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# COMPUTER-ASSISTED CARTOGRAPHY IN THE CANADIAN HYDROGRAPHIC SERVICE

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## 1. OVERVIEW

The Canadian Hydrographic Service (CHS) is a national agency responsible for the production and maintenance of Nautical Charts, Sailing Directions and Tide Tables to meet the needs of the marine public. In support of this role the Service conducts hydrographic, tidal and current surveys. Approximately 1 000 charts are used to provide coverage of Canada's 100 000 miles of coastline. In conjunction with this responsibility the CHS works closely with the Department of Transport in publishing the Notices to Mariners which provide the mariner with marine traffic information. Charts showing the territorial seas and fishing zones are also published and used in the management of Canada's offshore resources.

The CHS is also responsible for the production of offshore Natural Resource maps providing bathymetry, magnetics and gravity parameters in support of oil, gas and mineral exploration. This program is conducted in cooperation with the Department of Energy, Mines and Resources. Finally, as part of its role in the International Hydrographic Organization (IHO), the CHS contributes to the General Bathymetric Chart of the Oceans (GEBCO) and is involved with the drafting and printing of the eighteen sheets of the Fifth Edition.

The CHS, with headquarters in Ottawa, operates out of four regional institutes. Following a recent decentralization program the Service now has cartographic production units in each of these institutes. Each regional hydrographic office has

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the responsibility for the charts of its adjoining waters (Atlantic coast, St. Lawrence River, Great Lakes and Pacific coast) as well as a portion of the Arctic waters.

Hydrographic surveying and charting methodologies have changed considerably over the past several decades as new technological developments were introduced. Acoustics technology brought in the use of echo sounders, and side scan sonars; and now more sophisticated sonar systems currently in development will further enhance hydrographic surveying. Electronic navigation and positioning systems have had a major impact on hydrographic surveying, beginning with low accuracy surface wave propagation systems to the high accuracy systems using shore based transmitters or satellites. Continued improvements in these systems are also expected. Micro-electronics technology and digital processing are now a part of virtually all aspects of hydrographic surveying. However, the impact on the cartographic side has not been as dramatic. It is true that digital processing has been used for many related calculations used in preparing data for the chart, and automatic drawing systems have been used on a production basis since 1973 to draw mathematically generated functions such as chart borders and navigational lattices, but the major impact of this technology is yet to be realized fully. In the remainder of this paper the history of the cartographic developments will be reviewed, the present use of computer-assisted cartography will be described and its future use will be outlined.

## 2. HISTORY OF THE CHS COMPUTER-ASSISTED CARTOGRAPHIC PROGRAM

In 1973, following 4 years of cartographic development, base plots, borders and lattices were plotted on a production basis; the development of a digitizing system was well underway, with emphasis at that time on developing a capability to rapidly digitize soundings.

During the period from 1973 to 1975, the software for the plotter was refined to meet new Specifications, to increase flexibility and to resolve « bugs » in the software. The digitizing system was brought to production capability and a considerable amount of software was developed to manipulate digital cartographic data such as projection conversion, concatenation of files, scale changes, etc.

In 1975, the development of the software for the interactive editing of digitized data was undertaken. The development of the editing system finally made it practical to digitize, edit and plot cartographic data. Some of the symbolization of cartographic data was produced by « flashing » the plotter symbol disks; others were drawn. In 1976 and 1977, four charts were produced using the digital systems for the borders, contours, soundings and some shoreline. These charts were relatively simple charts to produce and not all of the cartographic data were digitized. Also in 1977, new equipment was purchased to expand the Digital Equipment PDP 11/40 to a full comprehensive cartographic station with digitizing, editing and verification plotting capability; a second station centered around a PDP 11/34 was also installed.

With digitizing and editing being used as a part of the production process, inadequacies in some of the cartographic computer programs became apparent. Many of these programs were originally written for experimental and developmental applications only, and needed to be rewritten and documented. A comprehensive program integrating many of the cartographic processing programs was put together, called MOSAIC; it is designed to handle a large portion of the number crunching needed for distortion correction, projection conversion, scale changes, and file concatenation.

In addition to developing the production procedures for using the digital systems, the cartographic effort has also been to refine further the presentation of data on the nautical chart involving the increased use of contours, and new symbolization to accommodate Canadian bilingual and metric policies and new international standards on symbology. A significant and important aspect of this process is the development of the cartographers themselves. Computer-assisted cartography was seen by many cartographers as a threat to their careers. The cartographers involved in this program, now that they have had exposure to the systems, have developed a positive attitude to their use and are using them effectively as well as contributing to the development. Nevertheless, it must be recognized that it takes time to re-orient and restructure the staff, as well as procedures, following decisions to implement changes, whatever they are.

As development projects move from the research side of development to the production side, a corresponding shift in resources allocation is required. When new equipments are introduced into the production environment, a production support program becomes necessary. Often such support will have been initiated during the development phase and will move across to the production side; if in the production phase there is an increase in the number of systems to meet production requirements, there is a need for a corresponding increase in the maintenance support. This applies to hardware and software maintenance. Further, once systems are moved into the production environment, there still remains a considerable amount of work to be done to upgrade, standardize and document the systems, to refine or develop new algorithms and generally to improve the level of efficiency of the systems, without really moving into any new development projects. To a large extent this represents a major part of the present CHS cartographic development program. The development work has been centered at CHS headquarters and is now being introduced into the regions.

In order to understand how computer-assisted techniques can be introduced into marine cartography, it is useful to review the source of data and the processes in the production phases of compilation, drafting and maintenance.

## 3. NAUTICAL CHART COMPILATION

The source data used in the compilation of a nautical chart can be divided into five principal categories, each drawing from a different data base and therefore requiring different consideration with respect to digital processing and automatic drafting.

### (i) Bathymetry

The hydrographic data base involves more than just bathymetry but its principal contents are depth soundings and contours. The collection of this data is also a major responsibility of the CHS, so it has control over the structure of this data. However data are also collected by other agencies such as companies involved in offshore oil exploration or coastal engineering. These data must be incorporated into the CHS hydrographic data base and, when necessary, published on the chart.

If, for each new or revised publication of a chart, all data were the result of new surveys and the data were collected in digital form, then the introduction of computer-assisted cartography would be vastly simplified. However, this is not the case; most of the source bathymetric data for presently scheduled new chart construction are in graphic form even though digital collection techniques are being introduced in the field. Also much of these data will be in Imperial units derived from surveys prior to metrication so that metric conversion and digitizing of this data are necessary before it can be used in the interactive digital compilation process.

### (ii) Shoreline and foreshore

Detailed shoreline and foreshore information is an important aspect of a nautical chart. It is used by the small craft mariner for near shore navigation and to identify safe areas to enter during a storm or to land. The source of this data is from topographic maps, aerial photographs, and hydrographic surveys. Standard panchromatic aerial photography does not normally delineate the shoreline and foreshore in sufficient detail (exposure is set for the inland and consequently the area below the highwater line is overexposed). Similarly, maps derived from this photography will have the shoreline overgeneralized. Hydrographic surveys must therefore supplement these data to meet the needs for the compilation of the nautical chart. Although there is an R&D program to develop an airborne shallow-water and shoreline mapping system which will provide digital data, at present these data are in graphic form and must be digitized.

### (iii) Topography and cultural features

Inland features such as topographic contours, streams, church spires and other prominent features provide the mariner with visual navigational information. Roads or other cultural features are useful in the vicinity of wharves or anchorages. Maps provide the principal source of these data and as digital maps become available, digital cartographic processing will be directly available. Nevertheless, digitizing the graphic data is presently a necessary step before digital processing.

### (iv) Navigational aids

The data base of navigational aids is the responsibility of the Department of Transport. CHS maintains a subset of this data base as required for the Nautical Chart. These aids are divided into two categories: fixed aids (those located on land, such as lights and beacons), and floating aids (those located on the water, such as buoys). The fixed aids presently form a part of the digital horizontal control data base and are available in digital form. The floating aids are only available in tabular listings. The most frequent changes to the nautical chart relate to navigational aids and are therefore a major concern in the chart maintenance program.

### (v) Geographic names

The geographic names data base as applicable to the nautical chart is a subset of the national geographic names data base which is the responsibility of the Board of Geographical Names in the Department of Energy, Mines and Resources. The names are not presently in a computerized data base, so the source data are not in computer compatible form. A second problem exists with names in that automatic drawing of text, particularly names with the variety of fonts that are used, does not compare favourably in quality with the typeset text.

In the foregoing it is evident that most of the source data for the nautical chart are not available in computer compatible form. Certainly this situation will change in the future, but the change will not be rapid. In the meantime in order to use digital processing techniques in the compilation process, the source will have to be digitized. Manual digitizing techniques are operational but they are labour intensive and their costs so far make any mass digitizing program impractical. Automatic digitizing, particularly for continuous line data such as contours and shoreline, will undoubtedly have an impact in the foreseeable future.

The compilation process is principally one of reducing the scale of the source data to the scale of the chart, selecting the data relevant to the chart and presenting it in a clear and concise way. Obviously, in many cases a considerable reduction of data exists between the available source and that finally shown on the chart. Cartographic generalization is exercised to emphasize important features and to de-emphasize less important ones. No attempt in the present systems has been made to develop automatic generalization routines. Generalization is conducted interactively by the cartographer.

The final manuscript contains all of the cartographic data. Separate overlays are produced for the Navigational Aids and Text.

The interactive digitizing and editing systems now in use in the CHS can handle all of the compilation steps and limited production has been carried out. However, because the cost of digitizing the source is many times greater than digitizing the compilation version, computer-assisted compilation is not widely

used in the chart production process. Digitizing the graphic following the compilation stage is another matter. At this stage the quantity of data has been reduced down to that which is required for the chart and digitizing becomes practical.

## 4. DIGITIZING AND AUTOMATIC DRAWING

The Gerber 32 precision plotter has been in use since 1973. It is designed to operate unattended and to switch off automatically when a plot is complete, thus facilitating unattended overnight runs. Shorter time plots are drawn during the day, and just before leaving work at the end of the day the operator mounts a plot for the overnight run to be completed when he returns to work in the morning. The system is in daily use and often is operated 24 hours per day. It is used early in the compilation process to draw the chart base. It is again used to plot the digitized compilation graphic, and finally to generate the plots for the colour separation negatives.

The digitizing systems are principally used to digitize the compilation graphic. Two special types of cursors have been developed for the digitizing process; one has a numerical keyboard to facilitate rapid digitization of soundings and the second is a swivel cursor for line digitization. Each digitizing table has a dedicated mini-computer and the software is designed specifically for this application. It is user oriented and does not require lengthy training of the operator. The standard practice in the CHS is to have the same cartographer who compiled the chart also follow through with the digitizing, editing and the preparation of the colour separation negatives. This involves less specialization and possibly inefficiencies in the operation but it does facilitate late corrections or compilation changes made at this stage, and, since the systems are user oriented, start up time is not excessive. Most important, it provides variation in the work for the cartographer, and gives him/her the responsibility for the job from start to finish.

The center of the computer-assisted system is the interactive editing system. This is the cartographic work station with the facility for entering data via a digitizing table or a CRT display. Digital data can be manipulated with the same general flexibility that the cartographer has at the desk with a graphic. Finally a verification plot can be generated at any time to provide a hard copy of the digital cartographic product (using a Calcomp 960 plotter).

In 1974 when the CHS investigated commercially available interactive systems, none were suitable for this application. This resulted in the in-house development of the Graphical On-line Manipulation and Display System (GOMADS). GOMADS is the heart of the interactive cartographic station, although several other programs also now support the processing at the cartographic station.

The GOMADS editing system is based on a three-way computer-user dialogue between an alphanumeric terminal, the user and a Tektronix 4014 CRT. GOMADS instructs the user for each step of the editing process so that a users' guide is not really necessary. GOMADS also requests that a verification be made for each change, thus helping to prevent hasty or careless moves.

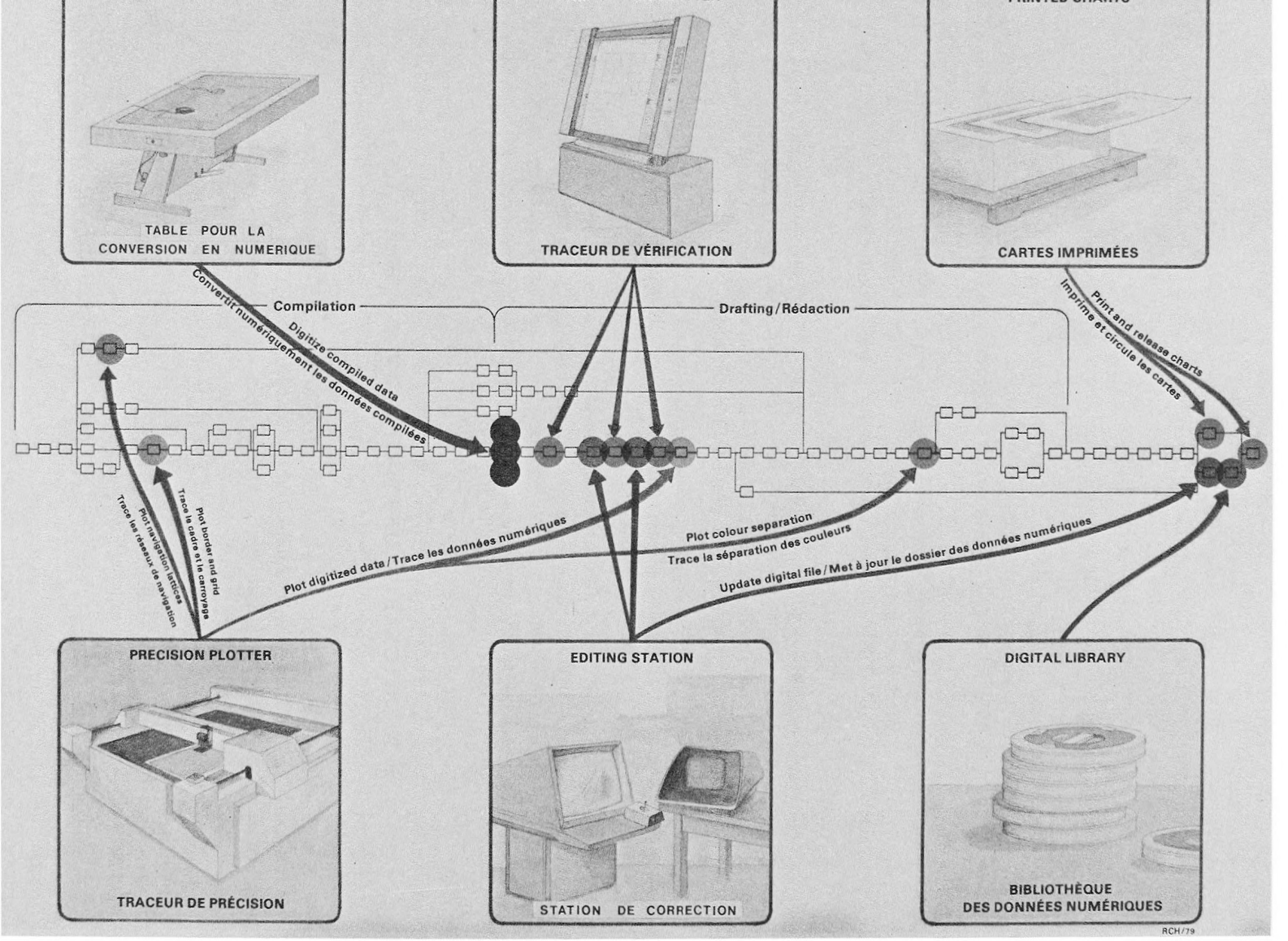


FIG. 1. – The use of computers in the cartographic process.

For editing with GOMADS, a magnified portion of the digital file is drawn on the CRT screen. The cursor and accurate pointer can then be used to delete, add to, change or move the displayed line, point, numerical and name data. GOMADS can also be used for sounding selection, where some soundings can be flagged, and the remaining data can be kept in the background. It can be used to concatenate two or more digital files as in the case of information that overlaps with another chart, or in adding a border.

GOMADS allows the manipulation of the above kinds of data in symbolized and unsymbolized form. An example of symbolized data would be a low water line that would be digitized as a solid line and output as a dotted line. If the low water line was being edited as a symbolized line, it should be changed by moving each dot separately. Data are usually edited in the unsymbolized form.

Although the cartographic station is presently used to edit and update the digital chart file after the compilation stage, it has full digitizing, editing and compilation capability. These systems are presently being implemented in three of the four regional institutes.

Following the drafting check the digital files are separated as necessary for the preparation of the colour separation negatives. Final plots are produced on the precision plotter. Manual additions such as the patching of names and text are made and then the negatives are prepared for printing.

A summary of the technical description is contained in Appendix 1. Also a summarized version of where the systems are used in the chart production process is in figure 1.

It is apparent from this figure that a considerable amount of manual interaction is required. This will always be the case as long as the graphic is the end product. The computer systems are only an added tool in the production process and must be designed to enhance the capability of the cartographer.

## 5. MAINTENANCE OF THE NAUTICAL CHART

Many of the published charts of Canadian waters are based on very old and usually sparse data (very limited bottom coverage) that are often of poor quality. The CHS has a systematic charting plan to survey these areas and replace these charts with new charts based on modern surveys, but this plan is long term and is not the highest priority. The highest priority is to maintain the existing charts with current information. The limited resources dictate that to a large extent only the critical information of new important changes are published. Notices to Mariners are the quickest way to provide the mariner with changes or updates to his charts. These accumulated changes are periodically incorporated on the chart negative and the charts are published as a Reprint. If more extensive changes in addition to those announced through the Notices to Mariners are required, then New Editions are produced. This maintenance program presently consumes the majority of the CHS cartographic resources. It is in this area that

computer-assisted cartography techniques offers the greatest potential, but it cannot be taken advantage of until the digital chart base is available.

## 6. CONCLUSION

When automated cartography first came on the scene, high expectations were held that it would automate the cartographic processes. Indeed, these expectations were met in the case of the automatic drawing of mathematically generated functions. However, automating the cartographic decision-making processes has been found to be extremely complex and, as it turns out, undesirable. The power of interactive graphics facilitates the development of manipulative routines which will give the cartographer greater flexibility in designing his graphic rather than less. He can process and evaluate larger volumes of data, apply smoothing routines to improve the final drawing and meet high drawing standards with less skill.

The technical capability of current systems provides the cartographer with a powerful system. However, creating the digital cartographic data base remains as a resource-intensive process. Automatic or semi-automatic digitizing technology will undoubtedly become available to improve this process. Similarly, as more and more data are collected in digital form, the magnitude of this problem will be reduced. In the meantime computer-assisted cartography will continue to be a developing methodology, taking advantage of new refinements in the technology, but not incurring any major changes one could compare to the switching over from manual to automated processes.

The obvious question that one may ask is whether or not computer-assisted cartography is a financially-viable proposition or is its use still in question. We, like other organizations, are riding on a technological wave, and we have wondered at times whether we were adrift in the sea of technology, buffeted by the shifting winds of bureaucracy, or whether we were indeed in control of our course and destination. Today it is no longer a question of "if" we will be fully developing the technology and methodology of digital processing of cartographic data, it is only a question of "how" and "when".

The economic factors must take into account many external factors like future requirements for digital data, cost and availability of skilled draftsmen, etc. Nevertheless, at the local production costs, automatic drawing of mathematically-generated functions provides considerable saving in both time and labour. The introduction of LORAN-C navigation systems has pushed our production units to their limits to produce charts with the LORAN-C lattices and the GERBER-32 drawing system has been central to this operation. Any down time on this system severely disrupts our production schedule. The cost advantages here are obvious. Similarly, where digital data is available, the cost advantages are clearly apparent. Since there is a trend towards digital data bases of the source data used for the chart, the cost advantages of computer-assisted compilation will progressively improve.

Finally, as production-oriented cartographers become more familiar with computer technology, its complexities as well as its potential for greater data processing capability and flexibility to meet specific needs of a wider number of chart users, I am confident that their own innovations with the application of this technology will further improve the use of computer-assisted cartography in the production environment.

## APPENDIX 1

## DESCRIPTION OF COMPUTER SYSTEMS

### 1. Digitizing system

Developed in the early 70's, these systems are used for the conversion of graphical documents to a digital form.

Computer. – PDP 8/E with 16k words of memory.

Data storage. – Dectape with later transfer to industry compatible 9 track tape.

Digitizing table. – Gradicon with 0.001 unit resolution, nominal accuracy of 0.004 inches.

Cursors. – i) Scribe cursor for line or point digitization.
ii) Hydrographic cursor for sounding digitization.

Voice input is available but has only been used experimentally.

### 2. Interactive editing and data processing system

Developed in the mid-seventies, these systems are mainly used for editing the digital hydrographic or cartographic data, but the following tasks are also carried out on them :

i) Verification plotting
ii) Data checking
iii) Symbolization for plotting
iv) Data separation for overlay plotting
v) Digitization

Each system consists of :

i) PDP 11/34 computer with 96 k words of memory and floating point hardware
ii) 2-9 track tape transports
iii) 2-RKO5 disk transports
iv) 2-RKO7 disk transports
v) Calcomp 960 plotter

vi) Gradicon digitizing table
vii) Tektronix 4014 storage display
viii) Miscellaneous terminals
ix) Line printer

### 3. Automated drafting system

Put into production in the early 1970's, this system is used to generate the film positives required for the printing of the charts. Magnetic tape input is generated either on the PDP 11 based system or on a Cyber 7400 system.

The system consists of:

i) PDP 8/E computer with 4k words of memory
ii) Gerber drawing table – Resolution of 0.0001 inches and an accuracy of 0.0009 inches
iii) Barr and Stroud light head
iv) 9 track magnetic tape for data input
v) Dectape for program storage

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