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MAP DESIGN FOR A 1:100000 GROUND/AIR PRODUCT(U) MAVAL
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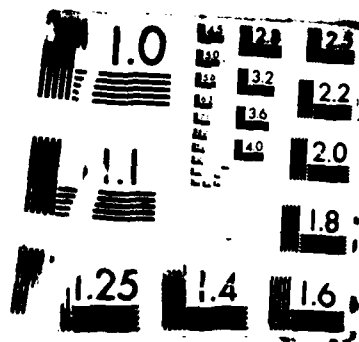
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AD-A181 448

Executive summary

This report documents the design process of an experimental 1:100,000 topographic map (Appendix B).

The map design study began in FY84 as an evaluation of ways that the Defense Mapping Agency (DMA) could improve digital production efficiency by tailoring its map specifications to the capabilities of current, off-the-shelf computer graphics technology. The FY85 effort was to implement study ideals in an experimental map.

The experimental map is designed for ground and air movement and is scaled to fill the gap between DMA's 1:50,000 and 1:250,000 products. A Naval Ocean Research and Development Activity (NORDA) study elicited the needs of its prospective users through direct questioning and a literature survey (Appendix A). The design concept is pictorial and relies on an alternate terrain depiction method, Tanaka contours, to meet the disparate terrain analysis needs of air and ground users.

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Contents

1. Introduction	1
Evolution of the 1:100,000 design concept	1
Production efficiency	2
Summary	2
2. Design	2
Color	2
Screens	3
Format	3
Grid and graticule	3
Marginal information	3
Terrain	4
Vegetation	4
Roads	4
Railroads	4
Culture	4
Aeronautical information	5
Hydrography	5
Drainage	5
Boundaries	5
Names	5
3. Conclusion	6
4. References	6
Appendix A: Map design for low-altitude aviation	7
Appendix B: Experimental map (envelope)	

Map design for a 1:100,000 ground/air product

1. Introduction

This report was written to accompany an experimental 1:100,000 topographic map produced through a joint NORDA/DMA research effort. The map is intended for air and ground vehicle movement and is scaled to fill the gap between DMA's 1:50,000 and 1:250,000 map series.

The map design project was spurred by DMA's changing production environment, in which computers are increasingly employed to perform tasks once left to humans. Many current maps, designed for manual production, use techniques that are difficult to render digitally. To overcome this problem, more sophisticated hardware and software can be developed, a slow and expensive process. Alternatively, map designs can be made more amenable to digital production.

The design of the experimental map was based on three principles.

- Satisfy the needs of a target user group.
- Capitalize on computer capabilities.
- Stay within the restrictions imposed by off-the-shelf digital production equipment.

The rest of this section details project goals and early problems. Section 2 states the reasoning behind each facet of the experimental map's design. Section 3 summarizes conclusions.

Prior to undertaking the map design, the needs of its targeted user groups were investigated. Because aviation user requirements are particularly difficult to meet, a trip to investigate those users' needs first-hand was made to Ft. Rucker, Alabama, where Army rotary-wing aviators are trained. A synopsis of the information requirements of low-altitude aviators, based on a literature survey, is provided in Appendix A. The experimental map is Appendix B.

EVOLUTION OF THE 1:100,000 DESIGN CONCEPT

A study of DMA's standard product line (Langran, 1985) revealed a gap in topographic products that could be a problem to DMA's users, particularly those moving rapidly near or at ground level. DMA provides standard 1:50,000 and 1:250,000 topographic maps for ground operations and low-altitude aviation. While the 1:50,000

product is useful in relatively static environments, broad area coverage at 1:50,000 introduces problems of bulk. The next largest scale, 1:250,000, does not provide sufficient detail for many operations. Thus, a 1:100,000 ground/air product is a useful supplement or alternative to standard products.

To map at 1:100,000, the designer must have a clear concept of what is to be achieved to avoid producing a compacted and profusely cluttered version of the 1:50,000 map. DMA's 1:50,000 maps provide the maximum amount of detail possible using point and line symbols. Thus, a 1:100,000 map in the same series will best complement the 1:50,000 product by not attempting the same level of detail, since this study revealed that it may be used in conjunction with, but seldom as a substitute for, a 1:50,000 map (see Appendix A).

Conversely, some air and ground users may substitute a 1:100,000 product for a 1:250,000 product in their operations, if one were available. The 1:250,000 Joint Operations Graphic (JOG) currently available to DMA's users is a somewhat pictorial topographic map used for air and ground mission planning and en route navigation. Thus, we decided to attempt a pictorial 1:100,000 map design. Because many of the JOG's users complain of clutter, we resolved to reduce clutter in any way reasonably possible.

Among the problems faced in designing such a map is how to satisfy the content requirements of two disparate user groups. En route aviation needs a stark format that promotes mapreading at a glance, depicting only information essential to mission success. A map designed solely for aviators would show only features visible from the air, eliminating boundaries, placenames, building functions, and certain road attributes. If, however, the map is also to serve ground users, it must depict the transportation network and terrain in enough detail to select optimum routes, and it must show a certain amount of cultural information for planning and en route navigation.

A related problem is how to depict terrain in a way useful to both aviators and ground personnel. Traditional pictorial terrain portrayal methods (i.e., shaded relief and elevation tints) provide the at-a-glance format needed by

aviators, but at cost of detail and at risk of misinterpretation. Contours add detail, but require time and skill to interpret, which makes them unsuitable for aviation. Using two or more hypsographic methods tends to obscure other mapped information.

The final challenge is supporting nighttime map use. Although DMA abides by a red-light readability requirement, the requirement has been dropped outside the United States and may eventually be replaced by a requirement for blue-green light readability. Designing for readability by either red or blue-green light introduces serious design constraints; designing for readability by both red and blue-green light requires adoption of radically different methods, such as a black background. Because requirements are unclear, the design experiments with certain red light and blue-green light readability techniques but does not strive to be fully red- or blue-green-light readable.

PRODUCTION EFFICIENCY

Manual production limitations tend to be obvious: some tasks are slow and laborious when rendered by cartographers or they exceed photocompositing capabilities. With the use of digital mapping equipment, production limitations change. Rather than attempting to implement on digital equipment designs developed for production by humans, the strengths and weaknesses of digital equipment should be analyzed and exploited. Only in this way can true production efficiency be realized.

Graphic processes that rely on subjective or knowledge-based judgments are the most difficult to implement with computers. Software to automate such cartographic processes is still under development and will not be available for production for some time. Conversely, computation and data processing are rapidly performed by computers. Given an appropriate data base, any numerical transformation is possible. Symbols can be scaled from their data base values and terrain can be represented in a number of quantitative ways. Illuminated contours, inclined contours, and slope zoning are three interesting techniques that effectively exploit computer capabilities.

Nondiscrete processes are difficult to perform with computers. Streams that taper from headwaters to mouth add to production expense disproportionately to their graphic value. Vignettes, too, are an inefficient technique to perform digitally.

Fine linework and detail must be excluded from the map design based on the aviator's need for information at a glance. The use of digital technology offers additional arguments for such an omission. Increasingly, maps will be scanned, transmitted, and displayed in softcopy—all

processes that can contribute to degraded resolution, loss of color contrast, and missing pixels.

While a major goal of this experiment was to design a map that is efficient to produce digitally, most of the map was produced manually. Digital processes are subject to exaggerated economies of scale; for a one-of-a-kind experiment, manual production was less expensive. Two notable exceptions were the illuminated contours, which were produced digitally, and the second interim proofing stage, which was performed in softcopy to allow the design team to interactively modify symbol sizes, shapes, and colors.

SUMMARY

A strict assessment of the map's content was critical to meet the needs of both ground and air users. All maps are compromises between scale limitations and the importance of information to users. In this case, the compromise extends to two user groups whose requirements sometimes conflict.

All possible efforts were exerted to minimize clutter. Symbols were simplified by eliminating detail. Text explanations were simplified. A background tint was used to reduce the glare of white paper. Symbol prominence was carefully controlled to match symbol importance.

The map was designed for digital production efficiency. In all decisions, production impacts and the possibility of fully automating the design technique were considered.

2. Design

COLOR

This overview of map colors describes the reasoning behind color choices. In general, traditional color/feature association was retained: brown for terrain, green for vegetation, red and black for cultural features, and blue for water.

Screened brown was chosen for land. Contour lines are unscreened brown or white, depending on their aspect. Large tidal flats are shown with an unlabeled brown area pattern. Thus, the map retains the traditional association of hypsometry with brown.

Major roads are solid black. Light-duty roads, most cultural information, and placenames are screened black.

Solid red is used for navigation lights and ferry routes. The red symbols against the blue water are readable by both red and blue-green lighting. Military boundaries are red.

Vegetation and forest boundaries are screened green. Information vital to aviators (powerlines, airfields, and latitude/longitude grid ticks) is solid green.

SCREENS

Only single-line dot screens are used, since biangle screens are hard to produce digitally. We anticipated problems with using only single-line screens: fine detail, when screened, could dissolve, and superimposed line screens tend to produce moire. As a precautionary measure we used only sans-serif type and eliminated all fine linework from symbols, since both type and symbols are often screened on this map. The first iteration of the map screened the contour lines and the UTM grid lines, which resulted in an unacceptably fuzzy appearance. The solution proved to be dispensing with the screens entirely in those two cases. We did not resort to random mezzotint screens; however, these could be useful in eliminating the moire that appears in some parts of the map.

FORMAT

A landscape format (i.e., width greater than height) was chosen for several reasons. First, the landscape format is easier to handle and allows a larger area to be mapped. Second, the majority of DMA's other maps and charts employ a landscape format. If products are to be generated from data bases, the most efficient method is to generate large-scale maps first, then progressively reduce and mosaic the data to smaller scales. Nested sizes ease digital mosaicking and production scheduling.

The 30' x 60' map is folded like a road map. Folding, too, allows a larger area to be handled easily, and provides additional margin space in which summary information can be provided. When folded, the front piece shows the map's title, scale, credits, and disclaimers. The back piece shows a reference graphic and road distances.

GRID AND GRATICULE

The graticule is abbreviated to ticks, since latitude and longitude are not employed for precise positioning by the map's intended users. Green is used for graticule ticks and labels to associate the graticule visually with other aeronautical information.

The UTM grid is solid blue. A very fine lineweight was chosen to offset the excessive prominence assumed by continuous lines. Since the neat line is logically associated with the grid, it, too, is shown in blue. The map's background tint easily distinguishes the map body from its margins, making a prominent neat line unnecessary.

MARGIN INFORMATION

Standard margin information is streamlined whenever possible. In particular, declination data is presented more simply. True North, not useful in the field, is eliminated from the graphic. "Compass" is substituted for "magnetic" in all explanatory text, "UTM grid" substitutes for "grid," and a specific declination equation is provided. Table 1 summarizes the changes.

Table 1. Summary of simplified margin information.

Experimental	Standard
Compass North	Magnetic North
"to convert a compass azimuth to a UTM grid azimuth ADD 21°."	"to convert a magnetic azimuth to a grid azimuth ADD G-M angle."
1970 declination 21° (380 mils)	
Annual magnetic change 3' westerly	

In the future, specific declination values could be stored in a data base or computed, then automatically inserted in the appropriate slots during map compilation.

Road distances, useful for planning optimum routes and estimating travel times, are provided in miles and kilometers on a network graphic. Distances are shown between major towns and villages likely to appear on road signs. Such distances could someday be computed from stored road vectors.

The reference graphic that shows the mapped area within the framework of the geographic region is visible without unfolding the map. This graphic could be adjusted to show adjoining sheets.

A graphic showing boundaries is also included in the margin. The graphic shows county, public forest, and military boundaries in their map colors (black, green, and red, respectively).

Stream spacing, elevation, and drainage graphics are provided in the margin for general reference. Drainage features shown are those streams passing major settlements, streams with more than four reaches, streams extending more than fifty miles, and major lakes. Vegetation stream spacing supports cross-country movement requirements. The elevation graphic provides an overview of the area's terrain.

TERRAIN

The map's brown background reduces clutter by reducing contrast, improves potential softcopy appearance, and adds distinction against the white margins. Additionally,

a medium-tone background is needed for the contouring technique employed.

We chose illuminated contours (Tanaka, 1950) to provide a pictorial terrain view to aviators without robbing ground users of detail. Illuminated contours are white on hypothetical sunlit hillsides and dark on hypothetically shadowed hillsides. Tanaka's version of the contours graduates contour lineweight according to aspect, thus further enhancing the three-dimensional effect. Although the technique is not new, the relative ease of production is; this portion of the mapping process was made far more cost-effective through the use of a digital system. The contours were generated by scan-digitizing and digitally mosaicking the 1:50,000 source maps' contour plates, vectorizing the contours, tagging them interactively, recompiling to a new contour interval, then computing aspect to determine color and lineweight. The negative was produced via a laser scanner from a raster file.

VEGETATION

Field outlines, woodlot shapes, and landmark vegetation (e.g., orchards and vineyards) are important locational indicators to aviators, but their mapped prominence must be balanced against the integrity of the data, which ranges from good to poor depending upon how recently the data were compiled.

Because orchards and park-like areas (e.g., parks, golf courses, and cemeteries) are prominent from the air, we were careful to symbolize them boldly enough to alert aviators to their potential as landmarks. We designed a new, more prominent, orchard symbol that is comprised of small, solid green squares. Park-like areas are filled in solid green.

ROADS

Road symbols key surface type to color, and road width to lineweight. Hard surface/all-weather roads are solid black. Light duty and unimproved roads are gray. Lineweights similar to those on standard topographic maps were chosen. Because we varied both screen value and lineweight in the road symbols, no dashed lines were needed. Thus, the map is "quieter," more easily produced, and more readily scanned.

To simplify the map, the dashed lines that customarily depict tunnels were removed. Instead, the road disappears and reappears between tunnel delimiters.

Standard ferry and ford symbols are shown in red instead of black. Because the blue of the water is interrupted beneath the symbols, they are readable in both red and blue-green lighting.

RAILROADS

All labels are omitted from railroad symbols. Railroad tunnels, like road tunnels, use no dashed lines between the tunnel delimiters. Dismantled railroads are shown as disturbed ground.

CULTURE

Individual buildings and minor roads, particularly in suburban areas, contribute significantly to clutter on 1:50,000 topographic maps. A 1:100,000 map must adhere to far more stringent selection criteria: space does not allow every structure to be depicted. If all structures are not shown, however, there must be a logical way to select those that are shown so map users clearly understand the selection strategy. Otherwise, included buildings can be confused with disincluded buildings and vice versa. The same problems exist for road selection.

The building and road selection strategy was based on the 1:50,000 source maps' building and road compilations. Landmark buildings are assigned distinct, bold symbols, but no other individual buildings are shown. All primary and secondary highways are shown. All-weather and unimproved roads are shown except

- dead-end roads shorter than 200 meters,
- unimproved roads that do not link two improved roads,
- unimproved roads in areas where the majority of the road network is improved roads,
- unimproved roads spaced less than 200 meters apart.

To provide a generalized picture of human settlement, a pale gray, moderately built-up area tint supplements the medium-gray built-up area tint. The built-up area tint was compiled directly from the 1:50,000 source maps. The moderately built-up area tint supplants individual small buildings and roads, and is employed when

- ten or more buildings are clustered with less than 200 meters of intervening space,
- road selection rules eliminated more than 3 km of unimproved roads in a 1-km square area.

We sought to quantify our compilation rules to make batch compilation from a data base possible, and to make the selection criteria easily expressed to the map's users so they can interpret the map's contents correctly. The compilation criteria expressed above were arrived at through trial and error, since we felt it was important to achieve the correct pictorial effect.

Cultural symbols are major contributors to map clutter. To counteract this effect, few labels are shown, and hachures, dotted lines, fine detail, openings, and open parallel lines were eliminated from symbols. These

alterations impacted the symbol set minimally. Screened tints substitute for hachures. Screened lines substitute for dotted and open parallel lines. Fine detail and flourishes were eliminated with no change to overall symbol shape (a good example is the wreckage symbol, see Appendix B, enclosure 3). A pictorial drive-in theatre substitutes for DMA's current symbol. Racetracks and stadiums, similar in appearance and function, were combined into a single symbol category.

AERONAUTICAL INFORMATION

Powerlines, airfields, and helicopter and seaplane landing strips, features of aeronautical interest, are shown in green. Latitude and longitude ticks and labels, potentially used by aviators, are also green.

An alternate powerline symbol was designed. The standard powerline symbol evokes an expectation that the symbol's pylons correspond to actual pylon locations. Additionally, Taylor (1976) found that the lowered resolution of projected JOGs caused some users to confuse powerlines with other linear features, a potentially critical error. For an experimental projected JOG he tried a zigzag powerline symbol. The zigzag symbol is prominent and its shape is iconically associated with electricity. Taylor noted, however, that the zigzag powerlines cluttered the map.

Zigzags, however, are ideally suited to computer construction, and their size could be scaled automatically to powerline height, if desired. Thus, we resurrected the zigzag powerline experiment for this map. Clutter was minimized by carefully adjusting the symbol's size during the interactive map proofing stage and using green against a brown map background, instead of black against a traditional white or yellow map background.

HYDROGRAPHY

To reduce processing time we elected to show only hydrographic features visible from land or air. Thus, no depth curves appear. Visible wreckage and navigation lights are shown, since they are valuable landmarks to all users. Navigation lights are red, a red-light/blue-light readability experiment (see the previous section on roads).

DRAINAGE

Production considerations dictate that single-line streams not be tapered at their headwaters or elsewhere. Gradual tapering is a nondiscrete process not suited to the computer that could add significantly to implementation time and expense. One alternative, using a series of discrete lineweights to depict different branches of the drainage network, requires that explicit hydrologic information be

stored in the data base. We elected instead to use a single lineweight for all branches of single-line streams.

Several other drainage symbols were changed. For production and esthetic reasons we substituted a screened blue line for intermittent streams rather than the traditional dashed line (in this case, line fuzziness from the screening process adds realism). We also altered the standard symbols for rapids and waterfalls. The waterfall symbol is currently only half as prominent as rapids, although their effect on users is far greater. The new rapids symbol is more feathered than the current rapids symbol. The new waterfall symbol adds a heavy solid line to the rapids symbol. Conceivably, the lineweight could be computed from the amount of vertical drop. In both cases, the length of the feathering should correspond to the extent of the white water.

BOUNDARIES

Boundaries could be eliminated from a dedicated aviation map, since most are invisible from the air. However, a map for ground movement requires boundaries, since most are marked by road signs that assist locational referencing.

For production and esthetic reasons thin bands of screened color replace the dashed line series more commonly used. Public forest boundaries are green, military boundaries are red, and county boundaries are black. Boundary labels are the same color as their respective boundary lines.

NAMES

Placenames are relatively less important than other map information. We minimized their prominence by screening the type and by labeling very selectively. Settlements located along major roads and crossroads are labeled, since their names are likely to appear on road signs. Only very large or obviously important hydrographic features are named. In the study area, Puget Sound is named but its various inlets and narrows are not.

Only one type style is used in the map's body. Scientific literature provides no evidence that multiple type styles are helpful to mapreaders; there is, however, some indication that the reverse is true. The style chosen, Univers, was selected because it is sans serif (thus relatively immune to screening problems), readable, popular with mapreaders and cartographers alike, and available in digital form. The U.S. Geological Survey has taken a moderate revisionary approach on its maps by reducing the type styles to one serif (Souvenir) and one sans-serif (Univers) face. By going one step further, this experimental map provides

an ideal opportunity to test type style theories using complete maps, as opposed to the crude maplike graphics that economics have forced on prior type style studies.

3. Conclusion

To promote production efficiency, the experimental map contained in the envelope (Appendix C) was tailored to the strengths and weaknesses of digital processing. A target user group was identified and their needs assessed prior to establishing a design concept.

Several production economies are demonstrated. Only one type style is used on the map. Single-line streams use only one lineweight from start to finish. Content has been strategically reduced. No biangle screens or vignettes were used. And, the size and shape of the 30' x 60' product fits within a hypothetical nested product series for data processing efficiency.

The abilities of computers are exploited. Illuminated contours, easily rendered by computer, are used. Selection criteria are quantitative and efficient to implement algorithmically. Several new symbols were designed so they

can be dynamically scaled from the data base, based on their features' attributes.

This map's effect on mapreaders will be tested. The performance of subjects using illuminated contours will be compared to performance using standard contours. The impact of the map's relatively low contrast and treatment of placenames will also be evaluated.

4. References

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Appendix A: Map design for low-altitude aviation

1. Introduction

This appendix was compiled to assess the cartographic needs of terrain flight prior to designing a 1:100,000-scale map for air and ground vehicle movement. The cartographic requirements of ground users are fairly well understood but low-altitude aviation requirements are unique and exacting, and need precise definition.

The next section is an overview of terrain flight, which is the practice of flying extremely close to the ground. Section 3 discusses problems relative to map use during terrain flight. Section 4 summarizes researcher and user opinions regarding appropriate feature content for an aviation map. Section 5 suggests map design approaches. Section 6 discusses experimental attempts to address the map needs of terrain flight. Section 7 contrasts ground user requirements to those of aviators. Section 8 discusses large-scale electronic cockpit display problems and softcopy technology's effect on hardcopy map requirements. Section 9 is a summary and conclusions, and Section 10 cites the references for this appendix.

2. Overview of terrain flight methods

The literature surveyed for this study analyzes both low-altitude fixed-wing and rotary-wing aircraft activities relating to map requirements. While fixed-wing aircraft generally fly at higher altitudes than rotary-wing aircraft, both are potential users of a 1:100,000 aviation map. Fixed-wing low-altitude and rotary-wing flight techniques are discussed below.

FIXED-WING, LOW-ALTITUDE FLIGHT

Fixed-wing, low-altitude flight occurs about 200 feet above ground level at speeds approaching 500 knots. Flying low to the ground at high speeds can be extremely disorienting and can make checkpoints difficult to locate or recognize, since features constantly change shape as a function of perspective (Paulson, 1982).

ROTARY-WING TERRAIN FLYING

Terrain flying refers to flight close to the earth's surface. The three methods of terrain flight are low-level, contour, and nap-of-the-earth (NOE) flight, described below.

- Low-level flight is generally at a constant heading, airspeed, and altitude.
- Contour flight follows the contours of the earth, and varies airspeed and altitude but not heading.
- NOE flight is as close to the earth's surface as vegetation and obstacles will permit. Airspeed, altitude, and heading are varied as required. Terrain features are used to mask the aircraft from enemy radar and optical detection.

NAVIGATION AT LOW ALTITUDES

Low-altitude navigators rely primarily on visual cues rather than their instruments to maintain geographic orientation. Earth features are matched to map features to determine exact location, a technique sometimes referred to as pilotage. Effective pilotage demands good terrain analysis and mapreading skills.

The oblique viewpoint of low-altitude flying poses serious pilotage problems. At low levels, the aviator sees the earth as if from a hole or canyon with his eyes at or below the rim. He must infer a planar feature's extent from the time required to traverse it rather than from its appearance. Without the bird's-eye view of higher altitudes, correlating the terrain with the map is difficult.

An oblique viewpoint also alters the relative importance of features on maps. Features with vertical development (e.g., hills, buildings, towers) are important checkpoints, since they can be seen from a distance and for some duration. Flat features (roads, streams) are in view a much shorter time than features with relief. If more than a few hundred meters away, flat features collapse into the horizon or are masked by intervening objects.

Difficulties experienced during terrain flying are summarized below. The closer the aircraft flies to the ground, the more severe each difficulty becomes.

- Navigation features come into view and pass out of sight quickly.

- Forward vision is limited to the next obstruction.
- The aircraft's altitude is rarely constant for more than a few seconds.
- The pilot must be constantly engaged in avoiding obstacles.
- Useful topographic features that are elevated to the side cannot be seen.
- Turbulent air can cause dramatic attitude changes that require swift correction.

3. Aviation map use

Despite the diversity of aircraft and techniques used at low altitudes, many aviation tasks requiring maps are quite similar (Rogers and Cross, 1979). This section discusses low-altitude flight tasks that require maps.

MISSION PLANNING

Successful mission planning depends on an aviator's ability to extract information from maps. The aviator must study the situation and visualize the terrain; select landing zones, checkpoints, and barrier features; and determine flight modes, altitudes, speeds, and durations (Rogers and Cross, 1979).

If preflight planning time allows, the map is stripped. The pilot sketches course lines and time marks on the map. This preparation allows the pilot to schedule and anticipate checkpoint passage during flight rather than to match features to the map extemporaneously.

The mission planning stage is likely to include the following tasks (Wright and Pauley, 1971).

- The pilot familiarizes himself with the terrain and with the known and likely disposition of enemy defenses.
- After locating the destination and base, the pilot searches for particularly prominent checkpoints between the two positions.
- A route that makes maximum use of the best checkpoints is selected and marked on the map.
- Each flight segment's heading is calculated and marked on the map. For higher-speed aircraft, the ground track turn radius at each turning point may also be plotted on the map.
- The route time is marked off in units that are based on anticipated ground speed. Pilots may also annotate the time each checkpoint will be passed.
- For flights where fuel may be critical, the anticipated minimum allowable fuel reading at each major checkpoint may be noted.
- Auxiliary information may be added to the map.

NAVIGATION

Only periodic checkpoint identification is needed for low-level navigation. Conversely, NOE navigation requires arduous pilotage.

The NOE aviator's field of view often extends less than 100 meters from the aircraft, which significantly reduces the number of useful checkpoints and increases the likelihood of geographic disorientation. Individual landforms are seldom seen in their entirety (Rogers and Cross, 1979).

Major navigation tasks during terrain flight are (Wright and Pauley, 1971)

- matching the terrain to the map (pilotage),
- minimizing lateral offset from the desired ground track,
- minimizing deviation from the planned schedule.

Maintaining course is highly related to maintaining schedule; an excellent navigation technique is to match the expected time of checkpoint passage to actual elapsed time. The time a feature is passed provides the basis for positive feature identification. Conversely, a deviation from the expected time a checkpoint will be reached is often an early indication of lateral ground track errors.

Fineberg et al. (1978) found that successful NOE navigators shared the following characteristics.

- A series of multiple checkpoints or terrain features were used for geographic orientation. Less successful navigators use single checkpoints, which are far more difficult to recognize than checkpoint combinations.
- Distance traveled was accurately judged in terms of time. Checkpoints may be confused when the time-distance relationship is inaccurate because they are anticipated too early or too late.

MASKING

Masking, or escaping enemy detection through the strategic use of intervening objects, is the central objective of terrain flight. Flying unmasked sharply reduces survival probability in a high-threat environment. On the other hand, unnecessary NOE flight should be avoided; more sorties can be flown and greater distances can be covered using contour or low-level flight, and higher altitudes are safer should aircraft emergencies arise (Rogers and Cross, 1979).

An aviation map should help aviators to plan masked routes, providing the types of information described in this extract from FM 1-1, Terrain Flying (from Rogers and Cross, 1979):

To (mask) in mountainous or rolling terrain, plan the route on the friendly side and below the crest of a ridgeline. In very

gently rolling terrain, plan the route across the low terrain such as stream beds where it does not serve as an avenue of approach to the enemy position. In arid or open areas, plan the route along stream beds or depressions where trees may exist.

GEOGRAPHIC ORIENTATION

Aviators often blame problems in locating targets and checkpoints during low-altitude flight on geographic disorientation. Geographic disorientation can be caused by failing to recognize a ground feature as a mapped feature, by believing that an unmapped ground feature is a mapped feature, by not finding a target or checkpoint because it is masked by other features, by expecting a ground feature's prominence to relate directly to its mapped prominence, or by misreading contour lines (Paulson, 1982).

The groundwork for geographic orientation is laid during mission planning, and efforts to maintain it continue throughout the navigation stage. Aviator training is likely to provide the following guidelines for maintaining geographic orientation during low-level flights (Wright and Pauley, 1971).

- Detailed planning is essential.
- Learn to navigate using only an annotated map and simple mental calculations or simple graphic aids that do not require extensive manipulation.
- Navigate by pilotage and by a planned schedule to track progress along the course.
- Try to maintain a ground speed that is an even multiple of 60 so an integral number of miles per minute is flown.
- Follow the planned schedule, regardless of doubt. Make changes only after a positive fix is made. Do not deviate from the schedule to search for orienting features.

PHYSICAL PROBLEMS

Maps can be difficult to orient properly in helicopters because of dynamic roll, pitch, and yaw. Vibration in the cockpit can make detail difficult to discern. Poor lighting, red lighting, or blue-green lighting may interfere with color perception. Cramped cockpits may cause map-handling problems.

MAP INTERPRETATION TRAINING

Standard aviation instruction does not include enough mapreading training to prepare aviators adequately for mission planning and navigation. In particular, many aviators lack skill at interpreting terrain from contour lines. For

this reason, cultural features, which are less reliable than terrain features, are frequently selected as checkpoints during low-level flight (Paulson, 1982).

Fineberg et al. (1978), after testing a total of 35 Army rotary-wing aviators in three field experiments, concluded that while NOE navigational capabilities do not necessarily improve with experience, they do improve with training. Not only did experienced navigators with terrain analysis training perform better than experienced navigators without training, but inexperienced navigators with only 15 hours of training performed better than experienced navigators without training. Clearly, specialized NOE training is valuable.

In 1975 the Army Research Institute sponsored a project to design and develop a map interpretation and terrain analysis course (MITAC) to improve the navigational accuracy of helicopter pilots at NOE altitudes. MITAC was designed to supplement conventional map interpretation training with more intensive terrain analysis exercises and with basic cartographic instruction. To supplement mapreading training, aviators are taught the rules cartographers use for selecting and classifying roads, coding vegetation cover, delineating relief and drainage, and grouping cultural features into standard symbol categories. Understanding cartographic practices aids in correct map interpretation (Qualy et al., 1982). MITAC-I was designed for the rotary wing community, and MITAC-II for fixed-wing low-altitude aviators.

TESTING NOE PROFICIENCY

In general, proficiency refers to a pilot's ability to maintain geographic orientation and stay on course. Components of proficiency are selecting a good route, selecting good checkpoints, recognizing selected checkpoints, judging distance traveled, and correlating map to ground.

Performance tests. Field tests have been used to measure most aspects of proficiency. Commonly, however, mission planning skills (e.g., route and checkpoint selection) are tested less than navigational abilities. Ability to stay on a charted course is an important measure of navigational proficiency (Fineberg et al., 1978; U.S. Army, 1974a). Ability to estimate current location has also been measured (U.S. Army, 1974b).

Scoring. A great deal of consideration is required in scoring performance tests. McGrath (1970) states that it is dangerous to use scoring methods that impose any additional burden on a pilot while in flight. He suggests having the pilot recall his ground track, chart use, checkpoints, and subjective orientation after the flight is completed. Although one may question the accuracy of pilot recall

or the validity of a postflight report, McGrath compared pilot reports with reports of chase pilots in four flight tests and found that pilots demonstrated a remarkable ability to accurately reconstruct a recently completed flight.

Fineberg et al. (1978) selected certain components of performance upon which to base test scores:

- finding an initial point,
- finding a landing zone,
- deviating from specified course line,
- total distance traveled from start to finish.

Using these aspects of aviation performance, a number of measurements were devised:

- probability of finding an initial point, determined by dividing the number of initial points found by the total number of initial points;
- probability of finding a landing zone, calculated by dividing the number of landing zones located by the total number of landing zones;
- 250-meter excursions, the number of times the pilot deviated from the specified course line by more than 250 meters but less than 1000 meters;
- 1000-meter excursions, the number of times the pilot deviated from the course line by more than 1000 meters;
- total distance traveled by the pilot, including excursions;
- percentage of distance traveled 250 meters off course, computed by dividing the summed distances traveled during all 250-meter excursions by the total distance traveled;
- percentage of distance traveled 1000 meters off course, computed by dividing the summed distanced traveled during 1000-meter excursions by the total distance traveled;
- percentage of distance traveled on course, computed by subtracting the previous two percentages from 100%;
- mean flight time in minutes.

Other possible performance measures include the subject's radial errors in estimating location, his along-route and off-route errors, and the number of times he became lost (U.S. Army, 1974b).

Fineberg et al. (1978) derived an overall measure of performance from component performance measures. Their objective mission success score (OMSS) is a single number computed from four weighted measurements: the number of initial points missed on the test course, the number of intermediate landing zones missed, the number of 250-meter deviations from the course line, and the number of 1000-meter deviations. OMSS scores had a 0.75 cor-

relation with subjective performance ratings by NOE instructors.

4. Map content requirements

Establishing feature selection criteria may be the most important step in designing an aviation map (McGrath, 1970). The information requirements for air navigation are difficult to satisfy and demand full evaluation.

FEATURE DENSITY

Visual pilotage requires sufficient checkpoints for continuous course corrections. There is, however, major disagreement over the best selection strategy. The dramatically different opinions represented here are an effective reminder that proper content selection is difficult.

Bishop et al. (1956) favor the principle of selection used for smaller-scale aeronautical products. This principle involves abstracting a network of landmarks to represent ground feature distribution. The goal is to neither strip the map of features nor to clutter it with detail. Relative feature density should be projected, but in sparsely featured areas the selection standards are relaxed to include adequate features for navigation. Bishop et al. state that abstraction is one of the properties that makes maps more useful than aerial photography.

McGrath (1970) feels that the principle of selection described above works to the detriment of navigators. He found that the high information content maintained over barren terrain on the Tactical Pilotage Chart led pilots to believe that the area was suitable for visual pilotage when, in fact, there were insufficient landmarks to be used as checkpoints. He postulates that when cartographers include below-criterion features on the chart in an attempt to provide some information, they unintentionally deceive aviators. Thus, McGrath favors showing barren areas as being truly barren and leaving cluttered areas cluttered. This strategy was used on a prototype 1:250,000 chart that, although unpopular, did improve geographic orientation in pilots.

Wright and Pauley argue that a map should show the maximum number of features that can reasonably be included. They state that terrain flight's limited viewpoint requires many assorted features and believe that aviators can use far greater detail than maps can possibly present. They suggest that users be provided with magnifying devices to expand the information limits of maps. Wright and Pauley accede, however, that map clutter degrades low-level navigation performance and affirm the requirement for an at-a-glance format.

CRITERIA FOR SELECTION

Perception. Features that make good checkpoints should be selected for the map. A checkpoint's recognizability is based on how well its attributes can be perceived. The elements of spatial perception are (Bishop et al., 1956)

- size—an object's extent relative to the visual field;
- shape—an object's perceived silhouette or outline;
- linear perspective—the apparent convergence of parallel lines with increasing distance;
- light and shade—an object's apparent variation in size, shape, clarity, and distance as illumination varies;
- atmospheric attenuation—the partial loss of color and outline sharpness from air, fog, or smoke;
- terrain texture—patterns of varying brightness as a function of distance;
- interposition—the partial covering of one object by a closer object;
- filled space—the effect of intervening objects on perceived distance to an object;
- vertical location—the nearer of two objects below the horizon appears lower in the visual field of the observer; the converse is true if objects appear above the horizon;
- relation to external reference—the relative position of an object as compared and contrasted with a known external reference;
- relation to internal reference—the relative position of an object as compared and contrasted with observer's perception of own body orientation;
- motion parallax—the relative motion of objects in visual field as a function of the distance from the observer.

Bishop et al. distill the spatial perception parameters above into the four most important cues for recognizing checkpoints from low levels: size, shape, contrast, and vertical dimension.

Positive feature attributes. Features that project above the terrain are the most important to include because they can be viewed for periods of minutes rather than seconds, and because they may constitute a hazard. Nominal vertical extent that would not be noticeable from high altitudes is prominent from low levels.

Bishop et al. (1956) outline the following rules for selecting visually prominent features to map.

- Select the largest available features.
- Select features that contrast in brightness, color, or form with their surroundings.
- Select objects that have unique shapes and groups of objects that form distinctive patterns. If possible, select features that can be unambiguously symbolized.

- Select objects with the greatest vertical dimension.

Wright and Pauley (1971) also state good checkpoint characteristics. Point features (building, bridge, or intersection) are good for checking against the flight schedule. Linear features perpendicular to the flight path are also good for checking against the schedule but may cause confusion if the aircraft is off-course enough to alter the expected angle of intersection. A funnel checkpoint (where two linear features intersect) is exceptionally useful; if the funnel is approached from the mouth when there is a lateral flight error, one of the features comprising the funnel's sides will be encountered and can be followed to the checkpoint, thereby putting the aircraft back on course.

A checkpoint must be unique; many visual navigation errors arise from mistaking one feature for another. If unique features are not available, unique sequences of features should be selected.

Criteria for eliminating features. In many cases, planar features are masked by intervening terrain or vegetation and may not be seen at all by the aviator unless they fall in or very near the flight path. Streams, roads, and towns, normally important for navigation and orientation, may be masked by vegetation at low levels.

Rogers and Cross (1978) establish four tests of checkpoint adequacy to be applied regardless of the nature or nomenclature of the checkpoint:

- availability (is it there?),
- reliability (has it changed?),
- perceptibility (can it be seen?),
- discriminability (can it be positively identified?).

These criteria make it difficult to rate the relative navigation value of hydrographic, vegetation, and cultural features without reference to the mapped area. Hydrographic features are usually available and reliable but they may not be perceptible or discriminable depending upon their size, number, and the surrounding vegetation. Vegetation is usually available and perceptible but only sometimes reliable or discriminable. Cultural features, when available, are easily perceptible and usually discriminable, but their reliability ranges from good to poor depending on a map's compilation date.

Selection techniques. McGrath (1970) recommends establishing parametric selection criteria rather than selecting by category. He related variations in feature parameters to navigational usefulness and found that size, both linear and area, is the most important criterion. Cartographers have always used size as a selection criterion, but McGrath's analysis provides insight into how much larger one feature should be than another to be significantly better. He also found that size interacts with other important parameters,

such as contrast to surroundings and number of similar features within a given area.

A technique useful for selecting features based on their visibility was proposed by Waters and Orlansky (1951). By combining human vision data with meteorological range and a sky-to-ground brightness ratio, it was possible to predict whether a feature of given size and contrast would be visible at a given altitude. Miller (1957) also developed a feature selection formula that made visibility a function of size, contrast, shape, and meteorological condition.

RELATIVE IMPORTANCE OF FEATURE CLASSES

Three studies have examined the relative importance of terrain features, drainage, cultural features, and vegetation patterns to pilotage. The results are summarized in Table A-1 and described in the next three paragraphs.

Table A-1. Relative importance of features to pilotage, based on studies by Qualy et al. (1982), Bynam and Holman (1979), and Bishop et al. (1956).

	Qualy et al.	Bynam and Holman	Bishop et al.
Terrain features	1	3	3
Drainage	2	4	2
Cultural features	3	1	1
Vegetation patterns	4	2	4

A group of 15 fixed-wing pilots, instructors, radar intercept officers, and navigators ranked topography as the most important cartographic feature. Topography was followed in importance by drainage, cultural features, and vegetation patterns. In response to more detailed questioning, the same group ranked topographic features extremely useful, and drainage and cultural features moderately useful. Vegetation patterns ranked only two on a scale of five. It was noted, however, that rank orders could change, depending on the type of terrain. In some areas of the world, the relative importance of drainage and vegetation is seasonal (Qualy et al., 1982).

Bynam and Holman (1979) found that during night flight a group of tested helicopter pilots had more difficulty identifying streams and draws than bridges and fields, although this was felt to be partially attributable to the test locale (Ft. Rucker, Alabama), where bridges are in open areas that serve major highways. Hilltops were slightly easier to identify at night than streams and draws, probably because their profile could be distinguished. Heavy

haze at night made low-lying and less prominent features difficult to identify. Overall, the data showed that natural terrain features, especially those with vertical development, make better checkpoints. Because terrain features are difficult to identify correctly, Bynam and Holman recommended that they be emphasized in training programs.

Marine helicopter pilots surveyed by Bishop et al. favored cultural and drainage features over relief and land cover. Bishop et al. believed this preference to be an expression of object uniqueness—any feature noticeably different from its background appears prominent and should be prominently mapped. Another interpretation of this preference is that a lack of mapreading training causes aviators to rely on features that do not require sophisticated mapreading skills to identify.

SPECIFIC FEATURE REQUIREMENTS

The following discussion summarizes some specific feature requirements stated by aviators (Rogers, 1982; Wright and Pauley, 1971).

Roads. Location of roads, shapes of intersections, and road surfaces are important to aviators. Other road characteristics are only moderately important.

Railroads. Railroad location is important. Other railroad attributes are moderately important. McGrath (1970) feels that railroad selection rates are too high.

Bridges. Only bridge location is rated important.

Structures. Built-up areas are highly important. Conspicuous monuments and building types are somewhat important. Other building characteristics are of low-to-moderate importance.

Vertical features. Features with vertical development are extremely important.

Large features. Dams and airfields are highly important. Cemeteries, power stations, and dam orientation are moderately important.

Vegetation features. The outlines of woods are highly important because of their cover and concealment value. Edges between vegetation types are detectable by color, height, or texture and can be useful for orientation, but because of a relatively high rate of change, air photos are the recommended data source.

Drainage features. Locations of rivers, streams, lakes, ponds, swamps, marshes, canals, and reservoirs are very important. Whether drainage features are perennial or intermittent is also important. The relief surrounding streams is useful, since streams are sometimes followed during pilotage.

Natural terrain contours. Landforms are very important.

Man-made terrain contours. Large man-made contours, e.g., cuts, fills, quarries, open pit mines, and strip mines are highly important.

Boundaries. Military and international boundaries are highly important.

Miscellaneous features. Powerlines, pylons, and telephone/telegraph lines are highly important, mainly because they are hazards to NOE flight. All other features (including wells and radar reflectors) are considered to be of only low or moderate importance.

Placenames. McGrath (1970) states that chart information with no real-world counterpart is useless for geographic orientation. For this reason, he dismisses placenames as clutter. To test the hypothesis, he produced a special Sectional chart without placenames. Experienced Marine Corps low-altitude pilots demonstrated no impairment in orientation using the experimental chart and, in fact, made fewer large (e.g., over 5 nautical mile) orientational errors. However, helicopter pilots have been known to drop down to read the name of a village off a sign. Some placenames, obviously, belong on maps.

5. Map design

GENERAL REQUIREMENTS

Bishop et al. describe the inadequacy of major products for low-level aviators. The 1:250,000 aeronautical chart does not contain enough terrain information and is cluttered by radio aids to navigation. Topographic maps are produced at 1:50,000 and 1:25,000 with ample landmarks for low-level aviation. They are, however, difficult to use because of the number of contour lines and other detail that is difficult to read while in flight.

The format of a pilotage map must promote rapid assimilation of facts and visualization of terrain from glimpses involving no more than three seconds. The standard 1:50,000 topographic map format is based on the assumption that periods involving minutes will be devoted to its study. Significant changes would be required to modify the tactical map format to an at-a-glance format (Wright and Pauley, 1971).

McGrath (1970) suggested that all maps and charts be accompanied by manuals explaining the conventions and criteria used in compiling the chart. An elementary cartographic understanding of shape generalization, feature displacement, and symbology would assist users in understanding discrepancies between the actual appearance of the earth and its depiction on the chart. The criteria used in selecting map features, too, would help in correlating map features to the correct ground features.

SCALE AND SIZE

Physical considerations. Map scale must compromise between the need for detail and the problem of bulk. Bulk quadruples as scale ratio is halved. Wright and Pauley (1971) cite examples of map coverage requirements for a 200 x 300 nautical mile area:

1:50,000	318 sheets	27 lb
1:100,000	80 sheets	7 lb
1:250,000	13 sheets	1 lb

While the bulk of 1:25,000 or 1:50,000 maps is not a serious logistics problem in a relatively static combat situation, logistics quickly become unmanageable for fluid, rapidly shifting, airmobile combat. Handling, too, is a problem; when using large-scale charts at moderate speeds, a new map sheet is required every few minutes. Smaller scales reduce costs, ease logistics and handling problems, and improve cartographic responsiveness in new operational situations.

Discussion of 1:50,000 pilotage maps. Rogers and Cross (1979) assert that scales even larger than 1:50,000 could be useful for terrain flight. They believe that 1:50,000 is the preference of most Army aviators for NOE flight.

There is likely to be a bias toward the 1:50,000 scale that is unrelated to its merits, since this scale is now used by most aviators and familiarity is known to engender bias. D. Paulson (personal communication, 1984) feels that such a bias could be negated if users were trained with other scales prior to performance tests and opinion polls.

Results of MAPPRO, a study testing new pilotage map formats, showed that of the products tested (topographic line maps, orthophoto maps, and enhanced orthophoto maps at 1:50,000 and 1:100,000), the 1:50,000 products were preferred in both performance measures and opinion polls. The research team, however, warned that the method of generating performance test statistics favored larger scales.

Bishop et al. concluded that 1:50,000 is the best scale for low-level aviation based on their survey of U.S. Marine helicopter pilots. Wright and Pauley, however, believe the survey data was interpreted incorrectly. Survey results are in Table A-2. Wright and Pauley reason that there is a preference for scale ratios relating two standard measurements. Thus, in a metric country, peak responses would be at 1:25,000; 1:50,000; 1:100,000; and 1:150,000. Nonetheless, preference for scales smaller than 1:50,000 is significant. For this reason, Wright and Pauley select the second modal opinion of 1:150,000 as the most favored of the scales.

Arguments for a 1:100,000 aviation map. Wright and Pauley feel that considerable reduction from 1:50,000 scale

Table A-2. Scale preferences of surveyed aviators (from Bishop et al., 1956).

Scale preferred	Percent favoring
1:25,000	19
1:31,680 (1 inch = $\frac{1}{2}$ statute mile)	4
1:36,481 (1 inch = $\frac{1}{2}$ nautical mile)	8
1:50,000	13
1:63,360 (1 inch = 1 statute mile)	6
1:72,962 (1 inch = 1 nautical mile)	15
1:100,000	4
1:125,000 (1 inch = approx. 2 statute miles)	5
1:150,000 (1 inch = approx. 2 nautical miles)	20
Other	7

may be possible without affecting performance of most military mapreading tasks. While acknowledging the lack of data regarding map scale's effect on military mapreader performance, they favor a 1:100,000 scale product for Army aviation, based on its suitability for general-purpose use and the popularity of the AMS series 1:100,000 scale map among Army aviators. When recommending design specifications for a 1:100,000 product, however, Wright and Pauley make little attempt to reduce content with scale reduction. Rather, their scale reduction is a form of data compaction.

Rogers and Cross observe that because maps at scales between 1:50,000 and 1:250,000 are seldom available, the aviator is forced to choose between a map portraying approximately 240 square miles (1:50,000) and one portraying about 6000 square miles (1:250,000). An interim scale is needed to lessen the gap.

The usefulness of an interim scale is illustrated by the habits of medium-scale aeronautical chart users. A survey of fixed-wing, low-altitude aviators showed that a 1:250,000 product was preferred for mission planning, while a 1:500,000 product was preferred during flight (Qualy et al., 1982). Rotary-wing aviators may benefit from a similar dual-scale system. In that case, the 1:50,000 could be used during mission planning and the 1:100,000 for navigation.

The best scale for a particular task may be related to terrain. McGrath (1970) compared pilot performance using Operational Navigation Charts and Sectionals, enlarged or reduced as necessary to produce each at 1:1,000,000 and 1:500,000 scales. He found that the larger scale produced better scores on routes with good checkpoints. Conversely, on routes with long, barren stretches the smaller scale produced better performance. He hypothesized that larger scales encourage pilots to refer to the chart frequently for navigation; thus, on routes where pilotage is easy,

larger scales are more effective. Conversely, smaller scales discourage visual referencing and force pilots to rely more on reckoned position, making smaller scales more effective in barren areas where pilotage attempts are less likely to meet with success.

CULTURAL FEATURES

Populated places. Bishop et al. suggest generalizing towns drastically, showing them as areas of gray tint or as open circles. Wright and Pauley choose purple or yellow for the tint and opt for maximum detail, including street patterns and prominent buildings.

Landmark buildings. Bishop et al. favor pictorial sketches of buildings drawn from an oblique perspective. Prominent features of each building would be shown in the sketch. If the building is not always clearly visible, it would appear on the map in gray, otherwise in black. Wright and Pauley disagree, feeling that gray is not sufficiently prominent, that pictorial symbols would be inefficient to produce, and that other useful features would have to be omitted to include them. Wright and Pauley argue for removal of redundant information on topographic map symbols. Thus, the school symbol (flag atop building) would be reduced to a flag and the church symbol (cross atop building) would be reduced to a cross.

Small buildings. Bishop et al. feel that small buildings should not be portrayed unless their form or arrangement make them unique or tall enough to serve as checkpoints, in which case they should be treated as landmark buildings. Wright and Pauley strongly disagree, saying that all small buildings (unless densely packed over large areas) should be shown. They maintain that at the 1:100,000 scale, building spacing down to 100 meters should be depicted. They do not favor pictorial symbols for buildings.

Roads. Interestingly, minor roads can be more important to terrain flying than major roads. Major roads are usually avoided to evade detection, but minor roads are sometimes followed to maintain geographic orientation and masking. Bishop et al. choose black and gray lines for roads, depending on importance. Wright and Pauley consider gray roads to be insufficiently prominent and favor black or magenta, instead.

Wright and Pauley observe that while three- and four-lane roads and roads with maintained right-of-ways stand out, different types of two-lane roads are hard to distinguish. They believe it is useful to distinguish surface type, although this causes a map to become outdated more quickly. They note, however, that only some changes in surface type are usual—dirt roads are paved but

pavement is rarely restored to dirt; concrete roads may be resurfaced with asphalt but asphalt roads are almost never resurfaced with concrete.

Powerlines. Powerlines must be very prominent. Bishop et al. prefer pictorial support towers. Wright and Pauley opt for dots that correspond with support tower location. Paulson (1984) suggests distinguishing between tower type, making steel pylons more prominent than wood poles to correspond with their real-world appearance. Taylor (1976) used zigzag lines for power lines on a prototype projectable JOG, since standard straight lines were confused with grid lines. While support towers cannot easily be shown with zigzag lines, towers are unlikely to be accurately placeable on a 1:100,000 or smaller scale map.

DRAINAGE

The entire drainage network should be included whenever possible. Wright and Pauley feel that minor streams should be shown in a slightly heavier than standard line width, since they help to define relief regardless of their actual prominence. McGrath (1970), however, thinks streams are overrepresented in terms of their usefulness.

VEGETATION

Depicting vegetation is among the most difficult of all mapping problems. Because vegetation is pervasive, prominent depiction obscures other mapped features. But subtle depiction may not provide sufficient information. Symbolization strategy, too, is a problem. Areal tints used for vegetation darken the background and may make other features difficult to discern. Iconic areal patterns for vegetation clutter the map, adding complexity and confusion.

Because vegetation is more changeable than most other geographical phenomena, vegetation data is difficult to maintain in a current state. Mapreaders should be trained not to place a great deal of trust in the presence and outlines of vegetation symbols on their maps unless the symbols have been verified by current aerial photography.

Despite cartographic difficulties, vegetation data is useful to aeronautical and topographic map users, being a prominent ground feature in the first case, and both obstacle and concealment in the second. Users are likely to be sensitive to how vegetation is shown on maps. MAPPRO subjects unanimously rated vegetation depiction as "needing improvement" on all six maps used in a performance test (U.S. Army, 1974). Problems with showing vegetation on maps are discussed in more detail in this section.

Vegetation symbols. Small-scale maps generally use tints to show vegetation, while larger scales use iconic point symbol patterns to depict vegetation type. Point symbols add quite a bit of information to the map, since from vegetation type one can infer actual appearance, canopy cover, height, stem size, and a number of other vegetation attributes. Maximum iconicity appears to be based on the profile rather than on the plan view of the symbolized vegetation (McGrath, 1964).

Although a pilotage map is of a scale large enough to use point symbols for vegetation, good arguments exist for using areal tints instead. First, aviators are mainly interested in the presence or absence of woods, easily conveyed by a tint. Second, point symbol clusters add clutter that could interfere with other map information.

Bishop et al. choose to symbolize only woodlots, using a light green pattern; cultivated and other types of vegetated areas would be found using air photos. Wright and Pauley opt for a saturated green to distinguish the outlines of woodlots more prominently.

Mapping relief and vegetation. Because all types of terrain information is useful to aviators and other map users, many attempts have been made to design a means of concurrently mapping vegetation and relief. No technique can be considered entirely successful for aeronautical purposes. If both vegetation and relief are shown by tints, colors interact unpredictably and make the map colors muddy or confusing. Pictorial vegetation symbols are not a suitable answer; they provide more information than necessary and are either not prominent enough to be seen at a glance or are so prominent that they clutter the map.

Wright and Pauley believe that developing a scheme for conveying both vegetation edge and relief is a critical mapping requirement. They suggest several possible means.

- Use area tints for both relief and vegetation, switching to crosshatching in areas where the two tints overlap.
- Use area tints for elevation and area patterns for vegetation. Delineate large vegetated areas with vignettes.
- Show only the boundaries of vegetated areas; use labels or point symbols over large vegetated areas.

The first technique would be likely to convey the information adequately, but crosshatching is noisy and, hence, undesirable. The second and third techniques are employed on current JOGs but are not recommended for an aviation map. Vignetting makes the map appear spotty and does not always produce a clear picture of vegetation patterns. Vignettes are also inefficient to employ in a digital production environment; for this reason alone, they should

be avoided unless they provide clear benefits unattainable by other means.

It may be that there is no ideal way to show vegetation and relief concurrently. Bishop et al. admit that continuous portrayal of multiple areal features on a map is a difficult problem that has not yet been resolved satisfactorily. If both land cover and relief cannot be effectively depicted on maps, the best strategy is to adjust the mapping technique to the mapped area. If production economy were unimportant, the salient visual characteristics of each region could be individually selected and mapped—land cover in flat areas, relief in mountainous areas.

Wright and Pauley state that the navigational value of vegetation depends on its uniqueness. In regions of heavy vegetation, only the location and shape of unvegetated areas is of interest. Conversely, vegetation can be a landmark in barren areas. Intermittently scattered vegetation is seldom useful for navigation.

TERRAIN

Wright and Pauley offer guidelines for relief portrayal, outlined below.

- Relief is more valuable than land cover except in areas with minimal relief variation.
- The lowest and the highest terrain in a given area provide the majority of the relief information. Thus, streams must be emphasized to define valleys, and also because they often define NOE routes. If both relief and land cover are mapped, relief portrayal should concentrate on mapping the highest features.
- A pictorial format is required so the user perceives rather than interprets the landforms.
- Boundaries of relief are important.

Shaded relief. Shaded relief on low-level aeronautical charts can cause disorientation via two related problems. First, the hypothetical light source for shaded relief must be from the northwest. Because the sun never assumes this angle in the northern hemisphere, shadows on the ground seldom match those on the map. Second, relief perception tends to reverse when a map is rotated to other than a north-up position. Wright and Pauley estimate that only 15% of Army aviators use north-oriented maps, leaving the other 85% at risk of misinterpreting the terrain.

Wilson (1970) distinguishes two types of relief shading. Plastically shaded relief treats only the shadowed hillside. Fully shaded and highlighted relief treats both hillsides; a medium-tone background allows the sunlit hillside to be highlighted while the shadowed hillside is shaded. Wilson maintains that fully shaded relief will not reverse,

as does plastically shaded relief. Thus, any light source direction and any map orientation can be used.

Contour lines. Rogers and Cross (1979) believe that most pictorial terrain depiction methods (e.g., elevation tints, shaded relief, and hachures) are of limited usefulness because they lack precision. Thus, while admitting the difficulty of interpretation, Rogers and Cross chose contour lines as the best means of depicting terrain information for NOE navigation.

An experiment testing aviator orientation and navigation performance when contour lines were the only available terrain data shows the seriousness of the problem of misinterpreted contour lines. Participants made a number of errors attributable to mistaking ridges for valleys and vice versa (Rogers and Cross, 1978). To counteract this problem, elevation tints or air photos are recommended to assist in landform visualization (Rogers and Cross, 1979).

Wright and Pauley also feel that contour lines alone are inadequate for low-level aviators because they do not provide at-a-glance terrain perception, and the time required to correctly interpret them is not available at very low altitudes. Wilson (1970) states this more strongly:

It is possible that it occurred almost simultaneously to most all mapping agencies that one of the evils we were perpetrating against the pilot was that we were forcing upon him the study of engineering while in flight, and that perhaps there were better ways to depict terrain relief on aeronautical charts than by the use of complex contouring. Engineers and cartographers can afford the time required to carefully study and to expertly interpret and translate contours into mental images of the terrain they represent, but even so, these mental images have a tendency to intermittently take form and then fade away so that it is difficult to visualize anything more than a very small area at a time.

Optimum contour interval is also a source of debate. Because nearer, smaller features may mask larger but more distant features, Army aviators generally navigate by small terrain features (hillocks, saddles, stream beds) that may have vertical development of less than 50 feet, despite nearby mountains rising hundreds or thousands of feet above the flight path (Rogers and Cross, 1979). Because minor terrain features are important during NOE flight, contour interval selection is crucial if contours are to serve their purpose.

NOE aviators generally agree that no larger than a 40-foot contour interval is acceptable for portraying the types of landforms employed during NOE navigation. The larger the interval, the more terrain detail is lost, introducing uncertainty in matching map contours to landform. Wright and Pauley confirm that the contour interval on aeronautical charts is frequently so large as to make

contours practically useless to Army aviators unless terrain is very steep. Unfortunately, while small contour intervals define terrain in more detail, they also converge in steep areas. Cartographers must compromise when selecting a contour interval. Supplementary contours can be added to better define small landforms.

Bishop et al. found that pilots like color-coded contour intervals. They recommend that a brown series be applied to contours in a method similar to elevation tints: contours in lowest areas would be colored the lightest brown, contours in highest areas assigned the darkest brown. Index contours would use a line of double thickness.

Tanaka contours (Tanaka, 1950). This technique combines the dimensionality of fully shaded relief with the precision of contour lines. Based on a theory of calculating a numerical brightness value for any point on an obliquely illuminated surface, contour color and thickness are varied, depending on aspect. Using a medium-toned background and a hypothetical light source, contours are light on the "sunlit" hillside and dark on the "shaded" hillside. Contour line thickness varies with the cosine of the horizontal angle between the direction of the light source and the horizontal direction of the slope.

Tanaka contours have not been in common use because they are time-consuming to construct manually. Their algorithmic nature, however, is conducive to automation. Poiker et al. (then Peucker, 1975) implemented a computer version of Tanaka contours and found it did not take significantly longer to run than a standard contouring program.

Wheate (1978) compared the performance of subjects searching maps with standard contours supplemented by shaded relief to subject performance using Tanaka contours. Wheate found that Tanaka contours did not reverse as shaded relief does, which makes them more appropriate for aeronautical use.

Elevation tints. Wright and Pauley advise against using a single-color graded series to code elevation, suggesting instead a spectral progression of layer tints as used on the JOG.

Slope zoning. Bishop et al. suggest slope zone tints as a viable alternative to other forms of relief portrayal, since by using terrain steepness rather than landform to identify position one is not handicapped by limited field of view. In addition, slope zoning quickly summarizes masking potential and clear routes.

Slope zoning provides a pictorial view of the terrain that can be interpreted at a glance. It does, however, resemble elevation tints somewhat, and to avoid confusion

some preflight training with slope zone maps may be required.

Alternate portrayal methods. A number of alternate forms of relief portrayal have been suggested. These are listed below with their respective rationales and authors.

- Relative elevation (Bishop et al., 1956). This device could be useful for lightening the map ground on sheets covering uniformly high elevations. It is not, however, likely to help with terrain analysis.
- Vary contour line weights with elevation (Wright and Pauley, 1971). The effect of elevation tints is simulated by increasing darkness with increasing elevation.
- Apply elevation tints in only a thin band on either side of each contour line, rather than filling the entire map ground (Wright and Pauley, 1971). This method effectively lightens the background but also contributes to clutter.

6. Prototyping efforts

The possibilities of black maps were explored by Johnson (1974), who designed a black-with-colors topographic line map to address the night readability problems experienced when standard topographic maps are used with red, blue-green, and inadequate lighting. A black background increases overall color contrast. Additionally, the black map has a low net reflectance, which reduces glare and reflections in the cockpit and makes it less conspicuous in the field.

Black maps, however, are difficult to design and reproduce. Opaque inks do not exist. Thus, white paper must be printed black on both sides with colored linework, a two-pass printing process. The effect of irradiation on traditional line weights and symbol sizes also needs to be defined. Although it is known that a light object against a dark ground appears larger than a dark object against a white ground, exact parameters are unlikely to be discovered, and some experimentation may be necessary to minimize noisiness and clutter. Finally, black maps cannot be annotated by users with the same markers used to annotate white maps.

Johnson's black maps were evaluated in several different ways. Glick and Wiley (1975) performed a subjective color-by-color comparison of contrast on the experimental black and standard white topographic maps when viewed through the AN/PVS-5 night vision goggles (blue-green light). The standard map had poor contrast for vegetation and water, fair contrast for contour lines, and excellent contrast for roads. The black map had good contrast for vegetation and excellent contrast for all other

features evaluated. It was noted that the black map produced equally good results when viewed under red lighting.

A group of Army aviators was polled subjectively on three prototype maps. One map was white with nonstandard colors selected to improve red light visibility. One map was white-on-black. The last map was Johnson's color-on-black product. Each aviator rated one map only—there was no comparison among experimental formats. Sample sizes are shown in Table A-3. The survey indicated that maps with white backgrounds are preferred to maps with black backgrounds, and that the white map with special overprint was the only map preferred to the standard line map by the majority of the users surveyed. It should be noted, however, that sample sizes were extremely small and heavily weighted toward traditional formats.

Table A-3. Numbers of users rating experimental maps (Stanford, 1975).

	Aviators	Ground users	Total
White with overprint	42	12	54
White-on-black map	14	10	24
Color-on-black map	13	9	22

Wright and Pauley (1971) and Johnson (1984) feel that a photomap is a good format for pilotage. Wright and Pauley add that photomaps could be adapted to provide an instantaneous perception of relief, clearly defined vegetation edges, and the maximum level of detail consistent with adequate discrimination.

Bynam and Holman (1979) tested three experimental 1:50,000 maps for night flight. They found that of the performance variables studied (aviator experience and training, amount of illumination, and map visibility), the type of map used was the most important determiner of navigation performance from the standpoints of number and magnitude of errors, and performance speed. Of the three maps tested,

- the Experimental Air Movement Data (AMD) Red-Light Night-Use Prototype No. 3A, a black background with white markings topographic line map;
 - the AMD Experimental prototype No. 1B, a white background colored topographic map; and
 - the Experimental Night Photomap No. 1C, a black background, colored, photo-based product developed to Army Research Institute specifications,
- the third contributed to significantly fewer performance errors. More errors and slower speeds were associated with

the black map with white markings. When navigators were asked to evaluate the interpretability of the three maps, they generally preferred the second of the three prototypes, a preference that was inconsistent with performance data. Bynam and Holman concluded that, since a special product was unlikely to be created, the standard 1:50,000 topographic map that formed the basis for the second prototype is acceptable for terrain flying if it is printed with red-light-readable inks and includes air movement data.

7. Contrasting air and ground user requirements

COMMONALITIES

Ground and low-level aeronautical users share an oblique viewing angle that contributes to mapreading difficulties. Perspective is an important perception problem at low levels: relative distance and masking alters feature appearance. Hardcopy maps must represent the ground from a bird's-eye view. Because a bird's-eye view is unavailable from low levels, feature identification cannot stem from planimetric feature size unless traversal time is used for size estimation. This factor makes features with vertical development potentially more important for visual orientation.

DEPARTURES

The crucial difference in ground and air map requirements stems from aviation's higher speeds and constant operational hazard, which demand that the map be readable in very short glances and with minimum error. To this end, map content must be strictly controlled.

The next sections briefly contrast content requirements of air and ground users. Once understood, a format to address both can be designed.

CULTURAL FEATURES

Cultural detail is not useful to aviators. Appearance, not function, is of overriding importance to pilotage. Ground users may need some functional information regarding cultural features, but a product designed for movement through an area should not attempt to provide a high level of cultural detail.

Buildings. Aviators need to know about building appearance, not building function. Thus, the current topographic practice of symbolizing or annotating schools, hospitals, churches, and monuments could be discontinued if a map were to serve aeronautical users only. In fact,

labeling buildings as such can be visually misleading—a church can be lodged in either a trailer or a cathedral (Paulson, 1984).

Transportation routes. Maximum possible detail is needed for ground movement. Road surface, width, number of lanes, and grade are all useful. Similar information should be provided for bridges. Aviators need information on surface type, width, and number of lanes (all factors affecting visibility).

Vertical obstructions. Prominent depiction of powerlines and other vertical obstructions is crucial for low-level aeronautical use. Powerlines and other features with vertical development also help orient ground users.

TERRAIN

An easily interpreted method of showing terrain is needed for both ground and air use. However, some applications could benefit from the detail provided by contour lines. Tanaka contours offer one way of satisfying both requirements, since when viewed at close range the contours are seen; when viewed from a distance terrain shape emerges.

HYDROGRAPHY

Neither ground nor air users need hydrographic data that cannot be seen from land. Thus, bottom information can be safely excluded. Visible natural shoreline features (vegetation, tidal flats, etc.), visible man-made shoreline features (docks and levees), and landmark features (visible wreckage and navigation lights) should be shown.

DRAINAGE

All possible drainage detail should be provided. No proper names are needed, however. Small streams will help in identifying draws; groups of lakes, even small lakes, make useful checkpoints.

BOUNDARIES

Boundaries are invisible from the air and generally are not useful to aviators unless they delimit international or military jurisdiction. On the ground, however, minor political boundaries are shown on road signs and can be useful if mapped.

8. Summary and conclusions

DESIGN STRATEGY

As expected, there is no consensus regarding either content or format requirements for a pilotage map. It is safe

to say, however, that the format must promote rapid acquisition of information and easy map-to-ground matching. Both these factors encourage a pictorial format with minimal clutter. To minimize clutter, judicious feature selection is instrumental.

The most important selection criteria are related to visual contrast or prominence:

- size, weighting vertical development more heavily than for general-purpose maps;
- unusual shape, to assist in checkpoint selection and positive checkpoint identification;
- unique occurrence, which also assists in positive feature identification.

The second and third criteria apply to individual features and groups of features; a water tower alone may have nothing to recommend it as a checkpoint, but its location next to a pond may be unique to an area.

If a dual-purpose ground-air product is required, minimizing clutter to maintain an at-a-glance format for aviators while still providing ground users with adequate cultural detail is the most serious problem to be overcome. Functionality, which is unnecessary to aviators, must be added for ground users. Other cultural information invisible from the air and, hence, unimportant to an aviation map (e.g., boundaries and placenames), must be added if the map is to serve ground users.

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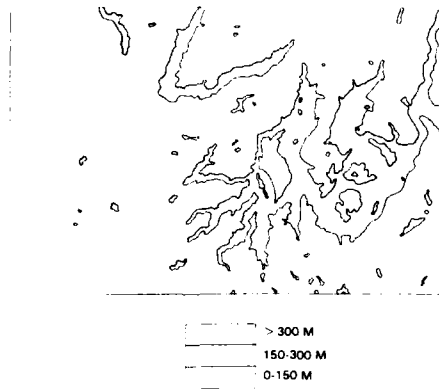
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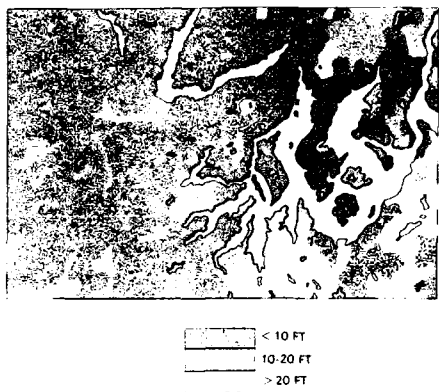
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Appendix B: Experimental map

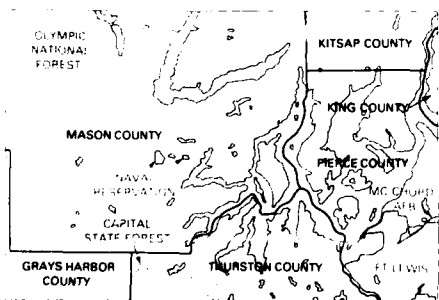
ELEVATIONS



STEM SPACING



BOUNDARIES

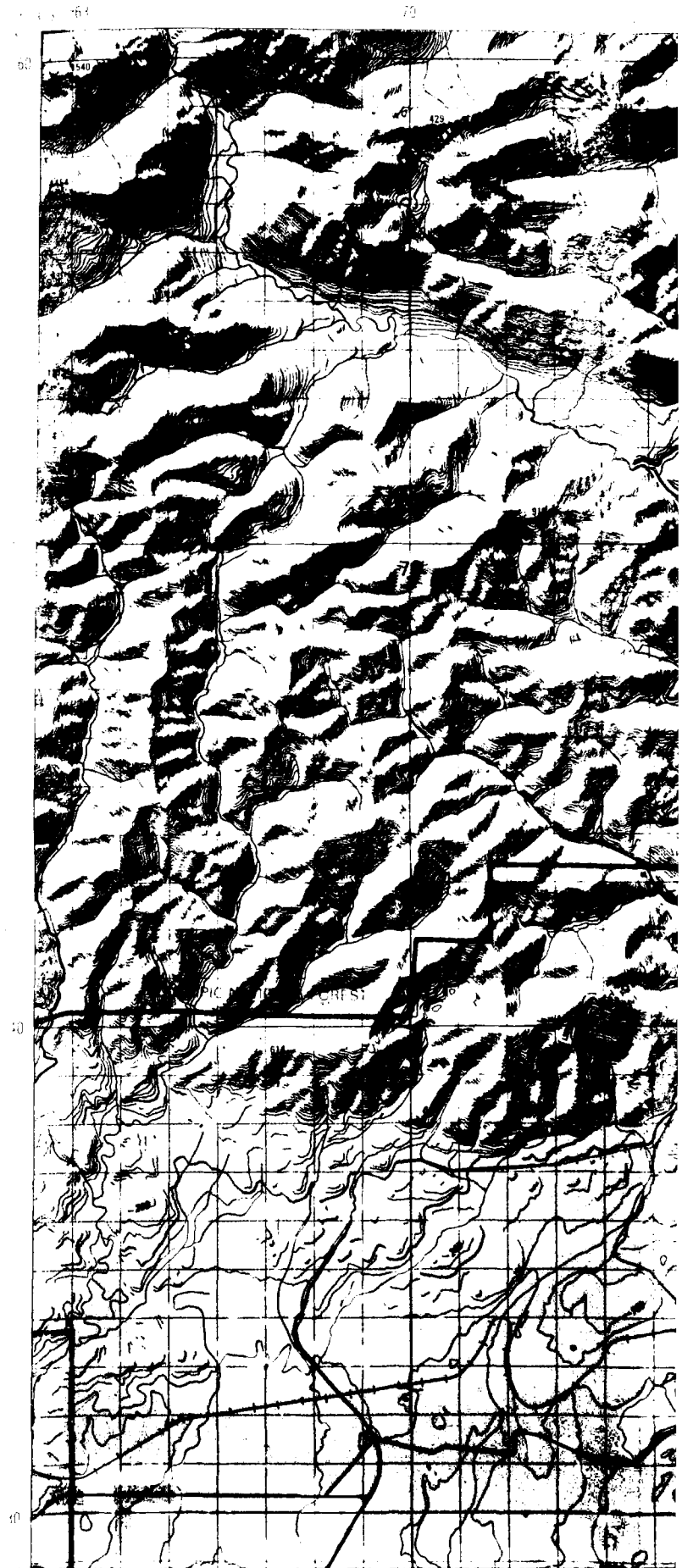


DRAINAGE



EXPERIMENTAL

LOWER PUGET SOUND, WASH., USA



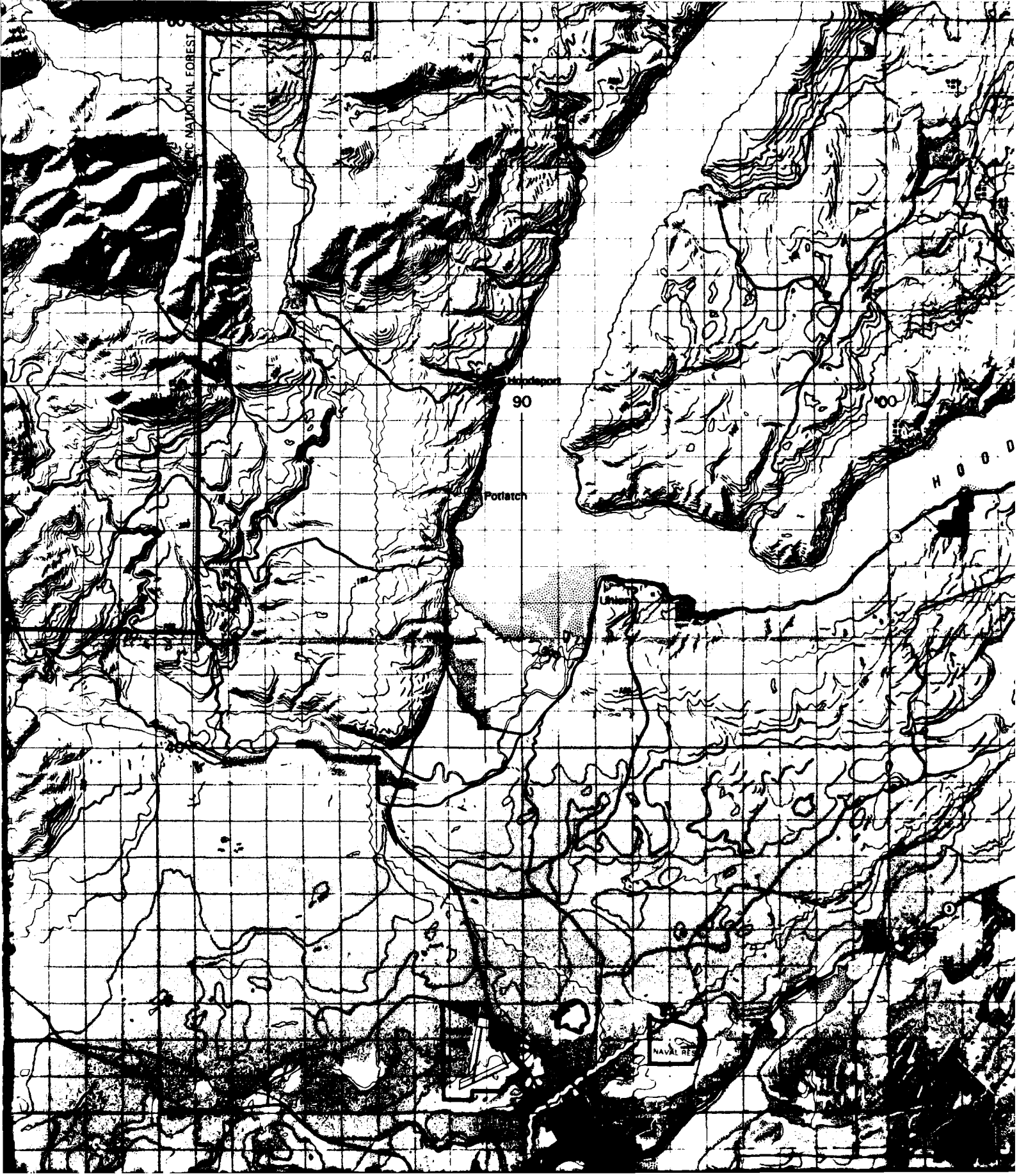
80
C NATIONAL FOREST

90

Portlatch

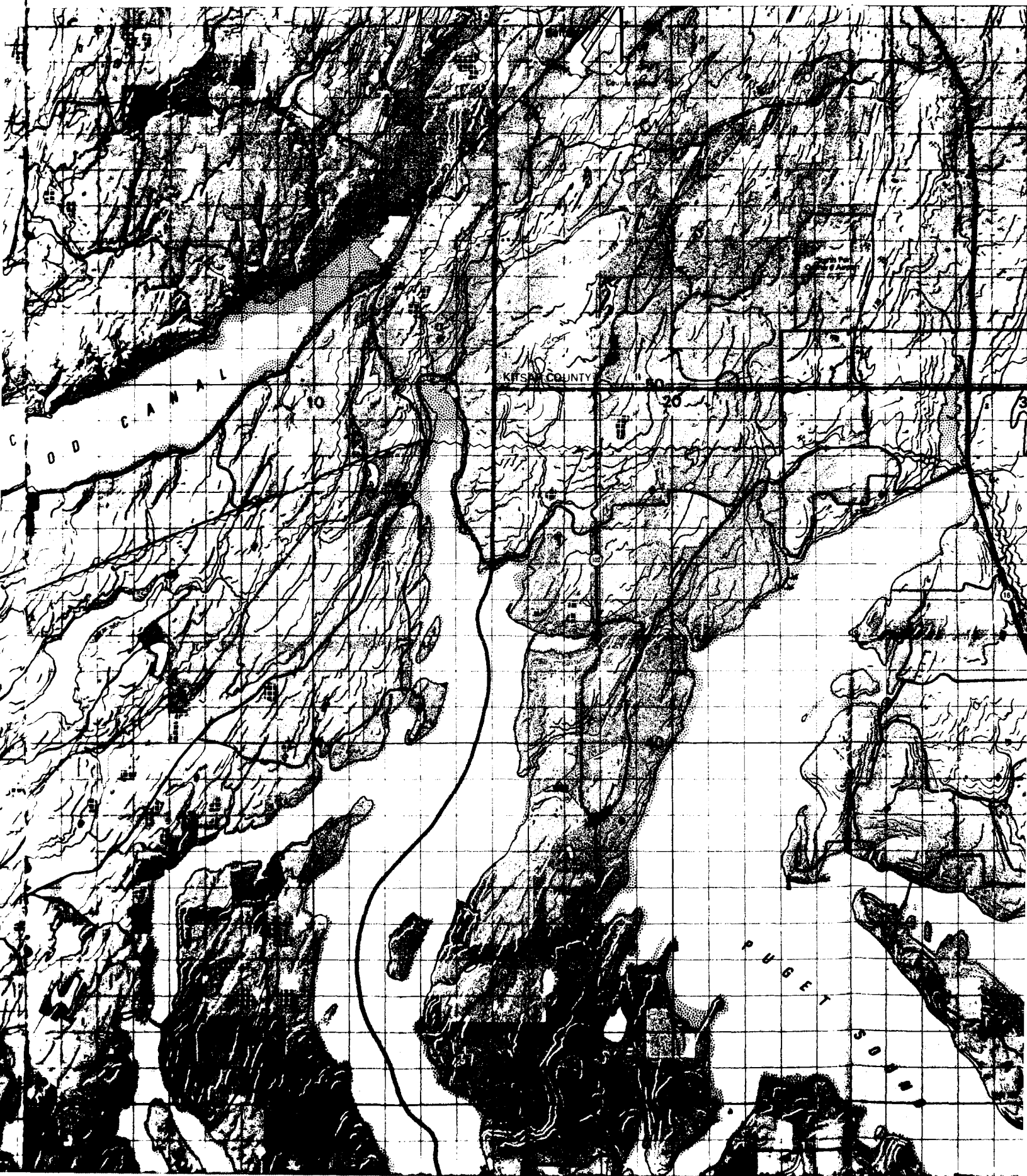
H O O D

NAVAL RES



3

25



4



Lower Puget Sound

WASHINGTON, USA

1:100,000

Compiled from Defense Mapping Agency
1:50,000 - scale topographic maps dated
1953-1981

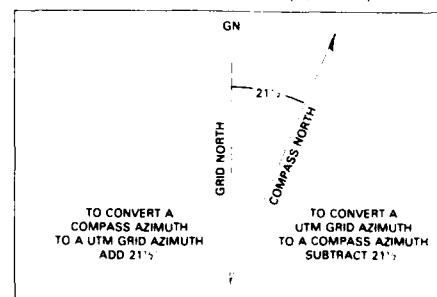
Transverse Mercator Projection

Sponsored by
Defense Mapping Agency
HQ/RE

30 x 60 minutes

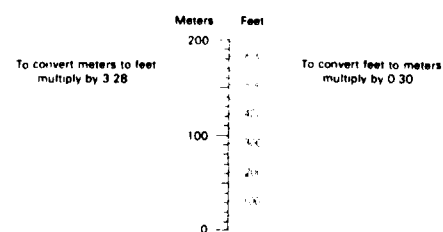
EXPERIMENTAL
NOT TO BE USED FOR NAVIGATION
OR PRECISE POSITIONING
Distribution Unlimited

1970 DECLINATION $21\frac{1}{2}^{\circ}$ (380 MILS)

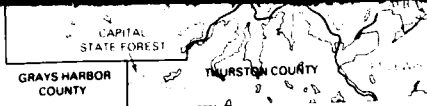


ANNUAL MAGNETIC CHANGE 3 WESTERLY

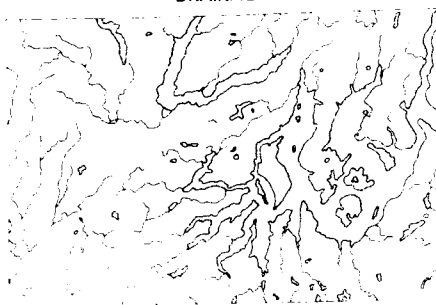
CONVERSION GRAPH



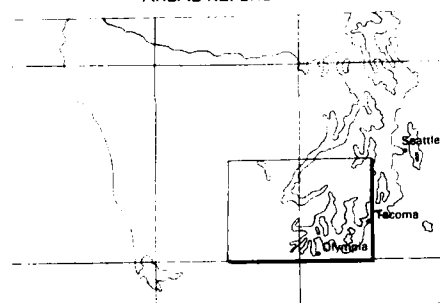
CONTOUR INTERVAL 20 METERS
SPHEROID CLARKE 1866
GRID 1 000 METER UTM ZONE 10 (BLUE NUMBERED LINES)
PROJECTION TRANSVERSE MERCATOR
VERTICAL DATUM SEA LEVEL DATUM 1929
HORIZONTAL DATUM 1927 NORTH AMERICAN DATUM



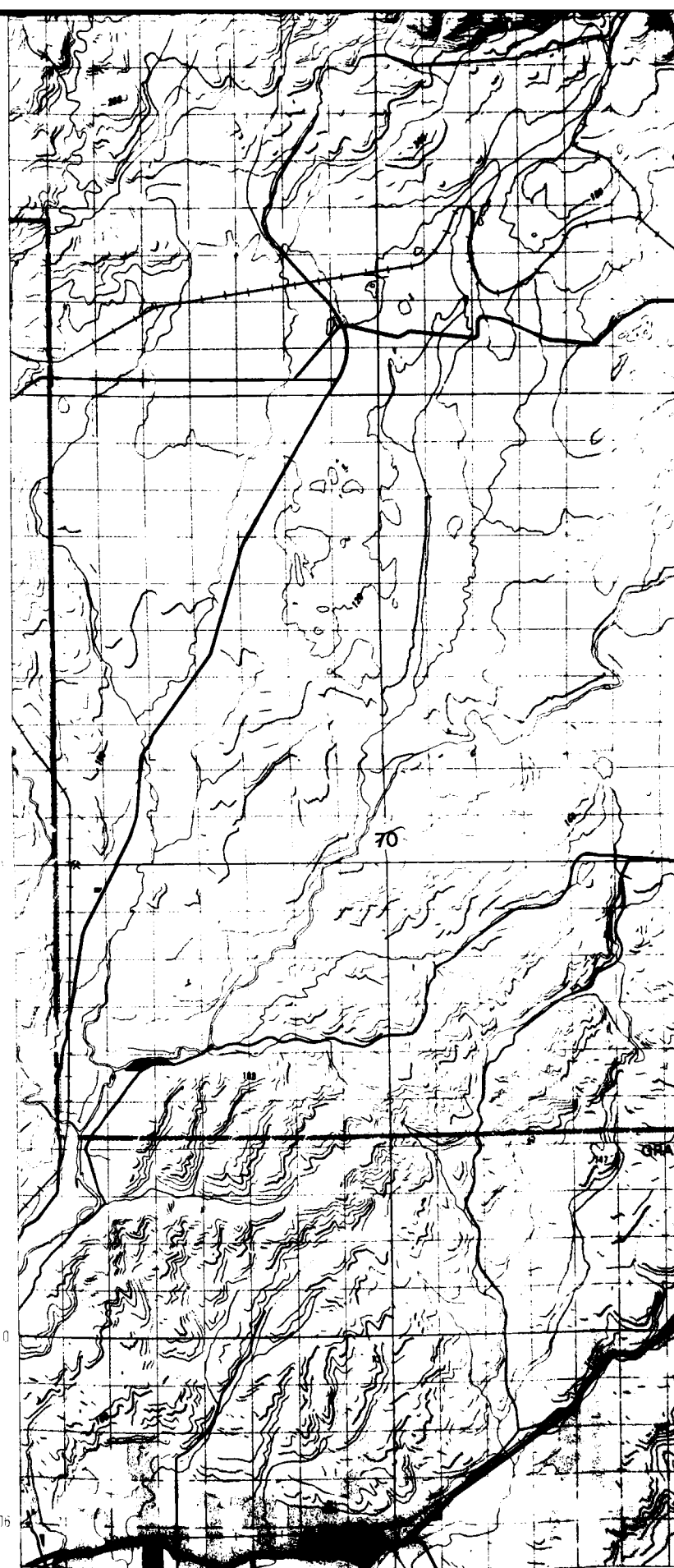
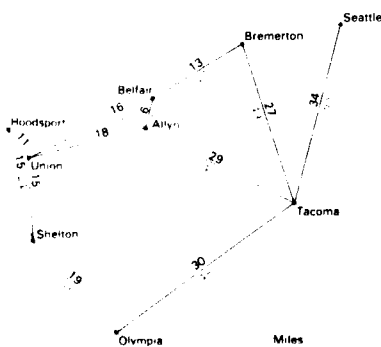
DRAINAGE

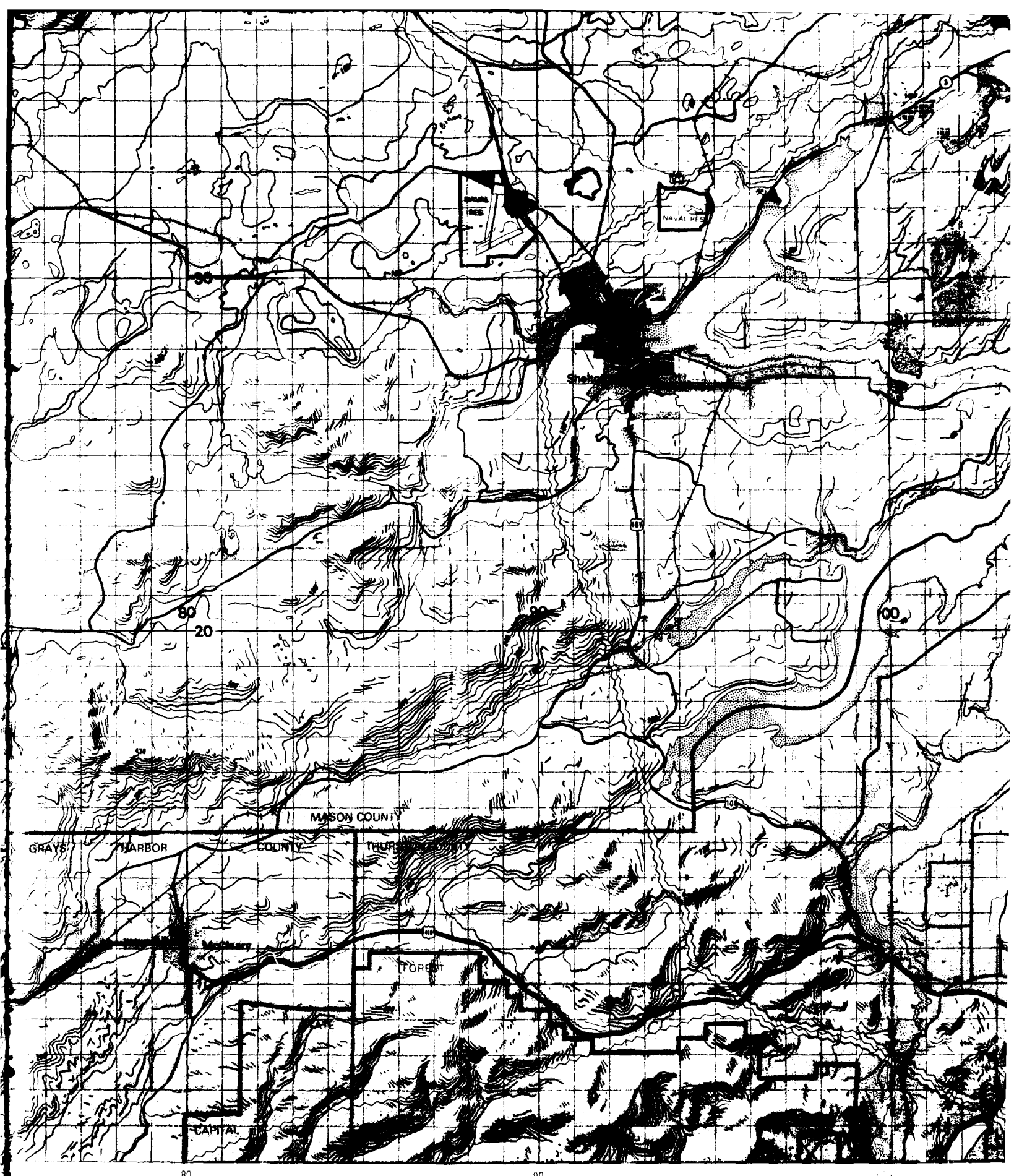


AREAL REFERENCE

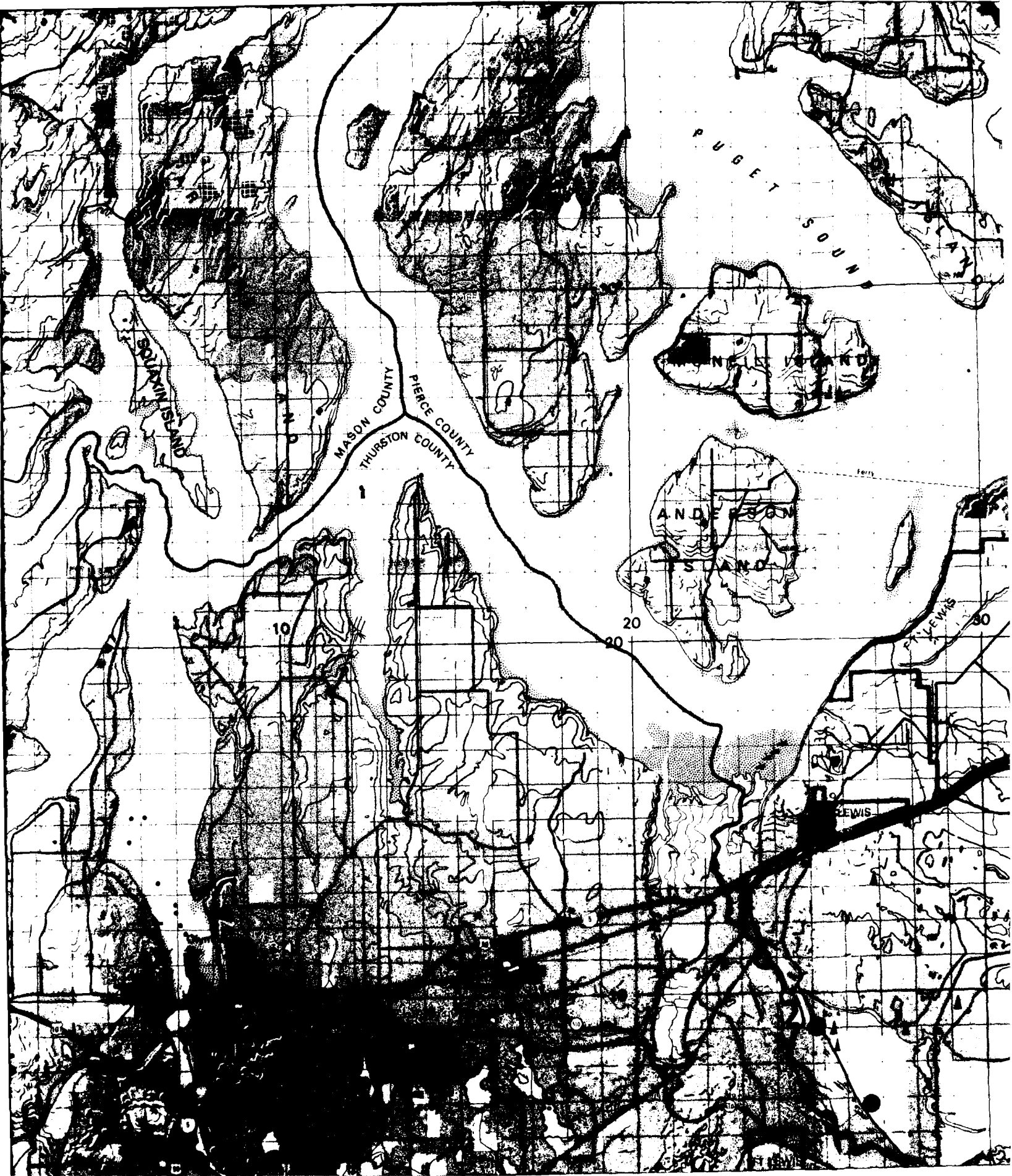


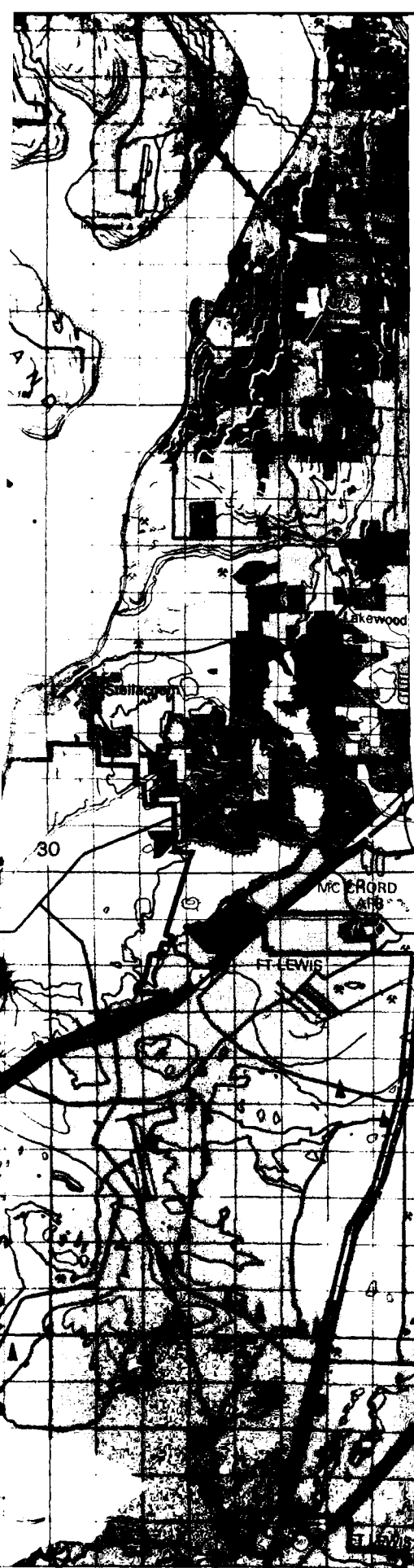
ROAD DISTANCES





SCALE 1:100,000
1 CM ON THE MAP REPRESENTS 1 KM ON THE GROUND
CONTOUR INTERVAL 20 METERS
NORTHWEST ILLUMINATION



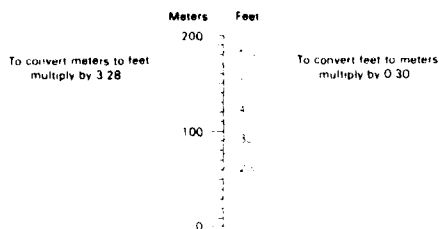


TO CONVERT A
COMPASS AZIMUTH
TO A UTM GRID AZIMUTH
ADD 21°

TO CONVERT A
UTM GRID AZIMUTH
TO A COMPASS AZIMUTH
SUBTRACT 21°

ANNUAL MAGNETIC CHANGE 3 WESTERLY

CONVERSION GRAPH



CONTOUR INTERVAL 20 METERS
SPHEROID CLARKE 1866
GRID 1 000 METER UTM ZONE 10 (BLUE NUMBERED LINES)
PROJECTION TRANSVERSE MERCATOR
VERTICAL DATUM SEA LEVEL DATUM 1929
HORIZONTAL DATUM 1927 NORTH AMERICAN DATUM

SAMPLE 1 000 METER GRID SQUARE		100 METER REFERENCE
46	45	Read large numbers labeling the VERTICAL grid line left of point and estimate tenths (100 meters) from gridline to point.
12	13	Read large numbers labeling the HORIZONTAL grid line below point and estimate tenths (100 meters) from grid line to point.
100 000 M SQUARE IDENTIFICATION		Example: 123456
EH		WHEN REPORTING ACROSS A 100 000 METER SQUARE LINE, PREFIX THE 100 000 METER SQUARE IDENTIFICATION IN WHICH THE POINT LIES.
GRID ZONE DESIGNATION		Example: EH123456
10T		WHEN REPORTING OUTSIDE THE GRID ZONE DESIGNATION AREA, PREFIX THE GRID ZONE DESIGNATION.
		Example: 10 TEH123456

LEGEND

ROADS

Divided highway, Primary all weather, hard surface	_____
Secondary all weather, hard surface	_____
Light duty all weather, hard or improved surface	_____
Fair or dry weather, unimproved surface	_____
Route markers: Interstate, Federal, State	95 99 200

RAILROADS (Standard gauge: 4'8" 1.44m)

Single track	_____
Multiple track	_____
Multiple track, non-operating	_____
Railroad station	_____

BOUNDARIES

County	_____
Military Reservation	_____
Forest	_____

POPULATED PLACES

Densely built up areas	_____
Moderately built up areas	_____

OTHER CULTURAL FEATURES

Factory, Prominent buildings	_____
Tower, Chimney, Monument	_____
Open pit, Drive-in theater	_____
Powerline	_____
Airstrip less than 800m, Maintained, Abandoned	_____

NATURAL FEATURES

Prarie	_____
Woodland	_____
Orchard, Park	_____

HYDROGRAPHIC FEATURES

Marsh or swamp, Dam	_____
Large rapids, Large falls	_____
Rapids, Falls, Intermittent lake	_____
Shipwreck	_____
Ferry	_____
Mud	_____
Lighthouse, Light	_____
Man-made shoreline, Pier	_____



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FIELD	GROUP	SUB GR														
19 ABSTRACT (Continue on reverse if necessary and identify by block number) This report documents the design process of an experimental 1:100,000 topographic map. The map itself comprises Appendix B. The experimental map is designed for ground and air movement and is scaled to fill the gap between DMAs 1:50,000 and 1:250,000 products. A NORDA study elicited the needs of the targeted users through direct questioning and a literature survey (Appendix A). The design concept is pictorial and relies on an alternate terrain depiction method, Tanaka contours, to meet the disparate terrain analysis needs of air and ground users.																
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