# NIGHT VISION MAPS By Gerald L. Greenburg 2002

**CALIFORNIA MAP SOCIETY OCCASIONAL PAPER No. 7**

Unusual designs and principles to enhance map perception have always intrigued the author throughout a long career in cartography, such as while working in private industry on computer-printed map design and cognition; during university research studies on maps for the blind and partially-sighted; in government work doing quality analysis and testing of thematic and orthophoto maps; and in the currently written summary on the designs, applications and sources of maps that "glow in the dark." This study covers most types of maps which are used at night and under low-illumination or darkened environments, including control and planning rooms, subterranean and underwater areas, polar and extra-terrestrial regions, and in blackout conditions caused by storms and volcanic ash eruptions. Night vision maps are used in critical operations by explorers, astronomers, navigators, meteorologists, military, police, and by others who must preserve dark visual adaptation while reading graphics. There are three basic ways these maps are made: (1) self-luminous graphics with phosphorescent painted symbols, (2) red-light or green-light illuminated graphics printed in negative like style with special tones and color tints that are readable as different shades of gray, and (3) fluorescent graphics which have symbols and/or backgrounds that become visible when illuminated by ultraviolet light. Physiological (perception-psychology) principles applied to the map design processes are explained, color examples are presented, reference sources are well documented and a technical glossary is included.

This research paper was first presented in a meeting of the Western Association of Map Libraries at the University of Hawaii in November 2001. Marianne Hinckle, a CMS member who measurably assisted with the graphic composition and printing, first suggested that this work could be submitted for consideration as a candidate for publication as a CMS Occasional Paper. Upon acceptance, a large number of copies were printed and donated for distribution to the CMS members. The paper was also presented at a CMS meeting in Santa Clara, June 2003.

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A subject of much research from the late 1930's to the present is maps and graphics utilized by persons who must retain scotopic or twilight vision (dark adapted) to work at night and in very low levels of light. The designs, applications and sources of such maps are topics often addressed by behavioral scientists, users and library archivists. Geographic and mobility references are often required at night and in low illumination environments. Special maps and terrain imagery are used in different kinds of dark environments such as outside at night; enclosed work areas including navigator cabins, air traffic control towers, military and police command centers, railroad and utilities control rooms, weather stations and astronomy observatories; polar regions in the dark winter season; total solar eclipse periods; severe dust, sand and atmospheric storms; thick volcanic ash eruptions; subsurface areas including caves, excavations, mines, tunnels and underwater; and outer space and extra-terrestrial regions. Development and production of these special maps and graphics is currently done by military and commercial mapping agencies, and historically, they were made by special navigation and strategic map research sections of European and American military agencies.

Night light maps must be less detailed than day maps, displaying only those objects visible at night, and avoiding items that are invisible to the night map viewer. In practice, the high cost of map production has resulted in "night enhancement" of selected symbolized objects on standard series of topographic maps and navigation charts. Night map users must scan information in short time periods, especially when in motion on foot or in vehicles. The generally adopted scales for maps, containing adequate details for night navigation and military movements, range from 1/24,000 (or larger for engineering data) to 1/1,000,000 for high speed air navigation. Readable symbols and notations must be fewer in quantity, appear larger than usual size, avoid overlap, and be easily recognized by conventional shapes, patterns or colors seen as shades of gray or black under dark adaptation night lighting.

The preferred night map background is gray or black which reflects minimal amounts of light, an aid to preserve dark visual adaptation and not detract from symbolized information. Symbols are printed in white, black, gray, and color tints of brown, red, orange, yellow, green, blue, magenta and purple. In red night lighting, colors appear as different shades (tones) of gray. On a medium gray map background, magenta and purple are seen as darker tones, and tints of blue, green and tan appear as lighter tones. Hence, a range of gray tones plus black and white are distinguished instead of colors. Dark tints of brown, blue and green appear black, and red, orange and yellow colors fade or disappear under red light. Recently there has been a move to blue-green illumination standards compatible with night vision viewing equipment for military and police uses. Dim green light permits retention of night vision while allowing high visual acuity and gray-tone differentiation of most colors. There are three applied and experimental night map printing variants of standard navigation charts and topographic maps: (1) red, blue or green light readable color symbols upon low-reflective white or dark (gray or black) map backgrounds, (2) white and color phosphorescent pigments on self-luminescent symbols readable under blackout conditions, and (3) fluorescent dyes for symbols and backgrounds with distinctive color luminescence when viewed under low intensity ultraviolet lighting. Most specially printed maps are made to be usable in both daylight and dark environments.

A common manner of making night maps employs a "negative-like" style of printing with white symbols upon a black or dark gray background. While preserving dark visual adaptation through minimal amounts of light reflectance, such maps may contain smaller or thinner symbols and be perceived at up to 30 percent greater viewing distance at night, as compared with similar maps with black symbols upon a white background. Examples of this type of map include topographic maps with white elevation contour lines (called illuminated contours) printed upon a black background, radar charts for identifying and plotting scope images (terrain features, flight paths, weather patterns), night-view satellite maps of the earth's surface, star charts and planetarium displays of the celestial sphere.

Pictorial terrain models of local-regional night landscapes have been made for training and operations movements of military and law enforcement agencies. These graphics, called "terrain boards," are constructed upon white fiber-board or waterproof plastic base material. Images are portrayed as oblique, simplified silhouette pictures of natural and culture features in special colors or tints favoring night perception in black, white and gray tones. When used with night vision goggles, these map aids help to demonstrate landscape appearances under various natural and artificial light (including infrared) intensity levels, light source orientations and viewing positions. Infinite adjustments can be made to simulate terrain observations under a range of night illumination levels and radiance angles (horizon to zenith and surface bearings) from full overhead moonlight to cloudy starlight and shadow effects. Terrain boards are custom made to enable detailed visual discrimination of types of natural terrain, weather effects and artificial features in current, planned or historic landscapes.

Luminescent map displays for low illumination environments employ different kinds of mechanical and electronic devices. Both symbols and/or backgrounds of large graphic panels have special white and colored lights (incandescent, fluorescent, light-emitting-diodes), which are controlled with manual or computer automated dimmers and switches to enhance, diminish and animate symbols and text. Maps on film are viewed with a microfilm reader or optical image magnifier and also by a film projector for enlarged image display upon reflective (front) or translucent (rear) projection screens. Radar displays use cathode ray tubes and optical projectors for viewing and matching images with mapped information. Electronic (digital) map records are viewed on television tubes and solid-state video panels (liquid crystal displays). Modern electronic map display systems provide options for static or moving images, colors and gray tones, image to background contrast control and reversal, image orientation rotation, three-dimensional and perspective appearances, and timing variations for image duration and movement. Large map display panels are used for military and police logistical planning; aircraft, missile, satellite, and celestial tracking; vehicular traffic (land, sea, air) and utilities flow routing; and weather event plotting. Small video map displays facilitate navigation and survey activities on foot or in vehicles. The perceptual efficiency of special cartographic displays depends upon their optimal design details.

Design characteristics of night vision maps employ perception principles and effects, which are helpful knowledge for persons who produce, acquire and use these special graphics. Behavioral science research and testing, called psycho-physical studies, are done to determine the relations between subject, environment and object variables, resulting in optimal design and use parameters for selected visual requirements. Subject variables include visual acuity, mental conditioning, health, fatigue, stress, motion and activity time-span. Environmental variables include illumination attributes, viewing field dimensions, area orientation, slope angle, time of day or night, season, latitude, altitude, noise, vibration, atmospheric composition, weather elements and terrain types. Object variables include symbol pattern, text style, size, shape, color, tone, background, complexity, contrast, reflectance, absorption and stability. Some definitive visual principles and effects are listed to supplement understanding of map examples described and illustrated in this presentation. A selective bibliography is also provided.

## Visual Principles and Effects

<u>Twilight (scotopic) Vision</u> - In contrast to daylight (photopic) vision, visual stimulation at scotopic low levels does not produce color vision anywhere along the spectrum. Color vision is only possible with levels of light sufficient to activate the cone system of the eye's retina. When only the rods are functioning, all wavelengths are seen as a series of lighter or darker gray tones. Weak light is visible and the iris opens wide to allow dark adaptation for maximum detection of different levels of light brightness, perceived as a range of gray tones from white to black.

<u>Purkinje Effect</u> - A physiological condition in twilight resulting in a shift in the maximum sensitivity of the eye from photopic to scotopic vision. The relative daylight spectral sensitivity curve for the cones (photopic curve) peaks at 555 nm., while during rod or scotopic vision the curve shifts 45 nm. toward the 400 nm. (blue) end of the spectrum with a peak at 510 nm. Visual sensitivity increases at shorter (green-blue) wavelengths and decreases at longer (red-yellow) wavelengths for the rod system. Although objects will be colorless under rod vision, a blue target will appear as a brighter or whiter tone of gray, more intense than a red target of equal brightness, due to this shift in visual sensitivity during scotopic (rod) vision. The visual spectrum ranges from about 400 nm – 700 nm. (nanometers).

<u>Irradiation Effect</u> - An optical illusion where dark images appear smaller on a light background, and light images appear larger on a dark background, even though these images have identical size and shape. In the latter case, the lighter image appears to "spread out" or "spill over" into the contrasting darker surroundings, producing illusions of image magnification, enhancement and also three-dimensional effects. Negative-like effects of irradiation have been found to have visual advantages at night and in low illumination environments. Negative-like graphics (white symbols upon a black background) can be seen up to 30 percent farther and made with smaller or thinner symbols and text than equivalent positive graphics (black images on white background).

<u>Mesopic Vision</u> - A range of visual perception involving both rods and cones. Cone vision can be activated with a lower intensity of green light than any other color. Objects may be seen at a minimum illumination level with a slightly greenish tinge of color from white or green objects, and all else will appear as shades or tones of gray or black. If colors are seen, then night vision has been compromised with excess or overload of illumination intensity (called blooming), which happens in certain activities for a brief duration, such as flying at night across the path of a searchlight beam, sudden dazzling bursts of light from flares or anti-aircraft missile fire, viewing colored stars or signals, or temporary illumination increases for examining colored objects of critical importance.

<u>Afterimage & Autokinetic Effects</u> - Visual image and movement sensations of a positive or negative nature which occur after stimulation by an external cause has ceased. Following a sudden dazzling from a bright light, a white "positive" or black "negative" image is perceived with successive fading until recovery of dark vision adaptation level. If the stimulus is color, the same color or a "negative" complementary color is seen with successive fading of brightness and sometimes changes in hue. A moving visual stimulus induces subsequent perception of an afterimage in motion across the visual field, either in the same "positive" or reverse "negative" direction from the initial vector, or else going in random directions if no fixed position and orientation frame of reference has been memorized. Moving image illusions can be inhibited by avoiding lengthy image fixations and by employing at least three location reference light signals within the visual field.

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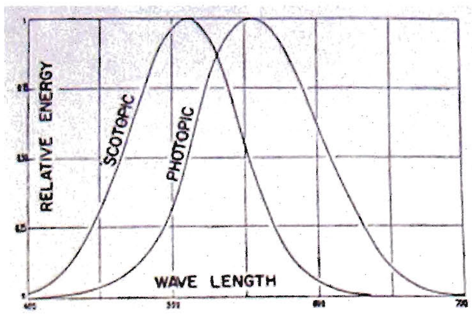


Figure 1A

Fig. 1A. Luminosity curves of the human eye. Average photopic curve defining the standard observer (I.C.I.) and average scotopic curve (Stiles and Smith,1944). The maximum of the eye's sensibility moves from green-yellow toward blue-green when passing from daylight vision to nightlight vision (Purkinje effect). In ordinates, relative energy-expressed in arbitrary units with a fixed maximum of 1. In abscissas, wave length is in millimicrons. Graph from Gaetan E. Jayle, et. al., *Night Vision,* Springfield, IL: Charles C. Thomas, Publisher, 1959, p. 14.

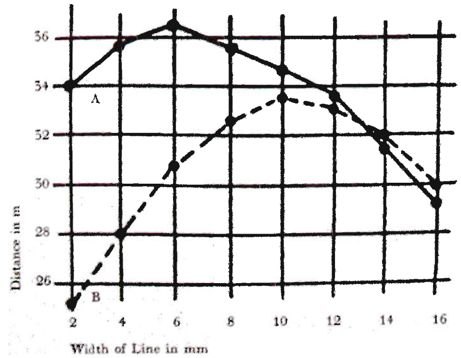


Figure 1B

Fig. 1B. Influence of line-width and background upon recognition distance. Solid curve A represents white numerals on a black background, and dashed curve B represents black numerals on a white background. Graph from Curt Berger, "Strokewidth, Form and Horizontal Spacing of Numerals as Determinants of the Threshold of Recognition," *Journal of Applied Psychology,* v. 28, n. 3, June, 1944, p. 217.

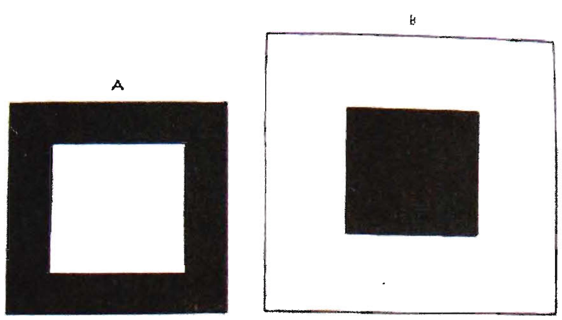


Figure 2A

Fig. 2A. Negative mode of irradiation effect. The white square (A) appears larger than the dark square (B), although both are identical in size. Diagram from Maitland Graves, *Color Fundamentals,* New York, NY: McGraw-Hill Book Co., Inc., 1952, p. 109.

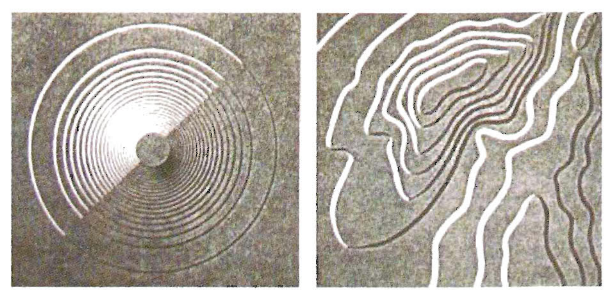

Figure 2B

Fig. 2B. Illuminated contour lines. Although exact thickness of each contour line is calculated according to the proportion of actual light received in standard oblique illumination at a given degree of slope, segments of white lines on northwest-facing slopes may appear wider than corresponding black lines on southeast-facing slopes due to the irradiation effect. A three-dimensional image appearance is also noticeable. Lines are drawn upon a medium-gray background (Munsell 5/ or 6/), and they are thinned where black and white lines meet to facilitate visual continuity with minimum black-white contrast at transition points. Diagram from Eduard Imhof, *Kartographische Gelandedarstellung,* Berlin, Germany: Walter de Gruyter & Co., 1965, p. 175.

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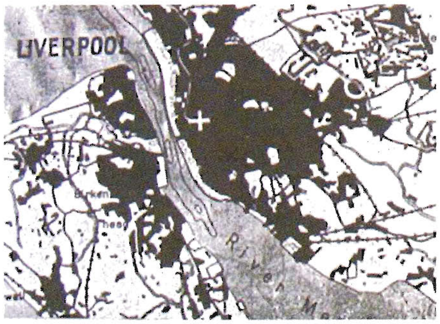


Figure 3A-D,R

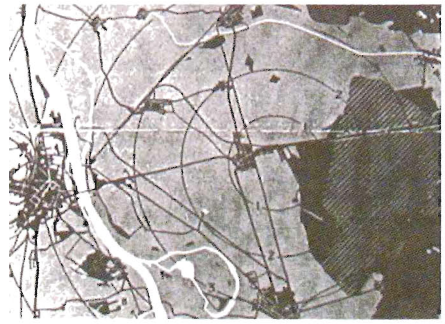

Figure 3B-D,R

Fig. 3A. German air map section. Fluorescent paint applied on rubber cloth before printing in four colors. Appearances in daylight and under ultraviolet illumination:

| Features | Daylight | Ultraviolet |
|---|---|---|
| hydrography. . . . . . . . . . | green | light blue |
| towns, roads, railways . . . . | sepia | black |
| woods and forests. . . . . . . . . | dark green | dark gray |
| background . . . . . . . . . . | yellow ochre | light gray |

Illustration from Gaetan E. Jayle, et. al., *Night Vision,* Springfield, IL: Charles C. Thomas, Publisher, 1959, p. 352-353.

Fig. 3B. U. S. Army Air Force aeronautical chart section. Fluorescent material is incorporated in paper before printing in three colors. Appearances in daylight and under ultraviolet illumination:

| Features | Daylight | Ultraviolet |
|---|---|---|
| hydrography. . . . . . . . . . . | . . light blue | blue gray |
| cities, landing strips . . . . . | . . . . gray | black |
| landmarks and inscriptions. | . . magenta | purple |

Illustration from Gaetan E. Jayle, et. al., *Night Vision,* Springfield, IL: Charles C. Thomas, Publisher, 1959, p. 352-354.

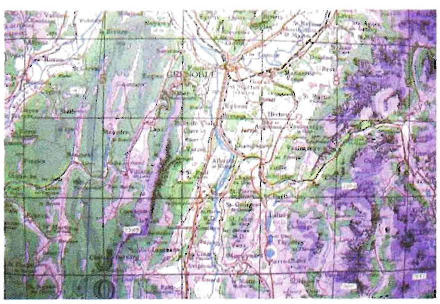

Figure 4-COL-D

Figure 4R

Fig. 4. Army/Air topographic map section, Grenoble, France area, AMS Sheet 32, 1:250,000 scale, red light printing, Washington, DC: U.S. War Office, Army Map Service, Second Edition, 1943. Appearances in daylight and under red light illumination:

| Features | Daylight | Red Light |
|---|---|---|
| rivers, canals, lakes . . . . . . . . . | dark blue | black |
| woods, orchards, brush . . . . . . . | green | dark gray |
| altitude (layer tints) . . . . . . . . . | purple tints | light-dark gray |
| roads, cities . . . . . . . . . . . . . . . . | red | medium gray |
| railways, grids, notes . . . . . . . . . | black | black |
| background windows . . . . . . . . . | white | white |

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Figure 5-R

Figure 5-COL-D,R

Fig. 5. Black topographic map section, Petry, Alabama area, *Experimental Air Movement Data, Red-light Night Use Black Map,* Prototype No. 3A (white symbols on black background), and Prototype No. 4B (white and color symbols on black background), Series V744-AMD, Sheet 3747 I, 1:50,000 scale, Washington, DC: U..S. Defense Mapping Agency Topographic Center, 1973, Symbols appear white at night on both black and three color printing; daytime color map appearance:

White - culture features, railways, minor boundaries, spot elevations, notations
Yellow-Ochre - airport runways, landmarks, obstructions, elevation contours, notations
Red - roadways, major boundaries, notations
Light Blue - hydrography, vegetation, notations

Figure 6-COL-D,R

Fig. 6. Radar chart section, Two color printing with terrain shown as gray tones of shaded-relief; cities, towns, airports and railways are white; hydrography, grids, isogonic lines and notations are black; spot elevations, city and town names are purple. In darkness, symbols appear as shades of gray and black or white. Example from *USAF Radar Chart,* RC-308, Illinois River, 1:1,000,000 scale, Washington, DC: U.S. Department of the Air Force, Aeronautical Chart and Information Service, 1951, revised.

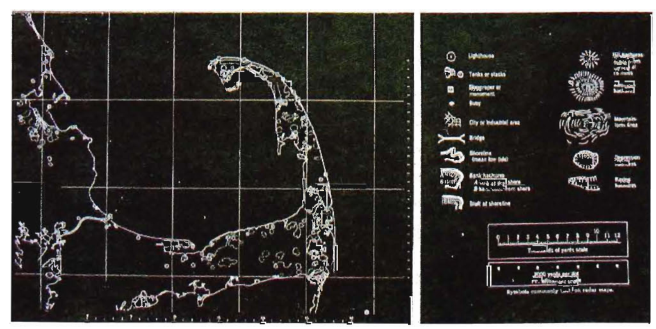

Figure 7-D,R

Fig. 7A, B. Radar projection chart and legend. Gray-white radar scope images are optically projected onto the black chart and matched with the thin, white standardized symbols and location graticule. Hachure symbols appear more legible than contour lines for depicting landforms on these maps. Simplified compilations of symbolic data are extracted from coastal navigation charts and topographic maps. Local charts are produced at 1:80,000 scale, and printed on dimensionally stable photographic film or microfilm. Example map from John S. Hall, Editor, *Radar Aids to Navigation,* New York, NY: McGraw-Hill Book Company, Inc., 1947, p. 347-348.

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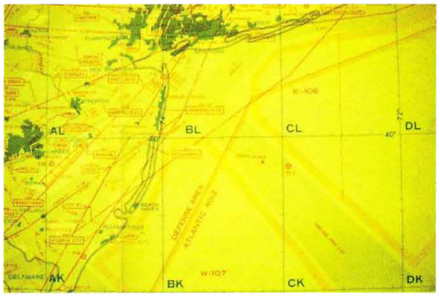


Figure 8-COL-D

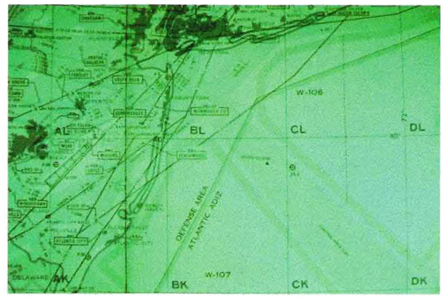


Figure 8-uV

Fig. 8. Military air-ground reference and training map. The map background is printed in yellow, green and orange fluorescent "Day-Glo" colors to produce high symbol-to-background contrast and luminance under low intensity blue (ultraviolet) light or in daylight. Example from "SAGE Reference Chart," Series SRC, No. 9, Atlantic coastal area, 1:200,000 scale, St. Louis, MO: U.S. Department of the Air Force, Aeronautical Chart and Information Center, *USAF Catalog of Aeronautical Charts and Aeronautical Information Publications, 1960.*

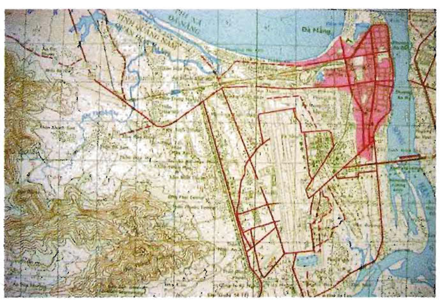

Figure 9-COL-D

Figure 9-uV

Fig. 9. Topographic map section. Multi-color printing in special inks visible under daylight, red, blue and ultraviolet illumination. U.S. Army Map Service base is 1:50,000 scale, on waterproof, low reflectance material, depicting area of Da Nang, Vietnam. Example from correspondence with Brice Burroughs, Director, Marine Charts Division, U.S. Naval Oceanographic Office, Washington, DC, 30 July, 1970. Appearances under different kinds of illumination:

| Features | White or Daylight | Red or Blue | Ultraviolet |
|---|---|---|---|
| contours | brown | black | gray |
| urban area, major roads | magenta | gray | orange |
| villages, airport, roads, towns | light green | gray | green |
| grids, notations, vegetation | dark green | black | green |
| vegetation | light green | gray | green |
| hydrography | light blue/dark blue | gray/black | black |

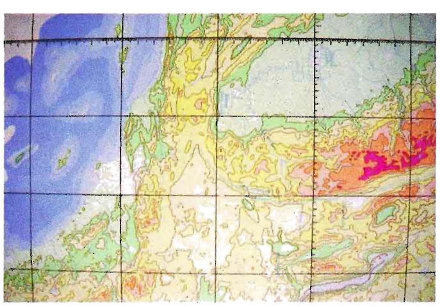

Figure 10-COL-D

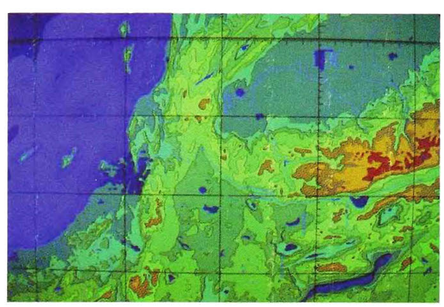

Figure 10-uV

Fig. 10. Special air navigation chart section. Land elevations and water depths are represented by experimental color layer tints bounded by index contour lines. Fluorescent hues of red, orange yellow, green and blue are used to give a three-dimensional relief effect from "warm - cool colors" viewed under ultraviolet night lighting. Brown contour lines and a black grid are printed in conventional inks. Map base is from *U.S. Navy Air Navigation Chart,* Series V 30, 1:2,188,800. scale, covering a part of southern California. Example from correspondence with Brice Burroughs, Director, Marine Charts Division, U.S. Naval Oceanographic Office, Washington, DC, 30 July, 1970.

# NIGHT VISION MAPS By Gerald L. Greenburg 2002

## CALIFORNIA MAP SOCIETY OCCASIONAL PAPER No. 7

LEGEND: A,B = related information or images COL = color image D = white or daylight view R = red light view G = green light view uV = ultraviolet light view

Note: Tones / tints of images seen may vary in perceived shades of gray or colors due to viewer (subject), object and environmental variables described in the text of this paper.



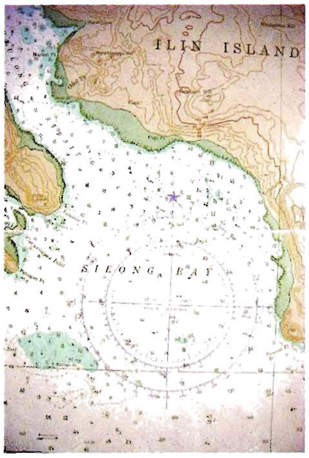


Figure 11-COL-D

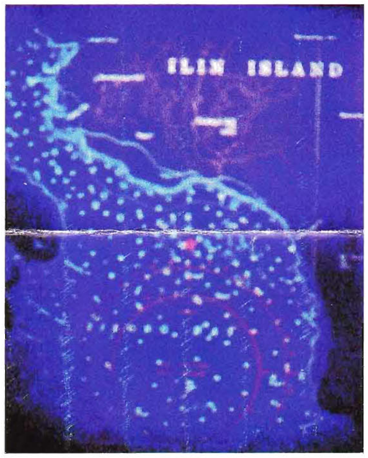


Figure 11-uV

Figure 12-COL-D,G

Fig. 11. Special nautical chart section. Five color printing in fluorescent hues for use in daylight and under ultraviolet illumination at night. Map base is from special *U.S. Navy Hydrographic Chart,* 1:25,000 scale, covering coastal islands and waters by southwestern Mindoro Island, Philippines. Example from correspondence with Brice Burroughs, Director, Marine Charts Division, U.S. Naval Oceanographic Office, Washington, DC, 30 July, 1970.

| Features | Daylight | Ultraviolet |
|---|---|---|
| island land area | tan | black |
| elevation contours | brown | brown |
| coastal vegetation | light green | green |
| shallow waters | light blue | gray |
| deep waters | white | black |
| grids, depth notes & contours | dark green | green |
| navigation symbols | purple | orange |

Fig. 12. Terrain board for night vision. Oblique, simplified silhouette pictures of natural and culture features are printed in special color tints favoring night appearance as a range of light, medium and dark gray tones plus black and white. Adjustments can be made to simulate a variety of landscape views from different points of observation and under various types and levels of night illumination. Illustration from Liberty Graphics, Inc., Technical Information Department, Philadelphia, PA, 1999, Internet publication.

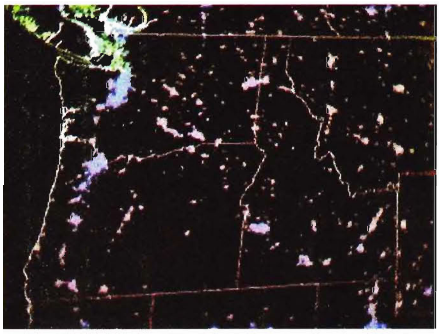

Figure 13-COL-D,G

Fig. 13. Satellite map of cloud cover at night. World and regional data for daytime and nighttime distribution of cloud cover is collected twice daily for weather analysis, visibility information (for astronomy, flying), and detection of air pollution, wild fires and volcanic activity. Mapped cloud patterns over the northwest United States are printed in blue, state boundaries are red, the coastline and international boundary are green and the background is black. Data collection is by the Defense Meteorological Satellite Program of the United States Air Force. Information is processed and accessible at the National Geophysical Information Center, and map displays are compiled by the International Dark Sky Association, Tucson, AZ. Internet publication.

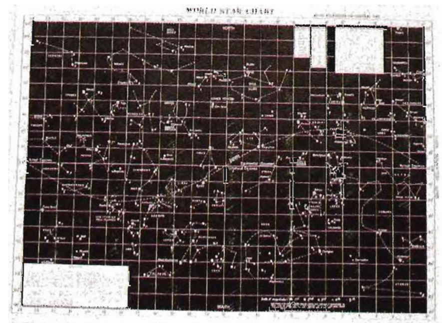

Figure 14-D,G,R

Fig. 14. Star chart. The black background of map aids for astronomic observation is a conventional design standard for preserving dark visual adaptation while working in a dimly lighted room or outside at night. *World Star Chart,* Map No. 9574, 1957 data, New York, NY: American Map Company, Inc.

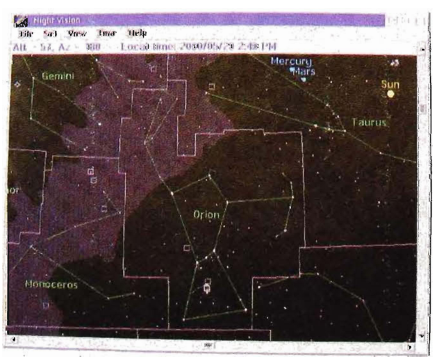


Figure 15-COL-D,G

Fig. 15. Star map video display. A computer-controlled planetarium program (OS/2) for displaying celestial map sections from any location and time on the earth. Viewing altitude (angle above horizon), azimuth (direction along horizon) and relative earth and star position and motion can be regulated; selected map views can be recorded or printed in colors and black-white-gray tones. Illustration from Brian Simpson, BMT Micro, Wilmington, NC, May 20, 2000, Internet publication.

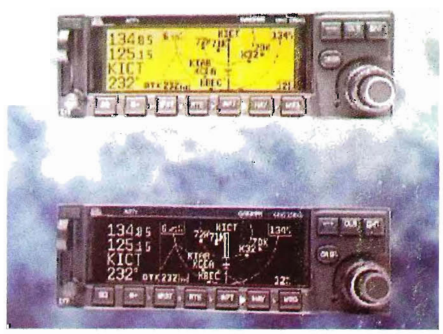

Figure 16-COL-D,G,R

Fig. 16. Global position system (GPS) map display. Day and night views of symbolized geographic and technical information are depicted upon high-contrast liquid crystal displays. Convenient panel controls allow selection of data and variations of image contrast level, speed of display motion and map scale resolution. A dark map background can be instantly switched on to enhance visual acuity in sudden blackout situations such as entering a tunnel. Illustration from GARMIN Corporation, Technical Information Services, Olathe, KS, 1998, Internet publication.

CMS Occasional Paper No. 7, "Night Vision Maps" by Gerald L. Greenberg

Unusual designs and principles to enhance map perception have always intrigued the author throughout a long career in cartography, such as while working in private industry on computer-printed map design and cognition; during university research studies on maps for the blind and partially-sighted; in government work doing quality analysis and testing of thematic and orthophoto maps; and in the currently written summary on the designs, applications and sources of maps that "glow in the dark." This study covers most types of maps which are used at night and under low-illumination or darkened environments, including control and planning rooms, subterranean and underwater areas, polar and extra-terrestrial regions, and in blackout conditions caused by storms and volcanic ash eruptions. Night vision maps are used in critical operations by explorers, astronomers, navigators, meteorologists, military, police, and by others who must preserve dark visual adaptation while reading graphics. There are three basic ways these maps are made: (1) self-luminous graphics with phosphorescent painted symbols, (2) red-light or green-light illuminated graphics printed in negative like style with special tones and color tints that are readable as different shades of gray, and (3) fluorescent graphics which have symbols and/or backgrounds that become visible when illuminated by ultraviolet light. Physiological (perception-psychology) principles applied to the map design processes are explained, color examples are presented, reference sources are well documented and a technical glossary is included.

This research paper was first presented in a meeting of the Western Association of Map Libraries at the University of Hawaii in November 2001. Marianne Hinckle, a CMS member who measurably assisted with the graphic composition and printing, first suggested that this work could be submitted for consideration as a candidate for publication as a CMS Occasional Paper. Upon acceptance, a large number of copies were printed and donated for distribution to the CMS members. The paper was also presented at a CMS meeting in Santa Clara, June 2003.