; 1:2,000,000 (aeronautical); and 1:12,500 (city). Hydrographic charts range from 1:50,000 to 1:600,000; Harbor and Approach charts can be as large as 1:2500.

Several factors should be considered when selecting product scale. One is the ease of converting map measurements to ground measurements, hence the emphasis on the metric system by Gilman's 45 x 60 cm format and by the ISO rational scales shown in Table 3. The ISO scales have been used in Europe for many years. In the minds of map users, questions of scale are translated to questions of content, resolution, and clutter. When aircrews were surveyed on their preference between a 1:500,000 and a 1:250,000 aeronautical chart, many preferred the smaller scale because they felt the content to be appropriate, finding the larger scale chart to be cluttered with useless information (Taylor, 1974a). Yet there is no reason why a 1:250,000 scale chart cannot be streamlined to show only those features currently depicted at 1:500,000.

Table 3. ISO-recommended rational scales for maps and charts.

Scale	Equivalent
1:10	1 cm = 100 mm
1:20	1 cm = 200 mm
1:50	1 cm = 500 mm
1:100	1 cm = 1 m
1:200	1 cm = 2 m
1:500	1 cm = 5 m
1:1000	1 cm = 10 m
1:2000	1 cm = 20 m
1:5000	1 cm = 50 m
1:10,000	1 cm = 100 m
1:20,000	1 cm = 200 m
1:50,000	1 cm = 500 m
1:100,000	1 cm = 1 km
1:200,000	1 cm = 2 km
1:500,000	1 cm = 5 km
1:1,000,000	1 cm = 10 km

There are, however, logical questions of scale that can be asked to help pinpoint problem areas. Most in evidence for DMA series maps and charts are the gaps between the 1:50,000 topographic map, the 1:250,000 JOG, and the 1:500,000 TPC. Charts at a smaller scale are more generally used for planning or for high altitude/long distance flight. But are the highly varied needs of large scale map and chart users being met?

It has been suggested that the 1:250,000 scale of the JOG is a classic compromise that satisfies no one. Low altitude/high speed users often prefer the 1:500,000 scale of the TPC because a 1:250,000 product requires too much paper to cover a mission area, causing handling problems in the cockpit. For nap-of-the-earth users, 1:250,000 does not provide enough space for the level of detail desired. It could be argued that there is also not enough space available to satisfy the needs of joint operations between air and ground. Unfortunately, the next larger scale supplied by DMA—1:50,000—is uncomfortably large for nap-of-the-earth users, being bulky to handle. And, it places heavy data demands on DMA if it is required for large parts of the world.

Wright and Pauley (1971) found significant preference among surveyed pilots and researchers for a 1:100,000 scale chart series to be used for low level navigation and for communication between ground and air.

SUMMARY

Reducing the size of DMA's large format aeronautical charts and the maximum size of its hydrographic charts and City Graphics is strongly recommended. Adopting a landscape format for the topographic map would facilitate digital mosaicking to derive small scale products from the topographic map, and it would make handling easier for users. DMA should develop a 1:100,000 scale product to meet the needs of nap-of-the-earth users and ground/air communication.

Analysis of Feature Portrayal

6. Terrain Features

The presentation of relief information is one of the most studied cartographic design issues and rightly so, since relief portrayal comprises and defines the appearance of map ground. Variations in the portrayal of relief, unlike variations in other aspects of cartographic design, provoke strong reactions among users.

In a survey of topographic maps, five different graphic techniques for showing terrain were found; often all five are used upon a single map. These techniques are (roughly in order of use): contour lines, layer tints, shaded relief (also known as hillshading and hachuring), spot elevations, and Maximum Elevation Figures (MEF). In addition to these five basic methods, DMA uses a descriptive method called Terrain Characteristic Tints on the Operational Navigation Chart (ONC) and Jet Navigation Chart (JNC) and a related technique called Area Tints on the Global Navigation and Planning Chart (GNC). These six techniques for representing terrain are discussed in this chapter.

Keates (1973) states that relief has two main elements: elevation and slope. Elevation is depicted using spot heights, contours, and layer tints. Slope can be inferred from both contours and layer tints and is directly represented by shaded relief. Elevation is the more important consideration for pilots and slope is more important for ground movement. The speed and accuracy required when extracting terrain information is also an issue in selecting a means for terrain representation. A secondary issue is how the method of relief portrayal affects the transmission of non-relief data.

CONTOUR LINES

Contour lines are the best known, most accurate, and most widely used means of terrain descriptive techniques. Contours are lines of equal elevation that divide and classify the surface into a series of areas within intervals on a range of elevations (Hopkin and Taylor, 1979). Contour lines provide an excellent quantitative yet a very poor qualitative description of the surfaces. Cliffs do not show up well and small features are not represented. Interpretation of contour lines must be learned and practiced. Even to expert mapreaders interpreting terrain using contour lines is exacting.

Contour lines and mapreading

A questionnaire survey by the Army Map Service found that of 3552 respondents, 25% had difficulty in interpreting relief from contour lines, 32% could not extract terrain information from contours rapidly enough to successfully execute military operations, and when time and situation permitted, 50% preferred to annotate ridges, draws, key contours, and important landforms (Skop, 1959). The extent to which this situation has been remedied in the 1980s is unknown.

How contour lines interact and interfere with non-relief information, especially point symbols, has been an important topic of investigation. Merriam (1971) states that map lines more than 0.02-inch wide tend to inhibit the perception of other symbols. Reading difficulties increase with line weight and number of lines until a condition is reached at a line width of about 0.03-inch with 0.03-inch of intervening space for black on white where "the dazzle is so great that it becomes almost impossible to hold a point at visual center (fovea) and completely impossible to center on another point and return to the first without getting lost. In other words, mapreading is brought to a halt" (Merriam, 1971).

Phillips et al. (1975), however, found no significant difference among the performances of subjects searching for towns on maps with contours only, on maps with shaded relief only, and on maps with combined contours and shaded relief. Similarly, reducing the emphasis of contour lines did not affect the efficiency of the search task. No significant difference was evidenced among subjects searching for point symbols on maps with standard brown contours, on maps with gray contours, on maps with screened contours, and on maps with standard contours with the interval doubled (half the contours removed). Only when all contour lines were removed from the map could a significant improvement in performance be observed (Cromie, 1978).

Contour lines and cartographic design

Selecting an appropriate vertical interval for contours is not straightforward. A large contour interval is required in areas of rugged terrain to prevent clutter. A small contour interval to show minor terrain variations is required in areas of low relief. Thus, a single contour interval for a map series covering highly variant terrain will not serve both flat areas and rugged areas equally well. Contours may completely converge in mountainous regions unless a large interval is selected. And, a large interval in flat areas results in widely separated lines that are difficult to visually relate.

Contours in very rugged terrain can be misleading to users. The high density of linework suggests a high level of accuracy. Yet resolution, a function of contour interval, is instrumental to contour reliability. The contour interval for DMA's 1:50,000 topographic map can be as high as 40 m (131.2 ft) when overall slope exceeds 45%. DMA's Joint Operations Graphic (JOG) uses 100/200 m contours for a large portion of the world; the vertical drop between contours is, in that case, equivalent to a 35- to 70-story building. In both cases, low resolution makes contours virtually useless for accurate terrain analysis. Without accuracy, there is little reason remaining to use contour lines. Other methods of terrain representation can convey terrain information to the mapreader more quickly, without a deceptive illusion of accuracy. As scale decreases, contour lines become even less useful.

When small landforms are important and space is available, supplementary contours are used. Hopkin and Taylor (1979) suggest that topographic maps designed for low level navigation should be designed with a smaller contour interval between sea level and the first contour than between other contours. This design would show the form of the coast in more detail and also provide better data on intervisibility (Hopkin and Taylor, 1979).

Assuring contour visibility without overriding other information is an inherent design problem. As areal symbology, contours must occasionally be interrupted to emphasize other symbology. Yet interrrupting contours, especially around built-up areas on the map, makes an individual contour extremely difficult to follow.

Brown contours are traditional because brown contrasts well with most map backgrounds, but effectiveness is dependent on other map colors. Due to low contrast with layer tints and hillshading, contour lines on the JOG were difficult to detect under normal viewing conditions. Taylor (1976a) felt that line weight could be raised to 0.02-inch to remedy the situation. Unfortunately, greater emphasis to contour visibility and contrast leads to an even noisier JOG. Increasing the contrast of contour lines should be avoided unless terrain features are substantially more important than other map features. This report asserts that contours are not an appropriate way to show terrain on aeronautical charts, being slow to interpret, adding to clutter, and increasing production expense.

LAYER TINTS

Layer tints (hypsometric tints, elevation tints) provide a generalized version of the information shown by contour lines. Layer tints are popular with users. As symbolic abstractions of the underlying terrain data, they are more quickly interpreted than contour lines but also provide considerably lower resolution.

Layer tints and mapreading

Test subjects were able to extract terrain information more quickly with no significant loss in accuracy when contour lines were supplemented by layer tints on test maps (Farrell and Potash, 1979). Brandes (1975) found that layer tints supplementing contour lines produced the best performance levels over a wide range of relief interpretation tasks. Apparently, by combining the two methods the communication qualities of each are used to their best advantage.

Using layer tints to depict relief unfortunately interferes with using other types of area symbols. Layer tints also appear to interfere with mapreaders searching for non-relief information. When Kempf and Poock (1969) investigated the effects of supplementing contour lines with layer tints, they used 12 tints that varied in color and intensity. Although this tint scheme improved the speed with which their subjects could estimate heights, it decreased the speed with which they could read grid coordinates.

Convention states and research has shown that a strong association exists between darkness and quantity. A single hue seems to be most effective in conveying the univariate message of "more" (Miller et al., 1951; Cuff, 1973; and Patton and Crawford, 1977). A single hue value progression was also recommended by Taylor (1972) and Crook et al. (1954).

DMA's Tactical Pilotage Chart (TPC) uses a single hue value progression; the JOG and the ONC use a mixture of spectral and value systems. Wright and Pauley (1971) state that combined with hillshading, the mixed spectral and value series is a more pictorial representation and is less easily misinterpreted, since a pilot can more readily distinguish green from orange rather than one shade of buff from another. However, during a test to evaluate the mixed spectral and value series on the JOG, subjects had difficulty sorting sample color cards of the layer tints into the correct progression. They were further unable to identify the tints without confusion, even with prior knowledge of the scale (Hopkin, 1972). When the JOG layer tint scale was compared to a progressive value system, the mixed spectral/value system of the JOG produced inferior performance by subjects attempting vertical profile identification and high and low area identification (Taylor, 1978).

Layer tints and cartographic design

There are two major decisions involved in designing a layer tint strategy: selection of layer intervals and selection of layer colors. The issues concerning these two factors are discussed in the following text.

Keates (1973) lists five problems associated with selecting colors for layer tints.

- The colors must form a progressive series with steps evenly balanced yet perceptively different. Such differences must be perceptible for small areas and not overpowering for large areas.
- The colors will influence all the other elements on the map to some degree.
- Since most of the cultural information is at low elevations, the colors selected for low elevations must not interfere with cultural symbology.
- The continuous change in elevation must be represented by abrupt changes in adjacent colors.
- One color scheme used over many regions will not optimally serve any single region.

Layer tints describe relative elevation of terrain areas; thus, it is important that the choice of colors appear graded in an orderly fashion so relations are conceptually clear. The two methods of establishing a series are the spectral series, which uses colors iconically associated with elevation (generally green-lowland, brown-mountain, etc.) and a graded series of a single hue value progression.

As mentioned previously, research has shown the single hue value progression to be superior to a spectral series. Yet there are associated design problems, as described below (Petchenik, 1983).

> Taking a conventional approach, I assigned the lightest blue to the shallowest water and the palest yellow to the land nearest sea level. I then varied the intensity of these colour families in what seemed to me a systematic fashion, as water and land became deeper and higher. As I looked at the first proof, however, I realized I had forgotten a basic matter, the need to establish a strong figure-ground contrast between the land and water so as to make the continent shapes emerge in a memorable fashion. The only solution to this problem is to lay the lightest water tint adjacent to much darker land, or vice versa. But if one follows this approach, other serious difficulties develop. The areas of either lowest land elevation or shallowest water will be the darkest tint. Furthermore, if the lowest elevation categories are darkest, many of the map's placenames will be illegible.
>
> Clearly, choice among conflicting demands is required, as there is no perfect solution. One can either stress the principle of quantitative change through value variation or one can emphasize the land-water contrast. It is not possible to do both simultaneously, on one map, and no amount of additional research will prescribe the preferred choice. The issue is not merely one of making graphic choices; it has become one of assigning priorities to values that are in conflict.

The problems described above are applicable to and exacerbated by military requirements. From a group of airmen surveyed regarding information requirements for VFR flight, a significant number responded that water boundaries are extremely important, some suggesting that they be outlined in black. A graded series also causes problems at high elevations, where the deeply saturated color interferes with the illusion of depth conveyed by shaded relief, and with the legibility of contour lines.

In a sharp departure from tradition, Miller (1933) designed an experimental air navigation chart that uses gray hypsometric tints graded from the darkest at low elevations to the lightest at high elevation; all hydrography is white to provide the exaggerated contrast requested by airmen (Fig. 6). Taylor (1976a) designed a modified JOG in which the first height interval was white in an effort to demonstrate a graded series that does not become overly dark at high elevations.

There is no consensus on the optimal choice of vertical intervals for layer tints. Keates (1973) distinguished four systems for selecting intervals:

- equidistant—the same interval throughout,
- equidistant and supplementary—low areas have twice as many layers as high areas,
- irregular—intervals vary with major breaks of slope,
- progressive—interval increases with increase in elevation.

Hopkin and Taylor (1979) argue that the vertical interval for layer tints should vary in accordance with the operational significance of the elevation difference or changes. Since small differences in elevation are more important at low elevations than at high elevations during flight at low altitudes, the method of representation must encode such differences.

SHADED RELIEF

Shaded relief lends a three-dimensional appearance to a map and is used extensively on aeronautical charts to provide pilots with a feeling for the shape of the earth below. Shaded relief does not depict elevation. It conveys slope and describes landforms.

Shaded relief and mapreading

Shaded relief contributes to the speed of interpreting terrain. It is not, however, an accurate means of conveying terrain information and has even contributed to an apparent deterioration in terrain interpretation (DeLucia, 1972).

Point symbols and type have been shown to be more difficult to read on maps using shaded relief. Shaded relief was found to increase the time taken by subjects to locate and match non-relief symbols (DeLucia, 1972). Farrell and Potash (1979) recorded a similar decrease in the performance level of subjects searching for symbols on maps with shaded relief.

Contradictory test results showing shaded relief to have no ill effect on interpreting other map symbols are available. Phillips et al. (1975) found no difference between shaded relief, contour lines, and layer tints concerning interference with other map features. Wheate (1978), after testing subjects with several types of relief symbols, found shaded relief to be a positive influence on search and suggested that shaded relief may serve as an organizing structure in which mapreaders can systematically search for non-terrain information. Subjects searched maps with standard contours, Tanaka contours, and shaded relief for three types of symbols: relief (spot elevations), relief-related (ski lodges, airports), and relief-independent (settlements). Shaded relief was moderated so that no areas appeared extremely dark. Subjects using maps with shaded relief performed significantly better than subjects using either standard or Tanaka contours. Because shaded relief is known to assist in visualizing terrain, the first and second cases are explainable. The third, however, indicates that an independent process is in effect. It was hypothesized that shaded relief provides a Gestalt structure to the geographic information, helping the subject to organize his search of the map (Castner and Wheate, 1979).

The beneficial effects of shaded relief are explained physiologically by Merriam (1971). In essence, as the map is scanned saccadic eye movements* accumulate and clarify map detail around the periphery of a foveal fixation. When the mapreader begins to project a pattern from this series of past fixation points, the figure-ground is crucial in picking out the design. However, this pattern projection process is best performed when there is less contrast between the figure and the ground. In practice it appears that, since map patterns must always appear to be on the surface of the ground, shading modulations have a positive effect on eye assimilation and provide a controlled means of suggesting location and direction.

Respondents to a questionnaire survey administered by the Army Map Service moved to eliminate all shaded relief and replace it with layer tints. They complained that shaded relief reverses, is difficult to interpret when rotated, and interferes with the legibility of contours, roads, populated places, names, and the outline of wooded areas (Skop, 1959). Wright and Pauley (1971) stated that shaded relief caused disorientation in airmen when a map was viewed at any orientation other than north-up. This effect could be a serious hazard to low level flight, since only an estimated 15% of Army aviators use north-oriented maps. Brandes (1975) found that the tendency to reverse a shaded relief image was randomly distributed over the sample population. Difficulty in discriminating ridges from valleys occurred even when the conventional light source was used.

*Saccadic eye movements are quick jumps from one foveal fixation to another.

TERRAIN CHARACTERISTIC TINTS

Terrain Characteristic Tints are a complex and subjective system of hypsographic tinting. They are intended to show a combination of elevation, slope, and regularity using green, gray, and yellow tints combined with shaded relief. Instructions for applying Terrain Characteristic Tints are, by necessity, fairly detailed: rolling uplands must be distinguished from lowlands, and some geographic knowledge of an area is imperative. Terrain Characteristic Tints are used on DMA's ONC and JNC aeronautical charts. The GNC uses a generalized version of Terrain Characteristic Tints, called Area Tints, in which a green tint distinguishes areas having no significant relief.

Problems with appearance

The surveyed literature does not comment on Terrain Characteristic Tints or Area Tints. The following remarks regarding the appearance of Terrain Characteristic Tints are based on an informal poll at NORDA (no major problem was found in the appearance of Area Tints).

Figure 6. Reversed hypsometric tints on experimental aeronautical chart (Miller, 1933).

- The color progression does not give the impression of increasing elevation. The gray appears to be higher than the yellow, although the reverse is intended.
- The two shades of yellow used are not sufficiently distinct.
- The gray used for relief does not contrast with the blue of non-perennial lakes.
- Populated places are shown in a yellow not sufficiently discriminable from the one used for relief.

Problems with automation

Some of those polled at NORDA expressed interest in the possibility of employing artificial intelligence to automate the process of applying Terrain Characteristic Tints and Area Tints. Regardless of the approach, developing computer procedures to delineate Terrain Characteristic Tints from terrain data would be a long-term project. Alternatives to Terrain Characteristic Tints are discussed in Section III, Chapter 16—Alternate Terrain Representation. It is recommended that an alternate technique be used to depict terrain on the ONC, JNC, and GNC.

SPOT ELEVATIONS AND MAXIMUM ELEVATION FIGURES

Spot elevations are relatively easy to include on the map, occupy little space, and provide accurate height data to mapreaders. An important research topic, as yet unexplored, is the extent to which spot elevations and Maximum Elevation Figures (MEF) are used independently of one another. Do they provide complementary information to aircrew or are they redundant, providing only more clutter on an already cluttered page?

Not a great deal of performance data on spot elevations exists; there is no performance or use data on MEF. In comparing spot elevations, contours, shading, and tints, Phillips et al. (1975) found that while spot elevations were optimal for judging absolute heights, they were less effective than layer tints in judging relative heights and were virtually useless in visualizing the landscape.

Findings indicate that the readability of spot elevations is improved regardless of the magnitude of the number, the type size, or the type spacing when the number is boxed (Bridgman and Wade, 1956). By boxing and by reducing clutter, the speed of searching for spot elevations would likely increase (Hopkin and Taylor, 1979).

USER REQUIREMENTS

Because of an apparent trade-off between the amount of relief portrayal and the searchability of non-relief information (Skop, 1959; Kempf and Poock, 1969; Farrell and Potash, 1979) there is a need to determine exactly how important hypsographic information is to users of a particular map, and how the information is to be used.

User requirements must be a driving force in selecting a means of depicting terrain. Certain tasks are more easily accomplished using one form of terrain depiction over another. In a comparison of four types of relief portrayal—contour lines only, contour lines supplemented with shaded relief, layer tints only, and spot heights only—it was found that maps with layer tints produced the best times in judging relative height and in visualizing the landscape. Contour lines only and contour lines supplemented by shaded relief were judged roughly equal in efficacy for all tasks. The spot height maps were best for judging height alone, but were very poor for other purposes (Phillips et al., 1975).

Speed of terrain identification and accuracy of interpretation are not supported equally well by all forms of relief representation. Contour lines are obviously fundamental to accurate terrain interpretation. Subjects using maps with relief shown by contour lines alone demonstrated better accuracy than subjects using maps with contour lines supplemented by layer tints or maps with contour lines supplemented by shaded relief (Potash et al., 1979). But when layer tints were added to contour lines, subjects extracted terrain information with increased speed without significant loss in accuracy (Farrell and Potash, 1979). Speed is promoted even more by shaded relief, which provides the most rapid view of the form and extent of relief features; shaded relief, however, does not provide any measurable level of accuracy in terrain analysis.

As part of their effort to analyze the effect of terrain depiction on terrain identification, Farrell and Potash (1979) enumerated eight types of terrain identification that are important to Army maneuvers. These identification types are listed below along with the means for testing:

- landform identification—identify an indicated landform as a hill, draw, spur, saddle, or depression;
- ridge-valley identification—state whether a line on the map is overprinted along a ridge or a draw;
- slope identification—state whether an arrow overprinted on a map is on a convex, concave, or uniform slope and whether the arrow runs up- or downhill;
- high and low area identification—from 64 four-grid squares, indicate the four highest and four lowest;

- spot elevation identification—determine the elevation at a point;
- vertical profile identification—match a profile indicated on the map with one of several illustrated profiles;
- terrain visualization—match a terrain sketch to one of several points indicated on the map;
- defilade or intervisibility—determine if observers at a pair of points drawn on the map are visible to one another.

Future map evaluation tests for topographic products will benefit from this analysis of terrain identification tasks. A corresponding set of terrain identification tasks for aeronautical needs would emphasize chart-to-ground correlation and identification of vertical obstructions, and would be likely to include many of the basic tasks listed above. Yet the required balance between speed and accuracy is different for aeronautical users than it is for those on the ground. The requirement for accuracy and resolution is relatively lower for aircrews than is the requirement for speed, for "information at a glance."

SUMMARY

All purposes are not served equally well by the five types of relief representation discussed in this section. It is essential to consider (1) the importance of terrain information to mapreaders relative to the importance of nonrelief information; (2) the accuracy with which the users must interpret relief features; and (3) the speed with which hypsographic information must be conveyed. Contour lines used alone are difficult for most mapreaders to use, but they depict terrain data as accurately as resolution allows. Layer tints are helpful in generalizing elevation data for mapreaders, but they add complexity to the map and make other area symbols less effective. The effectiveness of shaded relief is an unresolved issue. Shaded relief provides a rapid summary of terrain, yet for some mapreaders it reverses—a potentially disastrous effect. Alternative methods of relief portrayal that can be performed efficiently by computers are discussed later in the report.

7. Vegetation

Vegetation is characteristically shown in green, using iconic area symbols or color variations to detail vegetation types. Despite deterioration in the reliability of vegetation data over time, vegetation ranks among the most prominent features shown on maps and charts. A great deal of creativity has been devoted to developing ways to show vegetation on maps and charts. These will not be reviewed; rather it is argued that vegetation cannot be represented on hardcopy media in such a way that it is current or adequate to user requirements. In order not to mislead users or encourage dependence upon unreliable data, DMA should consider omitting vegetation from future hardcopy products, and encouraging the use of digital vegetation data.

RELIABILITY OF VEGETATION ON MAPS

An analysis of the reliability of the vegetation information shown on maps and charts would be an interesting and no doubt revealing study. Vegetation data should be considered perishable, becoming outdated rapidly. Cultivated areas in many parts of the world shift as the soil is depleted. Woodlots are logged and forest clearings regrow. Even within a single year seasonal variations can be considerable, and drought or rainfall may significantly alter ground cover. Paper maps are by nature permanent; ephemeral data such as vegetation is difficult to portray on them.

VEGETATION AND THE CLARITY OF MAPPED INFORMATION

When vegetation is shown on maps it is among the most prominent of all mapped features. A vivid green overprint is used by the USGS and by DMA on their topographic products. Subduing the vegetation was among the innovations demonstrated by the USGS Monterey and Santa Rosa prototypes. Both gray-green and gray were substituted for the standard green, and in some instances the vegetation overprint was omitted entirely. These changes effectively smoothed the background of the map and reduced distracting interference with point and line symbols.

It is common practice to map all possible occurrences of vegetation. Consistency is an admirable goal; but in practice entire maps are uniformly covered by complex and noisome vegetation symbols. The JOG's attempt to de-saturate the background by vignetting the interiors of large areas of vegetation results in a spotty and even more complex appearance. A topographic map of Amphoe Bang Khen, Thailand (series L7017, sheet 5136 IV) is nearly illegible because, in addition to overlarge, red, bilingual type, it is entirely covered by a spotty blue symbol denoting rice fields. Uniform vegetation is better explained by a note in the margin or by an inset as is currently used for boundaries and elevations. An inset has the advantage of being easily updatable without changing the entire map.

TOPOGRAPHIC REQUIREMENT FOR VEGETATION

An Army user survey ranked vegetation as useful but not essential to topographic maps (Landee et al., 1979). While Army terrain analysis incorporates such vegetation parameters as canopy closure, height of vegetation, and stem size, none of these values can be derived with certainty from vegetation as currently shown on the 1:50,000 topographic map. By redesigning the 1:50,000 product, some (but not all) of the needed parameters could be represented.

One suggestion arising from a survey of Military Topographic Standard Map Users was that vegetation be presented according to percentage of canopy cover (Huizar, 1972). The variability of such a measure raises the question of how useful and how misleading this strategy would be. Although canopy cover may be more useful data to topographic map users than descriptive vegetation data, it is prone to all factors affecting unreliability discussed earlier: disease, drought, fire, human occupation, and seasons.

AERONAUTICAL REQUIREMENT FOR VEGETATION

A survey of aircrews revealed that the outline shape of wooded and otherwise vegetated areas and the outlines of clearings were extensively used for orientation by navigators and pilots alike (Taylor, 1974a). Given the suspect nature of the data, this discovery is sobering. Only sophisticated mapreaders question the accuracy or the currency of the information shown on their maps; to protect those who do not, a complete review of the requirement to show vegetation should be undertaken.

8. Hydrography

Hydrographic features include seas, coastlines, estuaries, rivers, streams, canals, lakes, reservoirs, marshes, and swamps; in essence, all features both natural and manmade of which water is a constituent part (Hopkin and Taylor, 1979). Inland hydrographic features have the singular distinction of being less prominent than requirements indicate they should be. Offshore hydrography is overrepresented on aeronautical charts and on topographic maps; its presence on such charts is questionable. Except on hydrographic charts, the requirement to include offshore hydrographic features should be closely examined.

INLAND HYDROGRAPHY

Aircrews have affirmed that the shape of inland hydrography is the most reliable and distinguishable of all features from the air. River bends are good locational cues because their shape is very distinct. The shapes of coastlines, too, are important to aircrews. Great care should be taken when generalizing rivers and coastlines so that their shape is immediately recognizable from the air regardless of scale.

Generalization of hydrography poses interesting questions. For aeronautical users, visibility from the air should be the determining factor. Thus, charts intended for low level navigation (JOG and TPC) should include all drainage visible from 2000 feet and below. Charts intended for medium level navigation (ONC) can exclude any drainage not visible from above 2000 feet, and charts intended for high level navigation (GNC and JNC) can exclude drainage not visible at 25,000 feet and above. The possibility of simulating visibility given feature size is discussed in Chapter 17—Automated Generalization.

To topographic map users drainage is also crucial. Although an experimental reduced-detail topographic map excluded all bodies of water less than 60 feet wide with no significant harm to users (Granda, 1976), all ground movement is impacted by the drainage network. The drainage pattern provides a framework for interpreting relief from map symbols. Contour intervals assume definite meaning when valleys are distinguished by rivers and streams. The more prominent is the drainage, the less likely it is that shaded relief will reverse.

Given its importance, it is unfortunate that drainage is traditionally shown in blue. Blue is a poor choice for linework because it provides the least visual acuity of all colors due to short wavelength (see Chapter 3—Color). Yet few would suggest changing the most universally accepted of all iconic color codes.

One solution to the poor visibility of blue is outlining. Taylor (1974b) recommended that all coastlines, lakes, and double-line rivers be outlined in either black or screened black for clarity. Later, Hopkin and Taylor (1979) suggested dark blue for outlining. Outline colors should be tested on prototype maps, and the best solution should be employed on all DMA topographic, aeronautical, and hydrographic maps and charts. Experimentation will be required for blending a single-line river into a double-line river, or a single-line river into a coastline.

NEARSHORE FEATURES

Although nearshore features such as bottom material, reefs, shipwrecks, and rocks are shown in varying degrees on DMA's aeronautical charts, their exact utility is a puzzle. Added to this unclear requirement is their prominent depiction in black. Heavy black lines and symbols scattered offshore cloud the shape of the coastline and induce a cluttered appearance. Tides affect visibility of all nearshore features, making visibility a complex selection criterion.

Topographic maps, used when no combat charts are available, must show nearshore hydrographic features. To minimize clutter, however, such features should be shown in blue.

BATHYMETRY

Bathymetry is currently shown on all DMA maps and charts. Topographic maps show bathymetry in black depth curves. Aeronautical charts use depth curves or bathymetric tints to show bathymetry. Hydrographic charts show bathymetry using either spot soundings or contours or both, and a shoal line.

Bathymetry has no place on aeronautical charts and should be eliminated. Lacking a requirements analysis, bathymetry on topographic maps should be relegated to a lower level of prominence by showing depth curves in blue.

Spot soundings are one of the few sources of clutter on hydrographic charts. At a recent meeting of The Hydrographic Society, U.S. Branch (October 12-13, 1983, Lithicum Heights, Maryland), the possibility of eliminating spot soundings and replacing them with contours was discussed. Contours alone are not always trusted by navigators because they can camoflage inadequate or incomplete sounding information. In areas with complete bottom coverage, however, contours are preferred because they are more descriptive. Users seem to agree with this assessment. In two years of supplying contour and shoal line data to the USN hydrofoil PEGASUS digital charting system, DMA has not received a request for individual soundings from the crew. Thus, this report recommends that in areas where bathymetry is fully defined, soundings be excluded from hydrographic charts.

9. Cultural Features

Roads, railroads, airports, populated places, structures, and assorted landmarks (such as windmills, waterwheels, pumping stations, power plants, beacons, and towers) constitute cultural features. The only cultural features represented by area symbols are populated places and, occasionally, buildings and other landmarks drawn to scale. The transportation network on a map is shown by line symbols. All other man-made features are shown with point symbols. In this fact lies a key issue: man-made symbols are, as a rule, perceived as clutter on a map.

An effort was made by the USGS in the 1960s to weed out obsolete symbols. Interestingly, the culls were all cultural point features: mineral location monuments, gaging stations, corrals, tollgates, cliff dwellings, windmills, picnic areas, and campgrounds (not all recommendations of the design unit were enacted). A similar effort at DMA could produce an even richer cull of point and line symbols. Separate symbols for cisterns and wells are supported for no apparent purpose. Extravagant detail is exhibited in portraying roads and an impressive array of religious buildings are distinguished by unique symbols on topographic maps.

Because no definitive psychophysical or user requirements data exist for cultural feature symbols, the rest of this chapter subjectively discusses their use on DMA maps and charts.

ROADS

Requirements

Topographic users need detailed road information. A surveyed group of users affirmed a requirement for both surface type and road width (Huizar, 1972).

Aeronautical users are interested in size, contrast, and visibility from the air (Hopkin and Taylor, 1979). Paved roads are a useful landmark for low altitude flight. Trails and dirt roads were reportedly the least useful of eight feature classes for orientation or as checkpoints (McGrath and Borden, 1969). At 1:500,000 and smaller scales it has been recommended that no dirt roads be shown (Hopkin and Taylor, 1979).

In a survey of JOG users, many felt that main roads were overemphasized and that too many minor roads cluttered the chart (Lakin, 1967). This sentiment is not a universal; 69% of aircrews surveyed in a later study favored showing all minor roads on JOGs (Lakin, 1972). Taylor (1977) found that for low altitude night flight, highways ranked fifth in importance (tied with lighted obstructions) for fixing position; major roads ranked eighth; and minor roads ranked fifteenth.

Hopkin and Taylor (1979) recommend explicitly depicting cloverleafs and roundabouts on small scale aeronautical charts. Freeways and divided highways are highly visible from the air and should be distinct on the chart.

Figure 7a shows road types that can be distinctly coded on DMA standard products. The level of detail shown on each product is analyzed below.

1. Topographic. Topographic maps show a high level of road detail. Hard-surface roads are divided into four categories based on the number of lanes and median strip width. It has been argued that vehicle-related information is more useful than describing characteristics of road width and surface. Given a maximum size of vehicle, can it or can it not pass on the road? A version of vehicle-specific symbol coding was studied at some length by Morrison (1971, 1974, and 1975), who produced and tested experimental road maps that symbolize roads according to potential travel speed. Test subjects selected optimum routes with greater ease when using these vehicle-specific experimental maps.

2. JOG. Although the JOG is one-fifth the scale of the topographic map, it shows more detail in some cases, distinguishing between two and two-plus lanes on highways. The JOG, used by both air and ground personnel, presents interesting questions for coding road symbols. Clearly the current symbol set has been based on the needs of ground users; it does not particularly address the needs of air personnel.

Redesign of road symbols for the JOG-Air is recommended. Paved roads are important to both topographic and aeronautical users and should be emphasized. Footpaths and trails are not particularly visible from the air and should be eliminated. The JOG-Air should adopt the

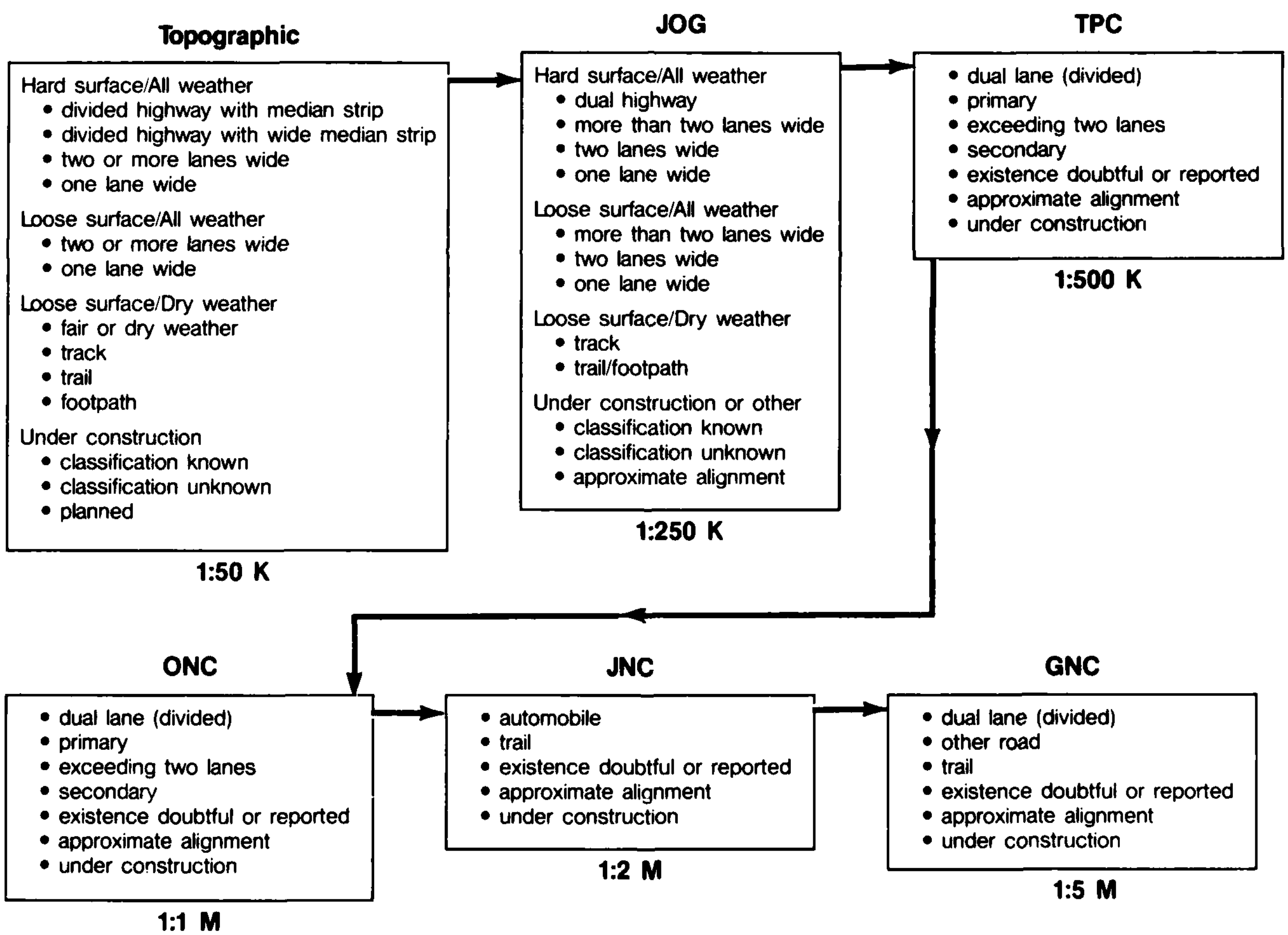


Figure 7a. Roads on DMA standard products.

coding categories for roads used by the TPC; these seem appropriate for both ground and air users at 1:250,000 scale if secondary roads are defined as being unpaved.

3. TPC, ONC, JNC, GNC. Each of these products is one-half or less the scale of its predecessor. Why, then, do the JNC and GNC at 1:2,000,000 and 1:5,000,000, respectively, revive a category for trails last used on the 1:250,000 JOG? This category should be eliminated. The ONC category for secondary roads should be discontinued. Strong language in the TPC specifications should state criteria for selecting secondary roads, i.e., that they are highly visible from the air or that there are few roads in the immediate area. Two categories—existence doubtful or reported and approximate alignment—should be combined. If, however, existence is truly doubtful the road should be omitted. Pilots have adjusted to seeing roads on the ground that do not appear on their charts. The reverse could be disconcerting.

Depiction

Qualitative differences between roads are shown using color, line width, and line pattern. DMA labels many of its road symbols for further amplification. Cased lines are commonly used with varied infills; because they are difficult to construct and also clutter a map, alternatives should be sought.

Wright (1967) found that differences in line widths are perceived more easily for thin lines than for thick lines. Color, too, is difficult to discriminate in lines; other than red and yellow, narrow lines are often perceived to be black. These factors were no doubt at work when subjects could not consistently recognize the principal, secondary, and minor road symbols used on the JOG (Taylor, 1976a).

Hopkin and Taylor (1979) state that while red and reddish colors are conventional for roads, it is due more to historical causes than any innate association. Red was used on early aviation charts because it disappeared under red lighting, as did unlit roads at night. Today, dark brown is used on the JOG, TPC, and ONC, maintaining contrast under red lighting.

DMA standard products code roads in one color (TPC, ONC, JNC, GNC) and one color plus black (topographic, JOG). Qualitative differences are shown by line pattern and by annotation. An alternate scheme is used on the USGS prototype Shelton maps (see Chapter 21 for a complete description; Fig. 5 for an illustration). Major roads are shown in red; all other roads are shown in brown lines of varied thickness, the least important ones being screened. Thus, major roads are considerably more prominent than secondary roads and trails. The road symbolization scheme of the Shelton maps managed to eliminate all dashed lines from road symbols, reducing clutter and facilitating scan digitizing.

Morrison (1981) introduced a theory of symbol dimensionality whereby each dimension of a feature is represented by a different symbol attribute. For example, color represents road surface; line width represents the number of lanes. Paved roads, in that case, would be a prominent color in keeping with their importance, with a line width related to the feature width.

RAILROADS

Requirements

Little data is available on topographic user requirements for railroad information. As lines of communication, however, they are undoubtedly important. Level of required emphasis and amount of representation are discussed subjectively under this heading.

Aeronautical users find railroads useful because they are highly visible from the air at both high and low altitudes, and because they follow straight lines from place to place with checkpoints along the way (such as crossroads, stations, etc.). Additionally, they are infrequent and easy to correlate to the chart (Hopkin and Taylor, 1979). Helicopter users find both operating and non-operating railroads very useful, since embankments remain prominent along disused lines for a long time (Barnard et al., 1976). Disused railroads are shown on the electric blue aeronautical overprint on the Ordnance Survey Northern Ireland one inch series (Hopkin and Taylor, 1979). Conversely, surveyed users of JOGs felt there was no need to show disused railways, although operational railways were felt to be very important (Murrell, 1970).

Figure 7b shows the categories of railroads separately symbolized on DMA standard products. Moderate reduction of detail is suggested, as follows:

1. Topographic. A single, broken-line symbol would suffice for all railroads that are disused or dismantled, whether they are multiple, double, or single track; or broad or narrow gauge.

2. JOG, TPC, ONC, JNC, GNC. The categories used on the JNC offer enough detail to satisfy aeronautical users. The issue of approximate alignment and doubtful existence

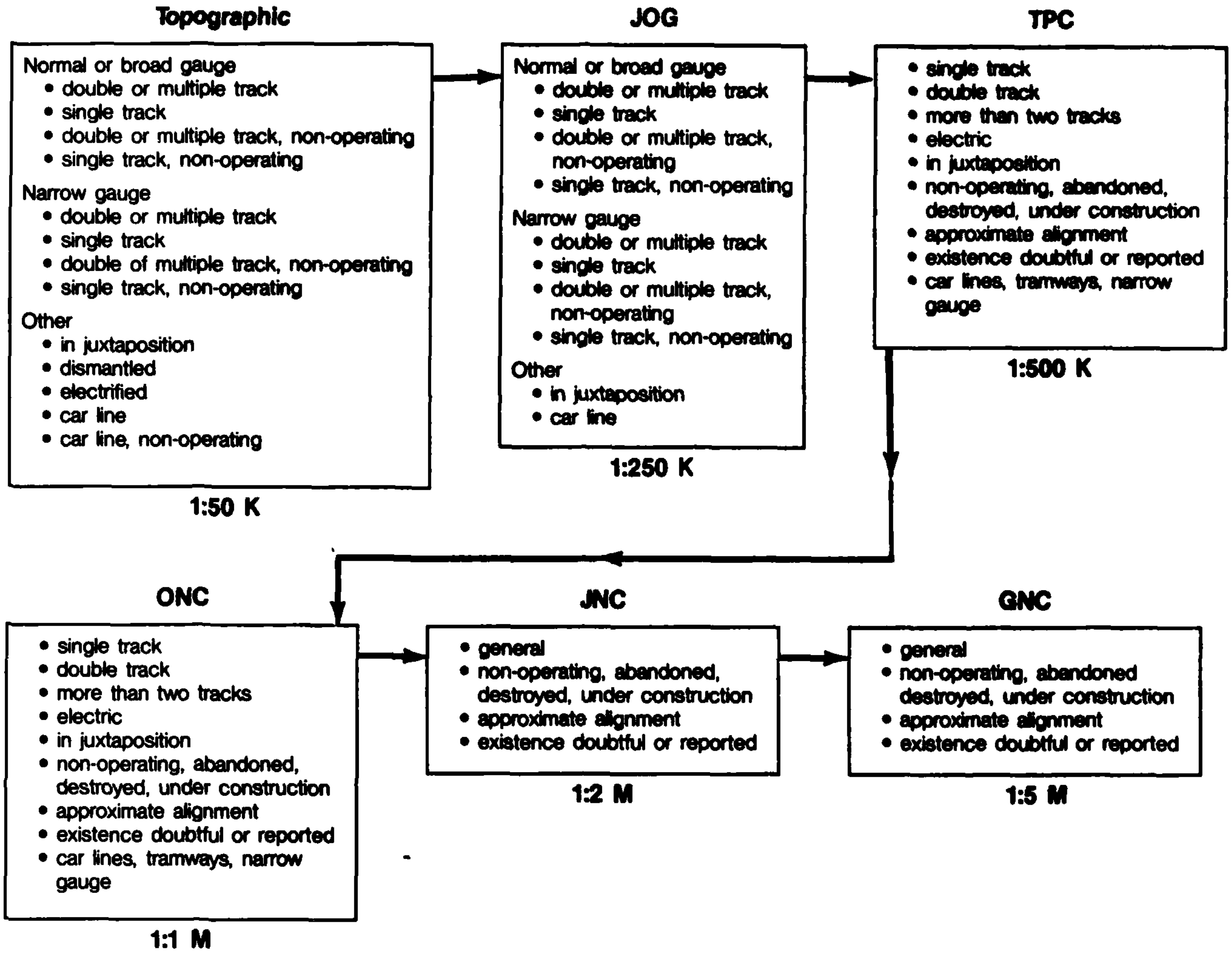


Figure 7b. Railroads on DMA standard products.

is discussed under the heading of roads and is also relevant to railroads.

Depiction

Most DMA products use standard railroad symbols that are moderately pictorial (black lines with crossties). Gilman (1982) recommends eliminating crossties, feeling that they add minimal information to the map while contributing to clutter and increasing production costs. This report does not recommend eliminating crossties except for small scale aeronautical charts. The JNC uses a simple black line for all railroads. The GNC (which currently uses crossties) should adopt the JNC's railroad symbol.

POPULATED PLACES

Requirements

Although outlines of populated places are represented whenever scale permits, they change rapidly and are determined subjectively. Important for all purposes, topographic and aeronautical, settlements should be distinct yet not contribute to clutter.

Depiction

Figure 7c shows the treatment of populated places on DMA's standard products. There is striking variation in the color used to represent populated places on DMA prod-

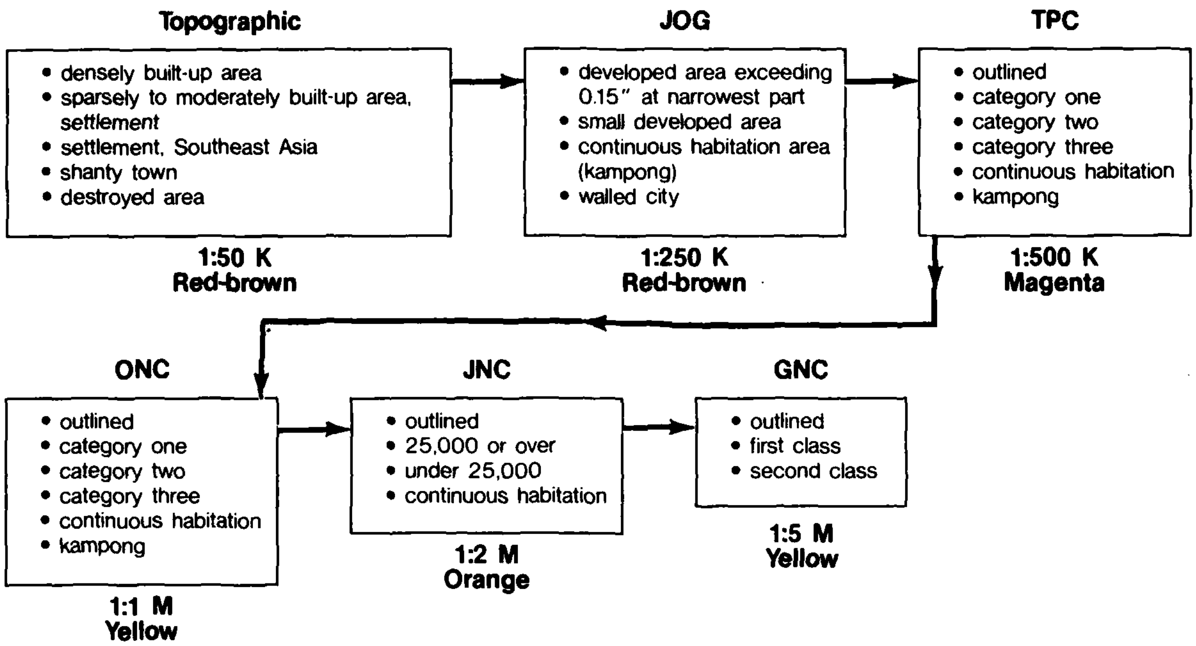


Figure 7c. Populated places on DMA standard products.

ucts. As color schemes on DMA products differ, so do the colors used for populated places. The TPC uses magenta, the JOG uses red-brown. While the JNC and ONC have similar color schemes, they employ different colors for populated places (orange for the JNC, yellow for the ONC). Given that the ONC's yellow is strikingly similar to the yellow used for Terrain Characteristic Tints, the orange used on the JNC is preferred. The GNC's yellow populated places are not a problem since the GNC does not employ yellow for terrain representation.

Gray has been recommended as a good color for settlements on topographic maps and aeronautical charts. It has good edge contrast for shape recognition and does not contribute to clutter. Gray is used on the USGS Monterey, Santa Rosa, and San Juan prototypes. This report recommends that gray show population density on DMA City Graphics. Topographic maps, too, would be improved by adopting gray for populated places. Destroyed areas, currently gray, could be distinguished by texture. The JOG-Ground, too should use gray for populated places. The JOG-A, however, as with other aeronautical charts in the DMA product line, may require a more prominent color for settlements.

BUILDINGS

Requirements

Buildings serve as landmarks to topographic, hydrographic, and aeronautical users. Ground personnel need an idea of the size of a building as well as shape against the horizon. Aeronautical users have varying requirements that depend on flight altitude. Low altitude users need height information. Helicopter users of the 1:50,000 topographic map expressed a strong need for tall chimneys, power stations, high-rise buildings, and church steeples in flat terrain (Barnard et al., 1976). Location of structure is an important selection criterion. A large building hidden in a forest is appreciably less important to aeronautical users than a small windmill built on a hill (Murrell, 1970).

Buildings are overrepresented on DMA standard products. Numerous individual building symbols are not helpful to aeronautical users and clutter the chart (Hopkin and Taylor, 1979; Taylor, 1974a). Settlement is better shown by area symbols. The same may be said for topographic maps.

Even landmark buildings are overrepresented on aeronautical products. Subjects ranked landmark features twelfth in importance for flight plannning, eleventh most important in flight (Lakin, 1972), and thirteenth most important for fixing positions at night (Taylor, 1977). Standardized symbology for structures is too prominent; it provides a false expection of visibility to aircrews (McGrath and Borden, 1969).

Depiction

Figure 7d outlines building types that can be shown on DMA standard products. There is striking inconsistency among the JOG, TPC, and ONC that could be easily remedied. The overblown symbol set used on topographic maps is cause for concern. Can there truly be a requirement to distinguish between 14 different types of religious stuctures? If there is such a requirement, it is poorly met by the minute symbols used to depict religious buildings. Redesign of all building symbols shown on topographic maps is strongly recommended. A further discussion is held in Chapter 21—Topographic Maps.

LOCATED OBJECTS

As defined in DMA product specifications, located objects are landmark features other than buildings or area

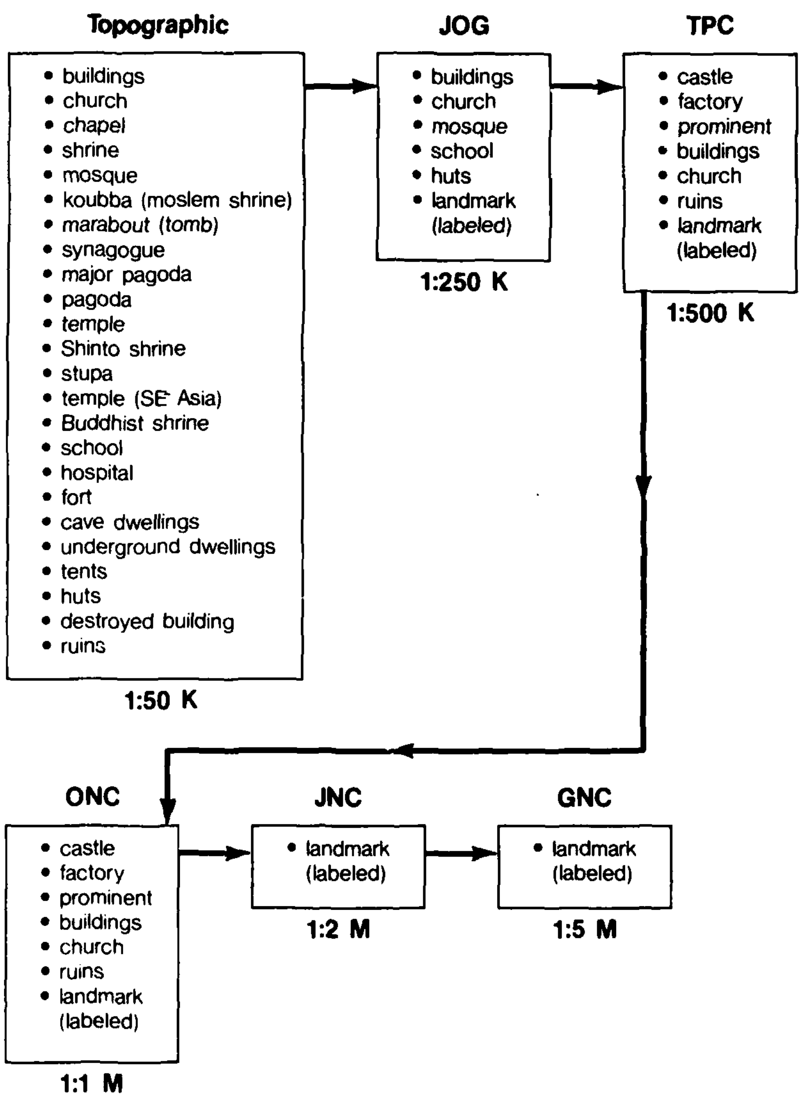


Figure 7d. Buildings on DMA standard products.

features that, because of size, shape, or location, serve as a means of positive orientation. Examples of located objects are towers, chimneys, media masts, air beacons, lighthouses, watermills, windmills, tombs, and monuments.

Figure 7e shows the symbol sets used by DMA products for located objects. While one would expect a logical continuum of detail decreasing with scale, it is not so. As with buildings, there is broad inconsistency in the symbols available for located objects among DMA's standard products. The JOG has essentially the same provisions as the JNC, and the greater detail allowed by TPCs and ONCs is inconsistent with the amount of detail supported by topographic map specifications.

MAN-MADE HYDROGRAPHIC FEATURES

Figure 7f shows the representation of man-made features in water on DMA products. Man-made features that appear in the water share the inconsistencies noted in the previous two sections. The JOG is curiously devoid of such symbols, presumably relying on labels. Yet the symbol sets used on the TPC and ONC represent features that would be highly visible from the air and that would be important to ground users. Thus, it is recommended that the TPC/ONC symbol categories be used on the JOG. The topographic map shows three symbols for wreckage: exposed wreck, exposed wreckage, and masts exposed. All three should be combined. An extended area with exposed wreckage can show several exposed wreck symbols.

Figure 7g shows man-made drainage features on DMA products. There is inconsistency between the JOG and the TPC, ONC, JNC, and GNC attributable to both terminology and level of detail. Astonishingly, the JOG, TPC, and ONC include symbols for two underground features (aqueducts and flumes). Also surprising is the distinction between aqueducts and flumes; these categories are combined on topographic maps.

Topographic symbols compensate for the austerity of combining aqueducts and flumes by itemizing an exhaustive list of canal characteristics. If abandoned, dry canals less than 18 m wide are necessary features, a less cluttered symbol must be designed. Abandoned canals currently are more prominent than navigable canals due to labeling.

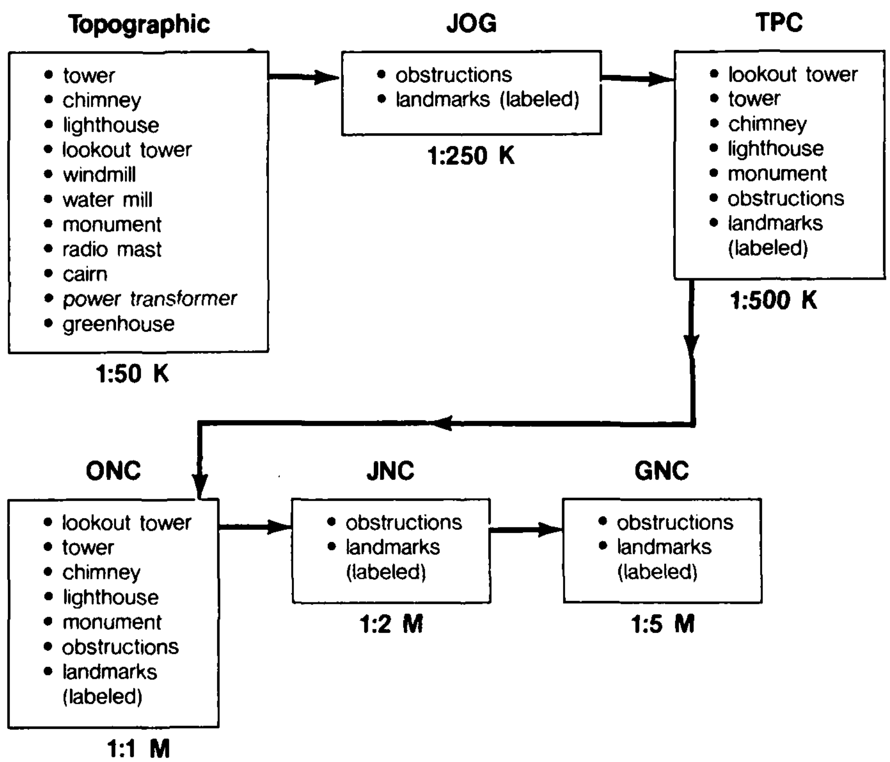


Figure 7e. Located objects on DMA standard products.

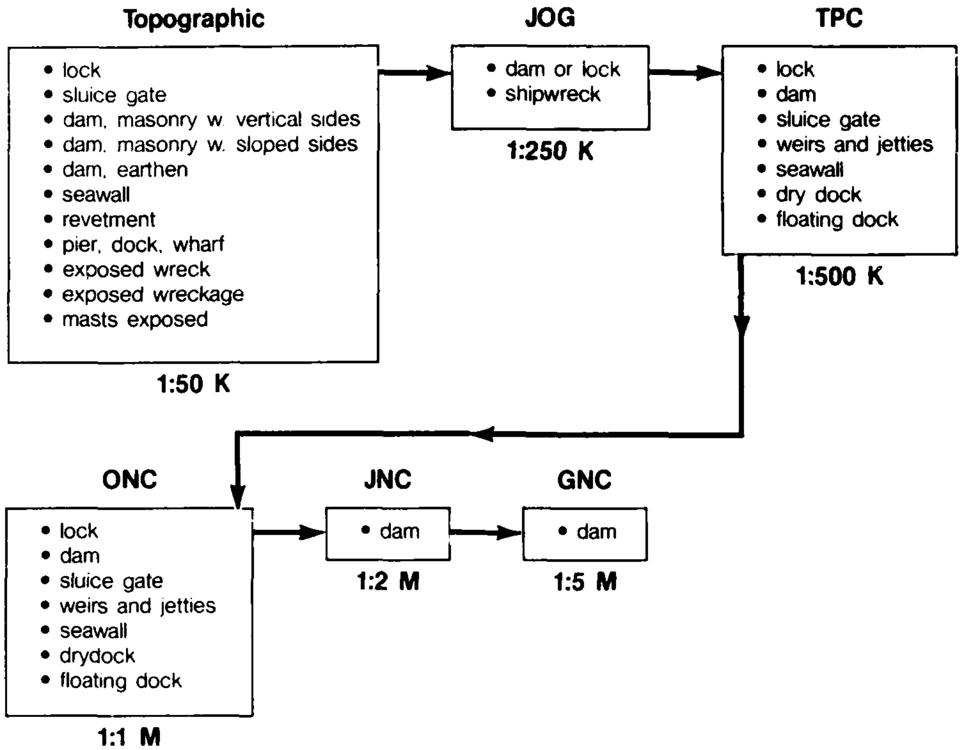


Figure 7f. Man-made hydrographic features on DMA standard products.

MISCELLANEOUS MAN-MADE FEATURES

Figure 7h shows the level of detail provided for miscellaneous man-made features on DMA products. Once again, no logical continuum of symbol sets is evidenced in DMA's product line (JOGs underrepresent man-made features throughout). Two practices are particularly strange: first, an isolated grave does not seem important to a 1:50,000 scale map. Second, on aeronautical charts shaft mines (not prominent from the air) share a symbol with quarries (extremely prominent from the air). The symbol is small and light, appropriate for shaft mines but inappropriate for quarries, which are strikingly visible from the air.

SUMMARY

The symbol sets for cultural features are solid evidence that DMA products have evolved independently. Different DMA production centers have been separately responsible for their products; the JOG has been a cooperative effort with other NATO countries.

Such diversity is difficult to justify. First, the level of detail supported by unique symbols bears little relation to product scale. Second, automated methods will be developed to perform all the graphic effects appearing on DMA products. Each eccentricity will be translated to dollars and development time. DMA should comprehensively overhaul its symbol sets so common symbols are used wherever possible.

10. Navigation Aids

NAUTICAL INFORMATION

Dependence upon hardcopy charts for navigating will be reduced in the near term by the Global Positioning System and by shipboard navigation systems. Navigation systems will incorporate electronic charts capable of correlating digital feature, bathymetry, and Loran-C data to radar and fathometer returns. Nonetheless, content requirements and graphic depiction continue to be serious issues in the digital age.

A recent survey by the German Hydrographic Institute was aimed at determining information required for marine navigation. Of necessity, requirements are broken out for nearshore and at sea. Navigation was defined as having three component parts: position fixing, route finding, and safety. Data required for each of these three purposes are

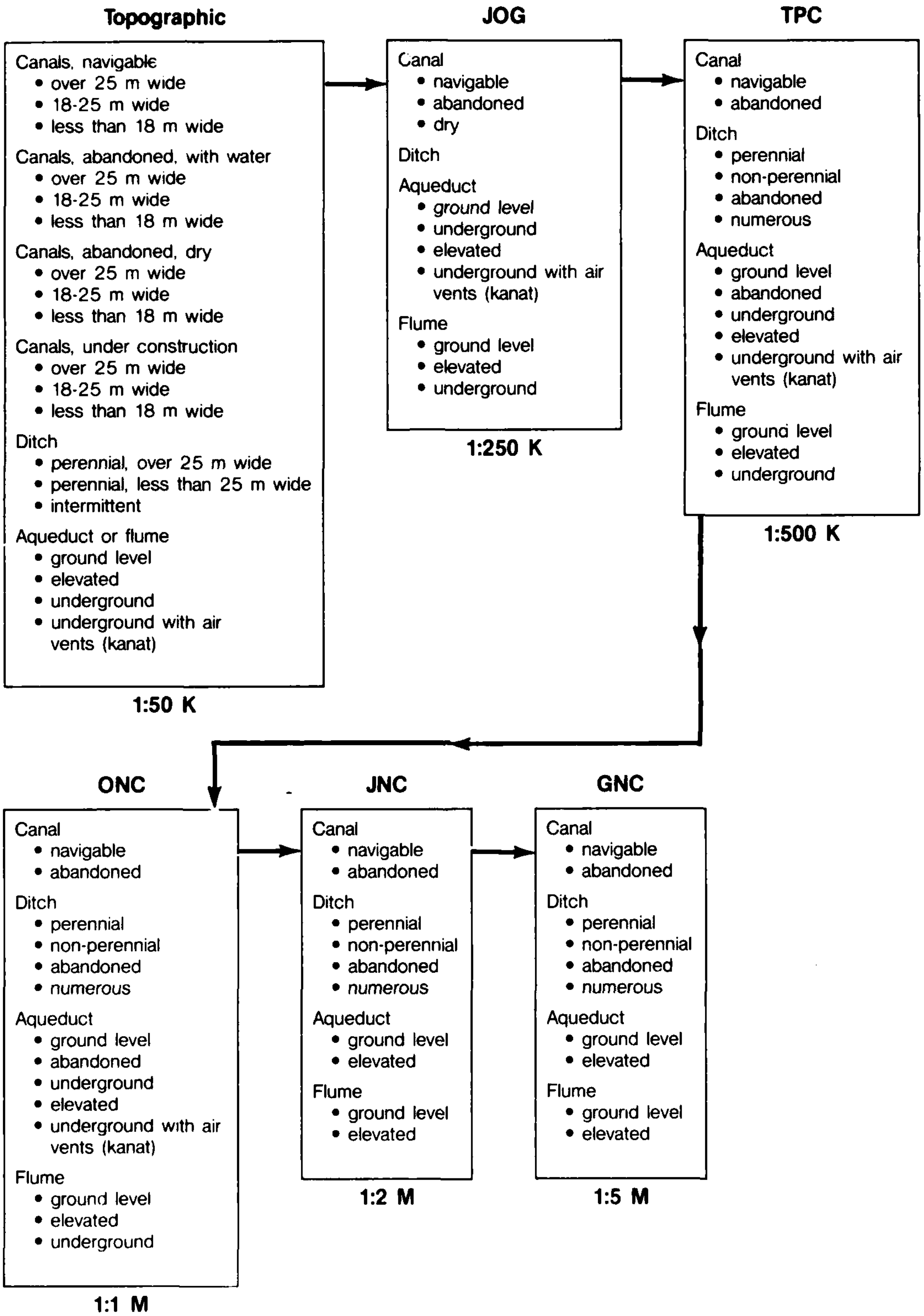


Figure 7g. Man-made drainage features on DMA standard products.

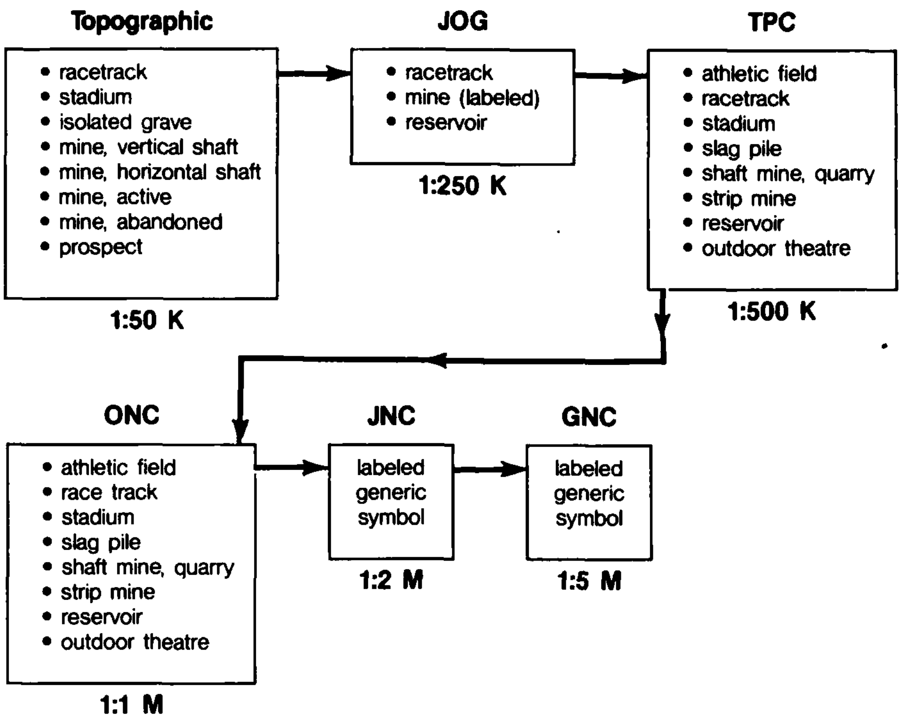


Figure 7b. Miscellaneous man-made features on DMA standard products.

shown in Tables 4, 5, and 6. Detailed land topography for position fixing is absent from DMA hydrographic charts. Including topography on hydrographic charts is recommended in Chapter 23—Hydrographic Charts.

AERONAUTICAL INFORMATION

Data on airports, air traffic control, radio facilities, airspace regulations, and obstructions constitute the most important aeronautical information shown on DMA aeronautical charts. Requirements differ for air navigation aids between medium scale and small scale charts. Medium scale charts are often used with Visual Flight Rules (VFR) procedures, making topographic information on the chart of competing importance. Smaller scale charts are used with Instrument Flight Rules (IFR) procedures, making aids to navigation by instrument of dominant importance. Requirements for aeronautical information on medium and on small scale aeronautical charts are discussed next, followed by a survey of symbol treatment on DMA aeronautical charts.

Medium scale aeronautical charts

Surveys indicate that air navigation aids are generally less important than topographic features to low altitude aeronautical users. Lakin (1972) surveyed aircrews on the aeronautical importance of features on the 1:250,000 JOG-A and found that the four most important features were topographical; airports ranked sixth, power lines and obstructions ranked seventh and eighth, aeronautical information ranked twelfth, and electronic navaids ranked fourteenth out of a total of 16 features. In fact, electronic navaids and magnetic information consistently ranked so low that Lakin concluded they should be omitted from future JOGs.

This apparent lack of importance of aeronautical information is further supported by results of a survey of aircrews who ranked eighteen 1:250,000 scale charts in terms of usefulness (Taylor, 1974a). No preference was found among aircrews for maps showing radio aids information, controlled airspace, or danger areas. Taylor concluded that at low altitudes the topographic base is important; clutter to this base is undesirable to aircrews.

McGrath (1973) notes that during any hostilities radio navigation facilities, air traffic control, etc. are unlikely to be available. He states that for low level missions, obstructions, airports, and radio facilities are most useful because they are sufficiently visible from the air to allow visual referencing. McGrath recommends that war stocks of aviation maps not be printed with controlled airspace or danger areas.

Table 4. Features required for position fixing (Schmidt, 1979).

POSITION FIXING	Charts used for: overseas navigation: ocean	marginal sea	inland sea	coastal navigation: offshore	inshore	approach	entrances, channels	port
Graticule	x	x	x	x	x	x	x	
Magnetic variation	x	x	x	x	x	x	x	
Coastal configuration[2]					x	x	x	x
Land topography[2]					x			
Detailed land topography						x	x	
Landmarks visible from afar		x	x	x				
All landmarks					x	x	x	
Soundings[1]	x	x	x	x				
All depth data					x	x	x	
Nature of bottom and depth data for echo soundings		x	x	x				
Nature of bottom					x	x	x	
Selected marks on land or at sea		x	x					
All marks on land or at sea				x	x	x	x	x
Leading lines				x	x	x	x	x
Radar conspicuous objects				x	x	x	x	
Selected maritime radio, radio navigation and radio determination stations		x	x	x	x	x	x	
Radiobeacons					x	x	x	
Limits of radar stations						x	x	x
Hyperbolic navigation grids	x	x	x	x	x	x	x	

1. Soundings and depth contours must be selected so that their depiction permits the mariner to draw conclusions regarding the density of the surveys. Even very deep soundings must be shown on charts since areas without depth data will suggest incomplete surveys. The depth data must be shown for the whole area, and not be limited to certain channels.

2. Coastal configuration and land topography are essential elements for position fixing and cannot be omitted, notwithstanding modern navigational methods. Topographic features extending inland from the coastal area may become necessary in the case of particularly conspicuous landmarks visible over a great distance, the depiction of spot heights alone being insufficient.

Table 5. Features required for route finding (Schmidt, 1979).

ROUTE FINDINGS	Charts used for: overseas navigation: ocean	marginal sea	inland sea	coastal navigation: offshore	inshore	approach	entrances, channels	port
Graticule	x	x	x	x	x	x	x	x
Magnetic variation	x	x	x	x	x	x	x	x
Coastline	x	x	x	x	x	x	x	x
Names of important coastal features	x							
Names of all important coastal features		x	x	x				
Names of all coastal features					x	x	x	x
Important harbours	x	x	x					
All harbours				x				
All harbours, roads and anchorages					x	x	x	
Ports, berths and landing places							x	
Port facilities and anchorages								x
Names to identify ocean bottom features	x	x	x	x	x	x	x	
Soundings and depth contours	x	x	x	x	x	x	x	x
Names of ocean parts	x	x						
Names of ocean parts and important bays		x	x					
Names of all ocean parts and bays				x				
Names of all ocean parts, bays and waterways								
Names of all bays and waterways						x	x	
All dangers	x	x	x	x	x	x	x	x
Ocean currents[1]	x	x	x	x	x	x	x	
Tidal streams[2]					x	x	x	
Prescribed and international routes	x	x	x	x				
Track recommendations		x	x	x				
All routes and fairways (channels)					x	x	x	
Channels								x
Areas with restricted traffic	x	x	x	x	x	x	x	x
Leading marks					x	x	x	x
Bridge or other clearances, vertical and horizontal							x	x

1. The axis of permanent ocean currents must be shown (e.g., the Gulf Stream).

2. Tabular information on tidal streams at selected places must be shown, giving their direction and strength (as for example on the British Admiralty charts).

Table 6. Features required for safe navigation (Schmidt, 1979).

SAFETY AND EASE OF NAVIGATION	Charts used for: overseas navigation			Charts used for: coastal navigation				
	ocean	marginal sea	inland sea	offshore	inshore	approach	entrances, channels	port
Military training areas[1]	x	x	x	x	x	x	x	
Limits	x	x	x	x	x	x	x	x
Submerged artificial features (pipelines, submarine cables etc.)		x	x	x	x	x	x	x
Notes, warnings, remarks	x	x	x	x	x	x	x	x
Radio direction finding stations		x	x	x	x	x		
Coast radio stations for port operations					x	x	x	x
Various stations (signal stations, pilot stations etc.)					x	x	x	x
Chart datum				x	x	x	x	x
Nature of bottom						x	x	x
Bridge or other clearances, vertical and horizontal							x	x
Harbour facilities								x
Places for clearance by the customs authority			-					x
Hyperbolic navigation grids[2]								x

1. Military training areas and other areas of traffic restriction must indicate the kind of restriction.

2. In the case of harbours, overprinting of hyperbolic navigation grids is desirable to enable calibration of instruments before sailing.

Small scale aeronautical charts

At scales above 1:1,000,000 interest in topographic detail diminishes and navigation aids assume increased importance in flight planning and in flight. Information on airports is of primary importance, although details come from Flight Information Publications (FLIPS). The requirement for information on vertical obstructions is questionable for scales smaller than 1:1,000,000. Hopkin and Taylor (1979), however, state that in the interests of flight safety vertical obstructions exceeding 100 m (300 feet) should be shown. They argue that such obstructions can be shown as point symbols and are infrequent enough that they will not add significantly to clutter; and that vertical obstructions are useful visual checkpoints, since they contrast well against the horizon and are often lit at night.

Air navigation symbols

Because in most cases aeronautical information is either abstract or verbal, establishing an iconic symbol set has not been possible. Although there is no objective evidence that the symbols currently used to depict aeronautical information are the most effective from a human factors standpoint, the fact that they have been learned and are in common usage makes arbitrary change undesirable.

Electric blue (also called aero blue) is the color used by DMA for air navigation symbols. Blue has been found to be the color most strongly associated with aeronautical information (Van der Weiden and Ormeling, 1972). The International Civil Aviation Organization recommends dark blue as the preferred standard color for aeronautical data; magenta is offered as an alternative. Hopkin and Taylor (1979) object, stating that while electric blue may be appropriate for aeronautical information in general, some air navigation symbols need to be more prominent. Obstructions are shown in red on the Royal Air Force (RAF) Low Flying Chart; arguably, red should be used for power lines as well. Both vertical obstructions and power lines are unfortunately inconspicuous on the JOG.

Hopkin and Taylor (1979) suggest using a yellow town infill to contrast with the electric blue obstruction symbol. They also suggest multicolored overprinting of aeronautical information as is used on the 1:500,000 RAF Low Flying Chart, to achieve greater visual separability than shape encoding alone. (This section was derived from Hopkin and Taylor, 1979.)

11. Grids

THE ROLE OF MAP GRIDS

Grids are used to locate and communicate position and to help in navigation. It is unfortunate, but necessary, that more than one grid must appear on nearly all maps and charts because ground force positions are given in UTM coordinates while aircraft navigate in latitude/longitude coordinates, requiring translation between the two systems. Electronic navigation systems may obviate this requirement, performing transformations automatically in the cockpit.

Aside from their use in measuring and standardizing the description of location, grids appear to have a more subliminal role. Kulhavy et al. (1982) hypothesized that when a grid isavailable on a map, subjects will give it priority in memory because it is their reference structure for other information on the map. After testing subjects on recall and accuracy of recall for features on maps with and without locational grids, findings indicated that the grid forms an interpretive framework for other map features. Subjects who used the map with the grid remembered fewer features, but remembered features could be located by the subjects with significantly greater positional accuracy.

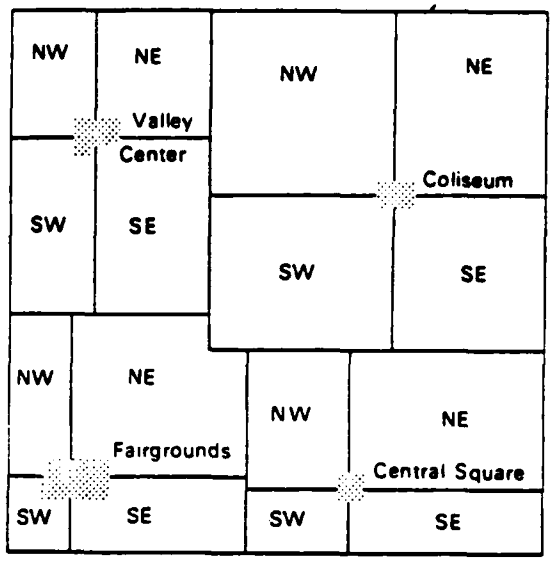


Figure 8. Landmark-based grid (Koleszar, 1981).

CITY MAP GRIDS

Size

The size of reference grid on a city map has been shown to affect search time. On a large format 1:12,500 map of Jerusalem the shortest search times for street names resulted when the grid was 0.5 km square. Coarser or finer grids caused increased search times. This phenomenon was partially explained by a second experiment which indicated that length of search time on city street maps is determined by two factors: the time required to locate the correct grid square from index coordinates, and the amount of time taken to find the street within the square. Thus, as the size of the grid decreases, the time to locate the correct square increases while the amount of time to find the feature decreases, resulting in a U-shaped relationship between grid size and search time (Stilitz, 1976).

Shape

Although a grid is commonly formed by regular and roughly perpendicular lines, alternatives are possible. Structuring the grid to be meaningful to the structure of the mapped area expedites the search task and encourages rapid familiarization with a city. A landmark-based grid system was proposed and tested by Koleszar (1981). In this system, grid cells are irregularly sized and spaced and are based upon landmarks in the city rather than on coordinates (Fig. 8). Each landmark forms the center of a grid cell quartet with cells varying in size depending on the distance to adjacent landmarks.

The advantages of a landmark-based system are overwhelming: the grid is easily used even when the map is folded; it references locations in the way that directions are given by residents of an area; and it relates the map to the landscape assisting the mapreader in learning the layout of a city and gaining a spatial familiarity with a city. Testing the proposed grid system on a cross section of subjects demonstrated the superiority of the proposed grid system. Subjects using the landmark grid system outperformed subjects using standard grid systems in accuracy, speed, and recall of spatial organization.

A proposed, but untested, alternative is the concentric circle grid, a grid formed by circles radiating from the centroid of an area, divided into cells by lines pointing N, NE, E, SE, etc. (Baybrook, DMAHQ, pers. comm., 1984) (Fig. 9). This grid shape is interesting because it takes advantage of instinctive knowledge (N, S, E, W) and helps the mapreader to become familiar with relative locations of referenced features in the mapped area, as does the landmark-based grid. If centered on the most densely featured area of the map, each grid cell will contain roughly the same number of features because as distance from center increases, feature density decreases and cells enlarge.

An alternate means of referencing a point on a circular grid is by dividing the grid by the hours of a clock. This method would be useful on softcopy displays, which are not always shown north-up. Radar systems use circular grids, but locations are referenced in a less instinctive manner.

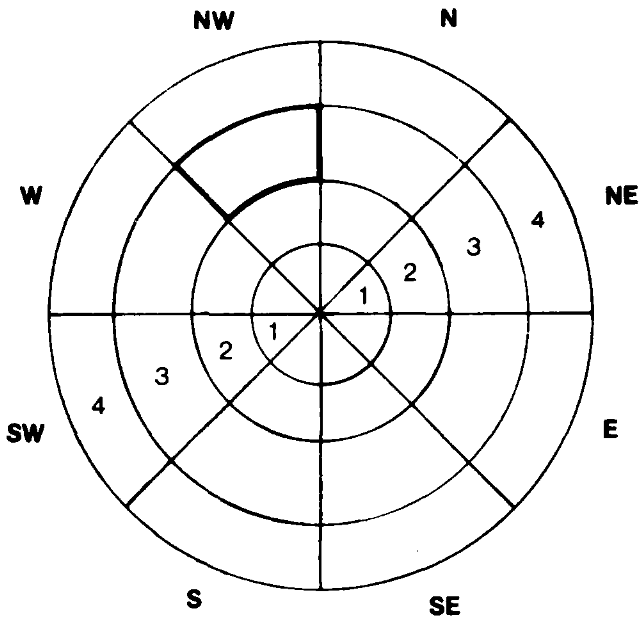


Figure 9. Grid formed by concentric circles. Highlighted cell is referenced as 3NW (Baybrook, 1984).

GRIDS ON NON-CITY MAPS

Size

Just as on city maps, it is likely that all maps and charts have an optimum grid size. Too many grid lines clutter the map, and too few adversely impact the accuracy of measurements using the grid. Too small an interval between grid lines does not necessarily improve the accuracy of interpolating position but can disrupt search patterns (Ericksen, 1955). On small scale maps, however, the convenience of using unit measurements (i.e., seconds, minutes, degrees) for grid lines dictates the grid interval to a great extent.

Shape

Alternate grid shapes as discussed above are not recommended for immediate use on hardcopy DMA maps and charts that already show a minimum of two grids. The landmark-based system offers limited benefit to topographic, hydrographic, or aeronautical users. A grid formed by concentric circles could be very useful when operations revolve around a central location. Electronic charts for C^3I should be equipped with a concentric grid, be displayable on demand, and be centered on a specifiable point with specifiable resolution. Constructing this type of grid on special-purpose products may be useful.

REDUCING GRID PROMINENCE

Grid prominence is a flexible design variable. Although grids have light line weights on DMA products, sometimes their colors make them relatively prominent (dark green is used on the navigation grid of the JNC and GNC, and black is generally used for graticules). An innovation that could help reduce the clutter caused by grid lines would be to alternate the current fine line weight used with an even finer line weight or a dashed line (Baybrook, DMAHQ, pers. comm., 1984). Alternating line character would provide mapreaders with an index line and help them to follow a grid line across the map, decreasing the need for interior labels and ladders.

A number of alternatives are available for grid line representation. Because grid lines are regular, they can be quite thin and remain easily discriminable. Taylor (1976a) experimented with a brown rather than a black grid and found no significant difference in legibility. Dashed lines are not normally recommended for maps because they are difficult to scan; but grids can use dashed lines if necessary because they are generated by computer and need never be scanned.

GRIDS ON DMA MAPS AND CHARTS

Table 7 shows the means of depicting the UTM/MGRS grid on DMA standard products, and Table 8 shows the means by which the graticule is shown on DMA standard products. Tables do not list detailed variations or polar grids and graticules, providing merely an overview of the range of grid depiction by DMA. It can be seen, for example, that the JNC has double the graticule resolution of the ONC. The JNC and GNC show dominant green navigation grids. The GNC compensates for the additional grid by using gray instead of black for the graticule. A similar gray graticule is recommended for the JNC.

12. Boundaries

Boundaries on maps generally outline political entities. Although not uniformly represented, each DMA product series depicts a number of boundaries (Table 9). It is evident from this table that differences in wording are responsible

Table 7. UTM/MGRS grids on DMA products. UTM/MGRS grids are used on hydrographic charts only in designated areas; intervals are dependent upon scale and projection.

	Interval	Border labels	Interior labels	Color
Topo 1:50K	1000 m	1000 m	1-2 ladders	black
JOG 1:250K	10,000 m light lines 100,000 m index lines	100,000 m	2 ladders	blue
TPC 1:500K	100,000 m lines 10,000 m ticks	20,000 m	100,000 m	blue
ONC 1:1M	15°	1°	2°	blue
JNC 1:2M	no lines; labels only	1° letters	numbers	blue, black

Table 8. Graticules on DMA products. Hydrographic chart grids are not listed because they are dependent upon scale and projection.

	Interval	Border labels	Interior labels	Color
Topo 1:50K	1′ ticks	5′	5′	black
JOG 1:250K	15′ lines, 1′ ticks	15′	30′	black
TPC 1:500K	30′ lines, 1′ ticks	30′	1°	black
ONC 1:1M	1° lines 1′ ticks	1°	2°	black
JNC 1:2M	1° lines 2′ ticks	1°	3° long. 2° lat.	black
GNC 1:5M	1° lines 5′ ticks	5°	10°	gray

Table 9. Boundaries on standard DMA products.

	City	Topo	JOG	TPC	ONC	JNC	GNC	Hydro
International-de jure				X	X	X	X	X
International-de facto				X	X	X	X	X
International	X	X	X					
International Date Line			X	X	X	X	X	
Separation of Sovereignty	X	X						
Interterritorial or intercolonial; autonomous zone			X					
Treaty or occupancy zone				X	X	X	X	
First-order administrative	X	X	X					
Second-order administrative	X	X	X					
Third-order administrative	X	X	X*					
Primary administrative				X	X	X	X	
Major administrative				X	X	X	X	
Municipal	X							
U.S./Russia Convention Line				X	X	X	X	
Reserve		X						
Insular Boundary			X					
Military Reservation		X	X					
	6	7	8	7	7	7	7	2

for the number of unique boundary types recognized by DMA—primary and major administrative boundaries must correspond in some way to first- and second-order administrative boundaries, just as the term interterritorial/intercolonial substitutes for separation of sovereignty. Inconsistent language should be revised so boundary type can be correlated from one product to another.

Boundaries are among the least important features shown on topographic, hydrographic, and aeronautical products alike (barriers to flight are shown on charts as navigation aids and are not considered in this report as boundaries). Taylor (1977) states that boundary symbols can be a problem on aeronautical charts because they are linear and interfere with other linear features. Since many of the most important features for flight are linear, only major political boundaries should be shown on aeronautical charts.

Topographic maps are at a scale where a more liberal stand on boundary lines can be taken. Even so, second- and third-order administrative boundaries can be only peripherally interesting to users.

GRAPHIC REPRESENTATION

All but one of DMA's boundary symbols are based on black lines of various weights that are interrupted by dots and dashes. The international boundary symbol is a black interrupted line banded in screened red, red/brown, or magenta (the JNC and GNC do not band the international boundary symbol). As demonstrated in Table 9, all but the hydrographic series allow a minimum of six different boundary types, encoded by varying line weights (ranging from 0.2 mm to 0.8 mm) and line patterns (using combinations of dots and dashes). This level of detail probably overestimates both mapreader skill and interest, given the amount of competing data on each chart.

RECOMMENDATIONS FOR DMA PRODUCTS

Uniform terminology for boundaries should be established. In all but extreme cases only international boundaries should be shown on aeronautical charts. De jure boundaries could retain the current symbol although a reduced line weight should be considered; de facto boundaries should have only a band with no black line.

The marginal inset used to show boundaries on the topographic map is a good idea. If necessary, it can be easily updated when boundaries change using "maplets" in the same way as *Notice to Mariners* uses "chartlets."

Some reduction in the number of boundary lines shown on the topographic product is still in order. The requirement for second- and third-order administrative boundaries on topographic maps should be reviewed.

13. Margins and Marginal Information

Margins are used by mapreaders as a guide to reading the body of the map. Content requirements and margin layout are evaluated in this chapter. DMA should strive for consistency within and across products. The speed of referencing information from margins can be improved if the user is not forced to search for the information he seeks. And, DMA will save time, money, and confusion by designing a standard margin format to be varied only when necessary.

MARGIN AREA

Of the DMA standard products that would be involved in product derivation (see Chapter 18) only the topographic map has a margin on four sides of the page. All others (the JOG, TPC, ONC, JNC, and GNC) have a two-margin format (bleeding edges) to facilitate stripping or joining together sheets required for flight use. There are good arguments for adopting a two-margin format for the topographic map. First, topographic maps must occasionally be joined. Second, sheet space is optimized. And third, if sizes and margins are made compatible across the product line, mosaicking for product derivation will be simplified. Wright and Pauley (1971) recommend a two-margin format in an experimental large scale map specification to be used for helicopter flight.

LEGEND

All DMA products show legends in their margins. Six levels of roads are commonly defined on aeronautical charts. Many types of vegetation, depending on the contents of the map, must be explained. Detailed contour accuracy information, coded in the contour labels, is interpreted. If symbols were less complex, the need for a legend would diminish. Throughout this report suggestions are made to reduce overall product complexity. If these recommendations are enacted, legend requirements will be simplified somewhat.

Symbols appearing in the legend should be shown in their graphic context. Thus, a dam symbol should appear on a river and vegetation symbols illustrated on appropriate background tints. The preferred method of showing relief tints (elevation, slope, etc.) is pictorially, as is done for DMA's Terrain Characteristic Tints on the ONC, JNC, and GNC (Hopkin and Taylor, 1979).

The extent to which users refer to the legend and other information provided in the margins would be an appropriate question to ask subjects of a requirements survey. Hopkin and Taylor (1979) warns that aircrews are unlikely to refer to the map margins during flight due to time constraints, and also since margins are frequently trimmed and discarded as waste during flight planning. He recommends issuing a small instructional booklet containing legend information and whatever instructions and glossaries that might have been included on the series for the area in lieu of marginal information. The USGS and the National Oceanic and Atmospheric Administration (NOAA) have successfully avoided including extensive legends in their map margins by publishing such keys. User groups are generally familiar with product series; this familiarity, and supplemental keys, would diminish legend requirements.

MAP IDENTIFICATION

The means by which a map or chart is identified is inconsistent across products but is easily remedied. All products need identification at two diagonally opposite corners so they can be recognized from any position in a drawer. The series and sheet numbers in the corners should always be accompanied by map scale. The title, centered below the map, should be followed by both numeric and graphic scales.

Techniques for Digital Production

14. Computer Production of Symbols

This chapter begins a section describing techniques and problems important to digital production. In the next section many of these techniques are incorporated into recommended new product designs to replace the current designs produced by analog methods. Symbology, focal to cartography, is discussed here in a digital context.

Computer production of maps and charts can be more efficient if a symbol set is designed to minimize certain requirements. To optimize the savings inherent in computer production symbols should, whenever possible,

- be independent of orientation;
- be easily recognized by automated techniques, i.e., structurally unique at the highest possible level;
- be simplified in design;
- not involve a great deal of computation to construct;
- avoid embellishments that are not important to the mapreader.

ORIENTATIONAL INDEPENDENCE

In the most basic sense, a circular symbol is preferred to a square symbol because a circle is independent of orientation. The original specification of the USGS 1:100,000 series map design avoids using 120-line dot screens, which must be angled to avoid moire patterns when superimposed. Mezzotint random pattern screens are used in lieu of regular dot screens for most area symbols and line work on the USGS San Juan prototype (Fig. 22 in Chapter 20) to avoid moire in area symbols and roping in line symbols. Biangle screens have been commended for avoiding moire, yet in some cases will produce line symbols that appear roped (Gilman, 1982).

EASE OF AUTOMATED RECOGNITION

Dots and, to some extent, dashes can be dropped or added by scanning equipment due to lost pixels. Thus, symbols should be distinct from one another in line weight or form. Examples of current DMA 1:50,000 topographic map symbology whose recognition could be threatened by dot dropout are: operating and non-operating railroads, church/synagogue, shrine/chapel, and major pagoda/pagoda. Feature recognition algorithms are far less complex when the number of possible identifications is reduced; if the cultural overlay is being scanned, only cultural symbol templates are compared. The 12 separations used by the USGS 1:100,000 series separate by feature rather than only by color, admittedly increasing the workload of the compilers yet creating a truly valuable analog archive. The content separation scheme used by this series is described in Chapter 18—Recommendations for multiproduct operations.

SIMPLICITY OF DESIGN

Gilman (1983) describes the efforts to simplify symbols on prototype maps made by the USGS in the 1970s. The symbols currently in use were felt to be intricate, wasteful of drafting time, not esthetically pleasing, and not conducive to automated processing. Symbols for obsolete features were discontinued; symbols for mapworthy features were redesigned. Dots, for example, which are often used for small distinctions between symbols, are not easily seen and are time consuming to make. All dots were eliminated from the experimental map symbols. For example, the benchmark symbol (a triangle with a small dot in the center) was replaced by a triangle drawn with a heavy line that left only a small empty spot in the center (Gilman, 1983). The number of dashes used in symbols was reduced for similar reasons. Line weights were carefully matched to symbol size, color, and desired emphasis.

EASE OF CONSTRUCTION

Cased line symbols and cross-hatching require an undue amount of time to compute. The standard cased highway symbol was replaced on the USGS 1:100,000 map by overprinting red on screened black, discontinuing the practice of scribing red fill to fit between scribed black casings. The railroad, fence, and open pit symbols used on the DMA 1:50,000 topographical map use cross-hatches, which will slow automated processing without any proven benefits.

AVOID EMBELLISHMENTS

This is a general homily more than a specific instruction. Many cartographic practices go unnoticed by the mapreader, serving mainly to please the cartographer. Typeface variations are one example; the practices of increasing the line width of a stream or river as it approaches its mouth, and of employing a vignette along a shoreline are others. The latter two practices (and there are assuredly others of their type) require specialized algorithms, processing, and expense for which there is no emphatic need.

15. Alternative Terrain Representation

Traditional methods of representing terrain were discussed earlier in this report. From the research reviewed, it was clear that no single method of terrain representation provides a perfect blend of speed and accuracy for terrain analysis. This unfortunate fact should encourage experimentation, since interpreting relief is a task of overriding importance to all military operations.

The methods described in this chapter are not all new to cartography. Slope maps and Tanaka contours were introduced long before computers. Neither are in common use, despite their attributes, because they are difficult to construct manually. Digitally, they are not significantly more difficult to construct than other types of terrain representation. Thus, these methods and the benefits they offer to mapreaders should be considered for standard use.

Two methods of terrain representation presented in this chapter are uniquely digital. These methods use digital terrain models or digital imagery to generate a tint scheme to represent the earth and could be used for aeronautical charts. They are offered here as possible alternatives for the Terrain Characteristic Tints currently employed by DMA on the ONC and the JNC. Terrain Characteristic Tints are applied through highly subjective means based on broad geographic knowledge. Aside from questionable graphic merit, they will resist automation and should be abandoned.

TANAKA CONTOURS

Tanaka contours offer an alternative to combined shaded relief and contour lines (Tanaka, 1950). Tanaka contours (also called shaded contours, relief contours, and illuminated contours) combine the dimensionality of hillshading with the precision of contours (Figs. 10-12).

Based on a theory for calculating a numerical brightness value for any point on an obliquely illuminated surface, contour color and thickness are varied depending on aspect. The horizontal angle between the direction of the light source and the horizontal direction of the slope is θ. With a medium-tone map ground, contours of aspect $\theta < 90^{o}$ are light while contours of aspect $\theta > 90^{o}$ are dark. Contour line thickness varies with the cosine of θ, i.e., if t is the thickness of a contour line at any point on the map, and t_o is the maximum allowable line thickness, then $t = t_o \cos \theta$. Thus, maximum thickness is when $\theta = 0^{o}$ or $\theta = 180^{o}$; minimum thickness is when $\theta = 90^{o}$.

While time-consuming to construct manually, the algorithmic nature of Tanaka contours is conducive to automation. Tanaka contours reduce processing by aggregating two types of relief symbology, providing "information at a glance" like hillshading and accurate detail like contours.

Tanaka contours have a major advantage over shaded relief: terrain analysis is less dependent upon map orientation. Tanaka contours appear to behave more like standard contours than shaded relief in their effect upon other map information (Wheate, 1978). After comparing subjects searching maps with standard contours combined with shaded relief to subjects searching maps with Tanaka contours, the Tanaka contours were found not to reverse as readily as shaded relief, and to be similar to contour lines in terms of interfering with other features. They did not, however, provide the apparent Gestalt effect of shaded relief (Wheate, 1978; see Chapter 6 for an explanation of the Gestalt effect of shaded relief).

This report recommends that Tanaka contours replace standard contours on the 1:50,000 topographic map once digital processes are enacted. No accuracy is lost by this change, but mapreading speed is improved. If the studies reviewed in this report are representative of the difficulties experienced by users in interpreting standard contours, Tanaka contours will be a major improvement.

SLOPE ZONES

An alternative to both layer tints and shaded relief is offered by slope zoning. Miller and Summerson (1960) have produced prototype maps that illustrate the terrain

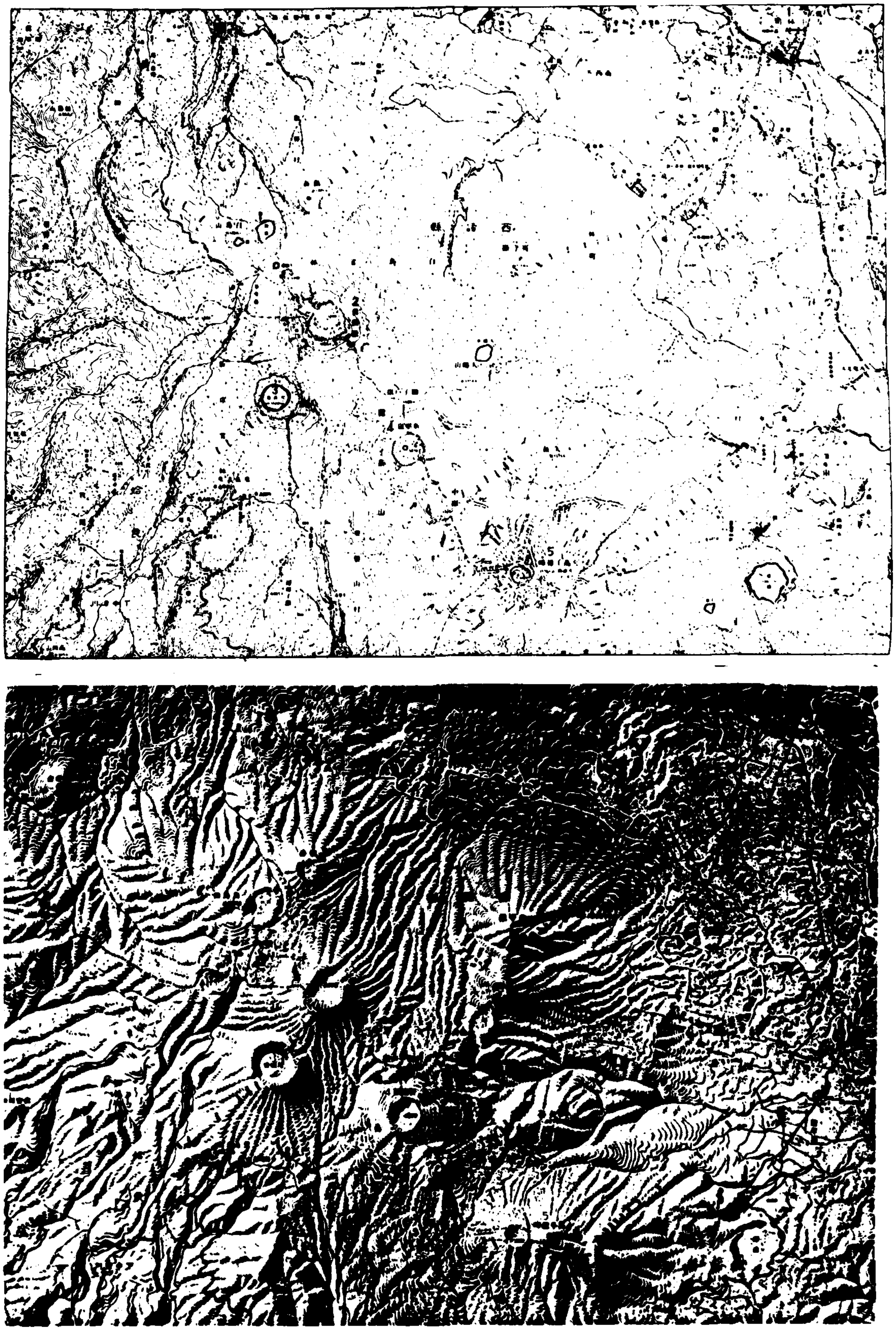


Figure 10. Tanaka contouring (Tanaka, 1950).

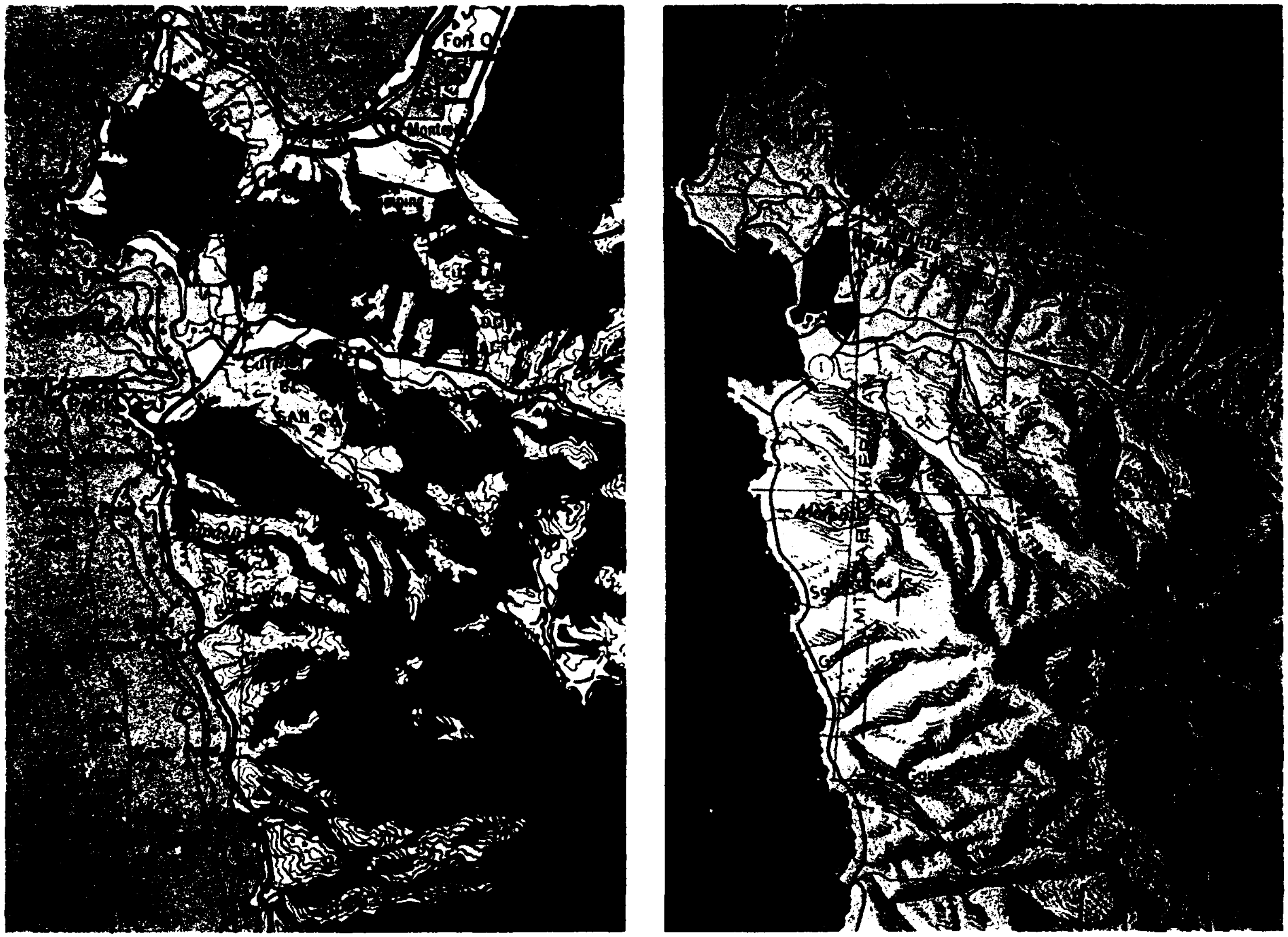


Figure 11. Standard and Tanaka contours on conventional USGS and prototype map of Monterey, California. 1:250,000.

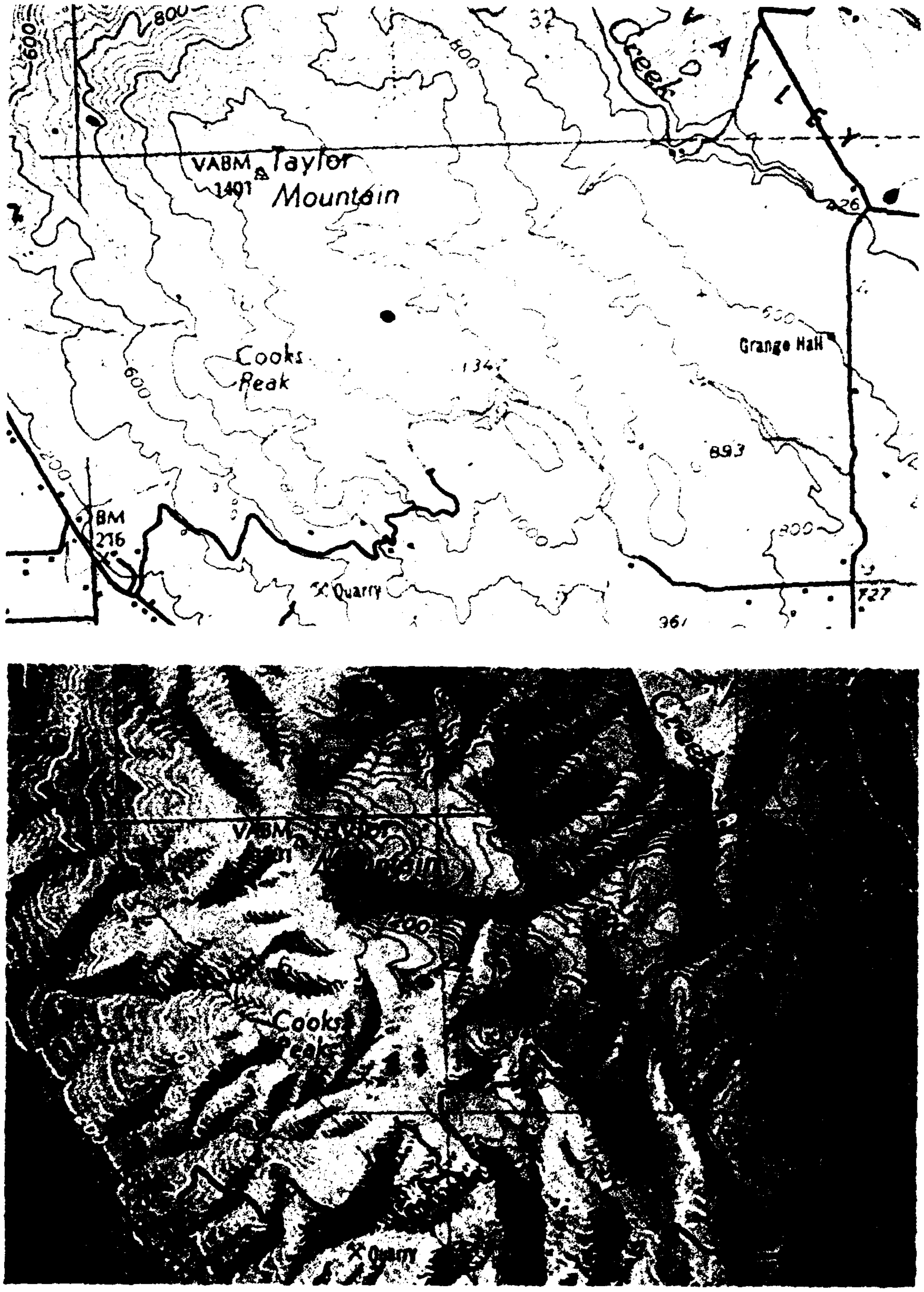


Figure 12. Standard and Tanaka contours on conventional USGS and prototype map of Santa Rosa, California. Detail of Taylor Mountain.

descriptive properties of slope zone tints (Figs. 13 and 14). Tints illustrate gradations of slope rather than gradations of elevation. The advantage of this type of slope zoning is that it describes the shape of terrain, but it does not reverse as does shaded relief.

Wright and Pauley (1971) consider slope zone maps useful for low altitude navigation because steepness of terrain is valuable information when locating position. They warn, however, that due to similarity in appearance to elevation tints, slope zones may be misinterpreted. Training will be necessary for users of slope zone maps if such a technique is adopted. But training is already recommended for low altitude aeronautical users; of slope zone maps if such a technique is adopted. But training is already recommended for low altitude aeronautical users; limited field of view and oblique viewing perspective cause frequent disorientation. Performance of helicopter users has been substantially improved by an Army-developed map interpretation and terrain analysis course (MITAC) (see Navy Domestic Technology Transfer Fact Sheet, May 1984).

Miller and Summerson (1960) describe the manual process of generating the slope zone maps shown in Figures 13 and 14. The process is tedious and does not tempt cartographers to employ slope zoning by manual means. Slope zoning is, however, easily implemented on digital terrain models using a computer; programs and algorithms are readily available.

DIGITAL TERRAIN CHARACTERISTIC MODELING

Four-color plastic hillshading as developed by Dutton (1982) would be a reasonable substitute for the Terrain Characteristic Tints currently employed by DMA on the ONC and the JNC. The process is surprisingly simple

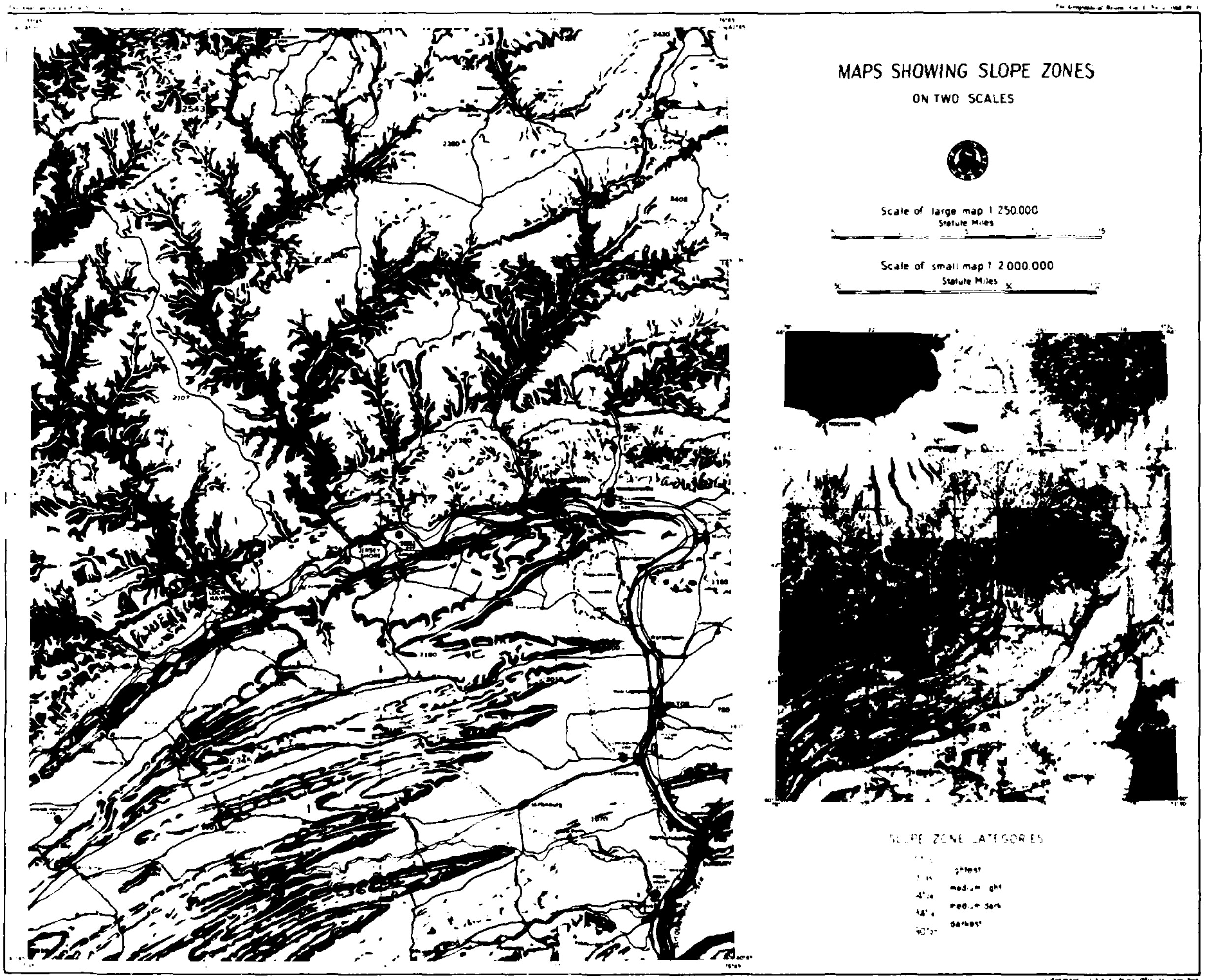


Figure 13. Slope zone maps (Miller and Summerson, 1960).

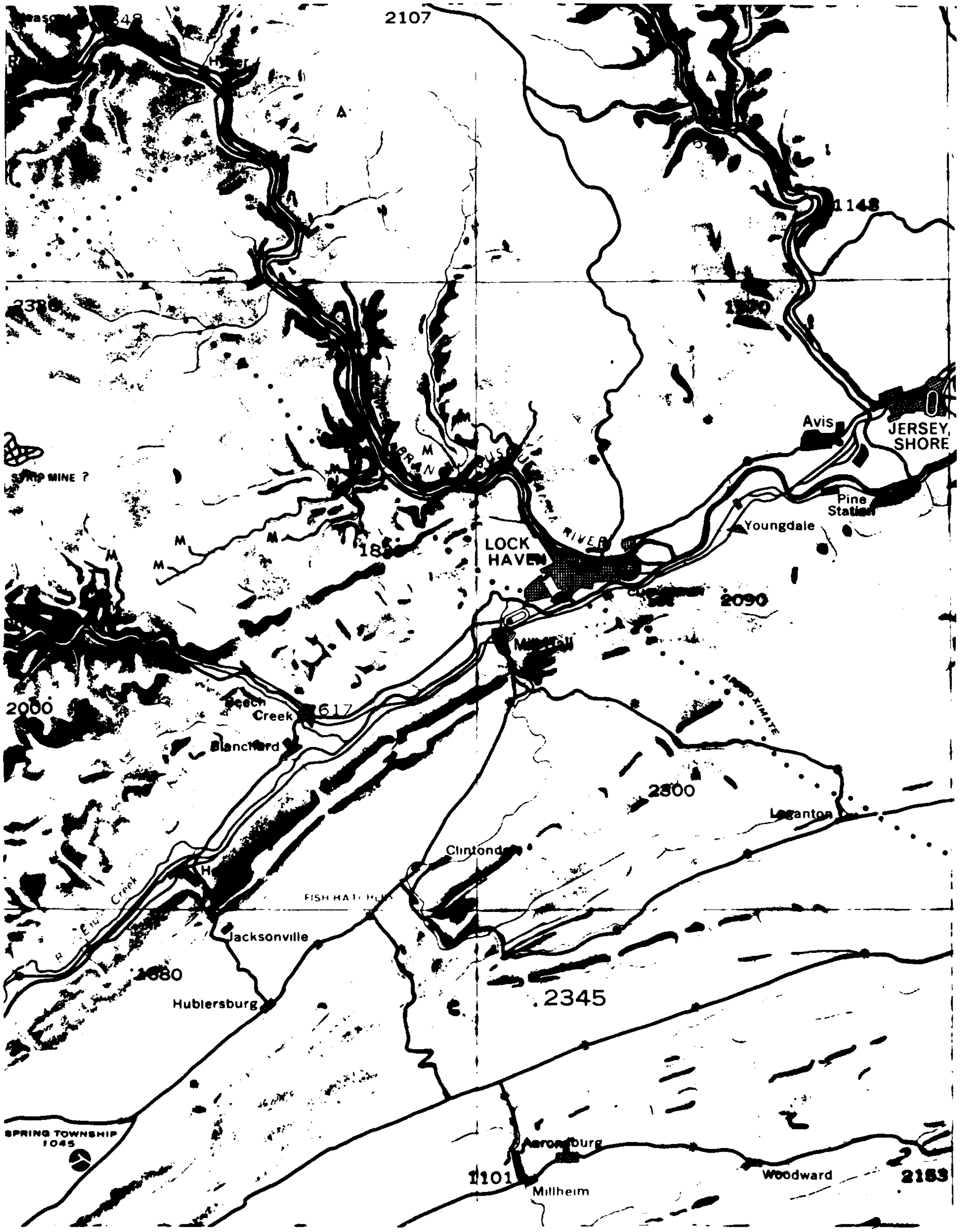


Figure 14. Enlarged slope zone map (Miller and Summerson, 1960).

considering the sophisticated outcome. Using a program called "Seurat," gridded elevation data is processed by four-pixel "quartets" in the following way: using four colors, the northwest pixel is assigned an intensity of one color based on its elevation; the southeast pixel is assigned an intensity of a different color based upon its aspect (or northwest reflectance); the northeast and southwest pixels are colored dependent upon their positive or negative slopes (Fig. 15).

NORTHWEST RED (elevation)	NORTHEAST BLUE (slope) or GREEN (flatness)
SOUTHWEST GREEN (flatness) or BLUE (slope)	SOUTHEAST YELLOW or WHITE (northwest reflectance)

Figure 15. Four-color hillshading pixel quartet. The color scheme used here resembles a spectral progression of layer tints with hillshading (Dutton, 1982). Color arrangements can be varied to control halftoning.

The four colors used to generate the effect of hillshading are selectable according to preference. Color separations can be produced by processing quartets in four stages, one pixel of each quartet for each color separation. Figure 16 shows an example of Dutton's four-color hillshading using the red, green, blue, and yellow combination described in Figure 15.

Most charts must display symbolic and textual information that would be obscured by the saturation of Dutton's example. Obviously, a less saturated color scheme would need to be developed if four-color hillshading is to become DMA's digital method of terrain characteristic modeling. Selecting an optimum color configuration could be performed interactively in softcopy, the additive colors later to be translated to their subtractive counterparts.

OTHER EXPERIMENTAL TERRAIN REPRESENTATION METHODS

Wright and Pauley (1971) present a group of experimental techniques for presenting relief/land cover. Although unstudied, each technique offers interesting possibilities for improved terrain representation.

- Vary the thickness of contour lines with elevation.
- Color code contour lines.
- Use only a narrow border of layer tint on each side of the contour line rather than tinting the entire area between contour lines.
- Stripe or crosshatch where relief tints and land cover tints overlap.

IMAGE MAPS

Digital imagery and digital elevation data can be merged and processed to serve as the terrain background for quick response and supplemental maps. The USGS and The National Geographic Society have produced handsome maps using mosaicked Landsat images. Depending on requirements, point and line feature symbols can be superimposed on the map. Recommendations arising from photomap design studies can be applied to the design of image maps.

Digital overlay allows a graphic merge of slope zones or Dutton's pixel quartets with land cover to provide a current pictorial view of the landscape. Image processing techniques should be developed that can automatically assign color schemes based on information to be shown, area of coverage, etc. Interactive experimentation will produce optimum color guides for such maps. Standard formats including margin layout and color codes will allow extremely rapid production of image maps.

16. Type and Digital Production

Placement, form, and design of type could, and arguably should, be affected by digital production. Of current research interest in the fields of cartography and typography are automating the process of type placement for both hard- and softcopy maps, and generating type fonts digitally. Manual type composition and placement require a disproportionate amount of production time as other processes are accelerated through automation.

Automated generalization of labeled features, automated composition of type, and automated type placement are essential processes to any computer mapping operation. Automation of type processes must keep pace with automation of other portions of map production or production lags. Electronic charting also requires automated generalization and placement of type if such advanced capabilities as interactive query and dynamic chart generation are to be implemented.

Figure 16. Four color hillshading of area in SW Switzerland. A gridded DTM of 220 rows and 200 columns is displayed at 512x480 resolution. (Dutton, 1982).

AUTOMATED TYPE PLACEMENT

Selecting named features for maps and placement of type upon maps are integral processes. Just as the approximate size of a feature symbol must be considered when deciding if there is map space in which to depict that feature, space available for placenames is largely determined by the arrangement of placename labels on a map.

An initial selection of named features is passed to type placement subroutines. Since placement algorithms tend to be complex, they must not be forced to work on intricate combinations of names that cannot possibly fit in the space available. Most currently proposed placement algorithms assume that the initial selection of placenames will be perfect, i.e. that space is available for each. But, without algorithms to continue the selection process throughout type placement a miscalculation in the initial selection of names prevents a final solution by the computer. The computer's solution is poor, and the analyst's burden consequently increases. Thus, the most successful methods of type placement integrate selection algorithms.

Automated type placement is an appealing research problem, attracting cartographers and computer scientists alike (Yoeli and Loon, 1972; Hirsch, 1980; Kelly, 1980; Lewis, 1982; Ahn and Freeman, 1983; Basoglu, 1983; Pfefferkorn, ESL, in prep.). As yet, no operational system of type placement is fully automated; all methods revert to interactive in editing of computer solution.

Type placement requires a control structure that virtually represents the map to the computer, algorithms for detecting and avoiding overlaps, and rules by which label positions are selected. Among the methods proposed to date are two general strategies: a label is placed only once, using a great deal of care to find a position that will not conflict with features or other labels; or labels are moved as conflicts are discovered until a solution is found. The first strategy requires imaginative use of a sturdy data structure. Quadtrees and graph structures have been used. The second strategy appears to be more flexible, but difficulties have been experienced with infinite looping due to inadequate parameters. The problem of type placement appears to fall into a class of graph problems for which no efficient solutions have been found.* Yet there is promise that a very high level of automation will be possible for type placement.

*Even (1979) includes optimal arrangement of components in his discussion of NP-Complete graph problems. NP-Complete problems are solvable, but no efficient algorithms for completion in polynomial time have yet been discovered.

On softcopy maps there is a tendency to place fewer names because of their adverse impact on legibility, and because many softcopy displays are linked to data bases that allow "what is there" types of queries. No proven adverse effects result from this trend.

DIGITAL TYPOGRAPHY

Chapter 2 reviewed findings that typeface variations on maps and charts are not helpful to mapreaders (variations in type size and type color, however, are useful). Research indicates that maps could be produced with no variation in typeface without harm to mapreading. It seems evident, however, that typeface variations on maps are here to stay. Digital typography offers an alternative to current methods of type storage and generation, and is discussed in the following paragraphs.

Storing digitized type fonts can be optimized by one of several compression methods. Run-length encoding is an effective means of compressing raster-encoded type. Spline encoding also reduces storage demands by storing only critical outline points, called spline knots, along with instructions for interpolating between the points. Elaborate curves can be interpolated to produce a highly accurate version of the original letter but the consequent increase in processing time must be considered.

Digital typographic design has evolved from spline-based letterforms. Several typographic systems store only a basic spline knot alphabet. Letters of this generic alphabet are manipulated by the computer to generate a wide variety of fonts. Contours of each letter can be scaled up, scaled down, and stretched. The Ikarus system (developed by Peter Karow of URW Unternehmensberatung in Hamburg) can compress or expand letters without altering stroke width (Fig. 17a); automatically correct the font design for different printing sizes (Fig. 17b) smoothly interpolate from one font to another—in Figure 17c the "a" at left is Bembo, the "a" at right is Helvetica Black, and the four "a's" between were generated by the Ikarus program. There are other spline-based systems: FRED (Patrick Baudelaire, Palo Alto Research Center, Xerox Corp.); a system based on spiral curves (Peter Purdy and Ronald McIntosh of Purdy and McIntosh, Watford, England); and ELF, based on ductal principles (David Kindersley and Neil Wiseman, University of Cambridge).

Metafont (Knuth, 1982) is a digital type system that generates type through pen stroke instructions. Virtual pen nibs are defined and are interchangeable on command; their strokes are calculated by the computer. Parameters of the virtual pen include stroke width, tip shape, angle

PREVIOUS PAGE IS BLANK

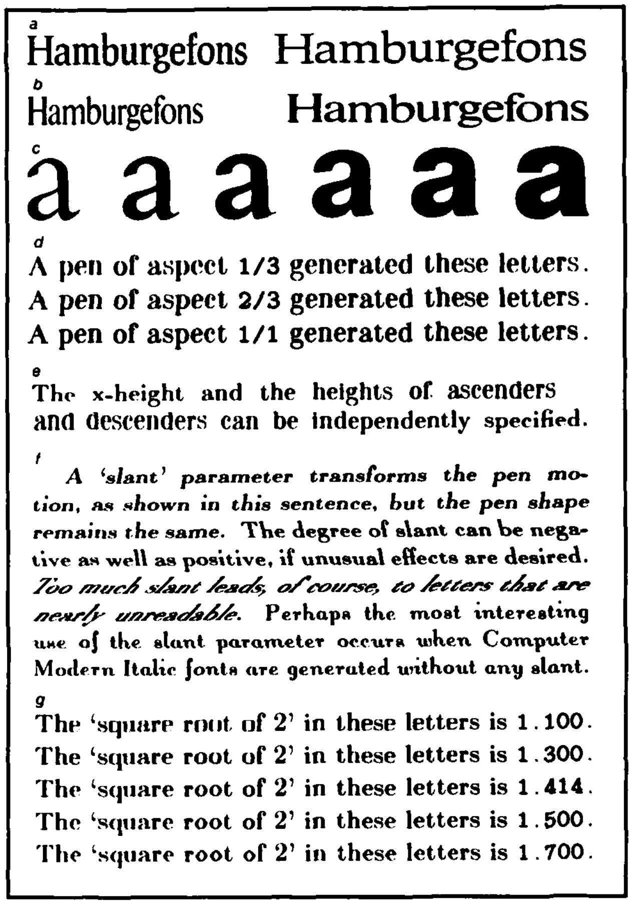


Figure 17. Digital letterforms produced by the Ikarus and Metafont systems (Bigelow and Day, 1983).

with respect to the page, etc. In Figure 17d the pen tip is an ellipse whose aspect ratio (ratio of the vertical to the horizontal axis) is as specified. Parameters of the letterform generated from the letter skeleton include slant, italic, curvature, etc. Presently the system is based on pen strokes (a ductal system); under development is an upgrade to Metafont that describes letterforms according to glyptal (engraving) methods. Figures 17e, 17f, and 17g show examples of letterforms generated by Metafont.

To date, digital type is judged by the extent to which it resembles ductal or glyptal type. It is predicted that new letterforms, suited to digital techniques, will be designed. Also predicted are advances in the study of visual perception that will stimulate design of type. Such improvements will enhance the speed and efficiency of reading, leading to characteristically digital letterforms that will add to the repertoire of letterforms produced during the ductal and glyptal eras (Bigelow and Day, 1983).

17. Automated Generalization

Generalization is a two-part process: selection and simplification. During selection, features are chosen to appear on the particular product based on their usefulness to the application. Entire classes of features may be rejected outright. Or, within a feature class only the most important might appear on the map. Selection algorithms, whether applied by human or by computer, must determine a hierarchy of feature importance.

Simplification occurs at all scales other than 1:1, the extent is based on the scale of the map. It is wasteful to process more coordinate points than are meaningful at a given resolution; thus, simplification algorithms have been developed to reduce data points to a coarser resolution. Features that are mapped areally at one scale are reduced to point symbols at a smaller scale.

PROBLEMS WITH MANUAL GENERALIZATION

Extensive research has been devoted to automated generalization in the interest of deriving a small scale map from large scale maps of the corresponding area. Most researchers begin by analyzing the manual generalization process before attempting to duplicate it digitally. Alternatively, researchers may judge the merits of an automated generalization technique by comparing its product to one that has been generalized manually. Yet the results of manual generalizations, especially with respect to feature selection, are far from ideal. Cartographers suffer from a universal temptation to overload maps and charts with features. Some examples of this problem at DMA can be drawn from JOGs that have been rendered nearly illegible by clutter.

A second difficulty with manual generalization is maintaining consistency. Inconsistency is a problem on a single chart or on neighboring charts. Charts are often compiled in pieces, a different cartographer responsible for each section. Due to individual interpretations of product specifications, the density of information across the chart (or chart series) can vary without regard to real-world distributions. Although anomalies are smoothed in the final stage of compilation, it is to be expected that some escape to confuse users. A similar problem can occur on neighboring charts of the same series.

Maintaining a consistent selection of features is also a problem on charts of the same area but different scales. Mapreaders are puzzled when a feature shown on a small scale chart is not also shown on a large scale chart of the same area. The mapreader is forced to compare compilation dates and somehow draw his own conclusions as to the existence of the feature.

Criticizing human decisions does not imply that introducing a computer will provide a blanket solution. It does imply, however, that automated generalization procedures should not necessarily be modeled on manual procedures. If flaws are detected in the results of a computer's compilation efforts, the flaws' seriousness should be considered relative to the current set of flaws. After contemplating the perils of clutter discussed in Chapter 4, any crimes of omission induced by a digital process seem mild when compared to the risks of using a chart illegibly blanketed with "landmarks."

Concise, uniform instructions for feature selection and generalization must be formulated before the process is automated. Most users agree that clutter makes maps ugly and difficult to use. From this tenet, appropriate restraints in product specifications must be enacted to prevent clutter. When these are firmly determined, they are available not only to programmers to be translated to computer instructions, but are also available to the users of map and chart products so they will be aware of the decisions made in selecting content.

SELECTION OF SETTLEMENTS

A revealing illustration of the preceding discussion can be found by analyzing proposed techniques for automatically selecting settlements from a data base to be shown on maps. Because a cartographer relies on geographic knowledge of the mapped area to select a subset of the most important regional settlements from the set of all settlements, several researchers have suggested imitating this process via computer (Kadmon, 1972; Stenhouse, 1979). A data base of the settlements is constructed. Then, an algorithm is devised to weight and compute the importance of each of the attributes shown in the data base. Kadmon's method requires 16 attributes for each settlement to be stored in the data base, including presence of a post office, location on the transportation network, and economic indices. Stenhouse groups settlements into four groups, depending on social and economic differences.

Using such a data base is intended to mimic the cartographer's geographic knowledge. Both methods attempt to incorporate an awareness of space and location—Kadmon by including an "isolation factor" to use as a weight, and Stenhouse through Topfer's Radical Law (Topfer and Pillewizer, 1966). The Radical Law (or The Law of Selection) describes the relationship of original map content to derived map content based on the square root of the ratio of the two scales:

$$N^n = N^o \sqrt{S^o/S^n},$$

where S^o and S^n are the old map scale and the new map scale, respectively, and N^o and N^n are the number of map elements contained on the old map and the new map.

Yet forcing the computer to imitate a human decision process fails in several ways. First, and worst, the distributions selected by these procedures appear arbitrary when viewed on a map. Mapreaders cannot be expected to decode all the importance factors used by either method. Also, such descriptive methods of determining settlement importance ignore quantitative research in geography that has produced and validated models relating settlement importance to population and area of influence.

A cartographer may use qualitative judgments based on familiarity with an area to select important settlements; this is the technique best suited to human capabilities. Computers, however, easily work with mathematical models. Constructing a data base to allow a computer to process information as humans do is, in this case, a poor use of resources. With data bases already threatening to exceed the gigabyte range, further data collection and expansion is cause for alarm.

Algorithms exist to select settlements based on population and location alone. All have been proven to produce a selection of settlements that compares well to distributions selected by a cartographer. Poiker (then Peucker, 1973) designed an assortment of this type of algorithm. The first draws an imaginary circle around each town whose radius is inversely proportional to the population of that town. Thus, a small town has a large radius and a large town has a small radius. No other town may intrude into the area of this circle. Settlement density is controlled by an exponent "a." The selection process begins with the largest settlement, adding to it the other settlements one by one, largest to smallest, which do not fall within the radii of any of the previously selected settlements. The formula used to compute radii is as follows:

$$\textit{radius (I)} = \left(\frac{\textit{reference city population}}{\textit{population (I)}}\right)^a * \textit{reference radius}$$

A second Poiker technique uses the Nearest Neighbor Index (R), normally used to estimate clustering or dispersion processes in a distribution, to select an appropriate areal distribution of settlements. R is computed for the five largest settlements, and recomputed as settlements are added to the distribution in order of decreasing size. A decrease in R denotes increased clustering; hence, a settlement is selected only if its introduction to the distribution increases or causes no change to R.

Poiker incorporated the geographer's gravity model into his third technique. The gravity model states that the influence of a settlement is measured by the following ratio:

$$influence\ (I) = \frac{size\ (I)}{p\ (distance\ (I))}$$

where $p\ (distance\ (I)) = (1 + distance\ (I) / alpha^2)$, alpha being the distance where size is halved. As with the other techniques, settlements are processed from largest to smallest; the influence of each is computed and then added to the sum of those previously processed. A settlement is selected if its population exceeds the summation of influence (I).

Topfer's Radical Law was implemented by Poiker to select settlements on maps, one segment at a time (segments determined by political boundaries or arbitrary partitioning). This technique is relatively less successful than the previous three. A second technique that works on map segments was proposed by Langran (then Lewis, 1982). A maximum density of settlements/cell is established and the map is processed cell by cell, the cells with the largest populations being processed first. A cell exceeding the maximum density can "credit" its overflow to surrounding cells until they, too, reach their maximum density or until a "credit limit" is reached. At this time, settlements must be deleted from the cell group.

The common thread connecting the techniques described above is their sole reliance on importance and location. Aside from the theoretical integrity of such an approach, it is the only practical means by which DMA can automatically select settlements for maps and charts in the near future.

OTHER POINT FEATURE SELECTION

Point features other than settlements are, for the most part, nominal rather than ordinal in value. Thus, inclusion on the map is dictated by product specifications and the computer can easily handle the decision. The exception is when a feature of a given category is to be included only if it will serve as a landmark. This concept is not fully defined and does not appear to be wholly mastered, even by current compilers. The human decision process uses reason—visibility, landmark value—strongly tinged with trepidation over the consequences of omitting the feature. The logical portion of the process is amenable to automation.

LINE FEATURE SELECTION

Line feature selection appears complex, but this, too, is amenable to automation. Rules for selecting the transportation network are related to importance, a concept easily conveyed algorithmically. Upper reaches of streams must be successively deleted as scale is reduced. In both cases the exact requirements for transportation and drainage networks on each product should be reexamined; aircrews have complained about roads with minimal navigational or orientational utility being included on aeronautical charts. Although some work will be required to establish automated methods for line selection, the problem is tractable.

SELECTION BY VISIBILITY

Feature visibility plays a major role in the selection process. A technique useful in selecting features for aeronautical charts based on visibility criteria was proposed by Waters and Orlansky (1951). Data on human vision was combined with meteorological range and the sky-to-ground brightness ratio to predict whether or not a feature of given size and contrast would be visible at a given altitude. Miller (1957) also developed formulas for selecting aeronautical chart features that made visibility a function of size, contrast, shape of feature, and meteorological conditions.

Disadvantages at the time of these experiments included lack of data: some of the information required for the formulas was not commonly available to cartographers. Data availability is less of a problem today, and digital format makes feasible rapid processing of such selection techniques. Supplementing visibility formulas with strong spatial constraints to avoid clutter is crucial; Miller's formulas selected more information than could be shown on a chart. Selecting features visible on scanned air photos or Landsat imagery is an appropriate way to choose content for aeronautical charts, since content is based on visibility from above. Algorithms determining resolution of features at given altitudes should not be difficult to design.

Criteria other than visibility would be required for selecting the content of topographic and hydrographic products, since visibility from above is not a major priority. Digital imagery can still play a useful role, however. Areal extent of a feature is always an important consideration.

AREA-TO-POINT OR AREA-TO-LINE SIMPLIFICATION

As scale is reduced, many features shown as areas must eventually be symbolized as points or lines. Settlements, airports, islands, lakes, rivers, and buildings, often area features on large scale maps, can become point or line features at smaller scales. Areal tolerances guide this transformation.

LINE SIMPLIFICATION

Assorted procedures are used to generalize lines. Early methods simply included every nth point, or computed a point at every nth distance along the line. The Douglas-Peucker method (1973) is employed by most cartographers, because it retains extreme points and produces a generalized line that closely resembles the ungeneralized line. Dettori and Falcidieno (1982) introduced a similar method that decreases computing time while producing good results.

Generalizing lines on maps ultimately affects line position. Displacement of one line segment can cause such peculiar effects as a railroad station far from the track, or a dock not meeting the coastline. Line simplification algorithms must incorporate logic to prevent inadvertent displacement of related features. Line simplification algorithms must also incorporate displacement algorithms; eliminating a point can cause overlap between neighboring features that did not previously exist.

Current automated line generalization techniques do not consider characteristics of the feature depicted by the line. Yet traditionally when a cartographer generalizes a coastline he/she attempts to show, by sinuosity, angularity, or irregularity, the type of landform it represents. A good cartographer can convey that a coastline is an estuary, a fiord, or a delta through linework alone. Buttenfield (1984) is working on recognizing coastal features by deriving a "spectral signature" from their point patterns as a first step toward improving automated line generalizations.

18. Recommendations for Multiproduct Operations

The time saved through automated production methods is nominal unless maps and charts are generated from data bases using common operations to select, simplify, symbolize, and reproduce. The most striking time and cost savings are realized by a comprehensive digital method of generating an entire product line. If data has been digitally transformed in one way for one chart, efficiency dictates that the same transformation not be performed a second time on the same data for another chart. Thus, generalization (i.e., selection and simplification) is performed to the extent possible on a data set generalized to the specifications of the next larger scale in the DMA product line.

To consider a data base methodology by which a map of 1:12,500 and also a chart of 1:5,000,000 can be compiled is to recognize the complexity of DMA's future auto-carto production problems. Regardless of when such a data base is developed, it is important to design an auto-carto strategy today that can accommodate such an ideal so future obstacles are genuine and not trivialities arising from poor design and lack of foresight.

This chapter discusses multiproduct operations using a hypothetical data base with 1:50,000 resolution to derive products at 1:50,000, 1:100,000, 1:500,000, 1:1,000,000, 1:2,000,000, and 1:5,000,000 successively. Using this strategy, City Graphics at 1:12,500 scale would be compiled from a separately maintained data base. Alternatively, one data base could serve both City Graphics and the 1:50,000 scale topographic product, with all smaller scale products sharing a separate data base. The objective is not to contemplate data base design, but to imagine such a data base exists and walk through product derivation from the data base. In this way one can foresee ways to gain efficiency and cost savings by product redesign.

SCHEDULING

The most logical way to approach multiproduct operations is to process one geographical area at a time, beginning at the largest scale of mapping and deriving progressively down to the smallest scale (Fig. 18). The process of product derivation can be visualized as traveling backward through a quadtree, from children to parents. Thus, product compilation from a data base is synonymous with hierarchical product derivation stemming from the data base.

It appears at first glance that it will take an exceedingly long time before a GNC (1:5,000,000) is derived due to the sheer number of topographic maps (1:50,000) needed for areal coverage. However, compilation is the only process that must occur hierarchically; once features in a product dataset are selected and simplified, that dataset can be labeled and stored. Further processing of derived datasets is dictated by a production schedule independent of the derivation schedule.

COMPILATION AND GENERALIZATION

The largest scale map in the product hierarchy is compiled from the data base first. All features and their

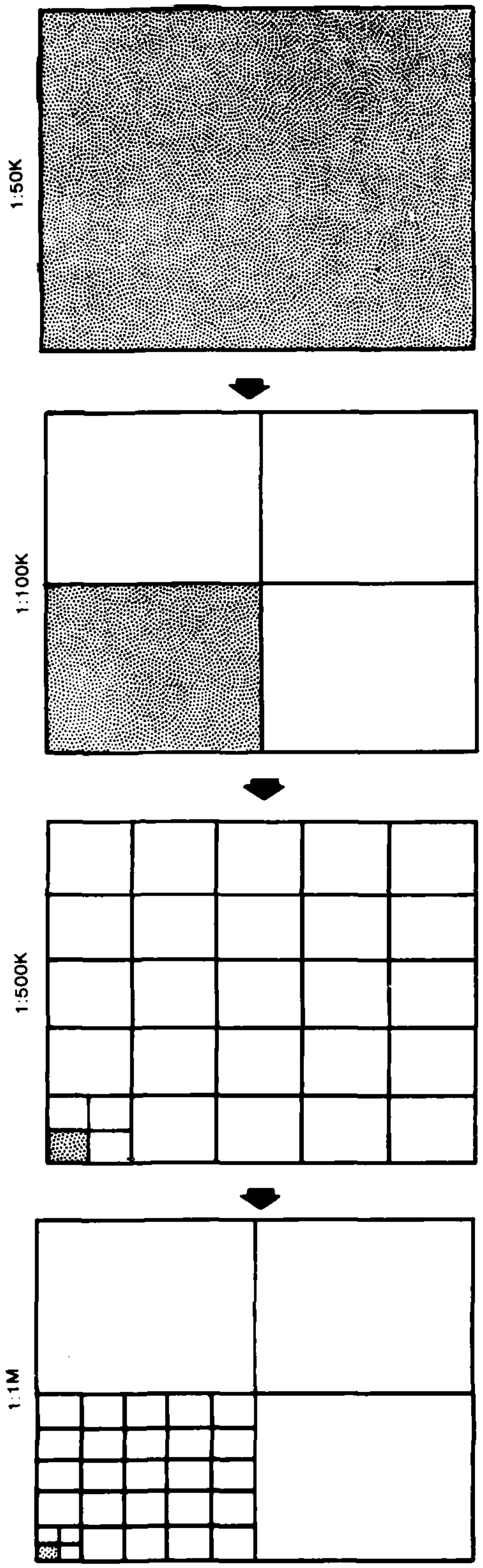


Figure 18. Mosaicked feature files for multiproduct derivation. JNC and GNC cannot be directly mosaicked. Instead they are pieced from saved datasets.

attributes falling in the area covered by the map are copied to a workfile.

Generalization of a compiled dataset is a team effort between batch computer decisions and an analyst equipped with a graphic workstation. Computer decisions use a set of coded rules for that particular product to control parameters for selection and simplification algorithms. The computer compilation is displayed at the workstation by referencing a symbol table for that particular product and matching features to their symbols. Features eliminated by the computer are flagged (but not purged) and may be recalled by the analyst if needed. Analyst decisions override the computer compilation.

Selection occurs first. Some features are eliminated entirely. Next, a subset is selected, in keeping with the map scale, from feature groups such as settlements or streams. Concurrent with the process of simplification are such functions as type placement and feature displacement that affect the space available in a given area.

Simplifying selected features is the second portion of the two-part generalization process. The outlines of linear and areal features are simplified to a coarser resolution. Gridded data is thinned; density of data points will eventually exceed the limits of resolution. If contour lines are not shown on small scale products, gridded terrain elevation data can eventually be thinned considerably.

Product derivation

The compiled dataset at this stage consists of features (attributes and coordinates), data structures, pointers to symbol tables, direction of symbol displacement (if applicable) and position of type. As schedule permits, production may continue through the final product, or the dataset may be archived to be completed later.

The dataset is digitally mosaicked with neighboring datasets that have been compiled to the same scale. The mosaic eventually covers the area of the next smaller scale product, the "parent." The process of generalization is repeated, this time using a new set of coded rules and a new symbol table for product compilation.

This method of product derivation encourages efficiency in several ways. Simplification algorithms operate on progressively fewer points. Selection algorithms, too, benefit from the lessened load. Direction of symbol displacement and type placement will frequently be unchanged from one scale to the next. If symbol tables are derived one from the other, pointers to symbol tables do not need to be changed (see next heading).

Depending on the extent of human interaction, a GNC dataset is derived from its constituent 1:50,000 topographic map datasets in a matter of weeks or months. The amount of time required to compile a small scale product can be decreased by skipping interim compilations of larger scale products. Instead, the computer is equipped with coded rules for compiling the smaller scale chart at the onset of compilation, bypassing intermediate scale products. Although this method is faster, efficiency is lost, as discussed in the previous paragraph.

Data resolution will, of necessity, vary by area in any data base with world-wide coverage used for automated cartography. A production scheme must include provisions for spotty coverage in an area. It must also be capable of either refusing to map at a scale for which there is insufficient data resolution, or be capable of symbolizing or annotating in such a way that poor coverage of an area by the data base is evident.

Compilation is not a continuous reduction of content from large scale to small scale. At some stages features are added. For example, topographic maps do not print extensive air navigation data. These data are reserved until needed.

A suggested alternative to the algorithmic/hierarchical method of product compilation described here is to permanently flag features in the data base that would appear at each product scale. Flags that dictate selection or rejection of a feature for a given product are, in this case, stored in feature records. This method of product compilation is not recommended. It is inflexible: changes in product specifications require changes to the data base. It would considerably complicate maintaining the data base: the content of the data base constantly evolves. And, it is an inefficient and redundant use of space: compilation can easily be handled algorithmically.

Symbol derivation

Derivation of product symbol tables, one from the other, was mentioned under the previous heading. Time and money can be saved by carefully considering all symbol sets used by standard DMA products, and by standardizing them across product series to the extent possible. Chapter 9 pointed out the inconsistencies between the level of detail allowed by product symbol sets and the scale of the products themselves. A hierarchy of symbol sets should be developed that represents a smooth and logical progression of detail on each product. Whenever possible, a symbol should not change from one product to another unless its role and importance to the user also changes significantly.

Hierarchically organized symbol tables will promote efficiency. DMA products will begin as digital datasets derived from the mosaicked datasets of the next larger scale products. During compilation, pointers are set from features in a dataset to their appropriate symbols in a symbol table. Thus, initially a derived product contains the pointers of the component datasets. Efficiency is gained if pointer movement is minimized.

Rather than reassigning all the symbol pointers to the derived product's symbol table, hierarchically nested symbol tables obviate moving symbol pointers of features whose derived feature symbol is unchanged. When symbols differ between original and derived products, the new version of the symbol replaces the previous version in the table and the pointer is untouched. When a feature is no longer symbolized on a derived product, the space in the table occupied by the original product's symbol remains unfilled. When a new chart feature is symbolized on the derived product (such as electronic navaids on small scale aeronautical charts) it can either be inserted in an empty spot in the symbol table or added to the bottom. A compact symbol table is not especially important; greatest efficiency comes from minimizing pointer transactions.

FEATURE SEPARATION

Mapped data is easier to manipulate when separation is by feature as well as by color. When feature separations are available, data are easily recaptured by scan digitizing; to recapture features from scanned color separations often requires editing. Feature separation makes compiling special-purpose maps easier, if separations are available from standard maps.

Feature separation could be instrumental in adapting a single product format to multiple users. Many of the JOG's problems (see Chapter 22) could be solved by selecting different color schemes for the JOG-A and JOG-G, and by using only applicable feature separations according to air and ground user requirements. Separation by feature is recommended for the proposed 1:100,000 ground/air product. Table 10 shows a feature separation scheme developed by the USGS.

DIGITAL MASKING

A technique to mask between separations using a positive mask made from a composite of plates was developed by the USGS. For example, a composite positive of road plates, for example, can be used to break streams, contour lines, and vegetation symbols.

Table 10. Experimental content separation scheme used by USGS (includes percentage screen values of mezzotint random pattern screens) (Gilman, 1983).

Positives	Negatives (Film, scribed, or peelcoat)		Combined film Negatives
Black lettering	Lettering and patterns	100%	
Black patterns	Format	100%	
	Principal culture	100%	
	Secondary culture	60%	Black
	*Principal highways	40%	
	Secondary routes	40%	
	Urban areas	10%	
Red lettering	Lettering	100%	
Land surveys lettering	Land surveys lettering	60%	
	*Principal highways	100%	Red
	Land surveys	60%	
	Corporate boundary banding	40%	
Contour numbers	Contour numbers	100%	
Contour numbers mask	Index contours	100%	
	Intermediate contours	100%	
	Supplementary contours	60%	
	Miscellaneous features	60% (?)	Brown
	Boundary banding	40%	
	Intricate surface areas	40%	
	Gravel		
	Sand		
Blue lettering	Blue lettering	100%	
	Principal drainage	100%	
	Marsh and swamp	100%	
	Mangrove swamp	100%	
	Miscellaneous patterns	100%	Blue
	Open water areas	20%	
	Intermittent fill	20%	
	Controlled inundation	20%	
	*Woodland	40%	
	*Green patterns	40%	
	Boundary banding	100%	
	Cemeteries and parks	60%	
	*Woodland	60%	Yellow
	*Green patterns	60%	
	Base tint	10%	

*A single negative used to print 2 colors

Digital masking performs the same operations using virtual (digital) plates. Mask features (this time, for example, digitized roads) are composited into a bit map that is subtracted from other virtual plates (digitized streams, contour lines, etc.).

19. Softcopy Display and Electronic Charts

There are different design constraints for maps and charts displayed on softcopy devices. Constraints on softcopy display are related to generally lower resolution and differences in perception related to light being transmitted rather than reflected. Standardizing softcopy displays is constrained by the multitude of individual variations among display devices, even among the same types of devices, in resolution, brightness, color reproduction, display size, and display controls.

Some softcopy maps and charts are also electronic maps and charts. Electronic charts are defined here as softcopy displays that are dynamically generated from a data base. Electronic charts can be interactively queried; components of their display are controlled by user commands. Electronic maps and charts afford interesting new design potential. This chapter summarizes differences in the display of graphics on hardcopy and softcopy media and describes new techniques offered by electronic maps and charts.

CONSTRAINTS ON SOFTCOPY MAP DESIGN

Irradiation effect

The tendency of a light image on a dark background to appear larger than a dark image on a light background is stronger when the image is directly transmitting rather than reflecting or refracting light (Greenberg, 1971). The brightness level of both the symbol and the background are major contributors to the phenomenon, as are the colors of the symbol and the background. The irradiation effect is of concern in the perception of line widths, point symbol sizes, and the selection of map colors.

The irradiation effect can be used to advantage by producing maps that are light figure on a dark ground, which allows increased viewing distance (see Fig. 19) even when line weight is decreased.* Clutter, too, seems to be a lesser problem when the brightness of the background is reduced; the dark background appears "quieter." Dark adaptation is preserved when the figure is light against a dark background because there is less light reflected in the eyes of the viewer. Where light is displayed on dark the irradiation effect is the reverse of dark on light. In this case, the symbolic parameters normally used for a dark-on-light display must be evaluated, including stroke width of type. An experimental black map for softcopy display is shown in Chapter 6—Clutter.

Greenberg (1971) suggests the constructive use of irradiation effects when designing maps that depict low-value/high-value phenomena such as surface/subsurface profiles, summer/winter transportation routes, or day/night contrasts. Empirical research is needed to determine and verify such psychophysical variables as perceived symbol size, given background contrast.

Perception of color

With the exception of images in short wavelength colors (blues) no known difference in the perceived acuity among different colors is produced by the subtractive process used in hardcopy production. This is not so in softcopy display, mainly due to irradiation.

Colors produced by the additive process used in softcopy display appear to be perceived with varying degrees of comfort by viewers. In particular, prolonged viewing

*A great deal of applicable work was intended to evaluate the readability of license plates at night (Case et al., 1952; Allen and Straub, 1955; Karmeir, 1960; Herrington, 1960).

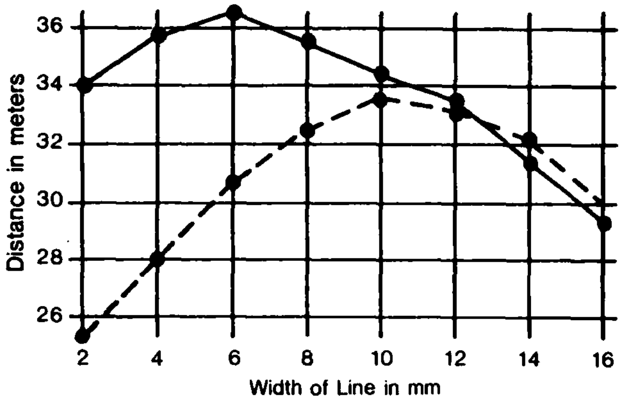


Figure 19. Influences of line-width and background on recognition distance. From Greenberg (1971).

(over 20 min) of only one color can cause temporary physiological problems, explaining the pink tones seen by green-screen users after terminal sessions.

Color has little effect on the perception of symbol size on hardcopy media, but symbol size perception is affected by color on softcopy media (Dobson, 1983b). The size of a color symbol and the perception of its particular color determine the size perceived by the symbol viewer (Shurtleff, 1980). In a practical sense, the accuracy of estimating areas of colored symbols and filled regions on softcopy maps and charts is known to vary with the colors of both the target and the background; yet the exact nature of the variation is not known and may never be known.

Dobson (1983b) cites the following areas requiring research.

- The effect of various figure-ground color schemes upon the performance of specific mapreading tasks.
- The effect of redundantly color coding point symbols to optimize search on softcopy devices.
- The effect of increased display complexity on the search task.
- The effect of blinking, fading, moving, and other dynamic symbol alterations.

The difficulty of planning colors for softcopy displays is exacerbated by the variations in color reproduction from one display device to another. Especially in video devices and photographically reproduced films, there are individual spectral weaknesses that make uniform color specification impossible. Short of only using color redundantly, the cartographer cannot control this effect.

Low resolution

The legibility of symbols displayed on a softcopy map is directly affected by the resolution level of the display device. The resolution level of a video system is defined by the number of scan lines per millimeter measured in a vertical direction; digital system resolution is defined by the pixel size. In either case, high resolution can be obtained by using a low-resolution system to display a small portion of a map, or by using a high-resolution system.

Low-resolution displays are neither an absolute nor a permanent state of affairs; however, there will always be a tradeoff between processing time and resolution. Thus, readability of low-resolution displays is relevent now and in the future. At least 10-12 scan lines per symbol height are required for video display (Kosmider, 1966; Shurtleff and Owen, 1966; and Shurtleff, 1969) and a dot matrix of at least 7 x 9 dots is minimum. After comparing circular dots to oblong dots in a test of legibility on a phosphor CRT, Vartabedian (1971) stated that circular dots were superior for both reaction time and accuracy.

The effect of the video process (in which the screen raster is created by a single electron beam scanning rapidly from top to bottom) on image perception is said to depend upon the viewer's facility for psychological closure (Zettl, 1973). In studies regarding the effect of resolution on the legibility of alphanumerics, a minimum of eight raster lines per symbol height were found to be necessary for legibility (Hemingway and Erickson, 1969) and if time is critical, no fewer than 10 lines per symbol should be used (Shurtleff and Owen, 1966). The higher resolution afforded by more lines per symbol appears to improve subject performance, up to and including 16 lines per symbol (Baker and Nicholson, 1967; Wong and Yacoumelos, 1973).

Almost identical resolution requirements were discovered among seven families of type fonts* tested for television viewing; lower case letters have slightly higher resolution requirements. A minimum resolution of 4.5 lines/mm was needed for 6-point type (approximately 9.4 lines/symbol) (Wong and Yacoumelos, 1971).

The effect of the number of TV lines/mm on mapreading has been studied by Wong and Yacoumelos (1971 and 1973). Within the map itself, three factors were assumed to affect legibility: symbol size and shape, symbol color, and density of symbols. They concluded that a resolution of 8 TV lines/mm provides a very good display for line maps of all scales. High information density caused problems in identifying building types. Color coded symbols also caused problems due to low system response in the red range. When resolution was decreased to 6 lines/mm, size and shape became significant determining factors in symbol legibility. Most standard symbols became difficult to distinguish at this resolution (Wong and Yacoumelos, 1971).

NEW TECHNIQUES OFFERED BY ELECTRONIC CHARTING

Symbol dimensions

The major coding dimensions for symbols in a static mapping format are shape, color, and size. Symbols in a dynamic mapping environment can be caused to blink, twirl, fade, vibrate, etc. These effects must necessarily be kept to a minimum to prevent confusion; there are certain functions, however, that one or another of the above techniques can perform with great efficiency.

By causing a target subclass to blink at a 3-Hz rate, search time was found to decrease by 50% (Smith and Goodwin, 1971). Such visual separation can be exploited in electronic charting applications when a particular element is of target interest or when an event changes a real-time display. Surprisingly, however, subjects searching a display on which all elements were blinking exhibited no worse performance than subjects searching steady, nonblinking displays (Smith and Goodwin, 1971). In a follow-up test, subjects were asked to find errors in linear prose on a CRT screen. The average time required by subjects scanning a blinking display was 10% greater than the average time required by subjects scanning a steady display. Errors, too, were slightly higher for subjects using blinking displays, although the difference was not statistically significant. The authors felt that the discrepancy was because reading text is quite different from searching a geographically-oriented display, and that findings from the second study should not discourage the use of blinking symbols on displays but, rather, should serve as a caution (Smith and Goodwin, 1972).

Electronic maps or charts (dynamically generated from an underlying data base) do not always have to use standard symbols in displays. If the display is to be searched for occurrences of some variable, colors and shapes that provide maximum searchability can be used. Potential loss of iconicity is not a serious problem when symbol mean-

*Spartan Medium Italic, Century Schoolbook, News Gothic, Slope Gothic, Century Expanded, Monotonic Gothic, and Century Italic. Within each family all available point sizes were used, ranging from 6 to 48 points.

ing can be garnered from the data base. Anderson and Shapiro (1979) designed a symbol set for an electronic map that contains progressively more angles and sides, depending upon the importance of the feature (Fig. 20). Symbol displacement on dynamic displays can be indicated to the user by moving the symbol between its correct position and its displaced position.

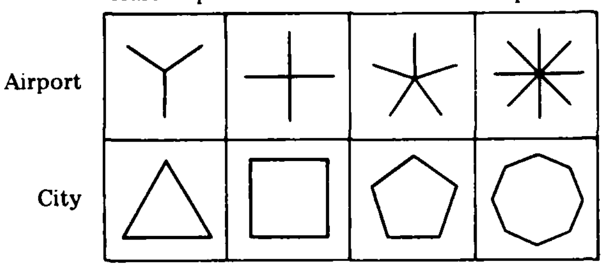


Figure 20. Relative symbology (Anderson and Shapiro, 1979).

Symbol clutter is controllable on electronic charts by several means. In a variation of the figure-ground method, unimportant feature symbols that provide only locational reference can progressively fade to emphasize important information. Data can be aggregated, and special purpose maps can be generated (Aumen, 1970).

Display techniques

Many techniques that are useful on electronic charts are not new, but have not been widely used because they are not practical for static media. Electronic charts make nonstandard displays available to the user as needed.

Reference grids are useful additions to displays. Electronic charts can generate virtually any kind of grid. Especially useful is the concentric circle grid described in Chapter 11. Although there is no practical way to include such a grid on hardcopy media, an interactive capability to center such a grid on an area or object of interest would be valuable to C^3I.

Perspective views of terrain are known to be extremely useful in terrain visualization, but viewpoint is critical. Electronic maps allow flexible viewing. Interaction with perspective views allows users to specify altitude, azimuth, and distance, as well as to zoom, pan, and rotate.

Terrain model presentation was studied by Rowles (1978). No significant difference was found in subject perception of relative elevation and relative distance when viewing altitude was changed from 15° to 75° (azimuth unchanged). Rowles concluded that mapreaders recognize the surface form and can compensate for distortions caused by the viewing angle.

Hyperbolic projection is an interesting technique suited to softcopy displays (Kadmon, 1975). The hyperbolic projection allows continuous display of a large geographic area when only a small portion is of special interest. The area is numerically transformed and distorted around the area of interest as if viewed through a fish-eye lens. The center of the fish eye is movable, producing a large scale map at the center of the fish eye that fades to a small scale map at the periphery. Thus, users can roam an area without losing geographic reference (Fig. 21).

Animation provides a way to show historical, predicted, or real-time changes in geographical state. Three examples of animation are the animated weather map; the map of the growth of Detroit (Tobler, University of Michigan, 1973); and a map of air traffic flow showing major U.S. airports as pillars whose height changes as planes arrive and depart (Dutton, Harvard Laboratory for Computer Graphics and Spatial Analysis, 1977).

Movie maps allow users to travel within a mapped area, zooming in for large scale information and zooming out for a bird's-eye view. Ciccone et al. (1978) produced a movie map that provided a tour of a fictional city using computer-generated, three-dimensional pictures. When comparing the spatial knowledge of subjects briefed with the movie map to those briefed with a traditional map, the movie map was found to have enhanced all major map performance skills including self-localization, knowledge of spatial relationships, and general topographic knowledge. The immediate applications recommended for movie maps were locale familiarization, maneuver aiding, and command coordination.

Electronic charting may introduce new approaches to mapping problems that have been virtually unsolvable on hardcopy media. One such problem is mapping several significant superimposed surfaces—for example, sea surface, ocean bottom, and objects in the intervening space; or concurrent and detailed depiction of air space, flight corridors, and terrain (Heath, 1967).

The results of predictive models and quantitative calculations performed by computer can be displayed on electronic charts. A route can be displayed that minimizes travel time subject to a set of constraints. Resources can be placed that minimize certain risks and exploit certain factors subject to a set of constraints. Time, distance, and most important, a wealth of stored geographic information too complex for adequate display in two dimensions can be factored into computations. Bolton and Tam (1974) describe a computer method for radar site selection. The

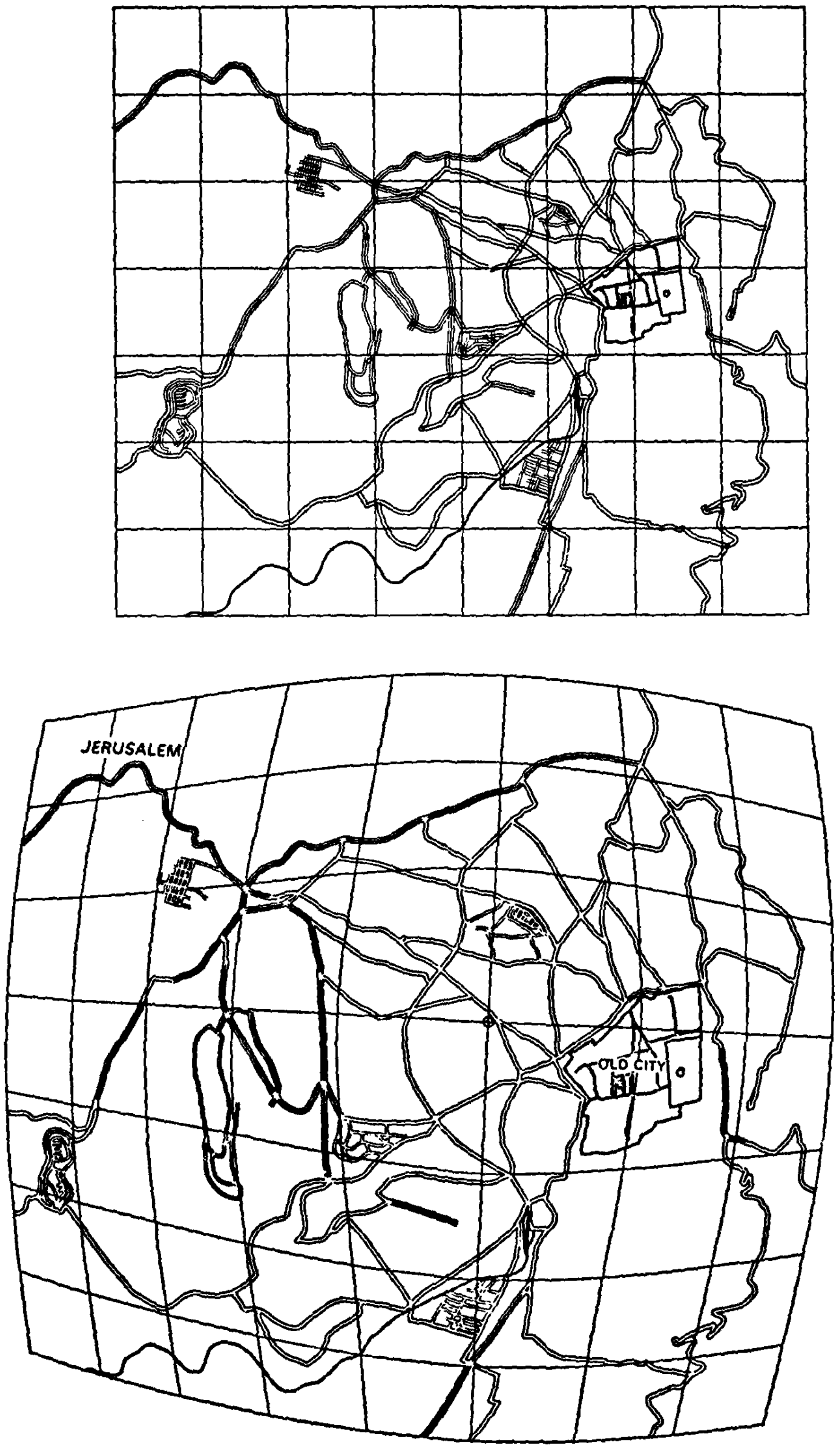


Figure 21. Hyperbolic projection (Kadmon, 1971).

computer can also be programmed to hypothesize hiding places and attack routes based on trafficability, vegetation, distance, etc.

SUMMARY

Softcopy display design is highly dependent upon the capabilities of the display device. Resolution determines symbol and letter sizes and designs. Both display devices and human factors affect color choice in softcopy display: color reproduction varies from one display device to another; and CRT displays produce color by an additive process that, combined with the irradiation effect, behaves unlike hardcopy color.

Electronic charting expands the possibilities for symbolization and display manipulation. Access to and interaction with a data base and exploitation of computational powers combine with dynamic and customized displays that provide customized presentations geared directly to user needs.

Applications to Existing DMA Maps and Charts

20. City Maps

The DMA City Graphic is intended for tactical operations, evacuation, intelligence, attache support, and training exercises. Its preferred scale is 1:25,000; deviations are allowed for well-defined reasons. The major fault of the DMA City Graphic observed by this study is in its use of color, which poorly serves the need to show streets and landmarks.

Research concerning city maps is discussed under the first heading in this chapter. Recommendations for improving the DMA City Graphic follow.

RESEARCH SUMMARY

City maps have been neglected by cartographic researchers. The diversity of cities inhibits extended evaluation. Individual areal extents, population densities, street patterns, and rates of change make setting a single standard for all city maps difficult.

Research, however, recommends optimum grid sizes and alternate grid shapes. Reference grids are instrumental to city maps. Color is also particularly important for city maps. All information cannot be equally prominent; features must be prioritized and colors assigned to emphasize or mute their symbols.

Grid size

As discussed in Chapter 11—Grids, the optimum size for a regular rectangular grid cell on a street map is 0.5 km^2. Coarser or finer grids increase search times.

Grid shape

Alternate grid shapes discussed in Chapter 11 include a landmark-based grid—an irregular rectangular grid whose cells are formed by quadrants surrounding major landmarks in cities, and a concentric circle grid—a grid centered on a point and divided by quadrants determined by compass divisions or hours on a clock face.

The landmark-based grid helps to orient map users to an area better than an artificial grid superimposed over the landscape and it also has been shown to improve user search times (Koleszar, 1981). The concentric circle grid offers similar benefits to those of the landmark-based grid: it, too, helps to familiarize users to relative locations in a city. It is also likely to produce improved mapreader search times. Yet the landmark-based grid could cause loss of efficiency in digital production, since landmarks around which the grid is constructed must be selected for each city individually and subjectively. The concentric circle grid has not been tested on mapreaders.

DMA's City Graphics currently show the MGRS/UTM grid in blue; the projection graticule is represented by black ticks in the margin. An additional grid could confuse mapreaders. Thus, recommendations for the DMA City Map will not incorporate a new grid until user requirements are identified.

Color

Several prototype city maps organize information and reduce clutter through careful use of color. Bartholomew and Kinniburgh (1973) compiled an experimental map of Edinburgh using a layered technique. The layered method separates information into visual planes rather than placing all information on the same plane. This method encourages perceptual organization according to the priorities awarded to each feature class.

To execute the layered method, first a hierarchy of important features was derived. Then, color and shape were used to encode each level of importance to map symbology on prioritized layers. The highest plane was reserved for street names, determined by the designers to be the most important information on the map. So that the highest plane might seem near the mapreader, black type in a clear, precise font was used. To maximize separation, all other fine linework on the map was minimized. The lowest plane showed areas of color representing land use. No outlines were used on the lowest plane for an indistinct and distant appearance. The lowest plane appeared to recede from the highest plane because of the contrast between bold names on the high plane and the pastel, recessive colors on the lower plane. The street pattern was formed by ribbons of white for maximum contrast with lettering. Items of interest were "raised" from the subdued background by symbolizing them in saturated colors.

Color helped to decrease clutter on a USGS experimental map of San Juan (Fig. 22). Built-up areas, which comprise the majority of map background on a city map, are gray rather than the customary pink. Commentary by users on the experimental design was enthusiastic; the map is attractive and easy to read.

The color scheme of the San Juan quad emphasizes a city map's most important features. Major roads are magenta. Minor roads are a gray tint, which contrasts adequately but not sharply with the gray tint of the built-up area. A darker gray tint is used for important buildings; only landmark buildings are black. Contour lines are brown. Boundaries are shown in brown and yellow bands. Green patterns (produced by overprinting blue on yellow) show vegetation. All hydrographic features, including bathymetry, are blue.

Recessive colors help another prototype city map to show an extremely high density of information without clutter. An experimental map of Casablanca, produced by the U.S. Army Engineering Topographic Laboratories (ETL) in 1974 (Fig. 23), uses a bivariate color scheme to detail characteristics of built-up areas. Structural type (masonry, reinforced concrete, wood, etc.) is represented by hue; building height (in stories) is represented by saturation. Because most buildings fell in the lowest height category, map colors are muted, avoiding a cluttered appearance.

All streets are gray on the Casablanca prototype, providing good but not startling contrast. Major thoroughfares are exaggerated in size and are colored a slightly darker gray. Streets are labeled within their bounds. Labels on major thoroughfares are placed within an open window of the same light gray as minor streets to highlight lettering. All type is dark gray, which makes landmarks hard to detect but contributes to an overall "quiet" appearance that belies the high density of information.

DMA CITY GRAPHICS

The experimental efforts discussed above deal with grid size, grid shape, and use of color to prioritize information. An experimental format, unlike that used in DMA City Graphics, was introduced in the Casablanca prototype. Grid, color, and format as they apply to DMA City Graphics are discussed under this heading.

Grid

As mentioned earlier, no change in the grid used on current DMA products is recommended at this time. Since grids are known to have an effect on map search, however, further research on grids for military users is encouraged. The landmark-based or the concentric circle grid systems could make major contributions to orienting mapreaders unfamiliar with city layouts.

It should be noted that the 1.0-km grid used by DMA is larger the 0.5-km size found to induce optimal search times, as discussed previously. This size difference is not felt to be a problem, since DMA City Graphics are not street maps per se; density of information is relatively low, and search is not the major mapreading task.

Color

If it is agreed that the information required from a city graphic is

- transportation network,
- landmark buildings,
- important buildings,
- general layout,

then the DMA City Graphic is not successfully presenting information in the required hierarchy. The street network is shown in the same brown used for contour lines and (screened) for sparse-to-medium development. The brown streets are thus confusable with the hypsography, and further become submerged in the red-brown tint of densely developed areas.

A complete overhaul of the City Graphic color scheme is recommended. The San Juan prototype discussed earlier uses an ideal color scheme for DMA City Graphics. Arterials and major buildings are highly prominent, yet the gray and blue tints that comprise the majority of the background give the map a quiet appearance. An informal poll at NORDA showed overwhelming preference for colors used on the San Juan prototype over those used on either the City Graphic or the Casablanca prototype. The only modification needed to the San Juan color scheme would be to incorporate gray levels showing three levels of development, as currently shown on DMA City Graphics.

Format

The format of the ETL Casablanca experimental map requires detailed data that may not be routinely available. The level of detail, too, may be unnecessary to users and would certainly outdate the map quickly. The design's handling of street labels is preferable to the current practice, but is incompatible with the San Juan prototype recommended as a design model for the DMA. The possibility of incorporating the street-labeling method used

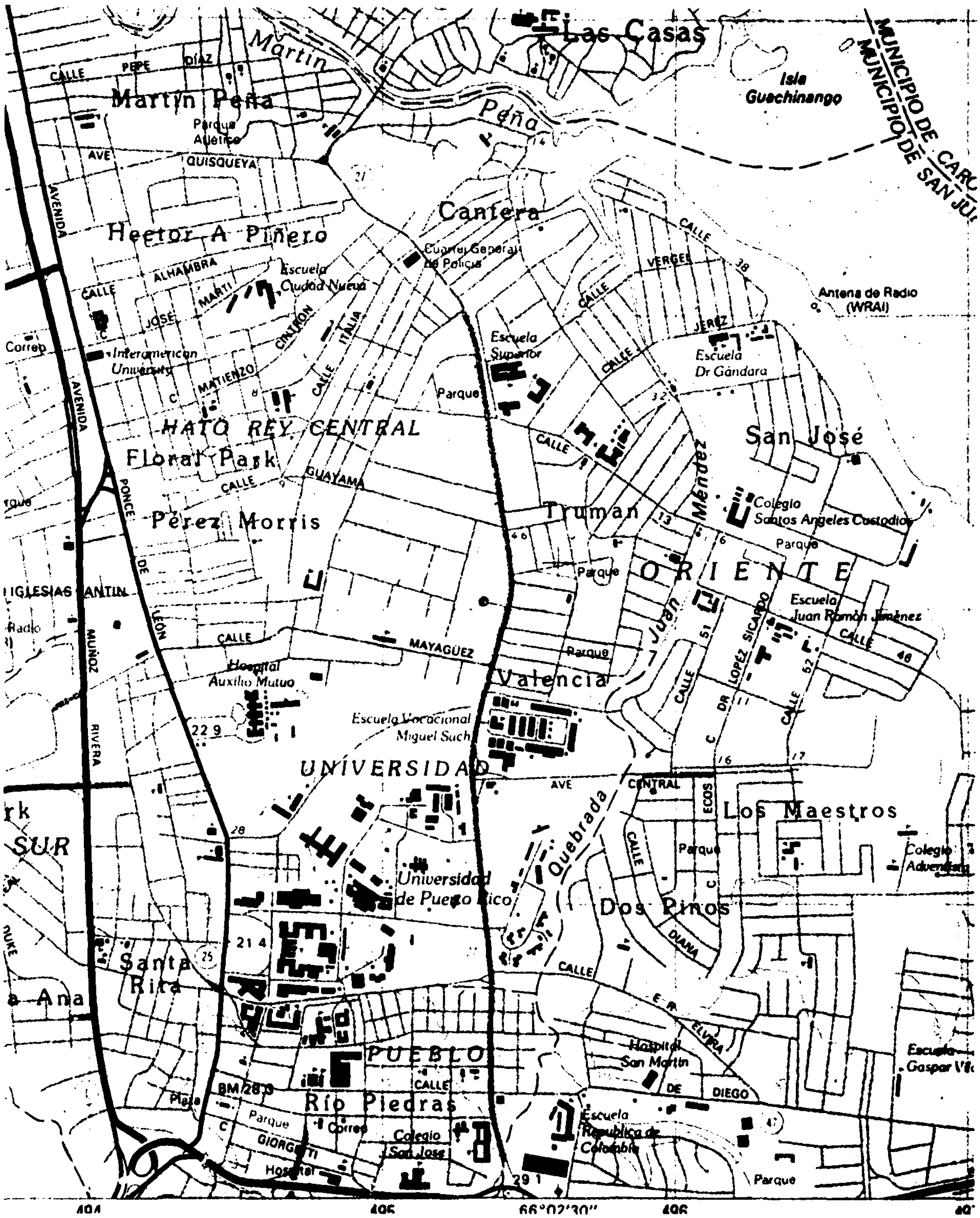


Figure 22. San Juan prototype by the USGS, 1969. 1:20,000. Random mezzotint screens and process printing are used to encourage efficient production.

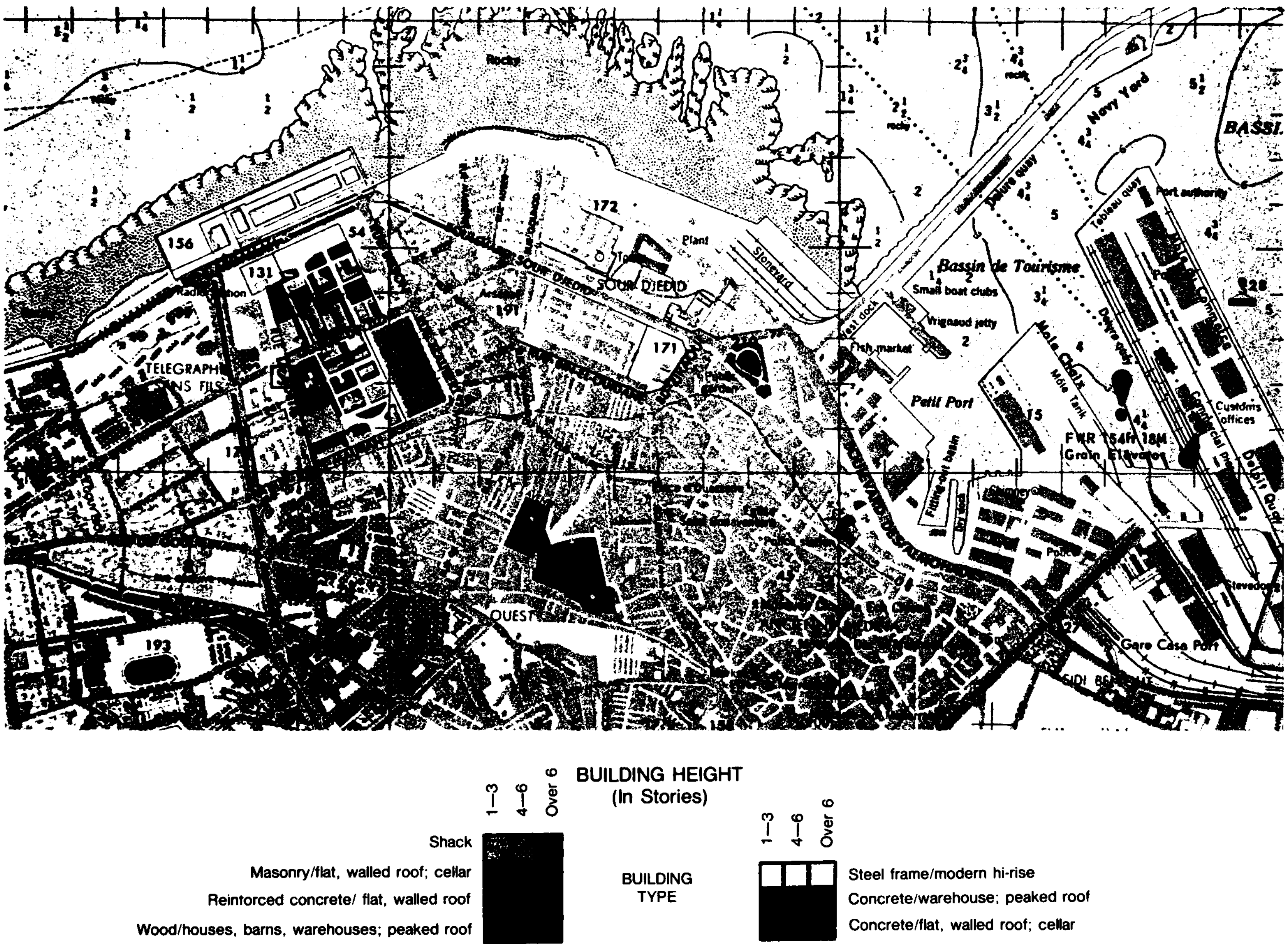


Figure 23. Casablanca prototype by the U.S. Army Engineering Topographic Laboratories, 1974. 1:12,500. Building heights and types are represented with a bivariate coding scheme (fictional data used).

by the Casablanca prototype into the general design of the San Juan prototype should be investigated.

21. Topographic Maps

Topographic map design presents a dilemma. A topographic map is often perceived by cartographers as an archive for large scale geographic data, leading to attempts to present information in the highest possible detail. A topographic map, however, must serve as a geographic information system; as such, it is essential that needed information be extracted quickly and accurately.

The first part of this chapter is a brief review of research that contributes to understanding the needs of DMA's 1:50,000 topographic map users. The second part examines a major prototype effort conducted by the USGS in the 1960s. The last part recommends modifications to help DMA's topographic product to better meet user requirements, to improve presentation, and to increase digital production efficiency.

USER REQUIREMENTS

Unless topographic maps are to be designed individually for each user and intended use, a compromise must be made in selecting content between high information density and high mapreading efficiency.

Information is sometimes defined as a reply to a question. Thus, it is important to discover what questions are generally asked of topographic maps in tactical situations. An ETL project in 1973 resulted in the development of several experimental topographic maps aimed at specific uses and users. The prototypes were evaluated in a user survey. Each item of information was rated "very useful," "useful," or "not needed." The following is a summary of evaluation results (Landee et al., 1979).

- Data on cross-country movement were considered very useful. These include barriers, corridors, fords, streams, bridges, and roads.
- Compacted and interpreted information was considered useful but not essential. This includes vehicular cross-country movement (an evalution of slope, vegetation, soil, and weather), percent of canopy closure, fields of fire, and line of sight.
- Highlighting high ground and showing slope zones were both considered to be very useful for reconnaissance work.
- Prototype products most popular with survey respondents were:
  —a 1:50,000 scale map showing high ground, hydrography, bridges, fords, terrain units, and avenues of approach;
  —four 1:50,000 graphics portraying road network, vehicular cross-country movement and high ground, generalized slope and vegetation, and cover and concealment.

A second-generation prototype product, a standard topographic map with four special-purpose graphics on the back, was based on this review. The four graphics showed vegetation and maneuver, terrain and sensors, photomap, and line of transportation.

A study by Landee et al. (1979) used a task-based method to decompose battlefield functions into constituent subtasks. Tasks were stated in question form (example: "Where can I expect the enemy to come from?"). Since the map is to provide an answer to the question, the only problem is what level of detail can and must be provided. To determine what comprises an adequate answer to important task questions, tactical role-playing was employed. A battlefield context was specified in terms of where, who, when, and what. A military expert was given a task to complete (i.e., determine the likely enemy avenues of approach), and his problem solving technique was studied. Landee et al. proposed that the study be used to identify common user requirements from which a single map could be developed to meet the information needs of several user groups. This study was not followed up by prototype maps.

Suggestions for useful design changes to the Military Topographic Standard Map arose from a survey of users by Huizar (1972). Comments by the users included the following.

- Map format should allow rapid updating.
- Vegetation should be presented according to percentage of canopy cover.
- Coding roads with color to indicate surface type and road width would be helpful.

USGS PROTOTYPES—THE SHELTON MAPS

In the 1960s the USGS experimented with a variety of topographic map formats and produced a group of prototype maps. The premise of the work was to take existing map standards and to demonstrate what could be done with good design rather than to attempt a broad change (Hinckley, 1984). Generally referred to as the Shelton maps (after Hal Shelton, director of the Map

Design Unit), most no longer exist except as slides. Figures 5, 11, and 12 are reproductions of a subset of these slides.

Color

The Shelton maps are exceptional in their use of color. Through careful color selection, yet with minimal reduction of content, they manage to declutter the standard USGS product. Following is a list of noteworthy modifications.

- Background tints are used on several of the prototypes, a practice recommended in many cartographic circles to enhance symbol contrast and to distinguish the body of the map from the margins.
- The vegetation overprint, considered deceptive and inaccurate, is subdued by substituting a gray or gray-green tint for the customary lurid green, or is eliminated entirely, so as not to interfere with relief representation.
- Urban areas are subordinated by changing their tint from orange or pink to gray.
- The importance of type on the map is substantially reduced. Although no names were eliminated and minimum type size remains the same as on standard USGS maps, large type sizes are generally reduced, and type is screened so as to appear less prominent. Bathymetry is blue rather than black, calming a previously riotous coastline.

Terrain features

The Shelton maps are especially interesting to military map users because they experiment with alternate forms of terrain representation. Several versions of Tanaka contours are tried: with and without labels, with dark index contours throughout, accompanied by shaded relief, and with and without vegetation.

Symbol redesign

Although terrain representation and color choice make the strongest impression when one views the Shelton maps, changes in individual symbols contribute to the success of the map designs. Point symbol modifications help to reduce clutter—the airport symbol, for example, was an airplane within a circle on the standard map. By simply eliminating the circle, a stronger and more streamlined symbol results.

Changes made to the symbol set also lead to economical production. When the prototypes were designed symbol changes were geared to easy scribing; however, many of the prototype symbols improve efficiency in digital production, as well. Efforts were made to eliminate dotted and dashed lines. Dashed lines are removed from the intermittent stream symbol: intermittent streams are shown by interrupting the background tint or by textured bands. Highway symbols, in particular, underwent an overall transformation. No dashed lines are used. Cased roads symbols are discontinued. Major highways are red. All other roads are red-brown, screened according to importance. Line width, too, is varied. The end result is an impression of all lines of transportation appearing in the same visual plane in a hierarchy of importance.

The Shelton maps were found to be more cost-effective than the old designs. Single-line drafting is simpler than double-line drafting. Some sheets of the Monterey prototypes required only three colors—red, blue, and black. Tanaka contours were also less expensive to produce than the (then standard) airbrushed shaded relief (Hinckley, 1984).

Economy in digital production

With the groundwork thus laid, experimental design efforts continued into the 1970s. This time, however, the focus shifted to efficiency in computer-assisted map processing. A major thrust was to simplify maps, thus improving timeliness by increasing production speed.

Many recommended changes in symbology are based upon techniques used on the Shelton maps, i.e., replacing the cased highway symbol with a series of red lines; and using a base tint, this time of 7% yellow. A serious attempt is once again made to eliminate dots and dashed lines. Labor-intensive to scribe, they are also unfortunately ephemeral for raster-to-vector and low-resolution digital displays. Thus, the design group recommended replacing the intermittent stream symbol with a fine blue line; replacing the ticked railroad symbol with a solid black line; and eliminating the dot within the triangular control mark symbol by drafting the triangle with a heavy line, leaving only a small space within the triangle to denote exact location.

To avoid screen angling, all line screens were discarded in favor of mezzotint random pattern screens. The San Juan prototype is an example of such screens.

Design experimentation is no longer a major focus of the USGS. But it is useful to study the past research efforts and prototype designs of the USGS, as well as the resulting standard map designs (some recommendations from the design group were implemented in the current

1:100,000 series). Design research seems to have fostered better USGS maps; USGS maps were found to be more legible than large scale military topographic maps in a test of softcopy mapreading speed and accuracy (Wong and Yacoumelos, 1973). This finding is significant despite the caveat that the military maps used were at a scale of 1:50,000 compared to the USGS 1:24,000.

SUGGESTED MODIFICATIONS TO CONTENT

The DMA 1:50,000 scale topographic map carries an extremely high density of information; it is also extremely cluttered. Determining optimum map content is beyond the scope of this report—pruning the map's contents, although essential if it is to be improved, is practical only after a thorough review of user requirements.

As a preliminary step, however, the intended purposes of the map (planning, tactical air and land operations, evacuation, intelligence, target acquisition, exercises) can be measured against its information content. This process is complicated by imminent changes in the role of hardcopy maps. In the future, current, detailed topographic data bases will be accessible by electronic maps carried on vehicles. Most cartographers assume that hardcopy maps will always be required. They are familiar and easy to use; they are convenient, portable, and permanent; and they are easily annotated. Hardcopy maps can provide very high graphic quality, still lacking in softcopy displays. In estimating content requirements, then, it is wise to consider the strengths of hardcopy maps versus their weaknesses: currentness of data and limited data density.

In keeping with the preceding discussion, future versions of the 1:50,000 topographic map series should focus on summarizing and displaying relatively nonperishable data. Terrain data is stable; it benefits from hardcopy reproduction techniques and is essential as a base map. Also appropriate for future hardcopy topographic maps are lines of communication (roads, railroads, etc.), drainage, and settlement patterns. Landmarks may or may not be needed, since these change with time and are easily transcribed from the data base when needed for operations.

The present topographic map and the future version as described above are worlds apart. The rest of this chapter describes problems with the current map design, while considering the direction in which the design will inevitably move.

Reduce number and prominence of placenames

An unwarranted number of placenames work to the detriment of terrain data. Type prominence can be reduced by screening and is recommended in the next section. There should, however, be a stricture against crowding placenames on the map.

Reduce representation of individual small buildings

After type, small structures constitute the most distracting clutter on this map series. They are numerous and prominent. Their reliability and utility is highly questionable. Except for isolated structures, they have little landmark value. On the Sayda, Lebanon, map (series K724, sheet 3057II) some settlements are represented by as many as 50-60 closely packed structures.

Boundary inset

The current practice of including a boundary inset in the margin is commendable and has been recommended for other DMA standard products. With a boundary inset, boundaries are not required on the body of the map.

Analyze requirement for navigation aids

Some helicopter pilots prefer a 1:50,000 to a 1:250,000 scale map. If a 1:100,000 map were available, as recommended in this report, could some of the navigation aids currently shown on the 1:50,000 map be removed?

Enlarge grid

The grid used on the 1:50,000 topographic map could be enlarged without detriment to the user. It is suggested that the grid interval be doubled. Alternating line weights would help mapreaders to follow a line across the page. If line weights are alternated, interior ladders could be removed.

SUGGESTED DESIGN MODIFICATIONS

This section focuses on ways the design can emphasize important features, reduce the prominence of less important features, and create a less cluttered, more readable map.

Too many typefaces

It is hard to imagine a mapreader sophisticated enough to decode the information represented by the 33 different styles, sizes, and weights of type used on current topographic maps. Type variations are traditional but conceivably harmful to mapreaders; economy and good sense dictate that their number be reduced.

Eight separate type forms (all Univers) are used for each of five classes of settlements, as well as for dispersed villages, scattered villages, and suburban areas. Five discrete sizes would suffice. Type should be selected based on importance alone and not according to location or areal extent. All but the most important names should be screened. Screened type, like type size, reduces the need for multiple typefaces by allowing quantitative variation.

Type used for woodland and large mountain features should be the same as that used for other area feature names. Specifications call for medium rather than light type, which only encourages clutter.

Different type styles are used for contour values and depth curve values. Specifications call for bold type for contour values and medium type for depth curves. This is reasonable; contours are brown and depth curves are black. But if depth curves are shown in blue, bold type could be used for all contours.

All spot elevations should use the same type style. All detailed map data should be labeled, if at all, with a style such as the 6-point Univers light condensed italic that is widely used on the topographic map, and whose size and boldness is appropriate for map detail. Using the same small typeface for all map detail would consolidate a number of variations and, in many cases, help to de-emphasize detail. Thus, bridge characteristics, enclosures, some peaks, terrain descriptions, and crevices will have reduced type size and weight.

The minor changes cited above reduce the number of type styles and sizes to 20 from the 33 currently used. More sweeping reform is not only possible but is encouraged.

Reduce type prominence

Type on this map series is a major deterrent to legibility. It is oversized, too dense, and too prominent. Type screening as done on some USGS prototypes, is recommended to reduce the prominence of placenames. Size specifications of 16 and 18 points should be evaluated: surely few features warrant type this large.

Substitute Tanaka contours for standard contours

Tanaka contours are ideal for topographic map requirements. Immediate impressions of landforms are provided with no loss of accuracy. The problem of reversing can be alleviated by emphasizing the drainage pattern (as recommended below). Optionally, hillshading could be added to further enhance the three-dimensional appearance provided by Tanaka contours. The decision to add hillshading can be based on production time and cost, and a test of mapreader performance.

Contours are currently used in areas where rugged terrain forces the use of a contour interval too large to provide any useful information. The product specifications state that at slopes of 45% and greater, the contour interval is 40 m (131.2 ft). In these areas DMA should consider abandoning contours in favor of shaded relief and spot elevations alone. Although this change could cause uneasiness on the part of users, large contour intervals are a poor source of information.

Reduce prominence of vegetation

Vegetation is too prominent on current DMA topographic maps. As discussed in Chapter 7—Vegetation, the requirement for depicting vegetation is barely supportable.

First, the vegetation requirement should be scrutinized. Terrain analysis requiring vegetation is best performed with accurate, current data using seasonal and water budget functions incorporated into electronic map software.

If vegetation is found to be necessary on hardcopy topographic maps, it should be a gray-green tint, selected to reduce its prominence. Vegetation symbols, too, should be simplified. Current product specifications list 10 area symbols for vegetation. An alternative to the current set of qualitative symbols is a quantitative symbol scheme using three shades of gray-green to depict canopy cover. At minimum, colors used for vegetation symbols should be evaluated. Inexplicably, one is screened brown (which blurs contour lines), most are green, and some are blue. All vegetation logically should be green unless it is difficult to traverse due to water, in which case it should be blue.

Use blue for coastal hydrography

Coastal hydrography is currently solid black, making even the water appear cluttered. If natural hydrographic features are shown, it is recommended that they be blue. Thus, depth curves and their labels, and symbols for flats, reefs, and ledges would be blue. All man-made hydrographic features would be black.

Outline drainage network and coastlines

For maximum prominence of the drainage pattern, black or screened black outlines for double-line rivers and streams are recommended. For single-line streams, midnight blue rather than the current medium blue should be tried. Coastlines should be outlined in the same black or screened black used to outline rivers and streams. The indefinite or unsurveyed shoreline symbol is too complex and should be replaced with a simple dashed line.

Reduce detail of drainage symbols

The level of detail in drainage symbology is questionable. Is it important to distinguish a cistern from a well? Both are simply water sources and neither can be considered landmarks. Yet cisterns have a unique symbol and are also labeled. Unless there is a strong requirement to distinguish types of water sources, cisterns and wells should share a single symbol.

Twelve symbols are used for canals and canalized streams. All canal symbols are highly complex, containing ticks and detailed labels (''abandoned canal,'' ''canal under construction,'' or ''navigable''). Logically, a straight stream is a canal; further explanation seems excessive. And, how important is a canal abandoned, dry, and less than 18 m wide? Is it important enough to justify the clutter of an ''abandoned canal'' label?

Reduce clutter from cultural feature symbols

Cultural features are a major source of clutter and reflect unreasonable optimism regarding the eyesight and ability of mapreaders.

The previous section listed small structures as being the greatest source of clutter on this map series after type. At minimum, small buildings should be screened black to reduce their prominence. Even better would be to implement a series of three gray tints to depict densely, moderately, and sparsely built-up areas; destroyed areas (currently gray) could be distinguished by texture. Built-up area tints would interrupt, not overprint, other map tints.

Symbols for religious structures are extremely detailed and highly intricate. The difference between the symbols for major and minor pagodas is a tiny dot within the (slightly less) tiny symbol. Separate symbols are defined for churches, chapels, and shrines; the distinction between a church and a chapel is that of a tiny square instead of a miniature circle; a shrine is slightly more differentiable, having an unfilled center. The exact requirement for distinguishing among religious structures should be determined. It may be useful to know whether a settlement has a Christian or a Moslem religious structure. More dubious is the utility of distinguishing between churches, chapels, and shrines.

The symbol used for a small hospital is difficult to recognize under less-than-ideal viewing conditions. A heavy, symmetrical cross alone (such as that associated with the Red Cross) would be preferable. Such a cross could be unfilled for small hospitals and filled for large hospitals.

The current system of road symbols is not particularly logical. Some road symbols are difficult to see. Some are difficult to construct by hand or digitally. Using the theory of symbol dimensionality (Morrison, 1981) the dimensions of roads can be seen as number of lanes and surface. Number of lanes is most intuitively represented by width; surface type is by the same reasoning best represented by color. All cased road symbols should be discontinued. Hard surface roads can be shown in red, loose surface/all weather roads can be shown in red-brown, and loose surface/dry weather roads can use a screened version of the color used for loose surface/all weather roads. There is no apparent need to show footpaths. This suggested road symbol scheme closely resembles the one employed for the Shelton maps.

With no roads shown in black, ticks on railroad symbols become optional. Although this report recommends retaining ticks, Gilman (1982) maintains that they contribute to clutter without substantially increasing the level of information. Gauge of track may be better shown by varying lineweight than by tick spacing. A very fine black line can be used for both dismantled and abandoned railroads.

Offshore cultural features, too, could be simplified. All three current symbols for wrecks could use the symbol for exposed wreck. More than one wreck symbol could serve to show wreckage. Whenever possible, generic labels should be avoided.

Detail is also a problem for miscellaneous cultural features shown on this product. Located object symbols are small and extremely intricate. Can a symbol so small even be noticed? If not, the symbol should be eliminated, since evidently it would not be missed; or, it should be enlarged. The risk of not noticing located objects appears to be recognized by cartographers at DMA, since in practice many miscellaneous cultural symbols are accompanied by labels, or a label alone is used to define such important features as beacons, power plants, pumping stations, and towers.

Do not label unique symbols

A single generic symbol would suffice for all labeled symbols. If there is no label, the symbol must be easily recognized. For optimal recognition, the design of the symbol would be associated with the feature itself (see Chapter 1). For optimal perception, the symbol should be boldly designed. A single lightening bolt could represent a power plant. A small wheel in a river could be used for a water mill.

Improve contrast of navigation aids

The solid blue used for flight hazards (transmission lines, obstructions, and airfields) can be confused with the blue used for hydrology. If flight hazards are important to the 1:50,000 map (see previous section), their color should be easily distinguished.

SUGGESTIONS FOR IMPROVING PRODUCTION EFFICIENCY

Modify type placement specifications

Instructions for type placement provided by the product specifications are fundamentally those of Imhof (1975). These specify curved names on irregularly shaped linear and areal features. There is disagreement among empirical studies whether this practice is effective. It results in a great deal of type that is unreadable without turning map or head. It also increases the complexity of algorithms used for automated type placement.

Change to landscape format

A landscape format rather than the current portrait format would improve the topographic map. It is easier to handle both standing and seated despite its departure from tradition.

Automated processing presents even stronger arguments for a format change. A landscape format is more compatible with the shape of most softcopy displays. All DMA aeronautical charts are wider than they are high. Products would be easier to derive one from the other using such a format for the topographic map, since compatible map and chart dimensions make mosaicking less complex when deriving charts of small scales from maps of larger scales.

This study also recommends that the topographic map use only two margins (bleeding edges) to maximize image space, and for compatibility with DMA aeronautical charts.

22. Aeronautical Charts

DMA standard aeronautical charts are at scales of 1:250,000 (Joint Operations Graphic-Air, or JOG-A), 1:500,000 (Tactical Pilotage Chart, or TPC), 1:1,000,000 (Operational Navigation Chart, or ONC), 1:2,000,000 (Jet Pilotage Chart, or JPC), and 1:5,000,000 (Global Navigation and Planning Chart, or GNC).

The first part of this chapter reviews requirements of aeronautical users as represented by research. The second critiques DMA standard aeronautical products with reference to user requirements, design practices, and ease of construction.

USER REQUIREMENTS

Aeronautical chart requirements have been studied extensively in terms of both content and presentation. Significant contributions to the literature have been made by Taylor (1972, 1974a, 1974b, 1975a, 1975b, 1976a, 1976b, 1977, and 1978), Taylor and Belyavim (1980), Hopkin (1972), and Hopkin and Taylor (1979) of the Royal Air Force Institute of Aviation Medicine.

JOG users in particular have been surveyed to determine types of information needs and chart design preferences. JOGs have been harshly criticized by users and researchers alike. Such studies concerning both the JOG and other aeronautical charts are focal in Section II, Analysis of feature portrayal, since aeronautical user requirements are more precisely defined than those of topographic or hydrographic users. This is fortunate; aeronautical charts are more dangerously cluttered than topographic maps or hydrographic charts.

This section summarizes the requirements of DMA aeronautical chart users. Later, findings of the reviewed research are applied to critique DMA aeronautical chart designs.

Important information to aircrews includes the following.

- Navigation data.
- Location and shape of features that are highly visible from the air. Such features include relief, drainage, coastlines, major roads, and excavations.

- Landmarks, such as (depending on the area) structures, patches of vegetation, distinct man-made features.

Generally, as altitude increases, so does the importance of navigation data relative to the importance of terrain and landmark information. Specific needs of aircrews are discussed by altitude in the following sections.

Nap-of-the-earth users

Nap-of-the-earth flight, of growing importance, is not well served by DMA products. Helicopter pilots generally use 1:50,000 topographic maps. They complain, however, that the volume of paper required for mission area coverage at this scale is bulky and difficult to manage in the cockpit. And, the 1:50,000 topographic series is designed for ground users who can study the map more leisurely, not for aeronautical users who must divide their attention between mapreading and flying an aircraft.

Nap-of-the-earth flight requires information at a glance, emphasizing vertical features and relief. Slope is especially important for nap-of-the-earth flight. Limited field of view and oblique perspective from flying close to the ground make features appear strikingly different from the traditional bird's-eye view.

This report proposes 1:100,000 ground/air product development to serve the needs of low altitude aeronautical users and ground/air communication.

Low altitude/high speed users

The JOG and the TPC are designed for low altitude use. A survey indicated that a majority of low altitude/high speed users favor the TPC, feeling that its content is more closely attuned to their needs (Taylor, 1974a). Those in the survey who favored the JOG did so because its larger scale provides better geodetic accuracy. A 1:250,000 product using 1:500,000 selection criteria would be useful to low altitude/high speed users.

The shape of drainage features is among the most important information to low altitude users. When haze and clouds do not obscure the ground, water is highly visible day and night. Railroads, too, are very useful for orientation and navigation. They are straight; they are relatively infrequent; in hilly terrain they are flanked by embankments; and they are intersected by roads, which makes it easier to find position. Paved highways are highly visible from the air; but if there are numerous paved highways in a limited area, each one's orientational value decreases. There is no consensus on the utility of dirt roads. Some users feel they clutter the map and are not reliably visible; others wish them included.

At low altitudes, aeronautical information other than vertical obstructions is slightly less important than terrain features.

Medium and high altitude users

Aeronautical information is more important as altitude increases. Although terrain features play a subordinate role in navigation, those most visible from the air must be shown: drainage, excavations, major towns and highways, and railroads.

The rest of this chapter applies the material discussed here and throughout the report to a critique of DMA's standard aeronautical products.

COMMON ELEMENTS IN CONTENT REQUIREMENTS

The following comments on content are applicable to all of the DMA aeronautical charts reviewed in this study.

Eliminate contour lines

Contour lines are the worst possible way to represent terrain on aeronautical charts. Elevation and rapid terrain identification are the primary needs of most aircrews. Nap-of-the-earth users do require a certain amount of accuracy, but they also need "information at a glance," which only expert mapreaders can get from contour lines.

Even accuracy is poorly served by contours on aeronautical charts. The contour interval possible at the scales used for aeronautical charts renders what accuracy there is virtually useless due to poor resolution (Table 11). Eliminating contour lines from aeronautical charts eliminates a source of clutter and wasted production time. Certain terrain features, including craters, escarpments, and bluffs, have landmark value and should continue to be shown.

Eliminate all but landmark vegetation

"Landmark" status must be strictly defined. The heavy saturation of the JOG's background, partially attributable to vegetation tints, contributes to its unreadability. As discussed in Chapter 7, vegetation is generally not a reliable feature for pilot orientation. Vegetated areas are seasonal and transient, making accuracy difficult to maintain. Maps showing vegetation quickly become outdated.

Table 11. Contour intervals on DMA standard aeronautical charts.

Joint Operations Graphic (1:250,000)

Slope:	<10°	10°-20°	>20°
Interval:	20-30 m	50 m	100 m
	(65.6-98.4 ft)	(164.0-98.4 ft)	(328.1 ft)

Tactical Pilotage Chart (1:500,000)

Flat: 152.4 m standard interval/76.2 m intermediate contours if required (500 ft standard interval/250 ft intermediate contours)

Hilly: 152.4 m (500 ft)

Operational Navigation Chart (1:1,000,000)

Standard: 304.8 m/60.96, 76.2, 152.4 m intermediate contours if required (1000 ft)/200, 250, 500 ft intermediate contours)

Jet Navigation Chart (1:2,000,000)

Contour at 304.8, 609.6, 914.4, 1524, 2134, 2743, 3658, 4572 and 5486/6096 m (1000, 2000, 3000, 5000, 7000, 9000, 12,000, 15,000, and 18,000/20,000 ft)

Global Navigation and Planning Chart (1:5,000,000)

No contour intervals.

Eliminate bathymetry

Bathymetry is represented on current aeronautical charts by depth curves or by depth tints. Bathymetry is of little conceivable use to aircrews. Its representation adds clutter and cost to the final product. Depth tints, used on JNCs, are particularly noisy, interfere with aeronautical information, and should be eliminated without delay.

Eliminate underground features

It is difficult to imagine how underground features came to be included in aeronautical chart specifications. The JOG, TPC, and ONC symbol schemes support symbols for underground aqueducts and underground flumes.

COMMON DESIGN PROBLEMS

The following comments on design are applicable to all of the DMA aeronautical charts reviewed in this study.

Emphasize hydrography

The shape of drainage and coastlines has been voted by aircrews as being among the most useful tools for orientation. Yet blue, used to outline lakes and coasts, provides minimal visual acuity (see Chapter 3—Color). All hydrographic features except those whose outlines are vaguely defined (unsurveyed shorelines, "numerous small lakes," and nonperennial features) should be outlined in black. Those not outlined in black should be shown in solid blue (not dashed lines). Man-made features on coastlines, such as seawalls and dams, can be shown with a heavy black line.

Reduce type prominence

DMA's aeronautical products suffer from prominent type in varying degrees. All would benefit if type were screened to reduce its prominence, as discussed in Chapter 21—Topographic Maps. DMA's aeronautical charts also suffer from too much type. Settlement names and names of relief features are less important to pilots and navigators than most cartographers suspect.

COMMON ELEMENTS TO IMPROVE PRODUCTION EFFICIENCY

The following suggestions for improving production efficiency are applicable to all DMA aeronautical charts reviewed in this study.

Reduce chart size

The TPC, ONC, and JNC measure 1083 mm by 1511 mm (42-5/8 by 59-1/2 inches). Problems associated with

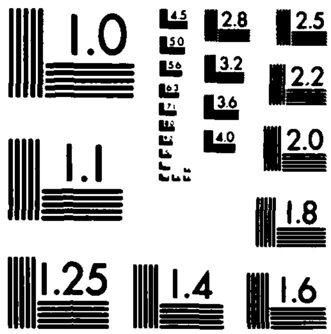
AD-A151 061 MAP DESIGN FOR COMPUTER PROCESSING: LITERATURE REVIEW AND DMA PRODUCT CRITIQUE(U) NAVAL OCEAN RESEARCH AND DEVELOPMENT ACTIVITY NSTL STATION MS G LANGRAN JAN 85 2/2

UNCLASSIFIED NORDA-72 F/G 8/2 NL

END

FILMED

DTIC



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

outsized graphics and digital production equipment are discussed in Chapter 5—Scale and Size. Is maintaining this size important enough to warrant additional hardware expense and inconvenient hardware use? Chapter 18—Recommendations for Multiproduct Operations discusses product derivation from large to small scale. The size of all aeronautical charts should be reduced to encourage the use of off-the-shelf production hardware, and a size should be selected to allow straightforward derivation and mosaicking from series to series, as described in Chapter 18.

Coordinate typefaces with other DMA products

Although the number of typefaces used on aeronautical charts is appropriately restrained, it is an entirely separate set of styles from those used on either hydrographic or topographic products. One set of typefaces should be enough for all three groups of maps and charts.

Do not taper streams

As with most nondiscrete manual operations, streams can be tapered using digital equipment if enough time and money are dedicated to the process. It would be far more practical and less expensive to eliminate this design requirement. Only JOG specifications instruct cartographers not to taper streams.

Five types of aeronautical charts produced by DMA are reviewed in the following sections.

JOINT OPERATIONS GRAPHIC

The JOG is a series of graphics for air (JOG-A), ground (JOG-G), and radar (JOG-R) maneuvers. Together they are used for planning, low-level navigation, joint air/ground operations, exercises, search and rescue and, in the case of the JOG-R, for identifying and predicting radar significant features. Only the JOG-A is reviewed in this report because its users suffer significantly from clutter. The JOG-G is a JOG-A with no aeronautical overprint; the JOG-R is not widely available.

This report recommends that a 1:100,000 series replace the JOG entirely. Suggestions for a prototype 1:100,000 series are stated in Chapter 25. The remainder of this section suggests improvements to the current product.

Major redesign of the JOG series is required. Multiple use (by both air and ground users) requires a broad range of information, raising feature density to an extremely high level. Crowded features and exhaustive terrain representation induce clutter that the JOG's design does little to camouflage. The JOG is not meeting its user's requirements if a requirement is that it be easily and quickly read. Base colors are dark; shaded relief adds complexity. A recent mandate to withhold placenames of fifth-order populated places and minor relief features will contribute to decluttering the JOG-A. Other remedies will come through arriving at a clear picture of JOG user requirements.

Set strict selection criteria

Clutter is a critical problem on the JOG. JOG specifications warn that "portrayal should include all significant features, yet avoid clutter. When congestion and clutter of a graphic tend to occur, the selection of features for omission must be judicious and in accordance with the guidance contained herein" (JOG Product Specifications, PS/1AE/201, November 1976). Evidently, more forceful guidance is required; all JOGs reviewed in this study were disastrously congested. Strict criteria for selecting roads are particularly needed. Pilots have complained of the number of roads crisscrossing the JOG and recommend the selection criteria be strengthened.

Improve relief representation

Terrain features on the JOG are shown redundantly by contours, tints, hillshading, spot elevations, and Mean Elevation Figures. Relief representation contributes heavily to clutter and to the JOG's deeply saturated background. The role of each technique in depicting terrain is discussed in Chapter 6—Terrain Features. Problems with JOG relief representation follow.

Layer tints are inconsistent across the series. Some of the progressions used lack sufficient contrast. Five different JOG-A charts produced in 1976 and 1980 use four different elevation tint schemes. It is especially surprising to find such variation among charts produced in the same year. JOG product specifications (amendment number 4, November 1978) list a graded series of yellows and browns, of which four are line patterns (line patterns are not recommended for computer production in this report because they are not independent of orientation). A less saturated tint scheme would improve the JOG.

A prototype JOG design for projected map display showed that clutter, complexity, and saturation are reduced when shaded relief is eliminated (Taylor, 1976a). Shaded relief has not proven to be particularly useful for terrain recognition in tests of pilots and navigators. Worse, it is an apparently random population that confuses ridges with valleys when using maps with shaded relief.

One alternative to combined layer tints and shaded relief is slope zoning. Slope zone maps are independent of orientation and provide a rapid view of landforms. Eliminating either spot elevations or Maximum Elevation Figures may be possible pending a survey of user requirements.

Reduce grid prominence

A lighter weight of line should be used.

Redesign road symbols

Cased lines should be eliminated. The strategy for road and railroad symbolization discussed for topographic maps is recommended for the JOG.

Simplify symbol sets

An example of overambitious symbolization is given by the boundary symbol set: eight kinds of boundary symbols can be shown, each one painstakingly encoded by varying dashes and line weights.

Standardize margin layout

There is excessive marginal variation among JOGs. This is poor practice for two reasons. First, it forces the mapreader to search for what is normally the only reliably accessible reference material on a map. Second, a standard map margin is mandatory for efficient computer processing. The USGS has developed a technique for margin layout whereby only variable information is entered by the analyst at the request of a program that incorporates the variables and automatically typesets the map margin.

TACTICAL PILOTAGE CHART

The TPC (1:500,000) is intended for planning, low-level navigation, air operations, training and exercises, and intelligence. This attractive chart conforms well with design principles discussed elsewhere in this report, and it suffers comparatively little from clutter. The selection of features and their relative emphasis is in line with the intended uses of a medium scale map. The exacting needs of aircrews are generally served by the contents of the TPC, but minor modifications will increase production efficiency.

Discontinue or simplify certain symbols

It is not necessary to maintain unique symbols that are also labeled. This problem was discussed for topographic maps, and is present to a lesser extent on aeronautical charts. The oasis symbol (a palm tree labeled "oasis") is a good example. If the symbol is adequately iconic, the label is unnecessary.

Reduce type variations

The TPC style sheet and the TPC product specifications contain radically different type specifications (10 fonts versus 4 fonts) (see Table 14d in Chapter 24). This confusion should be resolved. Some type variations are unnecessary. To minimize clutter, political regions—country, state, and province—should not be labeled as areal features. (There is, in fact, little reason to label provinces on aeronautical charts). In practice, few areal features are labeled across their extent, as specified, but rather are labeled on opposite sides of their boundary. If the only features labeled areally are water bodies, maximum type sizes can be reduced and the Caslon Openface font used for land areas can be eliminated.

OPERATIONAL NAVIGATION CHART

The ONC (1:1,000,000) is intended for planning, low-to-medium altitude navigation, evacuation, training and exercises, and intelligence. Relief representation and clutter are its most serious problems.

Decrease clutter

The ONC's clutter problem is serious because of excessive detail and heavy dependence on type. Navigation aids fight a noisy battle with relief representation and myriad labeled point features such as forts, tombs, stations, cases, wells, camps, and tanks. Epithets such as "rocky," "lava," and "karst" redundantly depict geology (28 "karst" labels in a 9 x 5 inch area and three "lava" labels in a 1-inch square of the ONC G-4 were counted).

Use four-color hillshading

A complex system of Terrain Characteristic Tints rather than elevation tints is used. These tints show a combination of elevation and terrain characteristics. Problems with their appearance are discussed in Chapter 6.

Appearances aside, the technique of applying Terrain Characteristic Tints is highly subjective as described in the product specifications. Developing a computer process to delineate Terrain Characteristic Tints would be an intriguing research problem. If DMA does not wish to undertake such a research effort, it should investigate more tractable alternatives. The best alternative found by this study is the four-color hillshading scheme developed by Dutton (1982). This scheme is described in Chapter 16—Alternative Terrain Representation under the heading of "Digital terrain characteristic modeling." Four-color hillshading uses elevation data to algorithmically assign colors based on elevation, slope, and aspect. To implement Dutton's program would require selection of a color scheme, adjustments to allow use of DMA's Digital Terrain Elevation Data (DTED), and construction of an interface to output devices.

Reduce number of point features

Strict guidelines should be provided to the compilers of features for the ONC. Certain features are useful landmarks when found in isolation or in remote locations. However, ONCs show a profusion of camps, tombs, power plants, etc. (complete with label) along roads and rivers, obscuring the road or river's shape. Since roads, rivers, lakes, and towns have been listed by pilots and navigators as being among the most important features by which to orient themselves, the effort expended on compiling these small point features is apparently misplaced.

Reduce the amount of type

Processing type is costly in dollars when producing the chart, and it is costly in time when reading the chart. Too many symbols on the ONC rely on text for amplification. Only unusual land features should be habitually tagged, since labeling a generic symbol is more economical than supporting an infrequently used symbol. Unnecessarily labeled symbols are:

- Falls and rapids—these features have unique symbols; neither should be labeled.
- Abandoned canals—it is unimportant to aircrews whether or not a waterway is abandoned. Labeling should be discontinued. Dry canals can be outlined in blue (since all permanent and surveyed water features are, according to the proposed scheme, now outlined in black).
- Kanats—the kanat symbol is distinct and does not require a supplementary label.
- Salt pans and filtration beds—both features have distinct symbols and no amplification is required.
- Mangrove, peat bog, and cranberry bog—all these features have distinct symbols. No label should be used.
- Wells—these features are not extremely prominent from the air. Their symbol is unique and no further prominence should be implied by adding a label.
- Levees—accurate perception of the shape of the feature is impeded by the label. The symbol is unique and no label should be used.
- Craters—eliminate label.
- Ruins—the standard symbol for ruins (three dots in a pyramid) adds less clutter to the map; type should be eliminated.
- Shelter belts—no additional amplification is required.
- Oases—one or more palm trees should be used based on the size of the oasis. No label is then required.
- Forest clearings—these should be self-evident. Arrows pointing into clearings obscure their shape.
- Railroad yards—if shown to scale, no label is required.
- Snowsheds—do not label.
- Causeways—do not label.
- Breakwaters—do not label.
- Seawalls—do not label.
- Piers—do not label.
- Forts—if shown to scale, do not label.

The color scheme and the symbol set used on this chart require a detailed redesign that is beyond the scope of this report. This critique highlights only the most evident flaws in the chart design.

JET NAVIGATION CHART

The JNC at 1:2,000,000 is intended for planning, long range/high altitude navigation, training and exercises, and intelligence. At high altitudes aeronautical information is more important to aircrew than topographic information. Thus, the JNC should follow the example of hydrographic charts and aim to be utilitarian rather than pictorial.

In appearance the JNC bears many similarities to the ONC, although its clutter does not reach the same extreme level. Added to the general changes to all DMA aeronautical charts suggested early in this chapter is the following recommendation.

Use four-color hillshading

The JNC has the same Terrain Characteristic Tints as are used on the ONC. Reasons for replacing them with four-color hillshading are discussed in the previous section.

GLOBAL NAVIGATION AND PLANNING CHART

The 26 GNCs produced at 1:5,000,000 by DMA provide world coverage to satisfy long-range aerospace requirements for logistical flights. As the GNC supports high altitude users, aeronautical information is of prevailing importance. Requirements for cultural and natural features are articulated in the product specifications. These are (in order of importance):

- major relief features,
- major hydrography and national boundaries,
- major transportation networks,
- secondary cities and towns in isolated areas,
- miscellaneous cultural features in isolated areas,
- secondary cities and towns in densely populated areas.

No major faults with the GNC were found by this study. Clutter arises from aeronautical annotation, about which little can be done. There are, however, areas for improvement.

Change relief representation

Relatively level areas with no relief discernible from high altitudes use a pale green area tint. The area tint is interrupted in more rugged areas so that background white underlies shaded relief, *making it shades of pearl gray.* The technique is illustrative and no doubt useful to pilots.

This scheme, however, shares the problems described for the Terrain Characteristic Tints used on the ONC and JNC. A technique to digitally determine which areas to hillshade must be developed. Product specifications give only the guidance that "major features be accentuated and only the most striking minor features shall be retained." Digitally, it can be as easy to execute hillshading or four-color hillshading as it is to decide whether or not the terrain warrants such treatment. Thus, it is recommended that a different form of terrain representation be adopted, possibly an image-based form that will describe all land cover.

Improve unattractive colors

Alone, the green and gray background colors are well chosen and attractive, as can be seen in the legend. But combined with the other colors and symbols on the GNC, the area tints contribute to the GNC's general unattractiveness. While this is not a severe flaw, an improvement in the GNC's appearance should be possible.

Simplify symbols

Previous admonitions apply here. The GNC symbol scheme supports too much detail ("abandoned" and "under construction" canals), redundant labeling ("falls," with a unique symbol for falls), and itemizes distinctions that are not useful to aircrew (i.e., labeling swamps as "mangrove," "peat bog," "cranberry bog," or "rice field").

SUMMARY

The problem of clutter is present in varying degrees in DMA aeronautical charts. A full awareness of the charts' purpose and conscientious attention to aeronautical needs are essential to overcome this problem. This chapter suggested design modifications to emphasize the features considered most important by aircrews (such as outlining coastlines in black) and to eliminate processes that add to production time and expense, yet contribute little to the orientation and navigational abilities of pilots and navigators.

23. Hydrographic Charts

DMA's hydrographic charts are produced at scales ranging from 1:2500 to 1:600,000. The largest scale charts are Harbor and Approach charts, used to depict harbor information to allow safe entry, exit, berthing, and anchorage in world ports. The smallest scale charts are primarily for navigation and for plotting ship positions.

The hydrographic series charts are attractive, utilitarian graphics that reflect a strong sense of their intended use, uncluttered by detail. Suggestions for further improvement are offered following a discussion of user requirements.

USER REQUIREMENTS

In contrast to the wealth of attention lavished on aeronautical charts, little critical analysis has been devoted to the subject of hydrographic chart design. Magee (1968) affirms the need to keep the hydrographic chart as uncluttered as possible to reduce the task of updating. He describes the efforts of the British Navy to simplify the design of the Admiralty Chart. Magee's recommendations include thinning out spot soundings and replacing them with close contour intervals.

A study by a working group of the German Hydrographic Institute divided navigational tasks into subdivisions as a means of determining the information needs of hydrographic chart users. Essential information for position fixing, route finding, and safety are discussed in Chapter 10—Navigation Aids and summarized in Tables 4-6 in that chapter.

Design recommendations from the working group include those listed below (Schmidt, 1979).

- Only two sizes are needed for charts. The larger should have a neat line size corresponding to that of the International Chart (630 mm x 980 mm). The smaller should be half the size of the larger to facilitate chart use and storage.
- Facts should be recognizable from symbols. If not, the facts should be labeled rather than symbolized.
- A logarithmic scale should be shown for the distance steamed in a unit of time.
- Different type styles should not be used to represent facts.
- No information should be placed on the back of the chart.

A preliminary study of the Canadian Nautical Chart design was undertaken by Castner and McGrath (1982) for the Canadian Hydrographic Service. Included in the report is a review of the literature on chart use and design, and listings as follows:

- Chart use tasks;
- Type of vessel to which each task is relevant;
- A breakdown of each task into two visual components: those tasks in which elements are searched for and isolated in peripheral vision, and those tasks in which isolated elements are fixated.

This itemized listing provides a basis for coding information onto charts to afford the most efficient communication.

SUGGESTED MODIFICATIONS TO CONTENT

Include a bar scale

Because hydrographic charts are irregular scales, it would be extremely useful to have a convenient form of measurement available on all hydrographic charts. Although product specifications require a graphic scale, not all charts have one.

Include a logarithmic scale

Include a logarithmic scale for distance steamed in a unit of time, as recommended by the German Hydrographic Institute working group.

Replace spot soundings with contours

Replace spot soundings with contours when data density permits. This issue is discussed in Chapter 8—Hydrography. The advantages of showing depth curves outweigh any inconvenience caused by lacking specific soundings.

Include all airports

Landings and takeoffs of aircraft can be seen from far out at sea.

Depict terrain

The profile of the land would be helpful information to mariners. In areas with rugged terrain, spot elevations help denote the profile of the land to the mariner. Perspective drawings to illustrate the appearance of the horizon from sea could be developed using digital terrain elevation data.

SUGGESTIONS FOR IMPROVING PRODUCTION EFFICIENCY

Standardize size and format

More than 20 pages of the product specifications provide directions for construction of borders, grids, and scales for all the permutations of hydrographic chart shapes and sizes. It would benefit both the mariner and the producer of the charts to set standard sizes and margins for hydrographic charts, into which the selected area could be scaled accordingly. This has not been practical without the help of the computer, but with minor modifications to existing scaling and projection change programs, areas of interest can be mapped into the standard chart format either interactively or in batch, based on specification of the area of interest.

Consolidate type fonts

It is suggested that hydrographic charts share a sans serif and a serif family of type fonts with topographic maps and aeronautical charts.

Automated selection based on line of sight

Automate land feature selection based on line of sight from coast. Land features visible from ships at sea should be added whenever possible.

Conclusions

24. Strategies for Improving Production Efficiency

This report surveyed the literature of cartographic design research, discussed techniques suited to digital production, and applied the study material to a critique of DMA product designs. Recommendations are geared toward improving communication of geographic information to mapreaders and toward maximizing savings made possible by the computer. The second objective in particular has led to a number of suggested departures from standard practices. It is, after all, unwise to prolong design practices that increase production cost without concrete evidence of their merit. Table 12 summarizes the modifications to DMA products suggested in the previous section.

DMA can take certain measures to ease the transition from analog to digital production. Some problems observed by this study do not require research or development to solve. Rather, solutions involve reviewing type, symbology, terminology, and specifications to remove vagaries, inconsistencies, and eccentricities. Specifications should be standardized, not branch by branch, but comprehensively throughout DMA. These measures will minimize the need to develop computer programs because one program can suffice for all three branches of DMA; and they will make computer programs less complex by simplifying intricate instructions, thereby making production more efficient. Suggestions for DMA action are discussed in this chapter. Chapter 25 describes areas requiring further research.

Table 12. Summary of suggested modifications

City Graphic	Adopt color scheme of San Juan prototype Evaluate street labeling system used on Casablanca prototype
Topographic map	Reduce number and prominence of placenames Reduce representation of individual small buildings Analyze requirement for navigation aids Enlarge grid Reduce number of typefaces Use Tanaka contours Reduce prominence of vegetation Use blue for coastal hydrography Outline drainage network and coastlines Reduce symbol detail Eliminate labels for unique symbols Improve contrast of navigation aids Modify type placement specifications Change to landscape format
Aeronautical charts *(general)*	Develop product for nap-of-the-earth flight Eliminate contour lines Eliminate all but landmark vegetation Eliminate bathymetry Eliminate underground features Emphasize hydrography Reduce type prominence Reduce chart size Coordinate typefaces Do not taper streams
JOG	Set strict selection criteria Improve relief representation Reduce grid prominence Redesign road symbols Simplify symbol sets Standardize margin layout
TPC	Discontinue or simplify certain symbols Reduce type variations
ONC	Decrease clutter Use four-color hillshading Reduce number of point features Reduce the amount of type
JNC	Use four-color hillshading
GNC	Change relief representation Improve unattractive colors Simplify symbols

OVERHAUL TYPE PRACTICES

Tables 13 through 15 were compiled to demonstrate inconsistencies in DMA's type specifications. Several related typographical problems work against efficiency.

Reduce the number of typefaces per product

The research reviewed found no evidence that mapreaders use typeface variations to decode feature attributes. It did, however, find evidence that typeface

Table 13. Typefaces used on DMA standard products. The families listed here are as listed on style sheets.

	TOPO	HYDRO	JOG	TPC	ONC	JNC	GNC	CITY
Techno Medium		X		X	X	X	X	
Techno Medium Italic							X	
Techno Bold		X		X	X			
Techno Bold Italic				X	X	X		
Caslon Openface				X				
Caslon Bold Condensed						X		
News Gothic		X		X		X		
News Gothic Condensed		X		X				
Alternate Gothic No. 3				X	X			
Formal Gothic Light Condensed				X	X	X		
Formal Gothic Demi-Bold				X	X	X	X	
Formal Gothic Demi-Bold Condensed							X	
Copperplate Gothic Italic				X				
Univers Light Condensed	X		X					X
Univers Light Condensed Italic	X							X
Univers Medium Condensed	X		X					X
Univers Medium Condensed Italic								X
Univers Bold Condensed	X		X					X
Univers Bold Condensed Italic								X
Clearface Italic			X					

variations can deter the search process. It is strongly suggested that no more than two fonts be used on all DMA maps and charts. Typographic variation is provided by size and darkness (adjusted by screening). The USGS has reduced its type library to only the Univers and Souvenir families, a move that also reduces the required amount of digitized type storage space. If DMA persists in using a large number of typefaces, a spline-based system of type generation is recommended (see Chapter 16).

Consolidate type libraries

Type libraries used by DMA's topographic, hydrographic, and aeronautical centers show little overlap. Font digitization and storage space could be minimized by specifying the same fonts on all maps. Most of the fonts used by DMA's Aeronautical Center are already digitized; thus, both centers of DMA should use a subset of these digitized fonts.

Reconcile product specifications with style sheets

Product specifications and style sheets for individual products are not in accord, as demonstrated by Tables 15a-g. With the exception of the JOG, none of the type sets specified by product specifications match the type sets specified on corresponding style sheets. To avoid error and confusion, this inconsistency should be resolved.

OVERHAUL SYMBOL SETS

Current symbol sets need two types of changes. First, the level of feature detail needs to be brought into line with product scale and intended use. Second, intricate symbols need to be made simpler and bolder. Both issues are discussed in this section.

Reduce level of feature detail

Chapter 9—Cultural Features and Chapter 12—Boundaries demonstrated that too many distinctions are made among such features as religious buildings on topographic maps and political boundaries on aeronautical charts. Sudden jumps in detail occur from one product to another for no apparent reason.

Chapter 18—Recommendations for Multiproduct Operations cites the need for orderly symbol sets that can be transcribed to symbol tables for digital production. A loosely hierarchical symbol scheme allows product symbol tables

Table 14. Type specification discrepancies between product specifications and style sheets.

	Product Specs	Style Sheets
Caslon Openface	X	X
Caslon Bold Condensed		X
Clearface Italic	X	
Alternate Gothic No. 3	X	X
Copperplate Gothic Italic		X
Formal Gothic Light Condensed		X
Formal Gothic Demi-Bold		X
Formal Gothic Demi-Bold Condensed		X
News Gothic	X	X
News Gothic Condensed	X	X
Techno Medium	X	X
Techno Medium Italic	X	X
Techno Bold	X	X
Techno Bold Italic	X	X
Univers Light Italic	X	
Univers Light Condensed	X	X
Univers Light Condensed Italic	X	X
Univers Medium	X	
Univers Medium Italic	X	
Univers Medium Condensed	X	X
Univers Medium Condensed Italic	X	X
Univers Bold Condensed		X
Univers Bold Condensed Italic		X

to be derived one from the other, much as products are derived one from the other. Using hierarchically organized symbol tables will save money if discrepancies between products are eliminated.

Reduce level of symbol detail

Symbols should be redesigned to be simpler and bolder. When digital data bases are used to generate products, the final stage of reproduction may be decentralized. DMA could lose control of the output media used to generate maps and charts. Hardcopy maps printed on five-color presses will be joined by hardcopy maps printed with pen and ink-jet plotters and photographic, photocopy, and thermal printers. Softcopy maps will use CRT, video, projected, light valve, and liquid crystal displays. Technology is moving so rapidly that attempts to summarize display limitations and commonalities can only hope to freeze a single moment in time.

The way, however, is clear: symbols should be designed so they are recognizable despite variations in resolution,

Table 15a. Variations in type specifications for City Graphics.

	Product Specs	Style Sheets
Univers Light Condensed		X
Univers Light Condensed Italic		X
Univers Medium	X	
Univers Medium Condensed	X	X
Univers Medium Condensed Italic	X	X
Univers Bold Condensed		X
Univers Bold Condensed Italic		X
Clearface Italic	X	
Spartan Medium Italic	X	

Table 15b. Variations in type specifications for 1:50,000 topographic maps.

	Product Specs	Style Sheets
Univers Light	X	
Univers Light Condensed	X	X
Univers Light Condensed Italic	X	X
Univers Medium	X	
Univers Medium Italic	X	
Univers Medium Condensed	X	X
Univers Medium Condensed Italic	X	
Univers Bold Condensed	X	X
Univers Condensed Italic	X	
Clearface Italic	X	

Table 15c. Variations in type specifications for hydrographic charts.

	Product Specs	Style Sheets
Techno Light Italic	X	
Techno Medium	X	X
Techno Medium Italic	X	
Techno Bold		X
News Gothic	X	X
News Gothic Condensed	X	X
Century Expanded	X	
Century Expanded Italic	X	
Univers Light Italic	X	
Lightline	X	

Table 15d. Variations in type specifications for Tactical Pilotage Charts.

	Product Specs	Style Sheets
Techno Medium	X	X
Techno Bold		X
Techno Bold Italic	X	X
Alternate Gothic No. 3	X	X
News Gothic		X
News Gothic Condensed		X
Formal Gothic Light Condensed		X
Formal Gothic Demi-Bold		X
Copperplate Gothic Italic		X
Caslon Openface	X	X

Table 15e. Variations in type specifications for Operational Navigation Charts.

	Product Specs	Style Sheets
Techno Medium	X	X
Techno Bold		X
Techno Bold Italic	X	X
Alternate Gothic No. 3	X	X
Formal Gothic Light Condensed		X
Formal Gothic Demi-Bold		X
Caslon Openface	X	

Table 15f. Variations in type specifications for Jet Navigation Charts.

	Product Specs	Style Sheets
Techno Medium	X	X
Techno Bold	X	
Techno Bold Italic	X	X
News Gothic		X
Formal Gothic Light Condensed		X
Formal Gothic Demi-Bold		X
Caslon Openface	X	
Caslon Bold Condensed	X	

Table 15g. Variations in type specifications for Global Navigation and Planning Charts.

	Product Specs	Style Sheets
Techno Medium	X	X
Techno Medium Italic	X	X
Techno Bold Italic	X	
Formal Gothic Demi-Bold		X
Formal Gothic Demi-Bold Condensed		X
Caslon Openface	X	

color reproduction, and viewing conditions. Many current symbols would fail this test (see Chapter 19). This report suggests bolder, simpler symbols throughout. Iconicity through contiguity will produce better symbols than the imitative pictographs often used (see Chapter 1). Changes that align symbol prominence with relative importance must be made comprehensively.

RECONCILE SPECIFICATIONS

Product specification has been an evolutionary process involving autonomous production centers. Organization and terminology vary. Some product specifications use metric, others use English measures. Some instructions are precisely and elegantly clear; others hedge.

Manual-to-digital conversion requires that processes be defined in detail before they are formalized by coded computer instructions. Unintelligible, vague, and irregular product specifications will increase software development costs and increase the risk of software inaccuracy. Programmers will be forced first to interpret design regulations before translating them to computer rules. DMA's product specifications must be tightened to avoid errors and added espense.

EXTEND STATEMENTS OF INTENDED USE

Intended uses for DMA standard products are only cursorily defined. For example, the intended uses of the JNC and the ONC are ostensibly the same although their content and format are significantly different. The JOG, the TPC, and the ONC are to be used for low altitude navigation.

For economy, each of DMA's products must meet a wide range of user requirements. Unfortunately, clutter results when requirements are unfocused. Limiting the number of intended uses (and users) of each product would contribute to better products. Conversely, designing only a single product for each type of activity would contribute to greater efficiency. If each product could be focused on a limited set of users, clutter would be more manageable.

25. Recommended Research Program

Imminent conversion to digital production must change DMA's product designs for efficiency's sake. Since human decisions dominate the mapmaking process in its present form, it is often assumed that the role of digital equipment will be to replace the draftsman until such time as artificial intelligence can duplicate the knowledge base and thought processes of cartographers. Yet to procure expensive digital production equipment merely to replace pen and scribe would be a shameful waste of computer resources.

Whenever current design practices require subjective decisions, DMA should try to revise the design practice itself before relegating it to interactive processing and artificial intelligence testbeds. Cartography has evolved to its present mix of art and science because humans excel at and enjoy art, not because artistry and subjectivity are essential cartographic processes. A firm commitment to digital production entails abandoning certain traditions to implement techniques that exploit the computer's fortes: computation and data processing.

This report describes ways for DMA to improve its product line and increase efficiency. Changes to current product designs are proposed throughout. This chapter outlines a research program to implement the recommended changes.

USER REQUIREMENTS ANALYSIS

Ultimately, the most effective remedy for clutter is to reduce the density of features shown. This report cites studies of user requirements to determine appropriate content for DMA products. In some cases (i.e., underground features and bathymetry on aeronautical charts), logic and reason substitute for actual requirements data. Other cases are unclear.

Questionnaire survey

Some questions of content raised by this report can be answered only by a comprehensive requirements survey. The proven way to perform a requirements survey is via questionnaire. Such a questionnaire would attempt to answer the following items.

- How helpful is vegetation to mapreaders?
- Have users found vegetation to be reliable?
- What would be the impact of substituting a 1:100,000 product for the 1:250,000 JOG?
- Must both the UTM grid and geographic coordinates be included on all DMA products?
- Are bilingual charts necessary?
- Are both spot soundings and contours needed on hydrographic charts?
- Are both spot elevations and Mean Elevation Figures needed on aeronautical charts?

The questionnaire survey would indicate initial user requirements. For ongoing requirements analysis, however, there are new alternatives springing from the rising use of electronic maps and charts.

Use of training simulators for requirements analysis

Gaming and simulation were used successfully in the surveyed literature to analyze data needs (see discussion of research in Introduction). Training simulators can be exploited in like manner to monitor performance as data availability and presentation are varied.

Analysis of transformed digital datasets

DMA, as a future supplier of digital terrain and feature data to electronic mapping and charting systems, has a unique opportunity to initiate a system of continuous user requirements analysis. Standard digital data bases will be transformed to suit the needs of individual applications, deriving system-specific datasets of required features and attributes. In Chapter 8, feedback provided from requests for digital hydrographic data helped to analyze the need for spot soundings. DMA will have more like opportunities to determine users' data requirements by examining requests for, and types of transformations performed on, digital cartographic data.

Analysis of electronic chart users

In the future, electronic map and chart users will command dynamic displays of interactively selected digital data. Transaction logs have been recommended for future navigation systems that incorporate electronic charts. As aircraft land or ships berth, all data transactions (queries, displays, etc.) involved in the activity would be recorded in the log. The log's primary purpose would be legal, like the current "black box" used on commercial aircraft. Statistics from such logs would help DMA to stay abreast of user requirements.

PROTOTYPE PRODUCT LINE

Recommendations have been made to change some portions of every DMA product reviewed in this study. A 1:100,000 ground/air product was suggested to eventually replace the JOG. Also worth investigating is a standard format for a medium scale, quick response product based on a merge of digital elevation data and digital imagery. This section outlines research and development needed to enact the changes suggested for DMA's products.

Common operations

The previous chapter outlined ways for DMA to promote efficient production, including overhauling symbol sets and type practices, reconciling irregularities in product specification, and extending and focusing the formal statements of intended use.

Improvements to the graphic quality of DMA's maps and charts are also recommended. Common to several products are

- computing product dimensions that will simplify product derivation and optimize image area within hardware constraints;
- standardizing map margins so common elements are in common locations;
- defining selection criteria to a level of detail where computer instructions can be coded for each product;
- refining feature selection algorithms for use by DMA;
- designing bolder, simpler symbol sets organized hierarchically for symbol table derivation;
- experimenting with grid techniques;
- developing an outlining technique to emphasize the shape of drainage features and coastlines;
- developing a technique to estimate terrain ruggedness, a judgment needed to support several current practices.

The preceding items are general to the product line. The following is a program to enact changes specific to individual products.

Topographic map

Changes to the topographic map require the operations listed.

- Select a color scheme, including a background tint.
- Design a margin layout with bleeding edges for the new landscape format.
- Implement Tanaka contouring.
- Compare speed of producing and interpreting Tanaka contours alone to Tanaka contours with hillshading.
- Incorporate changes to content suggested in Chapter 21 and confirmed by user requirements survey.

1:100,000 Ground/Air Product (GAP)

The product, geared to the needs of nap-of-the-earth pilots, will show slope zones and use a feature separation scheme allowing features to be portrayed differently on ground and air products. Required development follows.

- Define user requirements in detail.
- Develop feature separation scheme.
- Develop symbols that are compatible with product scale and that provide emphasis based on the importance of features to ground and air users.
- Develop color scheme.
- Implement slope zoning.

TPC

Only minor changes are needed. Some symbols should be discontinued or simplified. Type variations should be minimized.

ONC, JNC, and GNC

These products have similar problems, for which similar remedies have been suggested.

- Experiment with four-color hillshading and image-based backgrounds to derive a suitable alternative for Terrain Characteristic Tints and Area Tints.
- Develop a color scheme to emphasize aeronautical information.
- Incorporate changes to content that are confirmed by the user requirements survey.

Hydrographic chart

Two decision algorithms and one graphic technique need to be developed.

- Implement line-of-sight selection algorithm.
- Develop criteria and algorithm to determine when spot soundings rather than contours must be shown.
- Develop a technique to show the shape of the horizon from offshore.

City Graphic

The color and symbol schemes used on the USGS San Juan prototype are recommended for the DMA City Graphic. A better system of street labeling could also be developed.

PROTOTYPE IMAGE MAPS

Image maps from Landsat 4 Thematic Mapper data could provide DMA with a quick response product line. The USGS has compiled image maps at scales ranging from 1:100,000 to 1:1,000,000. Compilation processes included:

- choosing three from the seven available bands;
- assigning yellow, magenta, and cyan to the bands;
- image enhancement;
- geometric registration;
- reproduction from laser beam recorder negatives.

Image maps are informative and, more important, up-to-date. Features particularly important to military use (roads, drainage, relief, coastlines) are prominent on satellite images and can be enhanced for greater prominence. Special requirements (vegetation or soil moisture, for example) can be satisfied, since image maps can be made to order.

The only practical way to implement quick response image mapping is with standard formats, margins, and (to the extent possible) procedures. Prototype image maps were produced lithographically by the USGS from electro-optically acquired data and from film photographs.

Image maps can be enhanced by superimposing symbols on important features using algorithms from the Remote Work Processing Facility (a testbed for image understanding and feature extraction) to recognize and estimate the importance of features. Depending on image quality, road surface and width could be detected and coded. Annotation can be added; the USGS has found white type with a black halo to be readable.

Technology is available to implement quick response image mapping at DMA. A review of USGS prototype efforts should precede planning, design experimentation, and standardization of procedures.

MAP AND CHART DESIGN TESTBED

Map prototyping is hindered by prohibitive costs and other obstacles. Fortunately, the digital age offers relief. Experimental maps and charts can be designed interactively, with colors, symbols, and techniques dynamically interchangeable. Interesting new designs can be saved in hard- or softcopy to be evaluated by users.

An experimental design testbed is strongly recommended. Testbed hardware could be any high-resolution, large format graphic display accompanied by a library of mapping and graphic utilities, cartographic control structures, and hardcopy capability (a camera is sufficient). Standard product designs to serve both hardcopy and softcopy needs should be developed to reduce DMA's workload as much as possible.

MODEL PRODUCT DERIVATION

Using a sample dataset, product derivation from largest to smallest scale should be modeled so problems are anticipated at the earliest possible stage. To derive an entire GNC from 1:50,000 maps covering 1/26th of the earth is obviously too heavy of a data processing load for a simple model. Instead, derivation should focus on mosaicking formulas and selection results in small, selected areas.

SUMMARY

Steps to enact design change to the products reviewed are listed in this chapter. Designing a schedule to undertake the suggested research awaits feedback and prioritization of research by DMA.

Techniques mentioned are, in many cases, available and need only adaptation to run on DMA hardware using DMA standard datasets. In other cases, adequate techniques do not exist (generalization is one such instance). In both cases, development can take place outside the scope of design modification. However, some techniques have working or potentially working algorithms, but extensive experimentation is still required to achieve the desired results. Terrain Characteristic Tinting using four-color hillshading is one such technique. Developing a means to show the shape of the horizon from offshore is another. These techniques must be developed in tandem with design modification.

After allowing time to discuss the issues raised by this report, a comprehensive program of research, modeled to DMA's wishes, will be designed and implemented.

Bibliography

Ahn, John and Herbert Freeman (1983). *The Name-Placement Problem for Maps.* Image Processing Laboratory. Rensselaer Polytechnic Institute, Troy, New York, March.

Allen, T.M. and A.L. Straub (1955). Sign Brightness and Legibility. *Highway Research Board Bulletin* 127, pp. 1-14.

Amachree, Tomlinson K.P., Hubertus L. Bloemer, and Bob J. Walter (1977). Typographic Legibility on Maps: A Comparative Study. *Society of University Cartographers Bulletin* 11, January, pp. 27-39.

Anderson, H.C. (1970). User Requirements for Modern Nautical Charts. *Surveying and Mapping* 30, June, pp. 269-281.

Anderson, Robert H. and Norman Z. Shapiro (1979). *Design Considerations for Computer-based Interactive Map Display Systems.* Rand Corporation, Report R-2382-ARPA.

Andrews, R.S. and S. Ringle (1964). Certitude Judgements and Accuracy of Information Assimilation from Visual Displays. *USA PRO Technical Research Note* 145.

Anonymous (1980). The IHO International Chart—The Way Ahead. *International Hydrographic Review* 57, January, pp. 11-14.

Arnberger, Erik (1974). Problems of an International Standardization of a Means of Communication through Cartographic Symbols. *International Yearbook of Cartography* 14, pp. 19-35.

Arnheim, Rudolph (1976). The Perception of Maps. *The American Cartographer* 3, April, pp. 5-10.

Aumen, William C. (1970). A New Map Form: Numbers. *International Yearbook of Cartography* 10, pp. 80-84.

Baker, C.A. and R.M. Nicholson (1967). Raster Scan Parameters and Target Identification. *Proceedings of the 19th Annual Aerospace Electronics Conference*, May.

Baker, J.D. and I. Goldstein (1966). Batch vs. Sequential Displays: Effects on Human Problem Solving. *Human Factors* 8, pp. 225-235.

Baker, J.D., D.F. Morris, and W.C. Steedman (1960). Target Recognition in Complex Displays. *Human Factors* 2, pp. 51-61.

Balodis, M. (1981). Cartographic Typography and Map Readability. *Papers from the ACSM Fall Technical Meeting*, September, pp. 365-379.

Balodis, M. (1983). Positioning of Typography on Maps. *Proceedings of the ACSM Fall Technical Meeting*, September, pp. 28-44.

Barmack, J.E. and H.W. Sinaiko (1966). *Human Factors Problems in Computer Generated Displays.* Institute for Defense Analysis, Research and Engineering Support Division, Washington, D.C., Study S-234.

Barnard, J. et al. (1976). *Study of Map Usage in Helicopters in Low Level Flight.* Plessey Radar Research Center, Havant, Hampshire, Report 17/76/R063C.

Bartholomew, J.C. and I.A.G. Kinniburgh (1973). The Factor of Awareness *The Cartographic Journal* 10, June, pp. 59-62.

Bartz, Barbara S. (1969a). Type Variation and the Problem of Cartographic Type Legibility. *Journal of Typographic Research* 3, Spring, pp. 127-144.

Bartz, Barbara S. (1969b). Search: An Approach to Cartographic Type Legibility Measurement. *Journal of Typographic Research* 3, October, pp. 387-398.

PREVIOUS PAGE IS BLANK

Bartz, Barbara S. (1970a). Experimental Use of the Search Task in an Analysis of Type Legibility in Cartography. *Journal of Typographic Research* 4, Spring, pp. 147-167.

Bartz, Barbara S. (1970b). An Analysis of the Typographic Legibility Literature: Assessment of its Applicability to Cartography. *The Cartographic Journal* 7, June, pp. 10-16.

Basoglu, Unit. (1983). Automated Name Placement Phase II (Draft). CACI, Inc., Washington, D.C.

Bennett, H.A., L.A. Hogg, and A.A.H. Lockyer (1967). The Land Map and Air Chart at 1:25,000. *The Cartographic Journal* 4, December, pp. 89-95.

Berlin, B. and P. Kay (1969). *Basic Color Terms, Their Universality and Evolution*. Berkeley: University of California Press.

Berry, H.A. (1961). Topographic Data Output Study, Final Progress Report. Aeronutronic Division, Ford Motor Company, Newport Beach, California, Aeronutronic Publication u-1252.

Bertin, Jacques (1978). Theory of Communication and Theory of "The Graphic." *International Yearbook of Cartography* 18, pp. 118-124.

Bertin, Jacques (1981). *Graphics and Graphic Information Processing*. New York: Walter de Gruyter.

Bickmore, David P. (1980). Future Research and Development in Computer-Assisted Cartography. In: *The Computer in Contemporary Cartography*, D.R.F. Taylor (ed.), New York: John Wiley and Sons, Ltd.

Bigelow, Charles and Donald Day (1983). Digital Typography. *Scientific American* 249, August, pp. 106-119.

Board, C. (1973). Cartographic Communication and Standardization. *International Yearbook of Cartography* 13, pp. 229-236.

Board, C. (1978). How Can Theories of Cartographic Communication be Used to Make Maps More Effective? *International Yearbook of Cartography* 18, pp. 40-49.

Board, C. (1978). Map Reading Tasks Appropriate in Experimental Studies in Cartographic Communication. *The Canadian Cartographer* 15, pp. 11-21.

Board, C. and A. Buchanan (1974). Evaluating Thematic Maps—Current Trends in the United Kingdom. *The Cartographic Journal* 11, December, pp. 124-128.

Bolton, M.J.P. and C.C. Tam (1974). Computer Method for Radar Site Selection. *The Cartographic Journal* 11, December, pp. 117-120.

Bowen, H.M., J. Andreas, S. Truax, and J. Orlansky (1960). Optimum Symbols for Radar Displays. *Human Factors* 2, pp. 28-33.

Boyle, A.R. (1974). Geographic Information Systems in Hydrography and Oceanography. *The Canadian Cartographer* 11, December, pp. 125-141.

Brandes, D. (1973). Sources of Relief Representation Techniques. *The Cartographic Journal* 20, December, pp. 87-94.

Brandes, D. (1975). *Relative Effectiveness of Selected Relief Representation Methods for Topographic Maps*. M.A. Thesis, Department of Geography, University of Calgary, Calgary, Alberta.

Brandes, D. (1976). The Present State of Perceptual Research in Cartography. *The Cartographic Journal* 13, December, pp. 172-176.

Bridgman, C.S. and E.A. Wade (1956). Optimum Letter Size for a Given Display Area. *Journal of Applied Psychology* 40, pp. 378-380.

Brophy, David M. (1973). An Automated Methodology for Linear Generalization in Thematic Cartography. *Technical Papers of the ACSM 33rd Annual Meeting*, pp. 300-314.

Burt, Cyril (1959). *A Psychological Study of Typography*. Cambridge: The University Press.

Buttenfield, Barbara (1984). An Automated Method for Cartographic Line Discrimination. *Paper presented at Ann. Meeting, Association of American Geographers*, April.

Caldwell, Patricia S. (1981). Television News Maps: The Effects of the Medium on the Map. In: *Papers of the ACSM 41st Annual Meeting*, pp. 382-392.

Carmichael, L.D. (1972). Cartographic Depiction of Land Resources Information. *The Cartographic Journal* 9, June, pp. 52-53.

Case, H.W. et al. (1952). Analysis of Certain Variables Related to Sign Legibility. *Highway Research Board Bulletin* 60, pp. 44-54.

Castner, Henry W. (1979). Viewing Time and Experience as Factors in Map Design Research. *The Canadian Cartographer* 16, December, pp. 145-158.

Castner, Henry W. (1983). Research Questions and Cartographic Design. In: *Graphic Communication and Design in Contemporary Cartography*, D.R.F. Taylor (ed.), New York: John Wiley and Sons, pp. 87-113.

Castner, Henry W. and Gerald McGrath (1982). *Preliminary Study of the Design of the Canadian Nautical Chart in Relation to the Needs of the Users*. Bedford Oceanographic Institute, Nova Scotia, March.

Castner, H. and A.H. Robinson (1969). Dot Area Symbols in Cartography: The Influence of Pattern on their Perception. Technical Monograph No. CA-4, Cartography Division, American Congress on Surveying and Mapping, Washington, D.C.

Castner, Henry W. and R.D. Wheate (1979). Re-assessing the Role Played by Shaded Relief in Topographic Scale Maps. *The Cartographic Journal* 16, December, pp. 77-85.

Cerny, James W. and John Wilson (1976). The Effect of Orientation on the Recognition of Simple Maps. *The Canadian Cartographer* 13, December, pp. 132-138.

Chaloogin, E.I. (1967). Application of Photoluminescence in Cartography. *International Yearbook of Cartography* 7, pp. 93-95.

Chang, Kang Tsung (1976). Data Differentiation and Cartographic Symbolization. *The Canadian Cartographer* 13, June, pp. 60-68.

Christ, Richard E. (1975). Review and Analysis of Color Coding Research for Visual Displays. *Human Factors* 17, June, pp. 542-570.

Christner, C.A. and H.W. Ray (1961). An Evaluation of the Effect of Selected Combinations of Target and Background Coding on Map-Reading Performance. *Human Factors* 3, July, pp. 131-146.

Ciccone, D., B. Landee, and G. Weltman (1978). *Use of Computer-Generated Movie Maps to Improve Tactical Map Performance*. Perceptronics, Inc., Woodland Hills, California, TR PTR-10335-78-4, April.

Ciccone, Donald S., Michael G. Samet, and James B. Channon (1979). *A Framework for the Development of Improved Tactical Symbology*. Perceptronics, Inc., Woodland Hills, California, AD076017, August.

Clare, W.G. (1964). Map Reproduction. *The Cartographic Journal* 1, December, pp. 42-48.

Cole, Daniel G. (1981). Recall vs. Recognition and Task Specificity in Cartographic Psychophysical Testing. *The American Cartographer* 8, April, pp. 55-66.

Cornwell, Bruce and A.H. Robinson (1966). Possibilities for Computer Animated Films in Cartography. *The Cartographic Journal* 3, December, pp. 79-82.

Coueignoux, P. (1981). Character Generation by Computer. *Computer Graphics and Image Processing* 16, pp. 240-269.

Cox, Carleton W. (1973). Adaptation-Level Theory as an Aid to the Understanding of Map Perception. *Technical Papers of the ACSM 33rd Annual Meeting*, pp. 334-355.

Cox, Carleton W. (1975). Psychophysical Research and Map Reading Analysis. *Auto-Carto II, Proceedings of the Internatinal Symposium on Computer-Assisted Cartography*, September, pp. 233-237.

Cox, C.W. (1976). Anchor Effects and the Estimation of Graduated Circles and Squares. *The American Cartographer* 3, pp. 65-74.

Crawford, P.V. (1973). Perception of Graduated Squares as Cartograpohic Symbols. *The Cartographic Journal* 10, pp. 85-88.

Crocker, W.T. (1964). Type for Maps. *Cartography* 5, pp. 95-100.

Cromie, B.W. (1978). *Contour Design and the Topographic Map User.* M.A. Thesis, Department of Geography, Queens University, Kingston, Ontario.

Crook, M.N., J.A. Hanson, and A. Weisz (1954). *Aeronautical Charts Under Red Light.* Wright Air Development Center, Wright Patterson Air Force Base, WADC-TR-54-198.

Crowell, Wim. (1970). Type Design for the Computer Age. *Journal Typographic Research* 4, Winter, pp. 51-60.

Csati, E. (1974). *Automation: A New Trend in Cartography.* ICA and the Institute of Surveying and Mapping, Budapest.

Cuff, David J. (1972). Value Versus Chroma in Color Schemes on Quantitative Maps. *The Canadian Cartographer* 9, December, pp. 134-140.

Cuff, David J. (1973a). Colour on Temperature Maps. *The Cartographic Journal* 10, June, pp. 17-21.

Cuff, David J. (1973b). Shading Patterns on Choropleth Maps: Some Suspicions Confirmed. *Proceedings of the Association of American Geographers* 5, pp. 50-54.

Cuff, David J. (1974). Impending Conflict in Color Guidelines for Maps of Statistical Surfaces. *The Canadian Cartographer* 11, June, pp. 54-58.

De las Cuevas, Rodolfo Nunez (1967). Color in Topographic Maps. *International Yearbook of Cartography* 7, pp. 112-119.

DeLucia, Alan (1972). The Effect of Shaded Relief on Map Information Accessibility. *The Cartographic Journal* 9, June, pp. 14-18.

Dettori, G. and B. Falcidieno (1982). An Algorithm for Selecting Main Points on a Line. *Computers and Geosciences* 8, pp. 3-10.

Dobson, Michael W. (1975). The Map—in the Mind's Eye. *Auto-Carto II, Proceedings of the International Symposium on Computer-Assisted Cartography*, September, pp. 225-231.

Dobson, Michael W. (1977). Eye Movement Parameters and Map Reading. *The American Cartographer* 4, April, pp. 39-58.

Dobson, Michael W. (1979). Alternate Research Strategies and Map Reading. *Auto-Carto IV, Proceedings of the International Symposium on Cartography and Computing*, November, pp. 474-479.

Dobson, Michael W. (1980). The Influence of the Amount of Graphic Information on Visual Matching. *The Cartographic Journal* 17, June, pp. 26-32.

Dobson, Michael W. (1983a). Human Factors in the Cartographic Design of Real-Time Color Displays. *Auto-Carto VI, Proceedings of the International Symposium on Computer-Assisted Cartography*, October, pp. 421-426.

Dobson, Michael W. (1983b). A High Resolution Microcomputer-based Color System Examining the Human Factors Aspect of Cartography in a Real-Time User Environment. *Auto-Carto VI, Proceedings of the International Symposium on Computer-Assisted Cartography*, October, pp. 352-360.

Dobson, Michael W. (1983c). Visual Information Processing and Cartographic Communication: The Utility of Redundant Stimulus Dimensions. In: *Graphic Communication and Design in Contemporary Cartography*, D.R.F. Taylor (ed.), New York: John Wiley and Sons, pp. 149-175.

Dornbach, John E. (1959). Design Problems in Aeronautical Charting. *The Professional Geographer* 11, March, pp. 7-10.

Dornbach, John E. (1975). An Analysis of Approaches in Map Design. *Auto-Carto II, Proceedings of the International Symposium on Computer-Assisted Cartography*, September, pp. 194-203.

Douglas, David H. and Thomas K. Peucker (1973). Algorithms for the Reduction of the Number of Points Required to Represent a Digitized Line or Its Caricature. *The Canadian Cartographer* 10, December, pp. 112-122.

Drewitt, Betty (1973). The Changing Profile of the Map User in Great Britain. *The Cartographic Journal* 10, June, pp. 42-48.

Dutton, Geoffrey (1981a). *Realistic Display of Digital Terrain Data*. Graduate School of Design, Harvard University, Cambridge, Massachusetts., unpublished.

Dutton, Geoffrey (1981b). The Seurat Program. *Computer Graphics and Applications* 1, July, pp. 113-114.

Dutton, Geoffrey (1982). Land Alive. *Perspectives in Computing* 2, March, pp. 26-39.

Easterby, R.S. (1970). The Perception of Symbols for Machine Displays. *Ergonomics* 13, pp. 149-158.

Ekman, G. and K. Junge (1961). Psychophysical Relations in the Perception of Visual Length, Area, and Volume. *Scandanavian Journal of Psychology* 2, pp. 1-10.

Ekman, G., R. Lindman, and W. William-Olsson (1961). A Psychological Study of Cartographic Symbols. *Perceptual and Motor Skills* 13, pp. 355-368.

Ericksen, C.W. (1955). Partitioning and Saturation of Visual Displays and Visual Search. *Journal of Applied Psychology* 36, pp. 73-77.

Even, Shimon (1979). *Graph Algorithms*. Computer Science Press, Rockville, Md.

Farrell, John P. (1977). Effects of Terrain Portrayal Format on User Performance. *TCATA Proceedings of the Computer Graphic Symposium*, Fort Hood, Texas, August, pp. 51-81.

Farrell, John P. and Lawrence M. Potash (1979). *A Comparison of Alternate Formats for the Portrayal of Terrain Relief on Military Maps*. U.S. Army Research Institute for the Behavioral and Social Sciences, Alexandria Virginia, TR 428, November.

Flannery, J.J. (1971). The Relative Effectiveness of Some Common Graduated Point Symbols in the Presentation of Quantitative Data. *The Canadian Cartographer* 10, pp. 96-109.

Fleming, E.A. (1970). The Possibilities and Limitations of Photomaps at Scales of 1:250,000 and Smaller. *The Canadian Cartographer* 7, December, pp. 137-143.

Foster, J.J. and W. Kirkland (1971). Experimental Studies in Map Typography. *Bulletin of the Society of University Cartographers* 6, pp. 40-45.

French, Robert J. (1954). Pattern Recognition in the Presence of Visual Noise. *Journal of Experimental Psychology* 47, January, pp. 27-31.

Gardiner, Brigadier R.A. (1964). Typographic Requirements of Cartography. *The Cartographic Journal* 1, June, pp. 42-44.

Gilman, Clarence R. (1982). Map Commentary: 1:100,000 Map Series. *The American Cartographer* 9, October, pp. 173-177.

Gilman, Clarence R. (1983). Map Design at U.S.G.S.: A Memoir. *The American Cartographer* 10, April, pp. 31-49.

Glenn, Bernice T. (1984). Alphabet and Text in Presentation Graphics: Their Critical Contribution to Readability and Meaning. *Computer Graphics World* 7, January, pp. 10-22.

Gombrich, E.H. (1963). *Meditations on a Hobby Horse and Other Essays on the Theory of Art*. London: Phaidon, pp. 13. In: *International Yearbook of Cartography* 13, pp. 229-236.

Granda, Thomas M. (1976). *A Comparison Between a Standard Map and Reduced Detail Map Within a Simulated Tactical Operations System*. U.S. Army Research Institute, Alexandria, Virginia, TR 274, AD A028752, June.

Granda, Thomas M. (1978). *An Evaluation of Visual Search Behavior on a Cathode Ray Tube Utilizing the Window Technique*. Research Institute for the Behavioral and Social Sciences, Alexandria, Virginia, AD A053352, February.

Greenberg, G.L. (1971). Irradiation Effect on the Perception of Map Symbology. *International Yearbook of Cartography* 11, pp. 120-126.

Greene, Peter H. (1958). *Factors in Visual Acuity. Report on the Application of Information Theory to the Nervous System*. Contract AF 18(600)1454, August.

Guptill, Stephen C. (1978). An Evaluation Technique for Categorical Maps. *Geographical Analysis* 10, July, pp. 248-261.

Hanby, T.C. and A. Shaw (1969). *The Effects of the Legibility of Maps of Increasing Information*. U.S. Army European Research Office, Experimental Cartography Unit, Royal College of Art, London, Contract DAJA37-69-C-0832, AD 701954, December.

Harrison, R.E. (1959). Art and Commonsense in Cartography. *Surveying and Mapping* 19, pp. 27-38.

Head, C. Grant (1972). Land-Water Differentiation in Black and White Cartography. *The Canadian Cartographer* 9, June, pp. 25-38.

Heath, Willis R. (1967). Cartographic Perimeters. *International Yearbook of Cartography* 7, pp. 112-120.

Hemingway, J.C. and R.A. Erickson (1969). Relative Effects of Raster Scan Lines and Image Subtense on Symbol Legibility on Television. *Human Factors* 11, pp. 331-338.

Herrington, C.G. (1960). Design of Reflectorized Motor Vehicle License Plates. *Highway Research Board Proceedings* 39, pp. 441-446 (cited by G.L. Greenberg, Irradiation Effect on the Perception of Map Symbology, *International Yearbook of Cartography* 11, pp. 120-126, 1971).

Hill, A.R. (1974). *Cartographic Performance: An Evaluation of Orthophotomaps*. Royal College of Art, London, England, Final Technical Report.

Hinckley, Thomas K. (1984). The Reform that Failed. *Proceedings of the ACSM Annual Meeting*, March, pp. 150-156.

Hirsch, Steven A. (1980). *Algorithms for Automatic Names Placement of Point Data*. M.A. Thesis, Department of Geography, State University of New York at Buffalo.

Hitchcock, Lloyd (1969). Readability of Videotaped Moving Map Displays. *Geographic Orientation in Air Operations*, JANAIR, November, pp. 167-173.

Honick, Kenneth Robert (1967). Pictorial Navigation Displays. *The Cartographic Journal* 4, December, pp. 72-81.

Honick, Kenneth Robert (1970). Developments in Pictorial Navigation Displays. *International Yearbook of Cartography* 10, pp. 104-110.

Honigfield, A.R. (1964). *Radar Symbology: A Literature Review*. U.S. Army Human Engineering Laboratories, Washington, D.C., Technical Memorandum 14-64.

Hopkin, V. David (1972). *An Experimental Study of Height Layer Tints in the Joint Operations Graphic Map*. RAF Institute of Aviation Medicine, IAM Science Memo 108.

Hopkin, V. David and Robert M. Taylor (1979). *Human Factors in the Design and Evaluation of Aviation Maps*. AGARD Report 225, AD A07663, June.

Horn, B.K.P. (1981). Hill Shading and the Reflectance Map. *Proceedings of the IEEE* 69, pp. 14-47.

Huizar, N.R. (1972). Evaluation of 1:50,000 Scale and Experimental Air Movement Data and Military Standard Maps. Headquarters MASSTER (Fort Hood, Texas), MASSTER Evaluation Number 4012.

Imhof, Eduard (1975). Positioning Names on Maps. *The American Cartographer* 2, pp. 128-144.

International Aeradio Ltd. (1965). Mapping the Invisible. *The Cartographic Journal* 2, December, pp. 85-86.

International Cartographic Association (1976). *Bibliography of Works on Cartographic Communication*. London.

Jenks, George F. and Fred C. Caspall (1967). *Vertical Exaggeration in Three Dimensional Mapping*. Geography Branch, Office of Naval Research, Washington, D.C., Technical Report 2, NR 389-146, Nonr 583(15).

Jenks, George F. and Duane S. Knos (1961). The Use of Shading Patterns in Graded Series. *Annals of the Association of American Geographers* 51, pp. 316-334.

Kadmon, Naftali (1975). Data-Bank Derived Hyperbolic-Scale Equitemporal Town Maps. *International Yearbook of Cartography* 15, pp. 47-54.

Kadmon, Naftali (1980). Automated Selection of Settlements in Map Generalization. *The Cartographic Journal* 9, pp. 124-127.

Kamkov, Anatolij M. (1971). The International Language of Geographical Maps. *International Yearbook of Cartography* 11, pp. 209-213.

Kang-Tsung, Chang (1977). Visual Estimation of Graduated Circles. *The Canadian Cartographer* 14, pp. 130-138.

Karmier, D.F. (1960). A Comprehensive Analysis of Motor Vehicle License Plates. *Highway Research Board Proceedings* 39, pp. 416-440.

Karssen, Aart J. (1980). Design Research: A Reaction from a Designer. In: Communication from Readers, *The American Cartographer* 7, April, pp. 76-78.

Karssen, Aart J. (1980). The Artistic Elements in Map Design. *The Cartographic Journal* 17, December, pp. 124-127.

Kaufman, Lloyd (1975). The Uses of Color. Auto-Carto II, *Proceedings of the International Symposium on Computer-Assisted Cartography*, September, pp. 270-276.

Keates, J.S. (1956). The Use of Type in Cartography. *Surveying and Mapping*, pp. 75-76.

Keates, J.S. (1973). *Cartographic Design and Production*. New York: Longman Group Ltd.

Keates, J.S. (1982). *Understanding Maps*. New York: John Wiley and Sons.

Kelly, Paul C. (1980). *Automated Positioning of Feature Names on Maps*. M.A. Research Report, Department of Geography, State University of New York at Buffalo.

Kember, I.D. (1971). Some Distinctive Features of Marine Cartography. *The Cartographic Journal* 8, June, pp. 13-20.

Kempf, R.P. and G.K. Poock (1969). Some Effects of Layer Tinting on Maps. *Perceptual and Motor Skills* 29, pp. 279-281.

Kimerling, A. Jon (1975). A Cartographic Study of Equal Value Gray Scales for Use with Screened Gray Area. *The American Cartographer* 2, pp. 119-127.

Kimerling, A. Jon (1980). Color Specification in Cartography. *The American Cartographer* 7, October, pp. 139-153.

Kirby, R.P (1970). A Survey of Map User Practices and Requirements. *The Cartographic Journal* 7, June, pp. 31-38.

Kirby, R.P. (1975). A Cartographic Study of Equal Value Gray Scales for Use with Screened Gray Area. *The American Cartographer* 2, pp. 119-127.

Knuth, Donald E. (1982). The Concept of Metafont. *Visible Language* 16, Winter, pp. 3-27.

Kolacny, A. (1969). Cartographic Information—A Fundamental Concept and Term in Modern Cartography. *The Cartographic Journal* 6, June, pp. 47-49.

Koleszar, Frank W. (1981). A Landmark-Based Location Reference Grid for Street Maps. *Proceedings of the ACSM 41st Annual Meeting* , pp. 395-406.

Kosmider, G. (1966). *Studies of Display Symbol Legibility: V. The Effect of Television Transmission on the Legibility of Common, Five Letter Words*. The MITRE Corp., Bedford, Massachusetts, Report ESD-TR-65-135, May.

Kulhavy, R.W., N.H. Schwartz, and S.H. Shaha (1982). Interpretive Framework and Memory for Map Features. *The American Cartographer* 9, October, pp. 141-147.

Lakin, F.H. (1967). *Evaluation of the Joint Operations Graphic*. Army Personnel Research Establishment, Farnborough, Hampshire, Report No. 5/67.

Lakin, F.H. (1972). *A Further Evaluation of the Joint Operations Graphic Series 1501 (Air)*. Army Personnel Research Establishment, Farnborough, Hampshire, Report No. 19/72.

Landee, B.M., M.G. Samet, and D.R. Foley (1979). *A Task-based Analysis of Information Requirements of Tactical Maps*. Perceptronics, Inc., Woodland Hills, California.

Landis, Daniel, Robert M. Slivka, James M. Jones, et al. (1967). *Evaluation of Large Scale Visual Displays*. Franklin Institute Research Laboratories, Behavioral Science Laboratories, RADC-TR-67-57, AD 651372, April.

Lang, T. (1969). Rules for Robot Draughtsmen. *Geographical Magazine* 42, October, pp. 50-51.

Lees, E.F.W. (1921). International Aeronautical Maps. *The Geographical Journal* 57, pp. 336-354.

Lewis, Gail E. (1982). *Automated Point Labeling for Geographic Data Bases*. M.S. Thesis, Department of Geography, Western Washington University, Bellingham, Washington.

Little, J.J. (1977). *SLOPER: A Program to Produce Slope Maps*. Geographic Data Structures Project, Simon Fraser University, TR 13, January.

Lo, C.P. (1973). Cartographic Presentation of Three-Dimensional Urban Information. *The Cartographic Journal 10*, December, pp. 77-84.

MacEachren, Alan M. (1972). The Role of Complexity and Symbolization Method in Thematic Map Effectiveness. *Annals of the Association of American Geographers* 72, December, pp. 495-513.

Macioch, Andrzej (1983). The System of Cartographic Denotations: A Scientific Language for Cartography. In: *Graphic Communication and Design in Contemporary Cartography*, D.R.F. Taylor (ed.), New York: John Wiley and Sons, pp. 219-229.

Mackworth, N.H. (1965). Visual Noise Causes Tunnel Vision. *Psychonomic Science* 3, pp. 67-68.

Magee, G.A. (1968). The Admiralty Chart: Trends in Content and Map Design. *The Cartographic Journal* 5, June, pp. 28-33.

Magnenat-Thalmann, N. and D. Thalmann (1982). La Conception des Cartes Geographiques Assistees par Ordinateur [The Design of Computer-Assisted Geographic Maps]. *Cartographica* 19, pp. 44-50.

Makowski, Andrzej (1967). Aesthetic and Utilitarian Aspects of Colour in Cartography. *International Yearbook of Cartography* 7, pp. 62-85.

Malakhov, N. (1961). Consistency in Selecting Populated Places and Roads for Maps. *Geoesy and Cartography* 8, pp. 378-380.

Marchbanks, G. and H. Levin (1965). Cues by Which Children Recognize Words. *Journal of Experimental Psychology* 56, pp. 57.

Marcus, Aaron (1983). Graphic Design for Computer Graphics. *Computer Graphics and Applications* 3, July, pp. 63-70.

McCann, Carol (1980). *Maps for Command and Control: The Human Factors Issues*. Defence and Civil Institute for Environmental Medicine, Downsview, Ontario, DCIEM Report No. 80-R-06, AD A081886, January.

McCann, Carol (1982). *Classification of Map Reading Tasks*. Defence and Civil Institute of Environmental Medicine, Downsview, Ontario, DCIEM TR 82-R-59, AD B072721, December.

McCleary, George F. (1970). Beyond Simple Psychophysics: Approaches to the Understanding of Map Perception. *Proceedings of the ACSM 30th Annual Meeting*, pp. 189-209.

McCleary, George F. (1983). An Effective Graphic "Vocabulary." *Computer Graphics and Applications* 3, March/April, pp. 46-53.

McGrath, G. (1964). The Identification of Symbols to Represent Vegetation on Topographic Maps. *The Canadian Surveyor* 18, pp. 129-139.

McGrath, G. (1971). *The Mapping of National Parks: A Methodological Approach*. *Cartographica* 2, pp. 71-76.

McGrath, G. and R.P. Kirby (1969). Survey Methods on the Use of Maps and Atlases. *The Canadian Cartographer* 6, December, pp. 132-148.

McGrath, J.J. (1973). *Chart Interpretation in Low-Altitude Flight*. Anacapa Sciences, Inc., Santa Barbara, California, Report No. 1970-71, NAVTRAEQUIP-70-C-0306-2, AD 76646.

McGrath, J.J. and G.J. Borden (1969). *Geographic Orientation in Aircraft Pilots: An Analytical Study of Visual Checkpoints*. Human Factors Research, Inc., Santa Barbara, California, TR 751-9.

McGrath, J.J. and W.E. Osterhoff (1969). *Geographic Orientation in Aircraft Pilots: Validation of an Analysis of Visual Checkpoints*. Human Factors Research, Inc., Santa Barbara, California, TR 751-16.

McGrath, J.J., W.E. Osterhoff, and G.J. Borden (1964). *Geographic Orientation in Aircraft Pilots: Experimental Studies of Two Cartographic Variables*. Human Factors Research Inst., Goleta, California, TR 751-3.

Meine, Karl-Heinz (1959). Aviation Cartography—Its Nature and International Function. In: *Information Relative to Cartography and Geodesy, 2nd International Cartographic Conference*, Chicago.

Meine, Karl-Heinz (1966). Aviation Cartography. *The Cartographic Journal* 3, June, pp. 31-39.

Meine, Karl-Heinz (1978). Certain Aspects of Cartographic Communication in a System of Cartography as a Science. *International Yearbook of Cartography* 18, pp. 102-115.

Meister, D. and D. Sullivan (1969). *Guide to Human Engineering Design*. Bunker-Ramo Corp., Report No. 196-080.

Merriam, Mylon (1971). Eye Noise and Map Design. *Cartographica* 2, pp. 22-28.

Miller, G.A. (1956). The Magical Number Seven, Plus or Minus Two: Some Limits on Our Capacity for Processing Information. *Psychological Review* 63, pp. 81-97.

Miller, O.M. (1933). An Experimental Air Navigation Map. *Geographical Review* 23, pp. 48-59.

Miller, O.M. (1957). *A Design for a Navigational Chart for Low-Altitude Flights at High Speeds*. Mapping and Charting Research Lab., Ohio State University, Columbus, Ohio, MCRL Technical Report No. 205.

Miller, O.M. and C.H. Summerson (1960). Slope-Zone Maps. *Geographical Review* 50, pp. 193-202.

Misulia, Michael G. (1969). Tailored Products: A New Era in Cartography. *Geographic Orientation in Air Operations*, JANAIR, November, pp. 76-81.

Modley, Rudolf (1972). Needed: World-Wide Map Symbols. *La Revue de Geographic de Montreal* 29, January, pp. 97-101.

Moellering, H. (1980). The Real-Time Animation of Three-Dimensional Maps. *The American Cartographer* 7, June, pp. 67-75.

Monmonier, Mark S. (1978). Variations Among Subjects in Power-Function Parameters Estimated for Steven's Law. *Proceedings of the ACSM Fall Technical Meeting*, pp. 264-274.

Monmonier, Mark S. (1979). Modelling the Effect of Reproduction Noise on Continuous-tone Area Symbols. *The Cartographic Journal* 16, pp. 22-25.

Monmonier, Mark S. (1980). The Hopeless Pursuit of Purification in Cartographic Communication: A Comparison of Graphic Arts and Perceptual Distortions of Graytone Symbols. *Cartographica* 17, June, pp. 24-39.

Monmonier, Mark S. (1981). Maps, Distortion, and Meaning. *Association of American Geographers Resource Paper* 75-4, December.

Montagano, G.A. (1962). Generalization of Hydrographic Features. *The Canadian Cartographer* 1, pp. 8-11.

Morrison, Alistair (1971). Experimental Maps of Road Travel Speed. *The Cartographic Journal* 8, December, pp. 115-132.

Morrison, Alistair (1974). Testing the Effectiveness of Road Speed Maps and Conventional Road Maps. *The Cartographic Journal* 11, December, pp. 102-116.

Morrison, Alistair (1975). Methods of Evaluating Motoring Maps. *International Yearbook of Cartography* 15, pp. 110-122.

Morrison, Joel L. (1976). The Science of Cartography and Its Essential Processes. *International Yearbook of Cartography* 16, pp. 84-97.

Morrison, Joel L. (1978). The Implications of the Ideas of Two Psychologists to the Work of the ICA Commission on Cartographic Communication. *International Yearbook of Cartography* 18, pp. 58-63.

Morrison, Joel L. (1979). The Benefits of Computer-Assisted Cartography for Map Reading. *Auto-Carto IV, Proceedings of the International Symposium on Cartography and Computing*, November, pp. 496-502.

Morrison, Joel L. (1980). Computer Technology and Cartographic Change. In: *The Computer in Contemporary Cartography*, D.R.F. Taylor (ed.), New York: John Wiley and Sons, pp. 5-24.

Morrison, Joel L. (1981). National Atlas Map Symbolization Changes. *Papers from the ACSM Fall Technical Meeting 1981*, pp. 72-81.

Muehrcke, Phillip C. (1976). Concepts of Scaling from the Map Reader's Point of View. *The American Cartographer* 3, October, pp. 123-141.

Murrell, J.F. (1970). *Aircrew Choice of Information on a Topographic Map*. RAF Institute on Aviation Medicine, Farnborough, Hampshire, Report No. 491.

Newhall, Sidney B., Dorothy Nickerson, and Deane B. Judd (1943). Spacing of the Munsell Colors. *Journal of the Optical Society of America* 33, pp. 385-418.

Olson, Judy M. (1975). Experience and the Improvement of Cartographic Communication. *The Cartographic Journal* 7, December, pp. 94-108.

Olson, Judy M. (1976). A Coordinated Approach to Map Communication Improvement. *The American Cartographer* 3, October, pp. 151-159.

Olson, Judy M. (1979). Cognitive Cartographic Experimentation. *The Canadian Cartographer* 16, June, pp. 34-44.

Olson, Judy M. (1981). Spectrally Encoded Two-Variable Maps. *Annals of the Association of the American Geographers* 71, June, pp. 259-276.

Olson, Judy M. (1982). New Approaches to Map Design through Computer Graphics. *Computer Graphics News* 2, pp. 4-7.

Ostrowski, Jerzi (1975). Cartographic Conception of Tourist Maps of Towns. *International Yearbook of Cartography* 15, pp. 123-132.

Patton, J.C. and P.V. Crawford (1977). The Perception of Hypsometric Colours. *The Cartographic Journal* 14, December, pp. 115-127.

Petchenik, Barbara Bartz (1974). A Verbal Approach to Characterizing the Look of Maps. *The American Cartographer* 1, April, pp. 63-71.

Petchenik, Barbara Bartz (1975). Cognition in Cartography. *Proceedings of the International Symposium on Computer-Assisted Cartography*, U.S. Bureau of the Census and the ACSM, September, pp. 183-193.

Petchenik, Barbara Bartz (1983). A Map Maker's Perspective on Map Design Research 1950-1980. In: *Graphic Communication and Design in Contemporary Cartography*, D.R.F. Taylor (ed.), New York: John Wiley and Sons, pp. 37-68.

Peucker, Thomas K. (1973). *Four Methods for Quantitative Settlement Selection* (unpublished).

Peucker, Thomas K. (1980). The Use of Computer Graphics for Displaying Data in Three Dimensions. *Cartographica* 17, pp. 59-72.

Peucker, Thomas K., Robert Journal Fowler, J.J. Little, and David M. Mark (1978). *The Triangulated Irregular Network*. Proceedings of the DTM Symposium, St. Louis, Missouri., ASP-ACSM, pp. 516-540.

Pfefferkorn, C.E. (19—). ________________. E.S.L., Sunnyvale, California, in progress.

Phillips, Richard J., A. DeLucia, and N. Skelton (1975). Some Objective Tests of the Legibility of Relief Maps. *The Cartographic Journal* 12, June, pp. 39-46.

Phillips, Richard J. and Elizabeth Noyes (1977). Searching for Names in Two City Street Maps. *Applied Ergonomics* 8.2, pp. 73-77.

Phillips, Richard J., Elizabeth Noyes, and R.J. Audley (1977). The Legibility of Type on Maps. *Ergonomics* 20, pp. 671-682.

Phillips, Richard J., Elizabeth Noyes, and R.J. Audley (1978). Searching for Names of Maps. *The Cartographic Journal* 15, December, pp. 72-77.

Pielore, F.A. (1971). Special Purpose Navigation Charts. *The Cartographic Journal* 8, June, pp. 21-29.

Potash, Lawrence M. (1977). Design of Maps and Map-Related Research. *Human Factors* 19, pp. 139-150.

Potash, Lawrence M., John P. Farrell, and Thomas E. Jeffrey (1979). *An Approach to Assessment of Relief Formats for Hardcopy Topographic Maps.* U.S. Army Research Institute for the Behavioral and Social Sciences, Alexandria, Virginia, AD-A069462, April.

Preston, M.G. (1936a). Contrast Effects and the Psychophysical Functions. *American Journal of Psychology* 48, pp. 389-402.

Preston, M.G. (1936b). Contrast Effects and the Psychometric Functions. *American Journal of Psychology* 48, pp. 625-631.

Pridgeman, C.S. and F.A. Wade (1956). Optimum Letter Size for a Given Display Area. *Journal of Applied Psychology* 40, pp. 378-380.

Promisel, D.M. (1964). Visual Target Location as a Function of Number and Kind of Competing Signals. *Journal of Applied Psychology* 45.

Raisz, E. (1962). *Principles of Cartography.* New York: McGraw-Hill.

Ratajski, Lech (1978). The Main Characteristics of Cartographic Communication as a Part of Theoretical Cartography. *International Yearbook of Cartography* 18, pp. 21-32.

Rayburn, J.A. (1968). The Placement of Dispersed Community Names on Medium and Large-Scale Maps. *The Canadian Cartographer* 5, June, pp. 18-24.

Reilly, Susan Smith and John W. Roach (1984). Improved Visual Design for Graphics Display. *Computer Graphics and Applications* 4, February, pp. 42-51.

Rhind, David W. (1973). Generalization and Realism Within Automated Cartographic Systems. *The Canadian Cartographer* 10, June, pp. 51-62.

Riffe, Philip D. (1970). Conventional Map, Temporary Map, or Non-Map? *International Yearbook of Cartography* 10, pp. 95-103.

Robinson, A.H. (1950). The Size of Lettering for Maps and Charts. *Surveying and Mapping* 10, January-March, pp. 37-44.

Robinson, A.H. (1952). *The Look of Maps.* Madison: University of Wisconsin Press.

Robinson, A.H. (1959). The Curve of the Gray Spectrum. *Annals of the Association of American Geographics* 49, pp. 457-460.

Robinson, A.H. (1965). The Future of the International Map. *The Cartographic Journal* 2, June, pp. 23-26.

Robinson, A.H. (1967). Psychological Aspects of Color in Cartography. *International Yearbook of Cartography* 7, pp. 50-59.

Robinson, A.H. (1970). Scaling Nonnumerical Map Symbols. *Proceedings of the ACSM 30th Annual Meeting*, pp. 210-216.

Robinson, A.H. (1977). Research in Cartographic Design. *The American Cartographer* 4, pp. 163-169.

Robinson, A.H. (1982). Program of Research to Aid Cartographic Design. *The American Cartographer* 9, April, pp. 25-29.

Robinson, A.H. and Barbara Bartz Petchenik (1975). The Map as a Communication System. *The Cartographic Journal* 12, June, pp. 7-15.

Robinson, D.O., M. Abbamonte, and S.H. Evans (1971). Why Serifs Are Important: The Perception of Small Print. *Visible Language* 5, pp. 353-359.

Rogers, Steven P. (1982). *Importance of Topographic Features and Tactical Annotations on Maps Used by Army Aviators for Nap-of-the-Earth Flight.* Anacapa Sciences, Inc., Santa Barbara, California, ADA118101.

Rowles, Ruth Anderson (1978). Perception of Perspective Block Diagrams. *The American Cartographer* 5, pp. 31-44.

Saito, George Kazuo (1962). *An Investigation of Some Visual Problems of Cartographic Lettering*. Unpublished Master's Thesis, Department of Geography, University of Washington, Seattle.

Schaubel, E.V. (1971). Mapping Expedients to Meet Military Requirements. *Cartographica* 2, pp. 12-17.

Schmidt, M. (1979). The Nautical Chart: Its Purpose and Content. *International Hydrographic Review*, July, pp. 75-83.

Segall, M.H., D. T. Campbell, and M. J. Herskovits, *The Influence of Culture on Visual Perception*. New York: Bobbs-Merrill.

Shaw, M.A. and M.J.R. MacLagan (1972). *Interpolating Positional Information Using Contour Maps*. Unpublished report to Social Science Research Council, London, England.

Shellswell, Major M.A. (1976). Towards Objectivity in the Use of Color. *The Cartographic Journal* 13, June, pp. 72-84.

Sheppard D. and J.M. Adams (1971). A Survey of Driver's Opinions on Maps for Route Finding. *The Cartographic Journal* 8, December, pp. 105-114.

Shimron, J. (1978). Learning Positional Information from Maps. *The American Cartographer* 5, April, pp. 9-19.

Shontz, W.D., G.A. Trumm, and L.G. Williams (1971). Color Coding for Information Location. *Human Factors* 13, March, pp. 237-246.

Shortridge, B.G. (1979). Mapreader Discrimination of Lettering Size. *The American Cartographer* 6, April, pp. 13-20.

Shortridge, B.G. (1982). Stimulus Processing Models from Psychology: Can We Use Them in Geography? *The American Cartographer* 9, October, pp. 155-167.

Shurtleff, D. (1966). *Design Problems in Visual Displays: I. Classical Factors in the Legibility of Numerals and Capital Letters*. The MITRE Corp., Bedford, Massuchesetts, Report ESD-TR-66-62. In: *Journal of Typographic Research* 3, pp. 79-90, 1969.

Shurtleff, D. A. (1980). *How to Make Displays Legible*. Human Interface Design. La Mirada, California (Cited by Dobson, 1983a).

Shurtleff, D.A. and D. Owen (1966). *Studies of Display Symbol Legibility: VI. A Comparison of the Legibility of Televised Leroy and Courtney Symbols*. MITRE Corp., Hansom Field, Report ESD-TR-65-136.

Shurtleff, Donald (1969). Relative Legibility of Leroy and Lincoln/MITRE Fonts on Television. *Journal of Typographic Research* 3, January, pp. 79-90.

Siekierska, Ewa (1983). Towards an Electronic Atlas. *Auto Carto VI, Proceedings of the Sixth International Symposium on Automated Cartography*, October, pp. 464-474.

Skop, Jacob (1959). Modern Warfare and the Map. In: *Information Relative to Cartography and Geodesy, 2nd International Cartographic Conference*, Chicago.

Smith, Richard M. (1984). The Influence of Texture on the Perception of Cartographic Gray Tones. Paper presented at the *Annual Meeting of the Association of American Geographers*, Washington, D.C., April.

Smith, Sidney L. and Nancy C. Goodwin (1971). Blink Coding for Information Display. *Human Factors* 13, September, pp. 283-290.

Smith, Sidney L. and Nancy C. Goodwin (1972). Another Look at Blinking Displays. *Human Factors* 14, April, pp. 345-347.

Soar, Robert S. (1955). Height-Width Proportions and Stroke Width in Numerical Visibility. *Journal of Applied Psychology* 39, pp. 43-46.

Stager, Paul and Trevor G. Paine (1980). Separation Discrimination in a Simulated Air Traffic Control Display. *Human Factors* 22, October, pp. 631-636.

Stenhouse, Helen (1979). Selection of Towns on Derived Maps. *The Cartographic Journal* 16, June, pp. 30-39.

Stevens, S.S. (1957). On the Psychophysical Law. *Psychological Review* 64, pp. 153-181.

Stevens, S.S. and E.H. Galanter (1957). Ratio Scales and Category Scales for a Dozen Perceptual Continua. *Journal of Experimental Psychology* 54, pp. 377-411.

Stilitz, I. (1976). Target Location in an Urban Map as a Function of Grid Size and Road Density. In: Searching for Names in Two City Street Maps, *Applied Ergonomics* 8, pp. 73-77.

Tanaka, Kitiro (1950). The Relief Contour Method of Representing Topography on Maps. *Geographical Review* 40, pp. 444-456.

Tate, R. Matthew (1983). Increased Flexibility in Map Design with the Use of Computer Graphics Systems. *Proceedings of the ACSM Fall Technical Meeting*,

Taylor, D.R.F. (1983a). The Design of Maps for Telidon. *Auto Carto VI, Proceedings of the Sixth International Symposium on Computer-Assisted Cartography*, October, pp. 461-468.

Taylor, D.R.F. (1983b). Some Conclusions and New Challenges. In: *Graphic Communication and Design in Contemporary Cartography*, D.R.F. Taylor (ed.), New York: John Wiley and Sons, pp. 285-307.

Taylor, Robert M. (1972). *Layer Tints on Joint Operations Graphic*. RAF Institute of Aviation Medicine, Farnborough, Hampshire.

Taylor, Robert M. (1974a). *Subjective Assessment of 1:250,000 Scale Maps for Low Altitude En Route High Speed Navigation*. RAF Institute of Aviation Medicine, Farnborough, Hampshire, Report 544.

Taylor, Robert M. (1974b). An Application of Subjective Scaling Techniques to Map Evaluation. *The Cartographic Journal* 11, December, pp. 74-81.

Taylor, Robert M. (1975a). *Human Factors in Aircraft Map Displays*. RAF Institute of Aviation Medicine, Farnborough, Hampshire, Report 557.

Taylor, Robert M. (1975b). Information Theory and Map Evaluation. *International Yearbook of Cartography* 15, pp. 165-181.

Taylor, Robert M. (1976a). *Projected Map Display Legibility: An Evaluation of an Experimental 1:250,000 Topographical Map*. RAF Institute of Aviation Medicine, Farnborough, Hampshire, Report 545, March.

Taylor, Robert M. (1976b). Color Requirements for Aeronautical Charts. Paper presented at the *NATO Geographic Conference*., Brussels. (Cited by Taylor, 1979).

Taylor, Robert M. (1977). *A Survey of Operational Requirements for Map Reading at Night*. RAF Institute of Aviation Medicine, Farnborough, Hampshire, Report 560, June.

Taylor, Robert M. (1978). Empirical Derivation of Map Color Specifications. Paper presented at the *9th International Conference on Cartography*, Maryland.

Taylor, Robert M. and A.J. Belyavin (1980). *Colour Differences and Map Design for Moving Map Displays*. RAF Institute of Aviation Medicine, Farnborough, Hampshire, Report 587, June.

Taylor, Robert M. and V.D. Hopkin (1975). Ergonomic Principles and Map Design. *Applied Ergonomics* 6, pp. 196-204.

Thorndyke, P.W. and C. Stasz (1979). *Individual Differences in Knowledge Acquisition from Maps*. Rand Corp., Santa Monica, California, Report R-2375-ONR, ADA065040, January.

Topfer, F. and W. Pillewizer (1966). The Principles of Selection. *The Cartographic Journal* 3, June, pp. 10-16.

U.S. Geological Survey (1983). *Research, Investigations, and Technical Developments: National Mapping Program, 1982*. USGS, Reston, Virginia, Open File Report 83-568.

Van Cott, H.P. and R.G. Kincade (1972). *Human Engineering Guide to Equipment Design*. New York: McGraw-Hill.

Van der Weiden, F.L.T. and F.J. Ormeling (1972). An Inquiry into the Associative Properties of Colour, as Applied to Cartography. *K.N.A.D. Geografisch Tijdschrift* 6, September, pp. 282-289.

Van Zuylen, L. (1969). Production of Photomaps. *The Cartographic Journal* 6, December, pp. 92-102.

Vartabedian, Allen G. (1971). Legibility of Symbols on CRT Displays. *Applied Ergonomics* 19, September, pp. 130-132.

Wainer, Howard and Albert D. Biderman (1977). Some Methodological Comments on Evaluating Maps. *The Cartographic Journal* 14, December, pp. 109-114.

Waters, R.H. (1952). Proposed Field Tests of the Tiffany Visibility Forecasting Nomographs. In: *Minutes and Proceedings of the 30th Meeting of the Armed Forces NRC Vision Committee*.

Waters, R.H. and J. Orlansky (1951). *The Use of Mathematical and Meteorological Data in Aeronautical Chart Construction*. Office of Naval Research, Washington, D.C., Report No. 641-05-4.

Watson, William Craig (1970). A Study of the Generalization of a Small-Scale Map Series. *International Yearbook of Cartography* 10, pp. 24-32.

Weltman, G. (1979). *Maps: A Guide to Innovative Design*. Perceptronics, Inc., Woodland Hills, California, February.

Wheate, R.D. (1978). *Imageability vs. Commensurability: A Reassessment of the Role Played by Shaded Relief on Topographic Maps*. M.A. Thesis, Department of Geography, Queens University, Kingston, Ontario.

Wheaton, G.R. (1967). *Enhanced Photomap Evaluation Study*. American Institute for Research, Washington, D.C., TR AIR-FR-15-467-TR.

Wheaton, G.R., A. Zavala, and H.P. Van Cott (1967). *The Effect of Map Design Variables on Map User Performance*. American Institute for Research, Washington, D.C., Technical Report R67-3, AD 651396, April.

Williams, J.E. (1953). The Relief Map. *Professional Geographer* 5, pp. 7-10.

Williams, J.R. and R.P. Falzon (1963a). Relationship of Display System Variables to Symbol Recognition and Search Time. *Journal of Engineering Psychology* 2, pp. 97-111.

Williams, L.G. (1967). The Effects of Target Specification on Objects Fixated During Visual Search. *Acta Psychologia* 27, pp. 355-360.

Williams, L.G. (1971). Obtaining Information from Displays with Discrete Elements. *Cartographica* 2, pp. 29-34.

Williams, Robert L. (1958). Map Symbols: Equal Appearing Intervals for Printed Screens. *Annalsof the Association of American Geographers* 48, pp. 132-139.

Williamson, Glen R. (1982). The Equal Contrast Gray Scale. *The American Cartographer* 9, October, pp. 131-139.

Williges, R.C. and R.A. North (1973). Prediction and Cross Validation of Video Cartographic Symbol Location Performance. *Human Factors* 15, December, pp. 321-332.

Wilson, Joe F. (1969). An Improved Terrain and Elevation Display for Visual Aeronautical Charts. In: *Geographic Orientation in Air Operations*, JANAIR Symp., November, pp. 68-71, AD 709124.

Wong, Kam W. and Nick G. Yaconmelos (1971). Television Display of Topographic Maps. *Journal of the Surveying and Mapping Division*, ASCE, November, pp. 273-285.

Wong, Kam W. and Nick G. Yacoumelos (1973). Identification of Cartographic Symbols from T.V. Displays. *Human Factors* 15, pp. 21-31.

Wood, C.H. (1976). Brightness Gradients Operant in the Cartographic Context of Figure-Ground Relationship. *Proceedings of the ACSM 36th Annual Meeting*, pp. 5-34.

Wood, Michael (1968). Visual Perception and Map Design. *The Cartographic Journal* 1, June, pp. 54-64.

Wood, Michael (1972). Human Factors in Cartographic Communication. *The Cartographic Journal* 9, December, pp. 123-132.

Woodward, David (1975). *The All-American Map*. Chicago: University of Chicago Press.

Woodward, David (1983). Map Design and the National Consciousness: Typography and the Look of Topographic

Maps. In: *Papers from the 42nd Annual ACSM Meeting*, March, pp. 339-347.

Wright, J.K. (1942). Map Makers are Human: Comments on the Subjective in Maps. *The Geographical Review* 32, October, pp. 527-544.

Wright, R.H. and W.P. Pauley (1971). *Survey of Factors Influencing Army Low Level Navigation*. U.S. Army Human Resources Research Organization, Alexandria, Virginia, AD 728099.

Wright, Richard Dale (1967). *Selection of Line Weights for Solid, Qualitative Line Symbols in Series on Maps*. Ph.D. Dissertation, Deparment of Geography, University of Kansas, Lawrence.

Yoeli, Pinhas (1964). Relief and Color. *The Cartographic Journal* 1, December, pp. 37-38.

Yoeli, Pinhas and J. Loon (1972). *An Examination of Map Symbols*. Final Technical Report for the European Research Office, U.S. Army, London, England, June.

Zachrisson, Bror (1965). *Studies in the Legibility of Printed Text*. Stockholm: Almqvist and Wiksell.

Zettl, H. (1973). *Sight, Sound, Motion: Applied Media Aesthetics*. Belmont, California: Wadsworth Pub. Co.

Distribution List

Department of the Navy
Asst Secretary of the Navy
(Research Engineering & System)
Washington DC 20350

Department of the Navy
Chief of Naval Operations
ATTN: OP-951
Washington DC 20350

Department of the Navy
Chief of Naval Operations
ATTN: OP-952
Washington DC 20350

Department of the Navy
Chief of Naval Operations
ATTN: OP-987
Washington DC 20350

Department of the Navy
Chief of Naval Material
Washington DC 20360

Commander
Naval Air Development Center
Warminster PA 18974

Commander
Naval Air Systems Command
Headquarters
Washington DC 20361

Commanding Officer
Naval Coastal Systems Center
Panama City FL 32407

Commander
Naval Electronic Systems Com
Headquarters
Washington DC 20360

Commanding Officer
Naval Environmental Prediction
Research Facility
Monterey CA 93940

Commander
Naval Facilities Eng Command
Headquarters
200 Stovall Street
Alexandria VA 22332

Commanding Officer
Naval Ocean R & D Activity
ATTN: Codes 100/111/112
NSTL MS 39529

Commanding Officer
Naval Ocean R & D Activity
ATTN: Code 113
NSTL MS 39529

Commanding Officer
Naval Ocean R & D Activity
ATTN: Code 125L
NSTL MS 39529

Commanding Officer
Naval Ocean R & D Activity
ATTN: Code 125ED
NSTL MS 39529

Commanding Officer
Naval Ocean R & D Activity
ATTN: Code 110
NSTL MS 39529

Commanding Officer
Naval Ocean R & D Activity
ATTN: Code 105
NSTL MS 39529

Commanding Officer
Naval Ocean R & D Activity
ATTN: Code 115
NSTL MS 39529

Commanding Officer
Naval Ocean R & D Activity
ATTN: Code 200
NSTL MS 39529

Commanding Officer
Naval Ocean R & D Activity
ATTN: Code 300
NSTL MS 39529

Commanding Officer
Naval Research Laboratory
Washington DC 20375

Commander
Naval Oceanography Command
NSTL MS 39529

Commanding Officer
Fleet Numerical Ocean Cen
Monterey CA 93940

Commanding Officer
Naval Oceanographic Office
NSTL MS 39522

Commander
Naval Ocean Systems Center
San Diego CA 92152

Commanding Officer
ONR Branch Office LONDON
Box 39
FPO New York 09510

Officer in Charge
Office of Naval Research
Detachment, Pasadena
1030 E. Green Street
Pasadena CA 91106

Commander
Naval Sea System Command
Headquarters
Washington DC 20362

Commander
DWTaylor Naval Ship R&D Cen
Bethesda MD 20084

Commander
Naval Surface Weapons Center
Dahlgren VA 22448

Commanding Officer
Naval Underwater Systems Center
ATTN: NEW LONDON LAB
Newport RI 02841

Superintendent
Naval Postgraduate School
Monterey CA 93940

Project Manager
ASW Systems Project (PM-4)
Department of the Navy
Washington DC 20360

Department of the Navy
Deputy Chief of Naval Material
for Laboratories
Rm 866 Crystal Plaza Five
Washington DC 20360

Officer in Charge
Naval Underwater Sys Cen Det
New London Laboratory
New London CT 06320

Defense Technical Info Cen
Cameron Station
Alexandria VA 22314

Director
Chief of Naval Research
ONR Code 420
NSTL MS 39529

Director, Liaison Office
Naval Ocean R & D Activity
800 N. Quincy Street
Ballston Tower #1
Arlington VA 22217

Department of the Navy
Office of Naval Research
ATTN: Code 102
800 N. Quincy Street
Arlington VA 22217

Director
Woods Hole Oceanographic Inst
86-96 Water St.
Woods Hole MA 02543

Director
University of California
Scripps Institute of Oceanography
P. O. Box 6049
San Diego CA 92106

Working Collection
Texas A & M University
Department of Oceanography
College Station TX 77843

Director
Defense Mapping Agency
Washington, DC 20305

Director
Defense Mapping Agency
Hydrographic/Topographic Center
6500 Brooke Lane
Washington, DC 20315

Director
Defense Mapping Agency
Aerospace Center
St. Louis Air Force Station, MO 63118

Director
Defense Mapping Agency
Special Program Office of
Exploitation and Modernization
8301 Greensboro Drive, Suite 1100
McLean, VA 22102

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

1a. REPORT SECURITY CLASSIFICATION: Unclassified	1b. RESTRICTIVE MARKINGS: None
2a. SECURITY CLASSIFICATION AUTHORITY	3. DISTRIBUTION/AVAILABILITY OF REPORT: Approved for public release, distribution is unlimited
2b. DECLASSIFICATION/DOWNGRADING SCHEDULE	
4. PERFORMING ORGANIZATION REPORT NUMBER(S): NORDA Report 72	5. MONITORING ORGANIZATION REPORT NUMBER(S): NORDA Report 72
6. NAME OF PERFORMING ORGANIZATION: Naval Ocean Research and Development Activity	7a. NAME OF MONITORING ORGANIZATION: Defense Mapping Agency HQ/STT
6c. ADDRESS (City, State, and ZIP Code): Ocean Science Directorate, NSTL, Mississippi 39529	7b. ADDRESS (City, State, and ZIP Code): Washington, DC 20305
8a. NAME OF FUNDING/SPONSORING ORGANIZATION: Defense Mapping Agency HQ/STT; 8b. OFFICE SYMBOL (If applicable)	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER
8c. ADDRESS (City, State, and ZIP Code): Washington, DC 20305	10. SOURCE OF FUNDING NOS. PROGRAM ELEMENT NO: 63701B; PROJECT NO; TASK NO; WORK UNIT NO

11. TITLE (Include Security Classification): Map Design for Computer Processing: Literature Review and DMA Product Critique

12. PERSONAL AUTHOR(S): Gail Langran

13a. TYPE OF REPORT	13b. TIME COVERED	14. DATE OF REPORT (Yr., Mo., Day)	15. PAGE COUNT
Final	From ______ To ______	January 1985	142

16. SUPPLEMENTARY NOTATION

17. COSATI CODES			18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
FIELD	GROUP	SUB. GR.	Mapping, charting, design process, computer processing.

19. ABSTRACT (Continue on reverse if necessary and identify by block number)

A comprehensive review of DMA's standard map and chart products is necessary before DMA converts to digital production. Tradition has prevented product designs from evolving with changing technology. With digital production imminent, some current designs become prohibitively expensive because they rely on subjective or artistic decisions, or because they use nondiscrete processes unsuited to digital methods. To avoid extraordinary expense and delay in procurement, installation, and use of digital equipment, such designs should be replaced by graphic formats that are better suited to computer processing.

This study identifies current DMA practices that will resist automation and suggests alternatives. Content and appearance of DMA products have been evaluated following a survey of available research literature. User requirements surveys, performance tests, and psychophysical studies have been applied to a critique of DMA's product line. Originator Supplied Keywords include:

20. DISTRIBUTION/AVAILABILITY OF ABSTRACT: UNCLASSIFIED/UNLIMITED ■ SAME AS RPT ☐ DTIC USERS ☐	21. ABSTRACT SECURITY CLASSIFICATION: Unclassified
22a. NAME OF RESPONSIBLE INDIVIDUAL: Gail Langran	22b. TELEPHONE NUMBER (Include Area Code): (601) 688-4449; 22c. OFFICE SYMBOL: Code 351

DD FORM 1473, 83 APR — EDITION OF 1 JAN 73 IS OBSOLETE.

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE

END

FILMED

3-85

DTIC