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THE DIGITAL WORLD VECTOR SHORELINE DATABASE:
CURRENT AND FUTURE CAPABILITIES

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This report provides a general overview of the Defense Mapping Agency's (DMA) digital World Vector Shoreline (WVS) database. Topics that will be covered include the WVS data structure and format, content, methods of accessing the database for both simple and more complex applications, current and future Naval applications of WVS, suggested future additions to the database, and recommended user-oriented software to be developed. The WVS data structure and content were designed to meet Naval requirements for a digital global shoreline map, as outlined by the Oceanographer of the Navy (CNO OP-096) in memo number 006C/50322906, dated 5 August 1985. Applications and further suggestions are based on responses to a questionnaire prepared by NORDA to survey DoD users who evaluated a WVS prototype of the Mediterranean Sea area. NORDA's compilation of Navy feedback to DMA's WVS prototyping effort was requested by the CNO OP-096.

ACKNOWLEDGEMENTS

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INTRODUCTION:

NORDA'S ROLE IN THE DEVELOPMENT OF THE WORLD VECTOR SHORELINE PRODUCT

One of the most basic needs in Mapping, Charting and Geodesy (MC&G) is a global shoreline map. In FY85, a NORDA study of naval MC&G data requirements revealed that a large number of Navy systems currently use or plan to use a digital shoreline product. In August of 1985, OP-096 listed the Navy's specific requirements for such a product, which included the following (Langran and Connor, 1986):

- shoreline data must support a high resolution at a scale of 1:250,000
- shoreline and boundary vectors must be cross-referenced
- data structure must promote automatic data entry and display
- data structure must allow automatic identification of land and water sides of the shorelines
- data structure must allow automatic identification of countries on either side of political boundaries and indicate disputation status of boundaries

Digital (or computer-generated and displayed) maps are not new to the MC&G

community; the Central Intelligence Agency's (CIA) World Data Bank-II (WDB II), which has been the unofficial standard digital shoreline product, was first distributed over twelve years ago. WDB II, however, would not satisfy Navy requirements for several reasons, including scale restrictions, lack of geographic information, and division of file boundaries.

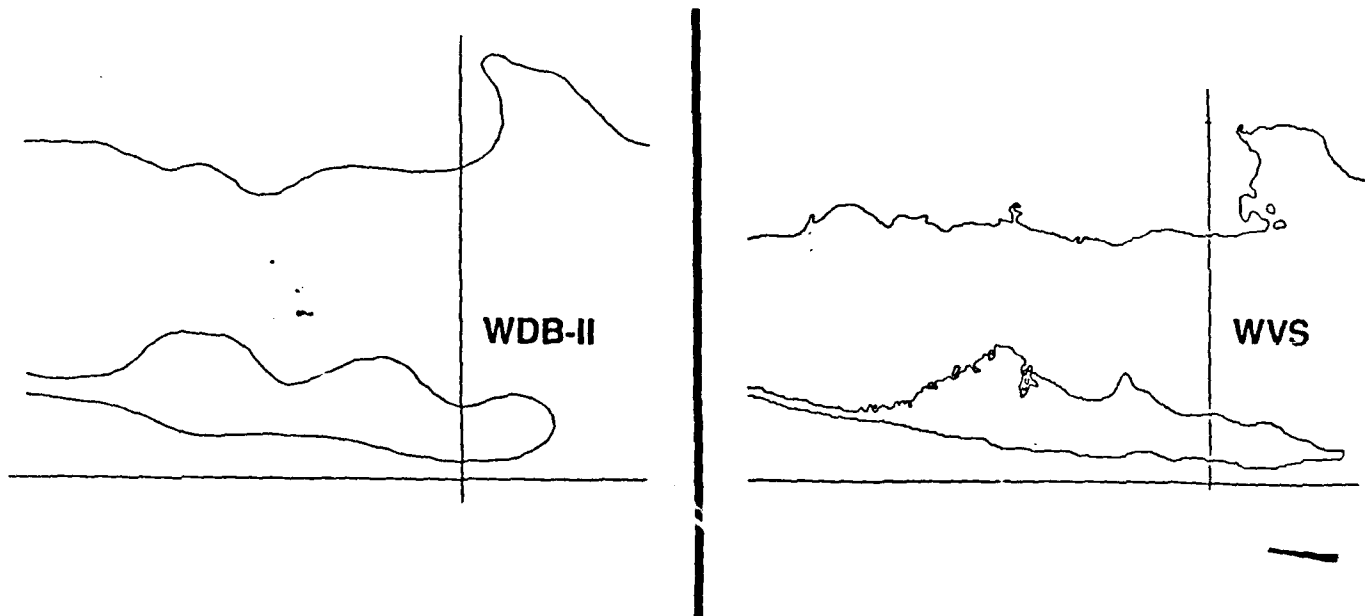


Figure 1. Shorelines of the Northern Black Sea (Odessa)

WDB II is an excellent base for small scale, simpler shoreline maps, but it is not accurate enough for the Navy's growing needs. WDB II was digitized at scales ranging from 1:1 million to 1:4 million, with an average scale of 1:3 million, or .02 inches/nautical mile (CIA, 1977). The Navy requires a scale of about 1:250,000 or better (about .29 inches/nautical mile). Figure 1 presents a comparison of these two databases with plots of the Odessa region and the Northern Black Sea. In addition to differences in scale, WDB II stores only the simple (x,y) coordinates of shorelines and political boundaries, while the Navy requires a dataset that would also define and store relatively complex geographic relationships. Finally, WDB II is distributed in land-based files (North America, South America, etc). Navy users would naturally find ocean-based files more readily applicable to their needs.

In FY86, the Defense Mapping Agency (DMA) developed a prototype for a new digital World Vector Shoreline (WVS) product that included political boundaries and country names with the shoreline vectors. The source of WVS' shorelines is DMA's Digital Land Mass Blanking (DLMB) dataset, a raster land mask gridded at 3 arc-second intervals, derived from nautical charts and maps with a scale of 1:250,000. The shoreline vectors were produced by contouring the land/sea interface of DLMB; political boundaries were added from separate sources and have an average scale of 1:1,000,000.

DMA sent copies of the prototype to four Navy groups, including NORDA, and requested feedback to determine whether WVS would meet the Navy's requirements for a digital vector shoreline dataset. In response, NORDA released two reports with recommendations on the database itself (Langran and Connor, 1986) and on the format in which it was stored - DMA's Standard Linear Format, or SLF (Langran, et.al, 1986). As a result, DMA requested that NORDA assist them in

designing a new WVS format to be certain the Navy's needs were met. The new format and data structure were completed in February of 1987 (Lohrenz, 1988).

In FY88, NORDA again assisted DMA in the production of WVS: NORDA developed a software package to convert input digitized vectors into the WVS-specific format. This software was completed and tested in May of 1988, in time to meet DMA's planned production schedule. To date, DMA has entered over half of the world's shorelines into the WVS database, and the entire world is scheduled for completion by the end of this fiscal year. Earlier this fiscal year, NORDA proposed to develop for DMA a package of utility software to help users process the WVS data (read, extract windows, compress, plot, etc.) This proposal is still under consideration at DMA for FY89.

WVS FILE DESCRIPTION

General

For portability, WVS data is ASCII coded and written to unlabeled, ANSI standard magnetic tapes. Records in the file have a fixed length of 48 bytes and are blocked by 200 on tape for a standard block size of 9600 bytes. The file begins with four header records that provide general file information (edition number, compilation date, origin of the map, number of features and segments in the file, etc.). Following the file headers are text records (giving any additional information specific to this file), feature records (providing feature identification codes and listing the segments belonging to each feature) and segment records (providing the actual X,Y data records). Feature and segment records are organized and stored by 1x1 degree cells, as described later in this paper.

Data Content

The first edition of the WVS dataset contains three geographic feature types: shorelines, political boundaries, and country names, which are identified by DMA's Feature Attribute Coding Standard (FACS) codes of 2A010, 6Axxx, and 9A010, respectively (DMA, 1985 b). Political boundary data are subcoded from 6A000 to 6A999 according to disputation status (e.g., established, disputed, unknown, etc.) The date of identification (i.e., when the boundary was established, or when it was last described as disputed) is also stored. Various file attributes are given, including the longitude and latitude extremities of the file, the total number of features and segments in the file, and the maximum number of vertices per segment.

Cell Structure

WVS data are partitioned into 1x1 degree cells that wrap the globe sequentially in the X (longitude) direction. A WVS file covering the globe contains 360 x 180 or 64800 cells numbered sequentially from 1 to 64800: the origin of cell 1 is 180 W, 90 S; the origin of cell 64800 is 180 E, 90 N. Data are collected into cells to facilitate windowing, repartitioning, and future expansions of the data set. This paper provides a simple algorithm to determine the cell number of any input point (longitude, latitude), which facilitates the collection and display of WVS data for any desired geographic area.

WVS feature and segment records (including the actual X,Y data points) are stored by cell number in the file. At the start of a new cell, a cell header record provides the number of features, number of segments, number of feature records, and number of segment records in that cell. Following the cell header

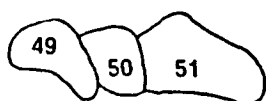
record are all the feature records for that cell, followed by all the segment records and X,Y points for that cell.

Data File Structure

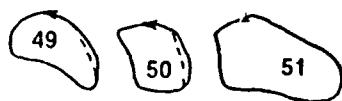
The WVS file structure was designed to minimize redundant data storage. Since a sequence of vertices (from here on referred to as a segment) may outline more than one feature, features are cross-referenced to their segments (and vice versa) via unique alphanumeric feature and segment keys. In this way, a segment that is shared by more than one feature is stored only once. The segment header record contains a list of each of the features that the segment delineates. Likewise, each feature in the map file is stored only once. The feature data record contains a list of each of the segments that delineate that feature. This method of data storage was also utilized in SLF and is referred to as "chain-node" (DMA, 1985 a). In sum, one feature may be comprised of many segments, or one segment may delineate several features, but in either case, each segment and feature is stored only once in chain-node.

To support advanced uses, all WVS segments define which feature types lie to the left and to the right of a segment (when moving forward through its vertices). For example, the left side of a shoreline segment may be land and the right side water. For boundary segments, the countries lying to the left and right are designated. For "left" and "right" to have any relative meaning, the order of vertices within a segment for a given feature must be provided. In describing a particular feature, WVS assigns a directional indicator (most commonly used are "F" for forward and "R" for reverse) to each of the segments delineating that feature. Thus, if a segment's vertices are to be read in reverse of the order in which they were stored, the direction would be "R".

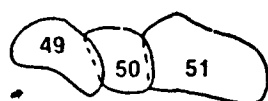
SEQUENTIAL DATA STORAGE



(A) FEATURES ON A MAP

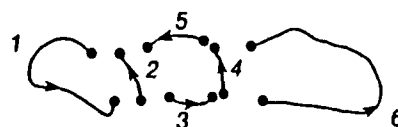


(B) DIGITIZED POLYGONS

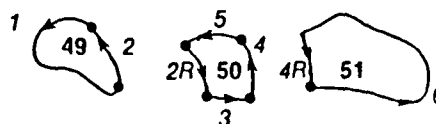


(C) DISPLAY OF DATA STORED SEQUENTIALLY

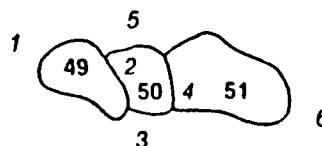
CHAIN-NODE DATA STORAGE



(D) DIGITIZED SEGMENTS



(E) INDIVIDUALLY DISPLAYED WVS FEATURES



(F) DISPLAY OF DATA STORED IN CHAIN-NODE STRUCTURE

Figure 2. Sequential vs. Chain-node Data Storage

Figure 2 shows the basic differences between conventional "sequential" data storage and chain-node data structuring, together with this directional capability. Figure 2 (a) shows three adjacent areal features as they might appear on a map. In the sequential storage method, each feature would be treated as a separate polygon, digitized independently (b), and stored as a string of (X, Y) coordinates. The common boundary between two abutting features would be digitized twice, and the two versions may not coincide. This often results in gaps or overlaps along the boundary (c).

In the chain-node method, the segments that comprise the features are digitized independently as shown in Figure 2 (d). The common boundary between adjacent features is digitized and stored only once, so that the features abut precisely. The coordinates of each segment are stored with a unique segment ID number and a list of the features associated with that segment. Likewise, each feature is stored with a unique ID and a list of the segments (with directional indicators) that define it. Therefore, features may be displayed either separately (e) or together (f) with no overlaps or gaps along the boundaries between them.

METHODS OF ACCESSING WVS

Determining Cell Codes for Extracting Windows of Data

The number of the geographic cell in which any point (Xn, Yn) is located may be determined with the following algorithm:

$$\text{CELL_CODE} = 1 + (\text{INT}(\text{ABS}(X_n - X_o) / \text{XCELL})) \\ + (\text{INT}(\text{ABS}(Y_n - Y_o) / \text{YCELL}) * (\text{XMAP} / \text{XCELL}))$$

where INT indicates truncation to integer
 ABS indicates absolute value (both are functions in the standard Fortran 77 library)

CELL_CODE = number of cell to be found
 Xn = longitude of the point in question
 Yn = latitude of the point
 Xo = longitude of the map origin (LONGOR, in File Header #2)
 Yo = latitude of the map origin (LATOR, in File Header #2)
 XCELL = width of cell in degrees longitude (in File Header #4)
 YCELL = height of cell in degrees latitude (in File Header #4)
 XMAP = width of the map in degrees longitude (in File Header #2)

In WVS, the following values may be substituted in the above equation: Xo = -180 deg, Yo = -90 deg, XCELL = YCELL = 1, and XMAP = 360. The algorithm for determining the number of the WVS cell in which any point (Xn, Yn) resides is therefore as follows:

$$\text{CELL_CODE} = 1 + \text{INT}(\text{ABS}(X_n + 180)) + \text{INT}(\text{ABS}(Y_n + 90)) * 360$$

Rectangular subsets or windows of the WVS file may be selected by extracting and aggregating cells of data. Determine the cell numbers for the upper and lower longitude and latitude boundaries of the window first (using the above equation), then simply fill in the rest of the area's cell numbers. If the window is to be selected directly from tape, the cells must be accessed sequentially, as described in the following section. A faster, direct access method is also described for those who will store their WVS data on disk.

Sequential Access

To access cells of WVS data from a tape or other non-random access device, a user must sequentially read through the file and pull out the desired cells of data, as follows:

1. Compute the numbers of the cells needed for the desired geographic area using the algorithm given in this paper.
2. Starting at the top of the file, read each record. When a cell header is encountered, read the cell number to determine if it is one of the required cells.
3. If the cell is required, collect its data. Otherwise, use the feature and segment record counts in the cell header to quickly skip all the records in that cell (to the next cell header).
4. Repeat steps 2 and 3 until the contents of all required cells have been recovered.

Direct Access

If the WVS file can be loaded onto a disk or other media allowing rapid direct access, this method is faster than the sequential access method to recover data for specific cells:

1. Create a look-up table that lists the number of each cell's first record (i.e., the cell header record) in the WVS file. Record 1 in the look-up table points to the location of Cell 1, Record 2 to Cell 2, etc. The look-up table need only be created once, when the file is initially loaded from tape.
2. Compute the numbers of the cells required for the specified geographic area using the algorithm given in this paper.
3. Access the look-up table by cell number, access the cell header, and collect the cell contents. For further illustration, see Table 1. Repeat this step until the contents of all required cells have been recovered.

Table 1. Using a Cell Table Look-up File

Sample Look-up File	Example: Collect the contents of WVS cell #5:
1	a) Find the starting WVS record number of cell #5: READ (ITABLE,REC=5) NREC where ITABLE is the logical unit number (LUN) assigned to the table look-up file, and NREC is the starting record number of cell #5 in the WVS file; in this example, NREC = 1609.
122	
345	
908	
1609 <--	
2099	b) Access the first record (the header record) of cell #5: READ (IWVS,REC=NREC) CELLHEADER where IWVS is the LUN assigned to the WVS file and CELLHEADER is the 48-byte cell header record.
3437	
3678	
4980	
5002	
...	c) Read and process the feature and segment records (which directly follow the cell header record) for cell #5.
...	

USERS' COMMENTS ON WVS

This section presents users' comments on the WVS database, based primarily on responses to the questionnaire that was distributed in March 1987 with the prototype WVS data set. Some information has also been drawn from papers that were presented at this year's Third Naval Digital MC&G Interest Group meeting, organized by the Navy's Digital MC&G Analysis Program (DMAP). The discussion is divided into three main topics: User Background (including system constraints such as memory, data storage and file access), WVS Applications (current and planned) and Future WVS Requirements. A more detailed look at the results of the 1987 WVS survey and a copy of NORDA's questionnaire may be found in Lohrenz (1988).

User Background and System Constraints

Over fourteen different computer systems were represented by the users who responded to NORDA's WVS questionnaire in 1987. The number of bits per word in these systems ranged from 8 to 60. This disparity points out the importance of standardization in databases such as WVS. The more Navy computers that can easily incorporate the database, the more useful that data base will be to the Navy. For example, users preferred ASCII to binary for the distributed WVS database, even though binary data would take up less storage space than ASCII. Different computers store binary data differently, but ASCII is a standard data storage format used by most modern computers and is easily input by all Navy computer systems.

The most critical system constraints cited were the following: size of system and display memory, disk storage, and display generation time. One respondent also mentioned array dimensioning (for storing segment vertices) as a potential problem. Array dimension limitations would impact the number of vertices that the computer could store for a single WVS segment.

The method of data storage used by WVS (i.e., 1-degree cells) reduces the chance that a segment array will become too large, since segments are split into smaller units along cell boundaries. Constraints on system and display memory and disk storage are also minimized by the use of data cells: if only certain cells are required for a particular application, then only those cells need to be copied from the distribution tape onto disk and displayed. If the whole world is needed, and memory or storage is limited, filtering should be done to reduce the size of the data set. All respondents liked the 1x1 degree cell method of data storage for another reason as well: they found it very valuable in speeding up data access, and therefore display generation time, particularly in geographic windowing applications.

Data access can also be accelerated by directly accessing WVS data with a cell table look-up file, as described in this report and in the WVS users' guide. Users at NOSC and NUSC have successfully implemented this direct access method, liked it, and went on to adapt it to other functions such as feature extraction. Other users were planning to try the direct access method in the future. Meanwhile, they found the sequential access method easy to implement.

Overall, automated "one-pass" data entry was successful. Users reported that the ease of data entry was significantly improved by the inclusion of record counts, feature/segment counts, other file and cell header information, and thorough documentation.

Due to data storage limitations, most users said they would like DMA to provide the WVS data set at more than one data density (resolution). Systems

with severe data storage limitations would be unable to store the entire, high density, data set on-line. Providing users with several WVS resolutions would also ensure a higher degree of compatibility between systems that will filter their data, since they could start filtering at the data density closest to their need (instead of always starting from the maximum WVS data density). At the time of the survey, all respondents used or planned to use a critical-point data filter.

WVS Applications

All programs surveyed in 1987 planned to use WVS as a base map on which to overlay other data. Digital Terrain Elevation Data (DTED) and Digital Feature Analysis Data (DFAD) were listed most frequently as the data to be overlaid on WVS. Other data types mentioned include bathymetric contours, Hydrographic Obstruction Data (HOD), cartographic data, and miscellaneous others. In this year's Naval DMAP meeting, McCleary and Wescott (1989) describe various methods of displaying geographic information (such as WVS) for their applications.

Scale requirements for WVS varied widely in the 1987 survey: from 1:7,300 (about 0.1 NM/inch) to nearly 1:33,000,000 (about 450 NM/inch). Obviously, this range is too large to be handled by the current WVS scale (1:250,000). As mentioned earlier, users would find it helpful if DMA provided several data densities from which to filter to the resolution and scale required. In any event, it should be noted that a scale of 1:7,300 is unreasonable for a global shoreline data set!

Two interesting data compression methods for shorelines were described at the Naval DMAP meeting this year. Sharman (1989) describes a fractal-based, resolution-dependent data compression method, which he terms "excerpolation," for reducing the bulk of data in detailed, vector-based databases. He has applied his method to WDB II shoreline vectors but not yet to WVS. It would be interesting to investigate this method both for reducing the size of the full resolution WVS database, with a minimal loss of information, and for filtering WVS into different resolutions. Hammack and Depner (1989) describe another suitable data compression method for high-resolution geographic data sets. They have successfully applied it to both WDB II and to WVS shoreline vectors.

All respondents to the 1987 survey used or planned to use color fills on the WVS data. Common color fill applications include blocking out water areas to emphasize land features, or vice versa, and shading certain countries to point out various political, geographic, or other relationships. For example, water areas could be colored blue; hostile nations may be red. WVS provides a "flag" in each cell header to indicate whether that cell contains all land, all water, or a combination (i.e., a shoreline). Users indicated that these flags would be very useful for filling in land and water areas.

Similarly, WVS provides a flag to indicate what country lies to the left and to the right of each political boundary. None of the respondents needed this information currently, but several foresaw future applications for it. For example, the boundaries of France could be easily picked out of the data set, since each of its boundary segments is marked with a "France" flag.

Future WVS Requirements

Asking users to identify future WVS requirements resulted in many good suggestions, most of which follow:

- WVS should be made available in several resolutions.

- Feature levels (e.g., an island within a lake within a continent) should be identified.
- Features such as islands should be ranked by size.
- Nodes (segment endpoints) should be stored explicitly, and should include the points at which different features meet (e.g., where a political boundary meets a shoreline).
- Additional feature types are needed, including navigable rivers, major cities, lakes, airfields, major roads, railroads, ports; there should be a distinction between river mouths and shorelines.
- Software to translate WVS to WDB II should be developed.
- Instructions for converting programs from WDB II to WVS input should be provided.
- Shorelines to the north and south of the 65 degree parallels are needed.
- Links between segments broken at cell boundaries would be helpful.

In this year's Naval DMAP meeting, Landrum (1989) discussed on-going MC&G product evaluations, many of which have been based on NORDA's evaluation of WVS. Future Navy requirements for the WVS database, including those listed in this paper, are being addressed by the Naval DMAP. In addition, the entire WVS database will be stored in the DMAP software library at NORDA, for ready access by interested Navy users. More information about the DMAP software library may be found in Current (1989).

SUMMARY

DMA and NORDA combined forces to design a data structure and format for the WVS that would best meet users' needs. The new WVS database meets Navy requirements as listed in the 1985 CNO OP-096 memo, ser 006C/50322906, and as summarized at the start of this report. Potential Navy users were given a copy of the new WVS prototype to evaluate, along with a questionnaire that addressed such issues as computer system limitations, WVS applications, and requirements. Overall, users responded very favorably to the WVS database, and offered many suggestions for future work. The most critical future needs for WVS have been listed in this paper.

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