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CONTOURS AND CONTOURING IN HYDROGRAPHY PART I : THE FUNDAMENTAL ISSUES

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"If you don't know where you are going, any road will get you there"
The Koran

PROLOGUE

In the final analysis, mapmaking is a graphic art — not a science. This is a notion that must be constantly reinforced. It is the final product which defines the nature of a particular enterprise and in hydrography our business is producing charts. The use of modern methods in arriving at that end product is a secondary issue. Behind all the computer printouts and reels of tape sit the artists. When one hydrographer speaks of another's professional calibre he doesn't speak in cold objective terms, but measures him out in the quality and beauty — or lack of it — in his colleague's work.

We raise this issue immediately for it will arise throughout our discussion of contours and contouring in hydrography. It is our intention to bring forward the issues as we see them, the advantages and disadvantages of taking yet one further step along the trail of mechanization — a one-way road with its origin in the industrial revolution and its end unseen and unknown. We are braced at the bottom of yet another hill to climb — the mechanization of contouring. It can be done — has been done elsewhere. The momentum of automation could easily carry us over this hill. To stop now would seem artificial and arbitrary. Yet this is a good place to stop for the moment and to re-examine what it is that we are trying to do. What do we hope to gain with this next step, what is the payoff ? What will it cost us and what will we lose ? These are the issues which must be confronted if we want to control progress. We should be stimulated by new technology, not pushed by it.

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Machine contouring is a current issue within CHS. Three regions have small study groups experimenting with off-the-shelf contouring packages. Trials are being conducted using hydrographic data of varying density and pattern to study these effects. A fully contoured field sheet complete with shoreline and title has been prepared in Central Region in an exercise to study, among other things, the impact of this format for error checking and general quality control. The interface between the digital field sheet and the compiled chart is being studied to see if the new format offers advantages in streamlining the compilation process. CHS have a contract with Barrodale Computing Services Ltd. of Victoria to revamp a contouring package with hydrographic requirements in mind. The talents and energy of many individuals are being expended on this project. We need to ask why.

It is our intention in these discussions to raise questions and to answer some of them. Why should we contour at all ? If we contour, what does machine contouring offer ? How do we do it — what are the mathematical structures on which it is built ? What are the assumptions made and how valid are they ? How can we err safely ? What are our limits and our constraints ? What are our musts and what are our wants ? What issues are relevant and which irrelevant ? How do we measure the effectiveness of machine contouring in the field and in the office ? How do we maintain our standards of excellence in field sheets ? Finally, what are the side effects that this step will introduce and are we prepared to accept them ?

These are the issues that must be addressed before we can go forward with confidence. The purpose of these discussions is to shed some light on the road ahead.

1. INTRODUCTION

Charts — indeed all maps — are caricatures. A chart does distort reality — just as the cartoonist distorts the facial features of some well-known personality. Yet the intent is always clear — we know instinctively who or what is being portrayed despite or perhaps because of the distortion. But to do this well calls for a careful distortion of just the right features. A good caricature has an uncanny precision behind the distortion — so it is with the chart.

A chart includes a summation of a large number of measurements carefully distorted and designed to give its main user — the mariner — an unambiguous image of the problems he faces. At least that is what it should be, that is the intent. In a traditional compilation, it is often the density of the soundings which draws the eye towards the dangers. A sudden cluster of soundings in a clear and uncluttered portion of the chart means one thing only — danger. This is more of an historical artifact than good cartography, a remnant from the days when every sounding measured made its way onto the chart. A more modern compilation shows the danger ringed with contours and surmounted with one critical sounding. There seems to be general agreement that the latter approach gives a better image of the feature and serves equally well in drawing attention to the danger. But contouring is only one of several cartographic devices which could serve equally well. We need to have some guidelines in order to find out which techniques will best serve us and our customers.

In this introductory article we wish to examine some of the more qualitative issues in contouring. We propose to examine the Why, Where and When, postponing for the moment the question of How. It is often more preferable to answer the How of such issues. Like most technical problems, there is a nut at the heart that must be cracked before success is achieved. The cracking of the nut is often mistaken for the objective. This is human nature. But the business of CHS is producing charts, not developing systems.

2. WHY CONTOUR ?

Contours help us perceive the shape of the surface we are measuring but hardly ever see. They are a means of portraying a 3-D object on a 2-D medium. They are not, however, the only method available for doing this.

It is the colour shading on the GEBCO charts which serves as the predominant mechanism for transferring to the user the image of the ocean bottom. The contours, subdued as they are, serve only to add the detail information. It is colour which highlights the deeps and the shallows, the ridges and the trenches.

Highlighting and shadowing are often dramatic techniques for showing relief. The ruggedness of mountainous areas can be particularly well displayed in this manner.

Perspective or trimetric plots which show a surface as viewed from a particular angle can give a very effective image of the bottom surface. Though not particularly useful as maps for navigation, they are excellent vehicles for displaying complex surfaces.

A thematic map would make an ideal chart if only all ships were alike or at least all had the same draught. Consider a simple two-colour chart, red and green. The green areas are safe, i.e. there is more water than the ship needs to navigate safely. The red signifies danger and marks off the area of potential grounding. Such charts would be cheap to produce and maintain and this format might be particularly well suited to the "electronic" charts of the future, but at the moment would be of limited value.

The field sheet is an example of a Digital Terrain Model (DTM), a device high in detailed data content but very low in its ability to transfer an image to the user. It serves reasonably well as a surveyor's tool but it comes to us by custom and tradition rather than by choice. The 1980s' field sheet emulates the lead-line field sheets of the 1880s, despite the modern methods used in obtaining and processing the data contained on it.

Finally we have contours. They serve reasonably well as image transfer mechanisms, particularly for an experienced map-reader. They are also high in detail content, i.e. the ruggedness of the terrain will result in contours which weave back and forth with each of the surface's undulations. The inclusion of more contours on modern charts was a fairly "soft" change, for the new appearance is not radically different. From the surveyor's point of view they are appealing, for they can incorporate high density survey data as well as low. For instance a shoal area can be crossed by many survey lines, each line refining the map-image. All of this sounding data can be accessed for the position of critical contour intercepts allowing for a very precise portrayal of the shoal's outline. The chartmaker will therefore have more information to work with when deciding how to portray the shoal on the chart. Contours also appear to be more amenable to other non-traditional uses of charts such as engineering, environmental monitoring, fishing, etc. On the other hand, contours imply a certain continuity of information which is often unwarranted.

2.1. How is survey quality transferred to the chart ?

All the above techniques must be evaluated for their ability to display the quality of information on which the image is based. A contour map of a smooth area based on a high density survey will not look radically different from that of one based on a much lower density survey. Yet survey density is an important criterion in evaluating the survey quality. The DTM, on the other hand, explicitly shows the differences in survey density. Furthermore, it makes no implicit assumptions as to the nature of the surface between data points, whereas the unadorned contour map implies a continuity of information at least along the contour. In hydrography this is seldom, if ever, valid; traditionally, hydrographers aim to intersect the contours at a point, thereby obtaining good information on the contour's location but nothing on its direction.

Figure 1 shows a contour line with its confidence region. At each survey line, the region is narrowest and conforms to the confidence region associated with individual soundings, say ± 1 m. Between lines the region expands since we are now interpolating between two measurements. The maximum uncertainty occurs midway between two lines.

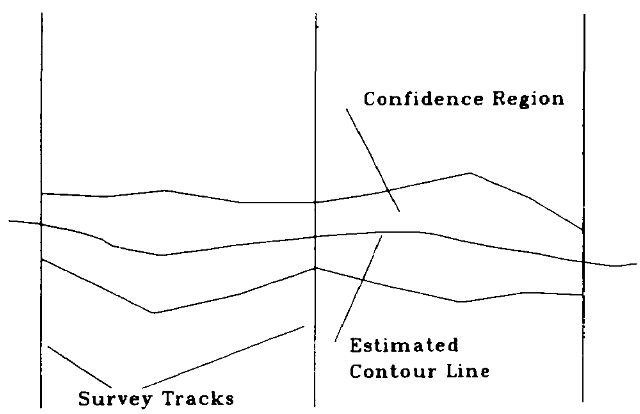

FIG. 1

Unfortunately, the survey tracks are not included on the chart, so the user has no means of gauging the quality of the survey work. Many new charts partially overcome this drawback by including a source diagram and indicators of survey quality. A chartmaker must make it clear somehow where information is adequate and where it is not.

In evaluating the different methods of image portrayal, we need to keep in mind the attributes of a nautical chart. A chart has three main attributes. Firstly, it should have detail information which is readily transferred to its user. For instance, we should be able to point randomly at the chart and say "how deep is it here ?" Secondly, it should be able to transfer an image of the bottom quickly and unambiguously. This is necessary for route planning and other strategic purposes. The navigator must be able to see at a glance the outline of a route which will minimize his sailing time and his risk. Finally, the chart must be easy to use, clear, unambiguous and of real value to its owner. We refer to this as its utility.

The relationship of these attributes is shown in Figure 2.

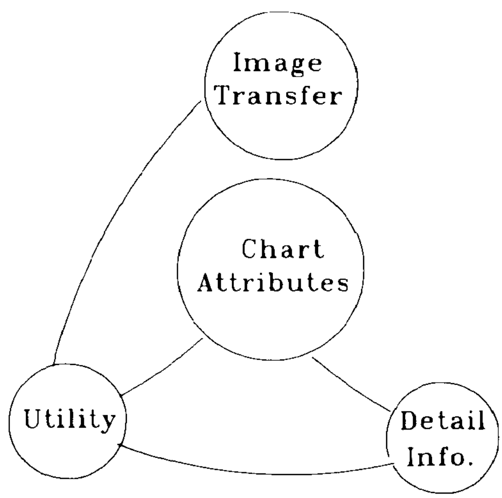

FIG. 2

The graph (Fig. 3) attempts to rank the order of merit of the various techniques by measuring their success in meeting the desired attributes. Although ranking is in general highly speculative and each of these particular scores debatable, we have found it useful to force some measure on the unmeasurable. This graph represents to us a reasonable compromise.

Not surprisingly, no one method is good at everything. Contours appear to be a good compromise. It is this universality which has made contours so appealing to a cross section of hydrographers and cartographers within CHS. If the contour format is the way of the future, the question becomes "can and should we mechanize this process ?".

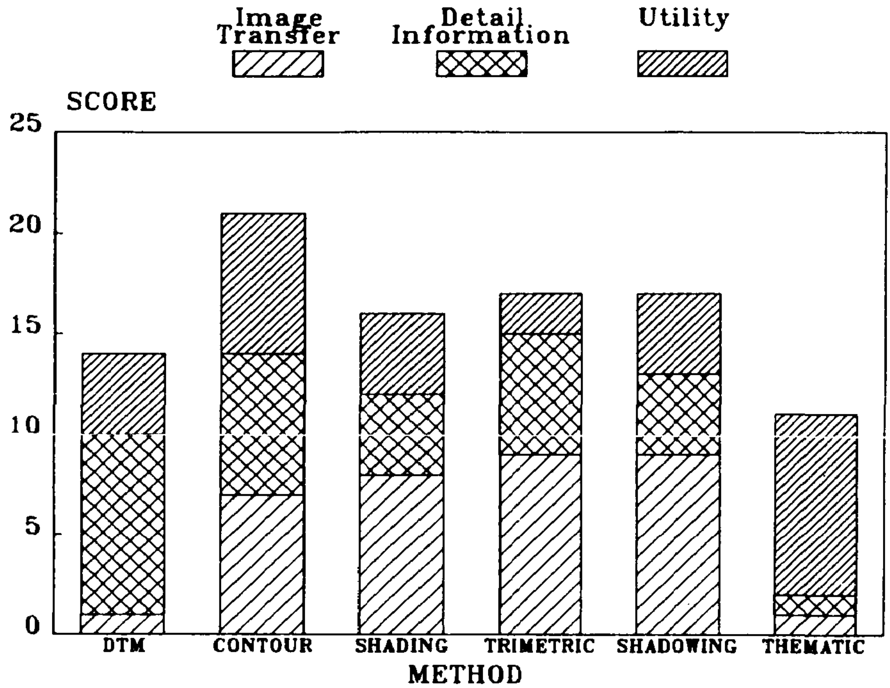

FIG. 3

3. THE DIGITAL(*) AGE

3.1. Why do we mechanize ?

Mechanization's main purpose is to help us perform a task more efficiently. It allows us more time to spend on tasks which are not particularly suited for machines, tasks which require some creative thinking. A combine-harvester is an example of good mechanization. Its efficiency gives the farmer freedom to choose the optimum moment for harvesting. The player-piano is an example of bad mechanization. It is a good example of the "if-we-can-do-it-we-should-do-it" school of engineering. We don't want to mechanize those tasks which require some qualitative interpretation or are judgemental.

It often isn't clear whether a task can or should be mechanized. A digital echo-sounder mechanizes the scaling of the echogram. This is a well-defined repetitive task seldom calling for interpretation or judgement. Nevertheless, at regular intervals it is not obvious, at least to the casual or novice observer, just where the noise ends and the bottom begins. It would be difficult to define the procedure that the scaler performs in these questionable areas. The information at his disposal is immense. He can look forwards and backwards in time. He can examine the echograms from adjacent lines. He can peer into the noise and detect

(*) By 'Digital' we mean machine-readable.

subtleties in its density which he can interpret as the bottom. Weeds, schools of fish, soft mud bottoms, etc., all give different acoustic signatures which the scaler detects and uses to help define the depth. Even "smart" digitizers cannot approach this level of skill and it is precisely in these noisy areas that the digitizers break down (or "fail reliably", as the optimists call it). Nevertheless, the digitizers work well the vast majority of the time, and as long as the total time spent in editing out the bad depths is less than the equivalent scaling time, we are ahead.

3.2. Digital field sheets

Dozens of field sheets have been completed using digital data. Except for the consistency of the machine-inked soundings, these sheets appear no different from their non-digital predecessors. The line information, including shoreline and contours, is still added manually using the principles laid down 100 years ago. The contour intervals are selected according to IHO standards. By using the field sheet as the point of departure, a sheet can also be drawn with many more contours than are prescribed by convention. Such a field sheet would be called contour-intensive to differentiate it from its more traditional brother. A very nice-looking contour-intensive field sheet was prepared recently in Central Region for research purposes. The contours were all drawn by hand. It was a painstaking piece of work performed by a craftsman and the result is an impressive document. The contours were all drawn using the traditional "safety-first" rule of hydrographic contouring.

This is one approach to a contour-intensive field sheet, but even its creators would argue that it was not an effective way of using digital data. Their purpose was to create a bench-mark standard to which a computer-contoured sheet would be compared. This is clearly an important criterion for a system to meet — it should be as good as the system it replaces. But there are other things a system must achieve.

The field sheet is, and will remain, the chief vehicle for survey quality control we have. The process of creating a field sheet is in fact a system, complete with checks and balances designed to highlight inconsistencies — the pointers to potential trouble spots. We must maintain this system or replace it with a better one. So the mechanization of contouring cannot simply take the form of pushing sounding data into a machine and pulling off the plotted sheet. If we mechanize this process, we must design in sufficient checks and balances, both manual and automatic, that preserve, if not enhance, the quality of our field sheets. We need to have our ideas clear on this before we take the next step.

4. THE RELEVANT ISSUES

4.1. Why

What is the payoff if we adopt machine contouring ? Why should we do this ? A great variety of reasons have been advocated.

4.1.1. Argument No. 1 — It is objective

The computer is alleged to be unbiased; it responds to one data set exactly as it would respond to another. In general, this is seen as being a good thing. Why, for instance, should Smith's survey data be treated differently than Baker's, provided they are from similar areas and at similar scales ? In fact, the computer system is not unbiased. It may be impartial but it is biased. This bias comes from the objectives and constraints placed upon the creator of the computer software. For instance, the mathematical algorithm chosen for interpolation can have a dramatic effect on the shape and course of the contours.

In our study, we have come across dozens of contouring algorithms — each claiming to be optimum. The optimized characteristic is different in each case. Some minimize a statistical parameter, others computing time or space. Each author argues that his algorithm is in some way superior to the others. Clearly, each user must decide what characteristics or attributes he wants from a system — but this process could hardly be called objective.

4.1.2. Argument No. 2 — It is consistent

Consistency is widely considered to be a desirable attribute. Two hydrographers given the same data will manually contour in a slightly different manner and the results will have many detail differences. This phenomenon is readily apparent each fall as the field sheets go forward to a checker who invariably points out numerous areas where he feels the contour interpretation is wrong. A computerized system is seen as a solution to this inconsistency.

In fact, the contours generated by computer can vary a great deal, even given the same data and the same algorithm. In some cases, the order in which the data is loaded has a strong bearing on the final look of the contours. In order to make their packages more general, authors have designed in parameters which can be varied to suit the tastes and requirements of the user. The variation of these parameters has a strong effect on the shape of the computed contours. Which "interpretation" is correct is left up to the user. So the problem of inconsistency is not solved.

In fact, inconsistency is not necessarily a problem, but an artifact of the way in which we conduct our surveys. If a sounding is measured more than once, it is rarely done on the same day. This alone would add an uncertainty or variance to the measurement due to the day-to-day variations in water level, speed-of-sound, vessel squat, EM propagation, etc. If the subsequent observations were made by a different vessel and operator, then vessel-to-vessel variation would add further to the variance. The effect this will have upon the contour location is unknown.

4.1.3. Argument No. 3 — It uses all the data

All of the contouring systems we have investigated assume that the input data is in point form and randomly distributed throughout the survey area. The measurements, therefore, are assumed to be samples from a discrete measuring system with no information available between the observations. In the hydrographic case, we have much more information in the form of continuous observations along parallel tracks. This is a feature we exploit in both our manual and digital methods for finding local extrema on a line. These critical soundings are then plotted and the contours derived from this reduced data set.

To improve on this a method would be required to extract from the continuous record the point at which the desired contours were intercepted. This has been done manually in the past (QUIRK, 1967) when surveying narrow channels. To emulate this process would call for new software to derive both critical soundings and contour intercepts from the raw data. This sub-set would then form the input to a contouring system. This could be done but would double or triple the number of data points selected for contour processing. This in turn might have enormous repercussions on the editing function since all of this data must be screened and erroneous depths removed. Editing is already a formidable problem.

Consider Figure 4. Here we have a contour defined about a shoal. The original shoal indication came from sounding lines and a check line. The shape and scope of the feature was further refined by a shoal examination. Observations were made on three different days and on two different launches. Contour intercepts were extracted, plotted and joined to define the final contour shape.

Clearly, some form of "smoothing" must be performed on the observed contour. At the same time allowance must be made for the "safety-first" rule. This might be accomplished by first defining the maximum area defined by the intercepts (the "convex-hull") and then smoothing or "generalizing" this line. Such a process can be mechanized but places an increased burden on the system. At present this operation is done manually and in an evolutionary manner as the data becomes available and is inked onto the sheet. It works rather well.

4.1.4. Argument No. 4 — It integrates well into the automated cartographic process

Postulate for the moment a scenario wherein the hydrographer at the completion of his work turns over to the cartographer a contour-intensive field

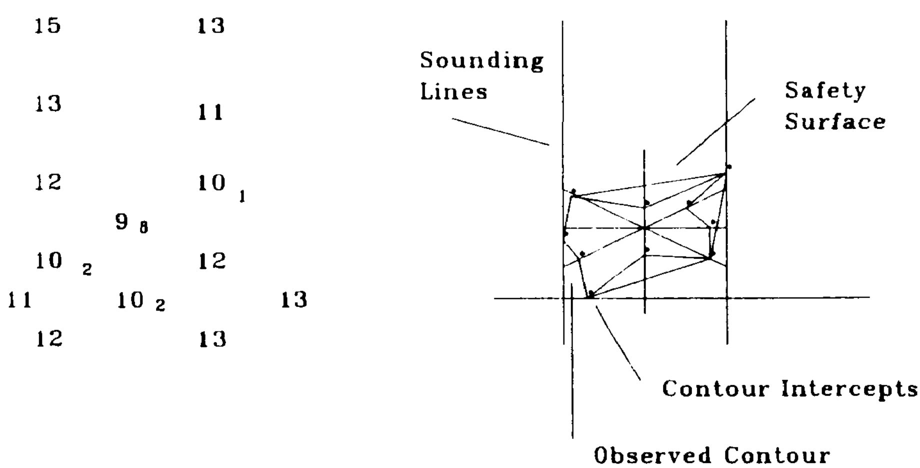

FIG. 4

sheet in a digital form. This is then mounted onto a cartographic work-station and flashed onto the screen. The cartographer's function now is to select the most appropriate contours and critical soundings directly from the given data set. Some further generalization will be required to smooth out those contours which, due to a scale reduction, are no longer cartographically acceptable. Other than that, the interface between the contour field sheet and the contour chart seems remarkably smooth. If all the field data for a new chart was available in this form, then the process would offer clear gains.

Unfortunately the vast bulk of our data is non-digital. If we move towards contour-intensive field sheets, only a small fraction of the data available to cartographers for new chart compilation will be in the desired format. This state of affairs will exist for many years. What are the contingency plans for new charts in this change-over period ?

Existing digital field sheets could be contoured either by hand or by machine. Non-digital sheets could be hand contoured or digitized and contoured by machine. The manual contours would then have to be digitized, verified and edited, as necessary, and added to the digital data base. Each of the operations adds time to the compilation of the chart. As discovered in the Central Region experiment, manual contouring is a slow, painstaking process requiring high skill and, most importantly, a dedication to excellence. The payoff from this form of automation will be slow in coming.

4.2. Where and when should we contour ?

If the field sheets are to be prepared in a contour format, when and where should this be done ? There are two avenues of approach.

Procedures could remain as they are. In this approach, the procedures now in use on "automated" surveys would continue to be used. At the completion of the survey, the verified data would form the input to a contouring package and the resultant contours would form the basis of the new field sheet. In this technique, all of the existing quality control procedures developed over the years could be applied. Soundings would be used to verify and justify the machine contours. In this case, then, the contouring would be done in the office on a main-frame computer *after* the field survey.

Alternatively the contouring could become part of the field processing. Hydrographers could see the image of the object they are measuring develop as their survey progressed. Shoals and other features such as narrow channels which need careful contour definition could be refined as the hydrographer saw fit. Quality control on the contours might be easier in the field where new survey lines could be run to clear up questionable areas.

Contour processing in the field makes sense from the survey point of view. If the hydrographer's objective is to measure contours, then he should see them as soon as it is technically feasible. Can they be processed on field computers ? Although nearly all commercial contour packages are designed to run on main-frame computers, there seems to be no underlying reason why they could not be run on computers of, say, the power of PDP-11. So it appears that machine contouring can and should be done in the field, if done at all.

4.3. Safety

Throughout this discussion we have mentioned the safety-first principle in chart-making. How can we preserve or enhance this principle if we move to contour format field sheets ?

Firstly, it is imperative that we do — this is our responsibility.

Secondly, we must realize that no existing contour package has navigational safety as a design consideration. We will have to devise our own package or extensively modify an existing one. If we do, there are two top-level design considerations we must include : we must preserve or enhance the current level of quality control in the field sheet; in contour interpolation, we must strive to err on the side of safety. The convex hull approach of figure 4 is an example of erring safely.

Safety is not an attribute that can easily be added to an existing contour package. It is a concept which must be considered throughout the package design.

4.4. Accuracy

In order to preserve the present level of accuracy in our surveys, as reflected in the resulting field sheets, we must not only consider the issues of quality control and deliberately erring safely, but also the processes involved in the machine generation of contours. In particular, we must consider the mathematical considerations which affect contour accuracy.

The machine-derived contour is an interpolated line. The interpolation is controlled by the spacing between soundings and by the choice of an interpolation algorithm. Although we postpone for the moment (to Part II) an investigation into the mathematics of interpolation, there is one high level issue that needs to be addressed. Should the observed data be "honoured" ?

By definition, an interpolated surface honours the observed data points when all points fall on the surface. Generally, this approach would be used when the data is assumed to be error-free. If the data contained large anomalies or outliers, then the surface would be grotesquely distorted to accommodate the points. This might be useful as a tool for searching for rogue soundings. The fact that the surface is obviously distorted acts as a safety-valve, preventing perhaps otherwise unseen errors from escaping correction.

An algorithm which does not honour the points generally fits an analytical surface to the data, usually minimizing the differences between observed depths and the interpolated depths. In contrast to the above case, one might assume that the data is not error-free. Rogue soundings will still distort the interpolated surface but not to the same extent. This approach is by far the most common in use and generally results in smooth-looking contours. Since this technique has also found a secure niche in the market place, contour packages of this type are usually more refined and easier to use than the more experimental packages which honour the data points. Optional line widths, contour smoothing and labelling are some of the options which produce a product with high visual appeal and sales.

They can also produce contour lines which pass on the wrong sides of observed depths. In the example in Figure 5, the 9.9. m depth has a relatively small weight on the interpolated contour since it is overwhelmed by the deeper depths surrounding it. One could argue that there is a statistical justification for this contour interpolation. No measurement is exact, each observed depth has a random error associated with it and one must use classical techniques such as least squares to find the contour's "most-likely" location. This is the philosophy hydrographers use in adjusting their horizontal control or for solving for vessel position when given redundant LOPs. There seems, however, to be a genuine reluctance to apply this same reasoning to depth measurements. Few hydrographers would be persuaded that this interpolation is correct. Data honouring is an important safety issue, particularly in shallower depths.

4.5. Usefulness

How useful are contours for the task at hand ? In particular, how useful are they at the survey stage ?

Many hydrographers extensively contour their field data as a measure of quality control. This serves a number of purposes. It highlights inconsistencies which must be clarified and shoals which must be examined. Unacceptably wide gaps are apparent. Finally, noise on the data surface becomes obvious. Hydrographers become doubly familiar with their inked soundings which in turn decreases the chances of allowing a rogue sounding to pass through the system.

Machine contour plots can be prepared in the field for the same purpose. The personal contact with the individual soundings, however, is lost and with it the opportunity of examining the soundings in the spatial context. Consequently, it must be replaced with a mechanism with the same degree of quality assurance. Machine contours have a high utility in chart compilation, provided a high percentage of the data base for the chart is in this form. If it is not, then the utility quickly fades away as more and more of the non-digital contour data is transformed.

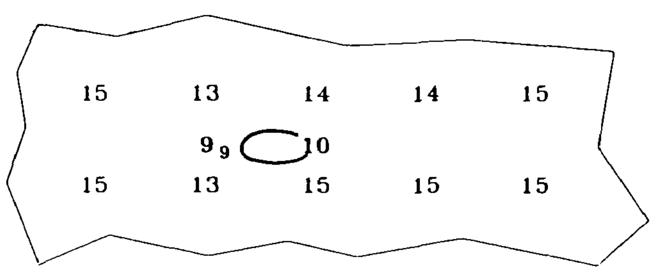

FIG. 5. — Field sheet fragment.

5. IRRELEVANT ISSUES

In our investigation into machine contouring we have found a preponderance of articles dealing with issues which, by and large, we feel have nothing to do with mapmaking. We call these the irrelevant issues and list them here.

5.1. Computer limitations

5.1.1. Processing speed

A great number of contour packages claim throughput as one of their chief attributes. This might be a result of the commercial nature of the EDP business, but we need not concern ourselves with this consideration. We will not be buying a service from an EDP group for contour processing. We want a package which runs on our own computers in the field. It should not be a burning issue with us whether a program runs in 30 minutes or 60 minutes. We will be there regardless. We want reasonable throughput, but place a much higher priority on the excellence of the output.

5.1.2. Memory constraints

Early contour packages were limited in their ability to contour large areas in one pass due to their inability to store the observed data in "core" in any great quantity. Modern 32 bit processors make these limitations a thing of the past. Desk top computers now have multi-megabyte addressing capability. Ultra-fast Winchester disk drives move megabytes of data into and out of computer storage, enabling these small computers to outperform the main-frames of only a few years ago. Minimizing computer storage in our case makes no sense. If we do not fill it, it will remain empty.

5.2. Aesthetics

Commercial contour packages place a high emphasis on the visual appeal of their output. The contour lines are smooth and clear of ripples — "realistic" in the view of their proponents. Contour labelling is automatic and nicely executed.

Aesthetic attributes like this can have a negative impact on the quality of a map. The smoothing over of wriggles on a contour line nullifies the hard fought effort in obtaining resolution of that order. The least smooth line on a field sheet is usually the shoreline. Ironically, this is the one contour line that we do know — and it is seldom smooth ! So much for realism.

What is the effect of smoothing on the size and shape of shoaling contours ? They might shrink in size. We cannot risk safety for the sake of aesthetics. Beauty must remain a secondary issue.

6. CONCLUSION : OUR MUSTS AND WANTS

If we decide we should move towards a contour format field sheet, we must state in advance what we want. We conclude with attempting to define what items we must have in a contour system and what we can live without — in other words, our musts and our wants.

6.1. Musts

6.1.1. Shoal biasing

This is the safety issue. The method we use to ensure it is not as important as the assurance that it has been done.

6.1.2. Data points are honoured

If the depth at a point is measured only once, then that measurement is our best estimate of the true depth there. This holds despite our knowledge that it is surely in error to some degree.

6.1.3. Field processing

To have the greatest utility and to retain our high standards of charting accuracy, the contouring must take place in the field where it can be monitored by the Hydrographer in Charge. This means the contour program must be compatible with existing field processing systems.

6.1.4. Inclusion of barriers

In order to prevent soundings on one side of a point or small island affecting the course of a contour on the other side, barriers must be included in the data structure to prevent inappropriate interpolation. Similarly, the course of a contour line at the foot of an underwater scarp must not be affected by soundings taken at the top — despite their apparent proximity.

6.2. Wants

6.2.1. Exploits linearization

Hydrographic data typically comes from sounding lines. We should exploit this feature. We can do this in the following ways.

6.2.1.1. Use all the data

All significant local minimums and maximums along the sounding lines should be extracted and used in the contour process.

6.2.1.2. Use contour intercepts

The intercepts should be extracted and used to control the course of the contours. As with honoured soundings, if we measure a contour intercept only once, then that is our best estimate of its true location.

6.2.2. Works on a variety of data

We have high density and low density surveys. The contour system should be able to handle both types of data.

6.2.3. Confidence intervals available

A quantitative measure of the goodness of the contour interpolation should be provided for quality control purposes. This is a non-trivial request but can be done with some approaches such as Kriging.

6.2.4. Interacts with user

In order that the hydrographer remains firmly in control of the operation, some system interaction is required. Unacceptable contours must be moved or deleted. Erroneous data must be removed and the contours recomputed. This interaction must be easy, unambiguous, accurate and fast.

6.2.5. Minimum edge effect

Running contours out to the edge of the soundings coverage causes weak interpolation. The results are often undesirable contour perturbations — artifacts of the interpolation algorithm used. Some algorithms seem more forgiving than others.

6.2.6. Unstable areas marked

In very flat areas the contour algorithm is often unstable, resulting in contours running wildly over the sheet. The contour intercept method would be particularly sensitive to this. Imagine the course of a 20 m contour in an area where the bottom was flat at about 20 m and there was a 1 m swell running when the soundings were taken. The resulting contour would be heavily affected by the waves.

7. SUMMARY

Contouring by machine could literally lead to disaster unless performed in a very careful manner. We are, in general, against any method or system which moves hydrographers further away from their data. Contouring can be mechanized in such a fashion that it works well nearly all the time. We have to be very clear as to where and when it will break down. Interactive procedures will then have to be engaged to use the skill and judgement of the people who actually acquired the data.

Machine contouring might prove to be the best link between the field-survey data-base and the cartographic work station. But the consequences of a bad design are far worse than the problems involved in smoothing out the bumps in our cartographic processes.

REFERENCE

QUIRK, A. : "Accenting the contour", Technical report, Canadian Hydrographic Service, Central Region, February, 1967.