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CANADIAN SPECIAL PUBLICATION OF FISHERIES AND AQUATIC SCIENCES 67

Centennial Conference of the Canadian Hydrographic Service

"FROM LEADLINE TO LASER"

April 5-8, 1983

Government Conference Centre

Ottawa, Canada

Sponsors

Canadian Hydrographic Service
Canadian Hydrographers Association

Conférence du Centenaire du Service hydrographique du Canada

"DE LA LIGNE DE SONDE AU LASER"

5-8 avril, 1983

Centre de Conférences du Gouvernement

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Centennial Conference Organizing Committee

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Foreword

The publication of the Proceedings of the Centennial Conference of the Canadian Hydrographic Service is the final stage in the most successful conference of its kind yet held in Canada. Four hundred people met in Ottawa for three days of plenary sessions, discussions with exhibitors and social events. The papers presented were of a high standard. As befits a Centennial Conference many reviewed various aspects of the history of hydrography in Canada but the rest covered a wide range of topics and were literally drawn from around the world. Our international visitors represented 16 different countries and two international organizations. They participated fully in the proceedings and enriched both the formal and informal discussions. The exhibitors provided an essential part of the conference by showing the latest developments that are available.

The Organizing Committee can take pride in its work but nothing would have been achieved without the wholehearted participation of all who attended. We hope that these proceedings will serve as a permanent record of the discussions and remind all of the enjoyable social events at which many new friendships were made.

A.D. O'Connor
President
Canadian Hydrographers Association

P. Richards
J. Bruce
Conference Co-Chairmen

Avant-propos

La publication du compte rendu de la Conférence du centenaire du Service hydrographique du Canada constitue la dernière étape de la conférence de ce type la plus réussie qui ait jamais été tenue au Canada. Quatre cents personnes se sont réunies à Ottawa pour trois jours de séances plénières, de discussions avec les exposants et d'événements sociaux. Les documents présentés étaient d'un très haut niveau. Comme il convient pour une Conférence du centenaire, nombre de conférenciers ont passé en revue divers aspects de l'histoire de l'hydrographie au Canada, mais plusieurs, qui venaient pratiquement de toutes les parties du monde, ont traité une large gamme de sujets. Nos visiteurs étrangers représentaient 16 pays et deux organisations internationales. Ils ont participé pleinement aux débats et ont enrichi les discussions tant officielles que non officielles. Les exposants ont été un élément essentiel de la conférence en présentant les plus récents progrès de la technique.

Le Comité organisateur peut être fier de sa réussite mais rien n'aurait pu être mené à bien sans la participation active de toutes les personnes présentes. Nous espérons que ce compte rendu restera dans les annales et qu'il rappellera à tous les événements sociaux agréables où de nombreux liens d'amitié ont été noués.

A.D. O'Connor
Président
Association canadienne des hydrographes

P. Richards
J. Bruce
Co-présidents de la conférence

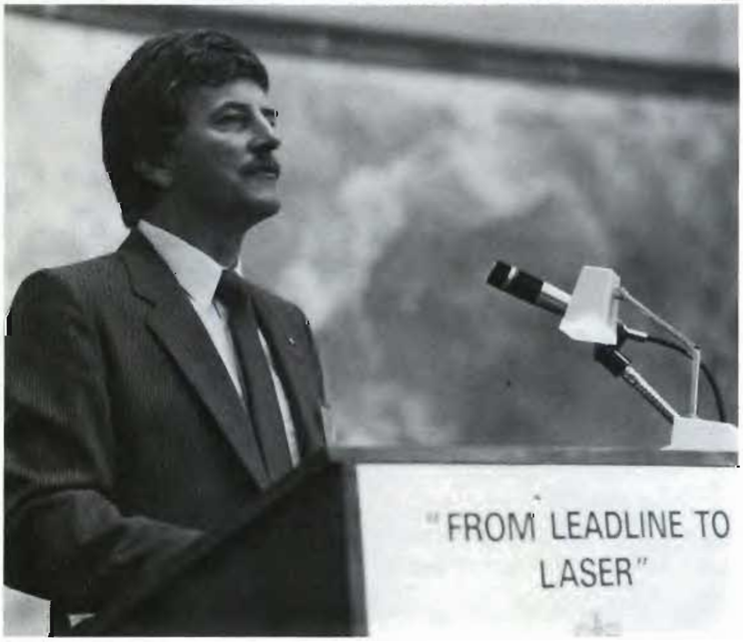
OPENING CEREMONIES

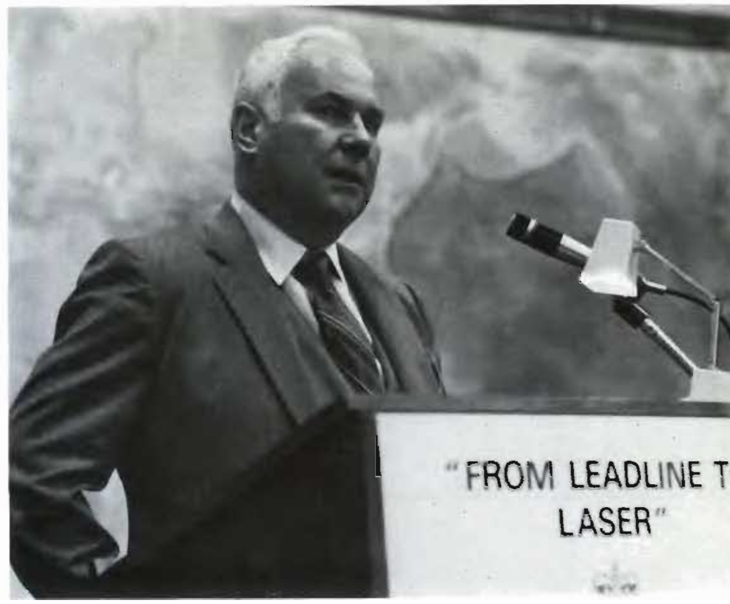
CÉRÉMONIES D'OUVERTURE

S.B. MacPhee
Director General / Directeur général
Canadian Hydrographic Service
Service hydrographique du Canada

Hon. / L'Hon. Pierre De Bané
Minister of Fisheries and Oceans
Ministre des Pêches et des Océans

P.D. Richards
Conference Chairman / Président de la conférence





G.N. Ewing
Assistant Deputy Minister
(Ocean Science and Surveys)
Sous-ministre adjoint
(Sciences et levés océaniques)
Fisheries and Oceans / Pêches et Océans

G.N. Ewing and/et J.P. Séguin
Attempt to open exhibits
Tentative d'ouverture des expositions

G. Macdonald
Past President / Ancien président
Canadian Hydrographers Association
Association canadienne des hydrographes

Front Row, left to right – Rear Admiral H.R. Lippold Jr., U.S.A. Lt. I. Ahmed, Pakistan S.B. MacPhee, Canada Ing. Gén. Jean Bourgoin, France Adm. A.S. Franco, Brasil Capt. J.E. Ayres, U.S.A.
Back Row, left to right – Mun-Sou Kim, Republic of Korea Capt. W.C. Palmer, U.S.A. Rear Admiral D.W. Haslam, U.K. Rear Admiral G.S. Ritchie, U.K. Cdr G.A. Whiting, U.S.A. Admiral H.H. Van Weelde, Netherlands O.L.C. G. LeJeune, Belgium Admiral L.H. Van Opstal, Netherlands Capt. G. Romero Ocando, Venezuela K. Yashima, Japan

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Rear Admiral G.S. Ritchie, Hydrographic Society

INTERNATIONAL VISITORS

VISITEURS DE L'ÉTRANGER

Address to the
Centennial Conference
of the Canadian Hydrographic Service
Ottawa, 6 April, 1983

S.B. MacPhee
Director General

Mr. Chairman, Honourable Minister, distinguished guests, ladies and gentlemen:

On behalf of the staff of the Canadian Hydrographic Service, it is indeed a pleasure to welcome you to our Centennial Conference. I wish to begin my address by thanking our Minister, the Honourable Pierre De Banē for coming here today to officially open the conference. We are all aware Mr. Minister of the tremendous demands placed upon your time and we thank you for being with us. I also welcome the international delegates, the delegates from other government departments and those from the private sector and the academic community, and I wish to extend a special welcome to the exhibitors who do so much to make these conferences a success. I am pleased to see strong CHS contingents from the four regions as well as from headquarters because in our decentralized service, these conferences offer one of the best opportunities to get together during an extended period to freely exchange opinions and ideas. They also provide an excellent opportunity for testing our concepts in an international forum and for broadening our attitudes on technical matters. It is gratifying to see a large number of retired CHS staff here today. Your continuing interest in hydrography and the CHS is admired and appreciated.

I will not this morning be reviewing the work of the Service for the past 100 years but note that it was in August, 1883 that Staff Commander Boulton arrived in Ottawa on secondment from the Admiralty. After a few days discussion with senior staff in the Department of Marine and Fisheries, he left for Georgian Bay and almost single handedly started a survey of the steamer routes from Owen Sound to Sault Ste. Marie. Commander Boulton started his survey in 1883 with a chartered vessel and his survey equipment consisted of sextants, theodolites, steel tapes, a chronometer, leadlines and a supply of pens and paper. Slowly the situation changed with the construction of fine ships in the early 1900's but with no fundamental change in instruments until the echo sounder was introduced on the Acadia in 1930 and electronic positioning was introduced in the 1950's. The first computer was installed on a Canadian Hydrographic vessel in 1962. Indeed there are hydrographers here today, Norm Gray for example who joined in 1930 and retired as Dominion Hydrographer in 1967 who remember very well the transition from leadline to echo sounder and from astronomic fixing to Decca. I think on this historic occasion that we should reflect on the changes in technology that have occurred during our own careers and speculate on the future. A quick visit through the commercial exhibits will demonstrate that we are living in an era of rapid technological change.

The ships and launches are now well outfitted with computer assisted data collection systems, and automatic plotters for data plotting. Yet there are many areas of Canada's coastal waters that have still not been surveyed, and many other areas that must be resurveyed to modern standards. One such gap in our survey data base was eliminated last year when Graeme Richardson led a survey party to Seymour and Belize Inlets on the Pacific Coast. By coincidence, his survey base was the barge "Pender" named after the master of the Royal Navy Vessel that in 1886 sailed into these majestic fiords extending 50 km into the coastal range. Prior to the 1982 survey, the only hydrographic data that was available for the area was Pender's single sounding line of "No Bottom at 40 Fathoms".

In 1982, Jim Vosburgh from the Pacific Region continued the Beaufort Sea corridor survey in another relatively unsurveyed area. With 90 per cent of the east-west corridor across the Pullen and Kugmallit pingo fields now complete, two pingos with minimum depths of less than 20 metres have been discovered. A further eleven pingos with minimum depths in the twenty to twenty-five metre range have also been found. These discoveries are quite significant as the tankers that will transit these Arctic shipping corridors could well draw in excess of twenty metres.

One of our largest surveys in the Atlantic Region was a survey under the leadership of Vic Gaudet to obtain up-to-date hydrography around Sable Island - the "graveyard of the Atlantic". This was a fully automated survey where the most modern techniques were employed and where the inshore bathymetry was obtained through air photo interpretation with only ground-truthing being provided through classical methods.

The Polar Continental Shelf Project (PCSP) of the Department of Energy, Mines and Resources is now well advanced on the Canadian Expedition to the Alpha Ridge or the CESAR program. Dick McDougall and his hydrographic party from Central Region are a vital part of this multi-disciplinary project. The hydrographers are attempting to obtain reconnaissance bathymetry on the continental shelf north-west of Ellesmere and Axel Heiberg Islands, an area in which we have no information. An integral part of our Arctic program is an accelerated tidal propagation research project including systematic tidal and current surveys along potential routes and the development of methods to install tide gauges and current meters below the ice with telemetry links to get the data to surface vessels or shore stations.

There are other surveys I could mention but as time is limited, I will now move on to the Chart Production Program.

The Canadian Hydrographic Service conducted surveys for twenty years before the Service produced its first chart. Up until 1903, all charts were published by the British Admiralty.

In 1903, a chart with some track soundings of the southern part of Lake Winnipeg entitled "Red River to Berens River" was published - this was the beginning.

In 1982, the Chart Production staff produced 27 New Charts, 68 New Editions and 103 Reprints. Two of these charts - charts 2243 and 2244 - have particular significance as they cancelled chart 2285, a chart produced from Commander Boulton's 1886 survey. This cancelled chart also included a section "engraved in hairline" from an 1822 survey by Lt. Bayfield.

I mention these facts to illustrate that although we are increasing dramatically our technology in chart production, we are still not producing nearly enough new charts. With our present resources, we are lucky to produce twenty-five New Charts a year. With a chart folio of 1,000 charts, this means that on the average we would only be publishing New Charts of areas on a forty-year cycle. We must attempt to half this time-frame if we are to adequately meet the needs of our clients.

We are making considerable advances in the area of computer assisted cartography but since most of the source data are available only in graphic form and must be digitized, the gains through automation cannot be readily achieved. It must also be remembered that with the advent of bilingualism, the metric system, the new International Association of Lighthouse Authorities (IALA) buoyage system and electronic positioning system latticing, chart production has become more complicated and time consuming.

Advances are however being made and we now have 30 per cent of our charts in bilingual format and 18 per cent in metric units.

In April 1982, the last sheet in the eighteen chart series that forms the General Bathymetric Chart of the Oceans - Fifth Edition (GEBCO) was published and a nineteenth world sheet is now almost ready for printing. This was an important task for CHS and the cartographers involved in this project are to be congratulated. While the GEBCO sheets were being drafted, the production of Natural Resource Maps suffered. We will now be concentrating on the production of the 1:1 million series of Geoscience maps. The year 1982 was also a strong one in the production of Sailing Directions and Small Craft Guides with thirteen publications being released - seven in English and six in French.

There are many support elements essential to the work of the hydrographers and cartographers. These include engineering and computer science support and, most important to the hydrographers, ship support. In the past, we have had a very difficult time in obtaining new ships with the last new science and survey ship, CSS Parizeau commissioned in 1967. However, over the past few years we have had a very successful launch replacement program and in January of this year, funds were approved for a major hydrographic/-oceanographic vessel for the Pacific Region to replace the WM.J. Stewart decommissioned in 1975. In addition, the former fisheries patrol vessel, The Cape Harrison, now renamed The Louis M. Lauzier and converted to carry out hydrographic/-oceanographic surveys, will be a strong asset to our program. She will work from Québec Region and carry out a much needed hydrographic survey in the coastal waters of îles de la Madeleine this summer. I am also optimistic that approval will be obtained for a Richardson replacement and for one or more additional new vessels over the next few years. They are urgently needed if we are to fulfill our mandate effectively and efficiently. In the ship support area, we are greatly indebted to the Department of Transport since much of our arctic hydrography is done from Canadian Coast Guard vessels assigned to CHS on a dedicated or opportunity basis.

In training we can look back on the successful completion of both the first francophone Cartography I Course and the first Cartography II Course for more senior staff. For the past few years we have had officers from foreign hydrographic offices attending our training programs and this year we are hosts to three naval officers from Pakistan, one on Cartography I and two on Hydrography I. This summer we will be carrying out a major review of the objectives and content of all courses to ensure that they optimally meet our operational requirements and facilitate the development of the personnel who will carry out the hydrographic task during the early decades of the next one hundred years.

Over the past few years, our research and development effort has received considerable support through the National Energy Program coordinated by the Department of Energy, Mines and Resources and through the Transportation Research and Development sector of the Department of Transport. Some of the more successful development programs have been the adoption of the spike coupled transducer for over-ice surveys; the experimentation being carried out on the Global Positioning System (GPS) in cooperation with the University of New Brunswick and Nortech; the design and construction of data acquisition and storage systems and the development of GOMADS, an interactive graphic system for processing hydrographic and cartographic data. In the case of the latter project, a license has recently been granted for a private company to further develop this system and to market it commercially.

In cooperation with the Canada Centre for Remote Sensing (CCRS) of the Department of Energy, Mines and Resources, we have continued with the Aerial Hydrography Project and recently a contract has been awarded for the design and construction of a scanning laser system. Work is currently underway on the ARCS project which is an Autonomous Remotely Controlled Submersible designed to operate through a hold in the ice and on the Dolphin project which involves the design and construction of a remotely controlled semi-submersible launch. We are also in the process of acquiring a multi-transducer electronic sweeping system and in 1983 anticipate evaluating at least one ocean mapping system.

The final development project I will discuss is the Electronic Chart. The Electronic Chart is envisaged as the data storage and display terminal that will provide the mariner with information on the ship's position, other shipping, navigation aids, weather, ice, tides and currents as well as the course made good and speed. This project is in its early stages of development and still requires considerable interaction with potential users in the marine community.

At the present time, approximately \$3M/year is being expended on research and development with the majority of the work being contracted to Canadian industry.

The adoption and signing of a Convention on the Law of the Sea by the Third U.N. Conference on the Law of the Sea will result in an increase in our offshore effort as during the next few years we will be required to carry out surveys for the determination of the limits of the continental shelf in accordance with the Convention.

The final point I would like to comment on this morning is our involvement in international issues in hydrography. Conferences to achieve some state of uniformity in hydrography were held as early as 1899 when a meeting was held in Washington. It was not however until 1919 at the suggestion of the Hydrographers of Great Britain and France that the first International Hydrographic Conference was convened. This conference was held in London and was attended by hydrographers from 24 countries. The object of the conference was to consider the advisability of all maritime nations adopting similar methods in the preparation, construction and production of their charts and publications and to facilitate mutual exchange of hydrographic information between member countries.

Following this first conference, an International Hydrographic Bureau was founded with its Headquarters in Monaco. In 1982, at the XIIth Quinquennial Conference, the Charting Standards prepared by the Chart Specifications Committee for the production of medium and large scale charts were approved. There were many other areas of interest to Canada discussed at this conference including the training of hydrographers and cartographers, the exchange of data in digital form, aid to developing countries, the world-wide tidal data bank and the General Bathymetric Chart of the Oceans (GEBCO) program.

In support of our work with IHO, and to deal specifically with boundary waters, cooperation with United States charting agencies has been a part of our activities for many years. In 1977, this was formalized with the establishment of the U.S./Canada Hydrographic Commission. The Commission has facilitated the adoption of common chart schemes, cooperative field surveys and chart production and an exchange of technical personnel. I consider it as one of my personal responsibilities to continue to foster this kind of international cooperation.

We are honoured to have at this conference presentation from France and England, the founding nations of hydrography in Canada who provided early surveys, as well as our partners of today, the United States and the International Hydrographic Organization.

In conclusion, I wish to encourage your full participation in the technical sessions of this conference and hope that you will find your stay in Ottawa enjoyable. Thank you for coming.

Allocution de S.B. MacPhee
Directeur général, à la
Conférence du centenaire du
Service hydrographique du Canada
Ottawa, le 6 avril 1983

M. le Président, honorable ministre, invités éminents, Mesdames et Messieurs,

Au nom du personnel du Service hydrographique du Canada, j'ai le plaisir de vous accueillir à notre Conférence du centenaire. Je commencerai par remercier notre ministre, l'honorable Pierre De Bané, d'avoir bien voulu venir ouvrir officiellement la conférence. Nous savons tous, M. Le Ministre, combien votre emploi du temps est chargé et nous vous remercions d'être avec nous aujourd'hui. Je souhaite aussi la bienvenue aux délégués internationaux, aux représentants d'autres ministères gouvernementaux, du secteur privé et de la communauté universitaire et j'aimerais tout spécialement souhaiter la bienvenue aux exposants qui contribuent beaucoup à la réussite de ces conférences. Je suis heureux de voir qu'un grand nombre de membres du SHC sont venus des quatre Régions ainsi que de l'administration centrale car, du fait de la décentralisation de nos services, ces conférences constituent une excellente occasion de nous réunir pendant une période prolongée pour échanger librement les opinions et les idées. Elles nous offrent également la possibilité unique de mettre nos concepts à l'essai dans un cadre d'échange international et d'enrichir nos connaissances techniques. Par ailleurs, il est réconfortant de voir ici un grand nombre d'anciens membres du SHC qui sont maintenant à la retraite. Nous vous remercions et vous félicitons pour votre intérêt soutenu vis-à-vis de l'hydrographie et du SHC.

Ce matin, je ne passerai pas en revue les activités du Service pendant les cent dernières années, mais je soulignerai que c'est en août 1883 que le Staff Commander Boulton était dépêché à Ottawa par l'Amirauté britannique. Après quelques jours de discussion avec les cadres supérieurs du ministère de la Marine et des Pêcheries, il est parti pour la baie géorgienne et a entrepris presque seul un levé des routes des vapeurs d'Owen Sound à Sault Ste-Marie. Le Commander Boulton a commencé son levé en 1883 à bord d'un navire affrété et il disposait d'un équipement composé de sextants, de théodolites, de rubans d'acier, d'un chronomètre, de lignes de sonde, de crayons et de papier. La situation a évolué lentement avec la construction de navires plus modernes au début des années 1900, mais sans que des changements fondamentaux interviennent sur le plan des instruments, jusqu'à ce que l'Acadia soit équipé d'un écho-sondeur en 1930 et que le positionnement électronique apparaisse dans les années 1950. C'est en 1962 que le premier ordinateur a été installé sur un navire hydrographique canadien. En fait, il y a ici des hydrographes, notamment Norm Gray, entré au Service en 1930 et parti en retraite en 1967 au poste d'hydrographe fédéral, qui se souviennent très bien de la transition de la ligne de sonde à l'écho-sondeur et de l'établissement du point astronomique au système Decca. Je pense qu'en cette occasion historique, nous devrions nous pencher sur les progrès techniques qui se sont produits pendant notre carrière et faire des spéculations pour l'avenir. Une rapide visite de l'exposition commerciale vous montrera que nous vivons à une époque de changements technologiques rapides.

Les navires et les vedettes sont maintenant équipés de systèmes de collecte des données assistés par ordinateur et de traceurs automatiques pour la restitution des données. Toutefois, un grand nombre de régions des eaux côtières du Canada n'ont pas encore fait l'objet de levés et de nombreuses autres doivent faire l'objet de nouveaux levés conformes aux normes modernes. L'an dernier, une lacune semblable de notre base de données hydrographiques a été comblée lorsque Graeme Richardson a dirigé une expédition hydrographique dans les inlets Seymour et Belize sur la côte du Pacifique. Assez curieusement, sa base d'opération était le chaland "PENDER" qui porte le nom du capitaine du bateau de la Marine royale qui en 1886, a pénétré dans ces fjords majestueux qui s'enfoncent de 50 km dans les terres. Avant le levé de 1982, les seules données hydrographiques disponibles pour la région étaient l'unique ligne de sonde de Pender avec la désignation "pas de fond à 40 brasses".

En 1982, Jim Vosburgh de la Région du Pacifique a poursuivi le levé du corridor de la mer de Beaufort dans une autre région relativement peu connue. En effectuant le levé du corridor Est-Ouest à travers les zones de pingo Pullen et Kugmallit, qui est maintenant terminé à 90 %, on a découvert trois pingos à moins de 20 m de profondeur. Onze autres pingos situés entre 20 et 25 m de profondeur ont été également localisés. Ces découvertes sont très importantes car les pétroliers qui passeront dans ces corridors de navigation pourraient très bien avoir un tirant d'eau de plus de 20 mètres.

L'un de nos plus grands levés dans la Région de l'Atlantique a été mené sous la direction de Vic Gaudet. Il a consisté à mettre à jour les données relatives aux environs de l'île de Sable, "le cimetière de l'Atlantique", à l'aide de méthodes entièrement automatisées et des techniques les plus modernes. La bathymétrie côtière a été obtenue par l'interprétation de photos aériennes, seule la vérification au sol étant assurée par les méthodes classiques.

L'Etude du plateau continental polaire (EPCP) du ministère de l'Energie, des Mines et des Ressources est maintenant bien avancée du point de vue de l'expédition canadienne sur la dorsale Alpha, que l'on a appelée le programme CESAR. Dick McDougall et son équipe hydrographique de la Région du Centre participent activement à ce projet multidisciplinaire. Les hydrographes s'efforcent d'obtenir des données bathymetriques de reconnaissance sur le plateau continental au nord-ouest des îles Ellesmere et Axel Heiberg, une région sur laquelle nous n'avons aucune information. Dans le cadre de notre programme sur l'Arctique, nous menons un projet de recherche intensive sur la propagation des marées, qui comprend l'étude méthodique des marées et des courants le long des routes potentielles et l'élaboration de méthodes pour l'installation de marégraphes et de courantomètres sous la glace avec liaisons télémétriques pour la transmission des données aux navires de surface ou aux stations à terre.

Je pourrais mentionner d'autres levés, mais faute de temps, je vais maintenant passer au Programme de production des cartes.

Le Service hydrographique du Canada a effectué des levés hydrographiques pendant 20 ans avant de produire sa première carte. Jusqu'en 1903, toutes les cartes étaient publiées par l'Amirauté britannique. En 1903, le Service a publié sa première carte: une carte de la partie sud du lac Winnipeg, intitulée "Red River to Berens River", qui avait été dressée à l'aide de sondages en route.

En 1982, le personnel de la Production des cartes a réalisé 27 cartes nouvelles, 68 nouvelles éditions et 103 réimpressions. Deux de ces cartes, les cartes 2243 et 2244, ont une importance particulière car elles annulent la carte 2285 qui avait été dressée à partir du levé du Commander Boulton en 1886. Cette carte annulée comprenait aussi une section "gravée finement" à partir d'un levé effectué en 1882 par le lieutenant Bayfield.

Cette anecdote illustre bien le fait qu'en dépit des progrès de la technique, nous ne produisons toujours pas suffisamment de nouvelles cartes. Avec nos ressources actuelles, nous parvenons à peine à produire 25 cartes nouvelles par an. Avec une série totale de 1 000 cartes, cela signifie qu'en moyenne, nous ne publierons de cartes nouvelles d'une région qu'une fois tous les 40 ans. Nous devons nous efforcer de réduire ce délai de la moitié si nous voulons répondre de façon appropriée aux besoins de nos clients.

Nous avons beaucoup progressé dans le domaine de la cartographie assistée par ordinateur, mais comme la plupart des données de base sont seulement disponibles sous forme graphique et qu'elles doivent être numérisées, nous ne pouvons tirer pleinement parti des avantages offerts par l'automatisation. Il ne faut pas non plus oublier qu'avec l'instauration du bilinguisme, du système métrique, du nouveau système de signalisation de l'Association internationale de signalisation maritime (AISM) et des réseaux des systèmes de positionnement électroniques, la production des cartes est beaucoup plus compliquée et demande plus de temps.

Toutefois, nous progressons sans cesse et à l'heure actuelle, 30 % de nos cartes sont bilingues et 18 % sont en unités métriques.

En avril 1982, la dernière feuille de la série de 18 cartes qui forme la Carte générale bathymétrique des océans (cinquième édition - GEBCO) a été publiée et une dix-neuvième feuille va être imprimée sous peu. Il s'agissait d'une tâche importante pour le SHC et nous devons féliciter les cartographes qui ont participé à ce projet. Cependant, cette participation s'est faite aux dépens de la production de la série de cartes sur les ressources naturelles. Nous allons maintenant nous concentrer sur la production de la série de cartes géoscientifiques à l'échelle 1:1 million. L'année 1982 a été aussi excellente pour les Instructions nautiques et les Guides du plaisancier avec la sortie de 13 publications: 7 en anglais et 6 en français.

Il existe de nombreux éléments de soutien qui sont essentiels au travail des hydrographes et des cartographes. Il s'agit du soutien procuré par le génie et l'informatique, et, le plus important pour les hydrographes, par les navires. Par le passé, nous avons eu beaucoup de difficulté à obtenir de nouveaux navires, le dernier navire hydrographique et scientifique moderne, le Parizeau, ayant été mis en service en 1967. Toutefois, ces dernières années, un programme de remplacement des vedettes a été mené à bien et en janvier de cette année, des fonds ont été approuvées pour la construction d'un grand navire hydrographique/océanographique pour la Région du Pacifique, qui remplacera le Wm. J. Stewart, retiré du service en 1975. En outre, l'ancien patrouilleur des pêches, le Cape Harrison, rebaptisé le Louis M. Laurier et transformé pour les levés hydrographiques/océanographiques, nous sera très utile pour notre programme. Il mènera ses activités à partir de la Région du Québec et effectuera notamment cet été un levé hydrographique essentiel dans les eaux côtière des îles de la Madeleine. J'ai aussi bon espoir que nous obtiendrons l'approbation relative pour le remplacement du Richardson et pour l'acquisition d'un ou plusieurs bateaux supplémentaires au cours des prochaines années. Nous devons disposer de ces bateaux de toute urgence si nous voulons remplir notre mandat de façon efficace et efficiente. Dans le domaine du soutien en navires, nous sommes largement redevables au ministère des Transports, étant donné que la plupart de nos études hydrographiques dans l'Arctique sont menées à partir de bateaux de la Garde côtière du Canada affectés au SHC à titre occassionel ou spécial.

Sur le plan de la formation, nous pouvons nous féliciter de la réussite du premier cours Cartographie I en français et du premier cours Cartographie II pour le personnel principal. Ces dernières années, des membres de bureaux hydrographiques étrangers sont venus suivre nos programmes de formation et cette année, nous accueillons trois officiers de la marine du Pakistan, un en cartographie I et deux en hydrographie I. Cet été, nous effectuerons une grande révision des objectifs et du contenu de tous les cours pour nous assurer qu'ils répondent de façon optimale à nos besoins opérationnels et qu'ils facilitent le perfectionnement du personnel qui sera chargé des tâches hydrographiques pendant les premières décennies des cent prochaines années.

Ces dernières années, notre effort de recherche et de développement a reçu un appui considérable du Programme énergétique national coordonné par le ministère de l'Energie, des Mines et des Ressources et du secteur de la Recherche et du Développement du ministère des Transports. Au nombre des plus belles réussites des projets de développement figurent l'adoption du transducteur couplé à pointe pour les levés au-dessus de la glace; les expériences menées sur le Système de positionnement mondial (SPM) en coopération avec l'université du Nouveau-Brunswick et la société Nortech; la conception et la construction de systèmes d'acquisition et de stockage des données et la mise au point du GOMADS, système graphique interactif pour le traitement des données hydrographiques et cartographiques. Dans le cas du dernier projet, un permis a été récemment octroyé à une société privée qui va perfectionner et commercialiser le système.

En coopération avec le Centre canadien de télédétection (CCT) du ministère de l'Energie, des Mines et des Ressources, nous avons poursuivi le projet d'hydrographie aérienne et un marché a été passé récemment pour la conception et la construction d'un système de laser à balayage. Les travaux se poursuivent actuellement sur la mise au point de l'ARCS, submersible autonome commandé à distance, conçu pour naviguer par un trou pratiqué dans la glace, et sur le projet Dolphin qui porte sur la conception et la construction d'un semi-submersible commandé à distance. Nous sommes aussi sur le point d'acquérir un système de balayage électronique mulitransducteur, et en 1983, nous prévoyons évaluer au moins un système de cartographie océanique.

Le dernier projet de développement dont je vais parler est la carte électronique. Il s'agit d'un système de stockage des données et d'affichage sur écran cathodique qui fournira aux navigateurs des renseignements sur la position du navire, d'autres bateaux, les aides à la navigation, le temps, les glaces, les marées et les courants ainsi que la route moyenne vraie et la vitesse. Nous n'en sommes qu'aux premiers stades de ce projet qui nécessite encore beaucoup d'échanges avec les utilisateurs potentiels de la communauté marine.

A l'heure actuelle, nous consacrons environ $3M par an aux activités de recherche et de développement, dont la plupart sont confiées sous contrat à l'industrie canadienne.

L'adoption et la signature d'une Convention sur le droit de la mer au cours de la troisième conférence de l'ONU sur le droit de la mer vont entraîner une intensification de nos activités au large des côtes car, pendant les prochaines années, nous devrons effectuer des levés pour déterminer les limites du plateau continental, conformément à la Convention.

Le dernier point que j'aimerais soulever ce matin est notre participation au règlement des questions internationales en hydrographie. Dès 1899, on avait commencé à étudier la question de l'uniformisation en hydrographie en convoquant une réunion à Washington. Toutefois, ce n'est qu'en 1919 que fut organisée la première conférence hydrographique internationale, sur l'initiative des hydrographes de Grande-Bretagne et de France. Cette conférence, tenue à Londres, a réuni des hydrographes de 24 pays. L'objet de la conférence était d'examiner l'opportunité, pour tous les pays maritimes, d'adopter des méthodes similaires pour la préparation, l'établissement et la production des cartes et des publications et de faciliter les échanges de renseignements hydrographiques entre les pays membres.

A la suite de cette première conférence, on créait un Bureau hydrographique international dont le siège se trouve à Monaco. En 1982, au cours de la XIIe conférence quinquennale, les participants ont approuvé les normes cartographiques préparées par le Comité des spécifications des cartes pour la production des cartes à moyenne et grande échelle. Nombre d'autres questions intéressant le Canada ont été examinées au cours de cette conférence, notamment la formation des hydrographes et des cartographes, l'échange des données sous forme numérique, l'aide aux pays en développement, la banque mondiale de données sur les marées et les programmes de la Carte générale bathymétrique des océans (GEBCO).

Parallèlement à nos activités avec l'OHI, nous collaborons depuis de nombreuses années avec les organismes cartographiques des Etats-Unis, plus spécialement pour les eaux frontalières. En 1977, cette collaboration a été officialisée par la création d'une Commission hydrographique E.-U./Canada. La commission a facilité l'adoption de schémas de cartes communs, la collaboration à des levés sur le terrain et à la production de cartes et l'échange de personnel technique. Je considère qu'il m'incombe en particulier de continuer à favoriser ce type de coopération internationale.

Nous avons l'honneur de compter parmi nous des représentants des deux pays fondateurs de l'hydrographie au Canada, la France et le Royaume-Uni, qui ont assuré les premiers levés, ainsi que de nos partenaires d'aujourd'hui, les Etats-Unis et l'Organisation hydrographique internationale.

Et conclusion, j'aimerais vous envourager à participer activement aux séances techniques de cette conférence et j'espère que vous passerez un excellent séjour à Ottawa. Je vous remercie vivement d'être avec nous aujourd'hui.

NOTES FOR AN ADDRESS
BY
THE HONOURABLE PIERRE DE BANE
MINISTER OF FISHERIES AND OCEANS
TO
CENTENNIAL CONFERENCE
CANADIAN HYDROGRAPHIC SERVICE

Ottawa, Ontario
April 6, 1983

Good morning, ladies and gentlemen. It is a great pleasure for me to be with you today to launch the Centennial Conference of my department's Canadian Hydrographic Service. All of us here today share the special sense of accomplishment which the Canadian Hydrographic Service feels on this, their 100th, anniversary. I welcome delegates from our "parent countries" of France and England, our neighbours from the United States and those who have travelled from countries as distant as Brazil, Peru and Japan. For those of you who are members of the Service, you know its fine traditions and I share with you your pride in its excellent work.

It is particularly appropriate that, as Minister of Fisheries and Oceans, I should have the honour of opening this conference. It was a predecessor of mine, the Minister of Marine and Fisheries, who, in 1883, persuaded the federal cabinet that his department should initiate a program of surveying. The need for hydrographic surveys was clear when, in 1882, the steamer 'Asia' sank in a storm in Georgian Bay, resulting in the loss of 150 lives. As a result of this tragic event, Staff Commander Boulton was sent out from Britain to survey that area and to begin other vital survey work which continues to the present day.

Hydrographic surveying and charting have been an integral part of Canada's history. Today it is the hydrographer, the sailor, and the fisherman who share with those early explorers the sense of awe at the dimensions of the chartmaker's task and have a keen appreciation of its critical importance.

A few days ago I came across a passage quoted from a recent publication titled "The Mapmakers" -

> "The greatest mountain range on Earth is not the Himalayas or the Rockies, the Andes or the Alps. The widest and deepest chasm is not the Grand Canyon of the Colorado. The broadest plain is not the steppes of Russia or the Great Plains of North America. It may come as a surprise to landlocked minds, but the greatest mountains, chasms, and plains all lie beneath the oceans, a grandeur unseen and until recent times unmapped and unmappable."

Last December I had the honour to be the alternate head of the Canadian delegation to the final session of the United Nations Conference on the Law of the Sea and to sign the convention on behalf of Canada. This convention creates far-reaching and unprecedented laws governing the uses of the world's oceans. The vast undertaking we were bringing to a conclusion, was brought home to all delegates by the display of the new General Bathymetric Chart of the Oceans or GEBCO. This GEBCO display also provides an appropriate backdrop for your own deliberations.

The GEBCO chart shows that the ocean floor is no longer unmappable. In fact, its broad outlines are now known. But it is clear that much remains to be done.

Much of the discussion and debate on the Law of the Sea since December has focussed on one narrow issue, the perception by some countries and the business community that the sections of the convention dealing with seabed mining are unfair. It would have been much more to the point, I suggest, to discuss the extent to which most of the nations of the world do not have the resources to determine the extent of their offshore areas and thus decide how best to use these new resources for the betterment of their own populations and mankind.

It is indeed a challenge to the developed countries to assist the developing nations to achieve a hydrographic capability. We are constantly being told that the economic well-being of the world depends upon the free flow of international trade, most of which moves in ships. How can that flow be achieved when many of the world's charts were surveyed by leadline at a time when few ships drew more than a few metres? There are now tankers that draw 25 metres but they are restricted to the few routes and ports surveyed to meet their needs.

In the light of present reality, the dimensions of the task that confronted the early French, British and Spanish explorers who came to Canada's shores can scarcely be conceived today. They came to make territorial claims and to establish trade. As an integral part of their explorations, they made maps and charts of each new area they reached. It was these maps and charts which the governments of the European countries used as evidence that they had explored and therefore claimed a new territory. We remember the names of our earliest explorers in place names throughout Canada - Jacques Cartier (Passage), Owen (Sound), Vancouver, Juan de Fuca (Strait) - these are only a handful of the names that live on.

During the course of this Conference, I know that you will be hearing much about the early days of hydrographic exploration in Canada, and the men, the ships and the major discoveries of that exploration.

In the next few days you will also learn a great deal about the new developments in hydrography from around the world. Technical developments such as electronic charting, use of the laser sounder, side scan sonar, and global positioning are just a few of the innovations achieved through research and development. These new technologies both highlight the progress in hydrography and allow us to foresee a time when today's survey techniques will be supplemented by ever more sophisticated technology.

While I have no crystal ball to gaze into the future, I do see some new developments in hydrography and the links which it has with other sectors of the economy such as transportation, offshore exploration and development, recreational boating and tourism and of course the fishing industry.

Hydrographic surveying and charting is as vital to Canadian economic growth today as it was to the countries who sponsored our early explorers. Today, the surveying and charting of the sea floor has led to the major oil and gas explorations off our East Coast and in the Beaufort Sea. The transportation industry on both coasts and in the Great Lakes is reliant on C.H.S. charts and is bound by law to carry these charts or their equivalent whenever sailing in Canadian waters.

In Quebec, my own province, the earliest settlers were so dependent upon water transportation that they used the seigniorial system to lay out their land with long thin "rangs" so that every settler had access to the water. The large aluminum industry at the head of the Saguenay is based on the close proximity of deep water harbours and cheap hydro power. The recent opening of a salt mine on îles de la Madeleine has provided a third employment alternative to the fishing and tourist industries. One of the keys to the development of the isolated settlements along the north shore of the Gulf of St. Lawrence will be the provision of better charts, a task for which the Hydrographic Service is now preparing.

The tourist industry in Canada has mushroomed in the last twenty years into a major contributor to the Canadian economy. Recreational boating is a major component of that industry. The Hydrographic Service has kept pace with this development by producing an increasing number of small craft charts for the recreational boater. Today, more than 60 per cent of the half million charts sold annually in Canada are used for pleasure boating.

Staff Cdr. Boulton could never have imagined, back in 1883, the growth and scope of the Canadian Hydrographic Service. It has faced the enormous challenge of charting the longest coastline and second largest continental shelf in the world, working in a climate that verges on the sub-tropical in Lake Erie in the summer, to the frigid wastes of the Arctic. Today the Service publishes more than 1,000 navigation charts, which makes it the largest hydrographic office in the world apart from those that maintain world wide coverage.

While technological innovation has revolutionized the techniques of hydrography, there are many aspects of both hydrography and cartography that remain an art, not a science. Human judgement still prevails in deciding when a survey is complete or what is the most suitable scale for a chart. These are decisions that have an immediate impact on cost of a survey, though not, if the judgement is good, on the safety of ships using the chart. Such judgements can only be exercised by men and women, not computers or lasers or any existing technological advancements. It must be exercised conscientiously day in and day out. It is here that I think that the Canadian Hydrographic Service can be most proud. Every successive generation that has worked in the Service has been imbued with the idea that the life of a mariner may depend upon his or her own judgement.

It is now my pleasure to declare the Centennial Conference of the Canadian Hydrographic Service open. I hope that you will all derive great benefit from your deliberations over the next three days and that the next century will be as interesting as the last.

NOTES D'UNE ALLOCUTION
DE
L'HONORABLE PIERRE DE BANE
MINISTRE FEDERAL DES PECHES ET DES OCEANS
A LA
CONFERENCE DU CENTENNAIRE
DU SERVICE HYDROGRAPHIQUE DU CANADA

A Ottawa (Ontario)
le 6 avril 1983

Bonjour mesdames et messieurs. Il me fait grand plaisir d'être parmi vous, aujourd'hui, pour inaugurer la Conférence du centenaire du Service hydrographique du Canada de mon Ministère. Nous tous, qui sommes ici, nous partageons le sentiment particulier du devoir accompli qu'éprouve ce Service à l'occasion de son centième anniversaire. Je souhaite la bienvenue aux délégués de nos mères patries communes, de la France et de l'Angleterre, de nos voisins des Etats-Unis, et de ceux qui sont venus de pays aussi éloignés que le Brésil, le Pérou et le Japon. Pour ceux parmi vous qui appartenez au Service hydrographique du Canada, vous connaissez bien ses traditions et je partage avec vous la fierté que vous avez de l'excellent travail que vous avez accompli.

Il me revient tout particulièrement, en tant que Ministre fédéral des Pêches et des Océans, d'avoir l'honneur d'inaugurer cette Conférence. Ce fut l'un de mes prédécesseurs, le Ministre de la Marine et des Pêcheries qui, en 1883, a persuadé le Cabinet fédéral que son Ministère devait entreprendre un programme de levés. Le besoin d'un tel programme était devenu criant après le naufrage, en 1882, du paquebot ASIA, lors d'une tempête dans la baie Georgienne qui entraîna la perte de 150 vies. Comme résultat de ce tragique incident, le Staff Commander Boulton fut envoyé de la Grande-Bretagne pour effectuer des levés dans cette région et commencer un autre travail essentiel de levés qui s'est continué jusqu'à nos jours.

Les levés hydrographiques et la cartographie font partie intégrale de l'histoire du Canada. Aujourd'hui, ce sont les hydrographes, les marins et les pêcheurs qui partagent avec les explorateurs des premiers jours le sentiment d'étonnement en face du travail de la cartographie, et ce sont eux qui témoignent le plus vivement de son importance essentielle.

Il y a quelques jours, je suis tombé sur un passage d'une publication récente intitulé "LES CARTOGRAPHES" -

> "Les cimes les plus élevées sur la terre ne sont pas celles des Himalayas ou des Rocheuses, des Andes ou des Alpes. Les élévations les plus hautes et les gorges les plus profondes ne sont pas celles du Grande Canyon du Colorado. Les plaines les plus vastes ne sont pas les steppes de la Russie ou les Grandes plaines de l'Amérique du Nord. Il peut s'avérer étonnant à l'esprit d'un observateur terrestre que les montagnes les plus élevées, les gorges et les plaines qu'on n'a pas réussi à découvrir jusqu'à ce jour, se retrouvent sous l'océan inconnues et inaccessibles."

Au mois de décembre dernier, j'avais l'honneur de partager conjointement la direction de la délégation canadienne à la dernière session de la Conférence des Nations Unies sur le droit de la mer et d'en signer l'entente au nom du Canada. Cette entente a créé une législation à longue portée qui n'a pas de précédent et qui régit l'usage des océans du monde. Cette vaste entreprise que nous avions menée à terme fut rappelée à tous les délégués par la présentation de la nouvelle Carte bathymétrique générale des océans (GEBCO), compilée par le Service hydrographique du Canada. Cette présentation de GEBCO constitue également une excellente illustration pour inspirer vos délibérations.

Cette carte GEBCO démontre que le fond de l'océan n'est plus inaccessible. En fait, ses larges contours nous sont maintenant connus. Mais il est bien évident qu'il reste encore beaucoup à faire.

La plus grande partie des discussions et des débats sur le droit de la mer depuis le mois de décembre s'est concentrée sur la question précise de savoir si la perception, qu'ont certains pays et la communauté des affaires, des articles de cette entente portant sur les droits miniers est ou non fondée et adéquate. Il eut été beaucoup plus approprié, comme je l'ai suggéré, qu'on discute de l'étendue pour la plupart des pays du monde de leurs zones hauturières, et qu'on décide ainsi de quelle façon ils pourraient au mieux en utiliser les ressources pour le mieux-être de leurs propres populations et de l'humanité.

C'est en effet un défi qui confronte les pays développés que d'aider aux pays en voie de développement, pour qu'ils arrivent à une certaine capacité sur le plan de l'hydrographie. On nous dit, d'une façon constante, que le bien-être économique du monde dépend du libre cours du commerce international, dont la plus grande partie se fait par bateau. Comment ce cours pourra-t-il se compléter quand la plupart des cartes du monde ont été établies à partir de sondes levées à l'époque où les bateaux ne tiraient pas plus de quelques mètres d'eau? Il y a maintenant des pétroliers qui jaugent 25 mètres et qui sont obligés de circuler dans quelques corridors et ports dont on a fait spécialement les levés pour répondre à leurs besoins.

A la lumière de la réalité actuelle, la grandeur de la tâche qui a confronté les premiers explorateurs français, anglais et espagnols à venir sur les rives de notre pays peut à peine être imaginée aujourd'hui. Ils sont venus conquérir de nouveaux territoires et établir de nouveaux postes de commerce. Tout en faisant l'exploration, ils ont dressé des cartes et cartographié chacune des nouvelles régions qu'ils ont atteintes. Ce sont ces cartes et ces relevés que les gouvernements des pays européens ont utilisés comme témoignages de leur présence dans ces nouveaux territoires, à l'appui des possessions qu'ils réclamaient. Nous nous rappelons les noms des premiers explorateurs en certains endroits du Canada; le passage Jacques Cartier le détroit Owen, Vancouver, le détroit Juan de Fuca - qui ne sont là que quelques exemples parmis tant d'autres.

Au cours de cette Conférence, je sais que vous entendrez beaucoup parler des premiers jours de l'exploration hydrographique du Canada, commes des hommes, des bateaux et des principales découvertes de cette vaste entreprise d'exploration.

Au cours des prochains jours, vous apprendrez aussi beaucoup à propos des derniers développements de l'hydrographie autour du monde. De ces développements techniques tels que la cartographie électronique, l'usage des sondeurs au lasers, le sonar à levé latéral, et le positionnement global, ne sont que quelques-unes des plus récentes innovations realisées par la recherche et le développement. Ces nouvelles méthodes illustrent à la fois les faits saillants et les progrès de l'hydrographie et nous permettent de prévoir le jour où les techniques, qui sont modernes aujourd'hui, seront remplacées par d'autres techniques encore plus sophistiquées.

Bien que je n'aie point de boule de cristal pour regarder dans l'avenir, je prévois quelques nouveaux développements de hydrographie dans ses relations qu'elle a avec d'autres secteurs de l'économie, comme le transports, l'exploration et l'expansion hauturières, la navigation de plaisance, le tourisme, et bien sur, l'industrie de la pêche.

Les levés hydrographiques et la cartographie sont essentials à la croissance économique d'aujourd'hui, tout comme ils l'étaient pour les pays qui ont parrainé les efforts des premiers explorateurs. Aujourd'hui, les levés et la cartographie du fond de la mer one amené l'exploration des principales exploitations pétrolières et gazières sur la côte est et dans la mer de Beaufort. L'industrie du transport sur les deux côtes et sur les Grands Lacs repose sur les cartes marines du Service hydrographique du Canada et elle doit, de par la loi, garder à bord de ses embarcations de telles cartes ou leurs équivalents, chaque fois qu'elle évolue sur les eaux canadiennes.

Au Québec, dans ma province, les premiers colons étaient tellement dépendants du transport par la voie des eaux qu'ils ont établi un régime seigneurial qui divisait les terres le long de minces rangs qui ont permis à tous d'avoir un droit d'accès à un cours d'eau. La grande industrie de l'aluminium, elle-même, qui s'est établie sur le Saguenay, repose sur sa proximité des ports en eaux profondes et la disponibilité d'énergie hydroélectrique à bon compte. L'ouverture récente d'une mine de sel aux îles de la Madeleine y a apporté une troisième possibilité d'emploi, en plus de la pêche et de l'industrie du tourisme. L'une des clefs du développement des villages isolés de la côte Nord de l'estuaire du Saint-Laurent dépendra de la disponibilité de meilleures cartes, et c'est un travail que le Service hydrographique du Canada est actuellement à accomplir.

L'industrie du tourisme au Canada s'est développée au cours des 20 dernières années en tant qu'élément principal de l'économie canadienne. La navigation de plaisance est un élément principal de cette industrie. Le Service hydrographique du Canada a évolué de pair avec ce développement en produisant un nombre grandissant de cartes pour petits bateaux à l'intention des navigateurs plaisanciers. Aujourd'hui, plus de 60 pour cent du demi-million de cartes vendues annuellement au Canada servent à l'intention des plaisanciers.

Le Staff commander'Boulton n'aurait jamais pu imaginer, en 1883, l'ampleur et la grandeur du Service hydrographique du Canada. Ce Service a dû affronter l'énorme défi de cartographier le littoral le plus long du monde et la plate-forme continentale, la deuxième en importance au monde. Il a dû travailler dans un climat qui va du sous-tropical, dans la région du lac Erié pendant l'été, aux espaces glaciaires de l'Arctique. Aujourd'hui, le Service publie plus de 1000 cartes de navigation, ce qui en fait l'agence hydrographique la plus importante du monde, mises à part celles qui soutiennent un réseau de distribution mondiale.

Alors que les innovations techniques ont révolutionné les méthodes de l'hydrographie, il y a plusieurs aspects de l'hydrographie, et de la cartographie qui demeurent largement un art, non une science. Le jugement de l'homme prévaut encore lorsqu'il s'agit de décider à quel moment un levé est complété ou encore à quelle échelle il convient d'établir une carte. Ce sont de telles décisions qui ont une influence immédiate sur le coût d'un levé, bien qu'elles en aient aussi, si le jugement est bon, sur la sécurité des bateaux qui se serviront de telles cartes. De tels jugements ne peuvent être exercés que par des hommes et par des femmes, non pas par des ordinateurs, des systèmes laser ou toute autre méthode de technologie avancée. Ils doivent être régulièrement exercés avec conscience professionnelle jour après jour et toujours. Et c'est ici, je pense, que le Service hydrographique du Canada a le plus raison d'être fier. Toutes les générations qui se sont succédées à l'emploi de ce Service ont été instruites du fait que la vie d'un navigateur peut dépendre de l'exercice de leur propre jugement.

J'ai donc le plaisir de déclarer maintenant officiellement ouverte la Conférence du centennaire du service hydrographique du Canada. J'espère que vous tirerez tous grand profit de vos délibérations au cours des trois prochains jours et que le prochain siècle sera pour vous aussi intéressant que celui qui vient de s'écouler.

NOTES FROM HIS EXCELLENCY,
THE GOVERNOR GENERAL'S, REMARKS
AT THE CENTENNIAL LUNCHEON OF
CANADIAN HYDROGRAPHIC SERVICE, OTTAWA
APRIL 8, 1983

Il me fait particulièrement plaisir de vous transmettre les plus chaleureuses salutations de Sa Majesté, Elizabeth II, Reine du Canada, en ce Centenaire de la Conférence du Service hydrographique du Canada.

In recognition of this significant milestone marking 100 years of service to your country in a most important area of endeavor, I want to express to the members of the Canadian Hydrographic Service the congratulations, appreciation and best wishes from your fellow Canadians all across our land.

Je sais que plusieurs participants à cette conférence sont venus de l'étranger. Au nom du peuple canadien, je souhaite à tous ces distingués visiteurs la plus cordiale bienvenue.

May I say at the outset how very pleased I am to be associated with the Canadian Hydrographic Service both in my role as Governor General, and as one who has more than a passing interest in your work. Baseball fans among you will understand my sense of delight in being here when I tell you that my presence is analagous to a lifelong baseball enthusiast being invited to participate in an intersquad game with the Montreal Expos, or even the Toronto Blue Jays.

I am sure there are times when the staff at Government House, noting the many survey charts and maps lying about the premises in almost continuous display, sometimes wonder just what my job really is.

En observant des cartes géographiques et marines, en visitant des vaisseaux utilisés pour les relevés, je suis heureux de constater que de grands progrès technologiques ont été réalisés. J'envisage avec plaisir de participer aux activités relatives à l'hydrographie de la région arctique du Canada. It must be admitted that the Polar Continental Shelf Project and its reconnaissance bathymetry on the Continental Shelf northwest of Ellesmere and Alex Heiberg Islands only serve to add to my addiction.

Therefore, when I say that I truly welcomed the kind invitation to be with you today, and that I looked forward with increasing anticipation to this conference, the comment may indeed be taken as an understatement.

You have listened to many papers during the past three days on the history of the development of hydrography in Canada including those on the contribution of France and Britain.

As the early explorers arrived by sea the earliest maps were in fact crude charts to permit a safe landfall and to show the safe harbours and channels for trade and commerce. Once this was accomplished the explorers began to move inland along the network of major rivers that facilitated their exploration. Behind the explorers came the fishermen, trappers, fur traders and farmers and not far behind the surveyors. Throughout history mapping has been a prime instrument of sovereignty claims and later to good administration. In the case of disputes over territory those with the best maps and charts had the best legal claim.

It is from the work of these early explorers that we can trace the roots of today's survey industry in Canada. What a proud roll-call it is! Erik the Red who came from Greenland to Lance-aux-Meadows in 1001. The Greenlanders' Saga, which dates from 1200, provided the first sailing direction for North America. It is one of the great "ifs" of history to think of what might have happened if the link between Denmark and the Norse colonists in Greenland had not been broken in the fourteenth century. As it was there was a gap of almost 500 years before John Cabot made his first landfall at the northern tip of Newfoundland, only five years after Columbus, and discovered the wealth of fish on the Grand Banks. In 1557, Martin Frobisher made his first voyage in search for a commercial North West Passage. A search which obsessed the British over the next three centuries. A search dogged by tragedy and epic tales of endurance which slowly showed what an unrealistic goal it was in the days of wooden ships, even if the men were daring and courageous. We have made so much progress in surveying and marine technology since Sir John Franklin but still have some challenges to face.

Samuel de Champlain entreprit son premier voyage sur le golfe et le fleuve Saint-Laurent en 1603 et les premiers colons s'y installèront au cours de la décennie qui suivit. Sept ans plus tard, en 1610, Henry Hudson navigua jusqu'à la baie d'Hudson où il établit le premier système d'échange au coeur du continent entre les commerçants de Montréal et la Compagnie de la Baie d'Hudson.

It was the French however who proceeded in the most logical manner with the appointment of a series of Hydrographes du Roi at Québec. The best of these was Deshayes whose survey in 1685-B produced the charts which served until the fall of Québec in 1759.

The foundations of James Cook's reputation as the grandfather of British Hydrography were laid when he guided the British fleet up the St. Lawrence for the siege of Québec. His reputation was sealed by his three year survey of the west and south coast of Newfoundland which started in 1764. His observation of an eclipse of the sun at Burgeo 1766 led directly to his three great voyages of discovery. On the last of these he refitted his ship at Nootka Sound. The pelts of the fur seals that his crew acquired and his description of the verdant forests led to the first British settlements in British Columbia.

George Vancouver followed Cook in 1791 and in five years surveyed the intricate network of fiords that lace the B.C. coast. These opened up the coast for trade and the extraction of lumber. One could go on with names like Bayfield and Boulton, but I have said enough to show that the primary impetus of hydrography is commerce, the safety of which is still the main motivating force of the Canadian Hydrographic Service.

It was the work of land surveyors which opened up the largely empty interior of Canada. It was the work of the Dominion Land Surveyors starting in 1871 that permitted the orderly settlement of the Prairies at a cost of about four cents an acre, one of the best investments ever made by the federal government.

It was the work of the railway surveyors and advance of the railways that permitted the dramatic flood of immigrants that settled the Prairies in the decades before the first world war. The Prairie economy initially rested on the export of wheat and the hydrographers who surveyed the St. Lawrence Ship Channel played an essential but generally unappreciated role in developing the Prairies.

On the Pacific coast the justification for the Grand Trunk Pacific Railway was its destination of Prince Rupert. This is close to the great circle course from Vancouver to the Orient and it was hoped to divert much of Vancouver's trade. Henri Parizeau began his almost legendary career on the Pacific coast in 1906 in the surveys to chart a safe route into Prince Rupert.

The Prairies farmers have always looked for the cheapest way to move grain. The hydrographers who surveyed Port Nelson in 1913-1914 and Churchill in 1930-33 were essential to the dream of moving grain the shortest distance by rail and the longest distance by the far cheaper marine mode.

Since the war hydrographers have had to switch much of their attention to the Arctic. Construction of the Dew-Line in the mid fifties gave a major impetus. The 1958 Geneva Convention on the Continental Shelf gave rise to perhaps one of the most successful Canadian undertakings, the Polar Continental Shelf Project. In almost any other country scientific expeditions of this magnitude would be headline news. Yet most Canadians do not realise that in the past quarter decade PCSP has wrought a miracle in the Arctic. The hydrographic program has been the mainstay of the project and we now at least have reconnaissance surveys over most of the Arctic.

Hydrographers had to chart the approaches to the Nanisivik mine at Strathcona Sound and the Polaris mine on Little Cornwallis Island to permit some of the richest lead-zinc deposits in the world to be developed.

There is another industry to which the Canadian Hydrographic Service has contributed much. Even though most Canadians live in towns we have retained an almost mystic love of the outdoors. A cottage on a quiet lake and the call of a loon is one of the most evocative images to Canadians. Canada probably has more lakes and navigable rivers than any other country. In many areas of Canada tourism is one of the few industries capable of expansion, and best of all it is labour intensive in areas where jobs are few and far between. Over the past thirty years a significant portion of our hydrographic resources have been used to produce charts of the more important lakes and rivers. For twenty years special strip charts have been published for the recreational boater. Indeed, about 70% of all charts sold go to pleasure boat owners.

Over the past twenty years another industry has posed major new needs. The dramatic increase in the use and increasing draught of supertankers rendered many existing charts and surveys inadequate. Surveys carried out when the maximum draught was 10 metres are obviously suspect for ships drawing 20 metres or more. The ecological catastrophy that followed the grounding of the Liberian tanker Arrow in Chedabucto Bay in 1970 showed clearly that oil spills must be avoided at all costs. As a consequence there are now regulations that require that the approach channels to all oil terminals must be surveyed by a system that provides total bottom coverage. A technological problem with which hydrographers are still struggling.

It is quite obvious that surveys and charts have been and will be a vital tool in the development of Canada. It is the men and women who have met that challenge during the first century of hydrography in Canada that I now salute, and to those that will meet the challenge during the next century that I offer my best wishes and hopes for your present and future work.

TROIS SIÈCLES D'HYDROGRAPHIE FRANÇAISE AU CANADA

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RÉSUMÉ

L'hydrographie française au Canada peut être décomposée en quatre phases:

- une première phase (1500-1605) correspondant à la découverte du Nouveau Monde et à la conquête du Canada par la France. S'appuyant sur l'Ecole de Dieppe, la cartographie est caractérisée par des planisphères à très petite échelle et des relevés d'itinéraire le long des voies fluviales de pénétration;

- une deuxième phase (1605-1665), qui démarre avec la colonisation, correspond à une cartographie d'exploration, basée sur des initiatives non coordonnées;

- une troisième phase (1665-1775), marquée par une prise en charge de l'hydrographie, officielle, par l'Etat et de grands progrès techniques; une cartographie s'appuyant sur des travaux plus sûrs, une compilation coordonnée et une meilleure connaissance des positions géographiques, se met en place;

- une quatrième phase (après 1775) voit la généralisation des techniques modernes au service d'une cartographie franco-anglaise des eaux canadiennes.

ABSTRACT

French hydrography in Canada can be divided into four phases:

- the first phase (1500-1605) is related to the discovery of the New World and the conquest of Canada by France. Influenced by the Dieppe School of Cartography is marked by charts at a very small scale and by route surveys along the main river arteries;

- the second phase (1605-1665) which begins with colonization is characterized by uncoordinated exploration;

- the third phase (1665-1775) is marked by the acceptance of responsibility for hydrography by the state and major technical progress. This resulted in charts compiled from better surveys based upon more accurate positions;

- The fourth phase (after 1775) saw the general adoption of modern techniques for French and British chart making in Canadian waters.

1. LES GRANDES DÉCOUVERTES ET LE CANADA (1500-1605).

Le "pays des merveilles", source des épices et des métaux précieux, qu'avait décrit Marco Polo à la fin du 13è siècle, fut à l'origine d'un véritable mirage nautique parmi les puissances occidentales.

Le mythe de la route maritime de l'Ouest pour gagner la Chine prit naissance après les découvertes de Christophe Colomb. Les Anglais et les Portugais plaçaient le passage au Cathay dans le Nord-Ouest du Labrador; les Espagnols entre la Floride et Terre-Neuve; les Français à hauteur du Canada. La croyance en un passage par l'Ouest dura jusqu'à la fin du 18è siècle: après J. Cartier Champlain, Jolliet, le Père Marquette, Cavelier de la Salle, de la Verendrye, Chateaubriant part encore dans cette intention en 1791.

Les précurseurs de Jacques Cartier.

À qui faut-il attribuer la découverte du Canada? à John Cabot, vénitien au service du roi d'Angleterre, qui reconnut les côtes de l'Amérique septentrionale en 1497, ou à Gaspard Cortéréal, navigateur portugais qui aurait débarqué à Terre-Neuve en 1501? Au premier sans doute à cause de son antériorité et du caractère officiel de sa mission de prise de possession. Mais ni l'un ni l'autre n'a laissé de rapport officiel, de sorte que c'est à Jacques Cartier que revint le mérite de prendre possession de la "Nouvelle-France", ou Canada, au nom de son souverain.

Les expéditions officielles ne représentent d'ailleurs qu'un des aspects de la réalité. Les pêcheurs ont été les premiers découvreurs des "Terres Neuves" comme on les appelait, c'est-à-dire des rivages de l'Amérique septentrionale. La famine quasi généralisée au début du 16è siècle et les 150 jours de jeûne par an imposés aux chrétiens, expliquent aisément le succès des entreprises de pêche de la baleine et de la morue devant les côtes du nouveau monde. Français et Portugais se donnèrent rendez-vous dès 1506 dans toutes les provinces maritimes du Canada pour pêcher la baleine et la morue, l'orientation de la politique française, jusque là inféodée à l'alliance castillane, changea en 1475 et rapprocha la France et le Portugal lors de la guerre contre la Castille et l'Aragon. Les rapports maritimes et comerciaux ne cessèrent de se développer entre la France et le Portugal aux 15è siècles.
Ils entraînèrent l'établissement en Bretagne et surtout en Normandie de pilotes et cosmographes portugais qui favorisèrent certainement la naissance de la fameuse Ecole de Dieppe sur laquelle nous reviendrons plus loin. Il est significatif que le pilote malouin Jacques Cartier ait été aussi interprète pour la langue portugaise.

Dans la première moitié du 16è siècle, près de 150 ports ou havres - normands, bretons, saintongeais, bordelais et basques - armèrent pour la pêche de la baleine et de la morue, et c'est de ce vaste mouvement maritime que sont issues les informations cartographiques qui servirent de base de données aux premiers hydrographes normands.

La pêche, d'abord très dispersée sur tous les rivages de la Nouvelle France, se concentra progressivement dans les régions les plus faciles à exploiter, et notamment à Terre-Neuve. Chaque groupe avait ses lieux de pêche préférés, comme l'atteste facilement la toponymie: les Bretons fréquentaient le Petit Nord, c'est-à-dire la côte Nord-Est de Terre-Neuve, et la côte Sud de l'île (Plaisance); les Basques fréquentaient les côtes Ouest et Sud ainsi que l'Acadie et les Normands le Cap Normand et la baie des Chateaux; les Portugais pêchaient entre les caps Bonavista et Race. Les expéditions pour la pêche de la morue partaient fin mars et revenaient à la mi-septembre, tandis que celles pour la pêche de la baleine appareillaient à la mi-juin et revenaient à la fin de l'année. La pêche dite de la "morue verte" ou "pêche errante" se pratiquait sur les bancs, hors de vue de côte, tandis que la pêche dite de la "morue sèche" se faisait en vue de côte. Dans le second cas, appelé aussi "pêche sédentaire" -parce que le navire restait mouillé près de la côte pendant toute la campagne - le poisson était séché sur les grèves, ce qui entraînait le besoin d'une main d'oeuvre non spécialisée, 5 fois plus importante que pour la pêche de la "morue verte". La vente de la morue sèche était aisée dans les pays méditerranéens et aux Antilles. Certains pêcheurs trouvèrent plus lucratif le commerce avec les indiens, échangeant les couteaux, des haches, des colliers et des casseroles contre des pelleteries. Le métier n'était pas exempt de risques: au danger des brumes, des glaces et du mauvais temps, il fallait ajouter celui des mauvaises rencontres. En septembre 1542, par exemple, 13 navires de guerre espagnols attaquèrent une flottille d'une centaine de bâtiments français qui revenaient de Terre-Neuve.

Humblement et de façon anonyme, les pêcheurs jouèrent indirectement un rôle important dans la naissance de l'hydrographie française au Canada. Les renseignements qu'ils accumulèrent dans le secret de campagnes répétées, diffusèrent progressivement dans les documents officiels; et surtout ils furent à l'origine du besoin hydrographique.

Jacques Cartier (Saint-Malo 1491-1557)

Pilote expérimenté, expert topographe, compagnon de Verrazano en 1524 lors de son expédition qui l'amena à longer les côtes de Nouvelle-Écosse et de Terre-Neuve, Jacques Cartier avait à son actif plus de 15 ans de navigation lorsqu'il fut présenté à François ler et pressenti pour diriger une expédition dans le but de découvrir le fameux passage du Nord-Ouest.

Jacques Cartier appareilla le 20 avril 1534 de Saint-Malo avec deux bâtiments de 60 tonneaux et 60 hommes. Parvenu à Terre-Neuve après une traversée de 20 jours seulement, il pénétra dans le golfe du Saint-Laurent par le Détroit de Belle-Isle, longea les côtes occidentales de Terre-Neuve, puis celles des Iles de la Madeleine et du Prince-Édouard, remonta en baie des Chaleurs, relâcha en baie de Gaspé, découvrit le passage entre la Gaspésie et l'île d'Anticosti, avant d'embouquer à nouveau le détroit de Belle-Isle et de faire route vers Saint-Malo où il arriva le 5 septembre 1534. L'expédition ramenait 2 hurons et la description des merveilles du Royaume du Saguenay.

Le 19 mai 1535, J. Cartier appareilla pour un second voyage avec la "Grande Hermine", la "Petite Hermine", l'"Émérillon" et 110 hommes. Pénétrant à nouveau dans le Golfe du Saint-Laurent par le détroit de Belle-Isle, il découvrit l'île de l'Assomption (Anticosti), puis gagna Hochelaga en octobre à bord de l'"Émérillon". L'expédition hiverna à Stadaconé (Québec), bloquée dans les glaces et en proie au scorbut. Elle prit le chemin du retour le 16 mai 1536 en longeant la côte méridionale de Terre-Neuve et arriva à Saint-Malo le 6 juillet. Vingt-cinq marins étaient morts mais J. Cartier avait fait la preuve de l'insularité de Terre-Neuve et découvert que le Saint-Laurent était un fleuve.

Jacques Cartier reprit la mer le 23 mai 1541 pour une troisième expédition commissionnée par François ler. La cargaison de pierres et de métaux précieux qu'il rapporta, se révéla sans valeur et le pouvoir royal se désintéressa de lui. Il mourut, ignoré de ses contemporains le ler septembre 1557, à l'âge de 66 ans.

Les débuts de l'hydrographie française : l'École de Dieppe et le Canada.

Dieppe fut dès la fin du 15è siècle le berceau d'une École d'hydrographie d'une grande renommée. Les pilotes dieppois, avec des titres de "cosmographe et pilote entretenu pour le Roy en la Maryne" ou d'"ingénieur et géographe du Roi", et pourvus de commissions royales les autorisant à délivrer aux navigateurs un brevet de capacité, furent aux 16è et 17è siècles les promoteurs de l'hydrographie française. Héritiers de la tradition lusitanienne, ils étaient à la fois explorateurs, professeurs et auteurs de traités d'hydrographie et de navigation, ainsi que cartographes.

Ils nous ont laissé de merveilleux planisphères sur lesquels il est possible de suivre l'évolution de la cartographie du Canada et spécialement de Terre-Neuve.

Terre-Neuve était cartographiée à l'origine comme une péninsule rattachée au Labrador. Les cartographes dieppois en firent, après la découverte du détroit de Belle-Isle par Jacques Cartier, en 1534, un archipel où de profondes baies se prolongeaient jusqu'à la côte Ouest. C'est le cas de Nicolas Desliens, dans sa mappemonde de 1541 et de Desceliers, dont la mappemonde de 1546, donne un morcellement excessif à Terre-Neuve.

Après une représentation sous forme d'une péninsule, puis d'un archipel, un réel progrès fut accompli en donnant à Terre-Neuve une forme compacte et triangulaire. C'est le cas des cartes de Nicolas Desliens, en 1566, de Pierre de Vaulx, en 1613, et Jean Guérard, en 1625,

2. LE 17è SIÈCLE : L'EXPLORATION DÉTAILLÉE DU CANADA PERMET LA CRÉATION D'UNE CARTOGRAPHIE DE PRESTIGE FRANCO-CANADIENNE.

Les entreprises antérieures au 17è siècle avaient été seulement des entreprises de découverte. La colonisation du Canada ne commença qu'avec Samuel Champlain, au début du 17è siècle. Il orienta d'abord ses efforts vers l'Acadie, la la Nouvelle-Écosse d'aujourd'hui, où il fonda Port-Royal (Annapolis) en 1605. Puis il fonda Québec en 1608, simple poste de traite à l'époque, et favorisa l'établissement de colons sur les rives du Saint-Laurent, là même où la race française devait s'implanter avec le plus de force. Après la mort de Champlain, en 1635, la création de Montréal en 1642, l'établissement de missions religieuses et de postes de traite sur la voie des Grands Lacs qu'empruntèrent en 1673 Jolliet et le Père Marquette en atteignant le Mississipi, jalonnèrent d'autres étapes de la pénétration française. Mais les résultats restèrent médiocres jusqu'à l'avènement de Colbert, le grand ministre de Louis XIV, en 1661, et l'annexion de la Nouvelle-France au domaine royal (1663). On sait l'attention particulière qu'il porta à la marine et aux colonies et son intérêt pour l'implantation d'établissements permanents au Canada.

Malheureusement, si l'ambition d'intallations permanentes en Nouvelle-France constitua un objectif du pouvoir de l'époque, sa contre partie naturelle en fut l'ambition rivale de l'Angleterre. Entre les deux communautés aux traditions culturelles et religieuses et aux intérêts aussi divergents, des conflits étaient inévitables. Les chutes provisoires de Québec, en 1629, de l'Acadie en 1659, marquèrent les temps forts de cette situation avant les luttes acharnées que se livrèrent les colonies française et anglaise de Terre-Neuve, basées respectivement à Plaisance et St.John's, pendant les guerres de la Ligue d'Augsbourg (1688-1697) et de la succession d'Espagne (1702-1713).

Dans le domaine maritime, et pendant la deuxième moitié du 17è siècle, il faut insister sur la remarquable puissance maritime française entre 1680 et 1688 et sur l'encouragement du pouvoir royal à la pêche sédentaire, favorisée elle-même par l'implantation de colonies permanentes. La pêche sédentaire, en faisant appel à une main d'oeuvre importante favorisait le recrutement dans la Marine Royale. Disséminée initialement sur tous les rivages de la Nouvelle-France, elle se concentra progressivement dans les zones les plus favorables: la rive Sud du Saint-Laurent, les côtes de Gaspésie, celles d'Acadie, les trois quarts des côtes de Terre-Neuve (les Anglais étant resserrés entre les caps Race et Bonavista). Les côtes du Labrador et celles de l'Île du Cap-Breton furent progressivement désertées.

Tel est le cadre dans lequel se développa l'hydrographie du Canada. L'École de Dieppe avait donné à la Marine ses meilleurs pilotes et Colbert eut soin d'associer l'hydrographie à l'immense effort qu'il déploya pour réorganiser la Marine. En 1661, il prit au compte de son Département l'École d'hydrographie de Dieppe et la création d'établissements analogues dans d'autres ports. Puis il créa l'Académie des Sciences en 1666, et l'Observatoire de Paris en 1667. En réalité, les moyens mis en place et les découvertes qu'ils entraînèrent concernant les mesures d'angle et de temps, ainsi que la localisation astronomique et géodésique, ne portèrent pleinement leurs fruits qu'au siècle suivant. Cependant, dès 1668, lorsque furent publiées les éphémérides de Cassini, il fut possible, à partir d'un observatoire terrestre, de déterminer la longitude avec la précision de la minute sexagésimale par observation des occultations des satellites de Jupiter et la publication des éphémérides de Newton, en 1713, permit la détermination des longitudes à la mer, par observations des distances lunaires, avec, il est vrai, une précision médiocre de l'ordre du degré.

La cartographie marine du Canada - et terrestre d'ailleurs aussi - du 17è siècle fut essentiellement une cartographie d'exploration ou de reconnaissance, basée sur la compilation. Colbert s'explique clairement sur le sujet dans une correspondance adressée le 18 août 1670 à l'Intendant de Marine Colbert du Terron: "il faut prendre garde de tirer de toutes nos navigations et des journaux qui sont tenus, des connaissances exactes et fidèles pour tous ceux qui auront à faire les mêmes voyages, et même, il faudra s'en servir pour composer des cartes marines". De très grossières erreurs de longitude subsistent, mais n'ont qu'une importance relative dans une représentation des côtes et des fonds qui s'affine lentement avec les seuls moyens des compas et du loch.

L'immense territoire découvert offrait un champ illimité aux hydrographes; ils jouèrent un rôle de premier plan dans une pénétration qui se fit le plus souvent par la voie d'eau. Un fait caractéristique retient notre attention: c'est la création à Québec même, dans le dernier quart du siècle, d'une école franco-canadienne d'hydrographie et de cartographie, illustrée par J.B. Franquelin. La cartographie de prestige qui se développa à cette époque, montre le prix qu'attachait le pouvoir royal à cette forme symbolique de souveraineté.

3. LE 18è SIÈCLE: DÉCLIN DES POSITIONS FRANÇAISES AU CANADA ET PROGRÈS DE L'HYDROGRAPHIE.

Le traité d'Utrecht (1713), qui mit fin à la Guerre de Succession d'Espagne, sanctionna les premières pertes territoriales subies par la France en Amérique du Nord. La France reconnaissait la suprématie anglaise sur la baie d'Hudson, Terre-Neuve, la Nouvelle-Écosse; elle conservait ses territoires le long du Saint-Laurent, dans les régions des Grands Lacs et du Mississipi, les îles Saint-Jean (Prince-Édouard) et Royales (Cap-Breton), ainsi que des droits de pêche le long des côtes de Terre-Neuve, entre le cap Bonavista et la pointe Riche en passant par le Nord, frange littorale dénommée "French shore".

En compensation de la perte de la capitale acadienne, Port Royal, base de la guerre de course contre la marine de la Nouvelle-Angleterre, elle s'empressa d'organiser les fortifications de Louisbourg (île Royale), tandis qu'elle faisait traîner en longueur la cession de l'Acadie. Les possessions françaises étaient désormais prises dans l'étau britannique de Terre-Neuve et de l'Acadie.

Dans la phase suivante des hostilités franco-anglaises (1744-1748), la France perdit Louisbourg dont elle obtint la restitution au traité d'Aix-la-Chapelle (1748). Les hostilités reprirent aussitôt après la signature du traité et apportèrent quelques succès à la France dans le secteur de l'Ohio et sur le lac Champlain, mais lorsque la guerre de Sept ans éclata en 1756, ils furent rapidement annulés par les victoires anglaises sur Louisbourg, qui tomba en 1758, et à Québec, en 1759, dans les sanglants combats des Plaines d'Abraham où Wolfe et Montcalm trouvèrent la mort.

Le traité de paris, signé par la Grande-Bretagne, la France, l'Espagne et le Portugal, le 10 février 1763, mit fin à la guerre de Sept Ans qui sévissait en Europe et dans les colonies et marqua la reddition des colonies française en Amérique du Nord. La France sacrifiait à l'Angleterre les territoires qui lui étaient restés après le traité d'Utrecht: le Canada et ce qui est aujourd'hui le Nouveau-Brunswick et toutes les îles adjacentes y compris l'île Royale (Cap-Breton) et l'île Saint-Jean (Prince-Edouard). A Terre-Neuve, elle conservait ses droits de pêche et recevait les îles Saint-Pierre et Miquelon.

Enfin, la guerre de l'Indépendance américaine (1775-1782) s'acheva en 1783 par les traités de Versailles(entre la France et l'Angleterre) et de Paris(entre l'Angleterre et les Etats-Unis). Le traité de Versailles accordait à la France une souveraineté complète sur Saint-Pierre et Miquelon, et réajustait les droits de pêche français sur les côtes Est et Nord de Terre-Neuve, droits qui s'étendraient désormais du cap Saint-Jean au cap Ray (au lieu du cap Bonavista à la pointe Riche) et couvraient un périmètre sur lequel il était interdit aux britanniques de se fixer.

Sur le plan maritime, les traités d'Utrecht en 1713 et de Paris en 1763 entraînèrent directement et immédiatement des crises de la pêche sédentaire et indirectement un affaiblissement de notre Marine par réduction des armements à la pêche. Il fallut, après 1713, abandonner Plaisance et la côte Sud de Terre-Neuve, et l'Acadie. La France put cependant sauver son armement à la pêche sédentaire en mettant en exploitation l'île du Cap-Breton, la côte Sud du Labrador et en maintenant ses installations en baie de Gaspé, à l'île Percée et à l'île Bonaventure.

La situation s'aggrava sérieusement après le traité de Paris, en 1763, puis qu'il ne restait à la France que la jouissance du "French shore" et l'usage non militaire des îles Saint-Pierre et Miquelon. Le gouvernement fit porter son effort sur l'aménagement de ces dernières. En 1774, la France proposa à l'Angleterre l'échange du secteur Bonavista-cap Saint-Jean * contre celui de pointe Riche-cap Ray; l'arrangement ne fut accepté qu'au traité de Versailles en 1783.

Le 18è siècle fut la période la plus riche en ce qui concerne les progrès de l'hydrographie et de la navigation. Colbert avait eu le grand mérite de reconnaître que l'importance des techniques et des moyens nécessaires à l'hydrographie justifiait une intervention directe de l'Etat.

*Des Irlandais avaient fait souche pendant la guerre de Sept Ans dans ce secteur dont les rivages poissonneux étaient fort inhospitaliers.

Les décisions qu'il prit portèrent leurs fruits tout au long du 18è siècle, amplifiés par un effort analogue poursuivi en Grande-Bretagne. Le grand problème resta celui de la détermination des longitudes: la mesure des distances lunaires fut rendue plus aisée après la mise au point de l'octant par Hadley, en 1731, mais il fallut attendre 1770 pour triompher définitivement des dernières difficultés, par la mesure directe des angles horaires au moyen du chronomètre.

Vers la même époque (exactement en 1775) Borda modifia l'octant et le transforma en cercle à réflexion d'un usage encore plus commode et précis. Ces progrès permirent de remplacer le compas par le cercle hydrographique dans le mesure des angles horizontaux et d'obtenir ainsi une excellente précision pour le positionnement. Mackenzie junior (1774) et Beautemps-Beaupré - en 1791-1792 lors de l'expédition dirigée par l'Amiral d'Entrecasteaux à la recherche de La Pérouse - furent les promoteurs de cette innovation capitale dans la technique des levés hydrographiques.

C'est dans ce contexte technique que se développe l'hydrographie. L'amélioration progressive des déterminations astronomiques permit de relier les résultats partiels en ensembles cohérents, surtout dans la deuxième moitié du 18è siècle. Du côté français, un jeune enseigne de vaisseau, le marquis de Chabert (né en 1724, et qui fut Directeur du Dépot des cartes, et mourut en 1805) attira l'attention du Ministre de Maurepas sur les dangers de la navigation dans les parages de l'île du Cap-Breton et de Terre-Neuve, et fut chargé en 1750 et 1751 de diriger une campagne d'observations astronomiques et géodésiques. Ses travaux lui valurent les louanges de l'Académie de Berlin, Stockholm, de Bologne, de la Société royale de Londres et de l'Académie de Marine de France. Mais en dehors des campagnes scientifiques, le Ministre de la Marine, comme l'écrit l'hydrographe Bellin (1761), continuait de remettre à chaque vaisseau du Roi une carte manuscrite en demandant qu'on la lui rende renseignée; il fit armer, par ailleurs, spécialement des bâtiments à Québec avec des offficiers et des pilotes qu'il chargea de visiter les côtes et les rivières *.

Si le jeune Chabert avait donné le coup d'envoi à l'hydrographie scientifique en Amérique septentrionale, c'est au célèbre capitaine James Cook que l'on doit d'avoir repris le flambeau; ses remarquables aptitudes pour l'hydrographie se révélèrent sous le feu de l'armée française, lors du siège de Québec (1759) et c'est lui, le premier, qui donna une vue d'ensemble correcte - bien qu'elle fut essentiellement basée sur l'estime - des côtes de Terre-Neuve (1765-1767). C'est encore lui qui, lors de son troisième voyage en 1778 effectua la première reconnaissance sérieuse de la côte Ouest de l'Amérique du Nord. Quelques années plus tard, en 1786, La Pérouse reçut la mission selon les termes du Ministre de "reconnaître les parties qui n'ont pas été vues par Cook, et sur lesquelles les navigateurs russes et espagnols ne fournissent aucune notion. Il cherchera avec le plus grand soin si, dans les parties qui ne sont

* 27 campagnes entre 1722 et 1737 partagées entre 14 bâtiments.

pas encore connues, il ne se trouverait pas quelque rivière, quelque golfe resserré, qui pût ouvrir, par les lacs de l'intérieur, une communication avec quelque partie de la baie d'Hudson". La Pérouse, malgré la rapidité de sa reconnaissance, fut le premier à soupçonner l'existence du chapelet d'îles qui borde la côte nord-américaine. Vancouver, en prenant le temps nécessaire, au cours de ses campagnes d'été de 1792, 1793, 1794, en fit une hydrographie beaucoup plus détaillée.

4. LE 19è SIÈCLE: LES PROGRÈS TECHNIQUES PERMETTENT LA RÉALISATION D'UNE HYDROGRAPHIE MODERNE FRANCO-ANGLAISE DES EAUX CANADIENNES.

Les évènements politiques du 19è siècle touchèrent de moins en moins la France dans les parages du Canada; il ne lui restait plus en effet que Saint-Pierre et Miquelon et des droits de pêche à Terre-Neuve. Sur le plan maritime, trois faits importants retiennent l'attention:

- le premier est le remplacement progressif, à partir de 1820, de la propulsion à voile par la propulsion à vapeur, illustré par le premier service régulier transatlantique, assuré par la "Cunard", d'Halifax, à partir de 1840. Il est à noter que ce changement fit passer la formation maritime au second plan sous le Second Empire;

- le second est le déclin progressif, à partir de 1850, de la pêche sédentaire basée à Terre-Neuve, après le regain qu'elle avait connu dès la fin des guerres de l'Empire. Le Parlement dont fut doté Terre-Neuve en 1833, et l'accroissement de la population, rendirent de plus en plus difficile le maintien d'une communauté française sur le "French shore". L'Entente Cordiale, conclue en 1904 entre la France et l'Angleterre mit fin aux droits exclusifs de pêche français à Terre-Neuve. Mais corrélativement Saint-Pierre et Miquelon était devenu un centre important et les morutiers fréquentant les Bancs venaient y décharger leur poisson;

- le troisième est l'établissement d'une certaine réglementation dans la circulation maritime concernant les approches de l'Amérique septentrionale. Le célèbre Maury, inventeur des Pilot charts, est à l'origine des voies recommandées sillonnant les atterrages du Canada. Il se rendit compte le premier, vers 1855, des dangers que faisait courir le trafic transatlantique aux terreneuvas en pêche et à leurs doris. Quatre grandes routes furent retenues officiellement en 1898, correspondant respectivement à deux périodes de l'année (printemps-été et automne-hiver), et aux deux directions de transit (Europe-Amérique et Amérique-Europe). Cependant, du 15 août au mois d'octobre, le système en vigueur exposait les pêcheurs du Grand Banc, dans la nuit et dans la brume, aux collisions avec les vapeurs. Pour cette raison, la Compagnie Générale Transatlantique française, malgré les dépenses et les retards importants qui en résultaient pour ses paquebots, renonça vers 1900 à passer sur le Grand Banc pendant la saison de pêche; elle empruntait des routes passant plus au Sud.

Le 19è siècle n'apporta pas beaucoup de changements dans les techniques de levé une fois que furent reconnues et adoptées les méthodes nouvelles imaginées par les Anglais et les Français. La détermination des longitudes n'avait plus de secret. Les triangulations et les cheminements topographiques servirent d'ossature au positionnement en mer effectué au moyen du sextant ou du cercle hydrographique; la mesure des profondeurs continua de se faire à l'aide du plomb de sonde. Par contre, le développement du trafic et la relève progressive de la voile par la vapeur créèrent de nouveaux besoins. Pour des navires plus nombreux, manoeuvrant mieux et marchant plus vite, il fallut entreprendre des levés systématiques, avec recherche des hauts-fonds, délimitation des chenaux, et tenir à jour les documents nautiques par des Avis aux navigateurs (à partir de 1850 environ).

Les pertes territoriales qu'avait subies la France n'affectèrent pas son activité hydrographique qui resta très soutenue le long des côtes de Terre-Neuve, à Saint-Pierre et Miquelon et sur les bancs. Les travaux que menèrent parallèlement les Anglais et les Français aboutirent progressivement à une cartographie d'ensemble et de détail de Terre-Neuve et des Bancs. Les Anglais avaient ouvert la voie à la fin du siècle précédent avec Cook et Lane et furent aussi à l'origine des premières Instructions nautiques modernes. Le caractère mixte, franco-anglais, des travaux sur le terrain et des documents - cartes et ouvrages - sur Terre-Neuve, qui impliquait un bon échange d'informations, est le fait marquant de cette période, sur le plan hydrographique. Il résultait, en partie, du partage des eaux de Terre-Neuve entre les Français et les Anglais, et en partie de l'ampleur de la tâche que réprésentaient les levés. Aujourd'hui encore, certaines cartes canadiennes s'appuient sur des travaux français du siècle dernier.

5. CONCLUSION.

La rétrospective de l'hydrographie française au Canada nous amène, en conclusion, à insister sur les points suivants:

La découverte anonyme de Terre-Neuve est contemporaine de celle du Nouveau Monde par Christophe Colomb en 1492. En 1520, Magellan montra que la Chine était séparée des Amériques par le "Grand Océan", et c'est en recherchant un passage vers le Nord-Ouest vers le fabuleux Cathay qu'en 1535, Jacques Cartier découvrit le Canada et en prit officiellement possession. Le Canada apparait ainsi à la fois comme le premier pays de l'Amérique du Nord découvert par les Français et comme la zone de passage présumée la plus favorable vers l'Extrême-Orient.

Avec une présence de plus de trois siècles dans les eaux canadiennes, l'effort soutenu par les hydrographes français bat le record absolu des travaux effectués en dehors de leurs côtes métropolitaines. En réalité, la page canadienne de l'hydrographie française illustre le rôle qu'a joué la France dans le passé comme promoteur d'une civilisation proprement maritime. Ce rôle fut évident pour l'installation de la France au Canada, mais il fut encore plus remarquable lorsque la présence française fut réduite dans les eaux canadiennes à un peuple de marins de l'État ou pêcheurs, sans support territorial, ou presque.

L'hydrographie française au Canada, en raison de son étalement sur une très longue période, offre un exemple relativement standard du développement de cette technique à travers le temps:

- la première phase (1500-1605) est une phase de découverte et de conquête. S'appuyant sur la découverte du nouveau monde et sur l'École de Dieppe, l'hydrographie développe, d'une part, une cartographie à très petite échelle (planisphères)et, d'autre part, une cartographie d'itinéraires, axée sur les grandes voies fluviales de pénétration;

- la deuxième phase (1605-1665), démarre avec la colonisation et s'affirme dans le développement d'initiatives individuelles. La cartographie de découverte et d'itinéraires se transforme en cartographie d'exploration. Il reste de nombreux blancs sur les cartes, souvent meublés par des scènes de la vie locale, mais l'information, auparavant de caractère linéaire, tend à devenir surfacique;

- la troisième phase (1665-1775) est décisive pour l'hydrographie: elle est caractérisée, d'une part, par la reconnaissance du fait que les levés en mer requièrent l'intervention de l'État par l'importance des moyens qu'ils mettent en oeuvre et la plus-value économique qu'ils entraînent; d'autre part, par les progrès techniques réalisés dans la mesure des angles et du temps, qui viennent définitivement à bout du problème du positionnement relatif et absolu. Pendant cette phase, on assiste au Canada à l'apogée de la cartographie de prestige, mais aussi à une amélioration substantielle des levés hydrographiques qui se multiplient et font l'objet d'une compilation coordonnée dans l'établissement des cartes marines. Le canevas des positions géographiques progresse et permet de mieux raccorder les sous-ensembles;

- La quatrième phase (après 1775) correspond à une maîtrise de plus en plus complète des moyens techniques requis pour l'élaboration des cartes marines modernes.

THE BRITISH CONTRIBUTION TO THE HYDROGRAPHY OF CANADA

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ABSTRACT

Almost inevitably, the starting point for an account of "The British Contribution to the Hydrographic Surveying of Canada" must start with Captain Cook. B.C. - or before Cook - most other British visitors to Canadian waters had produced "maps" rather than "charts". It is harder to decide on a finishing point: although the Canadian Parliament attained authority in 1867 over certain navigational matters and the Canadian Hydrographic Office was formed in 1883, it was not until 1908 that the first Canadian ship LILLOOET was available to take over the surveying task and HM Ships continued to survey off British Columbia until 1910, off Newfoundland till 1912 - indeed HMS CHALLENGER was surveying off Labrador from 1932 to 1934.

The paper considers the subject in the four sections of Canada's roughly rectangular boundaries.

On the west coast, Cook's work in 1778 was confined to Nootka Sound and its vicinity: two from this expedition - Dixon and Portlock - returned as fur traders but added to the scanty knowledge of the western channels as did other fur traders such as Barkley and Lieutenant Meares RN, whose acquisition of land at Nootka almost led to another Anglo-Spanish war and did lead to George Vancouver's return, in 1792, to put into effect the "Nootka Convention", signed in Madrid in October 1790: fortunately the non-political comradeship of hydrographic surveyors had already started and, although he agreed to differ on the territorial claims of the Spaniards whom he found surveying off British Columbia, Vancouver amicably exchanged copies of his surveys with them and his many fair sheets meticulously attribute the work done by the Spaniards. Some 60 years later, Captain G. Richards, in HMS PLUMPER and then HMS HECATE surveyed the west coast from 1856 till, in 1862 he returned home to become Hydrographer of the Navy - leaving Pender to continue his surveys in a hired vessel till 1871 when British Columbia joined the Dominion. The final British surveys of this coast were from 1898 in HMS EGERIA till she paid off in 1910.

The work on the northern coast perhaps does not fulfill the criteria of "surveying" being rather "exploration": in view of the small vessels employed in such appalling weather conditions, it is however remarkable how much detailed work was performed. Inspired by William Scoresby's reports of good whaling conditions in the Greenland Sea, the Navy Board mounted a succession of expeditions between 1818 and 1827 to find a North West Passage. Parry, Beechey, Franklin, John and James Ross and their valiant crews all struggled to fight their way through the ice and back with varying degrees of success or failure. Beechey, in HMS BLOSSOM, in 1826/27 discovered the coast from Icy Point to Point Barrow - leaving only about 140 miles of unexplored coast between this Point and Point Beechey.

From 1759 Cook, Colonel des Barres and Major Holland were engaged in surveying the coasts of Newfoundland, Nova Scotia and the Gulf of St. Lawrence: prior to this, Captain Taverner had produced in 1714 his "Trades and Plantations Map of North America" and Thomas Durell, in 1716 and 1732/35 had also explored extensively in this area. For the next 150 years, successive British surveyors worked off the east coasts of Canada, Newfoundland and Labrador - notably Joseph Gilbert (1767 - 1770), Michael Lane (1768 - 1785), Francis Owen (1800 - 01), Anthony Lockwood (1813 - 1818), Lieutenant Bullock (1823 - 26), Captain Bayfield (1827 - 1856), Commander John Orlebar (1857 - 64), James Kerr (1865 - 71), William Maxwell (1872 - 90), William Tooker (1891 - 1907) and Captain Combe (1908 - 13). A.G.N. Wyatt, in HMS CHALLENGER (1932 - 34) was the last British contributor to Canadian surveys.

The final section - the Great Lakes - was first tackled by Captain W. Fitzwilliam Owen in 1815 who handed over to Henry Bayfield (1817-1825): following his extraordinarily hard and accurate work, the British disappeared until Commander John Boulton was loaned to the new C.H.S. to take charge of the "Georgian Bay Survey" on 11 July 1883: in 1893, Boulton was succeeded by Mr. W.J. Stewart, but he - as the Chief Hydrographer of Canada from 1904 to 1925 - can hardly be counted as part of this account.

Thus, although - thanks to the ready acceptance of hydrographic responsibility by the Canadian Government much earlier than other members of the British Commonwealth - the Royal Naval surveyors' contribution tailed off towards the end of the 19th century, it will be seen that they had provided a comprehensive basic survey of all but the forbidding northern coasts for the Canadian Hydrographic Service one hundred years ago. Indeed, many of their surveys in Canadian waters - as in many other parts of the world - remained the best available even till modern times.

LA CONTRIBUTION BRITANNIQUE A L'HYDROGRAPHIE DU CANADA

Par le Contre-amiral D.W. Haslam (R.-U.)

RÉSUMÉ

Il est presque inévitable qu'un compte rendu de la contribution britannique aux levés hydrographiques du Canada commence par le capitaine Cook. Avant J.C. (James Cook), la plupart des visiteurs britanniques des eaux canadiennes avaient réalisé des cartes "géographiques" plutôt que "marines". Par contre, il est plus difficile de choisir une date pour la fin de cette contribution: en effet, le Parlement canadien s'est vu attribuer en 1867 la compétence sur certaines questions de navigation et le Service hydrographique du Canada a été créé en 1883, mais c'est seulement en 1908 qu'un premier navire canadien, le LILLOOET, a été chargé d'effectuer des levés, et les navires britanniques ont continué de réaliser des levés, jusqu'en 1910 au large de la Colombie-Britannique et jusqu'en 1912 au large de Terre-Neuve. Enfin le CHALLENGER, navire britannique, a effectué des levés au large du Labrador de 1932 à 1934.

Le présent document examine les activités hydrographiques menées dans les quatre parties du rectangle que forment approximativement les frontières du Canada.

Sur la côte Ouest, les travaux que Cook a menés en 1778 ont porté seulement sur la baie Nootka et ses environs. Deux membres de l'expédition, Dixon et Portlock, sont revenus plus tard sur les lieux comme pelletiers, mais ils contribuèrent à accroître les rares connaissances sur les chenaux occidentaux, tout comme le firent d'autres pelletiers comme Barkley et le lieutenant Meares RN. En achetant des terres à Nootka, ces derniers furent bien près de provoquer une nouvelle guerre anglo-espagnole, ce qui amena George Vancouver à revenir en 1792 pour appliquer la Convention de Nootka signée à Madrid en octobre 1790. Heureusement, un esprit de camaraderie avait déjà commencé à se développer chez les hydrographes malgré les luttes politiques, et, bien qu'il contestât les revendications territorales des Espagnols qui effectuaient des levés au large de la Colombie-Britannique, Vancouver échangea avec eux des copies de ses levés, et dans ses nombreuses minutes de rédaction, il indique avec un soin méticuleux les travaux réalisés par les Espagnols. Quelque 60 ans plus tard, le Capitaine G. Richards, à partir du PLUMBER puis du HECATE, effectuait un levé de la côte Ouest de 1856 à 1862, date où il est retourné en Grande-Bretagne pour devenir hydrographe de la marine, laissant Pender poursuivre ses travaux dans un bateau affrété jusqu'en 1871, année où la Colombie-Britannique est devenue membre du Dominion. Les derniers levés britanniques de cette côte furent effectués à partir de l'EGERIA de 1898 à son départ en 1910.

Les activités menées sur les côtes du Nord canadien relevaient plutôt de l'exploration que du levé. Toutefois, le travail minutieux accompli par les hydrographes est remarquable si l'on sait qu'ils opéraient à partir de petits bateaux dans un climat aussi rigoureux. L'intérêt suscité par les rapports de William Scoresby au sujet des excellentes conditions de pêche de la baleine qu'offrait la mer du Groenland a incité l'Amirauté à organiser une série d'expéditions entre 1818 et 1827 pour trouver un passage au Nord-Ouest. Parry, Beechey, Franklin, John et James Ross et leurs vaillants équipages s'efforcèrent avec plus ou moins de succès de se frayer un chemin à travers les glaces. Beechey, à bord du BLOSSOM, découvrit en 1827-1827 la côte de la pointe Icy à la pointe Barrow, laissant seulement 140 milles environ de côte inexplorée entre cette pointe et la pointe Beechey.

A partir de 1759, Cook, le colonel Des Barres et le major Holland effectuèrent des levés sur les côtes de Terre-Neuve, de la Nouvelle-Ecosse et dans le golfe Saint-Laurent. Auparavant, le capitaine Taverner avait produit en 1714 sa "Trades and plantations map of North America" (carte des commerces et plantations de l'Amérique du Nord) et Thomas Durell, en 1716 et de 1732 à 1735, avait aussi exploré cette région de façon très poussée. Pendant les 150 ans qui suivirent, les hydrographes britanniques qui se sont succédés dans la région ont travaillé au large de la côte Est du Canada, plus précisément de Terre--Neuve et du Labrador; on peut citer notamment les travaux de Joseph Gilbert (1767 - 1770), de Michael Lane (1768 - 1785), de Francis Owen (1800 - 1801), d'Anthony Lockwood (1813 - 1818), du lieutenant Bullock (1823 - 1826), du capitaine Bayfield (1827 - 1856), du commandant John Orlebar (1857 - 1864), de James Kerr (1865 - 1871), de William Maxwell (1872 - 1890), de William Tooker (1891 - 1907) et du capitaine Combe (1908 - 1913). A.G.N. Wyatt, à bord du CHALLENGER (1932 - 1934) fut le dernier Britannique à effectuer des levés dans les eaux canadiennes.

Dans la dernière partie, les Grands Lacs, des levés ont été entrepris pour la première fois en 1815 par le capitaine W. Fitzwilliam Owen qui confia la suite des opérations à Henry Bayfield (1817-1825). Après ces travaux si précis et si poussés, les Britanniques disparurent de la région jusqu'à ce que commandant John Boulton soit dé-

pêché auprès du tout nouveau SHC pour se charger du levé de la baie Géorgienne le 11 juillet 1883. En 1893, Boulton était remplacé par M. W.J. Stewart au poste d'Hydrographe fédéral, qu'il occupait de 1904 à 1925, mais on peut difficilement l'inclure dans ce compte rendu.

Il est à noter que le gouvernement canadien a accepté la responsabilité des activités hydrographiques beaucoup plus tôt que les autres membres du Commonwealth britannique de sorte que la contribution des hydrographes de la Marine royale a commencé à décroître vers la fin du 19e siècle. Toutefois, nous pouvons voir qu'ils avaient fourni il y a cent ans au Service hydrographique du Canada un levé de base détaillé de toutes les côtes canadiennes à l'exception des côtes reculées du Nord. En fait, un grand nombre des levés britannique des eaux canadiennes, comme ceux de nombreuses autres parties du monde, sont restés les meilleurs jusqu'à l'ère moderne.

INTRODUCTION

Although Captain Greenville Collins was appointed Hydrographer to King Charles II in 1683, his work was confined to British waters and the appointment lapsed until the appointment of Mr. Alexander Dalrymple as Hydrographer to the Admiralty Board on 12 August 1795. Some 35 years earlier, however, the Seven Years War (1756 - 1762) between Britain and France in North America, highlighted the need for both a British American Regiment and suitable nautical charts.

A chance meeting between the mathematical, Swiss-born, British American Regiment Engineer, Des Barres and the Yorkshire seaman, James Cook in 1758 led to the growth of a nucleus of British hydrographers whose great efforts subsequently grew to the present day British Hydrographic Service. Inevitably, having been spawned in the waters off the East coast of Canada and Newfoundland and with the obvious commercial potential of North America in general - and Canada in particular - a fair proportion of the embryo British hydrographic effort was therefore devoted to Canada.

Although, theoretically perhaps, this account should relate to events AD (After Dalrymple's appointment in 1795), some mention must be made of earlier events - even those BC (Before Cook) - despite the fact that, until Cook's influence on hydrography and British chart making, most British visitors to North America were explorers, traders and whalers who lacked the knowledge and instruments to produce anything much better than rudimentary maps. Edmund Halley, for instance, visited Newfoundland in HMS PARAMOUR in 1699 and produced a chart showing magnetic variations of the North Atlantic in 1701.

If it is difficult to establish a starting point, it is equally difficult to do justice to the subject in a short article and to decide on a finishing point. Although the Canadian Parliament attained authority in 1867 over certain navigational matters and the Canadian Hydrographic Office was formed in 1883, it was not until 1908 that the first Canadian hydrographic ship LILLOOET was available to take over the surveying task from the Royal Navy and HM Surveying Ships continued to survey off British Columbia until 1910 and off Newfoundland until 1912 - indeed, HMS CHALLENGER was surveying off Labrador from 1932 to 1934.

This inadequate account of the subject will consider the British contribution in the four natural sections of Canada's coastline - British Columbia, the Atlantic seaboard, the Great Lakes and the Northern coasts.

BRITISH COLUMBIA

Although the name "British Columbia" was not used before 1858, it is convenient to use this when referring to activities off Canada's Pacific Coast. Sir Francis Drake, in his GOLDEN HIND, abandoned his search for a passage north-about the Americas when south of the Cape Flattery in 1579; 13 years later, in 1592, the Greek navigator Apostolos Valerianos, better known as Juan de Fuca, was sent northwards by the Spanish Viceroy of New Spain or Mexico, and for many years was regarded as the first European to sail through the straits which now bear his name. No European seems to have visited this area until 1774 when the Viceroy of Mexico sent the Spanish Naval Officer Juan Perez to explore the N.W. Coasts of America primarily to try to stop the Russians from extending their claims southwards from present-day Alaska which they had already reached.

On his voyage north, Perez sighted (but did not name) the Queen Charlotte Islands, whilst, on his return south, he sighted Vancouver Island and anchored off Nootka sound but only carried out very sketchy surveys from his corvette SANTIAGO. Following the United States' Declaration of Independence in 1776, Spanish, British and American sailors went to British Columbia in rapid succession. The most notable, perhaps, of these was Captain James Cook who visited the coast during his third, and last, voyage to the

Pacific in command of HMS RESOLUTION, with Commander Charles Clerke in command of HMS DISCOVERY. Their aim was to find the long-sought-for North West Passage between the Atlantic and Pacific oceans - for the discovery of which the British Government had, in 1745, offered a reward of 20,000. It is worth noting that they had offered a similar sized reward in 1714 for a method of establishing longitude at sea.

When Cook arrived in the area in 1778 - interestingly with a young Midshipman George Vancouver in the DISCOVERY - his first work was based on what he first called King George's Sound but later named Nootka Sound wrongly thinking this to be the native name. After about a month at Nootka Cook sailed northwards directly to the Alaskan coasts and onwards to the Sandwich Islands where he so tragically met his death in 1779. Athough Cook therefore contributed little to the surveying knowledge of British Columbia other than at Nootka - a chart of which appeared in his published account - his visit there was to have very significant consequences.

When his ships arrived in China following his death, the profits derived from the sale of the furs which they had obtained at Nootka were so great that the North-West American fur-trade began to boom. The first fur-trading voyage was by Capatin James Hanna, who sailed from China in 1785 in the HARMON, a 60 ton brig and returned in the 120 ton "scow" SEA OTTER in 1786; he did some useful exploration work and named several features. (1)

Of the many British seamen whose fur-trading activities left their mark on this coast, George Dixon and Nathaniel Portlock, in 1787, in the scow QUEEN CHARLOTTE and ship KING GEORGE, had both been shipmates with George Vancouver in DISCOVERY. Dixon named Queen Charlotte Island after his vessel and, on return to England, Sir Joseph Banks gave Dixon's name to the opening on the northern side of these islands. Also in 1787, another fur-trader, Charles Barkley, in IMPERIAL EAGLE, discovered the large sound which now bears his name, south-east of Nootka Sound, and discovered and named Juan de Fuca Strait after the apocryhpal explorer of that name. Berkley's 17 year old bride, Francis, accompanied him and so must be the first English lady to visit these waters.

The final English fur-traders of this period that must be mentioned are John Meares and James Colnett. Meares, originally a Royal Naval Lieutenant, arrived in 1787 in command of a trading vessel FELICE together with a Captain William Douglas in IPHEGENIA; Meares purchased from the native chief a portion of land near Nootka and built a 40 ton vessel - the NORTH WEST AMERICA - launched in 1788 - the first ship to be built on these shores. Colnett, a Royal Naval Lieutenant on half-pay, also arrived the area in 1787, in command of the PRINCE OF WALES, accompanied by Captain Charles Duncan in the PRINCESS ROYAL; after wintering in China, Colnett returned to Nootka, this time in the ARGONAUT, in 1788; both Colnett and Duncan carried out useful surveys.

Also in 1788, the Spaniards read, in the account of Cook's third voyage, that the Russians had definitely settled in NW America. The Spanish frigate LE PRINCESA commanded by Don Esteban José Martinez and the packet-boat SAN CARLOS commanded by Don gonzalo Lopez de Haro, were sent to investigate. They carried out much exploration and eventually arrived at Nootka in 1789 and not only formally took possession of the port in the name of the King of Spain but seized first the IPHEGENIA (which was soon released), then the NORTH WEST AMERICA, the ARGONAUT and the PRINCESS ROYAL. Colnett was taken, as a prisoner in his own ship, to San Blas in Mexico. Meares was away from Nootka, but when he heard of the event, personnaly presented a memorial to the House of Commons claiming heavy compensation for "this unwarrantable outrage on British commerce". Very strong feeling was raised in England and the British Government demanded satisfaction from Spain and also fitted out a powerful British Fleet. This had the desired effect and, in October 1790, the "Nootka Convention" was signed in Madrid; this gave complete restitution of all captured property and also acknowledged equal rights between Great Britain and Spain for the exercise and prosecution of all commercial undertakings in the waters around America which had hitherto been considered as belonging solely to the Spanish Crown.

This Convention was considered so significant that it was deemed desirable to send a British representative to Nootka to formally receive back the properties concerned and, accordingly, in 1791, Commander George Vancouver (in the newly built 340 ton DISCOVERY) and Lieutenant William Broughton (in the armed brig CHATHAM) left to carry out this task and to make an accurate survey of the NW coast of N. America between 30°N and 60°N.

On the voyage out to Nootka, Vancouver did valuable exploratory work off Australia, New Zealand and Drake's "New Albion" - as the Pacific coast of North America, north of California was then known - until April 1972. Instead of going direct to Nootka, Vancouver started his explorations along the southern shores of the Strait of Juan de Fuca; he then discovered and examined Puget Sound and passed into the Strait of Georgia (which he first called the Gulf of Georgia). In June 1792, when near Point Grey - off the entrance to Burrard Inlet, he fell in with the 2 Spanish vessels SUTIL commanded by Dionesio Galiano and MEXICANA commanded by Cayetano Valdes, and, apart from learning much navigational information from them, also heard that 4 Spanish vessels were waiting for him at Nootka; having exchanged copies of their surveys, Vancouver passed through Johnstone Strait and into Queen Charlotte Sound. Shortly after entering this, on 6 August, his DISCOVERY ran aground, on a falling tide, close eastwards of Mary Rock in Ripple Passage. Fortunately, she was refloated on the next high tide without damage and the survey was resumed to be broken off, reluctantly one guesses, when Vancouver learned from a British fur trader - the VENUS - that a British ship DAEDALUS had arrived at Nootka with supplies for his expedition and that the Spaniards awaiting at Nootka were getting increasingly impatient.

Making his way round the north of Vancouver Island, the expedition reached Nootka on 29 August 1792 to find the Spanish brig ACTIVA flying the broad pendant of Captain Juan Francisco de la Bodega y Quadra. Unfortunately, Vancouver and Quadra could not agree on which actual portions of land were to be ceded and the matter had to be referred back to London and Madrid. Meanwhile, Vancouver and Quadra became such friends that Vancouver suggested that the large island whose insularity he had just established should be named "The island of QUADRA and VANCOUVER".

Although Quadra left Nootka on 22 September 1792 for Monterey (and, incidentally died in San Blas, Mexico in 1794), Vancouver continued his surveys until he finally sailed from Nootka for England on 17 October 1794. During these two years, he completed an entire survey of British Columbia; however, the chart prepared by Lieutenant Edward Roberts "showing part of the Coast of NW America with the tracks of His Majesty's Sloop DISCOVERY and Armed Tender CHATHAM, commanded by George Vancouver Esq. and prepared from the foregoing surveys under his immediate inspection in which the Continental Shore has been correctly traced and determined from Lat: 29°54'N and Long 244°33'E (ie, 115°27'W) to Cape Douglas in Lat 58°52'N, Long 207°20'E (ie. 152°40'W) during the summers of 1792, 1793 and 1794 meticulously attributes (by the omission of shading) those parts eastwards of Cape Decision which were provided from the Spanish explorers (as well as those to the westwards of Cape St. Hermogenes provided by the Russians). Two other charts resulting from this incredible survey were one covering the coast from Cape Lookout, on the coast of Oregon, to Cape Swaine, on the coast of British Columbia and including Queen Charlotte Sound and Vancouver Island and with plans of the Columbia River, Port Discovery and Gray's Harbour and another covering the coast from Cape Swaine to Cape Ommaney, on Baranof Island in Alaska. It is of passing interest that, although the Royal Navy had funded this expedition and had appointed Alexander Dalrymple as the first Hydrographer to the Navy in 1795, Vancouver's work was published, on 1st May 1798, by J. Edwards of Pall Mall and G. Robinson, of Paternoster Row.

However, between 1789 and 1791, Dalrymple had published 13 sheets of plans of anchorages in British Columbia which proved useful to Vancouver. Four of these plans were by James Johnstone, Colnett's Master in the PRINCE OF WALES; when Colnett returned to the Canadian Coast from China in the ARGONAUT, Johnstone was placed in command of the PRINCE OF WALES and returned in her to England (3), returning to the North West coast with Vancouver as Master of the CHATHAM. (4) Colnett's own surveys (which are mostly in the archives of the Hydrographic Department, Taunton) were never published. The fur-traders Meares, Dixon and Portlock included a number of charts and plans in the published accounts of their voyages. (5)

With the departure of Quadra and the two Spanish vessels - SUTIL and MEXICANA - that Vancouver had first met in June 1792, the Spanish exploration, which had done so much to open up these waters, came to an end. Agreement on the practical requirements of the Nootka Convention was finally reached on 28 March 1795 when General Don Jose Manuel Alava, the Spanish commandant handed over to Lieutenant Thomas Pierce of the Royal Marines.

With the departure of Vancouver, no further British surveys were carried out in British Columbia for over 50 years. In 1846 - because of the growing crisis over the disputed Oregon Territory - the HERALD, Captain Henry Kellett, and her consort the PANDORA, Commander James Wood, were sent to British Columbia to carry out surveys in Juan de Fuca Strait. The harbour of Victoria was also surveyed by Kellett, while Wood surveyed Esquimalt Harbour. Wood returned the following year to carry out some surveys in the Gulf of Georgia.

In 1853, Mr. George Inskip, Master of the VIRAGO, Captain James

Prevost, surveyed Port Simpson and wrote some Sailing Directions for the Queen Charlotte Islands. Inskip's brother, a schoolmaster on board the FISGARD, had earlier assisted Wood in the survey of Esquimalt Harbour.

In November 1857 Captain George Richards arrived in the steam-sloop PLUMPER to join Captain James Prevost of the SATELLITE (who had arrived 5 months earlier). Because of his previous experience of British Columbian waters, Prevost had been appointed as a British Commissioner of a joint United States Boundary Commission to determine the boundary between the two countries. Richards was also appointed to the Commission as surveyor and astronomer. In 1858 Richards in the PLUMPER assisted by the SATELLITE surveyed the waterways in the vicinity of the San Juan Islands. The Joint Commission became deadlocked - the Americans considered the boundary should run through Haro Strait, while the British favoured Rosario Strait. The dispute was not settled until 1872 when, as a result of arbitration by the Emperor of Germany, the American claim was upheld. (6)

In 1859 Richards started to resurvey Vancouver Island - a survey conducted with extraordinary energy and almost severe zeal; the survey continued the following year. In 1859 and 1860 Lieutenant Richard Mayne made two extensive journeys into the interior of British Columbia, during which he traced the course of the Fraser River for a considerable distance. (7)

As PLUMPER was proving too small and defective, the fine, roomy, coal-burning paddle-sloop HECATE was sent from England in 1861 to replace her. By the end of 1862, Richards had completed his survey of Vancouver and part of British Columbia and early in 1863 sailed for England in the HECATE. Daniel Pender was left to complete the coasts of British Columbia, using a hired paddle-steamer the BEAVER. Pender remained on this task for 8 years, being promoted to Staff Commander in January 1869 and returned to England in 1871, having completed the examination of the western seaboard of the islands which front the coast of British Columbia northward of Vancouver Island - including the inner ship-channels of communication as far as the northern boundary of British Columbia and many large scale surveys of anchorages.

The last British contribution to the surveying of British Columbia began in 1898 when EGERIA, commissioned the previous year by Commander Morris H. Smyth, arrived from England. EGERIA remained surveying off British Columbia until 1910; in 1898, the dangerous Ripple Shoal in Johnstone Strait was examined and the differences in longitude from Esquimalt and Vancouver to McGill Observatory, Montreal was determined with cordial cooperation from the Observatory and Canadian Pacific Railway telegraphs; at intervals, the ship broke off to complete soundings for telegraph cables across the Pacific - in 1899, for example, 166 soundings were obtained at 20 mile intervals with an average depth of 2,420 fathoms. Smyth was relieved in 1900 by Commander Cortland Simpson who, in 1903, handed over the task to Commander John F. Parry. Captain Frederick Learmonth took over the command of the ship in 1906, the year after the ship had damaged a bilge through grounding on an un charted reef near Thetis Island and her senior assistant, Lieutenant G.E. Nares had died, whilst Lieutenant I.B. Miles had joined the Canadian Hydrographic Service on Canada's assumption of hydrographic responsibility. Captain John F. Parry returned to command EGERIA in 1908 with orders to take her to Australia but she was unfit for this service and continued in British Columbia to the end of her useful life in 1910. In March 1911, Parry handed over to Lieutenant Oswald T. Hodgson who prepared her for sale in April 1911 thus completing British work on this coast.

There is a permanent reminder in Taunton of an important phase of British activity on this coast. Joseph Whidbey, the Master of Vancouver's DISCOVERY, spent more time away from the ship in small boats than any other officer; he later served as Master Attendant at both Sheerness and Plymouth before retiring on 31 March 1830 to Taunton where he died on 8 October 1833 and is buried in St. James' Churchyard - not 400 metres from my present house.

EAST COAST

In 1497, the Italian born John Cabot, sailing under Letters Patent by King Henry VII, discovered Newfoundland. As a result of this voyage and similar ones - such as those by the Frenchman Jacques Cartier - the east coast of Canada began to appear on maps in rudimentary form. Newfoundland, for instance, was depicted as a number of islands in Jean Rotz's world atlas, which he presented to Henry VIII in 1542. (1) Perhaps the first British chart showing the east coast of Canada is an undated, unsigned chart of the North Atlantic in Thames School style, attributed to Thomas Hood 159?, which also shows Newfoundland as a number of islands. (2) Gabriell Tatton's chart of the North Atlantic 1602, also of the Thames School, (3) depicts Newfoundland in a more recognisable shape. These early British manuscript charts and the engraved ones by John Seller published at the end of the 17th century were based mainly on Dutch sources. The first British map, based on personal experience, was that of Newfoundland by Captain John Mason, who spent the summers of 1616 and 1617 surveyings its southern coasts. This map was eventually published in 1625. (4)

It was not until the 18th century that the British carried out any detailed surveys off the east coast of Canada. In 1716 Captain Thomas Durell, assisted by Mr. Gaudy, surveyed the south coast of Newfoundland, producing 2 charts as a result. Durell returned to Newfoundland in HMS SCARBOROUGH in 1732-5 and produced plans of Torrington Harbour in 1732, Port Wager in 1734 and Franklands Harbour in 1735. In 1736 Durell surveyed the south coast of Nova Scotia. (5) It was not, however, until the start of the Seven Years War (1756-1762) that British Hydrography made any great impact. Some notable work was done in the 1760s by Charles Morris, Nova Scotia's Surveyor General, a dozen or so of whose surveys are held in the archives of the Hydrographic Department. A real boost, however, came in the unlikely guise of 2 British Army Officers (one Swiss and the other Dutch born), an emigré from Germany and an ex-merchant seaman trained in Whitby colliers - Des Barres, Holland, De Brahm and Cook.

In the 18th century, charts showing the east coast of Canada were issued by most of the leading British chart publishers - such as Faden, Sayer, Kitchen, Bowen and Mount and Page. It was the latter firm that published, in 1759, Cook's first chart, Gaspé Bay and Harbour. His later charts of the St. Lawrence were, however, first published by Thomas Jeffreys. Cook was allowed to publish his Newfoundland charts for his own benefit. However, when he was appointed in command of the ENDEAVOUR, Cook sold his copper plates to Jeffreys, who published them in atlas form as A Collection of Charts of the Coasts of Newfoundland and Labrador etc., which also incorporated the work of Michael Lane and Joseph Gilbert. After Jeffrey's death, the plates were bought by Sayer and Bennett and later acquired by Laurie and Whittle, who last advertised 2 of Cook's charts in 1886. (6)

Joseph F.W. Des Barres was born in 1721 probably in Basle, Switzerland where he was taught mathematics by father and son Bernouilli, who can be compared with Galileo, Newton, Legendre and Laplace. In his early 30s, he joined the British Army, and, after some 3 years at the Woolwich Royal Military Academy was commissioned in the newly formed British Royal American Regiment (23 February 1756) and sailed for N. America in spring 1756 as an engineer. Whilst he had learned little new whilst at Woolwich, he had used his time to study surveying and, during the winter of 1758, he began a survey which by 1759 had produced a large scale chart of the St. Lawrence which with those of others - including young James Cook - was used when Wolfe moved up river to Québec City; towards the end of the Seven Years War, Des Barres joined a 1762 expedition to recapture St. John's, Newfoundland and then surveyed many of the island's principal harbours.

His hydrographic work came to the attention of the senior Royal Naval Officer, Captain Richard Spry who arranged for Des Barres to be seconded to the Royal Navy as a hydrographic surveyor. The British had split their newly won possessions in N. America into two Districts, each with a Surveyor General; in charge of the North was Samuel Holland, in the South was William De Brahm - both appointed by the Board of Trade.

Samuel Holland was, appropriately, a Dutchman born about 1728 who, after mathematical training, enlisted in the Dutch Army before transferring to the British and joining the Royal American Regiment. De Brahm was a German military engineer who had - because of religious persecution - emigrated in 1751, to Georgia, where he became Provincial Surveyor in 1755. With these two appointments made, there was no room for Des Barres in the land surveying hierarchy so he concentrated his efforts on the eastern coasts of N. America under the direction of the Admiralty.

Holland, between 1764 and 1766, surveyed St. John's (Prince Edward) Island and Cape Breton Island and, until 1770, surveyed the lower St. Lawrence and many of its tributaries and the upper St. Lawrence from Montreal to what is now Ogdensburg in New York State before pressing his surveys south as far as Cape Cod.

Des Barres concentrated far more on hydrography than did Holland or the French surveyors, whose earlier excellent work was available through the charts published by Jacques Nicolas Bellin. Until Des Barres' work - as the English map-maker Thomas Jeffreys wrote in 1755 - "the generality of mariners seem to know of no qualities in observing latitudes, farther than to find the place where they are bound to; and when they come in sight of land, lay their quadrant aside - as an insturment no longer of use - and sail by direction of the coast". Geographers were often too broad in their observations, mariners too inaccurate

- regarding an error of 8 or 10 minutes (of latitude) as but a trifle. Des Barres was to put things right. Although he seems to have had no official staff, he borrowed many young Naval officers as his assistants and hired local civilians to man his small open boats (shallops), paying their wages out of his own pocket (he was then but an Army Lieutenant) and keeping a good table especially during the long winter months when - by the light of candles and under his supervision - the summer's work was translated into charts. Among the Royal Naval officers to assist both Holland and Des Barres was Thomas Hurd, who was to succeed Alexander Dalrymple as British Hydrographer in 1808.

Des Barres spent two years surveying the Isle of Sable alone; despite its low economic value, he realised the navigational importance of the sandbars extending over 15 miles from either end into the major shipping lanes and the dangers thereabouts due to fogs and strong currents: by 1769, he sent back to the Admiralty charts of the Isle of Sable, the eastern part of Nova Scotia, Chedabucto Bay, Richmond Isles and the Gut of Canso yet was unhappy at his slow progress. The first edition of his magnificent "Atlantic Neptune" appeared in 1777 and the fourth and last in 1784; in 1778 he published a set of sailing directions to accompany the first part of the Neptune - which was made up of five Books; unusually for this period (when pirating of data was common and copyright unknown) Des Barres gave credit meticulously to all sources of data other than his own. De Brahm had returned to England in 1771 as did both Holland and Des Barres in 1774; by 1776 both land Surveyors General had returned to North America; so, on the outbreak of the American Revolution, Des Barres was given the task of providing a British Fleet of over 100 capital ships with the charts and precise information they needed and was able to provide them with an advantage because not even the local American pilots could match the accuracy of Des Barres' information. His Neptunes were not improved upon until Henry W. Bayfield began his surveys of the Gulf of St. Lawrence in 1828 (continuing them until his retirement in 1856); the Bay of Fundy was next surveyed in the 1840s by Captain William FitzWilliam Owen and Nova Scotia in the 1850s by Captain Peter F. Shortland.

But, before dealing with the work of these later surveyors, mention must be made of the facet of Des Barres' life of perhaps even greater importance than the painstaking practical work which he produced. This was a very fertile period for British hydrography and the winter evenings spent in Des Barres' house must have resulted in much "shop" talk: certainly there was cooperation between Holland and Charles Morris whose joint survey of Saint John Harbour and River is in the Library of Congress. But the most important protege was James Cook. As has been mentioned earlier, the young James Cook had begun to produce surveys during the Seven Years War; he was later to work with both Holland and Des Barres, supplementing their profound mathematical and army backgrounds with his seaman's experience. It could be that his "mariner's eye" was helpful to the engineers. But when Cook sailed as Master of HMS PEMBROKE for Canada in February 1758, he had done no surveying. In May 1759, the advanced British forces had penetrated up the St. Lawrence to within about 30 miles of Quebec, where the main navigable channel changes from the north to the south bank over a complicated stretch of water known as The Traverse; the buoys had all been removed by the French defenders and, on 8 June 1759, the Masters of all the British ships present, Cook prominent amongst them, began to rechart and rebuoy the channel, working at night and within range of the defenders' guns; by 25 June, a British Fleet of over 200 ships surprised the defence by making the passage of The Traverse without a single casualty. Cook later drew a 10 foot long manuscript fair chart - of which three copies remain - probably in England in late 1762. Cook remained in Canada when PEMBROKE returned home in September 1759, as Master of HMS NORTHUMBERLAND, spending the winters in ice-free Halifax but spending the summers of 1760 and 1761 surveying in the St. Lawrence below Quebec when his other duties allowed, continuing in 1762 in Newfoundland and off the coast of Nova Scotia.

His work was so well received that Captain (later, Lord) Graves, the Governor of "Newfoundland, Labrador etc." took Cook with him to Newfoundland in 1763; that year, he surveyed the islands of St. Pierre and Miquelon before these were handed back to France under the terms of the Treaty of Utrecht. In 1764, when Captain Palliser became Governor, Cook was appointed in charge of the survey of Newfoundland as King's Surveyor (rating as Master) in a small schooner GRENVILLE, with a crew of nine.

Having measured a base at Noddy's Harbour, on the north coast, and extended his control westwards through the Strait of Belle Isle to Point Ferolle, Cook ran soundings over the Grand Banks on passage back to Deptford, where his tiny vessel was converted to a brig. For the next three years, Cook sailed GRENVILLE across the Atlantic for about five months surveying off Newfoundland, sailing for the last time for Deptford in October 1767. Perhaps even more significantly, he had, in August 1766, observed an eclipse of the sun at Eclipse Island in the Burgeo Islands; the accurate observation of longitude obtained brought him to the attention of the Royal Society and led to his appointment in 1768 to observe the transit of Venus in Tahiti and to his three circumnavigations of the world.

Whilst Cook was delineating Newfoundland, Joseph Gilbert was similarly employed, in HMS GUERNSEY, off the coast of Labrador in 1766 with Michael Lane as assistant; Lane relieved Mr. Parker as Master's Mate of Cook's GRENVILLE in late 1766 and, when Cook left at the end of 1767, Lane took command and continued to work for about five months each year off the coast of Labrador until, in 1772, he resumed more detailed surveys of Newfoundland including Placentia Bay (1772), St. Mary's Bay (1773), Conception Bay (1774), Cape Bonavista to Cape Spear and Trinity Bay (1775). Between 1776 and 1777 Lane was appointed Master in HMS LYON under Lieutenant Richard Pickersgill; Lane does not seem to have returned to Newfoundland again until 1784 when he surveyed the vicinity of the Virgin Rocks; in 1785 he surveyed Fogo Island and, in 1791, William Faden published a chart bearing the title "The Island of Newfoundland laid down from surveys taken ... by Lieutenant Michael Lane, Principal Surveyor of the said island 1790".

Another officer from GRENVILE who figured briefly, was John Cartwright who, in 1768, had reached the source of the River Exploits and drew a very beautiful chart of Lieutenant's (now, Red Indian) Lake, the River Exploits and part of Notre Dame Bay.

There seems to have been somewhat of a lull in British surveying on Canada's Atlantic seaboard from about 1776 till 1813 - apart from the years 1800-01 when Francis Owen, Master of HMS AGINCOURT was employed surveying St. John's and other areas on the East coast of Newfoundland. However, in about 1813, Anthony Lockwood (who was to describe himself as "Professor of Hydrography and Assistant Surveyor General of the Provinces of Nova Scotia and Cape Breton" but who was a Master RN was appointed by Sir Alexander Cochrane to carry out a survey of Nova Scotia. Using a hired vessel and crew and without an officer to help him, he completed his work in 1818 when he published a book containing charts of several ports in Nova Scotia; in the same year he published a chart of New Brunswick. Also, between 1814 and 1820, Mr. George Papps Holbrook, Master RN was employed in command of RN Brig SYDNEY surveying the east coast of Newfoundland; from 1817 to 1820, his astronomical surveyor was Mr. William Bullock whose elder brother Lieutenant Frederick Bullock joined the team, on half-pay, in 1821-22.

Mr. Holbrook was relieved in command of HM Brig SNAP by Lieutenant John Hose a month after commissioning her in 1821; Hose was probably the first to continue work over the ice in winter but his work was subsequently published under the name of Lieutenant Frederick Bullock who relieved him in May 1823. By the fall of 1826, F. Bullock had surveyed the whole of the coast between Notre Dame Bay and Cape Bauld; working under him in SNAP was Edward J. Bedford, another young officer who together with his brother, George Augustus, were to achieve later acclaim for their surveys around the British Isles. From 1821 to 1827, Thomas Smith also undertook surveys off Newfoundland in the SCRUB and the INSPECTOR, tenders to the SNAP. However, an even greater name was now to appear off Canada's East coasts.

Whilst in London from 1826 to 1827 drawing his charts of the Great Lakes, Bayfield managed to persuade the Admiralty that surveys were needed of the St. Lawrence River and Gulf of St. Lawrence, pointing out that there was still no chart whatever of the river between Montreal and Quebec or from Quebec to Anticosti Island (ignoring Cook's surveys in the 1760's and the work by Holland and claiming that Des Barres' charts were "very incorrect").

In September 1827, Commander Bayfield arrived in Quebec with two assistants - Lieutenant Philip Collins and Midshipman Augustus Bowen; a year later a Dr. William Kelly joined the St. Lawrence survey team - to remain for 20 years as a surveying surgeon. Bayfield ordered a 140 ton schooner, GULNARE, to be built to his specification with two boats; he also ordered two six-oared cutters to be built as survey boats. Bayfield spent the next fourteen years, 1827-1841, with headquarters in Quebec City, conducting the St. Lawrence survey including the entire north shore of the St. Lawrence River, Lac Saint-Pierre, Quebec and Montreal harbours, the navigable part of the Saguenay River, the northern Gaspé coast, the Strait of Belle Isle, the coast of Labrador from Belle Isle to Cape St. Lewis, the Belle Isle coast of Newfoundland, Anticosti, the Magdalens and other St. Lawrence islands, Baie des Chaleurs, the New Brunswick coast of Northumberland Strait and the main rivers and harbours along all these coasts.

During the summer, Bayfield drove his team very hard, setting very high standards; he worked from daylight to dark, six days a week and sometimes even on Sundays. In boats only 25 feet long, loaded with provisions, tents, bedding, extra clothes, instruments, cooking gear, etc., there was barely room for the oarsmen's feet but, even in the exposed, open areas in which they worked little water was shipped; when the weather became too severe in the fall to work in the exposed outer areas of the Gulf, Bayfield moved to Lake St. Peter or the sheltered waters of the river between Montreal and Quebec. In late October, the team returned to Quebec to plot their season's work. After meticulous checking by Bayfield himself, the plans and charts were sent back to the Hydrographic Office in London to be engraved.

Bayfield was promoted Captain in 1834, but, in September 1835, Lieutenant Collins died of apoplexy whilst surveying the Magdalen Islands; his place was taken by Lieutenant John Orlebar. At the start of the 1841 season, Bayfield moved his headquarters to Charlottetown, Prince Edward Island - a harbour more central to his next surveying project and with a longer ice-free navigation season. For the next fifteen years, Bayfield and his two assistants (Orlebar and George Agustus Bedford - who had replaced Bowen in 1939) concentrated on the coasts of Prince Edward Island and Nova Scotia; his assistants usually worked independently for a few days or weeks but Bayfield was always in command, issuing explicit instructions and requiring regular reports either in person or by post.

By 1848, Bayfield had surveyed the entire coastline of Prince Edward Island (including its bays and deeply indented harbours) and the Northumberland Strait coast of Nova Scotia and resurveyed the northern Gaspé coast which had not been surveyed in detail in 1828/29. For the next five years, he concentrated on a survey of Cape Breton Island, the Strait of Canso, Ile Madame and Bras d'Or Lake. His last survey was in 1852 and 1853 of Halifax Harbour and the adjacent headlands and bays. At the end of this, his health began to fail and he concentrated on his "Sailing Directions" for the Gulf and River of St. Lawrence" which he had produced, chapter by chapter, each year from 1828; this epic work was published in three stages, in 1837, 1847 and 1857; the entire work was revised and published, in 1860, in two volumes as "The St. Lawrence Pilot".

Finally, Bayfield wrote "The Nova Scotia Pilot" in two parts (in 1856 and 1860); in 1856 he retired, as a Rear Admiral, to live quietly with his wife and six children at Charlottetown until his death in 1885, aged 90. After his death, Captain Boulton RN said "The Admiralty Surveying Service had produced good men, from Cook onwards, but I doubt whether the British Navy has ever produced so gifted and zealous a Surveyor as Bayfield. He had a marvellous combination of natural talent with tremendous physical energy and was a man who would have gained the summit of any profession he might have honoured for his one thought was his work".

It might seem almost presumptuous to question his work; yet this was only as good as the equipment and techniques available to him; that they sufficed for well over 50 years is a great tribute to this man who above all others provided the foundation for hydrography in Canada.

When Commander John Orlebar relieved Bayfield in January 1857, he had been his senior assistant for over twenty-one years. He introduced the steam driven vessel LADY ST. MARCHANT to the survey and, between 1852 and 1864, surveyed from Codroy eastwards to La Poite, from Laun to Great Burin and from Capt St. Mary's and St. Mary's Bay to Capt St. Francis - including many excellent plans of harbours. Owing to failing eyesight, Orlebar retired at the end of 1864 and handed over to Staff Commander James Hooper Kerr.

In 1865, the Admiralty decided on a thorough resurvey of Newfoundland which was progressed systematically by Kerr until he handed over to Staff Commander William Frederick Maxwell in 1871/72. Maxwell not only worked around Newfoundland but also surveyed in the St. Lawrence River and triangulated the Labrador coast, during his eighteen years in Newfoundland.

Staff Commander William Tooker relieved Captain Maxwell in 1891 and resurveyed the west coast of Newfoundland from Cape Anguille to Cape Rich, White Bay on the east coast and the greater part of Exploits Bay. He also made several plans on the Labrador coast and, in conjunction with Commander Purey-Cust in HMS RAMBLER sounded out the Strait of Belle Isle; later, in 1903, continued sounding considerably to the eastward with Commander Learmonth in HMS GOLDFINCH. Tooker continued his work after his official retirement in 1907 handing over to Captain J.W. Combe in 1908.

Writing as long ago as 1913, Lieutenant J.A. Rupert-Jones RNR reported that during Captain Combe's five years in Newfoundland, the first months of each season were devoted to systematic sectional lines across the western approach to the Strait of Belle Isle which "are of extreme importance not only from a hydrographical point of view but from that of the geologists. They developed a tremendous area of shallow water in the centre of the Gulf of St. Lawrence, about 30 miles north of Cape Rich and stretching east and west for many miles directly along the steamship route. This submarine plateau ... carries a general depth of 30 fathoms with heads rising to within 20 fathoms of the sea level and appears to be straited by decayed basaltic dykes carrying 70 fathoms running NNE and SSW; these dykes or clefts are found on both the neighbouring shores of Newfounding and Labrador and form an interesting study ... to officers interested in geology". Prophetic words.

The final British surveys in Canadian waters took place in HMS CHALLENGER from 1932-34 under Captain Guy Wyatt: although she was echo-sounding at the time, she ran on a pinnacle rock and only the efforts of two divers working in water only a degree above freezing point got the leaks under control sufficiently for her to reach Battle Harbour whence she was escorted to Halifax for docking. A wintering party was landed at Nain, in November 1933 under Edmund H.B. Baker who made an epic sledge journey from Nain to Hebron to help a trader in difficulty with the Esquimaux; the party was collected in July 1934, shortly before CHALLENGER left Canadian waters, thus concluding the British surveys in Canadian waters.

THE GREAT LAKES

The early exploration of the Great Lakes was carried out by the French, and, as early as 1672, the shape of even remote Lake Superior was accurately depicted on a Jesuit map.(1) While navigation on the Lakes was mainly confined to bark canoes and boats there was no need for charts with their soundings and navigational aids. The Seven Years War illustrated the value of water transportation for the armies and, subsequently, its value as a means of carrying goods and passengers more cheaply, quickly and easily than by wagons.

In 1812, war started between Britain and America owing to America's objection to British restrictions with neutral trade with Europe and her insistence on searching vessels for naval deserters. During the two year war, there were naval battles on the Great Lakes. Following the Treaty of Ghent, in 1814, Captain William FitzWilliam Owen was appointed Senior Officer Commanding the Great Lakes and Naval Surveyor in March 1815; he had already distinguished himself as a navigator and surveyor in the Maldives and South-east Asia.

Originally it had been intended to operate from Quebec, but Owen chose Kingston as being closer to his intended survey area and recruited Lieutenant Alexander T.E. Vidal, Master's Mate Alexander B. Becher and John Harris, Master RN; using the schooner HURON, they proceeded up the St. Lawrence and, by the end of 1815, were surveying the eastern shores of Lake Huron and Georgian Bay. In January 1816, Owen also recruited Henry Wolsley Bayfield who had been born in Hull in January 1795 and accepted as a "young gentleman, supernumerary volunteer 1st Class" two weeks before his 11th birthday; within nine months he had served in three ships, including HMS DUCHESS OF BEDFORD in which young Bayfield was slightly wounded during an action in the Straits of Gibraltar. His captain, Francis Spilsbury reported to the First Lord that "though a youth (he was 11 1/2), he displayed presence of mind that would well become the greatest Warrior".

After this auspicious start, he was made a Midshipman in 1810 and visited Quebec and Halifax; after service in the West Indies and off the Iberian Peninsula, he joined the British Flotilla on Lake Champlain in October 1814. Although promoted to Lieutenant in March 1815, he was still serving as a Midshipman in HMS PRINCE REGENT when Owen persuaded him to join him in HM Sloop STAR in the 1816 surveys of Lake Ontario. He made such a good impression, that the experienced Owen commended him, within six months, to Mr. Croker, Secretary of the Admiralty and, at the end of the 1816 season Owen persuaded him to remain rather than return to England.

Bayfield accepted without hesitation and, when (as a result of scrapping of all Fleets on the Great Lakes in accordance with the Rush-Bagot agreement) Owen had to return unexpectedly to England in mid-1817, Bayfield - then aged 22 - was placed in charge of the surveys of Lakes Erie and Huron - but with a greatly reduced establishment, including an inexperienced Midshipman, Philip Collins, and but two boats, the TROUGHTON and the RAMSDEN. Having completed the survey of Lake Erie in 1818, Bayfield began to survey the more intricate Lake Huron, based at Penetanguishene. This was to last for the four seasons 1819 - 1822 - including the delineation of about 20,000 islands and numerous deep bays and coves; conditions must have been appalling - swarms of mosquitoes and flies in the summer, near zero temperatures in the winter, no shore facilities and, with at times six weeks' provisions in their small boats, barely room to sit - let alone lie down to sleep.

In the spring of 1823, Bayfield moved his party into Lake Superior with the Schooner RECOVERY, chartered from the Hudson's Bay Company, as a floating base, as he found it faster to survey in the boats. Even when wintering at Fort William, the party was very isolated, with no medical aid and mail only once in six months. Promoted Acting Commander in 1823, Bayfield persevered and by the end of the third season, in late 1825, the team had circumnavigated the largest freshwater lake in the world, and Bayfield and Collins were able to return to England to work up their results into charts that were to serve well for over 50 years.

The hardships they had endured and the excellence of their work resulted in Bayfield being promoted to Commander and Collins to Lieutenant in 1826. Despite his efforts,Bayfield was honest enough to report to the Hydrographer in 1827 that "whilst the charts which I have just finished are as critically correct in all the details as to render any future survey of them unnecessary for nautical or general purposes, it is highly desirable that they should be filled up with soundings which - except to a certain extent from the shore - I could not obtain without a vessel."

For the next 58 years, the only surveying done in the Great Lakes was by the United States Lake Survey who, from 1841 began to tackle the 5,500 miles of American coastline and about 61,000 square miles within the U.S. portion of the Great Lakes.

Following the tragic loss of the passenger and cargo carrier SS ASIA on 14 September 1882 during a violent storm on Lake Huron, unproven claims of her having hit an uncharted shoal provoked public opinion to demand more modern surveys than those by Bayfield within the Canadian sector. The volume of traffic and increased size of vessels since 1826 was certainly justification for a full scale Canadian surveying and charting programme.

Under the British North American Act of 1867, the Canadian Parliament had attained authority over certain navigational matters and no Imperial funds were available for surveying. The Canadian Government, unable to find a qualified hydrographer in Canada, approached the British Government and the British Hydrographer, Captain Sir Frederick Evans, instructed Staff Commander William Maxwell - the officer in charge of the surveys of Newfoundland (not then, of course, part of Canada) - to go to Ottawa to discuss the requirement. As a result, Staff Commander John G. Boulton was appointed, on loan to Canada, to take charge of the surveys, then called "The Georgian Bay Survey", from July 1883 until April 1893.

Boulton was an experienced surveyor having already spent nine years in Newfoundland and Labrador during which, in 1880, he had been loaned to the Hudson's Bay Company for a voyage to Fort Chimo. Although it was hoped that at least Bayfield's coastline could be accepted, this proved inadvisable and Boulton, accepting the U.S. geodetical control, decided to start his survey at the entrance to Georgian Bay from Lake Huron and the North Channel.(1) After chartering the fishing tug ANN LONG for the last working days of 1883, he spent the winter drawing up plans for the 1884 season and selecting a Canadian assistant William J. Stewart from the Royal Military College, Kingston.

Early in 1884, the 20 year old former American tug EDSELL was bought and, after a refit and conversion, was renamed BAYFIELD - for obvious reasons. Although his fair sheets were still rendered to the British Admiralty for inclusion in British Admiralty charts, Boulton also in each year produced, for local use, a new chapter of the "Georgian Bay and North Channel Pilot", starting in 1885 from his 1884 work. Also in 1885 he recruited a second graduate from the Royal Military College at Kingston and eventually added a third assistant. By the start of 1886, the first Admiralty chart from Boulton's surveys - No. 906 covering Lake Huron from Cabot Head to Cape Smith and the Entrance to Georgian Bay - was available.

Each year, BAYFIELD wintered at Owen Sound when the lakes became frozen over; by 1887, Boulton was working on the northern shore of Lake Huron which was progressed each year until, by 1891, the eastern shores of Georgian Bay were reached and, in April 1893, Boulton felt able to hand over to his Canadian deputy William Stewart and return to England. During his eleven years in the Great Lakes, the British Admiralty published thirteen general, coast and harbour charts for the Great Lakes - eight of Georgian Bay and five for the North Channel. Although British Admiralty charts were the primary documents for a considerable period and the Canadian Hydrographic Service was not brought into being until an Order-in-Council dated 11 March 1904, the appointment of Stewart may be considered to have brought to an end the British surveying contribution to the Great Lakes - or Georgian Bay - surveys.

The North Coasts

In 1817, William Scoresby - a whaling friend of John Barrow, Second Secretary to the Admiralty - reported that, after many years of whaling experience, he was confident that a seasonal recession of the Arctic pack ice had taken place. To Barrow, the senior civil servant in the Admiralty who had travelled in his youth in a whaler to Greenland, this suggested that the time was ripe to renew the attempts to find a North West Passage to the Pacific - which had begun some 200 years earlier when Luke Foxe had penetrated Hudson's Strait and explored Foxe Basin and since Baffin had passed through Davis Strait to Baffin Bay.

In 1818, Barrow strongly supported by Sir Joseph Banks and the Royal Society persuaded Lord Melville, the First Lord, to approve the first of many expeditions to Arctic waters. Commander John Ross (with his nephew James Clark Ross) in ISABELLA, with Lieutenant W. Edward Parry in ALEXANDER, sailed in April 1818 and passed through Davis Strait to the western side of Baffin Bay and Lancaster Sound before turning back. The next season, HECLA and GRIPER sailed with the intention of wintering in the ice, with Parry in command and with Captain Edward Sabine RA as his astronomer and Frederick Beechey as his First Lieutenant; they sailed through Lancaster Sound and, after exploring Prince Regent Inlet, carried on along the north side of Barrow Strait as far as almost 114° West before turning back to a sheltered winter haven on the south coast of Melville Island; in 1820, he discovered Liddon Gulf by an overland journey across the Dundas Peninsula, before returning to Deptford about the middle of November.

In 1821, Commander Parry set off again in FURY with Commander George Lyon in HECLA; passing south of Baffin Island, they carefully explored the western side of Foxe Basin and wintered on the eastern side of Melville Peninsula. After deducing from an Esquimau woman that a passage existed to the north of this peninsula, the ships started in early July 1822 to try to battle their way through the ice and islands of Fury and Hecla Strait but had to turn back frustrated by the currents and conditions; after a second winter in the ice, they returned to England in November 1823 to find that the second Hydrographer of the Navy, Thomas Hurd, had recently died.

Whilst Parry's expedition in HECLA and GRIPER had been reaching so far west, Lieutenant John Franklin had been sent overland to explore and survey the northern coasts with the help of the Hudson's Bay and North-West Companies; accompanied by Midshipmen George Back and Hood, Doctor John Richardson, two British Able Seamen and several local guides, the party travelled down the Coppermine River from the Great Slave Lake and reached the mouth by July 1821 when, turning east, they explored the coast by canoes for about 550 miles as far as Port Turnagain; their return to civilization was so difficult that few survived, but John Franklin, Back and Richardson were to return despite their frightful experiences.

In 1824, after Parry had become Hydrographer, perhaps the most ambitious three-pronged expedition was planned. Parry himself set off in 1825 in HECLA, with Commander Henry Hoffner in FURY: they entered Prince Regent Inlet hoping to sail south to reach the area explored by Franklin's canoe party. The ice was particularly bad that year and FURY was so badly damaged that she had to be beached to try to repair her; despite superb seamanship, she had to be abandoned and both crews had to return to England. The second party was a second overland trip led by Captain Franklin, again with Lieutenant Back and Dr. Richardson but, this time, taking all their stores with them; having built a base camp at the western end of Great Bear Lake, the team set off in June 1826, down the Mackenzie River. As soon as they reached the coast, Franklin and Back set off westwards (hoping to meet the third party - BEECHEY - of whom more later) but were soon attacked by Esquimaux; the calm bravery of their Eastern Esquimau interpreter, Augustus, and Franklin's refusal to use his firearms resulted in a peaceful return of most of their gear, so that they were able to reach Return Reef (near the site of present day Prudhoe Bay, in Alaska) before returning on 18 August 1826 - bitterly disappointed not to have met Beechey.

Meanwhile, Dr. Richardson had been more successful as, despite a similar encounter with the Esquimaux, his party had explored the coast eastwards in their two small boats DOLPHIN and UNION and reached the mouth of the Coppermine River before walking to the eastern shores of the Great Bear Lake and crossing this to their base camp to reunite with Franklin.

The third prong of the 1825 plan was Captain Frederick Beechey who sailed, in January 1825, in HMS BLOSSOM via Cape Horn to tackle the North-West Passage from the Pacific. Although he did not reach the Canadian coast, he reached the head of Kotzebue Sound - where he had hoped to meet up with Franklin - by 25 July 1826 and sent Mr. Elson, the Master, in a barge to survey the coastline and build beacons on any prominent points with messages for Franklin; having explored 125 miles, Mr. Elson turned back at Point Barrow - only some 160 miles short of Franklin's Return Reef. Beechey sailed south in mid October but returned next summer without any further success.

Parry's third voyage to the North-West - again in HECLA - was more scientific than surveying as was the privately organized expedition of John and James Ross which located the magnetic north pole in 1829, in a 150 ton steam vessel VICTORY (provided by the gin-distiller Felix Booth); after two winters in the Gulf of Boothia, the VICTORY had to be abandoned and the crew spent a third winter in Fury Bay (using supplies left by Parry in 1825) before very fortunately meeting the old ISABELLA, then whaling off Cape Liverpool (but in which John Ross had travelled in 1818) and returning home late in 1833.

After a lull of twelve years, successful work in Antarctica and the advent of screw propulsion, led Sir John Barrow to persuade Captain Francis Beaufort, the then Hydrographer, to send HMS EREBUS and TERROR on another attempt to force their way through the North-West passage; the 60 year old Sir John Franklin volunteered and was selected to lead the ill-fated expedition, which set off in May 1845. Stopped frequently by pack ice, they spent three winters without getting more than about 100°W and eventually all must have perished by the end of 1848.

Concerned by lack of any news or their non-return, some 25 separate searches were made between 1846 and 1859 to try to find their fate.(1) So much has been written of these searches, that mention can only be made here of a few. Captain Henry Kellett made three attempts from the Pacific; on the second of these, in 1849, one of his officers, Lieutenant William J.S. Pullen - using PLOVER's boats, explored the Alaskan coast, beyond the point reached by Mr. Elson in 1826 and, indeed, reached the Mackenzie River and made his way up this in his two whale-boats to Fort Simpson - thus completing the British survey of the western part of Canada's northern coast. Having made his way overland, nearly to the Great Slave Lake by 25 June 1850, he was amazed to find two Indians in a canoe with a message from Beaufort saying that he was promoted to Commander but would he return for a further search for Franklin; undaunted, he returned for another search without success.

A second expedition from the Pacific was that under Captain Richard Collinson in HMS ENTERPRISE with Commander Robert M'Clure in HMS INVESTIGATOR which left England in 1849, after an unsuccessful search by the two ships, under Captain Sir James Ross from the east in 1848. INVESTIGATOR, having met Kellett in HERALD off Alaska in 1850, pressed on alone and, entering M'Clure Strait, reached the longitude previously reached by Parry in 1819 but became stuck in the ice at Mercy Bay, on the north coast of Banks Island where he remained for three years. Collinson, not entering Bering Strait until 1851, followed the Alaskan coast and, in 1852/53 wintered at Cambridge Bay, 105°W, near the south-east corner of Victoria Island; both Collinson and M'Clure sent parties exploring by sledge and leaving cairns and messages about their achievements during the winters spent in the ice.

Meanwhile, a carefully planned expedition under Captain Austin with two 400 ton sailing barks RESOLUTE and ASSISTANCE and the screw sloops PIONEER and INTREPID had spent 1850 and 1851 making a thorough search by boats and winter sledge journeys and finding the first evidence of Franklin's tracks - his first winter's quarters at Beechey Island. In April 1852, the same four ships left England together with the sloop NORTH STAR as supply ship, under Commander Pullen, but with the well-named Captain Sir Edward Belcher in overall command, in ASSISTANCE, and the experienced Captain Kellett in RESOLUTE and Commander Leopold McClintock in INTREPID. On reaching Lancaster Sound, Belcher and Lieutenant Sherard Osborn, in PIONEER, search northwards through Wellington Channel whilst Kellett took RESOLUTE and INTREPID searching westward towards Melville Island, leaving NORTH STAR at Beechey Island. During the 1852 winter, Commander George Richards, Belcher's deputy, made an epic 95 day sledge journey to search and survey the islands and channels to the north of Melville Sound, during which he met a similar sledge party, under Lieutenant Hamilton from the RESOLUTE who reported that Kellett's group, whilst wintering at Winter Harbour, on Melville Island, had found a note from Commander M'Clure reporting that INVESTIGATOR had been iced in for the last three winters at Mercy Harbour, some 150 miles on the opposite side of Melville sound.

As early as possible in 1853, Kellett sent Lieutenant Pim by sledge and, on 6 April 1853, the first meeting took place between expeditions approaching from either end of the North-West Passage. But there was to be no single passage through by ship until the Norwegian Roald Amundsen achieved this between 1903 and 1906, and now disaster was to strike all the British ships. After a second winter in the ice, Belcher sent orders to Kellett to abandon RESOLUTE and INTREPID and make their way overland to the NORTH STAR with the crew of INVESTIGATOR: Belcher's own two ships were also abandoned and all five crews of the abandoned ships embarked in NORTH STAR on 26 August 1854 to return home; luckily, shortly afterwards, they met the PHOENIX and TALBOT with fresh stores and orders to abandon the search.

As a postscript, an American whaling bark, GEORGE HENRY, found RESOLUTE in 1855 and managed to tow her clear of the ice and took her to New London where she was bought by the United States Government, refitted and presented back to Queen Victoria at Spithead. When finally broken up in 1880, a large desk was made from her timbers and presented to the President of the United States.(2)

The mystery of the fate of Franklin and the crews of EREBUS and TERROR was not solved until Captain McClintock returned to the area in the FOX - privately equipped by Lady Franklin - which left Aberdeen on 1 July 1857 and found a cairn with a paper, signed by Captain Fitzjames of the TERROR, dated 25 April 1848 certifying that both ships had been trapped on 12 September 1846 and abandoned on 22 April 1848, on the western side of King William Island.

The final British contribution was to the furthest point north yet reached. On 29 May 1875, Captain George Nares, in the screw sloop ALERT with Captain Stephenson in the similar DIS COVERY passed up the east coast of Elles mere Island; leaving DISCOVERY on the west side of Hall Basin, Nares continued northwards through Robeson Channel, before wintering in a higher latitude than any earlier ship had reached. During the winter, sledge parties left under Commander Clements Markham to try to reach the North Pole and under Lieutenant Pelham Aldrick who surveyed the northern coast of Ellesmere Island as far as Alert Point; the whole of ALERT's crew were then attacked by scurvy and only skilled work from both ships enabled the expedition to return at the end of October 1876.

Thus, over a period of some 60 years, numerous British expeditions had explored the Arctic unknown, in robust but very small vessels, appalling weather and often very poor medical conditions but with enormous courage, energy and tenacity. Many lives were lost in the illusive search for a North West Passage, the economic potential of which was finally demonstrated when the 300,000 ton British Petroleum tanker MANHATTAN forced her way through Barrow, Melville and McClure Straits in 1969.

CONCLUSIONS

This account indicates that, thanks to the ready acceptance of hydrographic responsibility by the Canadian Government much earlier than other members of the British Commonwealth, the British Royal Navy's hydrographic surveyors' efforts in Canadian waters tailed off by the end of the 19th century but that, by that time, successive generations of them had given devoted service in order to produce charts which were very adequate for the purposes required at the time they were executed. As everywhere else in the world, however, improving technology enables hydrographers to react to improved accuracy requirements and succeeding generations of hydrographers must recheck the work of their predecessors - however illustrious and painstaking these may have been.

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VIGNETTES FROM HYDROGRAPHY'S PAST

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ABSTRACT

This paper takes a non-technical and humorous look at our predecessors in Canadian Hydrography. It touches on the value of history to the modern hydrographer and from historical records and personal correspondence of the day shows that the problems faced by yesterdays hydrographers are frequently the same as those faced today by the field man, the cartographer, Ship Division management and administrators.

RÉSUMÉ

Cette étude jette un regard humoristique et non technique sur les pionniers de l'hydrographie au Canada. Elle fait ressortir la valeur de l'histoire pour l'hydrographe moderne et, à partir de données historiques et de correspondances personnelles de cette époque, elle montre que les problèmes qui se posaient autrefois aux hydrographes sont souvent les mêmes que ceux que rencontrent encore aujourd'hui l'hydrographe, le cartographe, le gestionnaire et l'administrateur de la Division des navires.

At school, history frequently appears as a boring, mind-numbing, commitment to memory of lists of kings, prime ministers, wars and peace treaties.

Later in life in certain professions and viewed in different perspectives it comes to have a certain relevance, particularly in law and perhaps, surprisingly, in surveying. Historical precedents figure largely in surveying of lands and land ownership, and they also have a place in hydrography.

Every hydrographer in the course of his survey compares his present survey with the previous one of the area. Many of the surveys I conducted on the West Coast were resurveys of previous Admiralty work and meant a step back in time to the Egeria, which worked on the coast from 1898-1910 - and in some cases even back to the work of Captain Richards and Commander Pender in 1858-1870.

So when faced with not finding a shoal or rock in its charted position I was placed in the awkward situation of disproving a fact that mariners had been accepting from their charts for anything up to one hundred years - and to do this one has to be very certain that not only is it not there - but it is not in the vicinity. So how far afield should one look?

An appreciation of how the rock/shoal or whatever might have been fixed was obviously going to be of help. Also you got into the skin of your predecessors - A was an excellent man, always reliable and accurate, B had inexperienced assistants, C was just passing through the area on a reconnaissance survey, etc.

Thus I found that an appreciation of the history of hydrography, our predecessors, their instruments and methods had a practical application for the present day surveyor and that applied history could be interesting. As a corollary I also found that such information was sadly lacking; that history in hydrography was a neglected subject and that the cartographic historians, of whom there were legion, had little appreciation of hydrographic surveying.

However these aspects of the history of hydrography will be covered off in "The Chartmakers" and today I have chosen to pick a few notes from various historical documents that I came across whilst researching that book. These are non-technical fragments from our past which show that little is new in the life of the hydrographer.

For the hydrographer; the cartographer; the ship division types; the administrators; the problems; gripes; bureaucracy; paperwork are the same today as they were in the past.

I hope that there will be something for everyone, some incident that you can relate to and smile to yourself taking new heart from the fact that you are not the first to contend with some particular problem.

Periodically hydrographers bite their fingernails as they sally forth for their interviews with the CHS National Appraisal Board and the annual appraisal report time passed a month or two ago. Those of you who have to make these appraisals may be interested in a few choice quotations and phrases for this exercise.

On hearing of an appointment to his ship bound for B.C. surveys Captain Richards commented "I confess I should have been glad if Mr. H. had chosen China as the field whereon to make his reputation".

Or, "Our second master is more

than useless wherever he might have been picked up".

Admiral W.F.W. Owen was not quite so brief in his condemnation of a Lieutenant K. reporting that "he is no seaman, his vessel is his master, he mistakes tyranny for discipline, is most contentious, disrespectful even to insolence, and dangerously prone to litigation. Altogether a character as totally unfit for the place in which I find him as could have been found, I believe, in our Service". Try for a promotion after that report!

Owen had started up the surveys of the Great Lakes in 1815 and had gone on to carry out his great surveys on the African coast. Despite the hardships of work on that coast where he lost two thirds of his officers and half his crew to fever during the five years survey, he survived and retired to Campobello where his family had estates. Largely due to his exertions The Bay of Fundy survey was mounted by the Admiralty and its history, like the bay, was tempestuous.

The chain of command was unusual to say the least as Owen was nominally in charge of it but was not commissioned. His survey ship came out from U.K. with her own Captain who had his instructions, his estimates etc. There was an immediate clash as Owen, who was also an M.P.P. (Member of the Provincial Parliament) had arranged a reconnaissance cruise around the Bay with the Lieutenant Governor while the Captain naturally wanted to start on his survey. With Owen's holdings in Campobello where better to base the ship, erect a stores depot, set up a stock of coal, put in a tide gauge, hire a pilot than at Campobello - on property owned by the Owen family, with men who would vote for Owen. For the efficiency of the survey naturally - pork barrelling by an officer and a gentleman was unheard of.

Worse than all this however he got religion and the unctuous phrases one finds in his letters make peculiar reading these days.

Perhaps a Regional Hydrographer could try ending a letter to the Dominion Hydrographer "God bless and preserve you a thousand years", having previously scattered a few "God willings" throughout his proposed program for the Region.

In the midst of Owen's tirade against Lieutenant K. he wrote the H.O. "Let Mr. H., which the Providence of God and of the Admiralty may give me, be appointed to supercede Lieutenant K." but one year later, having had H. appointed Owen wrote "No task so repulsive and disagreeable as having to complain of my living instruments - but Mr. H. has quite disappointed me. He is too old to be teachable and too irascible and uncourteous to make any sort of rationalism agreeable even when the ends would be attainable. I know of no remedy but Abrahams with Lot - let us part". He reserved brevity for favourable comments and his highest approbation was "He is a gentleman".

But enough of Owen for the present.

Now the hydrographers may not have been happy with their most recent contract but what of working conditions in the past.

Bayfield on the St. Lawrence survey noted in his journal for 11th July 1842 "We gave ourselves and all hands a holiday today - the third in fourteen years; all the early part of the day however was occupied in cleaning the ship completely fore and aft".

And the following week "This if it had not been the Sabbath would have been a day in which we could have sounded 70 miles. I am convinced however that there is nothing lost in the long run by doing right".

Bayfield would probably have been quite happy to be in the field all year long as in 1827 writing of life in Quebec City he penned "This is the most dissipated place I ever was in, nothing but balls, dinners, suppers etc. and they that do not have the strength of mind to resist the temptation are likely to add about five years to their age for every one they pass at Quebec". And later, "There are also several very agreeable girls that I have no time to fall in love with permanently. I say permanently because I often fall in love with one or the other of them for a day or two - generally the last one I danced with. A kind look, or kind words lights up the flame - but triangles etc. quench at the next day". Think what a pocket calculator could have done for him!! "This is the case with C. - a fellow officer and when we happen to be in love with the same lady at the same time we play for her after dinner at Backgammon. I win nearly all of them from him to his great annoyance". I don't know if this is a reflection on Bayfields skill or the tact of his junior officer.

Later he wrote that he was half in love with two young ladies and that he was therefore like a jackass between two bales of hay but he married in 1838 and in January '39 "My beloved Fanny became a mother - this addition to my responsibility was given to me just nine months and twelve days after my marriage so you can see no great deal of time was lost".

By 1846 he was answering a letter "You asked me how many we have - only four with a narrow miss of having half as many more".

On the subject of families, Owen had two daughters, Portia and Cornelia - both named after ships he had commanded. Now Richardson McCulloch has a fine Scottish ring to it, Hudson Henderson an alliterative appeal, Sir John A. Macdonald Williams and Cartier Kerr would be politically committed for their lives but North Star Bolton!

We all have our problems with D.S.S. (Dept. of Supply and Services), who are keen on lowest bids and insist on supplying something similar to our requisition but not really filling the bill for our exact requirements. This type of bureaucratic stores control has been around for centuries as is evidenced by this reply to an Admiralty directive from Hurd, Hydrographer of the Navy in 1822. A fixed number of candles per ship per year had been laid down and Hurd commented "These vessels being employed on a particular service in search after hidden dangers and in the construction of sea charts for the general benefit of navigators which requires the free use of all kinds of mathematical instruments and apparatus whose delicate figures and divisions thereon marked, it would be difficult to make out without a good and strong light and as the duty of surveying officers on all open and fine weather days is occupied in making the necessary observations, they are constrained to commit to paper in the evening whatever has been the results of the day. Thus for the most troublesome part of their labours a strong light is absolutely necessary. I should presume a yearly sum of between ten and twelve pounds might be allowed the surveyor leaving him at liberty to supply himself with that kind of light most suitable to his own eye and the complex nature of his work".

I am sure that all Hydrographers-in-Charge would echo Bayfields comments from his journal for 30 May 1841 where he wrote "I made my cash accounts up to this day and thereby dismissed from my mind that part of my duty till next autumn, which will allow me to turn my undivided attention to the survey".

Those of you who have had to refer to old Admiralty charts may have wondered about the unusual scales used and apparent lack of standardization in these scales. Beaufort, as Hydrographer, wrote to Bayfield - "To lay down a priori any unbending rule to which a surveyor is to adhere in the scales of the several parts of his work is absurd. A chart larger than necessary is in my opinion a nuisance and the smallest space in which the most intricate places can clearly be shown is therefore the only rational law. The more compact in absolute as well as relative size, the more useful they are to the poor seaman".

But poor Captain Tooker of the Newfoundland survey had a blast from his Hydrographer when he submitted three sheets for engraving at a scale of 3/4 inch to the mile instead of 1 inch to the mile, the error being made during a change of command in the middle of the field season. A winters draughting was wasted. The error mitigated somewhat by the comment. "Do not put your inexperienced assistants to draughting charts for the engraver. To overhaul and correct such work here gives more trouble than if done here. We could not have engraved from the sheets sent in by them last year even if the scale had been right".

Another Hydrographer-in-Charge earned the following rebuke from London on his penmanship "It is also necessary I should point out that the figures used in your chart are of so diminutive a size it is very difficult to make out what the soundings are and will therefore thank you in future to have them enlarged".

As in the case today the hydrographer is always anxious to see his survey in print and cartographers were unable to meet production demands. Wharton wrote Boulton who was pressing for publication of his Georgian Bay charts "You must curb your impatience for its appearance. Our hands are very full but it will be taken up as soon as possible".

The chart planners of the last century also had their digs at the field men "Considering the short season in which the surveying vessel can work in Newfoundland too much time should not be taken up in superfluous detail. Distinction should be drawn as to the fullness of details bestowed on a harbour or anchorage of conspicuous merits, whether looked at politically or commercially and on a harbour or anchorage that in all probability is not likely to be of use at least to a very distant future".

However the same letter contained a paragraph that "Much that you have forwarded lately is so extremely minute in details that our Sailing Directions Department is becoming embarrassed as how to deal with such lengthened descriptions". That Stan Dee should be so embarrassed!

The practical mind of the hydrographers came to the fore in a flurry of correspondence about 1870 when the Fenian raids were a matter of concern. The Trans-Atlantic cable had just been completed to Newfoundland and thence across the Island to a second cable to the mainland. The brass bound military ashore were worried about the possibility of the Fenians getting a ship and cutting the cable offshore but in a matter of fact memorandum, Kerr of the Newfoundland survey pointed out that the weakest link in the system was its overland route where it was remarkably easy to shin up a pole and cut the wire. - End of correspondence with its schemes of patrols and on with the survey.

In the backward days of the last century tides were included in the general work of the survey and Owen got his first automatic gauge for Halifax in 1846, followed closely by Saint John Campobello - naturally - and Cape Sable. He agonized about the design for one for the Cumberland Basin with its 60 foot rise and fall however. As this was a previously unheard of range Owen had a grand plan for a series of gauges right up Fundy to measure the progression of the tide.

On the B.C. coast today the pilot of an inbound vessel can radio ashore and quickly obtain a height of tide for the Fraser. But one hundred years ago Pender arranged that the lightkeepers at Sand Heads signalled the height from a gauge by means of a special code of signals.

The problems facing todays ship division are those that have faced all ship operators throughout the ages. The ships assigned to survey duties were castoffs from the fleet. They were regularly surveyed and regularly condemned. Contractors were always trying to get a few more dollars for hire of their vessels. The ships found rocks the hard way. Their boilers wheezed their last. The first thing Pender had done for the Beaver was a new funnel casing for preventing the hurricane deck catching fire from the boiler room sparks.

One officer who served onboard the charter survey ship Ellinor of the Newfoundland Survey reminisces. "When in St. John's, Lloyds Survey on the ship came due and on inspection it was found that seventeen planks on the ships side required renewal. The Captain having satisfied himself that the contractor understood what was to be done went off on leave to New York. Later, when discussing the repairs with me, the contractor said he thought it was quite unnecessary to remove so many planks, and that a little paint would cover up any defects, remarking that it would mean £50 to me. I was rather shocked with this suggestion and on the Captains return told him about it - he laughed and said, don't worry they offered me £100!".

Good crews were hard to find for the tenders and other charter vessels. Lieutenant C. returned from Rivière du Loup with three men who "had never pulled an oar in their lives - we shall have to teach them" - and this comment in one form or another is recited by all survey parties.

Though there were no union contracts it was as difficult to fire poor seamen then as it is now. For example - "There was one man who had been drunk, insolent and disobedient, but upon reflection I could not punish him by stopping his wages without being subject to a lawsuit the result of which would have been doubtful and even if decided in our favour we should have had to pay the costs as he would sue me in forma pauperis. This took place last year when a man was declared to have partly forfeited his wages but the agent had to pay nearly double the wages forfeited in costs".

The crew were paid one months salary in advance and recovery of this advance was naturally well nigh impossible.

The lack of seamanship led to at least one incident which could have been serious but in retrospect was amusing. A poor Lieutenant returns to his base after a days hike over rough territory to report the loss of his boat and all equipment. It transpired that the Coxswain had anchored his boat for the night on too short a scope of cable. As the tide rose the anchor lifted and the boat drifted off in the darkness. The anchor caught ground again round a headland and on awakening the boat keepers were as surprised to find no one camped ashore - for one cove looked just like the next - as the shore party were to find no boat in their cove!

In another unseamanlike incident the Coxswain carelessly left the plug out of a boat which had been hauled on the beach at low water after having been scrubbed out at the end of a days work. At night the flood tide made, the boat filled, all the field notes and instruments were damaged and about ten days provisions were ruined.

William J. Stewart summed up the situation as well as anyone "It is a mistake to engage these young farmers who enjoy life at sea till the novelty wears off, then they want to go home to Mother".

For those of you who complain about the food onboard our ships I have some quotes illustrating the high standards of gourmet fare enjoyed by our predecessors.

"We began today to catch puffins and young gulls to make our provisions last out as long as possible. These are but indifferent food and my men would not use them until they learned my determination of not returning to the vessel till the work was finished and the consequent possibility of their being on short allowance".

Or on the Great Lakes.

"In the afternoon 17 chipmunks were trapped. Porcupine boullion for dinner, no pepper thus enhancing full porcupine flavour. We found a few potatoes which were duly incorporated in the boullion. Second course was hardtack, for tea fricassied chipmunk with the usual etceteras". However the following day "A supply of fresh trout put an end to fancy cookery".

William J. Stewart fired one cook with the remarks "He has not one redeeming quality, he cannot cook, is dirty and untidy". This coming about when the cook refused to bake bread as he was a chef - and it was not part of a chefs duties to make bread.

Of course even hydrographers are not infallible and have their moments of embarrassment.

His Royal Highness the Prince of Wales visited Canada in 1860 and the officer in charge of the St. Lawrence Survey wrote to the H.O. "I humbly suggest that the occasion of the Prince of Wales visit seems a proper opportunity for showing the usefulness of that branch of the service to which we belong and of which you are the respected chief. I believe no one afloat possesses a more thorough knowledge of the coast, of the soundings between Halifax, Sydney and Quebec than myself and no one can be more anxious to devote himself zealously and efficiently to the pilotage of the Royal Squadron through the Gulf of St. Lawrence. On no ordinary occasion would I have proffered my services but on the advent of H.R.H. the heir apparent to the British throne to these colonies I should be indeed gratified at having the opportunity of aiding in any way the successful prosecution of so auspicious an event".

Now the poor fellow has broken the old service rule of - never volunteer.

It may have seemed a good idea to get away from the monotony of the survey, meet with H.R.H. and all his accompanying brass, have a few decent meals, perhaps sample the Royal cellar etc. but little of this happened.

The Royal squadron left St. John's in a thick fog and had a dirty passage to Sydney. The weather was reasonable to Halifax but leaving there they were in thick fog through the Gut of Canso. Heavy rain and low visibility to Gaspé and there they went close in to allow H.R.H. a view of the town and took bottom. One hour later they were off again and picked up a pilot for the River Saguenay who promptly ran the ship Hero aground due to a buoy being out of position. Out sextant and fix the buoy and shoal. Onboard all the guns were run aft and off they went again.

However all ended well with - quote - gratifying testimonials from Commodore Seymour, The Duke of Newcastle and even H.R.H. the Prince of Wales did me the honour to thank me and make me a present of his own portrait. Perhaps Steve MacPheė could consider handing out autographed photographs to Hydrographers-in-Charge at the end of particularly successful seasons!

If anyone had the idea of going sick to avoid work it would appear from some journals that the cure was worse than the ailment. Entries in one medical case book or Nosological Journal as it was headed records "Bowels confined, which in all cases was dealt with by a dose of sulphate magnesia but one poor fellow who suffered from neuralgia of the facial nerve was treated by galvanic shock along the course of the reoccurrence of the paroxyms and quinine draft twice a day".

Though I've chosen my few anecdotes today from the lighter side of history I would like to end on a slightly serious note.

Today is yesterdays tomorrow. And every now and then we should look at our yesterdays to plan our tomorrows. A cliché it may be but history does repeat itself.

Governments in Canada have gone through periods of ignoring hydrography. It is not a high profile, vote catching way of spending money. But a neglect of continuing programs of hydrography has always ended in a tragedy the cost of which has often exceeded the costs of the abandoned survey program.

The French put their money into the fortress of Louisburg to the detriment of a survey program and the loss of the transport Elephant shocked them back to activity.

The loss of the steamer Asia in Georgian Bay after over fifty years of inactivity on the Lakes brought about the commencement of the Georgian Bay Survey, the immediate predecessor of the Canadian Hydrographic Service.

A few years ago the Sir John A. Macdonald was damaged in the Arctic. She could just as easily have been lost requiring a multi-million dollar oil spill clean up.

A steady but regular investment of a fraction of these costs, in well considered hydrographic survey programs would in the long haul be a saving to the Canada taxpayer.

There are lessons in history for all of us.

IMPROVED TECHNIQUES OF SHORT PERIOD TIDAL ANALYSIS

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ABSTRACT

Spectral methods of tidal analysis used in Brazil from 1971 onwards have been improved to analyse short tidal records. In addition, a cross analysis of short spans with the predicted tide of another place proved to be very fast and accurate enough to justify its current use. The predicted tide for Cananeia was used as driving function in cross analysis with the observed tide in Ubatuba for several spans. The two places are about 300 km apart and have very different topography. Notwithstanding high coherences were found even for the frequency corresponding to shallow-water constituents.

RÉSUMÉ

Les analyses de marée par la méthode spectrale, utilisées au Brésil, depuis 1971, ont été améliorées afin d'analyser les registres des marées de courte période. En outre, une contre-analyse des amplitudes de marées de courte période, en ayant recours à la prédiction des marées d'un autre endroit, s'est effectuée si rapidement qu'elle s'est avérée assez exacte pour justifier son utilisation courante. La prédiction des marées dans la région de Cananeia a été utilisée comme point de départ pour contre-analyser, avec la marée observée à Ubatuba, plusieurs amplitudes. Les deux endroits sont situés à 300 km de distance et leur topographie diffère. Malgré tout, on a découvert qu'il existait une grande cohérence, même pour ce qui avait trait à la fréquence correspondant aux composantes de marée en eau peu profonde.

1. BACKGROUND

As early as 1971 it was understood that the classical methods of tidal analysis were not sufficient to take all advantage offered by electronic computer. Thus the problem was studied in Brazil and a spectral method was drawn by Franco and Rock (1971), which proved to be as flexible as efficient. Hence an improved version of such a method was devised by France (1976) to analyse long series (2^{14} hours) of tidal records.

Very recently it has been more necessary to analyse short series (about three months) of hourly tidal heights and the refined mentioned method was generalized to handle tidal records of any length. Experience showed very good results.

However it has been concluded that shorter series would be better worked out through cross spectral analysis.

2. DIRECT ANALYSIS

The previously mentioned refined method of tidal analysis devised to handle long series of tidal heights proved to be very accurate and quick when 2^{14} hourly heights were analysed. Such a span is necessary to improve the resolution, reduced by the use of a cosine taper in the time series.

Recently, the method was generalized in order to handle shorter spans, because practical work showed that a series of 2048 (2^{11}) hourly heights the accuracy of the results were greater than that reached with the general method devised by Franco and Rock (1971). We will show now how we have arrived at this conclusion.

In the spectral methods of tidal analysis used in Brazil, the statistically unreliable constituents, selected according to the theory developed by Franco-Rock (1971), are preceded by an asterisk. Such a selection usually based on a 95% probability, showed so many astericks in a recent analysis of 2048 hours, that an attempt was made to apply the refined method. The results were not very different by the asterisk "constellation" was reduced. Thus the idea came to study the inverse symmetrical matrices multiplying the known vectors. A sample taken from a 9 species analysis (Table 2-1) shows that the matrix (upper part of the table) is almost diagonal. This means that the elements of the known vectors are almost independent of each other. In fact, the largest influence of neighbouring constituents is about 2.5%. The filtering effect produced by the cosine taper is excellent indeed.

It is interesting to note that the diagonals corresponding to the analysed species are all approximately equal to 0.667 and that the influence of neighbouring constituents are also about 2.5%. In addition, the background noise with frequencies different from each computed constituent has little effect on it.

The spectrum of residual amplitudes, in Table 2-1, indicates that, if any important constituent was ignored, its residual should be large and therefore should have been included in the analysis. This helps the selection of shallow-water constituents considerably.

3. CROSS SPECTRAL ANALYSIS

The method used to work out the

analysis is not the conventional one. Its theoretical basis is fully explained in Franco (1981), thus it is sufficient to mention here its main features.

If (t) is the observed tide and z (t) the predicted tide at a nearby port and the non coherent energy -

$$S_{vv}(p) = [1-\gamma^2_{z\zeta}(p)]S_{\zeta\zeta}(p) \qquad (3j)$$

are also computed. The latter is called here residual energy.

An important remark is that the results obtained with this method of analysis are nearly the same as obtained through the covariance method worked out with the same number of degrees of freedom.

In order to avoid to jeopardize the resolution of the analysis it is not convenient to use large values of ν. In current work we make $\nu = 3$. If the series is too short (15 days or less) we must use $\nu = 1$. In this case the coherence is equal to 1 for all ρ.

Since the tidal frequencies do not correspond to the Fourier frequencies the gain (3g) and the phase correction (3h) must be interpolated in order to obtain their values corresponding to the tidal harmonics. A second degree parabolic interpolation is sufficient. The interpolated gains multiplied by the amplitudes H of the constituents used to predict z(t) will give the amplitudes H corresponding to $\zeta(t)$. The interpolated corrections $\theta(p)$ added to the phase lags G of the above mentioned constituents in the series z(t), will give the desired G, referred to the observed series $\zeta(t)$.

An interesting remark is that even if the number of hourly heights is not a power of 2, the classical Cooley-Tukey F. F. T. algorithm can be used to work out the Fourier analysis. This is possible because the series z(t) and $\zeta(t)$ duly normalized, are both completed with the same number of zeroes, producing the same frequency shift in the harmonics of both Fourier series.

4. ACCURACY OF THE RESULTS

The spectral method is the most convenient to compare the accuracy of the results of several analysis. Using the harmonic constants obtained in any analysis, a tidal prediction is performed for any period covered by tidal observations. Then a spectral analysis of the residuals (difference between the prediction and the observation) is effected in order to obtain the residual energy spectrum. The spectral window ψ can be ignored in this case.

Since R_n is the amplitude of the residual auto-spectrum, the residual energy for each tidal frequency band is obtained by the sum of $R^2/2$, for the Fourier lines covering that band, and obviously the less residual energy the better the analysis results will be.

5. DESCRIPTION OF THE TIDAL ANALYSIS

The analysis was performed with hourly height samples from a continuous conventional tidal record obtained at Ubatuba, Flamengo Harbour, in 1977-1978. For the cross analysis, Cananeia was used as the standard port, about 300 km away from Flamengo Harbour (Fig. 1).

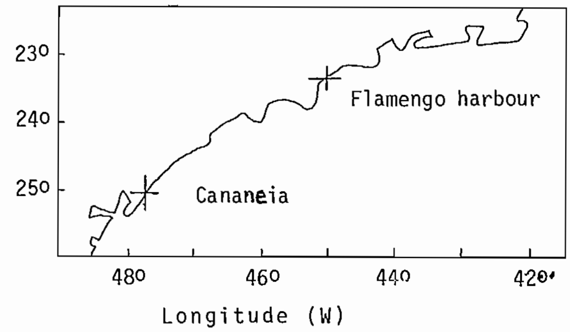

Figure 1 - Brazilian southeast continental shelf - Cananeia and Flamengo Harbour

The harmonic constants for Cananeia were obtained by finding the vectorial means of the harmonic constants computed in three analyses of 2^{14} hourly heights.

It is interesting to note that even the shallow water constituents were included in the prediction for Caneneia and in the cross spectral analysis. As a result of the cross spectral analysis, the coherence corresponding to the frequency bands of those constituents showed that the transfer function for these bands would be thoroughly used. Thus an important conclusion can be drawn: the shallow-water effect is a global phenomenon on the coast between Cananeia and Flamengo Harbour rather than in the very shallow-waters inside both harbours. Consequently cross spectral analysis is also valid to find harmonic constants of shallow-water constituents in large areas.

6. NUMERICAL RESULTS AND CONCLUSIONS

Table 4-1 lists the residual energy in cm^2 x hour for the tidal bands in each analysis as well as their constituents.

It is shown that for 360 hourly heights the harmonic constants obtained for 1C 360 are much more reliable than those found by D 360.

Except for 2048 hourly heights, the F method gave less accurate results than the D method. That can be easily explained: the F method reduces the resolu-

TABLE 2-1

CYCLES PER DAY: 2									
2NS2	MNS2	MU2	N2	M2	L2	S2	MSN2	2SM2	2SN2
0.6667									
0.0017	0.6667								
-0.0001	0.0017	0.6669							
-0.0000	0.0001	-0.0134	0.6669						
0.0000	-0.0000	0.0001	0.0017	0.6667					
0.0000	0.0000	-0.0000	-0.0001	0.0017	0.6669				
0.0000	-0.0000	0.0000	-0.0000	0.0001	-0.0134	0.6669			
-0.000C	0.0000	-0.0000	0.0000	-0.0000	0.0001	0.0017	0.6669		
0.0000	-0.0000	0.0000	-0.0000	0.0000	-0.0000	0.0001	-0.0134	0.6669	
-0.0000	0.0000	-0.0000	0.0000	-0.0000	0.0000	-0.0000	0.0001	0.0017	0.6667

DEGREES OF FREEDOM:	44
RESIDUAL ENERGY (CM2*HR)	5.02

SPECTRUM OF RESIDUAL AMPLITUDES									
DEG/HR	RES. cm	DEG/HR	RES. cm	DEG/HR	RES. cm	DEG/HR	RES. cm	DEG/HR	RES. cm
26.543	0.08	26.719	0.21	26.895	0.14	27.070	0.39	27.246	0.28
27.422	0.14	27.598	0.53	27.773	0.74	27.949	0.37	28.125	0.79
28.301	0.42	28.477	0.16	28.652	0.56	28.828	0.76	29.004	0.32
29.1B0	0.59	29.355	0.29	29.531	0.30	29.707	0.44	29.683	1.34
30.059	0.61	30.234	1.73	30.410	0.18	30.586	0.18	30.762	0.50
30.938	0.30	31.113	0.44	31.289	0.44	31.465	0.11	31.641	0.16
31.816	0.07	31.992	0.46						

at instant t, the Fourier analysis of these curves will be given the following complex Fourier coefficients:

$$c_n = \frac{1}{N}\sum_{K=0}^{N-1} z(k\Delta t)\exp(-i\omega_n k\Delta t)$$

and

$$c'_n = \frac{1}{N}\sum_{K=0}^{N-1} \zeta(K\Delta t)\exp(-i\omega_n k\Delta t)$$

where N is the number of samples, ω_n the angular frequency and Δt the sampling interval.

The smoothed cross spectrum is given by

$$S_{z\zeta}(p) = \sum_{n=p-\upsilon/2}^{p+\upsilon/2} 2c_n c_n'^{*}\psi(p-n) \qquad (3a)$$

where the asterisk indicates the complex conjugate of c_n, ψ is a smoothing function known as "spectral window" and $\upsilon+1$ is the number of harmonics covered by the spectral window.

The auto or energy spectra of the "driving function $z(t)$ and of $\zeta(t)$ are expressed, respectively by

$$S_{zz}(p) = \sum_{n=p-\upsilon/2}^{p+\upsilon/2} 2c_n c_n^{*}\psi(p-n) \qquad (3b)$$

$$S_{\zeta\zeta}(p) = \sum_{n=p-\upsilon/2}^{p+\upsilon/2} 2c'_n c_n'^{*}\psi(p-n) \qquad (3c)$$

The spectral window used in our practical work is normalized, i.e.

$$\psi(p-n) = [\psi_1(p-n)] / \Sigma\psi_1(p-n)$$

where

$$\psi_1(p-n) = \begin{cases} \sin \pi x / [\pi x(1-x^2)] & \text{for } x < 2 \quad (3d) \\ 0 & \text{for } x \geqslant 2 \end{cases}$$

$$x = 4(p-n)/\upsilon \qquad (3e)$$

Expression (3d) is the usual Hanning function.

The number of harmonics covered by the window is approximately equal the number of degrees of freedom.

The transfer function is obtained from (3a) and 3(b):

$$\omega(p) = S^{*}_{z\zeta}(p)/S_{zz}(p) \qquad (3f)$$

If we call $X(p)$ and $Y(p)$, respectively the real and the imaginary parts of $\omega(p)$ we have

$$|\omega(p)| = \sqrt{X^2(p)+Y^2(p)} \qquad (3g)$$

for the gain and

$$\theta(p) = \arctan [Y(p)/X(p)] \qquad (3h)$$

for the phase lead.

The coherence

$$\gamma^2_{z\zeta}(p) = |S_{z\zeta}(p)|^2 / [S_{zz}(p)\ S_{\zeta\zeta}(p)] \qquad (3i)$$

Table 4-1

ℓC - cross analysis with a spectral window covering ℓ harmonics
D - direct analysis without cosine taper
F - direct analysis with cosine taper

These symbols are followed by the span's extension in hours

Nº of Const. Species 1 - 6	A-nalysis: Code, Nº of Points \ Species	1	2	3	4	5	6	Residual Energy Species 1 and 2	Residual Energy Species 3 to 6	Residual Energy Species 1 to 6
32	1c 168	38.06	27.50	7.05	5.90	1.65	3.24	65.56	17.84	83.40
38	1c 360	10.53	17.47	2.55	3.25	1.69	0.94	28.00	8.43	36.43
08	D 360	12.76	29.80	2.80	10.53	1 54	1.38	42.56	16.25	58.81
32	3c 1024	7.01	12.20	4.11	2.38	1.90	1.20	19.21	9.59	28.80
17	D 1024	2.98	8.55	1.49	3.09	1.40	1.01	11.53	6.99	18.52
19	F 1024	2.93	9.45	1.35	3.03	1.54	1.09	12.38	7.01	19.39
33	3c 2048	7.94	7.20	1.53	2.68	1.40	1.02	15.14	6.63	21.77
29	5c 2048	6.86	8.80	1.08	2.26	1.53	1.18	15.66	6.05	21.71
20	D 2048	3.01	10.53	1.23	3.31	1.20	0.85	13.54	6.59	20.13
25	F 2048	3.05	8.70	1.11	3.41	1.28	0.90	11.75	6.70	18.45
29	3c 2880	4.62	5.24	1.26	2.39	1.37	1.18	9.86	6.20	16.06
23	D 2880	2.98	7.87	1.24	2.97	1.16	0.86	10.85	6.23	17.08
55	D 10944	2.02	4.17	0.86	1.36	0.96	0.59	6.19	3.77	9.96
57	F 10944	2.15	4.28	0.99	1.39	0.99	0.62	6.43	3.99	10.42

tion of constituents of nearby frequencies, thus when the series length does not balance the reduction of the resolution, no improvement results from the use of the cosine taper. This is exactly what happens with all the direct analysis, ex- for the 2048 hour series.

It became evident in this research that the statistical selection of the constituents in the direct methods of analysis is very efficient. In fact, when the flagged constituents are included in the predictions the results are worse than if such constituents are neglected.

The direct methods of analysis are very quick; consequently, even for a one year analysis, there is no harm done in considering a large number of constituents (about 100 up to the sixth diurnal), and use in predictions the not flagged constituents only.

An interesting remark is that in the F method, the adopted probability to reject constituents was 99%.

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THE LEGAL LIABILITY OF THE CHARTMAKER

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ABSTRACT

Recent developments in the law have imposed increased liability and responsibility on Government Departments and Agencies providing services to the public. The Canadian Hydrographic Service as the Crown Agency providing reliable information to the marine navigator must be aware of the legal responsibilities and duties and the extent to which the Crown may be liable for shipping casualties and other marine accidents.

The degree of reliance placed on charts and other nautical publications of the C.H.S. potentially expose the Government of Canada, under the Crown Liability Act to claims by ship owners, cargo owners for damages ranging up to many millions of dollars based upon misleading or inaccurate charts. Members of the C.H.S. need to be aware of this responsibility and take all necessary measures to protect and to limit this potential exposure of the Government of Canada. The importance of the C.H.S. establishing standards of excellence and providing for mechanisms to ensure that these standards of excellence are met is emphasized. Special reference is made to the legal problems and other scientific investigations and the manner by which the Crown can discharge its responsibility and limit its liability therefor.

The heavy reliance by Government and the marine public on the hydrographer's creditability and expertise is also described as well as the use to which the information and results are put. The legal problems associated with changing technology, new procedures and the updating of older charts and publications to meet modern charting standards are reviewed and discussed.

RÉSUMÉ

Des récentes réformes à la législation ont imposées de plus grandes responsabilités aux sociétés et ministères du Gouvernement qui assurent des services au grand public. En fournissant de l'information fiable aux navigateurs maritimes, le Service hydrographique du Canada, à titre de société de la Couronne, ne doit pas ignorer ses responsabilités et engagements juridiques et jusqu'à quel point le Gouvernement fédéral peut être tenu responsable d'accidents de navires et autres incidents maritimes.

Le degré de fiabilité que l'on accorde aux cartes et autres publications nautiques du S.H.C. peut, en vertu de la Loi sur la responsabilité de la Couronne, obliger le Gouvernement canadien à respecter les demandes d'indemnité de plusieurs millions de dollars, provenant des propriétaires de navires ou de cargos pour des dommages causés par des cartes erronées ou inexactes. Il faut ainsi sensibiliser les employés du S.H.C. à cette responsabilité et prendre les mesures nécessaries pour protéger le Gouvernement de cette éventualité, ou tenter du moins de la limiter. L'accent doit être mis sur l'importance pour le S.H.C. d'établir des normes d'excellence et de prévoir les dispositions visant à assurer qu'elles sont respectées. Nous nous reportons notamment aux problèmes d'ordre juridique qui sont reliés à l'adjudiction de contrats de levés ou d'autres enquêtes scientifiques et la façon selon laquelle la Couronne peut s'acquitter de ses obligations et ainsi limiter son degré de responsabilité.

La grande fiabilité du Gouvernement et des employés maritimes, pour ce qui est de la crédibilité et de l'expertise des hydrographes, y est également décrite, de même que l'utilisation de l'information et des résultats. Les litiges relatifs aux changements apportés aux techniques, aux nouvelles procédures et à la mise à jour des vieilles cartes et publications, afin de satisfaire aux normes modernes de la cartographie, sont également passées en revue et font l'objet de discussions.

Admiral Beaufort's Revenge

1. My topic is the legal liability of the hydrographer.

2. My text is taken from the eleventh edition (1910) of the Encyclopaedia Britannica. It is written by Captain Thomas Hull, formerly Superintendent of Admiralty Charts. He writes:

"The ocean and general charts are compiled and drawn at the Hydrographic Office, and as originals, existing charts, latest surveys and maps, have to be consulted, their compilation requires considerable experience and is a pains-taking work, for the compiler has to decide what to omit, what to insert, and to arrange the necessary names in such a manner that while full information is given, the features of the coast are not interfered with. As a very slight error in the position of a light or buoy, dot, cross or figure, might lead to grave disaster, every symbol on the admiralty chart has been delineated with great care and consideration, and no pains are spared in the effort to lay before the public the labours of the nautical surveyors and explorers not only of England, but of the maritime world; reducing their various styles into a comprehensive system furnishing the intelligent seaman with an intelligible guide."

3. My Subject Matter is hydrography which I define as follows:

HYDROGRAPHY (Gr. vowp, water, and ypaoelv, to write), the science dealing with all the waters of the earth's surface, including the description of their physical features and conditions; the preparation of charts and maps showing the position of lakes, rivers, seas and oceans, the contour of the sea-bottom, the position of shallows, deeps, reefs and the direction and volume of currents; a scientific description of the position, volume, configuration, motion and condition of all the waters of the earth.

4. The chart is the product of the hydrographers labours. The first Admiralty chart was published in 1801. The Admiralty had to be persuaded to put their charts on public sale, a major change from the days when national security was considered paramount. J.D. Potter Ltd., in the City of London, sold charts for 150 years. Potter's advertise that their chart warehouse has a stock of 65,000 charts. It is fair to say that millions of copies of charts are sold worldwide every year.

The chart is, or used to be, the navigators working document. Its objective must be clarity. The battle has always been to avoid encumbering the chart with detail which is not essential for its navigation purpose.

Unlike other surveys, the chart shows the navigator what he cannot see. The chart shows him the shape and depth of the bottom. For practical purposes, the navigator must put his faith in the chart to tell him where he can safely go and where he cannot go. The navigator may have no other means of knowing.

The chart's reputation for accuracy is legend. It is said that the first hydrographer of the Navy, Alexander Dalrymple, was hesitant to publish any material of which he was in doubt or of which he had no personal knowledge. Admiral Beaufort, we are told, personally signed each and every chart published during his 26 years as Naval Hydrographer.

Even though Dalrymple may have been meticulous, these high standards of integrity and accuracy are so well established today that no backsliding will be excused.

I have taken some of your valuable time to set this stage for my second discussion of the hydrographer's legal responsibility.

My purpose in doing so is to emphasize once again the reliance the navigator places on the marine chart and accuracy of the information depicted thereon.

When I last spoke to some of you in Victoria in 1969, I was able to say, and did say, "that the courts in Canada have not dealt with a case involving an allegation of negligence on the part of the chartmaker. If and when that case arises (and we hope it will not arise) it may be possible to give more advice."

As you may know, my last prediction was only good for five years.

Before I discuss the case of the GOLDEN ROBIN, I will outline the legal basis to which under the laws of Canada, the chartmaker (and more importantly, his employer), is exposed.

A. Legal liability may be based either on contract or in tort ("delict" in province of Quebec).

B. In contract, the liability will arise if there is an agreement to supply an accurate chart and the supplier provides an inaccurate chart. The other person can then claim there has been breach of contract and can sue the supplier of the chart for any damages resulting from the breach. This type of claim would be rare.

C. The more common case is a claim in negligence. The user of the chart sues the Crown for the negligence of a person to act carefully where the law imposes on him a duty to act carefully.

D. A chartmaker or hydrographer is a professional and, in law, is expected to exercise the skill and competence of an ordinarily competent chartmaker or hydrographer.

E. Under the Crown Liability Act, the Crown (H.M.Q.) is responsible for the negligence of the Crown-employed hydrographer and for any damages suffered by the chart-user caused by that negligence.

F. To succeed, the chart-user must establish:

1. He relied on the accuracy of the chart;
2. The chart was inaccurate or misleading;
3. The chart was inaccurate because the hydrographer was careless;
4. The damages claimed were caused by that inaccuracy and not by

an error of navigation.

In my 1969 paper, I reviewed a number of these issues in detail viz:

1. The duty to be careful;

2. The applicable standards and the application of those standards to specific facts;

3. The use and misuse of charts by navigators;

4. Warnings on charts and disclaimers of liabilities. I refer you to my 1969 paper for that discussion.

Now the GOLDEN ROBIN (Ex. Esso Oxford) which grounded on Dalhousie Island while approaching the harbour on a beautifully clear morning, 30 Sept. 1974. The owners sued the Crown under the Crown Liability Act for $2,000,000 for the ship as a constructive total loss. The claim was based on various allegations including a claim that C.H.S. Chart 4426 was both incorrect and misleading, as read in conjunction with two Notices to Mariners, which were alleged to be incomplete or inaccurate.

The trial was heard in Montreal in Sept., 1980 and the trial judge, Mr. Justice Addy, of the Federal Court of Canada, on Nov. 26, 1980, dismissed the action. The case is now under appeal. In doing so he did make some useful and some helpful remarks about charts in general and about the allegations in particular.

At page 16, he points out:

"Charts are representations of the nature, character and position of navigational aids as well as of the land and bottom configuration, depths and other features of both the shore and the sea bottom. The information given speaks, of course, as of the date of the last survey which is always indicated on the face of the chart. The last survey for the chart in issue was 1966, eight years previous to the accident. The previous surveys were taken in 1923 and 1964. In addition, a chart is to be read subject to all reservations shown on the chart itself and subject to any instructions, notices, cautions and other hydrographic and navigational information communicated in conjunction with, previous to or subsequent to the publication of the chart and which are required to be read with it.

All information contained on a chart is there primarily for navigational purposes. It is, therefore, addressed to mariners, that is, persons who are presumed to possess a working knowledge of seamanship, navigation and related subjects such as winds, tides and currents and who are, therefore, presumed to read and apply the information on the chart in the light of that expertise.

With regard to soundings, they are not a standing offer of depth, that is, they do not constitute guarantees that the depths shown will remain or be maintained, unless there is representation to that effect on the chart."

Addy J. reviews the survey evidence on which the Notices to Mariners were issued, and at page 20, says: "On examining the 1973 survey, there is no doubt that, at that time also, the defendant's servants in the Hydrographic Survey Services, if they even looked at the document, could not help but be fully aware that a shallow depth of some 26 feet extended across the range line to a distance of some 25 feet south of the line. The chart itself, since it was coloured white at that point, represented that all depths for some distance north of and on the range line as well as south of it were over 30 feet above chart datum and, furthermore, the nearest sounding figure showed seven fathoms or 42 feet above datum.

I reject the evidence of the expert hydrographer of the defendant who stated that the reason why the chart itself was not amended either in 1972, 1973 or before the accident was because, being of such a small scale, that is 1:36,360, more information could not be inserted without cluttering it up and rendering it difficult to read and decipher. In the first place, the warning could have been accomplished very easily by a proper Notice to Mariners describing the extension of the shoal as discovered in 1972, much along the same lines as the inter-departmental report quoted above, rather than by merely indicating the presence of two-spot soundings. In the second place, and more importantly, in 1976 an amendment to the chart was published extending the 30-feet contour by a dotted line well south of the range line and the chart remains every bit as clear and legible as it was previous to the amendment.

It is not an answer to say that no hydrographer contradicted this evidence at trial. A chart is not addressed merely to hydrographers."

Finally at page 24, Addy J. sets out the Court's opinion of the chart:

"In the case at Bar, not only is the representation made for a public purpose or object (i.e., aiding and assisting navigation in the area) as opposed to a private object (i.e., advising an individual), but the representation itself is made to and intended for the public, namely all mariners who might be expected to use the chart. It was also made with the full knowledge and expectation on the part of the authority making it, that it will be relied on by the masters of ships and other craft sailing those waters, to ensure the safety of their vessel, cargo and passengers. Where such public representations for public purposes are made, with full expectation of a reliance on the representations, there is no need for the existence of any greater particular or special relationship between the person making them and person relying on them for a duty to take care to arise. In addition, where, as in the present case, the safety of many lives and serious damage to property might well be at stake, and the breach of duty may thus result in very serious consequences, the degree of care must be correspondingly high."

The crux of the case appears on page 22. The Court finds that the two Notices to Mariners issued prior to the casualty were misleading in the context of hydrographer's knowledge at that time. As they dealt with soundings at or near a recommended track shown on the chart, a "critical and sensitive area" in the words of the court.

In the result, the court did not have to decide whether the hydrographer was liable in tort or not (p. 27). The Court found at page 36 that neither the Captain nor the Pilot ever consulted the chart and neither were, in fact, misled by the misinformation in Notices to Mariners.

So the issue is still open or is it?

As this case is under appeal, we must wait the final decision of the Court. There is always a possibility of further appeal to the Supreme Court of Canada which could take several years.

There are and will be other cases. In the world of modern shipping, and modern financing, shipowners are compelled to increase the earning capacity of their ship. To do so, it is likely that margins of safety and prudence will be compromised. The result can be the "excessive dependence" on the accuracy of the information on the chart.

Limitation of Legal Liability

You may ask why should a hydrographer or his employer render themselves liable for millions of dollars of damage for supplying a chart at a price of $5.00. This potential liability has also concerned some courts. In 1951, an English judge said this: "The Captain of the Queen Mary, in reliance on a map (i.e. a chart) and having no opportunity of checking it by reference to another chart steers her on the unsuspected rock, and she becomes a total loss." Is the unfortunate hydrographer to be liable to her owners in negligence for some millions of damage? If so, people in the future will think twice before making maps. Hydrography would become an ultra-hazardous occupation.

In 1965, I raised with the then Dominion Hydrographer, Mr. Gray, the possibility of the C.H.S. putting a cautionary note on the charts to the effect that Her Majesty does not assume any responsibility for any errors or omissions that may exist on the chart. Mr. Gray expressed the opinion that such a note would be "a retrograde step greatly lowering our prestige and not be in conformation with the policy with other major hydrographic offices or of the International Bureau". At that time, the total claims being made against the C.H.S. amounted to $500.00. Now the total claims against the C.H.S. are in the neighbourhood of ten million dollars. Assuming that there is no change in policy, the question remains as to whether the chart should be more explicit as to what it shows and, more importantly, what it does not show. Although each C.H.S. chart refers the navigator to Chart No. 1 (now a folder), I find that in practice, very few ships masters admit that they have ever seen chart No. 1 let alone read it in its entirety. This is a fact that must be reckoned with.

Contract Hydrography

It is an unfortunate sign of the times that hydrography can be privatized.

When the issue was raised in 1977, I provided an opinion to the Dominion Hydrographer which concluded with this paragraph:

"If all the essential steps of chart making are not carried on by the government, with government resources and government people, then the ability to provide legal proof of the data exhibited on a chart may be impossible where the private industry who did the work has gone bankrupt or has ceased to exist and its records destroyed. Essentially, the problem with these management techniques is that they do not give any weight to the quality of the survey work performed, the historical continuity of the surveys and the promotion of national and international standards of hydrography and chart making."

In spite of my advice, the Treasury Board directed the Dominion Hydrographer to contract out some hydrographic surveys. One of the most recent is the Survey of Lake Manitoba, Manitoba the contract for which I have read with interest. I am afraid to say that the difficulties raised in my letter have not been solved. The key question of legal liability is left largely in doubt. The contractor's warranty is only as to competency and qualification. The quality of service is only "at least equal to that which contractors generally would expect of a competent contractor in a like situation". Such a measure of legal liability cannot be tested in the courts because the concept is elliptical.

Furthermore, the contractor is not required to insure himself against future liabilities that may arise because the Crown relied on the data produced by the contractor which may turn out to be faulty. On this point, I should say that, in the good old days, such a situation would not arise. In 1766 the Royal Society proposed an expedition in the South Pacific. Dalrymple was suggested to be the leader. The Admiralty, however, insisted that the expedition be lead by a naval officer who turned out to be Captain James Cook who sailed in 1768 in command of what was to be the first of his three great voyages of discovery.

Conclusion

The fact is that allegations of negligence are being levelled at hydrographers in many marine casualties. Although we have escaped so far, the C.H.S. must be prepared to defend its actions and standards in court. There is no doubt, in my view, that hydrography has become an ultra-hazardous profession and the C.H.S. must govern itself accordingly.

A final word - in this modern age of digitizers, electronic distance measuring equipment, mini-computers and automated plotting, the hydrographer should not be afraid of getting his feet wet.

The opinions expressed in this paper are entirely those of the author and are not intended to represent the views of the Government of Canada nor the Department of Justice.

A HISTORICAL REVIEW OF TIDAL, CURRENT AND WATER LEVEL SURVEYING IN THE CANADIAN HYDROGRAPHIC SERVICE

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ABSTRACT

This paper presents a perspective of the history of tidal, current and water level surveying in Canada, highlighting the development of surveying techniques, instrument technology, data processing and archiving procedures, and analysis and prediction methods. Individuals making prominent contributions to the above fields are mentioned. Major organizational changes that have taken place over the years are described.

RÉSUMÉ

Ce présent document offre une perspective historique sur les levés hydrographiques destinés à étudier les marées, les courants et les niveaux d'eau au Canada, et il décrit la mise au point des techniques et des instruments de levés, des procédures de traitement et d'archivage des données et des méthodes d'analyse et de prévision. Les personnes qui ont largement contribué à faire progresser les domaines ci-dessous sont mentionnées. Les auteurs décrivent aussi les principaux changements survenus au fil des années au niveau de l'organisation.

INTRODUCTION

The history of tidal, current and water level surveying in Canada for navigational applications has always had a close association with the Canadian Hydrographic Service, although none of these activities actually got started under the auspices of C.H.S., they all eventually found their way into the Service.

The level of activity and development within each field of interest has had peaks and plateaus. The early days of tidal and current surveying under Dr. W. Bell Dawson and water level gauging under Mr. C.A. Price saw the rapid expansion of new programs under the guidance of dedicated individuals and often in spite of rather limited funding. The 1930's, 40's and early 50's generally saw less development but, rather, programs with well-defined objectives being properly managed. The late 50's and 60's heralded a period of rapid development in instrumentation and techniques which continued through the 1970's and into the 1980's as changing technology offered better methods of performing old tasks.

This paper will review each phase of development within the fields of tidal, current and water level surveying and will search out the highlights of each. That is to say each phase will be reviewed except for the 1970's and 1980's. Since the authors are part of this era it cannot be regarded as history and will be left for some future surveyor to chronicle.

TIDAL AND CURRENT SURVEYS

Prior to the establishment of a formal tidal survey group in the late 19th century little had been done in the way of systematic tidal or current surveying in Canada. Tidal records had been obtained at several major ports and were used to provide tidal predictions based on differences referred to the tide at various foreign ports. However, the only well documented records available were those collected at Halifax during the periods 1851 to 1852 and 1860 to 1861.

Concerned over the increasing number of shipping disasters in the St. Lawrence River and Gulf of St. Lawrence, the British Association appointed a committee in 1884 to collect information on the importance of publishing tide tables for Canadian waters and the necessity of carrying out tidal surveys. After several unsuccessful petitions to the government, authorization was finally given in 1887 for Lieut. Andrew Gordon of the Royal Navy to take tidal observations at Georgetown, P.E.I., and at Louisbourg, Pictou and Port Hawkesbury, N.S. These surveys confirmed that large errors existed in the predicted tides available at that time. Under pressure, the government finally authorized the expenditure of $2000.00 in 1890 to make some further preliminary observations, to purchase 3 tide gauges, and to process the records obtained at Halifax during 1860 to 1861.

The survey was conducted by Lieut. Gordon with the objectives of establishing the suitability of Halifax as a reference station and of determining tidal differences for the whole eastern coast of Nova Scotia. Mr. Carpmael, who was at the time the Director of the Meteorological Service, assisted the Minister of Marine in the design and procurement of equipment required to set up a self-recording tide gauge. After consultation with Professor G.H. Darwin, of Cambridge, three float-operated, drum-recording gauges devised by Sir William Thompson (Lord Kelvin) were acquired. The 1860-61 Halifax records were processed and analyzed by

Mr. Edward Roberts of the Nautical Almanac Office in London, and the harmonic constants obtained were used to predict the tide for 1891. This was done using a tide predicting machine designed primarily for the prediction of tides in India.

After the death of Lieut. Gordon in 1891, the tidal work was left entirely to Mr. Carpmael. Between 1891 and 1894, the department allocated $10,000 annually for tidal surveys. By 1893, gauges were operating at Saint John, N.B., St. Paul Island, N.S., Southwest Point (Anticosti), Magdalen Islands (Grindstone), and Québec, P.Q. In addition, construction of a gauge at Pointe-au-Père had begun.

The Dawson Era

The appointment of Dr. W. Bell Dawson (Figure 1) as Engineer-in-Charge of the Tidal Survey in 1893 marked the beginning of a systematic survey of tides and currents in Canadian waters which would result in a much improved understanding of the characteristics of these phenomena and an ability to produce accurate predictions of their occurrence. Dr. Dawson reported to Mr. P. Anderson, Chief Engineer of Technical Branch, Dept. of Marine and Fisheries, at the time of his appointment, and it was not long before he had submitted plans for both tidal and current surveys, including a request for $29,000 for the 1894-95 fiscal year. This budget allowed for the construction of new gauges at Halifax, Belle Isle and Yarmouth, the publication of tide tables and the charter and outfitting of a steamer for a 4-month current survey. Although only $10,000 were appropriated Dawson also obtained the use of the government steamer LANSDOWNE for 3 months.

Tidal Surveys

In 1894, Dawson submitted a plan to establish principal tidal stations at 4 sites on the East Coast and 3 sites on the West Coast. These were carefully chosen to provide tidal data required in the subsequent tidal current surveys and to serve as reference stations for the prediction of tides at other ports in the areas.

The typical self-recording tidal station of Dawson's era was equipped with two stilling wells secured to the side of a wharf or a crib. The well was made of planking with an inside dimension of about 10"x14". One of the wells served a float operated recorder, and the other a sight gauge. Piping was often required to extend the intake to greater depths, and the laying of the intake pipe was an expensive and labourious undertaking. One of the most difficult stations established by Dawson was that at Pointe-au-Père, where 2 sections of intake pipe were installed. The first section was 260 ft. long, and was made of 12 inch diameter logs with a bore 3 inches in diameter. It was laid in a trench 9 to 10 ft. deep dug through a rocky foreshore. The second section extended the intake a further 140 ft. and was made of 2" diameter iron pipe.

A shelter built over the well housed the recorder. In the winter, heat was supplied by an oil lamp or a small oil stove which frequently malfunctioned and generally produced considerable smoke. The smudge settled on the clockwork, necessitating frequent cleaning and occasional repair.

The 3 Kelvin tide gauges acquired initially by the department recorded the tide levels on a drum recorder whose rotation was clock controlled.

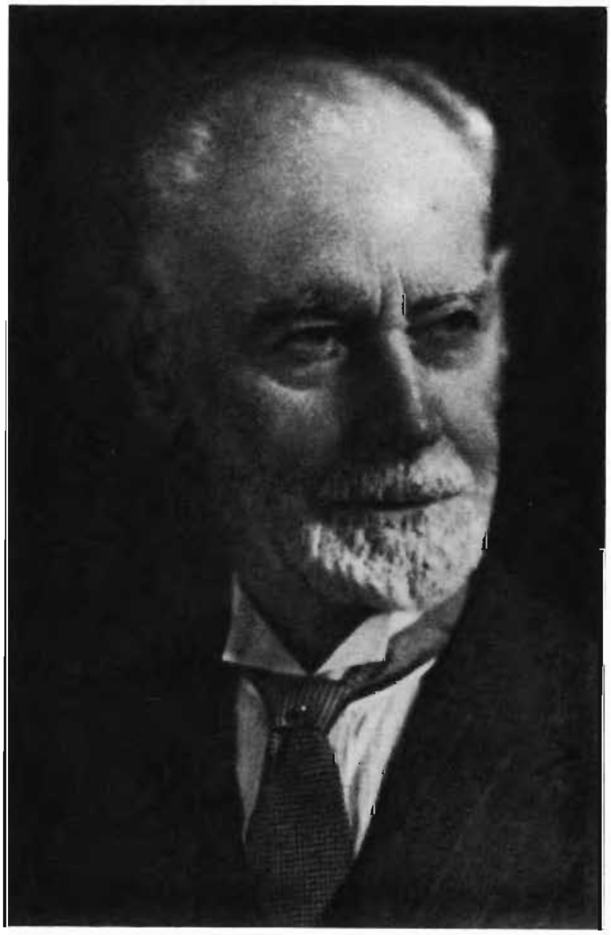

Figure 1. Dr. W. Bell Dawson

Where possible, the timing of the clock was regulated once a week by telegraphic exchange. Otherwise, a meridian instrument called a dipleidoscope was installed near the station to provide accurate time (Figure 2). In 1900 chronometers were installed at the tidal stations.

When the clock in a Kelvin gauge malfunctioned, the whole unit had to be removed and shipped for repair. To overcome this problem Dr. Dawson devised a gauge whose clock could easily be detached for repair and which was also capable of recording tides of different ranges. This gauge was manufactured by Messrs. A. Légé & Co., London, England and is shown in Figure 3 installed at Charlottetown, P.E.I.

The permanent gauging stations were visited on a regular basis and spirit levels run to the bench marks yearly (Figure 4). The work of establishing and documenting bench marks and datums was of considerable importance to Dawson (Figure 5). Prior to the establishment of the Tidal Survey, chart datums and the datum planes for marine construction or harbour improvements were not generally well documented. Dawson spent a great deal of effort to re-establish these datums by installing better bench marks, carrying out tidal observations and precise levelling, and documenting and publishing the information. His 2 publications "Tide Levels and Datum Planes on the Pacific Coast, 1923" and "Tide Levels and Datum Planes in Eastern Canada, 1917" are evidence of this commitment.

Dawson had also carried out short period tidal observations at many places to establish the tidal adjustment for secondary port predictions. The 1925 Tide Tables contain data for approximately 350 secondary ports.

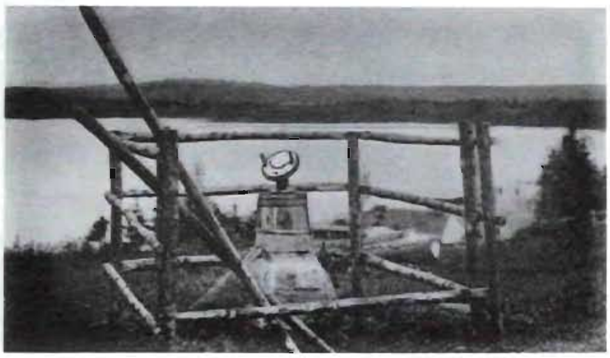

Figure 2. Meridian Instrument

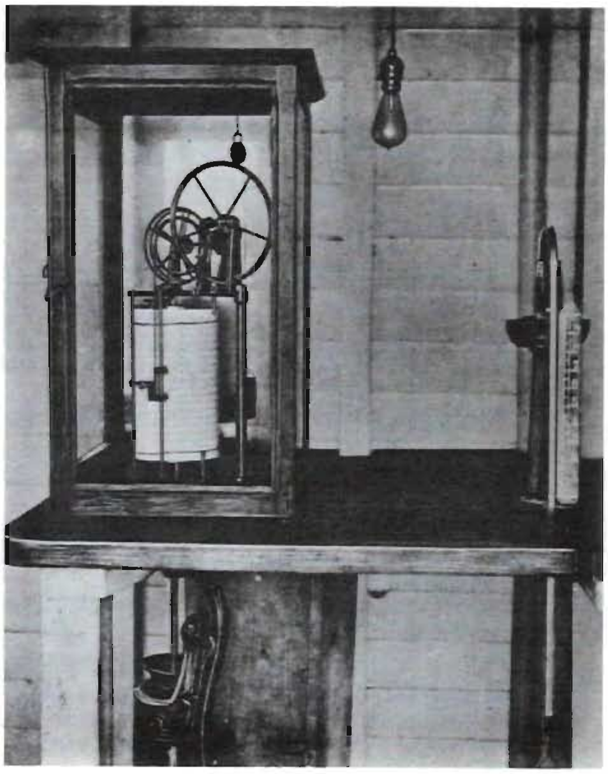

Figure 3. Tide Recorder and Sight Gauge, Charlottetown, P.E.I.

The tabulation of tidal records and their subsequent analysis were very time consuming and expensive. For example in 1900 Dawson estimated the cost of processing 2 years of records from Quebec City at $450. Because the analysis of all records could not be funded many were used simply to establish the tidal difference between the port where the record was obtained and a selected reference port.

A fire in February, 1897 destroyed the attics of the Marine Department in which the Tidal Survey Office was located. Copies of 3 years of tidal records from Victoria and Sand Heads, supplied by the Department of Public Works, were lost (although they were later replaced). In 1898, the whole of the original tidal record for the Pacific Coast was lost in fire at New Westminster, and the copies previously supplied to the Tidal Survey were the only ones left in existence. These events prompted Dr. Dawson to urge that more funding be made available for the tabulation and analysis of the tidal records.

The first predictions computed for a Canadian port from harmonic constants were those for Halifax for 1891 mentioned earlier. Although these were published they did not enjoy a wide

Figure 4. Dr. Dawson (left) and H.W. Jones Inspecting Port Alberni Tide Station, 1909

circulation. It was subsequently decided to supply the tables directly to the leading almanacs without any charge in hopes that this would improve distribution. In the following years tide tables were again supplied to almanacs but were also distributed directly to newspapers and to steamship companies. The first set of tide tables printed by the department were those for Charlottetown, Pictou and St. Paul Island beginning in 1898, and the second set were those for Victoria and Sand Heads in 1901.

In his 1897 annual report, Dr. Dawson indicated the need to print tide tables for Halifax, Saint John and Quebec City in one volume. Again the lack of funding prevented this and it was not until the publication of the 1904 tide tables that this volume was printed, and included, as well, predictions for Pointe-au-Père. In 1907 the tide tables were printed in two volumes, one volume for the Eastern Coasts, and the other for the Pacific Coast.

The last tide tables published under Dr. Dawson's supervision were for the year 1925 and contained a total of 16 tidal reference ports and 7 current reference stations. At that time there were 13 principal tide stations in operation, distributed between the East and West Coasts as listed below:

West Coast	East Coast
Vancouver	Quebec City
Caulfield	Pointe-au-Père
Prince Rupert	Point Peter
Victoria	Charlottetown
Clayoquot	St. Paul Island
Esquimalt	Saint John
	Halifax

Current Surveys

Dawson's eight year plan submitted in 1894, recommended that current surveys be carried out in the following areas: Anticosti Island, the Strait of Georgia and its connecting channels, Cabot Strait and the Strait of Belle Isle. The main objective of the surveys was to gather information along the routes of the steamship and sailing vessels on the Atlantic Coast, in the St. Lawrence River System, and through the Strait of Georgia. Although deep currents were occasionally measured, greater emphasis was put on the surface current, at depths of about 18 feet, which had a direct effect on vessel movement.

In 1894 Dawson carried out his first current surveys in the Strait of Belle Isle and Cabot Strait using the vessel S.S. LANSDOWNE of the Lighthouse and Buoy Service. The following year he surveyed the entrance to the St. Lawrence Estuary between Gaspé and Mingan and, in 1896, the channel between Anticosti Island and the Strait of Belle Isle. Whenever possible, records were taken day and night.

From the direct measurement of currents and other physical properties of the waters carried out during these three surveys, Dawson was able to provide badly needed information to the marine and scientific communities. These findings were cited in a variety of scientific and commercial journals.

Figure 5. Bench Mark at Halifax Dockyard

In 1897, after 3 successful seasons, the offshore current surveys were discontinued because Dawson felt that the vessel "Lansdowne" was not suitable for efficient survey operations. He requested that a properly equipped steamer be made available for future use.

In the meantime shored-based current surveys were carried out at L'Islet in the Upper and Lower Traverse of the St. Lawrence River in 1900, at First Narrows in Burrard Inlet in 1901, and at Cape Tormentine and Cape Traverse in Northumberland Strait.

The purchase of the steamer GULNARE in 1903 allowed offshore operations to resume. The survey that year took place mainly off the southeastern coast of Newfoundland along the European steamship route. The following year the survey moved to the entrance of the Bay of Fundy, extending from Grand Manan Island to Cape Sable. Areas surveyed in later years included Northumberland Strait and return visits to the Gaspé Passage and the Strait of Belle Isle.

Offshore current measurements were carried out by anchoring the ship on station and either lowering current meters over the side or tracking drift buoys, icebergs or other floating objects. Difficulty was experienced in maintaining the ship on station because of a lack of proper anchoring equipment. The LANSDOWNE, in particular, was very heavy and, having a high freeboard, could easily be moved off station by strong winds.

Current meters used during the surveys had either anemometer or propeller type rotors. Dawson felt that the anenometer type was more suitable for the marine environment because it was less affected by the vertical motion of the waves and the rolling of the vessel. The propeller type was apt to "head up" or "head down" as the vessel rolled and so gave an exaggerated record. The direction of the current was determined from the horizontal angle of the line supporting the meter. A deep fan was also used which consisted of two sheets of galvanized iron passing through each other at right angles and supported by a light wood frame. After a careful calibration, the vertical angle of the wire supporting the fan could be used to estimate the current speed in deep water with an accuracy of 0.1 knot.

Dr. Dawson actively solicited local knowledge of currents from fishermen and ships captains, and used this information extensively in his many reports describing current characteristics.

Tidal and Current Surveying, 1924-1950

After the retirement of Dr. Dawson in 1924 the Tidal and Current Survey Division was transferred to the Canadian Hydrographic Service. Mr. H.W. Jones, who had commenced his service with Dawson in 1904, continued the work of this group on the Atlantic coast, while based in Ottawa and reporting to the Dominion Hydrographer. On the Pacific coast, Mr. S.C. Hayden, who had worked with Dawson as early as 1899, had been stationed at the regional office in Vancouver since approximately 1920. He continued to work out of this office while reporting to the Dominion Hydrographer as well. These two men were, on their respective coasts, responsible for the operation of the permament tidal gauging stations.

Mr. H.W. Jones' major contribution to tidal current surveying involved a multi-year survey of the Lower St. Lawrence River which extended from Quebec City downstream to Pointe des Monts and which lasted from 1932 to 1937. This survey used a variety of techniques and ships, with the GULNARE being the most frequently mentioned vessel. One major product of this survey was the Tidal Current Atlas of the St. Lawrence Estuary published in 1939. This atlas is still the only one available for this area and the data from these 6 years of work form the basis for the majority of the current information appearing on present day C.H.S. charts of the Lower St. Lawrence River.

On the West Coast Mr. Hayden retired in 1940 and at this time the responsibilities of the tidal division were transferred to the Regional Hydrographer in Victoria. Under this arrangement Mr. G.W. Lacroix became the Tidal Surveyor and held this position until 1952. During this time he was responsible for permanent gauging and also conducted current surveys at First and Second Narrows, Seymour Narrows, and Yuculta Rapids. This work was enhanced no doubt by the commissioning in 1947 of the first hydrographic vessel on the Pacific Coast dedicated to tidal surveying, the reconverted R.C.N. patrol vessel PARRY. The PARRY was used in a tidal current investigation with the Fraser River Project in 1950. Mr. Lacroix was succeeded in 1952 by Mr. S.O. Wigen, who still serves with the West Coast office as Tsunami Adviser.

Turning our attention back to the tidal work in eastern Canada, Mr. Jones retired in 1946 to be succeeded by Mr. R.B. Lee. Mr. Lee had started his career with the Tidal Section in 1912 serving under Dawson. In 1954 Mr. C.M. Cross, who was later to become Superintendent of the integrated Tides, Currents and Water Levels Section,in turn succeeded Mr. Lee.

WATER LEVEL GAUGING ON INLAND WATERS

In view of the economic importance that navigation on the Great Lakes and Upper St. Lawrence River system has played in the development of Canada it is not surprising that early systematic gauging of these inland waters took place. Staff readings on the Beauharnois Canal near Montreal, though not continuous, date back to 1845. Daily staff readings were first collected on a year round basis at Lock No. 1 of the Lachine Canal starting in 1856. These were usually recorded by the lock master under the authority of the Department of Canals and Railways. The records available up to 1900 generally consist of the type of data just mentioned. Many of these have since been referred to present day datums but this is not always the case since vertical reference points were often not used in measuring the water level heights and, even when used, they were not always well documented.

In 1906 the continuous recording of water levels in the Great Lakes using self-registering gauges was started by the Department of Public Works in support of the Georgian Bay ship canal levelling program. Three Haskell graphic gauges (Figure 6) were installed during the first year and by 1912 nine were operating, but only during the navigation season.

In 1912 responsibility for the operation of these gauges was placed under the Chief Hydrographer, Department of the Naval Service. The section doing this work was initially called the Automatic Gauge Division but this was later changed to the more well-known Precise Water Level Division. From its inception in 1912 this division was under the direction of Mr. Charles A. Price (Figure 7), who continued in this role until his retirement in 1953.

The number of gauges operated by this division grew rapidly and the period of operation for many extended throughout the year. Self-registering gauges were installed on the Lower St. Lawrence River in support of the Montreal-Quebec Ship Channel Investigation in 1912, and on the Upper St. Lawrence River in 1915. By 1930 there were 19 gauges in operation on the Great Lakes, 15 on the Upper St. Lawrence and 10 on the Lower St. Lawrence River. All but 5 of these 44 guages operated year round.

Of interest during this period were developments such as the use of electric heat for the gauge well at Port Arthur (Thunder Bay) in 1914 and its successful operation to -42°F, and the installation of an automatic gauge in the Marine Signal Service Office at Trois Rivières in May, 1924 to, as pointed out by Mr. Price in his 1924 report, "provide exact time and correct depth in the ship channel for high and

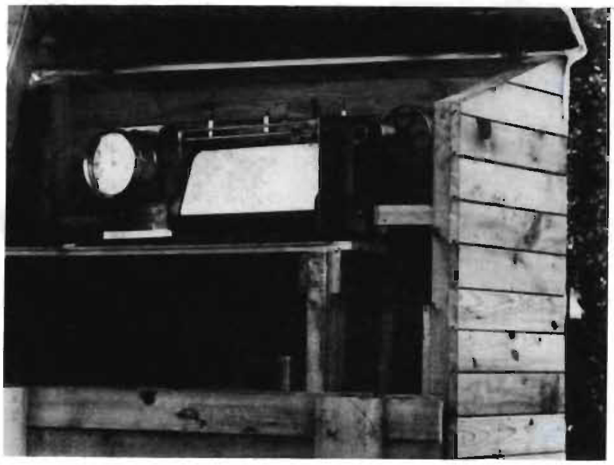

Figure 6. Haskell Gauge

Figure 7. Mr. Charles A. Price

low waters whether they occur during the day or night." Also of interest were the first publication and distribution of monthly and annual water level bulletins in 1925 and the distribution of water level information to the public through press releases in 1929. This latter action was precipitated by general interest over abnormally high lake levels at the time. In 1945 with high lake levels again causing concern a first attempt was made at predicting lake levels, in this case for the Toronto Harbour Commission. At about the same time the Division began to document photographically gauging stations and bench marks - a valuable procedure which has since been encouraged for all hydrographic survey parties.

Many of the problems encountered in the early operation of the gauging network are reminiscent of those faced today. Weather conditions on the St. Lawrence River have long worked against efforts to successfully gauge water levels year-round. The loss of four gauging stations to river ice in 1976 was thought to be a setback of unprecedented proportions. However the destruction of stations at Neuville and Pointe au Platon due to a storm on November 18, 1919 was undoubtedly just as severe a blow to the early development of the gauging system. Winter operations, in spite of the use of electric heating, were consistently difficult, then as now, due to the formation of ice within the stilling well and the resulting damage to equipment.

Personnel problems also appear to have changed little. To quote Mr. Price in his 1917 annual report, "The main difficulty in operating the gauges is in obtaining reliable men as attendants." One reads as well in the annual reports of rejected efforts to obtain more personnel or to have the car allowance increased.

A study of crustal movement in the Lake Ontario - Upper St. Lawrence River Basin completed by Mr. Price late in his tenure is worthy of note since it attempts to correlate records at various gauging sites back to 1860 in order to establish rates of crustal tilt. The Precise Water Levels Division expended considerable effort in tabulating the pre-1900 records from the various canal offices and in referring these data to current datum planes.

Upon the retirement of Chas. Price in 1953 direction of the Precise Water Level Section was taken over by Mr. A.S. Matthewman who had worked with Mr. Price in the group since 1923. Mr. Matthewman retired in 1958 and was succeeded by Mr. G.C. Dohler. In the meantime the Precise Water Levels Division and the Tides and Current Division had been consolidated in 1956 into the Tides, Currents and Water Levels Section under Mr. C.M. Cross, Superintendent. Within this section a further reorganization took place in 1960 to divide the work on the basis of vertical water level motion (Tides and Water Levels headed by G.C. Dohler) and horizontal water level motion (Current Surveys). The Tides and Water Levels group concerned themselves with water level measurements on both tidal and inland waters.

SURVEY DEVELOPMENTS SINCE 1950

Water Level Gauging

During the late 1950's and the 1960's a number of significant changes took place in inland gauging, both in the collection of data and in the subsequent processing of this data.

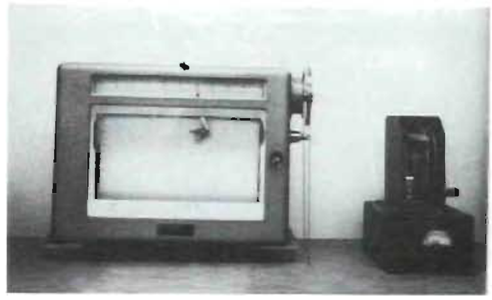

Figure 8. Strip Chart Gauge

In 1959 strip chart gauges (Figure 8) began to replace the older Haskell units and in the early 1960's dedicated telemetry units were installed for specific users of real-time data. At the same time automation of the data processing task was well under way. A scaling device had been developed for digitizing the strip charts and had been interfaced to a punch tape unit (Figure 9).

Figure 9. G.C. Dohler (left) Demonstrating Early Scaling Equipment

Digital data on punched tape were transferred to computer cards and then processed on an electronic computer. In 1962 the first annual summary of gauging station data utilizing the computer print-out was published.

In 1967 Ott punch tape gauges were first installed, helping to further automate data processing by eliminating the digitizing task. The development in 1969 of a telemetry system consisting of a Hagenuk punch tape gauge interfaced to Telex terminals resulted in the first deployment of a unit capable of transmitting data from a gauging station back to the central data centre, in this case using CN/CP Telecommunication lines.

At about the same time teleannouncing gauges were being introduced at a number of sites on the Great Lakes, the St. Lawrence River and the coasts where a real-time direct line to the gauging station was required for navigational applications as well as for other uses such as storm warning services.

Since then a number of improvements have been made to the telemetry system utilizing technological development from the electronics industry. The present unit is microprocessor controlled and stores data in semiconductor memory. These features permit novel data accumulation and storage techniques such as integrated data sampling and direct entry into memory of the gauge attendant's comparison data. This, in turn, permits faster and less labour-intensive data processing at the archiving centre. The gauges equipped with these units are interrogated on an auto-call basis by the central computer.

It is impossible to discuss the history of inland gauging without mentioning the establishment in the late 50's and early 60's of the International Great Lakes Datum. This project resulted in a uniform vertical datum for the whole of the Great Lakes - St. Lawrence River System.

Tidal Gauging, Data Processing and Publication

The late 1950's and 1960's saw many advances as well in the field of tidal surveying. Mechanical tide predicting machines were purchased in 1956 and were subsequently used to prepare predictions for secondary ports. In addition the analysis of short term tidal records to determine harmonic constituents using graphical and tabular techniques was first carried out in Canada in the mid-1950's. In 1962 the semi-automatic processing of data was implemented, for tidal records, as it was with the inland records and in the same year the analysis of tidal records and the prediction of tides using the electronic computer were carried out.

The development and use of the Ottboro tide gauge (Figure 10) was a major step in facilitating the collection of tidal records of short duration during hydrographic surveys and the subsequent processing of these records. This unit was a marriage of the Ott strip chart recorder, which was being used in permanent gauging stations, and a pressure bellows sensor which could be installed offshore and would transmit a pressure signal to the onshore recording unit via a capillary tubing link. The records from this unit could be digitized on the scaling equipment which had been developed for the Ott records.

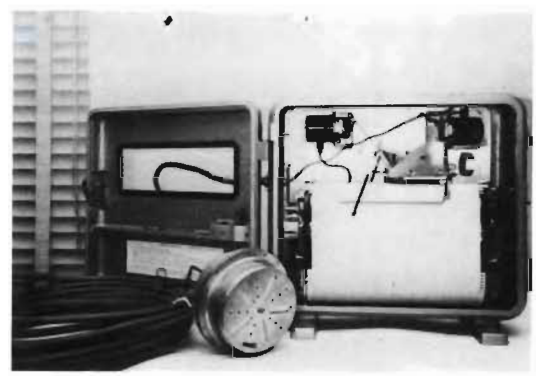

Figure 10. Ottboro Tide Gauge

The unit itself could be set up at a variety of sites with no requirement to have a wharf handy or to build an offshore crib such as had been necessary during earlier surveys (Figure 11). The Ottboros were first used around 1960 and continue today to be the major instrument for temporary tidal gauging during hydrographic survey work.

Figure 11. Crib Constructed for Float Gauge, Eastmain River, James Bay, 1958

The construction of permanent gauging stations at Brevoort Harbour and Resolute, Northwest Territories in 1957 in support of the International Geophysical Year marked the expansion of the tidal program into this new Canadian frontier. Since then, and particularily in the last 10 years, the tidal survey program in the Arctic has expanded considerably with a view to the future need for this type of data for navigational applications.

In 1967 a signal event in the production of Tide and Current Tables occurred when the first edition of these tables was published utilizing predictions computed entirely in Canada. It had taken some 70 years to find the funding that Dr. Dawson had first started searching for but the Canadian Tide Tables were finally home to stay.

Current Surveys

Current surveys in the early 1950's still depended on the use of current meters suspended over the sides of anchored vessels or the tracking of various types of drifting objects. The 1952 survey of Miramichi Bay is typical of the surveys of this day. Working from C.G.S. ANDERSON, current measurements were obtained using Price pattern Gurley current meters, Ekman current meters and current drag devices. None of these had continuous, self-recording capabilities. The current direction was obtained by aligning a "dummy" compass mounted on the current meter boom in the direction of the meter suspension wire (Figure 12). Similar instrumentation was used in 1954 during the survey of the Strait of Canso (carried out in connection with the causeway construction), and in 1957 and 1958 during the survey of Passamaquoddy Bay (carried out in connection with tidal power proposals). The latter survey also employed electromotive force recorders across narrow passages in the bay as a method of measuring flow.

It is interesting to take note of a current survey carried out in 1959 by W.D. Forrester in Little Current Channel in northern Lake Huron. The purpose of the survey was to determine the cause of the current that flows back and forth through the channel and included an assessment of the tidal and meteorological influences on this flow. On the West Coast the current survey of Seymour Narrows after the destruction of Ripple Rock in 1958 was, as well, a noteworthy event.

Figure 12. Gurley Current Meter and Dummy Compass

In the late 1950's the type of instrumentation, nature of survey operations and the treatment of data began to change. A 1958 survey carried out in support of the Northumberland Strait causeway investigation employed, for the first time, self-recording current meters. These Hydrowerkstaetten Paddle Wheel meters were bottom-moored to obtain continuous records for periods of up to 24 days. In 1959 surveys of Hudson Strait and Cabot Strait also employed self-recording current meters (both Paddle Wheel and BBT Neyrpic Courantograph models).

On the West Coast the first use was made of self-recording meters in 1963 on a survey of a section across the Strait of Georgia to investigate the residual pattern of the tidal streams. Cross-sectional type current surveying had earlier been used during a survey of the St. Lawrence River between Montreal and Quebec in 1960. This technique had been chosen in order to satisfy data requirements for hydraulic studies as well as for navigational applications.

Even with the radical changes seen in the instruments described above the current surveyors were not satisfied. Commander W.I. Farquharson, who had been recruited from Britain by Cross in 1956, was Officer-in-Charge of Current Surveys in the late 50's and early 60's. He was concerned with the vast amounts of data that were being acquired with the new instruments and stated in a 1961 report that "every effort must be directed towards the automation of the processing stage, if an ever increasing backlog of work is to be avoided." These words tend to ring true even today. The harmonic analysis of tidal streams data using electronic computers began under Farquharson as early as 1959. The lack of digitally logged data was an impediment to automation in the early 60's that was later overcome with the logging of data on magnetic tape. The early meters had other problems which Farquharson felt required solutions, including: high threshold speeds (0.5 knots for the Paddle Wheel), depth limits, short deployment periods and the inability to measure current directions close to the magnetic pole. All of these problems save that of measuring direction at northern latitudes have been alleviated in modern instruments.

EPILOGUE

The history of tidal, current and water level surveying within the Canadian Hydrographic Service does not end with the publication of the 1967 Tide Tables. As was pointed out at the beginning of this paper a whole new set of developments unfolded during the 1970's and continues to unfold in the 1980's.

Numerous organizational changes have taken place since 1967. Field operations are now carried out entirely by the regional tidal offices in Bedford, N.S., Burlington, Ont., and Patricia Bay, B.C., with a fourth office soon to be created in the newest C.H.S. region, Quebec. An instrumentation development group resides, as well, in the Burlington office. Data processing and archiving tasks now deeply involve the Marine Environmental Data Services Branch of our department.

Instrumentation, surveying techniques and data processing, analysis, archiving and distribution methods have all changed remarkably during the past 15 years. However there is not sufficient space within the framework of this paper for a description of these "recent" events which will do them justice. The reader is referred to De Wolfe et al (1981) for a discussion of some aspects of this work.

The people and events that have been described in this paper have had an undeniably positive influence on the history of the Canadian Hydrographic Service. Leaders such as Dawson and Price had the determination and foresight to initiate and implement programs which not only met immediate data needs but also provided for future requirements. They have set an excellent example for present and future generations of surveyors to follow.

ACKNOWLEDGEMENTS

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CHART LATTICING - PAST, PRESENT AND FUTURE

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ABSTRACT

Hyperbolic radio navigation systems have been shown on Canadian Hydrographic Service charts since the 1950's. The author traces the development of the various systems: Loran-A, Decca and Loran-C and the draughting methods by which they were drawn on charts. The accuracies of these systems and alternate systems presently available and future systems are compared. The author foresees the demise of the present day lattice chart with the advent of other positioning systems and with the commercial production of automatic co-ordinate converters and plotters and the possibilities of charts displayed in video screen images.

RÉSUMÉ

Les systèmes hyperboliques de radionavigation sont indiqués sur les cartes du Service hydrographique du Canada depuis les années 1950. L'auteur retrace l'élaboration des divers systèmes: Loran-A, Decca et Loran-C, ainsi que les méthodes employées pour les dessiner sur les cartes. Il compare la précision de ces systèmes, d'autres systèmes actuellement disponibles et des systèmes futurs. L'auteur entrevoit le moment où les réseaux actuellement représentés sur les cartes deviendront périmés par suite de la mise au point d'autres systèmes de positionnement, de la production commerciale de convertisseurs et de traceurs automatiques de coordonnées, et du visionnement futur des cartes sur écrans vidéos.

INTRODUCTION

This conference is a suitable time to reflect back on what a chart looked like 100 years ago, what it looks like now and what it might look like 25 years from now (see figure 1). The typical chart a century ago was of small scale, without graduated borders or grid lines. It had a few individual lead line soundings but certainly no deep-sea soundings and no bottom contours. Printing was done in single colour from an engraved copper plate. Over the years, graduated borders and grid lines have been added, the waters are being filled in with a multitude of representative soundings with reliable contours to the greatest of ocean depths, shoals are now tinted blue, the land depicted in buff and topographic details shown. On top of all this information, radio navigation lattices are printed in a rainbow of colours.

The cycle is now in full swing the other way. The number of representative soundings is being drastically reduced and contours emphasized with the metrication of charts, and superfluous topography is also being deleted. The next likely charting element to be removed may be the navigational lattices. Also there may well be an end to the use of paper as the exclusive means of portraying a chart. The lines and digital information on a chart will be recorded on magnetic tape or microfiche and displayed separately or in conjunction with the radar screen.

NAVIGATION SYSTEMS

Radio navigation started, and indeed continues, with the use of direction fixing from coastal radio beacons by which a mariner with a directionally sensitive antenna can obtain intersecting bearings. But a latticed chart is not necessary. The need for latticed charts really started with the Consol, Loran and Decca systems developed in the Second World War.

Consol was developed by Germany for the positioning of submarines in mid-Atlantic to about a five mile accuracy. Essentially, it is a direction bearing system with radials of constant number of dots and dashes that repeat in adjacent sectors. The few Consol stations remaining are in the Norwegian Sea.

Loran (later renamed Loran-A) was an American developed system that operated in the 2000 kHz frequency band. Loran-A was a pulsed hyperbolic system that provided several hundred mile range from the two transmitters and gave one to two mile positioning accuracy. As a daytime navigational tool, it helped convoys along the Canadian and American Atlantic seaboard. Nighttime use started once it was realized that skywave signals, which are so evident at night, could be accommodated with the use of correction terms thereby aiding the nighttime bombing of Germany in the latter stages of the war. After the war, the United States extended the system as a military requirement, and through encouragement of other nations, as a domestic navigational system. In its heyday, it provided navigational assistance throughout most of the maritime world including the American and Canadian east and west coasts. (see figure 2). Canada operates the last two Loran-A rates and these will close down at the end of 1983.

The development of Loran has gone from the original version, now called Loran-A, as far as a fourth version - Loran-D. Loran-B was an unsuccessful attempt to use the individual cycles within the Loran-A pulse. It was realized that a longer wave length, i.e., lower frequency, was required. Therefore the next development, Loran-C, uses 100 kHz transmissions where the wave length is 20 times as long as Loran-A. With the lower frequency, the range of reception increases and it is possible to transmit over land, but larger antennae are required. Because the system uses pulses and only analyzes the cycles at the early part of pulse, the skywave interference that occurs at long ranges is avoided. Loran-C became operational in 1958 and was adopted by the United States as the prime coastal radio navigation aid in 1974. It is deployed in Canada and the United States for domestic purposes and in the North Atlantic, Mediterranean and Pacific for American military reasons (see figure 3). The USSR operates two chains of their equivalent to Loran-C. The Decca Company operates its own version of Loran-C, called Pulse 8, in the North Sea for several oil companies.

Decca was developed by the British using several low frequencies (70, 84, 112 and 126 kHz) each transmitted continuously from separated transmitters. The interference pattern, when the received signals are compared at the lowest common multiple, is a family of hyperbolae. The result is a system that has slightly shorter range than Loran-A but greater precision. Decca was used in the Normandy landings and for close tactical support by aircraft, for which several Decca chains were established as the front advanced. After the war, Decca chains were established by many nations so that there is, or has been, coverage throughout northern Europe, the Canadian Maritime provinces, and elsewhere (see figure 4). Two of the original four Canadian Decca chains were reconfigured in the 1960's, two chains have been closed down recently and the other two chains will close down by 1985.

Omega is a very low frequency hyperbolic system that uses only eight transmitters to provide positioning capability to most of the globe. Again, the system was developed by the United States for military reasons, principally because submarines can receive low frequency transmissions under water. There are serious diurnal effects that limit the positioning accuracy to about 5 km.

To date, CHS has published Loran-A, Loran-C and Decca charts but has not yet published any Omega charts. The British Admiralty, U.S. Defense Mapping Agency, and other charting organizations have published latticed charts, including Omega, of Canadian waters.

Since 1977, Canada has been changing its radio navigation aids from Loran-A and Decca to Loran-C. Table 1 shows the activity of providing latticed charts in the last few years by the CHS.

Satellite positioning is sufficiently complex to negate the possibility of showing the position fixing as a family of intersecting hyperbolae, although that is exactly the method of solution. The TRANSIT system has been available to the public since 1967. But a position can only be computed each time a satellite passes overhead which occurs once every two hours on the average. A positional accuracy of 200 m is possible but is dependent on the maximum elevation angle of the satellite, the length of time that signals are received and accurate course and speed of the ship during that period. The GPS (NAVSTAR) satellite system is still being put in place, but once established, it will provide world-wide continuous positioning to 100 m, or less, accuracy. In fact, discussions are going on to decide how the accuracy ought to be degraded artificially.

LATTICING

In the 1950's and early 1960's when most of the Loran-A and Decca lattices were being prepared, the computations and draughting was a manual operation. Simplifications of the procedures were the order of the day. An average velocity was assumed, tables of hyperbolae (LOP) intersections along successive meridians and parallels were computed, and splines were used to draw the lattice lines through these plotted points. The spacing between lines was decided by the draughtsman as the lines were being scribed.

When automated cartography started, lattices were prepared using computer assisted flat-bed plotters for enormous savings in manpower. Then, it was necessary to provide the

Table 1

CHS Chart Latticing Activity

Radio Navigation System	Charts Cancelled since 1979	Charts in Stock	Charts in Preparation
Loran-A	16	25	0
Loran-C	17	58	51
Decca	25	40	2
Omega	0	0	0

(Dec. 1, 1982)

basic information such as transmitter locations, lane width along the baseline, and desired lane interval as well as chart scale, projection and limits.

When Loran-C lattices were beginning to be required, it was realized that these simplifications were no longer needed nor justified. In fact, they were detrimental. A sophisticated velocity model is now used as well as a mathematical model to reflect the delay caused by transmissions over land. This last step is undergoing a three pronged development analysis: polynomial in latitude and longitude, a grid of data, and computation of the delay as needed, which in itself needs a data bank of digitized coastlines and conductivity areas.

POSITIONING WITHOUT LATTICES

Satellite positioning and radio direction fixing have never required latticed charts. These two methods are at opposite ends of the cost spectrum. However electronic hardware is making such rapid development that the user of the other systems no longer requires latticed charts either.

Only the simplest of Omega receivers provide the raw data. Most receivers sold today track all Omega stations, provide the propagation corrections by internally stored mathematical models, by computed corrections from the most recent satellite fix, or by transmitted corrections from a local (within 300 miles) shore monitor. The typical outputs from such a receiver are the geographic position, its reliability, course and speed made good, and bearing and distance to desired points.

Loran-C receivers once cost $10,00D but now start at $2,000 thanks to electronic technology and mass production. Many of today's receivers can give the geographic position and other associated data, such as previous Decca or Loran-A LOP's, either as a built-in or an add-on feature. Some receivers compensate internally for the propagation over land. Until recently, Loran-C receivers operated on only one chain at a time and they operated with only two master-slave pairs. However there are many receivers available now that track several master-slave pairs and some that are master independent thus providing slave-slave LOP's. Some receivers can operate on two chains simultaneously so that cross-chain fixes are possible, making position fixing more assured and providing a larger coverage area. The next generation of receivers may have only an "on button". It will search for the strongest master signal, find the associated slaves, compute the position and verify against an internal library for the correct LOP's to use.

CHART DATUM

The future output of all radio navigation systems, whether Omega, Loran-C, TRANSIT or GPS satellites will be in geographic coordinates. Therefore, CHS will have to be sure that charted features are in the correct geographic position relative to the position from the radio navigation system or that the relationship between the two coordinate systems is provided. Receivers of each of these four systems are presently computing positions in the World Geodetic System - 1972 (WGS-72) coordinate system. But most CHS charts are on the 1927 North American Datum (NAD-27) and at large scales there may be plottable differences between the WGS-72 and NAD-27 value for the same point. Some charts are worse, for they are not based on the currently recognized NAD-27 values. The problem will only be rectified once all charts are converted to the 1983 North American Datum (NAD-83) where there should be no plottable difference from WGS-72.

Up to now, it has really only been a matter of convenience that all charts be on the same datum. But once positioning and navigation are done by an external system, such as discussed here, it is paramount that coordinates on a chart and from the navigation system be compatible.

DIGITIZED CHARTS

The Canadian Hydrographic Service is developing methods to have charting information in digital form as an alternate method of producing a chart - the traditional paper chart. The digitized method could possibly save person-years in the preparation of charts, particularly since data is arriving from the field in digital form. The updating of charts by notices to mariners as they occur, could reduce the time needed to prepare a reprint and hence the capability is possible of doing cyclical printing to reduce the amount of hand corrections to stock not yet distributed.

A real bonus to digitized charts, and perhaps the more crying need, is the eventuality of selling the chart in digital form. No more just selling paper versions of a chart, but rather also marketing a cassette tape of a chart. This cassette is plugged into a computer that is connected to a colour video screen. Also connected to the computer are one or more radio positioning systems so that the ship's position is displayed at the centre of the screen.

A radar scanner could also be connected to the system so that radar images could be shown on top of the charted information. Images such as other ships could be flagged much as air traffic controllers do. The computer could predict possible collision courses, particularly if the ship's intended course had been entered into this system via keyboard or cursor.

At least one manufacturer has already developed the first stage. The Loran-C position from a receiver/converter is the centre of the image of a portion of a chart that is back-projected from a colour slide of the chart.

CONCLUSIONS

What lies ahead for the Canadian Hydrographic Service? There is the need for the charts to be converted to the 1983 North American Datum as quickly as possible so that positions computed from radio navigation systems can be used directly on the charts. The overland propagation anomolies of Loran-C, commonly called ASF, need to be mapped as accurately as possible, probably by a combination of predictive and surveying techniques so that mariners can safely use Loran-C in more restrictive waters than they can today. Charts will have to be transcribed into digital form so that they can be marketted as a cassette in lieu of paper.

And what is the time span required to do these projects? In five years, given reasonable resources devoted to these projects, CHS could have: the relationship between existing charted coordinate values and the 1983 North American Datum values, even if no NAD-83 charts had been published by then; a reasonable mapping of the Loran-C ASF; and maybe some charts available in, at least partial, digital form. Considering that the NAD-83 coordinate values will not be available until 1985, that the Loran-C will not be in its presently recognized final form until 1984, and that digitizing procedures are still being developed, this time estimate of five years is optimistic. Churchill, during the darkest hours of World War II, when being pressed for resources, likened himself to a sow with only so many teats; it appears to be the same for CHS. Fortunately, he never gave up hope.

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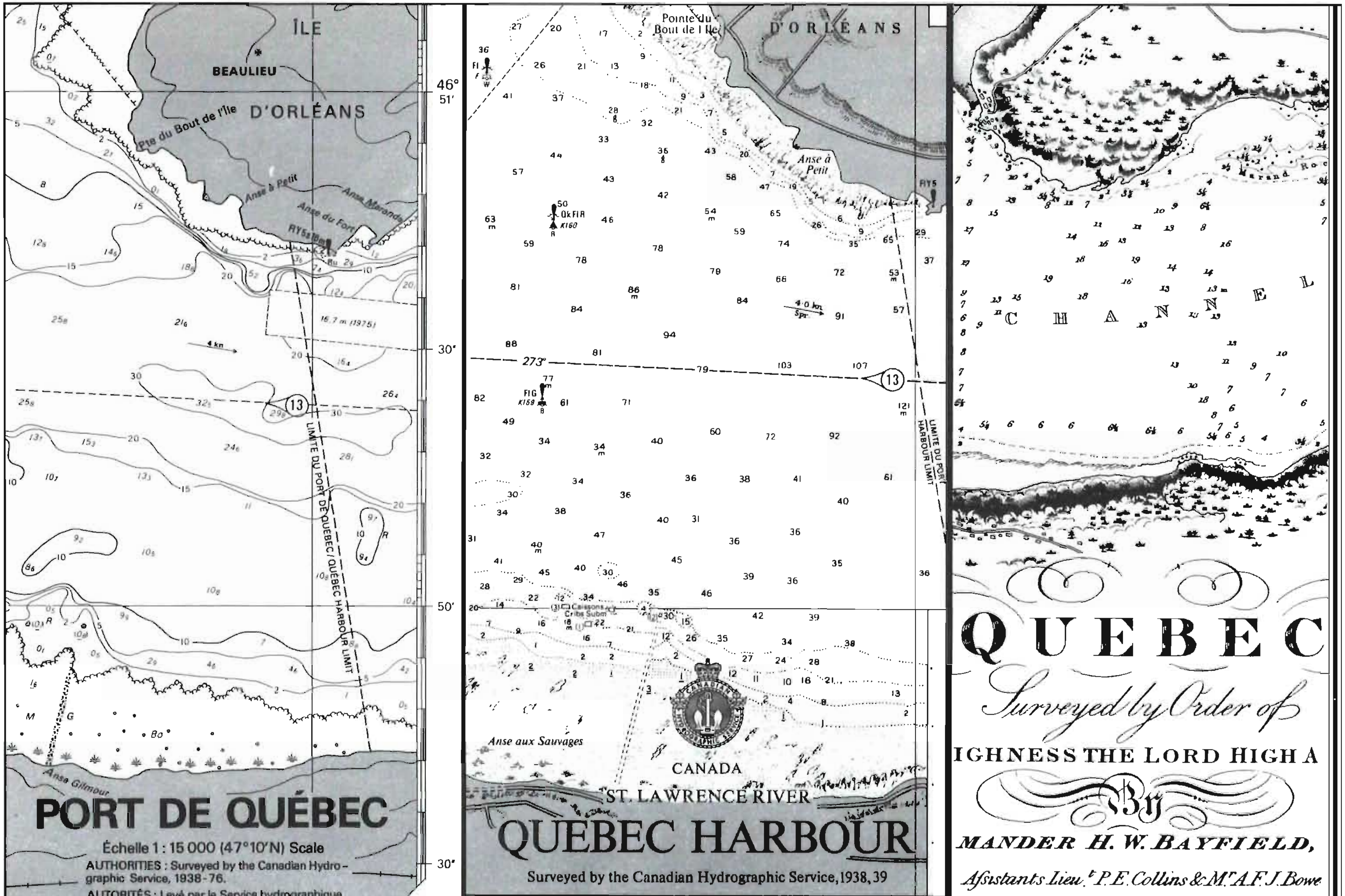


FIGURE 1 : CHART STYLE DIFFERENCES OVER 150 YEARS

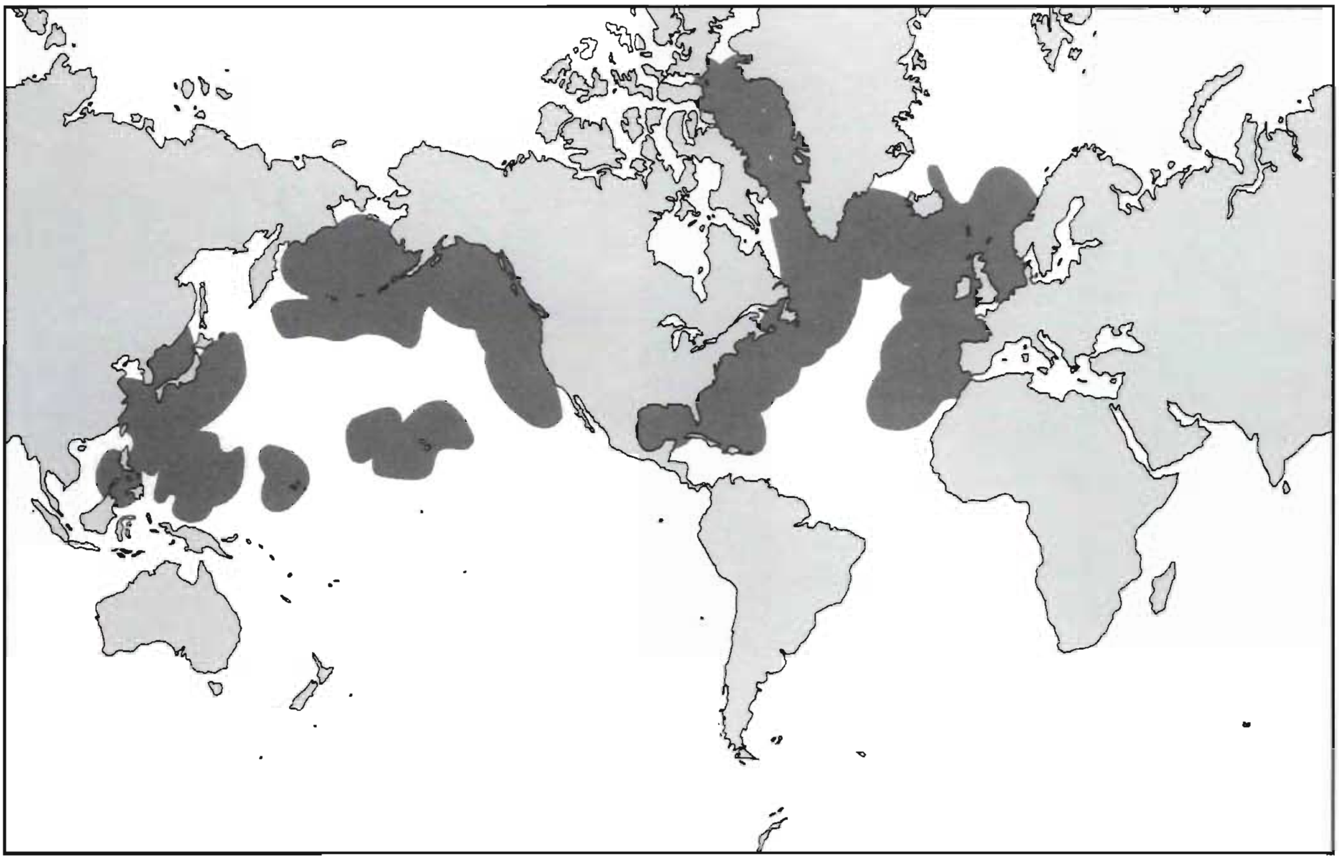
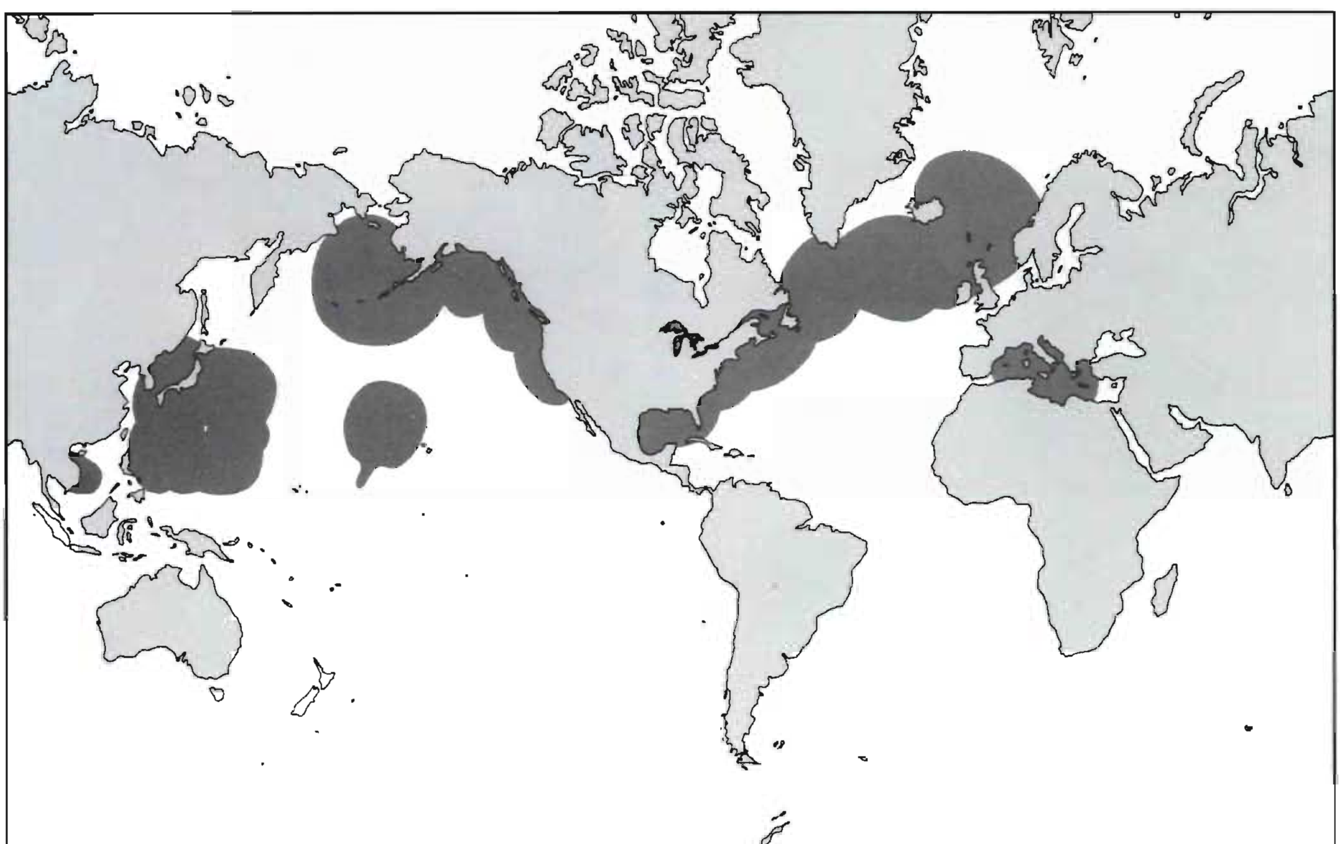


FIGURE 2 WORLD-WIDE LORAN-A COVERAGE

FIGURE 3 WORLD-WIDE LORAN-C COVERAGE



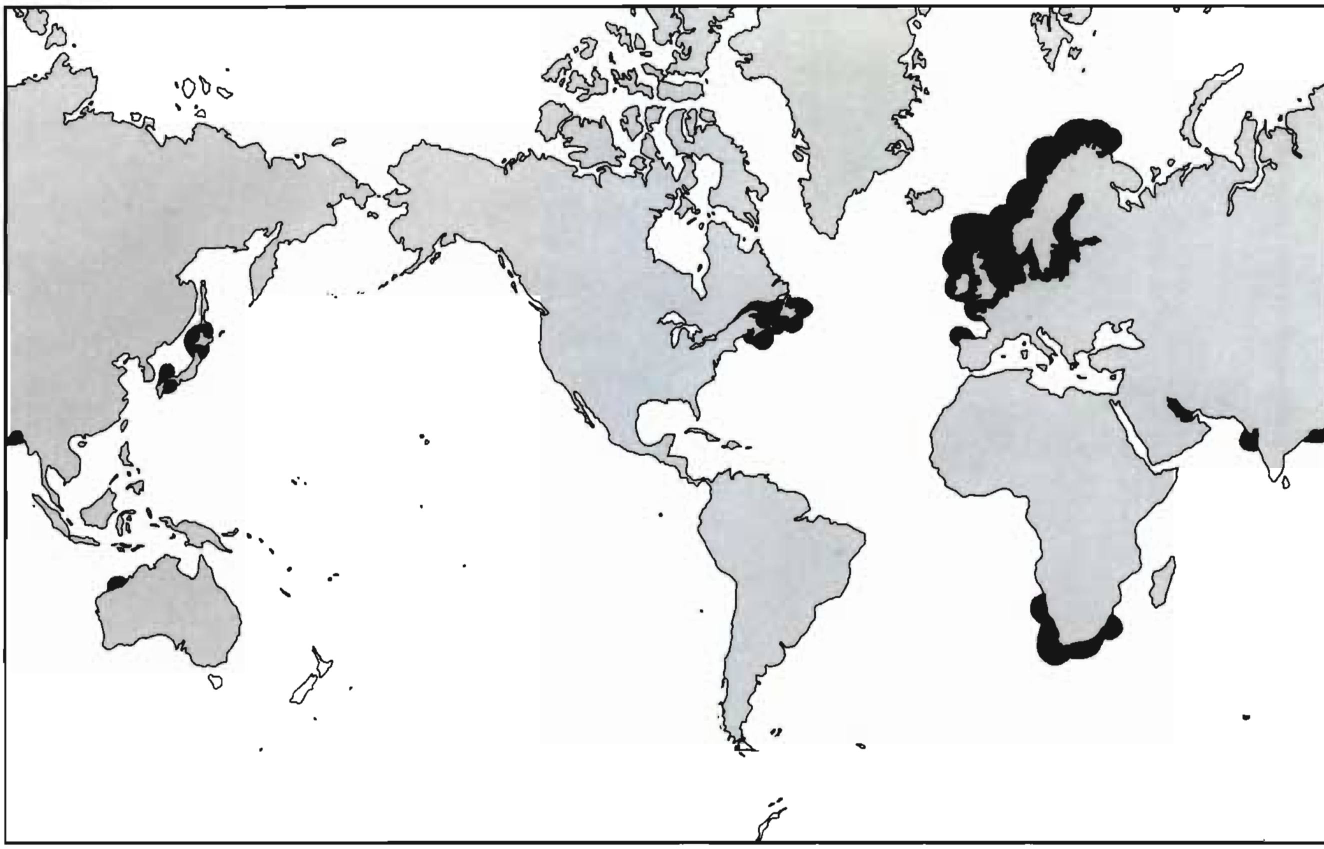
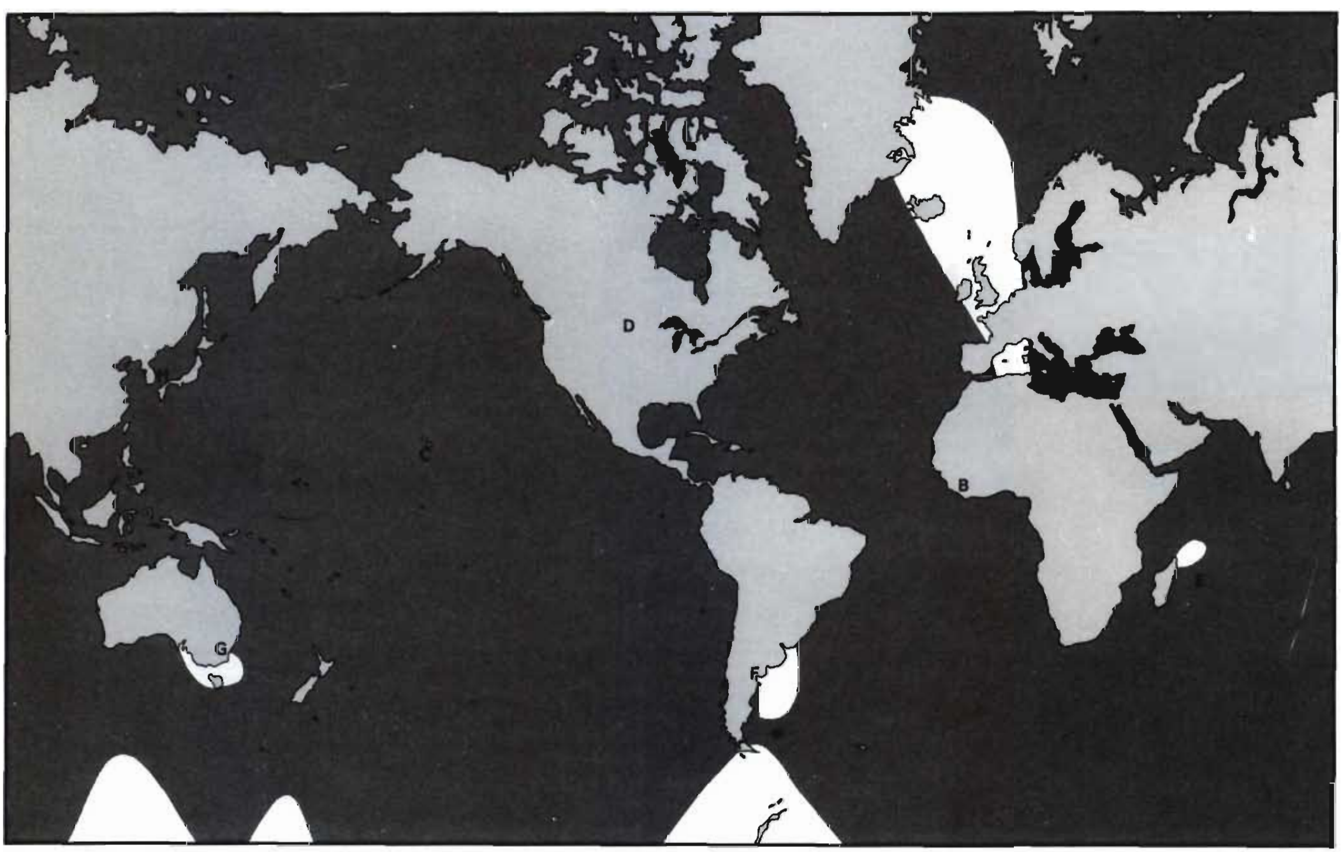


FIGURE 4 ▬ WORLD-WIDE DECCA COVERAGE

FIGURE 5 ▬ WORLD-WIDE OMEGA COVERAGE



IMPACT OF THE GLOBAL POSITIONING SYSTEM ON HYDROGRAPHY

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Michael Eaton[3]
Stilianos Mertikas[1]

ABSTRACT

In Navigation Satellite Timing and Ranging (NAVSTAR) system, also known as the Global Positioning System (GPS) is scheduled to be fully operational by the end of this decade, and will be capable of providing real-time continuous positions accurate to about 10 metres. Policies regarding what GPS accuracy will be made publicly available, and which of the other navigation systems supported by the U.S. Government should be shut down (and when) once GPS is available, have been proposed in the recent U.S. Federal Radionavigation Plan. In this paper we discuss the impact of GPS on hydrography from four points of view. First, we describe GPS performance today in its partially-implemented state, and discuss its near term (pre-1990) impact on hydrography. In particular, we describe our joint project to develop a GPS/BIONAV system for arctic hydrography. Secondly, we adopt an optimistic stance, assume that something close to the full GPS capabilities will be publicly and inexpensively available, and explore the usefulness of GPS for various hydrographic surveying tasks. Thirdly, we discuss the implications of the pessimistic scenario, in which GPS capabilities are sharply curtailed to the general public. Finally we explore various possibilities for using GPS differentially to improve the accuracy available.

RÉSUMÉ

Le nouveau système automatisé de navigation par satellite (satnav) NAVSTAR, également connu sous le nom de Système de positionnement global (GPS) a son échéancier prévu pour être pleinement fonctionnel à la fin de cette présente décennie, et pourra fournir en temps réel des positions interrompues précises à 10 m près. Les politiques concernant l'exactitude du GPS seront rendues publiques et lequel des autres systèmes de navigation qui ont l'appui et le soutien du Gouvernement des Etats-Unis devront être discontinué (et quand ils le seront) lorsque deviendra disponible le nouveau GPS, voilà ce que propose le tout récent Plan fédéral de radionavigation des Etats-Unis. Dans ce document, nous discutons l'influence du système de positionnement global sur l'hydrographie à partir de quatre aspects différents. D'abord nous décrivons le rendement actuel du GPS dans son état d'application initiale partielle et nous discutons de son influence lorsqu'il sera presque complètement établi (avant 1990) sur l'hydrographie. En particulier, nous décrivons notre projet conjoint de développer un système de navigation GPS/BIONAV pour l'hydrographie de l'Arctique. Ensuite, nous adoptons une vue optimiste et présumons que quelque chose d'approchant la pleine capacité du GPS sera disponible publiquement et à peu de frais, et nous explorons l'utilité du GPS à des fins d'execution de diverses fonctions de levés hydrographiques. Troisièmement, nous discutons les implications d'un scénario pessimiste dans lequel les caractéristiques du GPS sont sévèrement restreintes à l'égard du grand public. Enfin, nous explorons diverses possibilités d'usages différents du GPS afin d'en améliorer l'exactitude disponible.

INTRODUCTION

NAVSTAR/GPS is a military navigation system being developed by the U.S. Department of Defense (USDoD). However GPS will also have a double impact on civilian navigation.

In the first place, GPS is capable of accurate (10 metre), four-dimensional (three coordinates plus time), continuous, realtime, all weather position fixing. No other present or planned navigation system has all these attributes. However, the full performance of GPS may not soon be available to civilian users.

In the second place, navigation systems which are presently freely available, such as TRANSIT, LORAN-C, and OMEGA will eventually be shut down once GPS satisfies most military navigation needs.

Hydrographers (and other civilians requiring precise positioning) will be critically affected by the relationship between the timing of these shutdowns and the timing of civilian access to full GPS performance.

Before discussing these future uncertainties, and their impact on the use of GPS for hydrography, we first summarize the present status of GPS, and some results we have already obtained using GPS. These are the outcome of a joint agreement involving Nortech Surveys (Canada) Inc., the University of

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New Brunswick's Oepartment of Surveying Engineering, and the Bedford Institute of Oceanography. The goal of this NUB (Nortech/UNB/BIO) project is to develop an offshore GPS marine navigation capability, to be used in hydrographic surveys of Baffin Bay, starting in 1984. So far, three NUB sea trials have been conducted on BIO ships using Nortech GPS equipment (see Figure 1). Further tests are planned.

PRESENT STATUS OF GPS

The principles of GPS are similar to those of rho-rho LORAN-C. A GPS receiver makes time-of-arrival measurements on signals from several (usually four) GPS satellites. The resulting pseudorange observations are then used to compute both position and the time bias between the satellite and receiver clocks. For marine navigation, and if we carry a cesium clock aboard ship, four kinds of solution are possible. The unknown parameters can be

(1) latitude and longitude only (height and time bias held fixed)
(2) latitude, longitude and time bias (height held fixed)
(3) latitude, longitude and height (time bias held fixed)
(4) latitude, longitude, height, and time bias.

The values to which we hold the height or time bias fixed must be close to their actual values, or the position fix will be corrupted. Sufficiently accurate ellipsoid heights can easily be obtained from available geoid maps, or geopotential coefficient sets. Establishing a sufficiently accurate synchronization between a shipboard cesium and the GPS satellite clocks is a little more difficult, but possible.

The signals used can be either of two binary coded modulations on the GPS carrier--the "P-code" or the "C/A-code". The higher frequency P-code yields higher position fix accuracy (10 to 25 metres). Oetails of GPS signals and operation are described in ION [1980] and Wells et al. [1982].

GPS can be used today, but the coverage is incomplete. Prototype GPS satellites were launched in 1978 and 1980. Four such satellites (which we designate here as Space Vehicles (SV) numbers 5, 6, 8 and 9) are currently operating, with a fifth (SV4) scheduled for launch in June 1983. Three more prototype satellites are available, and it is likely they will be used to maintain a five-satellite constellation between 1983 and 1986 [Kruh, 1983]. Between 1986 and 1989 these prototype satellites will be replaced by 21 production model GPS satellites (18 operational plus 3 active spares). Oespite warnings that GPS signals may be unreliable and inaccurate until the production stage [Healy, 1981], many months

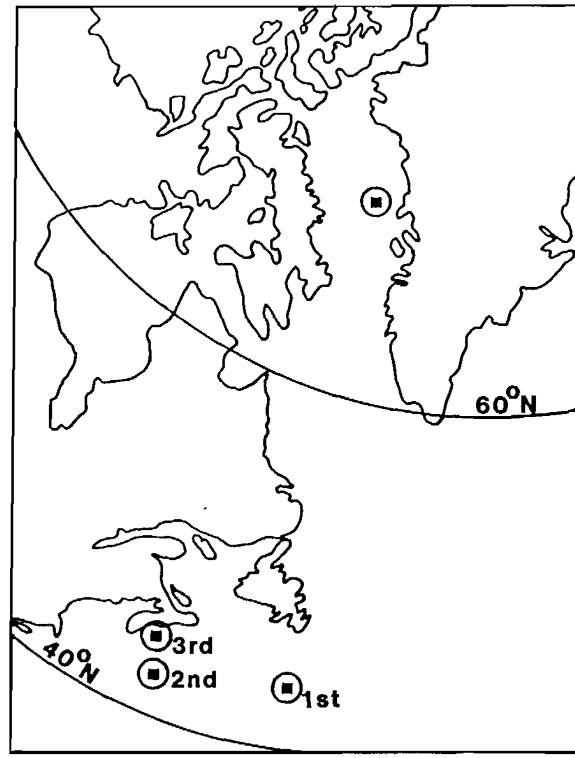

Figure 1. Location of the Baffin Bay test point, and of the first three NUB sea trials, held in November 1981, June 1982 and November 1982 respectively.

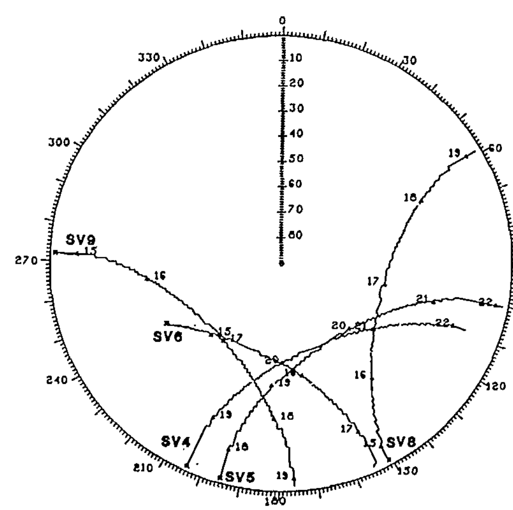

Figure 2. Polar plot of GPS satellites (azimuth and elevation relative to Baffin Bay test location, for 1982 November 16).

of tracking by Nortech and others indicate that GPS signals and ephemerides are almost always stable, consistent and accurate.

GPS satellites have orbital periods of nearly 12 hours, so that coverage nearly repeats from day to day. Typical coverage for Baffin Bay is shown in Figure 2. In order to translate a particular satellite configuration into position fix accuracy, we introduce the concept of Dilution of Precision (DOP). This is a simplistic conversion factor from range measurement accuracy to position fix accuracy. For example, if the range measurement error is 8 metres, and the DOP factor is 2, the position fix accuracy would be 16 metres. The DOP value reflects the geometrical strength of the satellite/user configuration, however it also depends on which of the four kinds of solution listed above is being computed. We will use the following kinds of DOP:

(1) HDOP (Horizontal DOP) for latitude, longitude solution;
(2) HTDOP (Horizontal/Time DOP) for latitude, longitude, time bias solution;
(3) PDOP (Position DOP) for latitude, longitude, height solution;
(4) GDOP (Geometrical DOP) for latitude, longitude, height, time bias solution.

The DOP value at a given location will vary over a 24 hour period, but will nearly repeat from day to day. Comparisons between these various DOPs are shown in Figures 3 to 6. Figures 3, 4 and 5 show predicted values for DOPs for three different satellite constellations (the present four-satellite, the expected five-satellite, and the final 18-satellite constellations, respectively). Until the final constellation is in place, it is clear that there are significant advantages to using an externally synchronized cesium clock: HDOP is below six for 11 hours per day in Figure 3 (four satellites), and is below ten for 16 hours per day in Figure 4 (five satellites). Figure 6 corresponds to the same satellite constellation as Figure 4, but represents actual DOP values at Halifax rather than predicted values in Baffin Bay. HDOP at the two sites are remarkably similar, indicating that the sea trial results should represent GPS performance in Baffin Bay.

The number of GPS receivers presently available to civilian users is limited. The three NUB sea trials so far have used the Stanford Telecommunications Inc. 5010 P-code receiver acquired by Nortech in mid-1980 and described in Lachapelle and Beck [1982]. This is a bulky piece of equipment, weighing 550 kg, and is a single-channel receiver (capable of measuring ranges to only one satellite at a time), requiring 50 to 70 seconds to switch between satellites. In order to use this receiver for marine navigation, it must be used in conjunction with ship's speed and heading data. This limitation should be removed, now that a portable, fast switching receiver is available--the Texas Instruments 4100 multiplexing receiver shown in Figure 7 [Ward, 1982]. Nortech has acquired two of these receivers, and they will be used for NUB trails during 1983.

CURRENT GPS MARINE NAVIGATION CAPABILITIES AND RESULTS

We will summarize results obtained in the NUB trials so far. These results are fully described in Wells et al. [1983] and Lachapelle et al. [1983].

As already mentioned, the STI 5010 GPS receiver used in these trials must be used with ship's speed and heading data. The accuracy of the combined GPS/dead reckoning system will be affected by both errors inherent in GPS and noise in the ship's log and gyro data used to estimate the ship's displacement between successive GPS pseudorange measurements. In order to evaluate the inherently GPS error component, the quasi-instantaneous accuracy of GPS position fixes were studied with the receiver static. Position fixes were computed using series of two to four pseudorange observations to different satellites over time intervals of two to five minutes to obtain a series of independent fixes. Typical results are shown in Figure 8. Similar accuracy and repeatability has been obtained consistently over the past three years by Nortech [Lachapelle and Beck, 1982]. The accuracy of 16 metres quoted earlier for an HDOP of 2 was obtained not only 50% of the time (as implied by GPS specifications) but consistently for 80% to 90% of the time. Using the TI 4100 receiver, this static accuracy and repeatability should also apply in the dynamic mode.

The integration of STI 5010 pseudorange observations with ship's speed and course was carried out in realtime using three different types of algorithms, namely a TRANSIT type, a sequential type, and a Kalman filter; these are discussed in more detail in Wells and Delikaraoglou [1982] and Lachapelle et al. [1983]. Positions derived from this aided GPS navigation system were compared with positions derived using other navigation systems, such as LORAN-C and Miniranger. Typical results obtained during the second NUB sea trial, in June 1982, are shown in Figure 9. The TRANSIT type algorithm was used in this case to combine pseudoranges with speed and course. The unknowns consisted of latitude, longitude and time bias (at least three satellites were available). The track of the ship was relatively smooth during this

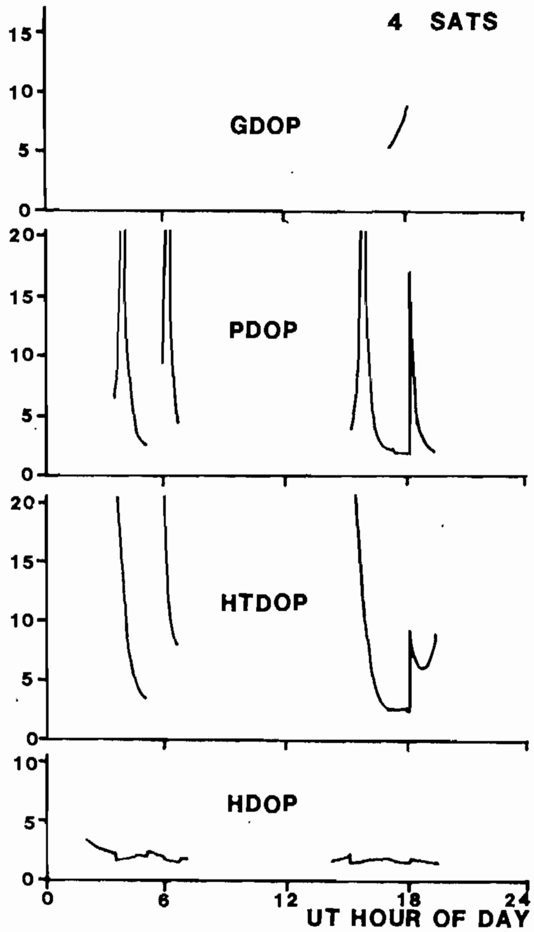

Figure 3. Predicted dilution of precision (DOP) values for Baffin Bay test point, for November 16, 1982, using the present four fully operating GPS satellites.

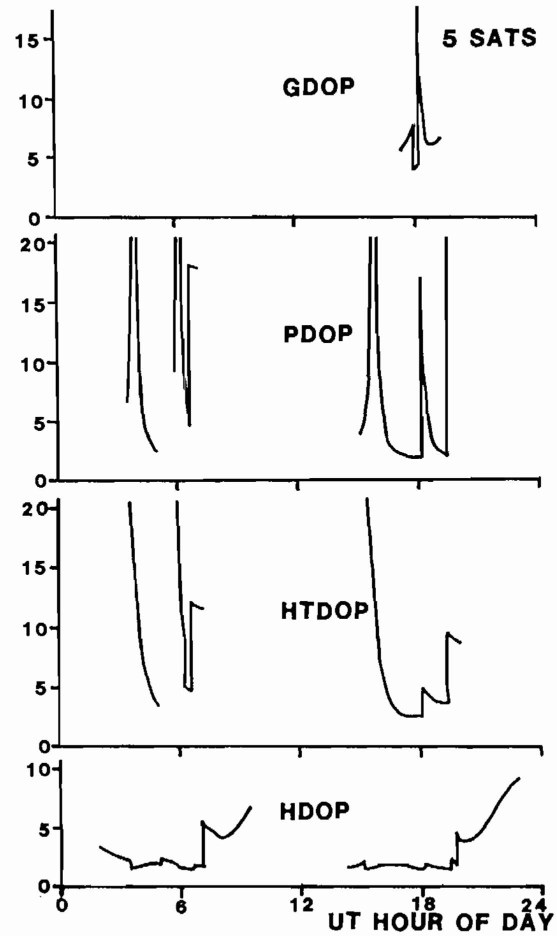

Figure 4. Predicted dilution of precision (DOP) values for Baffin Bay test point, for November 16, 1982, using the five GPS satellites expected to be available from June 1983.

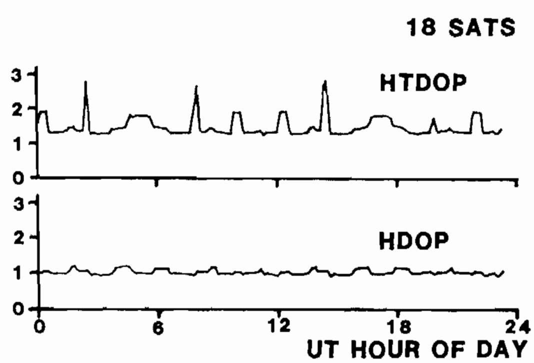

Figure 5. Predicted dilution of precision (DOP) values for Cape Race, assuming a complete GPS 18-satellite constellation.

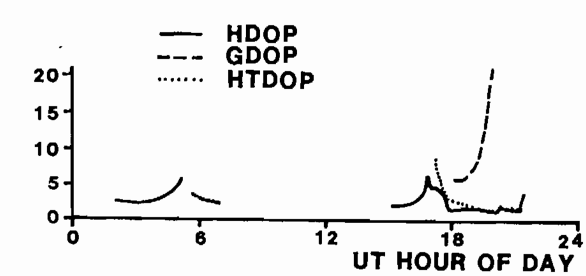

Figure 6. Actual dilution of precision (DOP) values for Halifax for November 1, 1982 (four GPS satellites available).

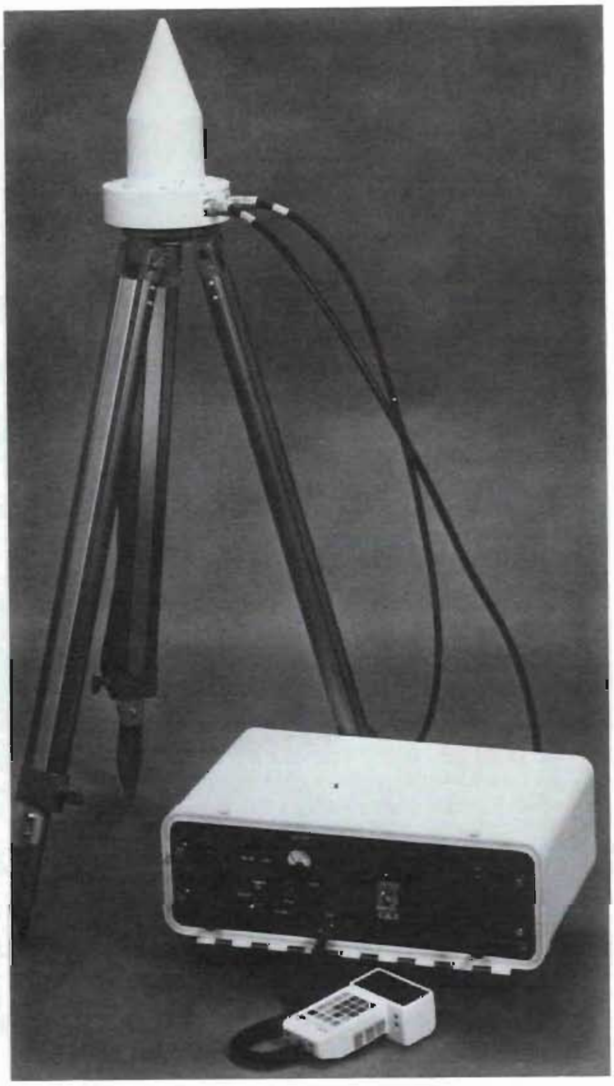

Figure 7. Texas Instruments 4100 GPS geodetic receiver.

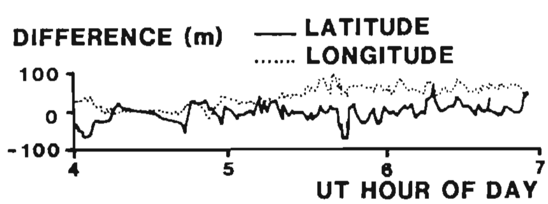

Figure 9. GPS marine navigation performance, using LORAN-C as a reference. From second NUB sea trial, June 3, 1982. Transit-type algorithm used for GPS.

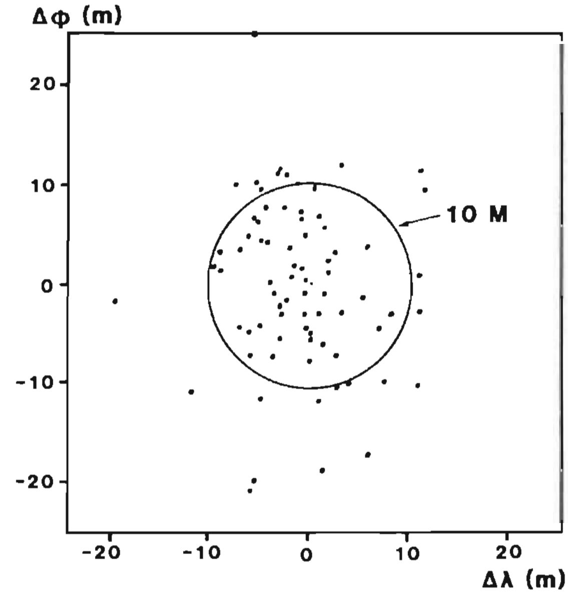

Figure 8. Scatter plot of 75 quasi-instantaneous two dimensional GPS position fixes, collected over a four day period in May 1982 at the Bedford Institute of Oceanography. P-code pseudoranges from the Nortech STI 5010 GPS receiver were used.

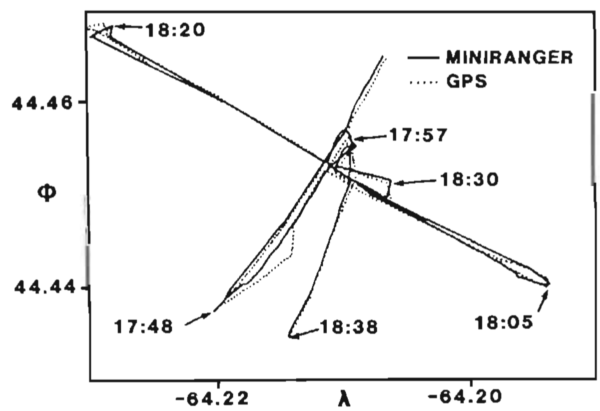

Figure 10. GPS and Miniranger track plots during a buoy check on the third NUB sea trial, November 17, 1982.

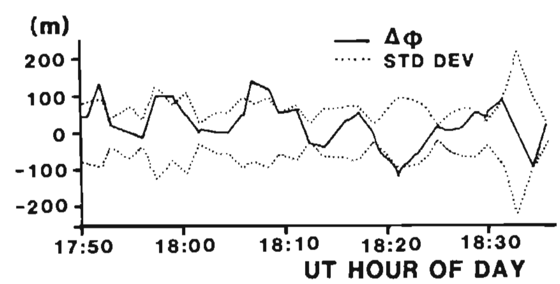

Figure 11. Difference between GPS and Miniranger latitudes from Figure 10. The longitude differences were similar. Also shown is the GPS standard deviation estimated by the Kalman filter used.

period. LORAN-C was estimated to be accurate to 50 m, hence the rms difference of 50 m to 75 m between GPS aided and LORAN-C derived positions is excellent. Figure 10 shows both Mini-ranger and GPS position fixes during a buoy test conducted as part of the third sea trial in November 1982 in Mahone Bay. Several 180° course changes were made, and an adaptive Kalman filter was used to combine GPS pseudoranges with speed and course. Figure 11 shows the position difference in latitude together with the standard deviations estimated by the filter. Within straight segments of the path, rms differences are of the order of 25 m. The larger position differences that occur during sharp turns are attributed to delays in recording and processing log and gyro data; this problem was due to the particular hardware configuration used during the test and has since been rectified. The estimated standard deviations of latitude and longitude are consistent with the position differences, indicating that a realistic weighting scheme was used in the filter. Variations in the standard deviations are due to the variable system noise of speed and course (during turns), and to changing GPS geometry as the receiver sequences through the four satellites available during the test.

FUTURE UNCERTAINTIES IN GPS PERFORMANCE

GPS is principally a military system, but will be available as well to civilian users. This brings into contention the two concerns of military security and civilian economic benefits. Originally it was expected that the more precise P-Code signal would be available to military users, and the C/A-code signal (expected to be an order of magnitude less accurate) to civilian users. However, early experience with the two codes showed C/A-code position fixes were only about a factor of two less accurate than P-code fixes. Consequently new concepts have been introduced: distinction between the two GPS signals has been replaced by distinction between the two services to be provided by GPS--these are the "Precise Positioning Service (PPS)" and the "Standard Positioning Service (SPS)". PPS is intended for military (and selected non-military) users and will provide full P-code GPS accuracy. Access will be controlled by encrypting the P-code signal, and an annual user's fee to non-DoD users of $3700 per receiver will be enforced through sale of these encryption devices. SPS will be available for general worldwide use, but will provide less than the full C/A-code accuracy.

The authoritative statement regarding SPS accuracy is the Federal Radionavigation Plan [USDoD/DoT, 1982], in which three accuracy specifications are given:

> Predictable Accuracy: The accuracy of a position with respect to the geographic, or geodetic, coordinates of the earth.
> Repeatable Accuracy: The accuracy with which a user can return to a position whose coordinates have been measured at a previous time with the same navigation system.
> Relative Accuracy: The accuracy with which a user can measure position relative to that of another user of the same navigation system at the same time. This may be expressed also as a function of the distance between the two users. Relative accuracy may also refer to the accuracy with which a user can measure position relative to his own position in the recent past. For example, the present position of a craft whose desired track forms a specific geometric pattern in search operations of hydrographic survey, will be measured generally with respect to a previously determined datum.

Referring to SPS, the FRP states that it is policy to

> make the NAVSTAR GPS Standard Positioning Service (SPS) continuously available worldwide for civil, commercial and other use at the highest level of accuracy consistent with U.S. national security interests. It is presently projected that a predictable and repeatable accuracy of 500 metres (2 drms) horizontally and 820 metres (2 sigma) vertically will be made available during the first year of full NAVSTAR GPS operation with possible accuracy improvements as time passes.

and

> the relative accuracy will be 10 m (2 drms) horizontally and 16.4 m (2 sigma) vertically.

The "2 drms" accuracy level quoted is the radius of a circle containing 95 percent of all possible fixes that can be obtained with the SPS at any one place. In addition to this Denial of Accuracy concept, there is also a user-pay policy for SPS which will be enforced by encrypting the signal for SPS as well, and charging an annual fee of $370 per receiver for the necessary SPS encryption device.

The FRP also describes how GPS may affect other U.S. government supported navigation systems. The present policies are to

(1) phase out DoD use of TRANSIT between 1987 and 1992, after which the system will be shut down for all users.
(2) phase out DoD use of LORAN-C between 1987 and 1993. Civilian use will continue at least to 2000. Coverage may increase if LORAN-C is adopted for aviation use. On the other hand, LORAN-C may be phased

out in favour of GPS.

(3) phase out DoD use of OMEGA between 1987 and 1992, except for U.S. Navy use, which will continue. However, OMEGA too may be phased out in favour of GPS.

The FRP describes two key events in the process of determining what the impact of GPS will be on these other systems. In 1983 DoD/DoT will make a preliminary recommendation on the future navigation system mix. Four years (1983-1986) are scheduled for consultations with other nations, NATO, IMCO, and ICAO. Then in 1986 DoD/DoT will formulate final decisions.

DIFFERENTIAL GPS

Noting that the SPS relative accuracy will remain undegraded, it is natural to ask whether using the SPS differentially would permit civilian users to recover much of the full C/A-code accuracy. Figure 12 represents

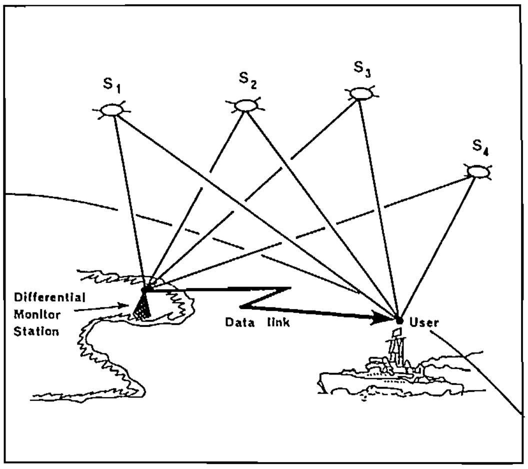

Figure 12. Differential GPS navigation concept. Variations in GPS ranges or coordinates are measured by monitor and sent to users over data link, to correct their positions.

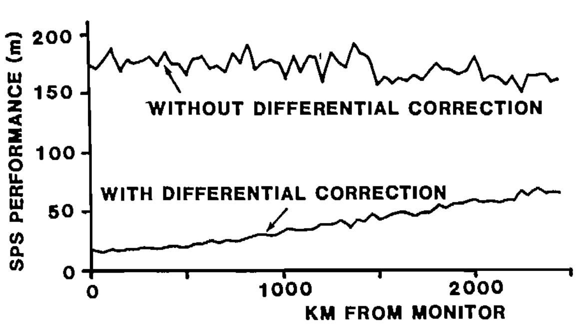

Figure 13. Typical differential GPS results. SPS performance is measured by the 50th percentile of the radial deviations from the "true" positions.

this concept. We have studied some aspects of differential GPS navigation, in particular changes in the geometrical effect as the user moves further away from the monitor [Mertikas, 1983]. We postulated that the C/A-code accuracy may be degraded to meet the above SPS specifications in one of three ways; by adding errors to the broadcast satellite ephemeris parameters, to the broadcast clock parameters, or to both. The monitor station was postulated to continuously measure either the variation in its coordinates, or variations in the biases in the measured ranges to each GPS satellite in view, and to transmit these variations to users in realtime. Typical results are shown in Figure 13, for the case of clock parameter degradation; measured range biases; and a user solution for latitude, longitude and clock bias. These results indicate that the differential technique may be useful up to several thousand kilometres from a monitor. Many questions remain regarding differential GPS, some of which we intend to study during the 1983 NUB trials.

IMPACT OF GPS

A great advance in positioning for hydrography has been the post-World War II development of radio navigation, from DECCA and LORAN-C through Hi-Fix to Miniranger and Syledis. In GPS we may see the final step in that revolution.

Every one of our present radio positioning methods has problems. With LORAN, DECCA and Hi-Fix, where we make the measurement using groundwaves that follow the earth's curvature, we suffer from range errors due to propagation over land or ice, and interference from skywaves. Direct propagation microwaves reflect from the sea surface to give range holes, and VHF signals propagated by diffraction reflect from hillsides and buildings. All these problems go away if instead of battling to transmit a signal along the earth's surface we transmit straight down from a satellite.

From experience one suspects that nothing is going to be perfect: signals from satellites are very weak and so subject to interference, but because they use very high frequencies, they can be coded to overcome this. There probably will be some snags with precise satellite navigation, but nothing we have seen so far suggests serious problems. It looks likely that GPS, and its successor systems, will eventually replace all our terrestrial radio navaids leaving terrestrial laser systems to satisfy the highest accuracy requirements.

There will be some years of uncertainty for this final stage of the radio positioning revolution to sort itself out, and as this period will extend over the next decade it is important that some effort is put into considering how it will affect hydrography. Let us consider three possible cases, when GPS is fully operational, and look at the impact of each on hydrography.

Worst case. In this case, SPS accuracy is degraded in such a way that we cannot recover it using differential techniques, and we are left with 500 m positioning. Most mariners, and many oceanographers are quite well served, but hydrographers are worse off than at present.

The FRP states that LORAN-C and TRANSIT will be phased out once GPS is operational. If this happens while GPS is still at the 500 m accuracy level, we will be worse off than at any time since 1969. With no LORAN-C or TRANSIT we will be unable to fix accurately beyond the 300 nautical mile range of Accufix transmitters.

Probable case. In this case, SPS accuracy is degraded in a manner that allows us to recover by differential operation. The degree of recovery may not be complete, and will be some function of distance from the differential reference receiver. For SPS Denial of Accuracy to be effective, it must obviously change at intervals, perhaps even continuously. That means we must broadcast corrections to the survey vessel continuously, in real time. We have the technology to do this, but it will take effort and money to set it up.

Best case. In this case, DoD decides not to apply any Denial of Accuracy. We get full access to the C/A-code (20 m accuracy) and perhaps the P-code (10 m accuracy). We may pay a user fee, which seems a very reasonable requirement.

SUMMARY

At present, GPS is in the development stage, and we have full access to all its codes. It will become fully operational towards the end of this decade, and at that time, or possibly even earlier, some as yet unspecified form of deliberate accuracy degradation will probably be applied, in order to deny the enemy full use of this military system.

At present four or five satellites are up and, with their 12 hour period, these give two fix periods per day, each lasting between three and eight hours, depending on location. Fix accuracy is about 50 m. It will cost about $1,000 per day to rent a receiver.

Under this limited time coverage, applications are limited to special uses, such as an urgent requirement to survey Baffin Bay, where there is no LORAN coverage. GPS would cost about one third the amount required to put in our own Accufix (portable LORAN) transmitters and would avoid the uncertain logistics of that operation in a very hostile environment. However, GPS at present provides fixing for one third to one half of the day. Keeping a ship usefully employed for the remainder of the day is a tricky problem.

If we can find one convenient site on shore where we can put a single Hi-Fix or Accufix transmitter, then the range from this can be integrated with the range from a single GPS satellite (as long as it gives a good cut) to further extend the time of hybrid GPS coverage.

We plan to test GPS thoroughly under the NUB agreement during the run-up to full deployment. We expect to have the experience to know what performance and limitations to expect. We will know, for instance, whether we need to operate a monitor receiver in the survey area to verify accuracy, by fixing on the same satellites, using the same broadcast ephemeris, and under the same fix geometry, as the survey vessels. Until full GPS deployment, and the consequent SPS Denial of Accuracy, there should be no need for real time transmission.

At that stage we can decide whether to pension off LORAN, Hi-Fix, Miniranger and Syledis in favour of GPS.

ACKNOWLEDGEMENTS

Ray Banks, Norm Beck and Pierre Heroux at Nortech, Demitris Delikaraoglou at UNB, and Steve Grant and Mike Ruxton at BIO have all contributed to development of the algorithms, software, data collection, and results described in this paper. The UNB contribution to this work was funded in part by operating and strategic grants from the Natural Sciences and Engineering Research Council of Canada, and in part by the Bedford Institute of Oceanography.

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EXPLORING ARCTIC SEAS - TODAY AND YESTERDAY

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ABSTRACT

The surveys of beaches and routes in preparation for landing supplies for the DEW line set off a new wave of Arctic hydrographic exploration. This was followed by the unique through-the-ice sounding operation with the Polar Continental Shelf Project and more recently the major surveys carried out in the Beaufort Sea and throughout the Northwest Passage in preparation for the transportation of oil and gas through these Arctic Seas. Hydrographers on all these surveys have followed in the footsteps of the British Navy expeditions in the nineteenth century. Survey bases have often been established on the same site where those early explorers had wintered, such as at Winter Harbour where Lieutenant Parry spent the winter in 1822 and at Beechey Island from where Franklin set off on his ill-fated voyage. This paper discusses the surveys both old and new, comparing the conditions under which the hydrographers worked and the results they achieved.

RÉSUMÉ

Les levés des plages et des routes maritimes, effectués en vue de l'approvisionnement des stations du RAPA, ont relancé l'exploration hydrographique de l'Arctique. Ces levés ont été suivis par l'expérience unique de sondage à travers la glace, dans le cadre de l'Etude du plateau continental polaire et, plus précisement, par les grands levés réalises dans la mer de Beaufort et le long du passage du Nord-Ouest, pour permettre le transport des hydrocarbures, dans des navires, à travers les mers arctiques. Pour tous ces levés, les hydrographes ont suivi la même itinéraire que les expéditions de la marine britannique, au 19e siècle. Les bases ont souvent été établies aux endroits mêmes où ces pionniers avaient hiverné: à Winter Harbour où le Lieutenant Parry a passé l'hiver en 1822 et à l'île Beechey, d'où Franklin est parti pour sa tragique expédition. Dans son étude, l'auteur met en parallèle les levés d'hier et d'aujourd'hui, en comparant les conditions dans lesquelles ils ont été effectués et les résultats obtenus.

INTRODUCTION

The Canadian Arctic is comprised to a large extent of islands separated by channels and was explored primarily by seafarers. Most of the journeys of the explorers were either by ship or by sled across the frozen sea. The catalyst for much of the exploration was to discover a new sea route to the Orient. In this paper we wish to touch upon some of the major journeys of exploration, particularly those which actually mapped the Arctic coastline and waters, and then to march forward to this century and show how those modern Arctic explorers - the hydrographers, have progressively surveyed the channels and seas of the Canadian Arctic.

Throughout this paper it will not be possible to cover every voyage of exploration or the work of every modern hydrographer. Our intention is to follow the history and dwell on those people and events where ancient and modern exploration have come together.

Although the Vikings are believed to have travelled from Greenland to the Canadian Arctic Islands we shall begin our story with the Elizabethan sailor, Martin Frobisher. In the period 1576-78, this tough Elizabethan sailor made three voyages to southeast Baffin Island, landing in what is now known as Frobisher Bay. With his two small vessels, the GABRIEL of 20 tons and the MICHAEL of 25 tons, he initially arrived near Resolution Island.

There was considerable confusion about the exact location of his discovery and on early maps Frobisher's Straits are shown near the southern tip of Greenland. Although he was disappointed in failing to reach the Orient he did bring back some ore which set off a "gold rush" but unfortunately this turned out to be "fool's gold", and Frobisher ended his Arctic endeavours in some disgrace.

In the nineteen fifties the bay which Frobisher had visited had assumed some importance as an administrative centre and strategic air base. The need for a safe route for shipping through the tortuous channels in the bay with the strong tides led the Canadian Hydrographic Service to send the chartered vessel ALGERINE there in 1954. This was followed by the new RCN icebreaker LABRADOR with a team of hydrographers aboard led by Mike Bolton which located and surveyed the important Pike - Resor Channel. This in turn was followed by surveys using the brand new

Arctic survey ship BAFFIN in 1958 with D'Arcy Charles as hydrographer.

In 1585, another tough Elizabethan seaman, John Davis with his two ships the SUNNESHINE and the MOONESHINE, building upon Frobisher's knowledge, sailed around the south coast of Greenland and headed north. In three successive voyages Davis penetrated Baffin Bay and followed the west coast of Greenland and on his last voyage reached the latitute of 72°42'N.

From the late nineteen sixties, the Canadian Hydrographic Service has systematically surveyed its offshore waters. These surveys, known as multi-parameter surveys, are combined surveys of bathymetry, gravity, magnetics and other geophysical measurements. These surveys which had started in the south, had by 1981 reached Davis Strait and in that year the HUDSON with Gary Henderson in charge and DAWSON with Steve Grant in charge, surveyed the Strait which John Davis had found so many years before in his little ship.

The fate of Henry Hudson is well known. In 1610 he was sent out in command of DISCOVERY to find a passage to the other ocean called the Southern Sea. In what is now James Bay his crew mutineered and he was set adrift in a boat to perish. Nevertheless, prior to the mutiny he managed to explore the south side of Hudson Strait and the east side of Hudson Bay and down into James Bay.

The precise charting of Hudson Bay and approaches was started by the CHS in 1913. The new survey vessel ACADIA was dispatched to survey a port intended for the export of Prairie grain. The entrance to the Nelson River was first chosen but was later changed to Churchill. Parts of the coast of Hudson Strait were surveyed using a shore party deployed from an icebreaker. This party was under the charge of F.C.G. Smith who later became Dominion Hydrographer. Later in the mid nineteen fifties BAFFIN and the two chartered vessels THERON and ARCTIC SEALER surveyed a major section of Hudson Strait.

During the early part of the Seventeenth Century several explorers, followed up Hudson's discoveries. Amongst these were Thomas James, who, in the HENRIETTA MARIA in 1631-32 circumnavigated both James and Hudson Bays spending a miserable winter near Charlton Island in the bay which bears his name.

Interest in Hudson and James Bay has waxed and waned over the years as a result of various economic developments.

The Canadian Hydrographic Service has followed these economic trends, which usually come on an urgent basis and then fade as interest in the development itself wanes. In the mid fifties hydrographers working aboard charter ships surveyed Rankin Inlet, Eskimo Point and later the Belcher Islands. In 1961-62 interest in Moosonee was so high that a winter survey party was dispatched to survey the channel through the ice. Hydrographers Bob Golding, Earl Brown and Neil Anderson were on this winter team. About this same time, 1961 but during the summer, the chartered sealing vessel NORTH STAR IV surveying at the entrance to James Bay struck a rock and sank. In 1973-74 the Coast Guard vessel NARWHAL with Bob Marshall in charge was dispatched to survey the route into Grand Riviére. The ship was equipped with modern high speed launches and for the first time an automated data processing system HAAPS was used. In 1975, the need for multi-parameter surveys to better define the hydrocarbon prospects, came to the fore and NARWHAL was used once more to systematically survey the entirety of the offshore waters of Hudson Bay - this time with Bruce Wright as hydrographer-in-charge.

By the middle of the 17th Century, the avenues to the west through Hudson Bay were almost exhausted as the explorers defined the perimeter of the bay. One of these explorers, Luke Foxe, had discovered the northern appendage to the Hudson Bay that bears his name. However it was left to a British naval officer nearly two hundred years later to really probe its northwesternmost extremity to discover the narrow channel that leads to the west. In 1821-23 Lieutenant Parry, who had already won fame in extending the northern channel to Melville Island attempted to penetrate the Strait named after his two ships FURY and HECLA. Unfortunately the heavy ice which presses down through the Gulf of Boothia and the fierce currents that set through the straits provided an impenetrable barrier in that era of sailing ships. The first surveys in Foxe Basin were carried out using the ice breaker the LABRADOR under the command of Capt. O.C.S. Robertson with hydrographers Blandford and Bolton onboard. These surveys were in support of the sealift required for the DEW Line sites.

Fury and Hecla Straits were first travelled overland by Charles Francis Hall in 1868 but it was not until

1948 that the U.S. icebreakers EDISTO and EASTWIND finally made the first ship transit and in 1957 the icebreaker HMCS LABRADOR now under the command of Captain T.C. Pullen made the first east to west transit and carried out the first hydrographic surveys. Onboard again was a party of CHS personnel. Not only did this party carry out useful surveys of Fury and Hecla but also carried out the first detailed surveys of that other narrow but critical Arctic channel, Bellot Strait. In 1959 the CHS returned again, this time with CSS BAFFIN having surveyed a cross section of Fury and Hecla. In 1975 with R. Pilote as Hydrographer-in-Charge (HIC) and in 1976 with Dick Lelievre as HIC BAFFIN was involved in surveying the eastern approaches to Fury and Hecla but did not penetrate the strait and it was left to Gary Henderson on BAFFIN and Bud Swim on LABRADOR in 1981 to complete the surveys of the narrow constriction of this waterway. These surveys located several dangerous shoals which further narrowed the navigable water which at the time was being contemplated as a route for LNG tankers.

The numerous voyages into Hudson Bay, culminating in Parry's attempts to enter Fury and Hecla Strait had exhausted the possibility of making a westwards passage through Hudson Bay and interest turned to the north. Sir John Ross set out in 1818 with the ISABELLA and the ALEXANDER to explore Davis Strait and Baffin Bay. Although his scientific observations were successful he unfortunately failed to recognize the entrance to Lancaster Sound and this glory was left to his second in command, Lieutenant Parry, a year later. Parry sailed his ships HECLA and GRIPER through the length of Lancaster Sound and into Viscount Melville Sound being finally stopped and forced to winter at Winter Harbour on the south coast of Melville Island. The following year Parry, who had spent a most organized and relatively trouble-free winter in camp set off west again and reached 113°47'W in M'Clure Strait before being stopped by the heavy ice. Nevertheless Parry's voyage was highly successful and he returned to England in 1820 having surveyed a large part of the main Northwest Passage.

In 1960 Prime Minister Diefenbaker's "dream of the north" was having some political reality and BAFFIN was dispatched again under Charles, to systematically survey Lancaster Sound. In the years that followed this important waterway from Bylot Island to Beechey Island was progressively surveyed. D'Arcy Charles using BAFFIN was followed by Russ Melanson and later by Ken Williams on LABRADOR and Tony O'Connor on HUDSON. Full use was made of the helicopters and survey launches and life was generally easier than for Lieutenant Parry 140 years previously. In 1971 Ken Williams as Hydrographer-in-Charge aboard the CCGS LABRADOR attempted to survey westwards from Barrow Strait. The ice conditions in Viscount Melville Sound are far more difficult than the comparatively clear waters of Lancaster Sound and it became increasingly apparent that west of Barrow Strait would always require the use of major ice breakers such as LABRADOR or JOHN A. MACDONALD to carry out any useful work.

At about the time that Parry was setting off to find a Northwest Passage by sea another naval officer, John Franklin, was setting out to confirm the reports made by explorers from the fur trading companies and to map the northern mainland coast of Canada. John Franklin made two epic overland journeys to the northern coast in the company of Dr. John Richardson and Lieutenant George Back. The first nearly ended in disaster, although he succeeded in exploring a substantial length of coastline east of Coppermine. The second was highly successful; he travelled down the Mackenzie and split his party into two groups. One group travelled eastwards with the boats DOLPHIN and UNION from which the Straits into Coronation Gulf were named. The other group encountered greater difficulties but succeeded in travelling west as far as Return Reef at 149°37'W. With these arduous travels he had delineated most of the coast which surrounds the Beaufort and Coronation Gulf.

In the nineteen fifties the DEW line Stations sited along the 70th parallel were constructed at points along the northern mainland shore. This stimulated a need for hydrographic surveys at places such as Cape Parry and Cambridge Bay.

The first of these at Tuktoyaktuk was surveyed by Phil Corkum, A. Rogers and J. Robichaud with the Mackenzie River Survey Party but other surveys were carried out by the U.S. Navy and Coast Guard with participation by Canadian hydrographers such as Harvey Blandford. In 1954 the Beaufort Sea Expedition with the U.S. icebreaker BURTON ISLAND worked into Prince of Wales Strait. The following year Ralph Wills and later Tom McCulloch, accompanied the U.S. Coast Guard icebreaker STORIS and carried out surveys in the western Arctic. In 1960 the Canadian Coast Guard replaced the U.S. vessels with CAMSELL and with hydrographers from the CHS aboard began a program of surveying in Beaufort Sea and other areas of the western Arctic that has continued to this day. In 1961 Tom McCulloch who had been working previously on CAMSELL transferred his attention to the borrowed RCMP launch SPALDING, which proved to be less than a success and in 1962 he arrived with the new 66 foot survey vessel RICHARDSON. In RICHARDSON he surveyed many of the coastal harbours stretching from the U.S. border as far east as Spence Bay. Surveys were made of many of the areas such as Bathurst Inlet and the Coppermine River where so many years before Franklin and others had toiled so hard to map that northern coast.

In spite of the efforts of hydrographers working from the RICHARDSON and the Coast Guard icebreaker CAMSELL the amount of surveying that could be completed during the brief ice-free season was miniscule compared with the task at hand. Today much of the southern waterway through Dolphin and Union Straits, Coronation Gulf and Queen Maud Gulf contains some of the most poorly charted waters in Canada. The Beaufort Sea was another matter and following the discovery of oil both on the mainland and offshore, a major drive was made to survey those waters. In 1967-68 PARIZEAU under hydrographer Stan Huggett started systematic offshore surveys. In 1969 the voyage of MANHATTAN to Prudhoe Bay with its attendant escort of icebreakers revealed an unusual and very significant hydrographic hazard. This was the existence of submarine pingoe-like features, or PLF's, similar to those that can be seen on the adjacent mainland of the Tuktoyaktuk peninsula. These pingoes are thought to be ice-covered hills that rise abruptly from the seafloor and since they rise to as close as 14 metres from the sea surface, pose a serious hazard to the anticipated deep draft supertankers of the future. In 1970 the CHS tasked the area with the major survey ships, PARIZEAU under Sandilands, BAFFIN under Burt Smith, and HUDSON, which was used primarily for oceanography. The hydrographic party of the Polar Continental Shelf Project (PCSP) also became involved with the surveys in Beaufort Sea and carried out through-the-ice spot sounding, and in 1968 under the direction of George Yeaton and John O'Shea a hovercraft was first used for hydrographic surveys. It happens that the major offshore oil discoveries in the Beaufort Sea lie in areas where the PLF's are most dense and during the last four years the CHS has directed considerable attention, including the development of technology to surveying a corridor into the oil fields. Major surveys have been carried out recently by O'Connor and Vosburgh.

In 1845 Captain Franklin was given a seagoing command and with two ships, the EREBUS and TERROR, set out to accomplish what other British naval officers to date had failed to achieve. While he personally failed and he and all his crew perished, the subsequent searches for his expedition resulted in the exploration of huge areas of the Arctic and eventually led to the discovery of the elusive Northwest Passage. The actual wanderings of Franklin are speculative as there is limited evidence but it is now believed that he circumnavigated Cornwallis Island passing the site of the modern lead-zinc mine on Little Cornwallis Island. He most certainly wintered on Beechey Island where his monument is located. He eventually made his way into Peel Sound but his two ships were beset and foundered in the ice northwest of King William Island in Victoria Strait, an area today recognized as extremely difficult to navigate because of heavy concentrations of pressured ice.

Over many years the Canadian Hydrographic Service has been fortunate in being able to place hydrographers aboard the Coast Guard icebreakers. Although in most cases the icebreakers' first task is to escort shipping, there are numerous opportunities to gather soundings from the ships or to lower a launch and survey a harbour. It is from this work that a steady buildup of knowledge has been acquired, particularly in areas where navigation through the ice is difficult for CHS's own ice-strengthened survey ships. It has been in the area around Barrow Strait and Cornwallis Island, the site of Franklin's limited journeys that this work has been most successful. Hydrographers Blandford, Williams, Lelievre, Gaudet, Hemphill, to name but a few, have extended our knowledge of Wellington Channel, Macdougall Sound and Barrow Strait on this opportunity basis. The icebreaker captains, themselves, have added immeasurably to this program.

Evidence of Franklin's final journey was eventually found on King William Island. He himself had died in June 1847 and the command was taken by Captain Francis Crozier who in April 1848 began a fateful march with 105 men towards the Back River during which they all perished. Arctic history then records a vigorous period of searches with ships being dispatched to both the east and western Arctic. The searches were numerous and only those whose wanderings can be related directly to modern hydrographic surveys will be discussed.

During the winter months when the ships were iced in, the search was carried out by sledge journeys. These led to the discovery of much of the central part of the Arctic Islands. One of those who sent out such parties was Captain William Penny who in 1850-52 explored the area through Wellington Channel and north to the Grinnell Peninsula. The strait between Devon Island and Bathurst Island which bears Penny's name was surveyed by Mike Eaton in 1962. This survey was conducted through the ice and was one of the first examples of the use of Hi-Fix over ice. It showed that the propagation of the signals could vary as the ice moved to and fro on the tide.

The last and greatest search expedition sent out by the British Admiralty was commanded by Sir Edward Belcher. The expedition from 1852-54 had two thrusts, one to proceed west to Winter Harbour to search for M'Clure and Collinson who were themselves searchers from the west, having set out in 1850; the other to search for Franklin north through Wellington Channel. Belcher himself took two ships ASSISTANCE and PIONEER and proceeded north as far as Northumberland Sound on Grinnell Peninsula where he went into winter quarters. From this vantage point sled parties explored much of the northern coasts of Bathurst Island and the Grinnell Peninsula, and many of the off-lying islands. Lieutenants Osborn and Richards travelled west and explored the Sabine Peninsula; Kellett travelled around Prince Patrick Island and picked up M'Clure who was stranded at Mercy Bay. Others from the expedition travelled through Belcher Strait as far as Hell Gate and Cardigan Strait.

Hell Gate and Cardigan Strait are important marine passageways into the Queen Elizabeth Islands. Icebreakers travel each summer through the former en route to Eureka, one of the most northern Arctic settlements. It was for these reasons that in 1962 Mike Eaton and Ross Douglas, then working with the Polar Continental Shelf Project, carried out detailed surveys of Hell Gate and Cardigan Strait. Eaton developed a novel technology for these surveys using a helicopter-towed sounding system. The area has fast tidal currents which keep the ice broken up and provide large open water areas. The helicopter system could be flown to the open water area and deployed. Although the surveys of these narrow channels were completed in detail the system proved to be difficult to use and dangerous. Attempts to overcome these difficulties led to the use of hovercraft noted earlier.

Earlier mention has been made of M'Clure, who with Captain Richard Collinson in the ENTERPRISE and INVESTIGATOR set out to search from the west. Together Collinson and M'Clure charted large sections of the coast of the western Arctic Islands, including the latter's almost total circumnavigation of Banks Island.

Prince of Wales Strait is today recognized as the western entrance to the North West Passage. Regular navigation through M'Clure Strait has proven to be impossible even for the major icebreakers and only one ship to date, the American icebreaker "NORTHWIND" has made the passage passing west to east. The southern route through Dolphin and Union Strait, Coronation Gulf and out through Victoria Strait, sometimes provides a relatively ice-free passage when Prince of Wales Strait is blocked but the southern route is shallow, particularly at the east end of Dolphin and Union Strait. It is certainly out of the question for deep draft tankers. Earlier information on the hydrography of Prince of Wales Strait was from a survey by U.S. icebreakers. In 1970 BAFFIN with hydrographer Burt Smith in charge carried out a detailed survey of the area around the Princess Royal Islands, the narrow west portion of the strait where the channel is less than twelve miles wide. The looming significance of the Beaufort Sea oil discoveries and talk of oil tanker shipments through the Northwest Passage in the mid-eighties forced the Canadian Hydrographic Service to consider further, more detailed surveys of this waterway. But in three consecutive years, surveys planned using icebreakers failed to take place due to their inability to reach the strait across Viscount Melville Sound from the east. In 1982 the narrow waterway was finally systematically surveyed using through-ice sounding methods from helicopters.

It remains to discuss the work of one last member of the Franklin search, Captain Leopold M'Clintock. Although the Admiralty felt that it had done all it could to search for Franklin, Lady Franklin was not satisfied and outfitted the FOX, sending it out under the command of M'Clintock. The vessel sailed in 1857 and after an initial delay in Baffin Bay M'Clintock addressed his attention to the channels leading south from Lancaster Sound. During the spring of 1859 the expedition finally found the traces of the Franklin expedition on King William Island, including written messages.

These south reaching channels, Prince Regent, Peel and M'Clintock have always presented difficulties to navigation and they become progressively more difficult from east to west. Prince Regent and Peel Channel are sometimes navigable but M'Clintock Channel, which is open to the full sweep of ice pressing down from Viscount Melville Sound is normally impenetrable. It is through this channel that the heavy pack ice sweeps down and against King William Island and into Victoria Strait. During 1981 the ubiquitous Polar Continental Shelf hydrographers under Paul Davis carried out a systematic through-ice survey of M'Clintock Channel not so much for navigation but simply to provide the regional coverage that is needed to complete our scientific knowledge of the Arctic.

The concentration on the Northwest Passage and the subsequent expeditions involved in searching for Franklin had tended to by-pass the channel that leads northwards from Baffin Bay to the Arctic Ocean. In spite of it being named after a British naval officer this area was predominantly one of American exploration as some of the names along its track, such as Kane Basin, testify. In the latter part of the nineteenth century interest was directed to reaching the Pole along this route and amongst those persons with this in mind were Hall, Greely and eventually Peary, who finally, early in this century, reached the North Pole.

To the Canadian Hydrographic Service this channel has presented several interesting challenges. Neil Anderson in 1966-67 surveyed Robeson Channel and the Lincoln Sea at the northern exit of the channel. He carried out soundings through the ice but had the greatest difficulties using a Hi-Fix positioning system over the heavily pressured and rafted ice. The medium frequency signals were seemingly incapable of propagating across the very heavy ice.

In 1971 Gerry Wade, working with the Polar Continental Shelf Project continued the survey southwards through Robeson Channel. This survey also became associated with a boundary dispute between Canada and Denmark involving the small uninhabited Hans Island, lying near the centre of Kennedy Channel. The position of the boundary could be altered depending upon the ownership of Hans Island, which was a matter for contention. After considerable historical research the matter was put aside with the boundary being tentatively agreed to be broken on each side of the island. In 1975 Jack Wilson continued Wade's work southwards through the channel in a cooperative venture with the Danish Hydrographic Office.

Until the turn of this century the channels between the Queen Elizabeth Islands had been relatively unexplored. Belcher had conducted a number of explorations on sled as part of the Franklin search along the north shore of Devon, Bathurst and Melville Islands. However it was Otto Sverdrup and his Norwegian exploration team that really opened up much of this area. In Nansen's former ship the FRAM the expedition started off to explore the northern coast of Greenland but in several successive seasons heavy ice directed their travels elsewhere. During the summer of 1901 he actually sailed FRAM into Norwegian Bay but had to retrace his steps back through Cardigan Strait after meeting heavy ice. His main explorations were by sled and dog team and his expeditions explored and claimed for Norway the entire eastern part of the Queen Elizabeth Islands including Ellesmere, Axel Heiberg, Amund and Ellef Ringnes Islands. This large area known today as the Sverdrup Islands, was eventually ceded to Canada in 1930 by Norway. Denmark laid claim to Ellesmere Island during the early part of the 1920's but the presence of Canadian postal and other governmental organizations such as the RCMP and military has strengthened Canada's sovereignty claim. Denmark no longer claims Ellesmere Island.

It was the uneasiness of the Canadian Government concerning the sovereignty of these Arctic Islands that led it in 1958 to launch an expedition which has had a major impact on Canadian hydrography to this date. This was the Polar Continental Shelf Project which has already been mentioned several times. The initial aim of this expedition was to survey the continental shelf of the Arctic Islands and some of the earliest work involved the setting up of a Decca Lambda Chain. The expedition was under the able leadership of a geologist, Dr. Fred Roots, who had considerable experience in polar operations. Hydrographers Blandford, Eaton and Kerr were originally assigned to the expedition. Much of the early work involved surveying the location of the Decca transmitters, calibrating and developing methods of sounding through the thick ice. Not the least of the problems was discovering and overcoming the limitations of modern electronic instruments, such as tellurometers when operating in temperatures as low as -50°F.

During the subsequent twenty-four years that the Polar Continental Shelf has been in operation the expedition has reached out from its original base camp at Isachsen on Ellef Ringnes Island to provide a basis of logistic support for an almost limitless range of scientific field research covering the entire Arctic, with base camps at Tuktoyaktuk and Resolute. Aircraft have been the main mode of transportation and every year the PCSP charters numerous helicopters and fixed-wing aircraft. Hydrography has always been a major component of PCSP and over time the systematic mapping of the seafloor through the ice has been extended to cover almost all the Arctic Islands and much of the continental margin extending into the Arctic Ocean. The work has always been closely related to that of the geophysicists with the measurement of gravity going hand in hand with the bathymetry. Some remarkable sorties have been made into the Arctic Ocean itself. In 1967 Neil Anderson accompanied the geophysicist Hans Webber to take soundings at the North Pole. In 1980 a geophysical expedition called LOREX was mounted to explore the tectonic character of the Lomonosov Ridge and included in this scientific expedition were studies of satellite navigation by Dave Wells. In 1983 another seafloor ridge in the Arctic Ocean, the Alpha Ridge, will be explored and on this occasion hydrographer Dave Pugh will be involved in measuring the deeper ocean depths beneath the ice.

CONCLUSION

It would be impossible in a story of this kind to mention every explorer either ancient or modern who has helped to accumulate knowledge of these Arctic coasts and Arctic seas. Clearly in the case of the earlier explorers there have been some obvious omissions of several great names such as Stefannson, Amundsen, Bernier, Larsen of "St. Roch" and numerous earlier explorers. In recent years there has been the important work of surveyors with the Surveys and Mapping Branch and the Army Survey Establishment in establishing basic control including the Shoran triangulation and the pioneering work of photogrammetrists. Mention should be made of two names in the ranks of recent surveyors; one is of Frank Hunt, a tough Newfoundlander, who has followed the fortunes of the Polar Shelf Project from the start until today and the second is Hans Pulkinen, who has probably surveyed more Arctic Seas than any man alive. There are very few of today's hydrographers who have not spent some of their career fighting off mosquitos in the sub-Arctic or freezing in the high Arctic be it aboard ship, or working from the Polar Continental Shelf over-ice surveys. The explorers of the 19th Century discovered the Northwest Passage; the hydrographers carried on their work.

SIDE SCAN SONAR - AN ALTERNATIVE TO WIRE DRAG FOR ITEM INVESTIGATION

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ABSTRACT

Since 1906 Charting and Geodetic Services (C&GS) and its predecessors (including the National Ocean Survey and the U.S. Coast and Geodetic Survey) have relied mainly on standard wire drag methods for conducting investigations to prove or disprove the existence of charted dangers to navigation. Despite its effectiveness, wire drag has usually proved inefficient and cumbersome when prosecuted by vessels and field parties not specially equipped for it. As a consequence, many investigations were deferred to special wire-drag survey vessels.

C&GS has recently approved the use of side scan sonar by hydrographic ships and field parties as an alternative to wire drag for conducting item investigations. This paper describes item investigations, wire drag, evaluations of sonar, and discusses the C&GS policy on side scan sonar use. A brief discussion of operational requirements for sonar search is also provided.

RÉSUMÉ

Depuis 1906 le National Ocean Survey (NOS) et ses prédécesseurs ont employé surtout la drague hydrographique à fil, pour mener des enquêtes afin de vérifier ou de réfuter l'existence de dangers signalés pour la navigation. Cependant, cette technique se révèle généralement inefficace lorsqu'elle est utilisée par des équipages et à bord de bateaux non spécialisés dans ce genre de travail. Aussi, plusieurs enquêtes, surtout celles qui portent sur des dangers signalés au large des côtes, sont confiées à des navires spécialement équipés d'une drague.

Le NOS a récemment approuvé l'utilisation d'un sonar à balayage latéral, au lieu de la drague, par tous les navires et les équipes hydrographiques qui effectuent des recherches pour localiser des dangers signalés. L'auteur de cette étude y décrit la politique et les procédures actuelles du NOS pour l'utilisation du sonar à balayage latéral, afin de localiser les dangers pour la navigation.

INTRODUCTION

To the navigator who trusts in nautical charts to keep a safe course and avoid danger, a charted wreck or obstruction not accurately shown can be as much a menace to navigation as one which has never been discovered. While undiscovered dangers are one problem in hydrography, dangers shown inaccurately on charts are quite another matter.

Complete hydrographic surveys usually include supplemental operations which are intended to verify the charting accuracy of all dangers shown. In Charting and Geodetic Services (G&GS) these supplemental field operations are generally referred to as "item investigations".

ITEM INVESTIGATIONS

An item investigation is a very thorough search, using approved methods, which will reveal either that:

1) a charted danger actually does exist; or that,

2) a charted danges does not exist within an areas, accounting for a reasonable amount of uncertainty in its reported position.

If the danger does exist, a hydrographic examination will then verify its charting accuracy by confirming its true position and its least depth. If a thorough search by approved methods has failed to find the danger, this search may be considered satisfactory proof of the danger's nonexistence where it had been reported or charted, permitting its removal from the charts.

There are three primary requirements for reliable, credible results in an item investigation. First, the search must cover an areas for a reasonable amount of error in the reported or charted position. Second, within the search area, the major portion of the water column and/or sea bottom must be scrutinized, using a positive detection method, in such a way as to leave no doubt about the completeness of the coverage. Third, the search must resolve all indications which may be the danger being sought, continuing either until the specific danger is found or all indications within the area are proven false.

The hydrographer must apply certain principles of search theory in order to establish a search area of sufficient size to make the investigation credible. In specifying the search area, the basic consideration is the reliability of the charted position. The source with which the charted danger originated is a useful indicator of the reliability of the charted position.

In general, the positions of dangers which originate with prior surveys are known, reliable positions. For these features, a simple search in the immediate vicinity of the charted position will almost always suffice to relocate the danger. Item investigation then becomes a matter of normal hydrographic examination.

Most item investigations, however, involve "reported" dangers. These are the wrecks and obstructions, often shown on charts as "PA" (position approximate), "PD" (position doubtful), and sometimes even "ED" (existence doubtful), which originate with sources such as Local Notice to Mariners, etc. These dangers have been charted on the basis of the "reported" position supplied in the source document. While reported positions may have been faithfully determined, they do not often reflect true positions because of fixing errors associated with the methods by which they were observed.

For a credible search to locate a reported danger at its true position, the hydrographer must take into account a reasonable amount of fixing error in the reported position. Opinions vary on the amount of fixing error which is considered reasonable. At the present time, the C&GS policy is to assume a fixing error of 1 nautical mile, and to require the hydrographer to search an area 1 nautical mile in all directions from the reported position. In actual practice, this requirement applies when no additional positional information is available which can serve to reduce the search area with confidence. If information is available, which can reduce the search area to a smaller area of high probability, a smaller search area can be specified.

Within the search area considered appropriate to the situation, it is essential that all points on the bottom be covered during the search. If a danger is not found by the search, there must be no possibility that it may have been missed because of gaps or "holidays" in the coverage. No claim of disproval of a charted danger can be accepted unless the completeness of the coverage has been assured.

Most dangers which are investigated are considered to possess certain attributes. They are usually discrete features, having only limited physical extent, such as a wreck. All are assumed to be stationary and of a solid nature. Finally, to a greater or lesser degree, they are assumed to be protruding above the general surrounding bottom. This will usually be the case for an obstruction of unknown nature, which a vessel reports encountering while navigating in what were thought to be safe depths.

Clearly, for features with such attributes, sounding methods alone will be incapable of providing the high degree of assurance required of the search. The search must be accomplished using a method which provides wide-path overlapping coverage of the bottom in order to effectively cover all points within the search area. The equipment must incorporate some means of positively indicating to the hydrographer the presence of a feature on or protruding from the bottom. In the negative sense, when no features are present, the search operation must also serve to indicate that fact.

An item investigation is not considered complete until every indication, which may be the object of the search, has been resolved satisfactorily. It must continue until the item is located, or until the entire search area has been covered and all indications have been proven not to be what the hydrographer is looking for. For example, if a hydrographer is searching for the wreck of a 40-foot fishing vessel and happens upon the wreck of a 40-foot barge, the search must continue until the hydrographer proves that the fishing vessel is not within the search area.

CONVENTIONAL METHODS AND THE NEED FOR AN ALTERNATIVE

The conventional method used by C&GS and its predecessors (including the National Ocean Survey and the U.S. Coast and Geodetic Survey), for accomplishing item investigations has been with the standard wire drag (figure 1). This venerable apparatus is a true contemporary of the lead line.

The wire drag was introduced in 1904 and adopted in 1906.(1) It has undergone only minor improvements since that time. The standard wire drag was developed by integrating, into a single system, certain aspects of similar devices described by the U.S. Army Engineers (2) and the French Hydrographic Service.(3) The result was a mechanical sweeping device suitable for ocean use, because its depth could be adjusted for tidal height changes.

Originally, wire drag was used exclusively as a means to supplement standard hydrographic surveying methods whereby all obstructions lying between sounding lines would be revealed. Incident to this, a further use of the drag suggested itself. This was to determine with certainty that an area, such as a channel, was free from obstruction to a specified maximum

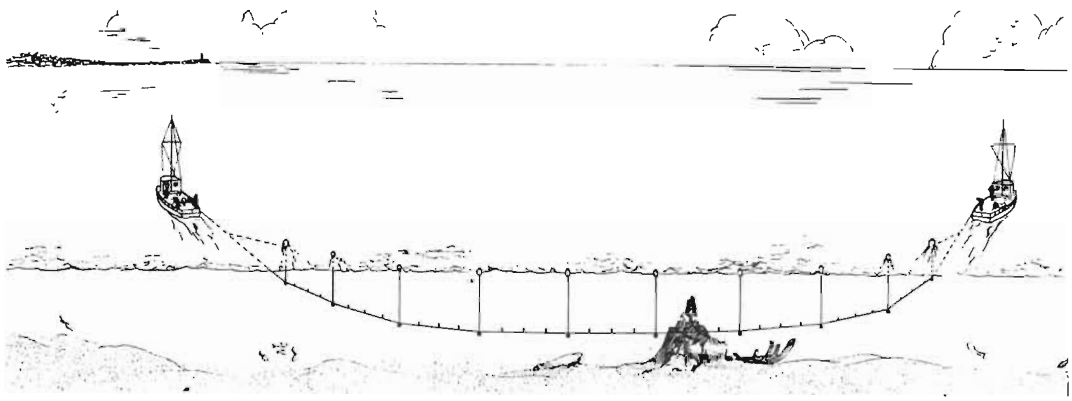

FIGURE 1 Standard Wire Drag

depth. Its use for these purposes was usually in conjunction with the sounding survey and was oriented more to general areas rather than specific individual features.

Item investigation, as we perceive the process today, began to become more prominent as a required hydrographic operation during World War II. Wire drag was pressed into service to locate and correctly chart the wrecks of ships which had fallen victim to submarine action along the east coast of the United States--a job which continued well into the 1950's. Since that time, wire-drag operations have been devoted almost totally to item investigation.

By virtue of its construction and method of operation, wire drag has long fostered great certitude in its results. If a wire could be passed close to the bottom over an entire search area, it would surely "hang" on an obstruction if one were present. Conversely, if a wire could be passed close to the bottom over an entire area without incident, then surely no danger could exist in that area. In item investigations, a long-standing wire-drag policy has been that complete, overlapped coverage of the search area, at a bottom clearance of 3 feet, is sufficient to disprove the existence of a danger to navigation.

Normally, a few wide drags will satisfactorily cover a large item investigation search area. As a practical matter, however, most hydrographic ships and field parties cannot mount wire-drag operations of such magnitude. They simply are not designed or equipped for it. At best, the hydrographic launches which must be used could handle a drag of about 500 feet. To investigate full search areas with such small drags would require large amounts of usually scarce project time, and would require most, if not all, of the available survey launches.

Because of this, hydrographic units defer some investigations of wrecks and obstructions, particularly those offshore, to the special wire-drag unit. When there was a renewal of emphasis on item investigations to increase the overall quality of hydrographic surveys and nautical charts, it quickly became apparent that success would depend upon some alternative to wire drag being available to make investigations of large search areas in a cost-effective manner.

C&GS EVALUATION OF SONAR AND ITS ACCEPTANCE

Various forms of active sonar equipment have been used by C&GS predecessors in the years since World War II. Despite observations made by hydrographers concerning the effectiveness of these instruments as detection devices, a great deal of caution was shown in accepting any but a mechanical means for detecting a danger or proving that it does not exist.

As early as 1955, the U.S. Coast and Geodetic Survey was using an "asdic" type sonar. This sonar was used as an adjunct to the standard wire drag for making preliminary searches of the area surrounding the reported position of wrecks.(4) On one project, it was noted that "not one wreck was found by dragging after a thorough sonar search. In some cases, a wreck was found by sonar outside the required drag limits that would have been missed, had not a sonar search been made."

The 1959 edition of the Wire Drag Manual(5) clearly stated that use of sonar had proven "very valuable" in the location of wrecks and obstructions whose exact locations were doubtful. Perhaps the reason that sonar failed to be accepted as a stand-alone detection device, at this point, was that success with the early sonars depended so much on the operator's skill in aurally distinguishing between wreck echoes, echoes from other reflectors, and noise.

A side-scanning sonar, the Ocean Bottom Scanning Sonar (OBSS), was first used in 1965. However, this use was not for hydrographic surveying purposes; rather, it was to investigate submarine faulting in the vicinity of Montague Island after the great 1964 Alaska earthquake. The use of this device did, however, finally begin to foster an awareness that fixed-direction-scanning sonar had potential hydrographic applications.

It was 10 years later, after towed side scan sonar systems were more widely available, that side scan sonar received its first thorough evaluation by C&GS, demonstrating its potential as an alternative to wire drag. In 1975, NOAA Ship DAVIDSON performed a practical test designed to evaluate side scan sonar's performance in detecting submerged dangers against that of wire drag. This evaluation spanned 2 months and was conducted during an actual survey project under typical working conditions. This comparison was conceivably the fairest which could be made since the standard wire drag was operated from launches--the situation in which the width of the drag is comparable to the swath width of the side scan sonar.

A total of 18 investigations were made for various submerged dangers. The side scan sonar was operated as the primary detection device on all searches, while the wire drag was used for confirmation whenever the side scan sonar search had negative results. Nine investigations resulted in side scan sonar detections of the dangers, followed by verification by divers. All remaining investigations resulted in negative findings by the side scan sonar. In six of these, the subsequent wire dragging confirmed that no danger was present. In the remaining three, all in shallow water over irregular bottom, the drag found the danger when the side scan sonar had indicated clear.

The 15 of 18 success rate was a significant finding. However, perhaps even more significant, from an operational standpoint, was the comparison of the survey times and resources required by the two methods. This comparison is summarized in table 1. The wire drag typically required <u>three times</u> the amount of onsite time as did the same investigation using the side scan sonar. Wire drag is both equipment- and labor-intensive. There was a <u>three-fold</u> difference in the number of vessels required and a <u>six-fold</u> difference in the number of person-hours. If side scan sonar is nothing else, it is certainly more efficient in terms of resources!

Table 1. Comparison of various operational aspects between wire drag and side scan sonar.

	Wire Drag	Side Scan Sonar
Launches	2	1
Skiffs	1	0
Personnel	12	6
Load/unload time in hours	1	0
Transit time in hours	1 1/2	1
Deployment time in hours	1/2	0
Search time in hours	2 1/2	1
Recovery time in hours	1/2	0
Total time in hours	6	2
Total person-hours	72	12

It was probably the 1975 DAVIDSON test that had more to do with making side scan sonar the obvious alternative to wire drag than any other single internal event. It dramatically proved that acceptable results could be produced with reasonable consistency by a nonmechanical method. One additional bit of evidence, which tipped the scale toward side scan sonar, was a fairly informal evaluation conducted in 1976 by the specially designed wire-drag ships RUDE and HECK. These ships are capable of deploying drags over 12,000 feet in length. While the side scan sonar again demonstrated its effectiveness by detecting wrecks which had previously been located by wire drag, it reinforced this effectiveness by detecting a wreck which <u>had not</u> been found within its search area by the drag.

In 1982, after the side scan sonar had been regularly used during wire-drag projects for 5 years, the side scan sonar was approved for general use by all C&GS hydrographic ships and field parties as an acceptable alternative to the more cumbersome and time-consuming wire drag for making item investigations. Item investigation has now joined other aspects of hydrographic surveying in the electronic era.

POLICY ON USE OF SIDE SCAN SONAR FOR ITEM INVESTIGATION

For detecting many of the commonly encountered submerged dangers which require the hydrographer's investigation, side scan sonar has been found essentially equal to mechanical methods in its effectiveness. In view of this finding, C&GS has developed a basic policy to guide the use of this instrument for making item investigations.

As a matter of policy, side scan sonar may now be used as a primary survey tool for the <u>detection</u> of submerged dangers with characteristics and/or circumstances which make a detection highly probable. It is recognized, however, that not <u>every</u>

danger may be reliably detected by this acoustic method. The following conditions are presumed to define those characteristics and/or circumstances which will make a detection highly likely:

(1) when there is adequate reason to expect that the danger is capable of returning echoes of sufficient intensity to exceed the intensity of the general reverberation background against which they must be detected;

(2) when there is adequate reason to expect that the danger has sufficient size (length, breadth, height) to produce a marking on the sonargram which is distinguishable from the generalized trace corresponding to the seabed.

When it can be reasonably determined, a priori, that a particular danger to be investigated satisfies these conditions, that danger may then be selected and assigned as an item for side scan sonar investigation. Side scan sonar may only be used as the primary detector for those items which have been specifically selected and identified as sonar candidates.

Once a side scan sonar search candidate item has been detected and properly identified as the danger being sought, the hydrographer must proceed with further examination using only standard methods. Position and least depth of the danger must be established to the accuracies required by the Hydrographic Manual. Side scan sonar determined positions and estimates of the least depth will not meet the required standards of accuracy.

A thorough side scan sonar search having a negative result with respect to the specific danger being sought shall be acceptable as conclusive proof of that danger's nonexistence where it had been charted or reported to be. If all procedural requirements of the search have been satisfied, such a negative investigation shall be the authority for the removal of the danger from all pertinent nautical charts.

PROCEDURAL REQUIREMENTS FOR SIDE SCAN SONAR SEARCHES

The first requirement of a side scan sonar search in item investigation is that it be systematic rather than random. By searching systematically, a danger can often be found with the least amount of searching effort being expended by the hydrographer. A search done systematically will give greater credence to the claim of disproval if eventually the danger is not found.

The most efficient systematic search pattern for covering a search area with a wide-path detector is the parallel-track pattern. This pattern is repeatable, requires only a minimum number of turns to produce uniform coverage, and permits ease of overlap of swept paths.

Related to the search pattern is the second requirement of a side scan sonar search in item investigation. This is the requirement for complete scanning coverage of the bottom as the search progresses. There are two determinants for complete coverage: the search track spacing and the side scan sonar's scanning range. To achieve complete scanning coverage, the area swept from one search track must, at least partially, overlap with the area swept from the adjacent search track. All points between any two tracks will have been scanned from at least one of the tracks. To achieve this degree of coverage, the side scan sonar's scanning range must be greater than one-half the track spacing to be used.

Each search pattern that the hydrographer runs must achieve the minimum 100-percent coverage between the search tracks. To obtain the highest probability of detecting a danger, the hydrographer should run two parallel search patterns, the second being run normal to the initial pattern. This will provide two "looks" at each point in the search area and prevent, as much as is possible, a chance of having overlooked a danger, should it have been scanned from its "least photogenic" aspect during the initial pattern. If a danger truly does exist within the search area, it should have been detected by this level of searching effort. If no danger has been detected to this point, the hydrographer shifts the emphasis to proving that the danger does not exist.

"Proof" that a danger does not exist within the search area is presumed when additional searching effort from "splitting" the search tracks of the first two patterns also fails to detect the danger. When this level of searching effort has been completed, the hydrographer has scanned every point between any two parallel search tracks four times, and has viewed each point from four different directions.

The final procedural requirement is to resolve each detection made by the side scan sonar which might be the danger being sought. Detections are indicated on the sonargram. The hydrographer must determine, through interpretation of the shape, size, shadow, tonal, textural, and pattern information from the recorded echoes, which detections may be the danger sought.

Examinations of these indications must be made which are sufficient to establish whether or not each is the danger under investigation. For these examinations, the hydrographer must use all the tools available, including divers. Until all possible indications are disposed of, the search must continue.

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U.S. NAVAL OCEANOGRAPHIC OFFICE
HYDROGRAPHIC SURVEY OPERATIONS
1972 - 1982

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ABSTRACT

The U.S. Naval Oceanographic Office (NAVOCEANO) located at the National Space Technology Laboratories, Bay St. Louis, Mississippi, conducts oceanographic, geophysical, and hydrographic survey operations with twelve Military Sealift Command Ships (MSC) under NAVOCEANO technical control and three specially modified P-3 Navy aircraft operated by Oceanographic Development Squadron EIGHT.

This paper will discuss the world-wide hydrographic survey operations conducted by the U.S. Naval Oceanographic Office from 1972 to 1982 including the resources and programs used to collect hydrographic data. The operations and programs described will include those by coastal hydrographic survey ships, USNS CHAUVENET and USNS HARKNESS; the Hydrographic Survey Assistance Program (HYSAP) which provides participating countries with technical resources and advice to conduct their own surveys and produce charts; the Hydrographic Contracts (HYCON) program which uses private contractors to survey selected areas; national and international cooperative surveys with other national agencies and foreign hydrographic organizations; and independent survey teams using other Navy ships, portable boats, or locally hired vessels. Furthermore, this paper will describe the expansion of NAVOCEANO's survey resources and capabilities including the implementation of such future systems as the Hydrographic Airborne Laser Sounder (HALS), the Hydrographic Information Handling (HIHAN) system, the Active/Passive Multi-Spectral Scanner (A/P MSS), and the Global Positioning System (GPS).

RÉSUMÉ

Le U.S. Naval Oceanographic Office (NAVOCEANO), situé aux National Space Technology Laboratories, Bay St. Louis (Mississippi), effectue des opérations océanographiques, géophysiques et hydrographiques, à l'aide de 12 navires du Military Sealift Command (MSC), placés sous le contrôle technique du NAVOCEANO et de trois aéronefs, P-3 modifiés de la Marine, exploités par l'escadron VXN8.

L'auteur de cette étude décrit les activités hydrographiques effectuées dans le monde entier par le U.S. Naval Oceanographic Office, de 1972 à 1982, ainsi que les ressources et les programmes servant à recueillir les données hydrographiques. Les opérations et les programmes décrits comprennent les opérations effectuées par le CHAUVENET et le HARKNESS; l'Hydrographic Survey Assistance Program (HYSAP) qui fournit des ressources et des conseils techniques aux pays participants pour leur permettre d'effectuer leurs propres levés et de produire des cartes; le programme Hydrographic Contracts (HYCON) aux termes duquel des entreprises privées sont chargées d'hydrographier certaines régions, les levés effectués dans le cadre d'une coopération nationale et internationale; les activités d'équipes hydrographiques indépendantes qui ont utilisé d'autres navires de la Marine, de petites embarcations ou des navires affrétés sur place. L'auteur décrit, en outre, l'expansion des ressources et des capacités hydrographiques de NAVOCEANO, notamment la mise en place de systèmes tels que l'Hydrographic Airborne Laser System (HALS), l'Hydrographic Information Handling System (HIHAN), l'Active/Passive Multi-Spectral Scanner (A/P MSS) et le Global Positioning System (GPS).

INTRODUCTION

The ocean is the traditional environment of the Navy. Operating in this environment requires the Fleet to have available the best information possible to provide for the Nation's defense in war and to insure the safety of all those who use the sea in peace. The U.S. Naval Oceanographic Office (NAVOCEANO) located at the National Space Technology Laboratories, Bay St. Louis, Mississippi, conducts oceanographic, geophysical and hydrographic survey operations with twelve Military Sealift Command (MSC) ships under NAVOCEANO technical control and three specially modified P-3 Navy aircraft operated by Oceanographic Development Squadron EIGHT (VXN-8), located at Patuxent River, Maryland (see Table 1). Since 1830 when NAVOCEANO began as the Depot of Charts and Instruments, the Office has been in the forefront of hydrographic survey practice.

The year 1972 marked the beginning of a new era in hydrography for the U.S. Naval Oceanographic Office. First, chart compilation, production, printing and distribution functions were separated from NAVOCEANO and combined with similar Army and Air Force mapping functions to form the Defense Mapping Agency (DMA). With this reorganization, NAVOCEANO retained the responsibility for the collection of hydrographic data. Second, two new ships -- USNS CHAUVENET and USNS HARKNESS -- began hydrographic survey operations. These ships, unlike previous Navy hydrographic

TABLE 1. NAVOCEANO SHIPS AND AIRCRAFT

SHIPS	LENGTH (FT)	COMMISSIONED	COMPLEMENT CREW	SCIENTIFIC	PURPOSE
USNS LYNCH (T-AGOR 7)	209	27 Mar 65	27	15	Oceanographic Research
USNS DESTEIGUER (T-AGOR 12)	209	28 Feb 69	27	15	Oceanographic Research
USNS BARTLETT (T-AGOR 13)	209	31 Mar 69	27	15	Oceanographic Research
USNS SILAS BENT (T-AGS 26)	285	24 Jul 65	50	26	Oceanographic Surveys
USNS KANE (T-AGS 27)	285	19 May 67	50	26	Oceanographic Surveys
USNS WILKES (T-AGS 33)	285	28 Jun 71	50	26	Oceanographic Surveys
USNS DUTTON[1] (T-AGS 21)	455	12 Sep 58	67	39	Geophysical Surveys
USNS BOWDITCH[1] (T-AGS 22)	455	12 Sep 58	67	39	Geophysical Surveys
USNS WYMAN (T-AGS 34)	285	3 Nov 71	41	10	Geophysical Surveys
USNS HESS (T-AGS 38)	563	16 Jan 78	67	39	Geophysical Surveys
USNS CHAUVENET (T-AGS 29)	393	13 Nov 70	69	73	Hydrographic Surveys
USNS HARKNESS (T-AGS 32)	393	29 Jan 71	69	73	Hydrographic Surveys

[1]Note: Scheduled to be replaced in 1985 by converted C3-33a class cargo ships.

AIRCRAFT	TYPE	COMPLEMENT CREW	SCIENTIFIC	PURPOSE
BIRDSEYE	RP-3A	12	5	Arctic Studies
SEASCAN	RP-3A	12	5	Oceanographic/Acoustic Surveys
MAGNET	RP-3D	12	5	Geomagnetic Surveys

survey ships which had military crews, are manned by civil service mariners employed by MSC with an embarked military Oceanographic Unit (OCEANOUNIT) responsible for conducting survey operations.

The continuing need for hydrographic surveys is substantiated by DMA requirements for the collection of over 200 ship-years of hydrographic data to support current charting needs. Also the combination of shifts in the world economic and political balance resulting in increased traffic into newly developed ports, the emergence of the deep-draft supertanker and the increasing ability in the near future to navigate precisely anywhere in the world with the NAVSTAR Global Positioning System (GPS), combine to highlight the inadequacy of the existing hydrographic data base.

This paper will discuss the world-wide hydrographic survey operations conducted by the U.S. Naval Oceanographic Office from 1972 to 1982 including the resources and programs used to collect hydrographic data. The operations and programs described will include those by USNS CHAUVENET and USNS HARKNESS; the Hydrographic Survey Assistance Program (HYSAP) which provides participating countries with technical resources and advice to conduct their own surveys and produce charts; the Hydrographic Contracts (HYCON) program which uses private contractors to survey selected areas; national and international cooperative surveys with other national agencies and foreign hydrographic organizations; and independent survey teams using other Navy ships, portable boats, or locally hired vessels. Furthermore, this paper will describe the expansion of NAVOCEANO's survey resources and capabilities with the planned implementation to the hydrographic program of advanced technology such as the Hydrographic Airborne Laser Sounder (HALS), the Hydrographic Information Handling (HIHAN) system, the Active-Passive Multi-Spectral Scanner (A/P MSS), and the Global Positioning System (GPS).

USNS CHAUVENET (T-AGS 29) AND USNS HARKNESS (T-AGS 32)

The USNS CHAUVENET and USNS HARKNESS (Figure 1) are the largest hydrographic survey ships built specifically for this role for the U.S. Navy (Table 2).

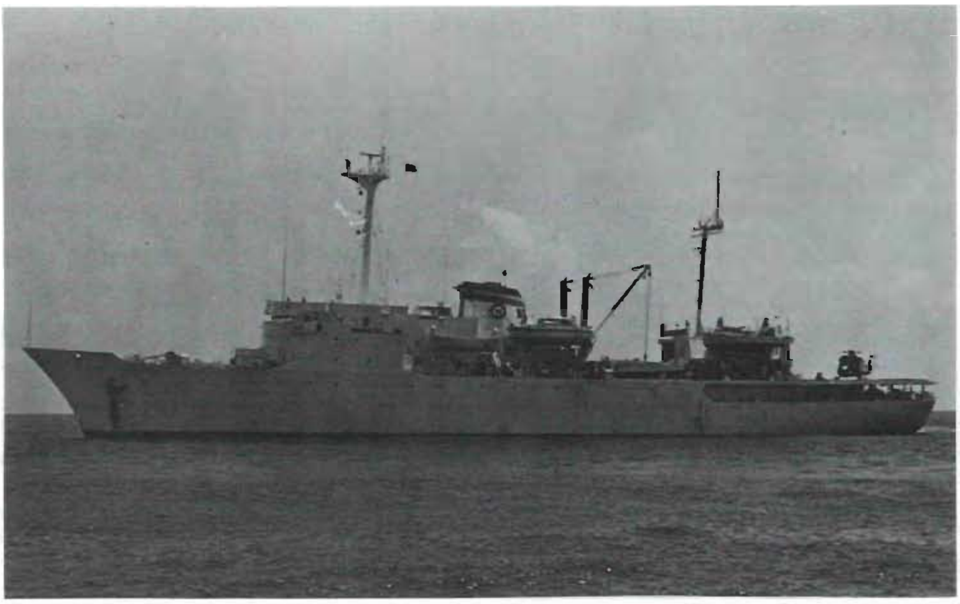

FIGURE 1. USNS HARKNESS (T-AGS 32)

Both ships were built by Upper Clyde Shipbuilders, Govan Division, Glasgow, Scotland. The CHAUVENET's keel was laid on 24 March 1967; it was launched on 13 May 1968 and delivered on 13 November 1970. After a shakedown cruise off Virginia and North Carolina in May-August 1971, the CHAUVENET began hydrographic operations surveying Korean waters in July 1972. The HARKNESS' keel was laid on 30 June 1967; it was launched on 12 June 1968 and delivered on 29 January 1971. In July-November 1971, the HARKNESS also performed a shakedown cruise off Virginia and North Carolina and in July 1972 began hydrographic survey operations in Greece.

The USNS CHAUVENET and USNS HARKNESS are operated by Military Sealift Command (MSC) with a military Oceanographic Unit (OCEANOUNIT) aboard responsible for conducting the hydrographic survey operations. Each OCEANOUNIT is augmented and supported by: civilian NAVOCEANO hydrographers and electronic engineers and technicians to provide the hydrographic expertise; Navigational Aids Support Unit (NAVAIDSUPPUNIT) personnel and equipment to operate and maintain the shore-based electronic position fixing stations; a Helicopter Antisubmarine Squadron Light (HSL) detachment to fly and maintain the embarked HH-2D helicopter used to support shore-based NAVAIDS sites and geodetic survey teams; and, as required, a U.S. Marine Corps Coastal Survey Team (USMC CST).

Table 3 is a listing of each ship's complement. Each ship carries four 36-foot survey launches which are used to conduct the shallow water hydrography, two 36-foot landing craft (LCVP) and one helicopter for logistical support, and two 16-foot utility boats. Table 4 is a listing of each ship's major survey equipment and instrumentation.

TABLE 2. USNS CHAUVENET AND USNS HARKNESS CHARACTERISTICS

Length	393 feet
Beam	54 feet
Draft	17 feet
Displacement	4300 tons
Propulsion	Two 1800 HP diesel engines driving one controllable pitch propeller through reduction gear
Speed	15 knots
Endurance	12,000 n. miles
Hull	Steel, ice strengthened
Winches	2 hydrographic, 1 magnetometer
Design	The only U.S. survey ship with a full helicopter support capability

TABLE 3. USNS CHAUVENET AND USNS HARKNESS SHIP'S COMPLEMENT

MSC	69
OCEANOUNIT	52
NAVOCEANO Civilians	7
HSL detachment	14
NAVAIDSUPPUNIT detachment (ashore)	12
USMC CST	As needed, up to 22

TABLE 4. LIST OF SHIP'S SURVEY EQUIPMENT AND INSTRUMENTATION

Aircraft	1 HH-2D Seasprite helicopter
Boats	4 36-ft survey launches 2 LCVP 2 16-ft utility boats
Electronic Positioning	
	USNS CHAUVENET
Short range	Mini-Ranger III 10 shore stations 10 mobile stations
Medium range	ARGO DM-54 3 shore stations 8 mobile stations
Long range	LORAN C, SATNAV
	USNS HARKNESS
Short range	Trisponder 520 6 shore stations 6 mobile stations
Medium range	ARGO DM-54 2 shore stations 4 mobile stations
Long range	LORAN C, SATNAV
Depth sounders/ sonars	
Precision shallow water	6 DSF-600 (20^{o} beamwidth, 40 KHz)
Portable shallow water	1 DE-719 (8^{o} beamwidth 200 KHz)
Deep water wide beam	2 Raytheon Blue Water Systems (33^{o} beamwidth, 12 KHz)
Deep water narrow beam	Harris Narrow Beam Echo Sounder System ($2\text{-}2/3^{o}$ beamwidth, 12 KHz)
Side-scan sonar	2 Klein 400 systems (CHAUVENET) 2 EDO Western 606 systems (HARKNESS)
Automated data collection/processing	Ship Hydrographic Oceanographic Data Acquisition System (HODAS) Launches Boat Data Logger System (BDLS)
Geodetic Equipment	2 AN/PRR-14 Geoceivers 6 T-2 theodolites 2 T-3 theodolites 3 N-2 levels 6 DM-20 Electrotapes 1 Ranger IV laser
Oceanographic Equipment	5 nitrogen gas purging tide gages 1 over-the-side current meter 1 XBT launcher and recorder various bottom samplers
Chart production	1 Harris offset rotary press 1 Robertson gallery camera 1 hydraulic paper cutter 1 IBM Electronic Selectric Composer

Data Handling

A typical hydrographic survey involves the collection of: geodetic information to reference the survey to the geocentric World Geodetic System 1972 (WGS 72) datum or to an acceptable regional datum; time correlated position and depth data to chart the bottom; side-scan sonar information to delineate submerged dangers to navigation; tidal data to define a vertical reference datum and to adjust the depths to that datum; bottom samples to determine safe anchorages; and current flow information to assist the mariner in navigating safely.

During the 1972-1982 period, data handling by CHAUVENET and HARKNESS has been a mixture of automated and manual methods. Each ship was equipped with the Hydrographic Data Acquisition System (HDAS) which consisted of two Digital Equipment Corporation PDP-9 computer subsystems, one for real-time data acquisition and the other for post-time data editing, sharing a common drum memory. Each subsystem had an assortment of peripherals including flatbed and drum plotters, magnetic tape drives, teletypes, and paper reader/punch units. Although the HDAS was designed to collect and process ship's hydrographic data completely by automated methods, the HDAS had no capability to edit and correct the sounding data recorded on the magnetic tapes. Consequently, soundings were digitized from the echo sounder analog traces using a Wang Digitizer System and the soundings hand-inked on the field/smooth sheets. Survey launch data for most of this period were collected and processed manually except that launch echo sounder analog traces were also digitized using the Wang system.

Normally, survey manuscripts (field sheets) and data received from the field are recompiled and smooth sheets produced, edited, and reviewed in the Office for quality control before sending them to the Defense Mapping Agency Hydrographic and Topographic Center (DMAHTC) for compilation into nautical charts. Alternatively, in emergency situations, both ships have the capability to perform all the survey data processing and the compilation and printing of multi-color nautical field charts for immediate distribution to Fleet units.

USNS CHAUVENET (T-AGS 29) Survey Operations

The USNS CHAUVENET began its first survey in July 1972 when it assumed the mission of surveying the coastal waters of the Republic of Korea (ROK) (Figure 2) from the survey ship USNS KELLER. For the next three years, in the summer and autumn seasons until November 1975, the CHAUVENET conducted survey operations in Korea. The CHAUVENET's survey of Korea was complemented in the inshore areas by Korean survey vessels operating under the US-ROK Cooperative Survey Program. In April 1973, the CHAUVENET commenced survey operations in Mindoro Straits, Philippines (Figure 3) and for the next three years, in the winter and spring seasons until June 1976, the CHAUVENET performed hydrographic surveys in the Philippines and the Bashi and Balintang Channels between Luzon, Philippines and Taiwan. After the termination

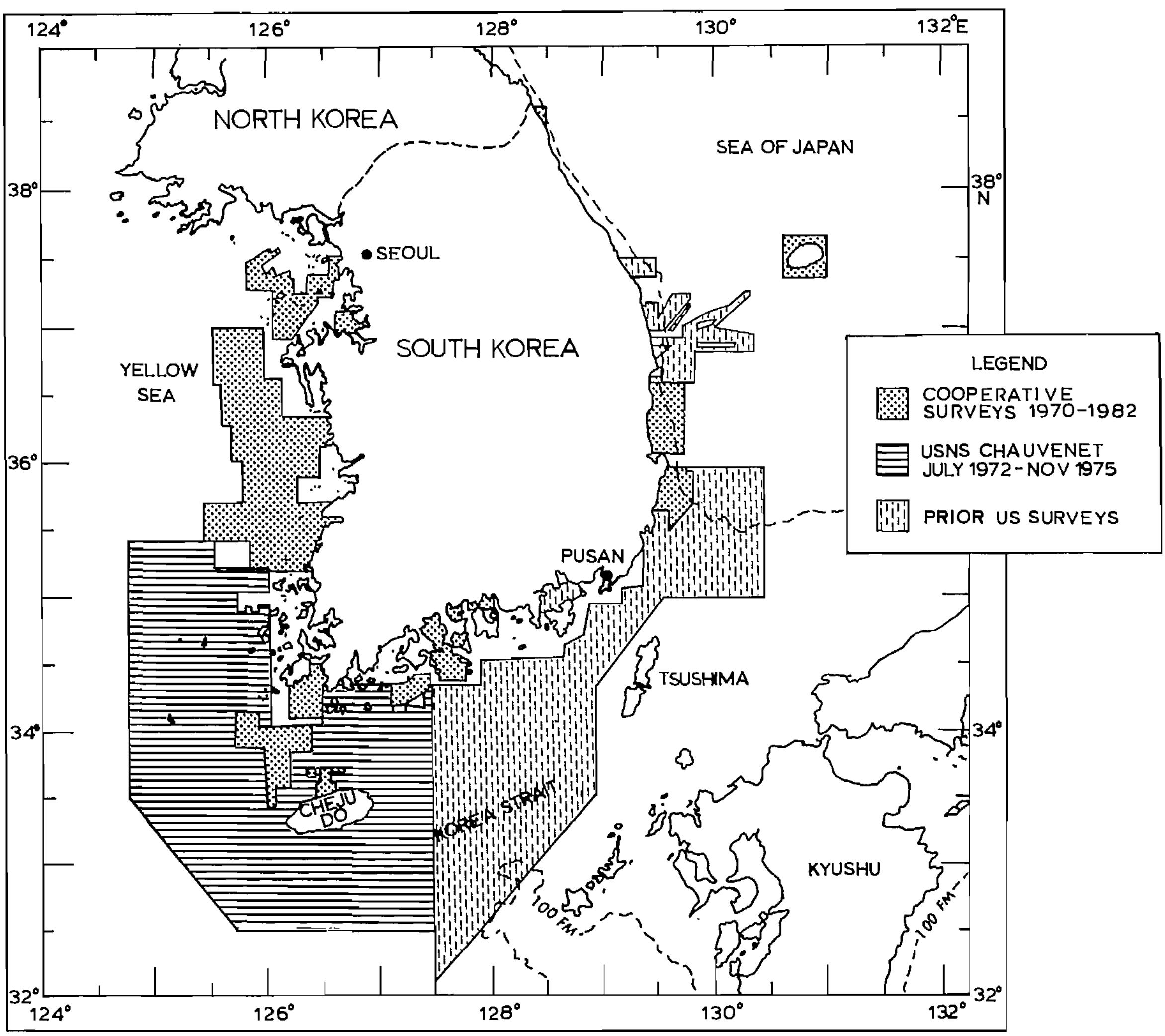

FIGURE 2. Hydrographic Survey Operations in Korea

of the Korea-Philippine surveys, the CHAUVENET conducted hydrographic surveys of Ulithi Atoll, Caroline Islands (September-October 1976) and off Maui, Hawaii (November 1976-January 1977). In February 1977, after completing its transit across the Pacific Ocean, the CHAUVENET began surveying the Bay of Panama. It operated in Panamanian waters until October 1978 when it finished the northern entrance to the Panama Canal (Figure 4). In the survey of the Bay of Panama, CHAUVENET was assisted by USNS BARTLETT, USNS DESTEIGUER USNS LYNCH and the Hydrographic Survey and Charting (HYSURCH) system. After returning to the Far East in April 1979, CHAUVENET began conducting hydrographic surveys of the Makassar Straits, Indonesia, in cooperation with the Indonesian Navy Hydrographic/Oceanographic Office (JANHIDROS) (Figure 5). This cooperation includes assisting Indonesian Naval vessels in surveying the western inshore portions of the Makassar Straits. Unfortunately, on 8 May 1982, while transiting from Subic Bay Naval Station in the Philippines to the Makassar Straits survey area, the CHAUVENET went aground near Cagayan Island, Philippines, and severely damaged its hull. Even then, the expertise of the CHAUVENET's survey personnel was required to conduct a mini-survey of the reef area to assist the salvage operations. In January 1983, the CHAUVENET resumed the Makassar Straits survey.

USNS HARKNESS (T-AGS 32) Survey Operations

The USNS HARKNESS began survey operations in Greek coastal waters in July 1972 and until October 1974 conducted hydrographic surveys near Samothraki, Lesvos, northern Greece, Peloponnesos, Andikithira and Crete (Figure 6). Upon completion of survey operations in Greece, the HARKNESS shifted operations to the Caribbean area. In March 1975, the HARKNESS began surveying the western and northern portions of Mona Passage, and then extended its operations in September 1975 to include the entire coastline of the Dominican Republic (Figure 7). The HARKNESS survey of the Mona Passage was adjacent to the Cooperative Surveys by National Oceanic and Atmospheric Administration (NOAA) survey ships, MT. MITCHELL and WHITING. By August 1977 HARKNESS completed the Dominican Republic survey and commenced surveying Port-au-Prince harbor, Haiti (Figure 8). With the return of friendly diplomatic relations with Egypt, the HARKNESS began surveying the north coast of Egypt in January 1978 and continued on to survey the Gulf of Suez separation zone, finishing that shipping channel in January 1979 (Figure 9). After a transit to the United States, HARKNESS was placed in reduced operating status (ROS) and the OCEANOUNIT decommissioned due to a lack of operating funds. In October 1980, when funds again became available, the HARKNESS was taken out of ROS and the OCEANOUNIT recommissioned. The HARKNESS renewed its survey career by surveying an area in the Jamaica Channel(Figure 8), during July-November 1981 and the Yucatan Channel (Figure 10), during November 1981-February 1982. Both these operations completed areas partially surveyed by NOAA, U.S. Coast Guard and the British Hydrographic Department under the Cooperative Surveys Program. In April 1982, USNS HARKNESS commenced surveying the coastal waters of Haiti (Figure 8) and is scheduled to continue survey operations there until July 1983.

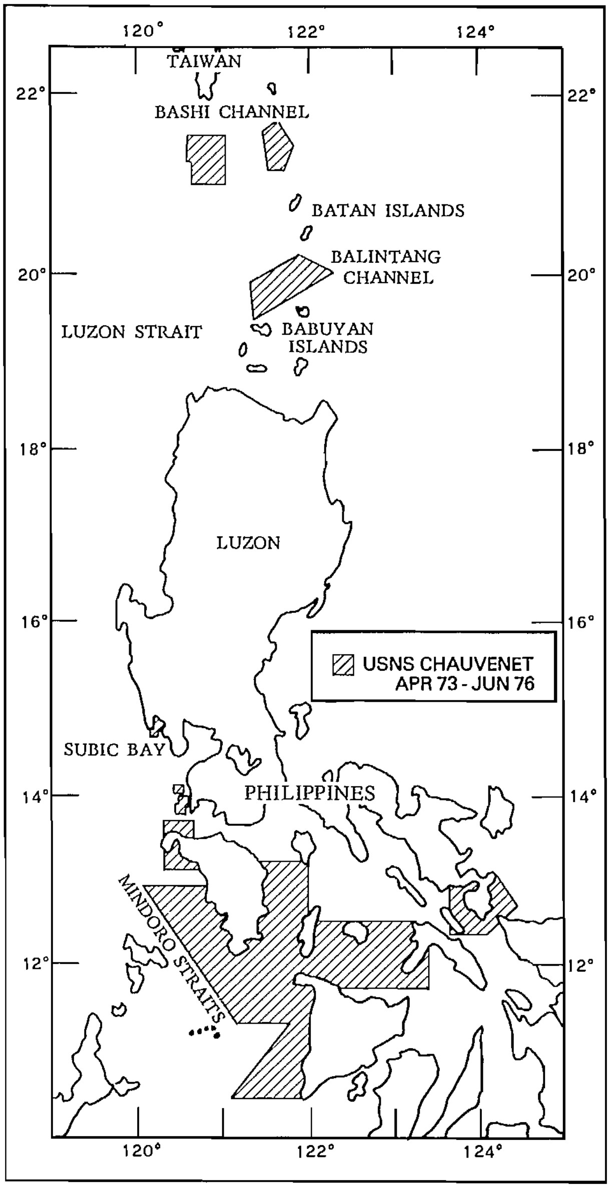

FIGURE 3. Hydrographic Survey Operations in the Philippines

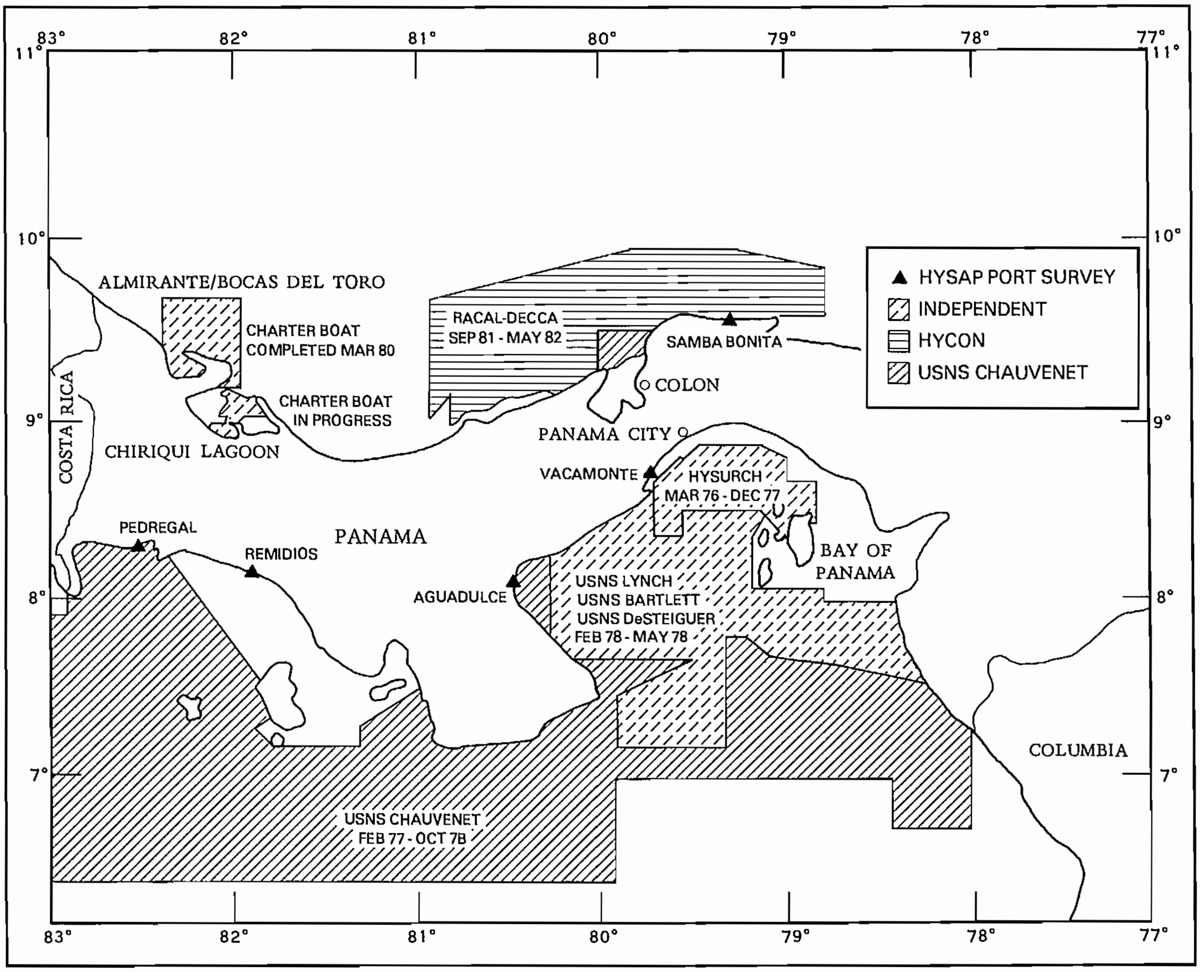

FIGURE 4. Hydrographic Survey Operations in Panama

Improvements of Survey Ship Capabilities

Improvements of survey ship capabilities by replacing obsolescent equipment have been planned or are already made. These improvements are necessary to expand the quality and quantity of CHAUVENET and HARKNESS surveys.

Automated data collection and preliminary data processing of survey information is now performed by each ship's brand-new Hydrographic Oceanographic Data Acquisition System (HODAS). This system consists of two subsystems -- one for real-time data acquisition and the other for post-time data editing. As indicated by Figure 11, each HODAS subsystem consists of a Digital Equipment Corporation PDP-11/34 computer, two five-megabyte disk units, 64 K word main memory, a teleprinter terminal, a plotter, and two TU-58 cassette cartridge units. Also the real-time subsystem has one nine-track ½" magnetic tape unit and the post-time subsystem has two nine-track ½" magnetic tape units, a graphic CRT terminal, a digitizer table, a paper tape reader and punch, and a MFE-250 cassette reader. The HODAS has the capability to switch the data collection from the real-time subsystem to the post-time subsystem upon a failure of the data acquisition computer. Data acquisition by each ship's four survey launches will be performed using the Boat Data Logger System (BDLS) which is scheduled to be installed in all survey launches in April 1983. The BDLS is an Ocean Data Equipment Corporation Model HSS-600 microprocessor-based data logger which displays, prints, and records navigation, depth and time data. Data are recorded on magnetic digital cassettes which are then processed on the ship's HODAS for data editing and display via the MFE-250 cassette reader.

Major equipment acquisitions are planned to maintain and expand the survey capabilities of both ships. First, it is expected that in 1983 funds will be made available to add more shore and mobile ARGO DM-54 stations for HARKNESS hydrographic operations. Second, funds have been budgeted and orders placed for eight new

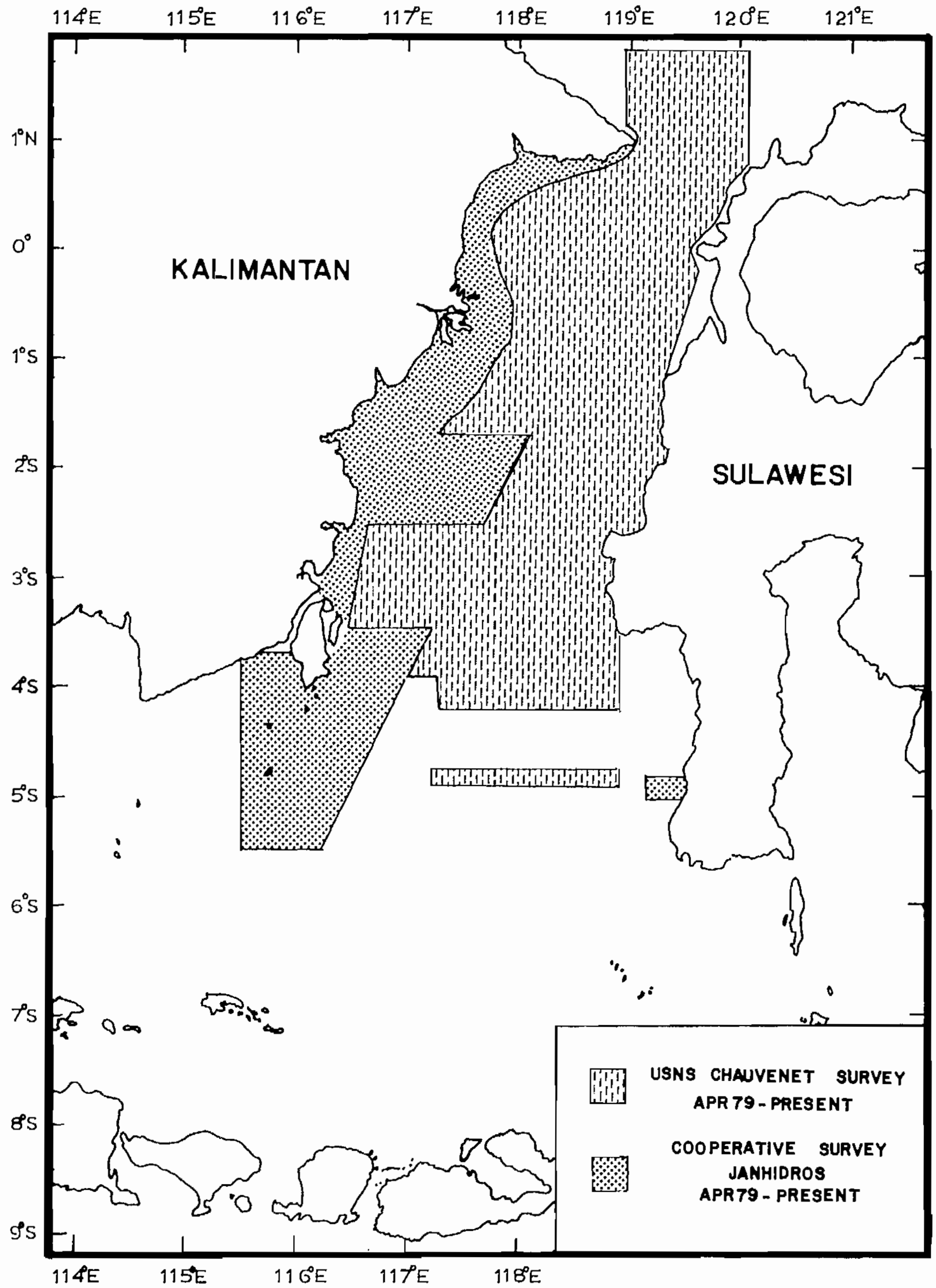

FIGURE 5. Hydrographic Survey Operations in Makassar Straits, Indonesia

hydrographic survey launches, to be delivered in 1984. These launches will be a variation of the 36' LCP(L) MK12 landing craft with a top speed of 17 knots. Third, preliminary investigations are being made to find candidate replacements for the AN/PRR-14 Geoceivers and the DM-20 Electrotapes. These systems are over 15 years old and are now failing too frequently to retain.

SUPPLEMENTARY HYDROGRAPHIC PROGRAMS

In addition to conducting surveys with CHAUVENET and HARKNESS, NAVOCEANO further augments its hydrographic data collection efforts with the following programs: Hydrographic Survey Assistance Program (HYSAP), Hydrographic Contracts (HYCON), National/International Cooperative surveys, and Independent Operations.

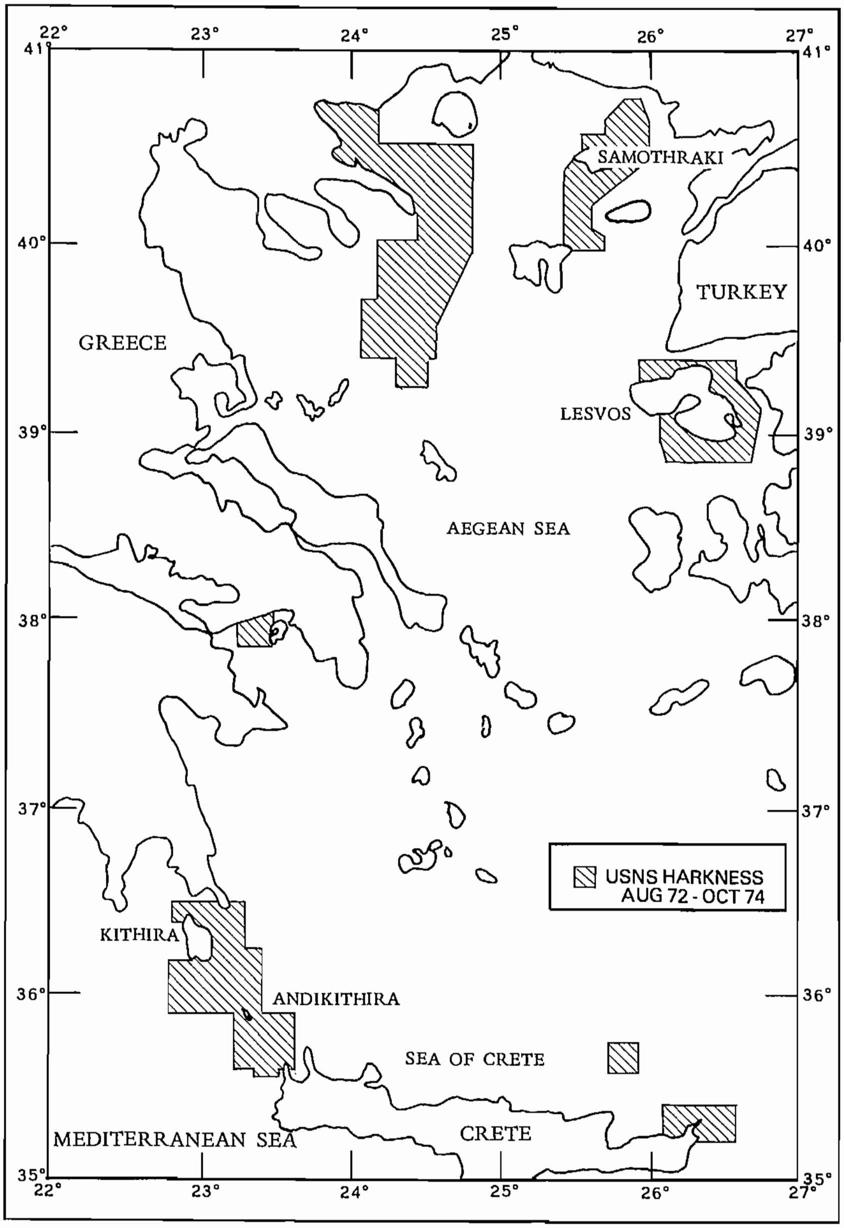

FIGURE 6. Hydrographic Survey Operations in Greece

Hydrographic Survey Assistance Program (HYSAP)

The Hydrographic Survey Assistance Program (HYSAP), formerly known as the Harbor Survey Assistance Program (HARSAP), is a program to provide technical assistance to foreign countries in conducting hydrographic surveys primarily in ports, harbors and near-shore areas where large scale charts are required for safe navigation. This program augments NAVOCEANO capabilities in hydrographic data collection, yet is tailored to the particular needs of each participating nation. Through HYSAP, the U.S. has been able to obtain more than 100 new and updated charts of Latin American harbors and coastal waters that comply with U.S. and International standards.

The program began operations in 1964 by assisting the Port Authority in Guayaquil, Ecuador and has since expanded to its present level of providing continual support to eleven Latin American countries. Figures 4, 7, 8, and 10 indicate the ports completed by HYSAP in Panama, Dominican Republic, Jamaica, Bahamas and Honduras. Not shown are surveys completed in Colombia, Costa Rica, Ecuador, El Salvador, Guatemala, Nicaragua and Peru.

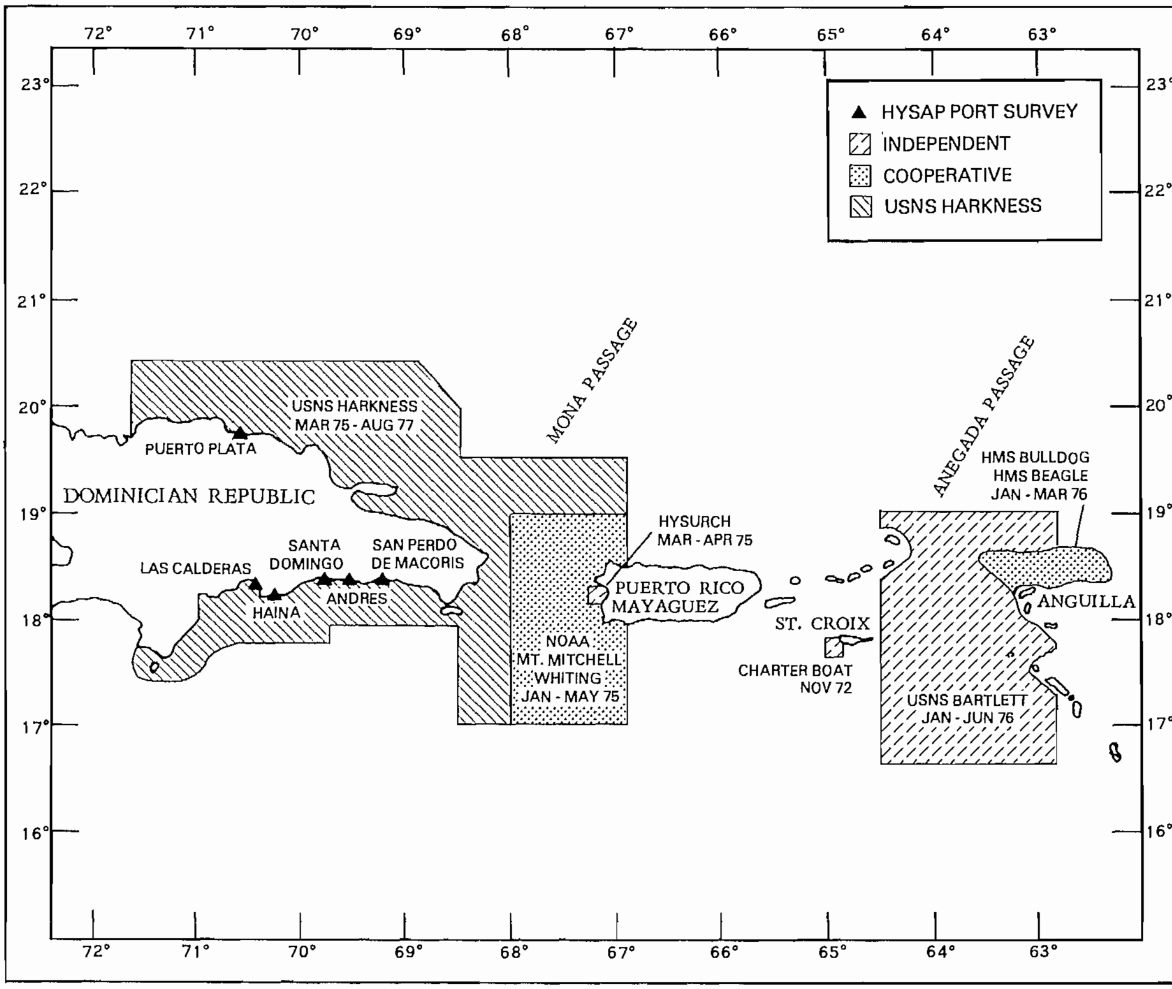

FIGURE 7. Hydrographic Survey Operations in the Dominican Republic, Mona Passage, and Anegada Passage

Other countries receiving HYSAP support are Sudan, which is receiving hydrographic assistance under a HYSAP managed contract from Martel Laboratories, and Nigeria which received a jointly prepared Navy and DMA plan for the establishment of a hydrographic office that includes HYSAP assistance. Additional requests for participation in HYSAP have been received from 13 countries in Africa, Asia, the Caribbean, and Latin America. In 1970 the first regional HYSAP office was established in the former Panama Canal Zone. This Office closely works with the Inter-American Geodetic Survey (IAGS) in the compilation and construction of nautical charts based on HYSAP surveys and also in providing Spanish language instruction in hydrography at the IAGS Cartographic School in Panama. Future expansion of HYSAP is being considered and may include increasing resources to allow for expansion from one to four regional offices, and to establish a practical six-month training course in hydrographic surveying at NAVOCEANO.

Hydrographic Contracts (HYCON)

Hydrographic Contracts (HYCON) is a program which uses private contractors to perform hydrographic surveys.

HYCON surveys typically contract for the collection of geodetic information, correlated position and depth data, suspected hazards to navigation investigations, side-scan sonar records, tidal data, and Sailing Directions information. Deliverables include all raw analog records, field sheets, smooth sheets, and a final edited nine-track magnetic data tape for each smooth sheet. The first HYCON survey was awarded to Tetra Tech, Inc. for $0.93 million on 15 December 1980 for 3,200 linear nautical miles at two sites along the coast of Oman. Field survey work began in January 1981 off Salalah and subsequent surveys were performed off Al Masirah Island. A total of 3,334 linear nautical miles for both areas was completed in April 1981 and final delivery of data was made in June

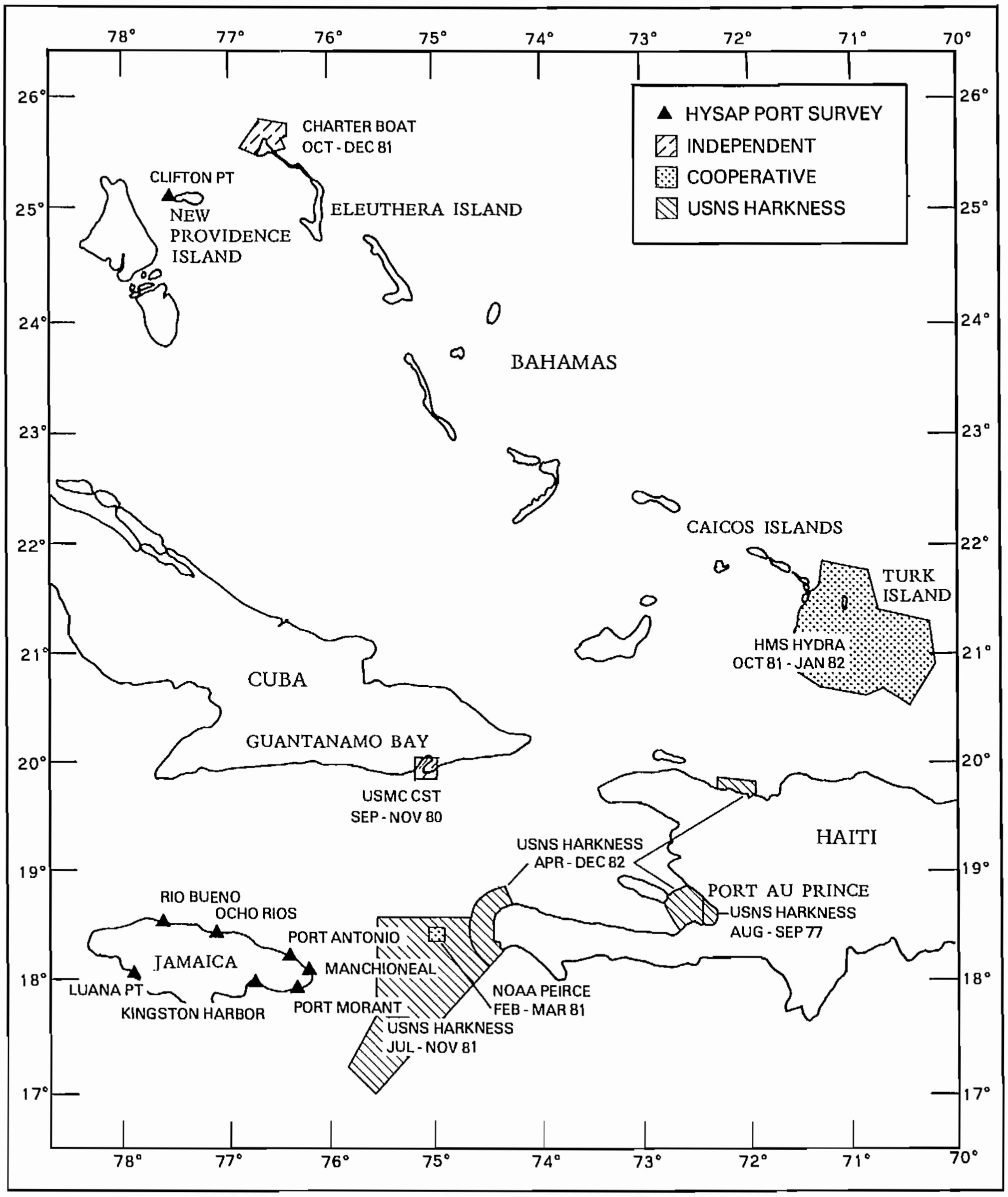

FIGURE 8. Hydrographic Survey Operations in the Central Caribbean Area

1981. The second HYCON survey was awarded to Racal-Decca Survey, Inc., for $2.4 million on 27 July 1981 for 12,200 linear nautical miles along the north coast of Panama (Figure 4). Field survey work began on September 1981 in the Approaches to the Panama Canal. Racal-Decca completed only 8,900 linear nautical miles (73%) when the contract expired in June 1982 because funds were fully expended. Delivery of data was made in September 1982. The third HYCON survey was again awarded to Tetra Tech, Inc. for $1.4 million on 12 April 1982 for 11,400 linear nautical miles in the Rosalind Bank area (Figure 10). Field work began on July 1982 and a total of 6,730 linear nautical miles (60%) was completed when the contract expired on 19 November 1982 because funds had been fully expended.

Since HYCON is a valuable program to NAVOCEANO for satisfying survey requirements, funds have been programmed in fiscal year 1983 for another HYCON survey in the Caribbean Sea area.

Cooperative Surveys

Cooperative surveys with other national agencies such as NOAA and the U.S. Coast Guard (USCG), and with foreign hydrographic organizations, such as the Korean Hydrographic Office, JANHIDROS, and the British Hydrographic Department (HYDRO UK), are the most cost effective surveys available to NAVOCEANO. These surveys make available to NAVOCEANO, at a fraction of what survey operations would normally cost, data for areas of high marine interest.

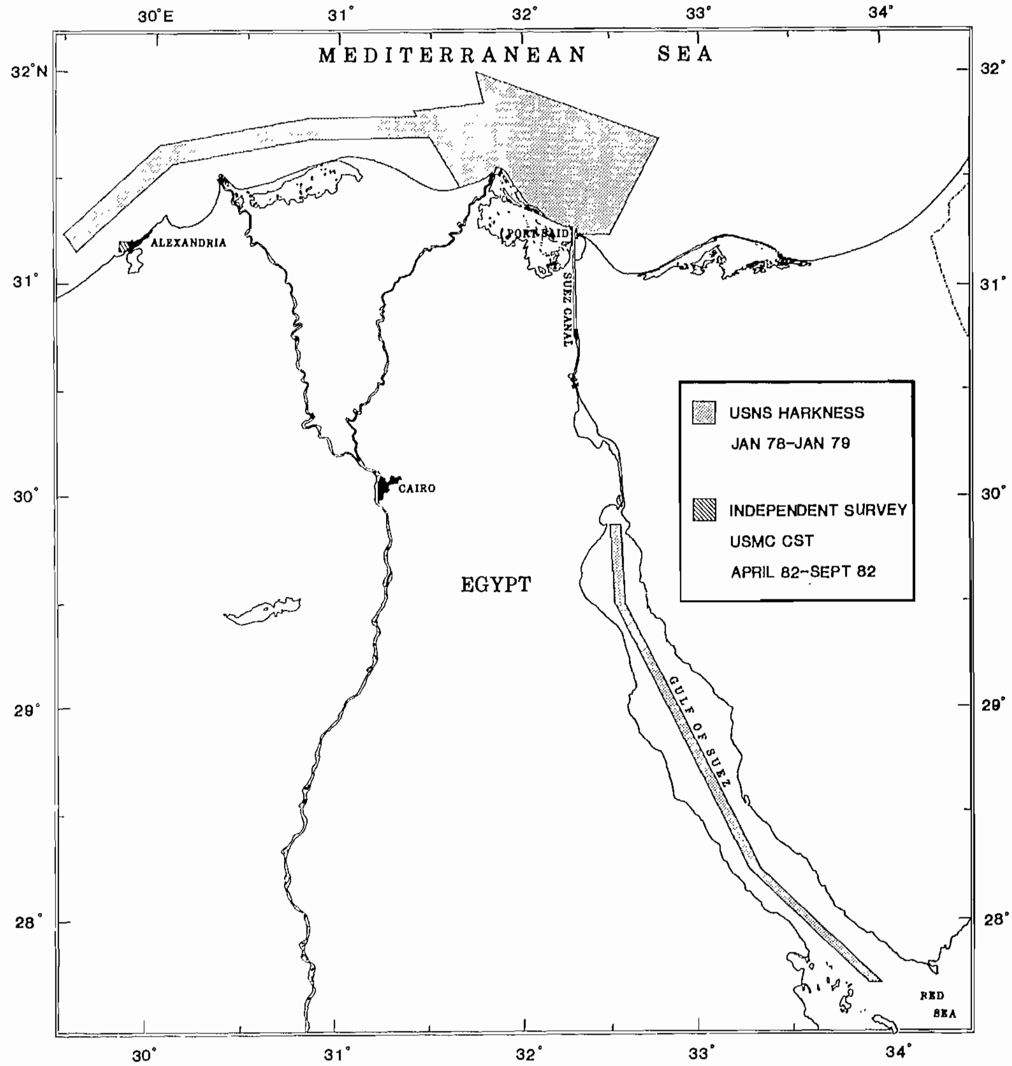

FIGURE 9. Hydrographic Survey Dperations in Egypt

Furthermore, such surveys are advantageous to the cooperating organization whenever mutual survey requirements exist for the same areas or whenever ship and personnel costs can be partially paid for by extending the ship operating season at NAVDCEAND expense. Figure 2 indicates the extensive areas surveyed under the US-RDK Cooperative Survey Program since 1970. The Korean Hydrographic Office has made such significant advances in its technical capabilities to perform hydrographic surveys that since 1976, NAVDCEANO has been able to reduce its role to providing just technical services and advice and providing supplementary survey equipment. Figure 5 indicates the areas surveyed by JANHIDROS ships and boats in the Makassar Straits of Indonesia. The Indonesian vessels operate using the same ARGD DM-54 positioning nets as the USNS CHAUVENET or by using NAVDCEAND supplied Mini-Ranger III positioning equipment. NAVDCEAND has also outfitted the Indonesian ships and boats with depth sounders and other hydrographic survey equipment and provided the technical advice and assistance in the operation and maintenance of that equipment. Figure 7 indicates the Mona Passage area surveyed by the NDAA ships MT. MITCHELL and WHITING in January - March 1975 using a Raydist DRS electronic navigation net established and operated by a NAVAIDSUPPUNIT detachment. Figure 7 also shows the Anegada Passage area surveyed by HMS BULLDDG and HMS BEAGLE (January - March 1976) in conjunction with the USNS BARTLETT, operating off the same NAVDCEAND supplied ARGD DM-5D positioning net. Figure 8 indicates the cooperative surveys conducted by the NDAA ship PEIRCE in the Jamaica Channel during February - March 1981, and HMS HYDRA near Turk Island Dctober 1981 - January 19B2. Figure 1D indicates extensive cooperative surveys in the Yucatan Channel by three organizations -- NOAA, USCG, and HYDRD UK.

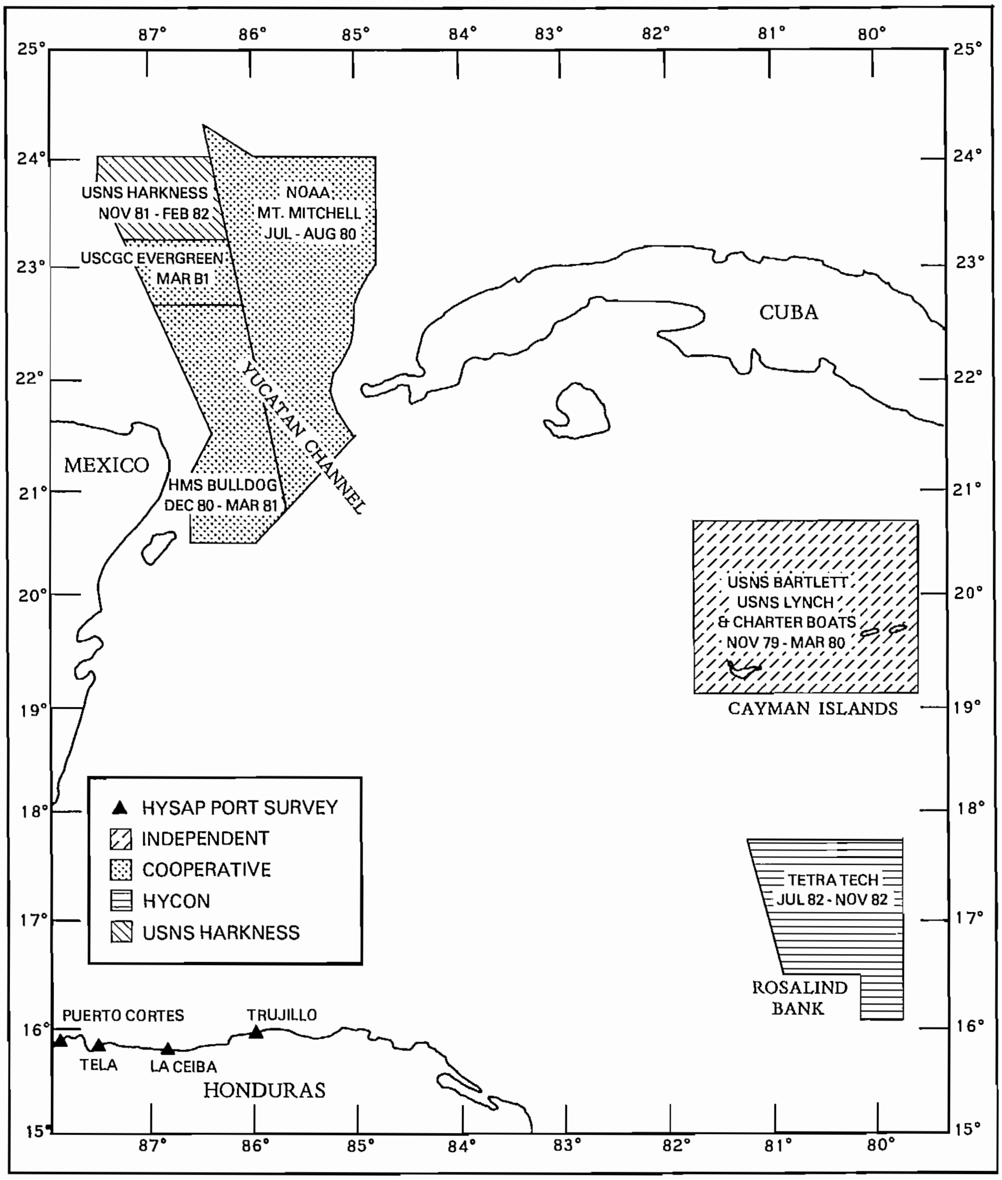

FIGURE 10. Hydrographic Survey Operations in the Yucatan Channel Area

In July - August 1980, NOAA ship MT. MITCHELL surveyed the eastern side of the Channel; in December 1980 - March 1981, HMS BULLDOG, using a NAVOCEANO furnished integrated navigation system, surveyed the southwestern portion; and in March 1981, USCGC EVERGREEN surveyed part of the western side. The western side was then completed by USNS HARKNESS in February 1982. Cooperative surveys are presently underway by Royal Navy ships HMS FOX and HMS FAWN near Pedro Bank (southwest of Jamaica) and by NOAA in the Bahamas.

Independent Surveys

Independent surveys are hydrographic surveys conducted by NAVOCEANO using NAVOCEANO ships not normally used for hydrographic surveys (e.g., oceanographic research ships USNS LYNCH, USNS DESTEIGUER and USNS BARTLETT), other Navy ships, portable boats, or locally hired vessels. It also includes the associated survey capability of the USMC Coastal Survey Team (USMC CST). Figures 4, 7, 8, 9, and 10 indicate most of the major independent surveys conducted by NAVOCEANO over the last ten years. As indicated by Figures 7, 4, and 10, USNS BARTLETT, USNS DESTEIGUER and USNS LYNCH conducted extensive hydrographic survey operations in Anegada Passage (Jan-

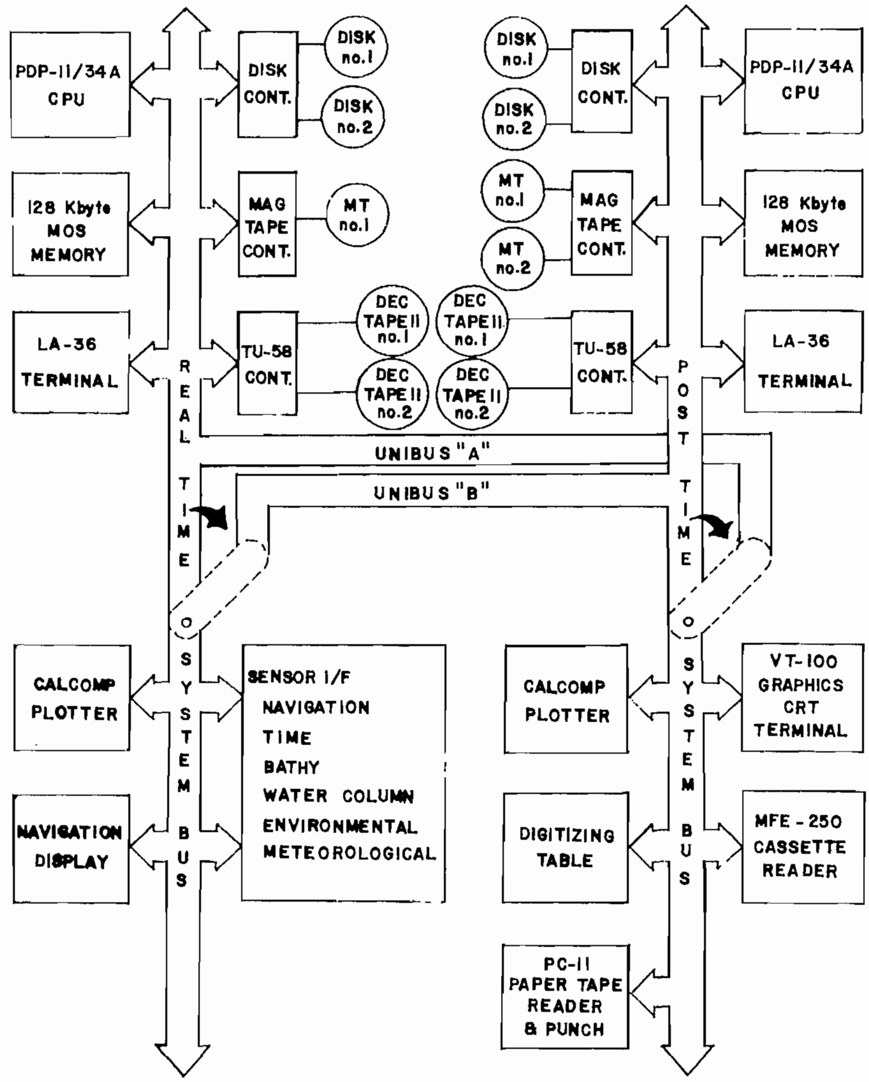

FIGURE 11. The Hydrographic/Oceanographic Data Acquisition System (HODAS)

uary - June 1976), Bay of Panama (February - May 1978), and the Cayman Islands (November 1979 - March 1980). Figures 7 and 4 indicate the areas surveyed by the HYSURCH system in Mayaguez, Puerto Rico (March - April 1975) and the Bay of Panama (March 1976 - December 1977). The HYSURCH system consisted of two fully automated portable survey boats and a data processing center housed in a portable van. Figure 7 also shows an independent survey of St. Croix, Virgin Islands, using a chartered boat (November 1972). Figure 4 also shows independent survey operations on the north coast of Panama, Almirante/Bocas del Toro (completed in 1981) which was conducted using a boat chartered from the Panamanian Instituto Geografico Nacional (IGN) and Chiriqui Lagoon (in progress) which is also being conducted using a boat chartered from IGN. Figures 8 and 9 indicate the port surveys conducted by the USMC CST in Guantanamo Bay, Cuba (September - November 1980) and Alexandria Harbor, Egypt (April - September 1982). Figure 8 also indicates an independent survey of Eleuthra Island, Bahamas using the chartered NOAA MV VIRGINIA KEY in October - December 1981. Generally, independent surveys may be very cost effective, especially when using NAVOCEANO ships (e.g., LYNCH, DESTEIGUER, and BARTLETT), in conjunction with other survey ships such as in the Bay of Panama and Anegada Passage surveys. Unfortunately, since NAVOCEANO operates these ships for the use of other Navy laboratories to conduct oceanographic research, availability of these vessels for hydrographic surveys has become virtually nonexistent. Other types of independent surveys have not been entirely successful generally due to the unsuitability of the survey platform to perform a hydrographic survey under less than ideal conditions.

IMPLEMENTATION OF ADVANCED TECHNOLOGY

The following new technology is under development or is planned in support of Navy hydrographic programs and will significantly improve and increase NAVOCEANO data collection capabilities.

The Hydrographic Airborne Laser Sounder (HALS)

The HALS will be an airborne laser hydrographic survey system which will measure water depths using a frequency-doubled Neodymium YAG laser (Figure 12). When completed and after extensive evaluations, the HALS will be mounted on the HH-2D helicopter aboard USNS HARKNESS in 1985. The HALS laser transmits five nanosecond-long laser pulses at a pulse repetition rate of 400 Hertz and at a wavelength of 532 nanometers. The time differences between initial transmission, surface reflection, and bottom reflection are used to compute aircraft altitude and water depth. Maximum depth penetration is highly dependent on water clarity, but will be 50 meters in many cases. Typical area coverage for the HALS, flown at an altitude of 150 meters, speed of 70 knots, pulse repetition rate of 400 Hertz, and a 36^{0} off-nadir scan angle, is designed to be 8000 square meters per second. Average data density for these operating conditions is one sounding per 20 square meters. The helicopter-mounted HALS will be able to achieve almost any data density merely by varying the aircraft's speed and altitude and the scanner angle. With just 50 missions per year, the HALS will double the shallow water data collection rate on USNS HARKNESS.

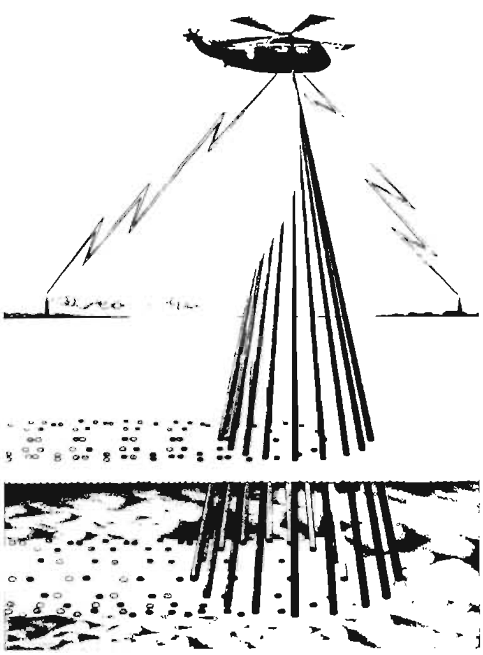

FIGURE 12. Artist's Conception of HALS

Hydrographic Information Handling System (HIHAN)

To improve its effectiveness in hydrographic data processing, NAVOCEANO is planning to upgrade its hydrographic information handling capabilities aboard CHAUVENET and HARKNESS and at NAVOCEANO's main office. The Hydrographic Information Handling (HIHAN) system will consist of software and hardware needed by the hydrographer to process hydrographic data from its initial input into the system until the final output format is generated for delivery to DMAHTC. The system will automate the preprocessing, merging, integration, and preparation of hydrographic data from a variety of sources such as HODAS-equipped ships (CHAUVENET/HARKNESS), BDLS-equipped launches, HALS, contract vessels with other automated data collection systems, and automated or manually collected data from independent surveys or HYSAP. In addition to the current HODAS shipboard system, HIHAN will include a developing in-house system, the Hydrographic Automated Information System (HYAIS) which will function in both on-line and off-line modes with NAVOCEANO's UNIVAC 1100/82 mainframe computer as the host.

The Active/Passive Multi-Spectral Scanner (A/P MSS)

The A/P MSS is a hybrid active/passive scanner which collects data in the blue-green and near-infrared portions of the electro-magnetic spectrum (Figure 13). A pulsed blue-green laser which is boresighted with the passive scanner provides calibration data to derive quantitative water depths from the passive data. This system is scheduled to be operational with NAVOCEANO after 1988 and will operate from a fixed-wing aircraft. With the availability of positioning information from the Global Positioning System (GPS), the A/P MSS-equipped aircraft will be able to conduct high-speed, wide-area coverage hydrographic surveys in any part of the world with minimal ground support. Normal operations will consist of several low-altitude flights over the survey area to obtain calibration data with the laser and passive scanner. The actual survey will be conducted at higher altitudes with the passive scanner only. Resolution is expected to be 10 meters at an aircraft altitude of 3000 meters. Maximum depth penetration is highly dependent on water clarity, but will be approximately 10 meters in most cases.

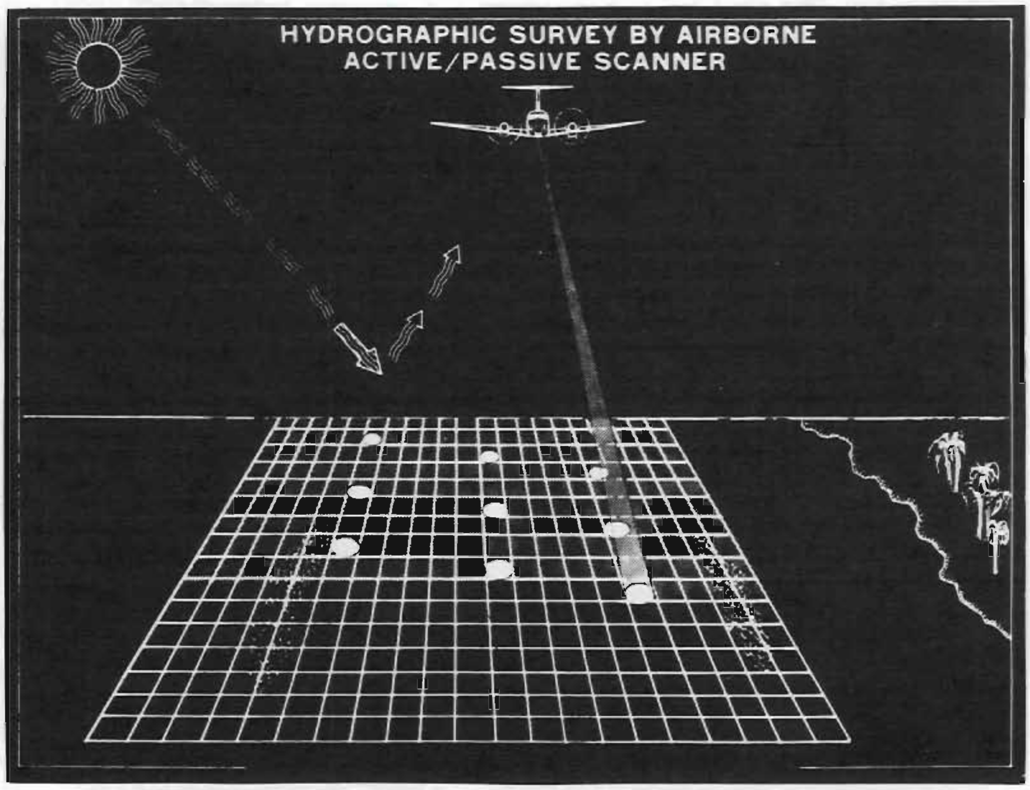

FIGURE 13. The Active/Passive Multi-Spectral Scanner (A/P MSS)

NAVSTAR Global Positioning System

The NAVSTAR Global Positioning System (GPS) is being designed to provide late 1980 users with world-wide, continuous three-dimensional position and velocity information, along with Coordinated Universal Time. The final GPS space segment will consist of 18 satellites in circular 10,900-nautical mile orbits with 12-hour periods. Each satellite continuously transmits a unique precise timing and waveform signal which contains a navigational message including orbital parameters and clock correction terms. CHAUVENET and HARKNESS are scheduled to receive six medium-dynamic GPS receivers apiece (one for the ship, one for each survey launch, and one for the helicopter) in 1990. Furthermore, the procurement of geodetic-type GPS receivers is also planned.

SUMMARY

During NAVOCEANO's Sesquicentennial celebrations on May 8, 1981, the Secretary of the Navy, John F. Lehman, Jr., stated:

> Since its establishment in 1830 as the Depot of Charts and Instruments, the Naval Oceanographic Office has been involved in every major event in which naval forces of America had a part.....The proud history of one of the oldest continuing organizations in the Navy -- the Naval Oceanographic Office -- has brought great credit to the United States.

The U.S. Naval Oceanographic Office takes its responsibilities to conduct world-wide hydrographic surveys in support of navigation and charting requirements very seriously and is constantly striving to expand and upgrade its capabilities.

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AIRBORNE HYDROGRAPHY TECHNIQUES -

AN EVALUATION

By

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The Canadian Hydrographic Service has to date tested the following airborne techniques: Conventional Photogrammetry, fixed baselength simultaneous photogrammetry, photo-interpretation, multi-spectral scanning and the laser sounder. This paper outlines the successes to date and points the way to a fully operational, integrated system which is obtainable within the next few years.

ÉVALUATION DES TECHNIQUES D'HYDROGRAPHIE AÉRIENNE

par

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Le Service hydrographique du Canada a mis à l'essai jusqu'ici les techniques aériennes suivantes: photogrammétrique conventionnelle, photogrammétrique simultanée avec longueur de base fixe, photo interprétation, balayage multispectral et sondage au laser. Dans le présent document, nous examinons les succés obtenus et signalons un système intégré totalement opérationnel qui pourrait être mis au point dans les prochaines années.

INTRODUCTION

The initial factors for carrying out hydrographic development in Canada are quite simple. (Monahan, Casey and MacDougall, 1982) Canada is an enormous country; much of the area to be surveyed is afflicted by ice and/or bad weather for large portions of the year multiplying the magnitude of the problem. Secondly, launches and ships are extremely slow; they are even slower when operating in shallow and therefore dangerous waters. Finally echo sounders measure only a profile, leaving vast areas unmeasured. All development projects are ultimately tied to one of these factors and when a project is proposed which is potentially both fast and measures over areas, that project is so intrinsically appealing that it must be pursued. The Aerial Hydrography Program in its many guises has such appeal. Here we evaluate some results of this program.

Systems for Aerial Hydrography

There are at present four separate remote sensing techniques which have been used to survey shallow coastal areas by the CHS, while a fifth, pulsed radar, is currently being evaluated by industry. Certain features of the data sets produced by each technique are complementary and can be used to compensate for some of the disadvantages in other techniques. As in most remote sensing, a multi-sensor package will likely obtain the best results. A brief description of each of the techniques is given in the following subsections.

Area-Measuring Systems - Photo Interpretive Hydrography

This technique (Hunter 1982), which uses colour aerial photography and a knowledge of the local geomorphology, is a very quick way to carry out a reconnaissance survey. Although the cloud cover and sun angle requirements are stringent (sun elevation 35^{o} and no cloud more than 37^{o} above the horizon), acceptable data can be acquired during a conventional photo survey. In some circumstances even archived data can be used. Very little field verification is needed beyond a few selected acoustic or lidar depth profiles perpendicular to the shoreline and a "feel" for the water conditions, the aquatic vegetation, the bottom type, and the bottom topography. Contours can be drawn very easily by trained personnel provided bottom features are recognizable in the imagery and the observed water colour only changes as a result of changes in water depth Additional surface transects may be required to follow the depth contours through areas where this assumption does not hold.

The position and depth accuracy of contours established by this technique vary with depth. In Lake Huron, Monahan et al (1982) report that the 1 m contour was excellent, the 2 m contour acceptable but that beyond those depths, contours could only be considered as form lines rather than true depth contours. Even form lines are, of course, very useful.

Stereo Photogrammetric Hydrography

In the measurement of water depths by means of stereo photogrammetry an operator measures the parallax to an identifiable point on the sea floor and, after correcting for the refraction at the water surface, is able to compute the depth. A system of this type has been described by Reid et al. (1980). An analytical plotter is essential when there are no fixed reference points for the operator on which to set up his stereo model. Instead, the analytical plotter takes precise position and attitude data recorded at the moment of exposure of each photograph and calculates the correct orientation for the stereo model. The analytical plotter also handles the refractive correction and uses lidar and acoustic soundings to remove any residual errors in the photogrammetric measurements. The analytical plotter and its companion plotting table are used to locate the shoreline and to plot the resulting water depths onto a field sheet.

This technique allegedly yields high quality water depth data where clear water overlies a highly figured bottom. The necessary precision can be obtained only if sufficiently accurate attitude and position data are available or there is sufficient shoreline in the stereo pair that the model can be leveled correctly. In addition, the operator must be able to recognize bottom features to measure the parallax. This is not possible with the low contrast features found when the bottom sediment smooths the features with a uniformly coloured layer. Similarly, slowly varying bottom structures are difficult to handle. Scattering by turbid water also reduces the contrast of bottom features. Rather than following an underwater contour under these conditions, the operator is forced to measure the depth only on discrete bottom features on which he can fuse the cursor.

It is, on the other hand, straight forward to measure the relative positions of rocks and shoals photogrammetrically, trace the shoreline and to locate cultural features. With sufficiently precise navigation data or using conventional photogrammetric manipulations (aero triangulation) it is possible to locate these within the accuracy demanded by the CHS charting specifications.

An evaluation of results in Canada has revealed that this approach is virtually useless. Nowhere was it possible to draw contours: spot depths could only be obtained in less than one quarter of the water shallower than six metres and none in water deeper than six metres; the depths that were obtained were widely inaccurate (Monahan <u>et al</u> (1982). Consequently, this technique as a depth measurement device has been abandoned in Canada.

<u>MULTI-SPECTRAL SCANNING</u> (Passive Electro- Optical Imaging)

Unlike the photographic methods discussed above, MSS provides continuous coverage through a device from a pixel (picture element) by means of which the entire image is divided into adjoining squares or rectangles. The average value being measured in each pixel is printed on the map. Pixels as small as 2 m x 2 m are possible; since the data are recorded digitally, the possibility exists for having a digital depth every 2 metres. Such dense coverage is enormously appealing.Unfortunately, enthusiasm must be tempered with the realization that those pixels cannot as yet be located on the earth very accurately. Imagery over land is "corrected" for distortions by fitting identifiable points on the imagery to known points on the ground and then "stretching" the rest of the image to agree with the fitted points. Over water, of course, this is impossible since there are no identifiable points. The only recourse is to some extremely precise measurements of the sensor attitude followed by some elaborate computations. The theoretical mathematics involved has been developed (Gibson 1982) but an enormous amount of computer software is required before the effectiveness of this approach can be assessed.

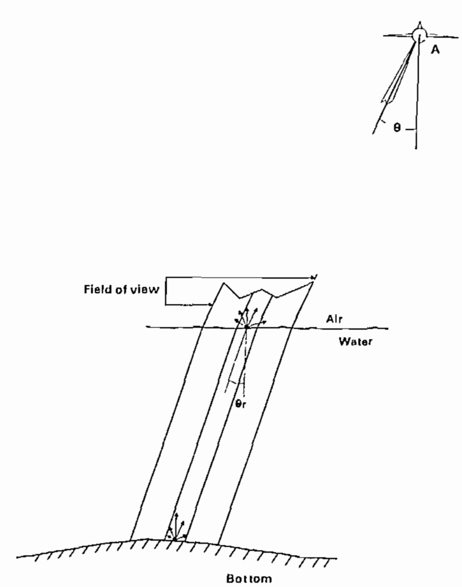
Within any pixel, the passive e-o technique is an elaborate water colour measurement in which a multispectural scanner measures the radiance of the water surface in the visible and near infrared portion of the spectrum. Through the use of a mathematical model describing the propagation of light in the water as a function of wavelength and correcting for atmospheric effects, it is possible to produce a map-like picture which has some resemblance to depth. The results to date are impossible to evaluate properly, because of the geometric distortions mentioned above, but some images bear enough resemblance to acoustically determined depths to encourage some hope that the technique will prove viable.

One of the most serious limitations of passive e-o imaging is the need to know the bottom reflectivity for each pixel in which the water depth is to be measured. At present this must be estimated using a knowledge of the local conditions; thus, the technique is suspect when the bottom reflectance is very non-uniform It is believed that the model can be improved to correct for the bottom reflectance in each pixel. Because the model used to reduce the e-o data is not yet sophisticated enough to handle the varying sky radiances found on a cloudy day, the technique also requires atmospheric conditions similar to those of photogrammetric hydrography.

<u>Profiling Lidar Bathymeter</u>

In the CCRS MkII lidar bathymeter (O'Neil 1980), a short pulse of green light (= 532 nm) from a frequency doubled Nd:YAG laser is launched towards the water surface. At the surface part of the pulse is reflected back towards the aircraft and part is transmitted through the interface and propagates to the ocean floor where it is reflected. This latter portion of the original incident pulse travels back up through the water and through the air water interface. This is shown schematically in figure 1. The difference in arrival time between the surface pulse and the bottom pulse is a measure of the water depth:

Figure 1



$$d = \frac{ct}{2}$$

Where: d = water depth
c = velocity of light in water
t = difference in arrival time between surface and bottom pulses

The depth to which a lidar bathymeter can sound depends, among other things, on the attenuation coefficient of the green light pulse through the water column. As a rule of thumb, for the CCRS MkII lidar bathymeter the following holds:

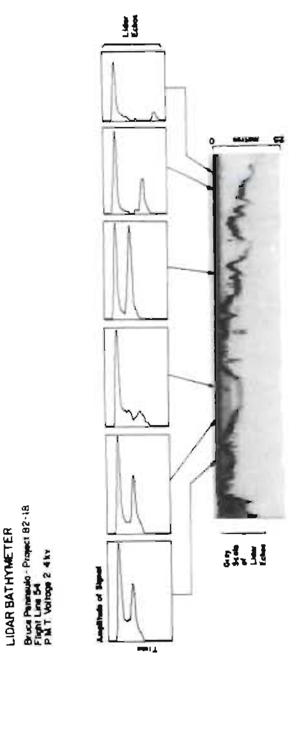
$$ad_{max} = 14$$

Where: a = beam attenuation coefficient*

d_{max} = maximum depth which can be sounded

In Canadian field trials the beam attenuation coefficient has varied between 0.7-1.7 m^{-1}. Although the sounding depth is expected to be less than 10 m for an attenuation coefficient greater than 1.4 m^{-1}, these large values tend to occur in shallower water close to shore, thus a bottom echo can still be detected. The attenuation coefficient is largest in areas with high concentrations of suspended solids, chlorophyll or disolved organic materials. During trials in Lake Huron where the flight lines were flown perpendicular to the shore, the maximum depth obtained was between 17 and 20 m on most flight lines. Figure 2 shows some typical data from the lidar bathymeter. In the shallows, the effect of turbid water is apparent: some photons have been backscattered from the water column as the pulse travelled from the surface to the bottom causing the long exponential trail of the surface return.

Figure 2



The minimum depth which can be measured is approximately 0.8 m. At this depth the bottom echo causes a small but noticeable broadening of the surface return pulse.

A comparison of data of this type with that obtained from a precision high density acoustic survey showed that the lidar data exhibited a constant bias of 1.8 m deeper than the accepted acoustic data; most of this bias can be removed by reducing the lidar depth to the chart sounding datum. The standard deviation between the lidar and acoustic depths was slightly less than 0.3 m. In deeper water ($d \simeq 10$ m), there was some indication that the error was correlated to the water depth. With the available surface measurements it was not possible to determine whether this was a correlation with depth or with water quality.

Guenther (1981), using early bathymetric data obtained with the NASA- Wallops Airborne Oceanographic Lidar has examined the error sources which affect the depth measurement process. Although the present results obtained with the CCRS MkII lidar meet the hydrographic charting standard, this may have been fortuitous particularly in that the CCRS instrument is a profiler in which the laser beam enters normal to the water surface. In order to correct the depths obtained by the lidar under varying environmental and operating conditions,Guenther's calculations are being reworked using the characteristics of the existing lidar. The same calculations will provide both guidance in the design of the new scanning lidar and the depth corrections appropriate for the new system.

Other Techniques

Recently, a series of experiments have been reported (Hickman 1980) in which a high power infrared laser pulse is absorbed at the water surface causing an explosive vapourization of the water. The resulting acoustic pulse propagates to the ocean floor where it is reflected and travels back up towards the water surface. It was demonstrated that the acoustic echo could be detected either in the water with a conventional sonar transducer, or in the air above the water surface using a sensitive directional microphone. The technique is not influenced by water turbidity as are the optical techniques and the penetration depth is expected to be substantially greater than the other airborne techniques discussed.

Mono-pulse and synthetic pulse radars are used to measure fresh ice thickness. Under certain situations these have been shown to measure sea-ice thickness as well. Several airborne

* The effective attenuation coefficient, which determines the lidar performance, is a function of the system parameters (especially the receiver field of view) It is generally believed to be numerically closer to the diffuse attenuation coefficient than the beam attenuation coefficient. The beam attenuation coefficient is used in this rule of thumb because it is easier to measure using conventional oceanographic instrumentation.

systems have been designed for sea ice thickness measurement and it has been proposed that an appropriately designed radar might also be used for shallow water hydrography. The radar techniques may prove to be very useful in rivers where the high turbidity and possibility of bubbles and foam will limit the application of optical techniques.

It has been suggested that the electro-magnetic (e-m) technique often used in airborne geophysical exploration for conductive ore bodies may provide water depth information. Because a low frequency e-m signal is used for the sounding, the bottom area sampled in any one measurement will be very large, and hence, it will be difficult to achieve the accuracy demanded by the charting standard.

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BEGINNING THE SECOND HUNDRED YEARS - THE LASER SOUNDER

By

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The Airborne Laser-based Lidar Sounder is, at this Hundredth Anniversary, sufficiently advanced in design and testing to indicate that it represents viable technology for some time into the second one hundred years of hydrography in Canada. It offers advantages of speed and mobility over a vessel mounted echo-sounder in much the same way as the acoustic echo-sounder offered speed and mobility over the leadline. This paper presents an overview of the system now flying, an evaluation of results to date, and indicates the future development and development of this second centenium device.

À l'occasion de ce centenaire, nous pouvons annoncer que la conception et les essais du système lidar de sondage aérien au laser sont suffisamment avancés pour indiquer qu'il représente une technique efficace qui sera employée quelque temps encore au Canada dans le cours du deuxième siècle d'hydrographie. Il offre l'avantage d'être plus rapide et plus mobile qu'un écho-sondeur installé à bord d'un navire, toute comme l'était l'écho-sondeur acoustique par rapport à la ligne de sonde. Le présent document décrit brièvement le système en vol, évalue les résultats obtenus jusqu'ici et indique le perfectionnement et le déploiement futurs de cet instrument du deuxième siècle.

1.0 Introduction

There are at present five independent research and development programs taking place in the area of laser bathymetry[1,2,3,4,5]. Each has as its goal the eventual deployment of a scanning laser sounder into production hydrographic surveying. Such a high degree of interest indicates the value which many of the leading hydrographic nations attach to such a development. Several cost-effectiveness studies[6,7,8] have been performed which give ample evidence of the system's economic viability. It has also been[10] shown[9] that (once the propagation biases have been compensated for) laser soundings can meet the IHO Accuracy Standard. It appears therefore, that laser bathymetry is a viable concept and its development and progress should be followed closely by all those interested in future developments in hydrography.

The purpose of this report is to examine in some detail the basic underlying concepts behind laser bathymetry and highlight the major components of a typical scanning laser system.

2.0 Principles of Lidar Bathymetry[11]

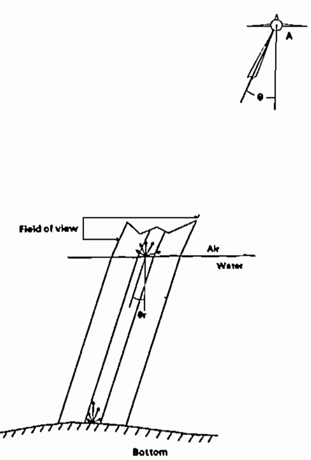
A Lidar (Light Detection And Ranging) is an active optical measuring device which uses electromagnetic radiation in the optical spectrum to sense the position of remote objects - in this case both the water surface and the bottom. It is active since it supplies its own source of illumination - the laser. As with an acoustic sounder the idea is to measure the time differences from transmission of signal to detection of the reflected pulses.

Figure 1 shows the system concept. The laser, on board the aircraft at A, fires a short pulse of laser light downward at an angle θ. At the water surface a portion of the incident pulse energy is reflected upward and the remainder refracts into the water at angle θr. The refracted pulse undergoes scattering and absorption within the water column. Depending on water quality and depth, a portion of this pulse eventually reaches the bottom and is scattered upward. The optical receiver at A thus receives a pulse corresponding to the surface reflection and then, some time later, receives the bottom reflected pulse. The time difference between surface and bottom pulse receipt can then be used to determine the depth as

$$d = \frac{\Delta t\, c}{2\, n} \left[\cos\left(\sin^{-1}\left(\frac{\sin \theta}{n}\right)\right)\right] \qquad (1)$$

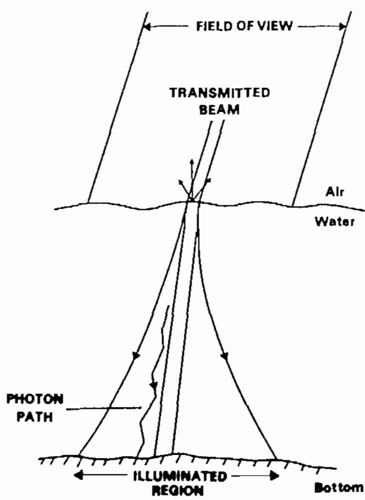
where d is the water depth
t is the time difference
c is the velocity of light in air
n is the index of refraction of water

Figure 1



Scattering phenomena in the water column cause significant spatial and temporal spreading of the returning energy which complicates the depth determination process. See Figure 2. This phenomenon is extremely important since, if this "beam stretching" is ignored, significant depth measurement biases could be incurred[12]. Bias correctors based on certain water quality parameters have been calculated as a result of a Monte Carlo simulation of the in-water scattering process[13]. Recently these results have been expanded upon to allow for the necessary water quality parameters to be estimated directly from the wave form shape[14]. This alleviates the need for making in-situ water quality measurements.

Figure 2



Determining the true location of the surface return can pose a serious problem for a scanning system. This occurs because only a small fraction of the incident energy is reflected back towards the receiver at large scan angles. In fact, the surface return can originate from two distinct areas - the interface and the volume[15]. An interface return originates at the air/water interface and corresponds to a "true" surface. The volume return on the other hand results from a diffuse backscattering return from particulates in the underlying water column. The peak location of this volume backscatter can be as much as a pulse-width deeper in the water than the interface return. For a 7ns pulse this corresponds to a depth uncertainty of about 0.8 metre. This bias can be corrected for provided a mechanism is established to discriminate between what is an interface and what is a volume return. The problem lies in the uncertainty of knowing what kind of surface return has occurred.

Several solutions have been proposed for this problem. One study has been completed which shows the return peak power of volume return versus surface return for various wind speeds and directions[16]. Under low wind speed conditions the volume return dominates resulting in a shallow bias in the depth measurement. Unfortunately for a substantial portion of operating conditions one type of return does not significantly dominate over another which leads to an uncertainty as to where the return originated; surface or volume. This uncertainty has been termed the "flip-flop" problem. This flip-flop bias can be reduced by using a laser with a pulse width no wider than 2ns[16]. Lasers of this speed and with the necessary power are not, as yet, commercially available. An alternative solution which shows considerable promise is the measurement of the Raman backscattering[17]. Because of the high attenuation coefficient at the Raman wavelength the location of the surface return is expected to be sharply defined. The measurement of the Raman return adds a new complexity to the system but does alleviate another severe problem - the dynamic range of the received laser power.

The cost-effectiveness of laser bathymetry hinges on its penetration. The penetration varies with receiver sensitivity and with peak laser power. Clearly a more sensitive receiver will detect bottom scattered return pulses from deeper water than less sensitive ones. The problem lies in the variance between the surface return power and the bottom return power. As much as 6 decades difference can exist between a surface return at a 0^{o} nadir angle and a weak bottom scattered return. This problem is compounded by the fact that such differences can occur over a period of say, 30 nanoseconds. The result is spurious responses in the Photomultiplier Tube (PMT). A number of techniques have been employed to reduce this dynamic range. They include polarization, optical blocks, time-variable-gain PMT's and logarithmic amplifiers[18].

These problems, although complex, are surmountable and scanning laser system construction is proceeding in the United States, Australia, Sweden and Canada. In the next section a typical system is examined component by component.

3.0 The Canadian Scanning Lidar Bathymeter

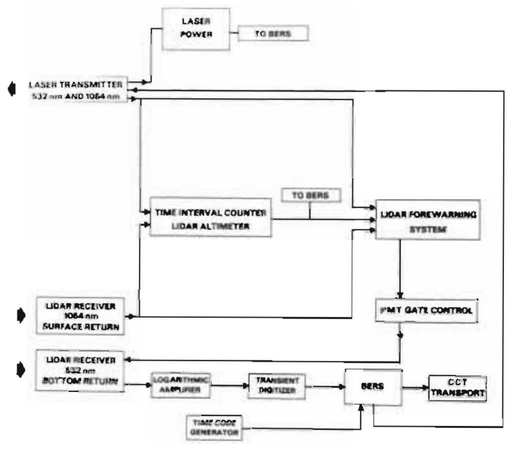
The Canadian system - known internally as the Larsen 500 - has evolved from the Lidar Profiler which has shown considerable promise towards becoming a viable survey tool. The new system comprises four major subsystems

i) scanning lidar transceiver
ii) data acquisition
iii) navigation and guidance
iv) data processing.

3.1 The Scanning Lidar Transceiver[19]

Figure 3 is a block diagram of the Mk II Transceiver unit. The transmitter is an International Laser Systems NT 462 frequency-doubled Nd-Yag laser which delivers up to 10 MW peak pulse power at 532 nm and 15 MW at 1064 nm simultaneously. The output pulse width at 532 nm is 5ns. The laser pulse repetition rate is 20 Hz.

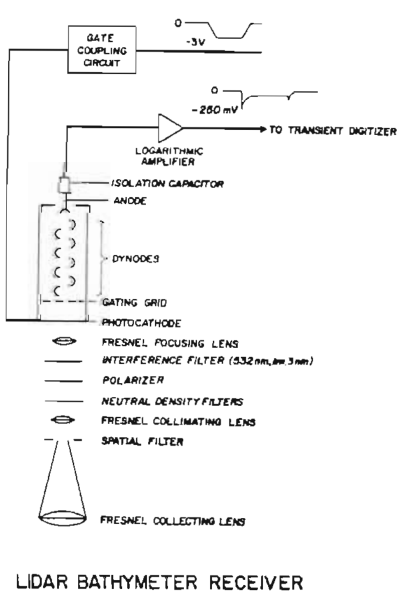
Figure 3



LIDAR BATHYMETER SYSTEM

A schematic of the 532 nm (green) receiver is shown in Figure 4. The receiver consists of a 20 cm aperture, f/1 refracting telescope, a 3 nm bandwidth filter, variable field stops and an ITT F4084 gridgated PMT with a 2ns risetime. A logarithmic amplifier (LA-80-HS) with a 2ns rise time and fall time of 5ns is used to compress the dynamic range of the PMT output signal. The 1064 nm (infrared) receiver incorporates a 5cm aperture, f/2 refracting telescope, an 8.3 nm bandwidth filter and a General Electric LE-103B Laser-Eye photodiode detector with 8 ns risetime. The two receivers were designed and integrated with the transmitter by Optech Inc. of Downsview, Ontario.

Figure 4

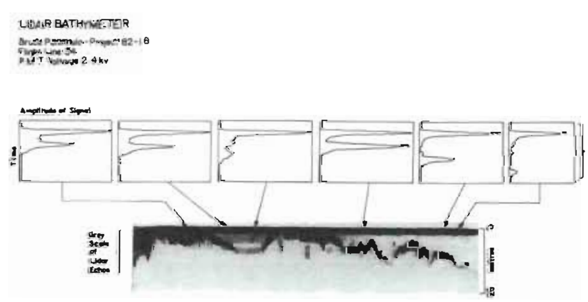


LIDAR BATHYMETER RECEIVER

The lidar altimeter measures the slant range from the transmitter to the water surface. The trigger pulse for this circuit is obtained from the IR receiver. The measured lidar slant range is used to drive the lidar forewarning system which in turn permits the bathymeter operator to select the time at which the green receiver PMT is gated on thereby compensating for electronic propagation delays in the system. By appropriate selection of the magnitude and risetime of the gating pulse the operator can set the PMT gain to a relatively low value at the water surface where the reflected laser signal is strong, and then increase the PMT gain as the return signal becomes weaker on the way to the bottom. This gain variability feature when used in combination with logarithmic compression of the PMT output signal, enables the green receiver to accommodate a 90dB range in input power.

Since a reliable sounding digitizer has yet to be developed the entire waveform of each individual lidar return pulse is digitized and recorded. This is accomplished by using a Biomation Model 6500 transient digitizer[20]. Figure 5 show some typical digitized waveforms[20]. The Biomation has a timing accuracy of 0.2 ns[21].

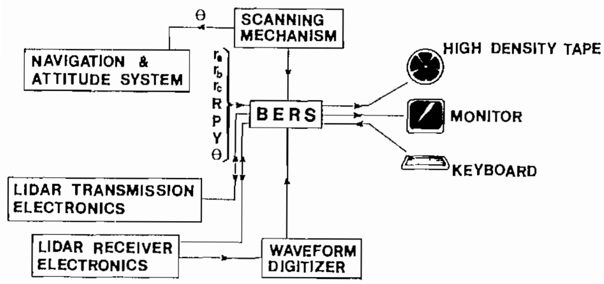
Figure 5



3.2 Data Acquisition System

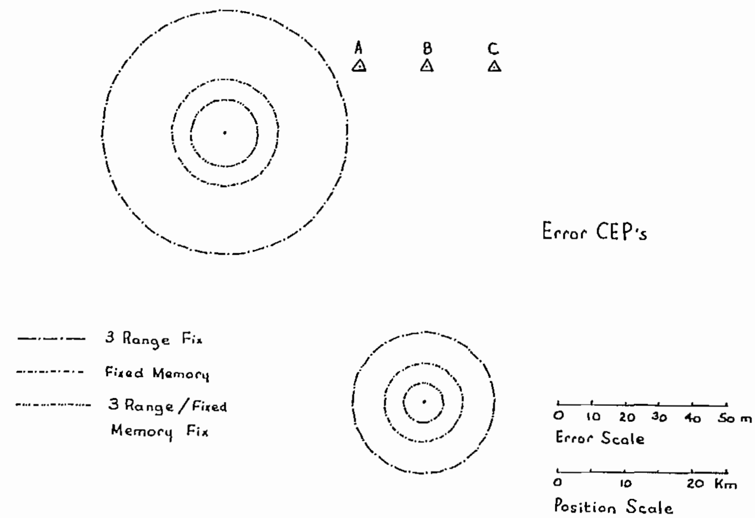
Figure 6 is a block diagram of the Larsen data acquisition system. The BERS (Bottom Echo Recording System) subcomponent is charged with the logging of all relevant data. BERS is a PDP 11-23 based control system which orchestrates the entire on-board suite of processes. Laser arming and firing, scan-pattern control, receipt and quality control of incoming data, formatting output-files and operator interaction are its major tasks.

Figure 6



BOTTOM ECHO RECORDING SYSTEM

Figure 7



The data - which includes extensive header records detailing system parameter settings as well as time, navigation data and the return pulse waveform-are recorded on a Kennedy 9800 computer compatible tape (CCT) transport.

3.3 Navigation and Guidance

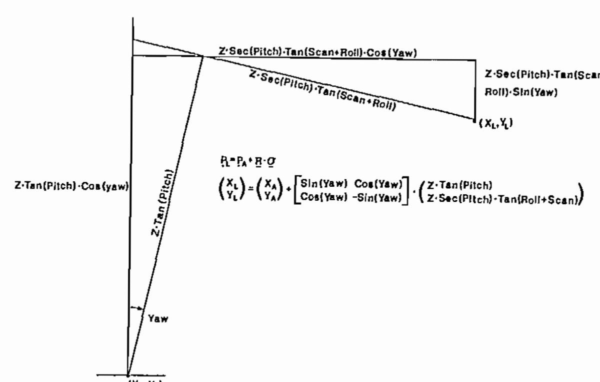
The design of an appropriate navigation system is usually driven by the accuracy specifications which it must meet. In the case of the LARSEN system this has been defined to be 25m CEP[22]. This figure has been derived to meet the Canadian Hydrographic Service standards for a 1:25,000 survey.[23]

The error budget can be split into two sub-components, one to position the aircraft in an absolute (X,Y,Z) system such as UTM and the other component to position the lidar sounding relative to the aircraft. If the error dynamics of the two positioning mechanisms are statistically independent then the two error budgets can be summed in quadrature. This implies a 18m CEP for each sub-component if the error budget is subdivided evenly. The independence assumption is justified by the fact that the airplane positioning is accomplished with a microwave ranging system and a radar altimeter and relative positioning controlled by an inertial attitude sensor and shaft encoders on the mirror assembly[24].

Figure 7 shows CEP values plotted for various locations with respect to the 3 shore-based transponders at A,B and C. The 18m CEP is clearly achievable by employing a three range fix. Each range will be filtered to remove the spurious range spikes.

Figure 8 shows the geometric effects of attitude changes on the position of the lidar sounding (X_L, Y_L) for a simple single-axis mirror system. Figure 9 shows the growth of the CEP for various flying heights and scan angles for a system with the error tolerances given there. Again the 18m CEP is easily achievable for a 15° system flying at 500m.

Figure 8



TRANSFORMATION OF CO-ORDINATES

Figure 9

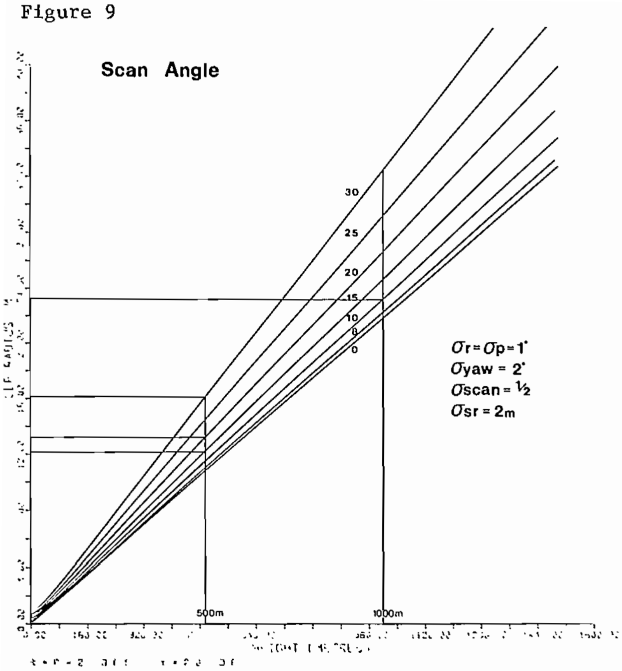
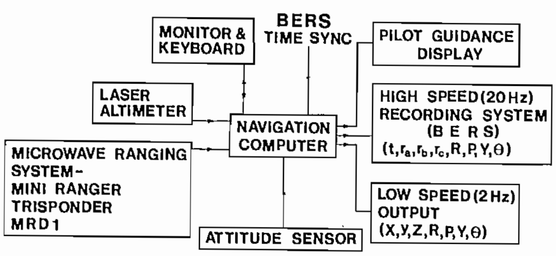


Figure 10 is a block diagram showing the various components of the Navigation and Attitude System. Real time filters in the navigation computer will enable us to maintain quality control as well as interpolate unique navigation vectors for each lidar shot. The guidance display will use a standard aircraft avionics package which shows rate-of-closure as well as position relative to the desired track.

Figure 10



NAVIGATION AND ATTITUDE SYSTEM

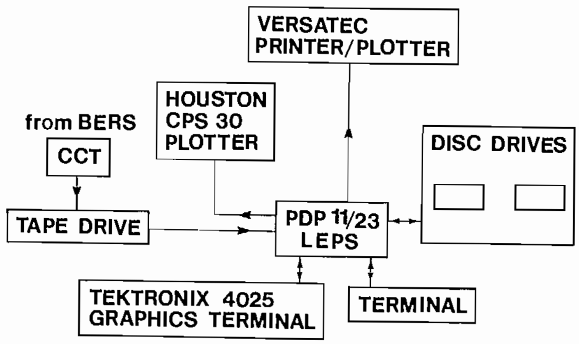
3.4 Data Processing System

Figure 11 is a block diagram of the Lidar Echo Processing System (LEPS). This is a PDP 11-23 based system which takes the high density CCT from BERS and processes the data to the field sheet stage. The system is designed to generate data in a format compatible to that used on conventional (i.e. acoustic) hydrographic surveys.

Figure 12 is a data processing block diagram[25]. Because a reliable method for estimating the water depth from the aircraft has not yet been developed, the system hinges upon digitizing an analogue trace of the bottom profile. This procedure is in place and working albeit slowly. We are seeking faster methods for this analogue to digital conversion. Depth selection will follow traditional CHS practise of showing all the critical depths which are plottable.

The data processing system will be housed in a mobile container which will be moved to each airstrip.

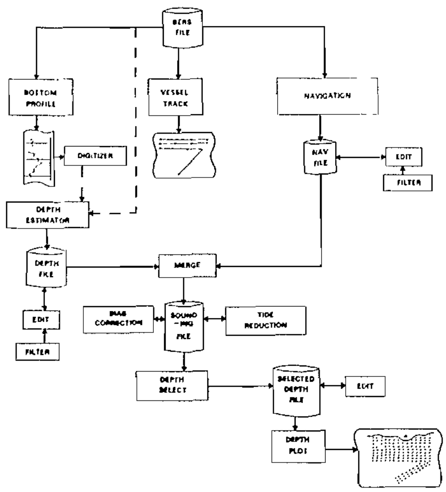
Figure 11



LIDAR ECHO PROCESSING SYSTEM

Figure 12

DATA PROCESSING BLOCK DIAGRAM



4.0 Deployment of a Scanning Lidar System

Deployment scenarios have been outlined by various agencies pursuing development of scanning laser systems[26,27,28].

The HALS (Hydrographic Airborne Laser Sounder) system achieves a flexibility in deployment over the Canadian and Australian systems since it is mounted in a helicopter as opposed to a fixed-wing aircraft. Canadian and Australian survey planners must always be conscious of ferry time from the nearest airstrip to the survey area. A fixed-wing deployment therefore is considerably different from a helicopter-mounted one.

The Canadian plan is to have two deployment strategies; one for a lidar survey in conjunction with a conventional launch or ship-based survey and one for an independent, lidar-only survey. In both cases a surface team will be required to establish the horizontal and vertical control. A good communication link between the surface team and the airborne team is clearly a strong requirement.

In the "flying launch" mode the scanning system would act as another survey tool available to the Hydrographer-in-Charge (HIC) of a conventional survey. The shallow water areas would be allocated to the lidar. A survey has been conducted[25] to define the geographic areas where water clarity and depth enable the lidar to work effectively. The chief advantage of the "flying launch" concept is that the surface resources are already in place. On the other hand this places an extra logistic burden on the HIC which is compounded by the shoreline-parallel nature of the aircraft flight-lines and its ability to forge far ahead of the acoustic survey making new demands on horizontal and vertical control.

If the lidar is deployed independently it becomes very effective as a sounder. Horizontal and vertical control networks can be established and shoreline photography flown. The HIC of a conventional survey can therefore be presented with a field sheet complete with shoreline, foreshore detail control and all shallow water areas outlined and sounded. This would enable him to tailor his resources to the exact requirements of the task. For route planning purposes the lidar can highlight suitable areas or, more importantly, highlight unsuitable areas - so that a conventional survey need not be done. The drawback to this deployment scenario is that a dedicated surface team is required in the survey area and this might prove a difficult task in some situations.

There are strong advantages and disadvantages to both strategies - the optimum one will vary with location and conditions.

Summary

The scanning laser concept has arrived; its feasibility has been demonstrated. Equipment has undergone continuous refinement to improve upon its accuracy and efficiency. Hardware and software are being constantly re-worked and improved. Dozens of papers have been written detailing the work progress and the design turning points. Money continues to be poured into its future. Yet to date no laser-based soundings have found their way onto a field sheet or a chart. The time has come to push the system out into the real world and to come to grips with real survey pressures. Major scientific and technical breakthroughs come when people and machinery are pushed to their limits. Its time to put laser bathymetry under stress and see what happens.

Acknowledgement

The Aerial Hydrography Team would like to acknowledge and pay tribute to all the laser bathymetry researchers who have gone before us. They have charted the route admirably, highlighting the shoals and foul grounds, showing clearly the safe passage way. We are indebted to them. We hope that by our efforts we too contribute to those who will follow us.

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BATHYMETRY ANO ITS UTILIZATION TO OEFINE SHORT TERM EVENTS ON THE UPPER AMAZON

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ABSTRACT

The long term importance of the Upper Amazon for the economic growth of the Amazon region has warranted the initiation of a hydrological data collection program to allow more effective utilization of specific areas of this dramatically changing river system.

The Peruvian Port of Pucallpa on the Ucayali River is one of three which have been upgraded as part of the trans Andean transportation project financed by the World Bank. Predicted siltation has occurred close to Pucallpa and concentrated monitoring of the riverbed in this area was therefore included in the first phase of the port development program. Excellent bathymetry from this monitoring gives an opportunity to examine recent events chronologically, in this part of the river. Flows of nearly 20,000 m^3/sec and sediment loads of nearly 500,000 tonnes/day were measured. This paper describes the first phase of the ongoing monitoring project, which is being financed by the World Bank and carried out on behalf of the Oirectorate of Water Transport (OGTA) of the Peruvian Ministry of Transport and Communications. The Canadian author acted as advisor to the program and worked closely with the Oirectorate of Hydro graphy and Navigation (OHNM) of the Peru vian Navy, which was contracted by OGTA to carry out the field measurements.

KEY WOROS

AMAZON, RIVER, PORT, RIVER-PORT, CROSSOVER-BAR, POINT-BAR, MEANOER THALWEG, SEIMENTATION

RÉSUMÉ

L'importance du bassin supérieur de l'Amazone, dans la croissance économique à long terme des régions avoisinantes, a justifié le lancement d'un programme de collecte de données hydrologiques. Ces données permettront une utilisation plus efficace de certains secteurs de ce système fluvial qui subit des changements spectaculaires.

Le port péruvien de Pucallpa sur la rivière Ucayali est l'un des trois ports qui ont été modernisés dans le cadre du projet de transport transandin financé par la Banque mondiale. Un alluvionnement s'étant produit à proximité du port comme on l'avait prévu, la première phase du programme d'aménagement portuaire a porté entre autres sur une surveillance intensive du fond de la rivière. Grâce aux excellentes données bathymétriques recueillies, les scientifiques ont pu examiner chronologiquement les modifications survenues récemment dans cette partie de la rivière. Ils y ont mesuré des débits de près de 20 000 m^3/s et des charges de sédiments de près de 500 000 tonnes par jour. Le présent document décrit la première phase de ce programme permanent, financé par la Banque mondiale et exécuté pour le compte de la Oirection générale du transport par eau (OGTE) du ministère péruvien des Transports et des Communications. L'auteur canadien faisait fonction de conseiller pour ce programme et il a collaboré étroitement avec la Oirection générale de l'hydrographie et de la navigation de la marine du Pérou, qui a effectué les levés, aux termes d'un contrat signé avec la OGTE.

INTROOUCTION

The flat slope (1:24,000) of the River Ucayali between Iquitos and Pucallpa offers an opportunity for considerable river navigation. The economic savings from waterborne transportation encourages the establishment of industries in communities along the river. Not only is protection for rapidly eroding riverbanks often required but a dependable channel is needed upon which the products and raw materials of these industries, together with the commodities used by the communities, can be shipped economically.

A literature search for information on the morphology of the Upper Amazon reveals that the river data being collected and analyzed are the first to be obtained for that region. The author has examined maps of other river systems in the Upper Amazon and has concluded that there are other settlements similar to Pucallpa, also without data, which undoubtedly will play an integral role in future traffic navigation. For examples, in Peru on the Rivers Ucayali, Maranon, Huallaga and Napo, there are approximately 30 such sites. In Bolivia, there are sites on the Rivers Mamore, Madre de Dios and Grande; in Western Brazil, on the Rivers Solimoes, Purus, Madeira and Negro.

During 1977, the Director General of Water Transport (DGTA) of the Peruvian Ministry of Transport & Communications contracted Acres International Limited of Canada in association with CESEL SA of Peru (Acres/CESEL) to review designs and supervise construction of port facilities at Iquitos, Yurimaguas and Pucallpa.

It was obvious from previous aerial photographs of the area that Pucallpa, taken from 1952 onwards, that the changes taking place in the river course were very significant. As there was little data available, it was difficult to predict quantitatively the channel movement and hence the best location and alignment for a dock.

Nevertheless, after examining carefully this limited information in conjunction with a geotechnical investigation and a bathymetric survey of the vicinity of the port area, the dock was located at what appeared to be a boundary between appreciable accretion on the upstream side and appreciable erosion on the downstream side. The final design incorporated a floating dock as opposed to the fixed dock arrangement which had been previously recommended. The dock which was completed in 1982 consists of three basic elements; a cargo and passenger berth, floating access bridge and a shore abutment. During the low water period, the access bridge is designed to rest on the bank with a maximum slope of 12 percent. The intention is that the floating dock can be relocated at intervals in accordance with observed and predicted changes in the river. (see Photo 1).

As part of the Peru Ports Project, Acres/CESEL were also contracted to initiate a hydrological program which would eventually yield data for estimating pay loads and transit times of shipping through parts of the river system as well as for locating and analyzing specific areas inhibiting efficient utilization of the river system. The Hydrological Unit is intended to study the behavior of the river regime generally as well as those specific sections which could be used as models for future planning elsewhere on the Upper Amazon.

If the changes in the river are to be predicted quantitatively as well as qualitatively then the significant characteristics including river discharge pattern, the quantity and character of the sediment loads (both on the riverbed and in suspension) the natural bed formation (dunes, sand, waves, etc) and the composition of the bank material have to be known. The Directorate of Hydrography and Navigation (DHNM) of the Peruvian Navy in acknowledging the importance of the program, expressed interest in being associated with the work and subsequently contracted to DGTA to implement the data collection with Acres/CESEL as consultants.

PHOTO I

DEFINITION OF STUDY AREA

The River Ucayali (Figure 1) is a large river. It is the major tributary of the Amazon, having a length of over 1,800 km. The river is migrating downstream through a vast alluvial plain covered in dense jungle and composed mainly of easily eroded sandy silt. It is similar to most other rivers in the Upper Amazon, with the typical characteristic of meandering from one bank to the other (see Photo 2), and carrying large quantities of sediment. The study area is considered an ideal one for a microcosmic study of the Upper Amazon system as it includes both eroding concave banks, accreting convex bends, sand bars and an important secondary tributary. There are outcrops of erosion resistant, silty clay known locally as "Capa Roja" which have been an important factor in affecting the river regime.

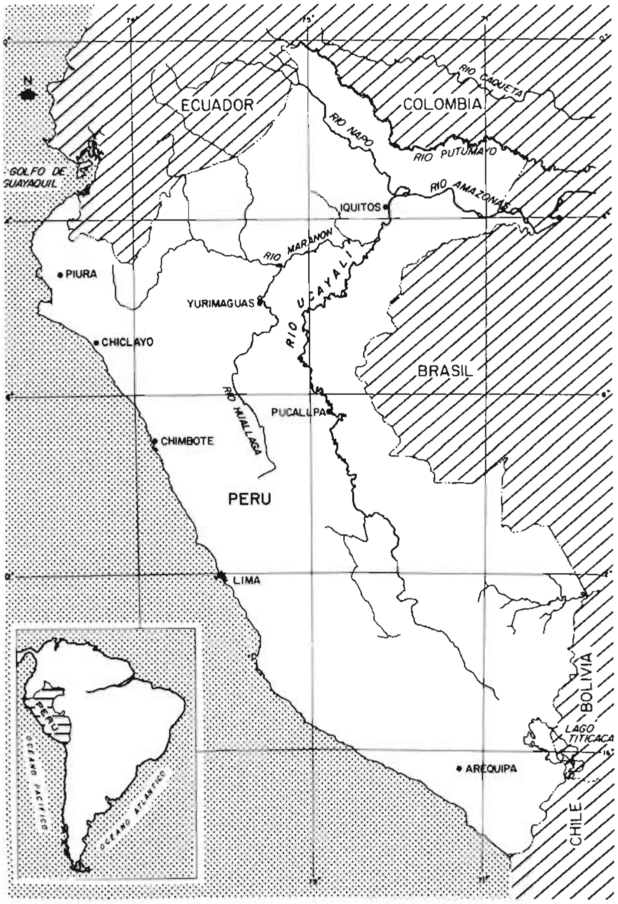

FIGURE I MAP OF PERU

The river discharge ranges from about 3,000 m^3/sec in the low water season to 15,000 m^3/sec in the high water season.

The difference in elevation between the high water (January to March) and low water (July to September) periods has been between 9 and 10 m in recent years.

Pucallpa is situated on the south bank of the Ucayali approximately 5,000 km upstream from the Amazon River mouth on the Atlantic Coast of Brazil. The city, with a population of 100,000 people, lies at the eastern end of the only road across the Andes from Lima on the Pacific Coast, passing through Huanuco and Tingo Maria.

CHANGES TO RIVER COURSE SINCE 1952

Figure 2 shows the configuration of the River Ucayali at the study area based on the aerial photography surveys of 1952, 1963, and 1972. Figure 3 is an outline of the river taken from the first complete bathymetric survey. A direct overlay comparison of the latter survey (July 1980), with the former surveys, is not justified because of the lack of ground control for the older photography. Nevertheless, a sound qualitative assessment can be made when comparing the general changes that have taken place between 1963 and 1980. Between 1963 and 1972, the main filament of flow in the upstream leg of the meander at Pucallpa had moved downstream and impinged on the northeast corner of one of the "Capa Roja" outcrop upon which the city is situated.

The following Tables 1(a) and (b) and Figure 4 show the changes that have taken place in these same sections since the base survey of July 1980.

The most significant changes have occurred between survey cross sections (4) to (13) and (16) to (21). During the latter half of 1981, the data from Sections 4 - 13 were examined closely because of the large movements that had taken place over the previous 12 months (see Figure 4).

During these 2 years, it appeared that the riverbank had moved the most at Sections (6) to (8) at the point where maximum curvature occurs in the meander. The rapid erosion and the banks lateral movement will probably continue. Because the erosive forces are now acting on a less resistant material in the vicinity of Section (9) where the harder "Capa Roja" zone previously limited erosion, it seems likely that erosion may now be more rapid and some modification in the channel may soon occur in this area.

PHOTO 2

Similarly, in the reach from Sections (9) to (13), the right-hand bank has been severely eroded at the same time as the downstream growth of the sand bar between Channel A and the main channel. Erosion of the right bank at Sections (10) and (11) has been exceptionally rapid, as can be seen from the information in the Table.

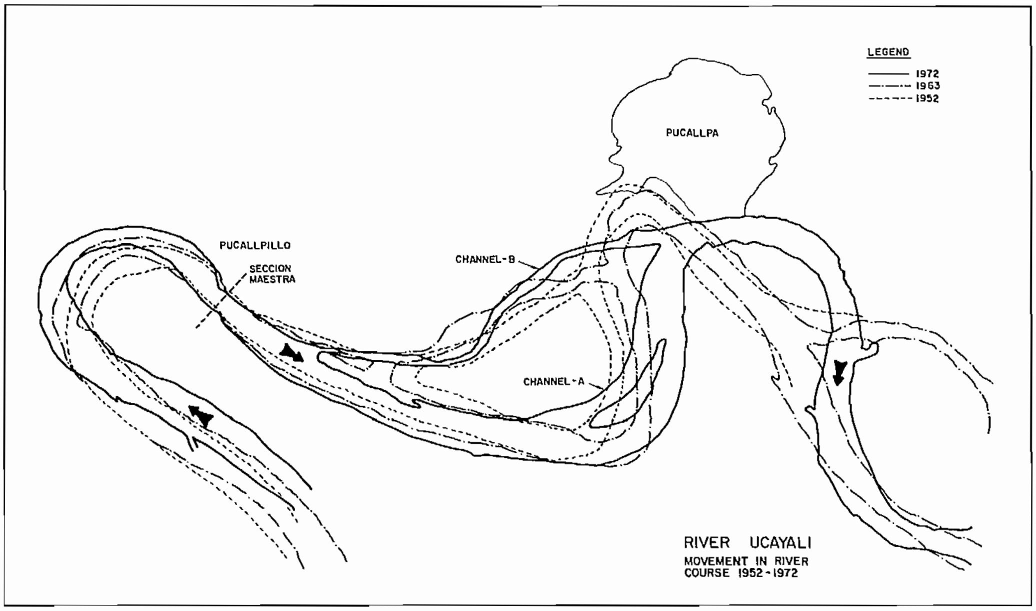

FIGURE 2 SCHEMATIC OUTLINE RIVER UCAYALI 1952-1972

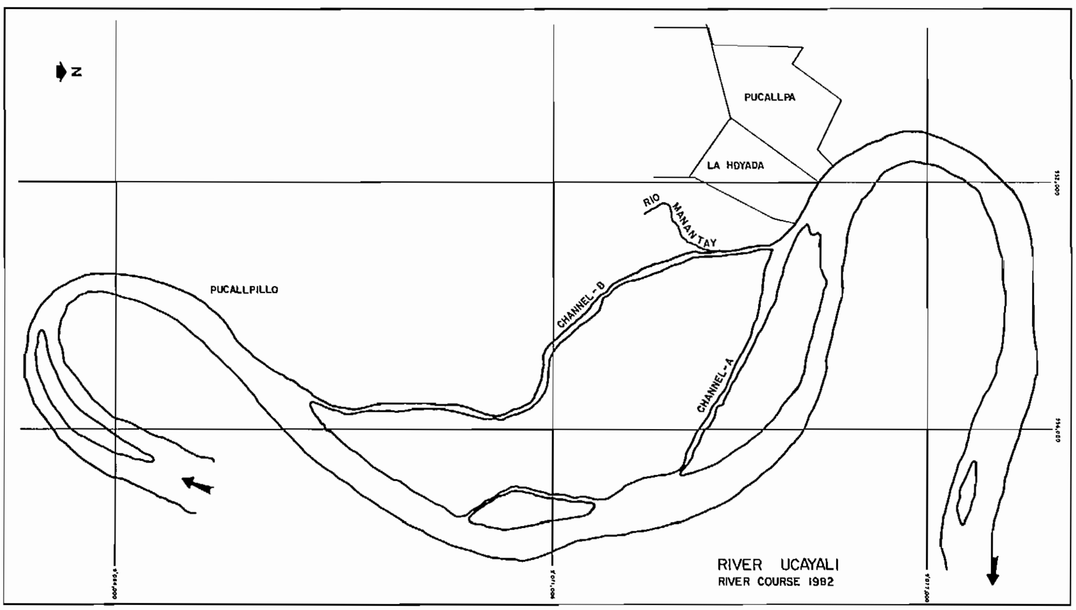

FIGURE 3 SCHEMATIC OUTLINE RIVER UCAYALI 1982

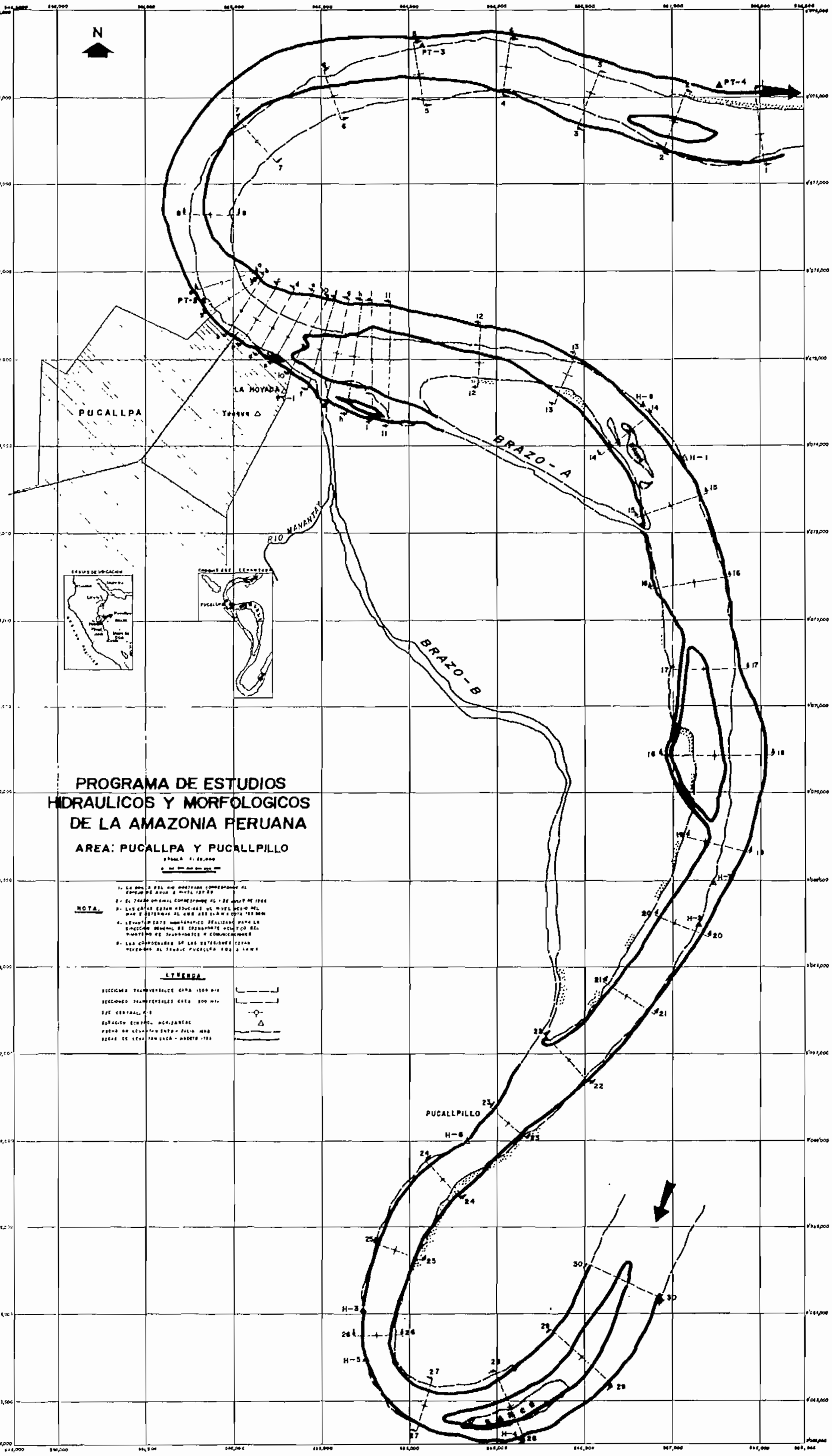

FIGURE 4 CHANGE IN RIVER COURSE 1980-1982

At Section (18) there has also been erosion of the right bank, although the river width has not changed significantly because of the accretion along the opposite left bank.

TABLE 1(a)

MOVEMENT OF LEFT BANK (m)

Section	1980 to 1981	1981 to 1982	Annual Rate (m/yr)
4	-100	0	- 50
5	-120	- 30	- 75
6	-220	-180	-200
7	-200	-270	-235
8	-175	-120	-147

TABLE 1(b)

MOVEMENT OF RIGHT BANK (m)

Section	1980 to 1981	1981 to 1982	Annual Rate (m/yr)
9	+ 20	-210	- 95
10	-180	-180	-180
11	-140	-240	-190
12	- 80	-130	-105
13	- 15	- 25	- 20

BATHYMETRY IN THE PORT AREA

General

The first bathymetry of the port area was carried out by ENAPU-CONTROLAMAR (ENAPU - Empresa Nacional de Puertos) in 1977 and covered the area from Section (b) to Section (12). The survey was not part of the hydrological study, but was part of the field investigation prior to final design of the dock facility. The first bathymetry under the present study was carried out by DHNM in July 1980. It included in greater detail (Figure 4) 12 sections between (a) and (11), each approximately 200 m apart. This detail allowed excellent comparisons with subsequent surveys to be made. Since the study was initiated, a total of 12 surveys have been carried out. This section examines chronologically, the changes that have occurred in these first 2 years of the study.

Movement of Thalweg

Using the initial survey of Controlamar (1977) and the DHNM (July 1980) survey, the two thalweg positions were examined and a northward (offshore) movement of about 200 m was measured. Although a movement of thalweg in this direction was expected, after a period of 2 1/2 years, it meant the main flow path

TABLE 2 - SUMMARY OF THALWEG MOVEMENT

Survey Nos.	Period	River Levels*	h (m)	River Stage Rising/Falling	Thalweg OFF/ON ** Movement	Dist. D(m)	D/h OFF	D/h ON
2 - 3	Jul.80 - Nov.80	136.5 - 141.5	5	R	ON	95		19
3 - 4	Nov.80 - Jan.81	141.5 - 144.5	3	R	OFF	30	10	
4 - 5	Jan.81 - Aug.81	144.5 - 137.5	7	F	OFF	280	40	
5 - 6	Aug.81 - Oct.81	137.5 - 139.5	2	R	OFF	50	25	
6 - 7	Oct.81 - Dec.81	139.5 - 144.5	5	R	ON	175		35
7 - 8	Dec.81 - Jan.82	144.5 - 146.0	1.5	R	ON	25		17
8 - 9	Jan.82 - Mar.82	146.0 - 146.5	0.5	R	ON	85		170
9 - 10	Mar.82 - May 82	146.5 - 142.0	4.5	F	OFF	190	42	
10 - 11	May 82 - Jun 82	142.0 - 140.5	1.5	F	OFF	35	23	
11 - 12	Jun.82 - Aug.82	140.5 - 138.5	2	F	OFF	40	20	
12 - 13	Aug.82 - Sep.82	138.5 - 137.5	1	F	OFF	45	45	

*Figure 6 gives the river water levels as measured at the port of Pucallpa.

**OFF - offshore (away from the left bank)
ON - onshore (towards the left bank)

was moving downstream of the dock area and consequently some small reductions in water depth in the vicinity of the dock site had resulted.

The availability of a reliable sequence of bathymetry has permitted a closer examination of the movements of the thalweg and a correlation has been found between the onshore-offshore direction and the river stage. Figure 5 shows the movement of the thalweg since 1977. In the 5-yr period from 1977 to 1982, the thalweg has a net movement offshore of approximately 500 m. On occasions, however, the thalweg does move onshore particularly approaching the high water season.

Table 2 summarizes the observed thalweg movements over the eleven periods since July 1980. The data show that when the river rises, the onshore movement is about 60 m for every 1 m rise in river level and when the river falls, the offshore movement of the thalweg is about 35 m for every 1 m fall in river level.

Accretion and Erosion Maps

General

By mid-1981, after a further four surveys, it was clear that considerable increases in the overall elevation of the riverbed close to the dock were occurring. However, when an overall comparison was made later of Sections (a) to (11) there was a clear indication that a more general change was also taking place offshore.

Again, because of limited hydrological equipment and instrumentation, the analysis is generally a qualitative one and emphasizes the urgency in obtaining the hydrological measurements needed to understand better the mechanism associated with the serious changes to the morphology of the Upper Amazon.

To obtain a better concept of the changes that can occur with time, accretion and erosion maps were prepared. These maps were drawn by laying one bathymetric chart over another and plotting the differences as contours. Figure 7(a) to Figure 7(n) show the net changes in river topography derived in this manner, for the twelve survey periods discussed previously.

July - November 1980

This was the first period compared in this manner and covered the low to high water season. From Figure 7(a) it can be seen that in an area approximately 100 m from the dock, there are net losses of up to 3 m. About 800 m downstream of the dock, gains of up to 10 m were found along the left bank side of the

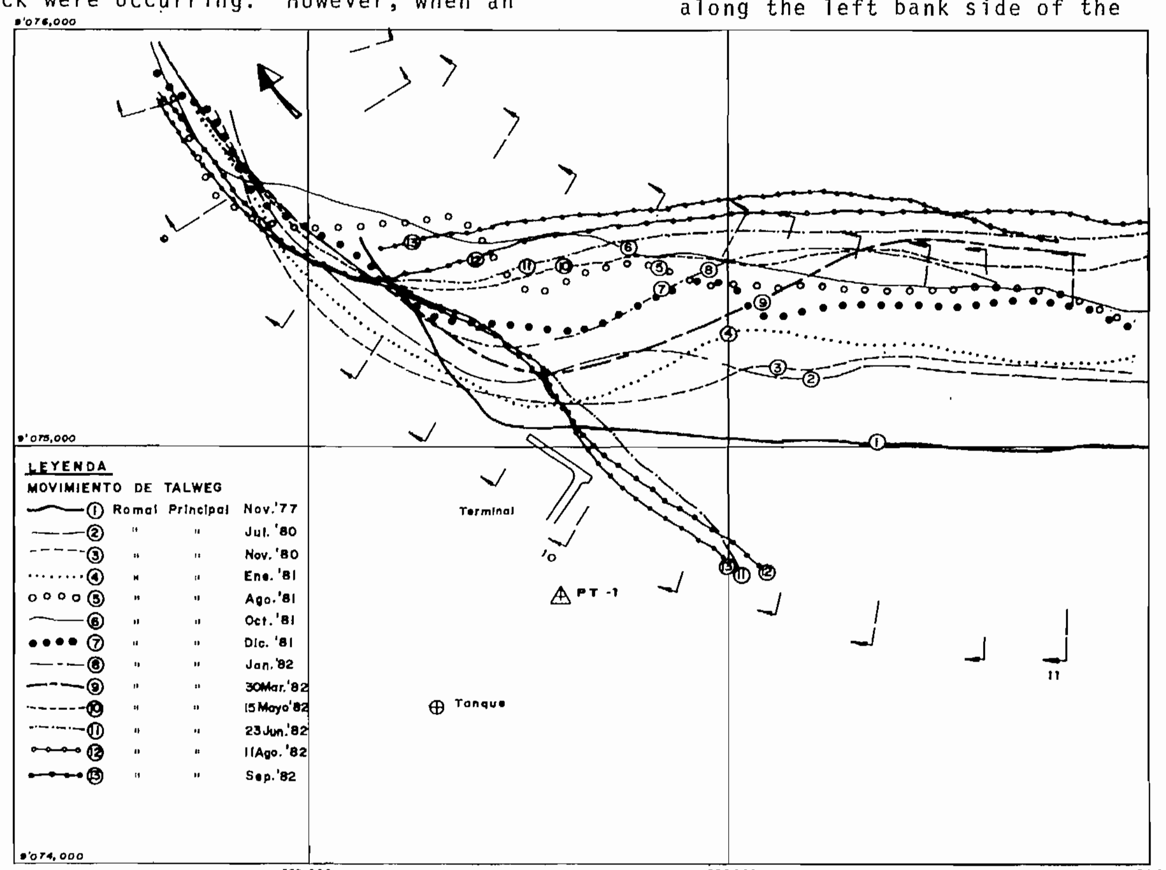

FIGURE 5 MOVEMENT OF THALWEG

river. In the upstream area of the dock there were also other gains up to 6 m which were attributed to the confluence of Channel B and the tributary, the River Manantay.

November 1980 - January 1981

During this period, velocities are at their highest and, predictably, significant erosion was recorded. In Figure 7(b), a large area with losses up to 3 m can be seen while on the left bank side of the river downstream of the dock, losses of up to 7 m were found.

January - August 1981

Figure 7(c) shows remarkable evidence of the instability of the River Ucayali. Compared to the preceding period when large areas of losses were measured, there were now equally large areas of accretion. In fact, net gains of up to 11 m were found approximately 100 m from the dock. The area of deposition has forced the channel further towards the middle of the bend with the result that erosion on the right bank is clearly evident. This erosion of up to 7 m opened up a path for the main filament of flow to attack the left bank further downstream, causing a northward movement of the meander.

August - October 1981

During this period of low flow, erosion on the right bank continued as the main thalweg maintained its new path. In Figure 7(d), it can be seen that downstream of the dock there are accretions of up to 10 m which result possibly from a simple transfer movement of the gains from the dock area found in the previous comparison.

October - December 1981

As the river rose during this period, the thalweg moved onshore (southward) approximately 175 m. With the higher velocities of the main filament of flow, erosion resulted with general losses of up to 5 m being measured. Figure 7(e) shows the accretions, between Sections (10) and (11), which can be attributed to the sediment laden Channels A and B meeting the resistance of the main river flow.

December 1981 - January 1982

By this time, it was evident from the study of Sections (4) to (8), the meander was migrating northwards at a rate of about 200 m/yr. The progressive movement northward of the main thalweg for the same period supported the evidence of migration combined with

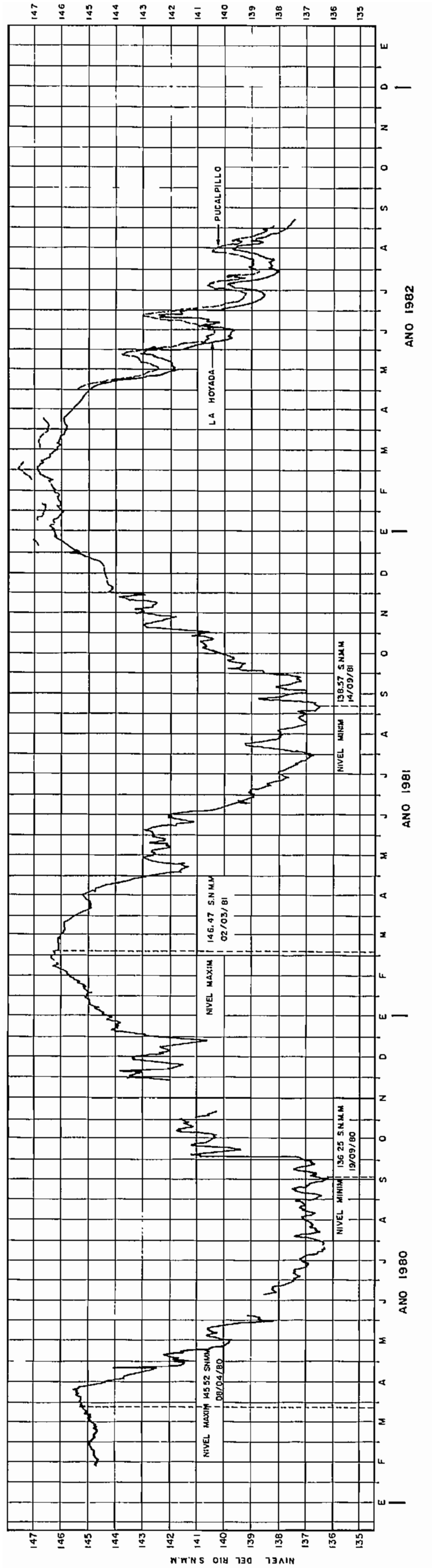

FIGURE 6 WATER LEVELS-RIVER UCAYALI 1980-1982

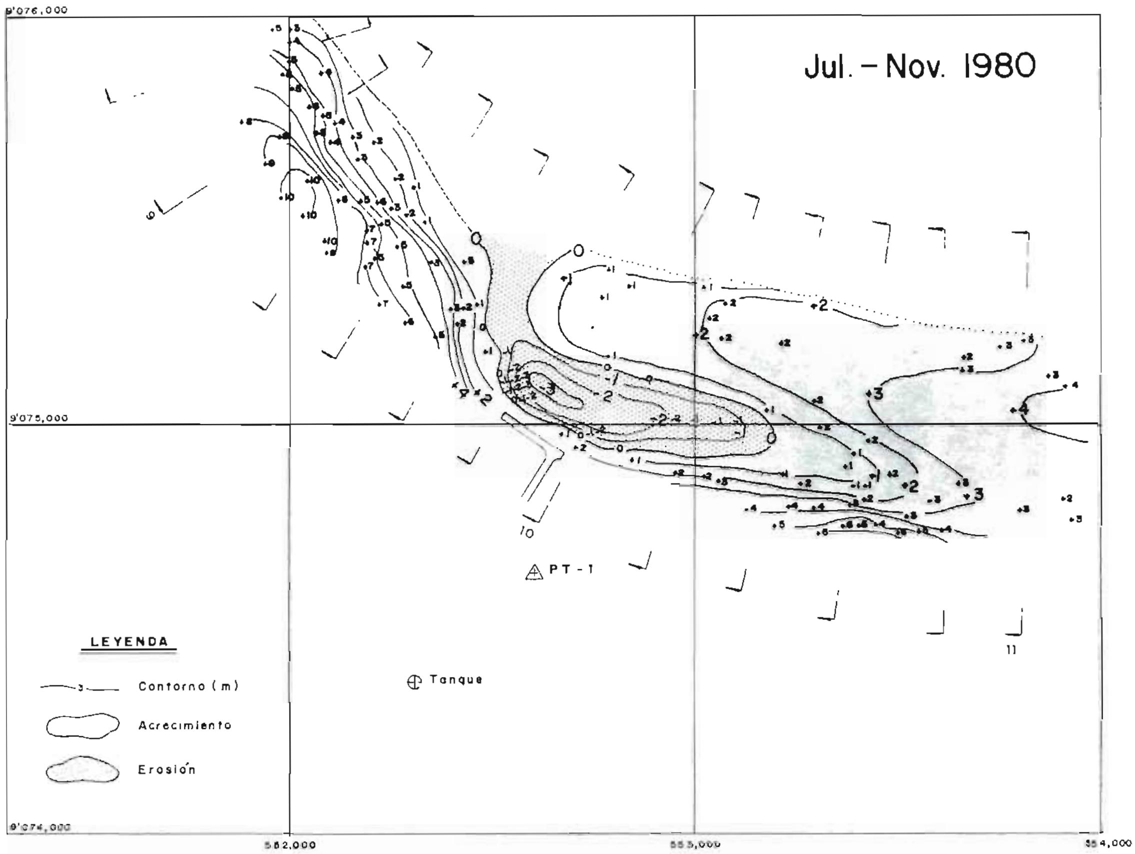

FIGURE 7(a) ACCRETION AND EROSION JULY TO NOVEMBER 1980

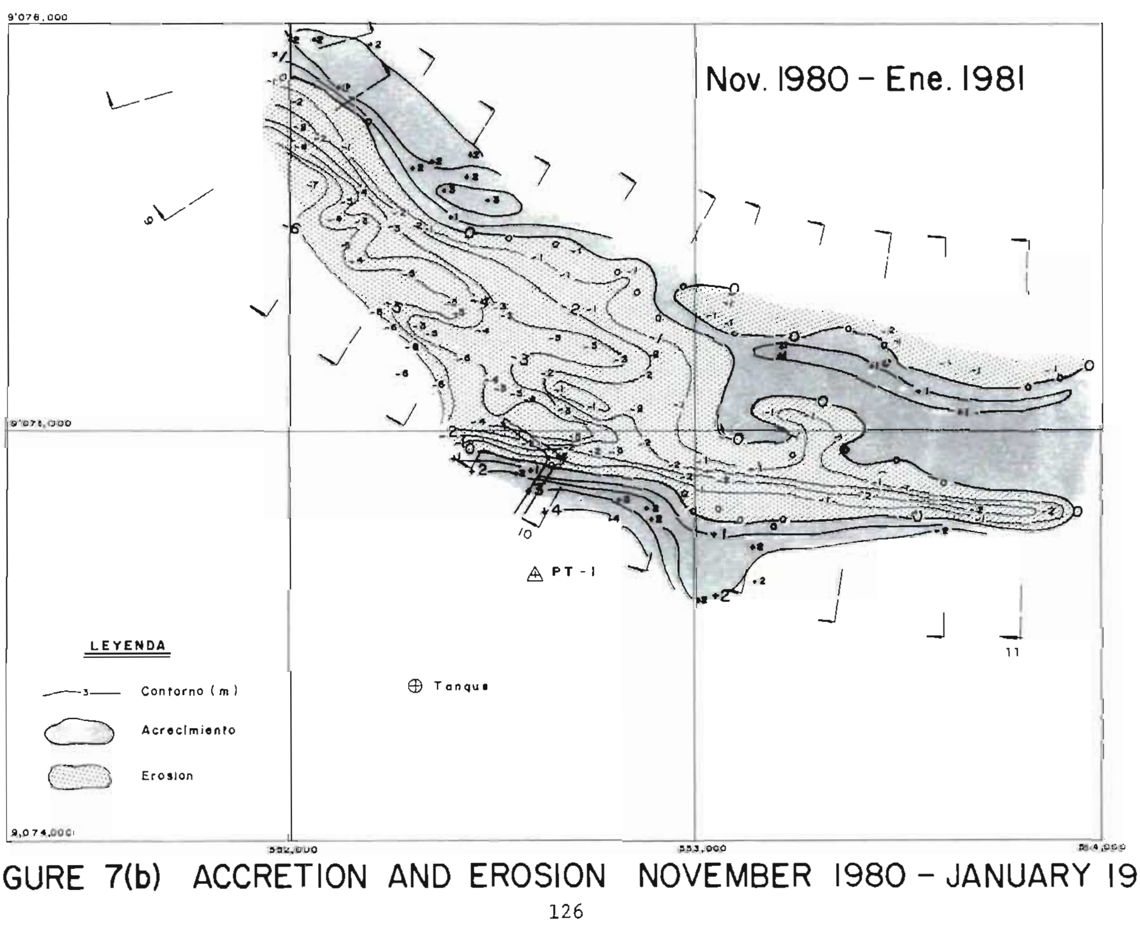

FIGURE 7(b) ACCRETION AND EROSION NOVEMBER 1980 - JANUARY 1981

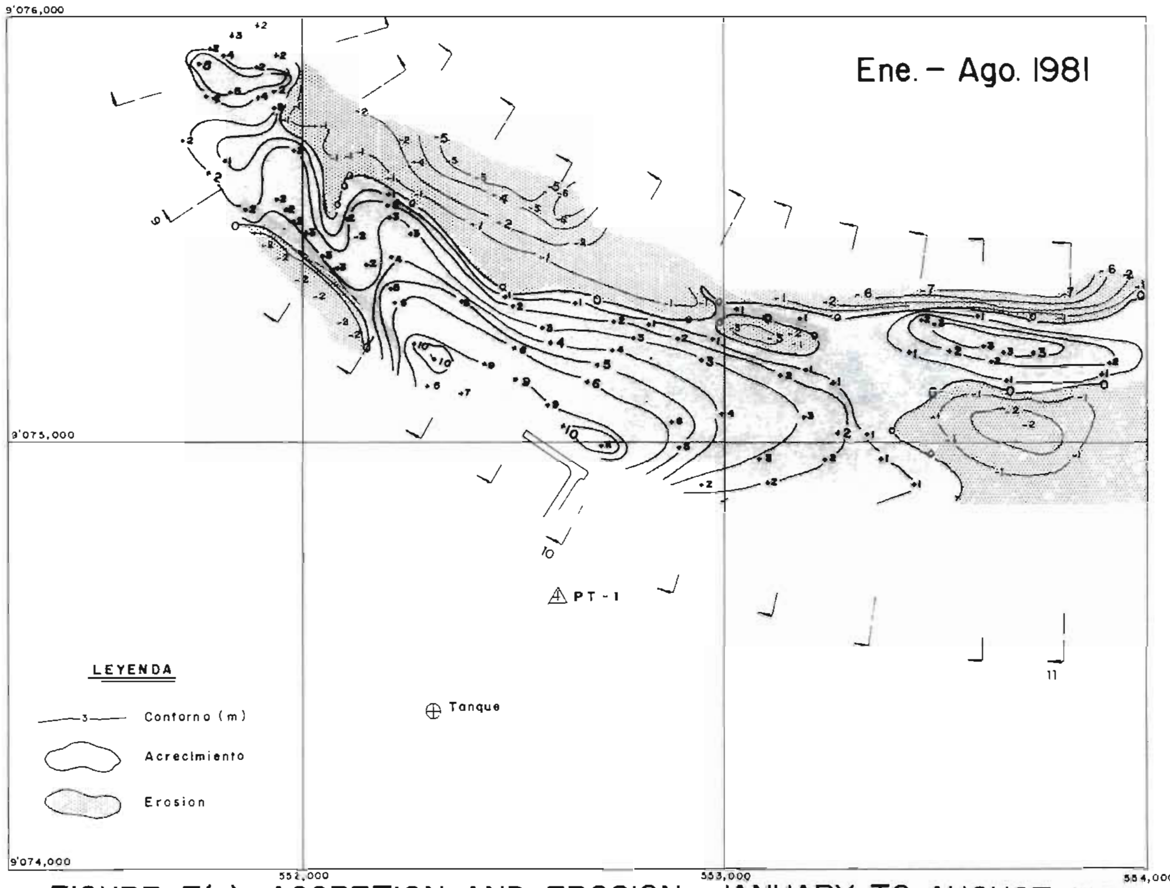

FIGURE 7(c) ACCRETION AND EROSION JANUARY TO AUGUST 1981

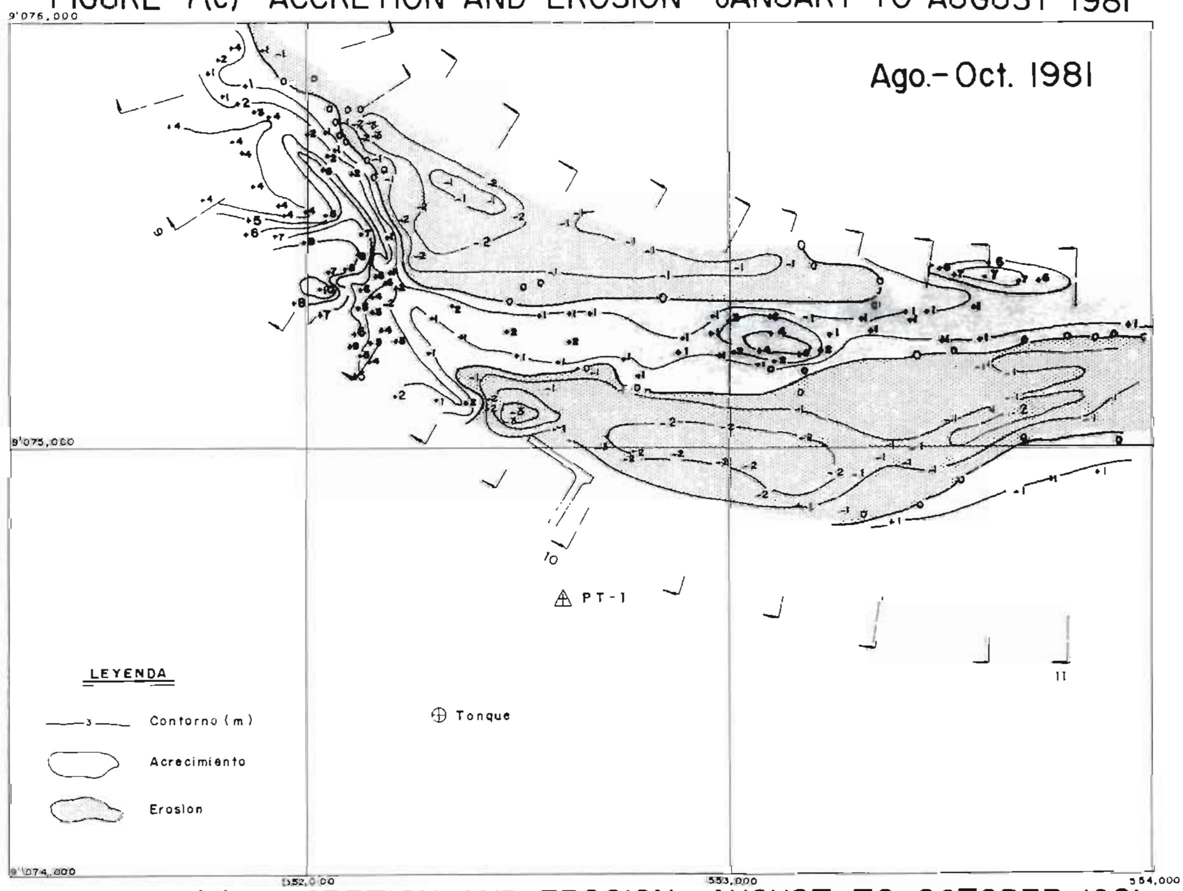

FIGURE 7(d) ACCRETION AND EROSION AUGUST TO OCTOBER 1981 the growth of a sand spit upstream of the dock. If we examine the contours of the survey of January 1982 (Figure 7(f)), it can be seen that a considerable area of riverbed would be above low water during the low water (137 m) period. The growth of the sand spit began with the accumulation of sediment at the west point (downstream) of the confluence of Channel A and the River Ucayali during the period October to December 1981 (previously discussed). During the period December 1981 to January 1982 (Figure 7(g)), the increase in the same area was more significant and accretions of up to 7 m were recorded. Furthermore, a 7 m accretion was found on the upstream side of the confluence.

January to March 1982

From the previous comparison, it was seen that large areas of accretions on the upstream side of the port were causing the main filament of flow to be contained within the bounds of the right riverbank and the newly formed sand bar. During the period now under discussion, the river discharge was at its highest (Figure 6). Further erosion of up to 6 m was recorded in the right bank (convex side of the meander (Figure 7(h)). Immediately downstream of the main body of the sand bar, however, the thalweg still made its way in a southerly direction to the nearshore bank. The sand bar continued to grow as further sediment was brought down from Channels A and B and deposited at the confluence.

March to May 1982

This period follows high water and is classified as falling stage. Figure 7(i) shows the resulting erosion that occurred on the point bar covering an area of about 1 1/2 km^2.

Approximately 200 m from the dock there was a small pocket of erosion of up to 6 m.

The crossover bar shows accretion of up to 5 m associated with small gains in the deeper water near the left bank of the river.

During this period, the river no doubt contained less sediment in suspension because of lower flows, but the velocities were still high enough to cause some erosion of up to 3 m in the area of confluence with Channel A.

The main bar appeared to be advancing rapidly and further gains of up to 5 m in the same area were causing some concern.

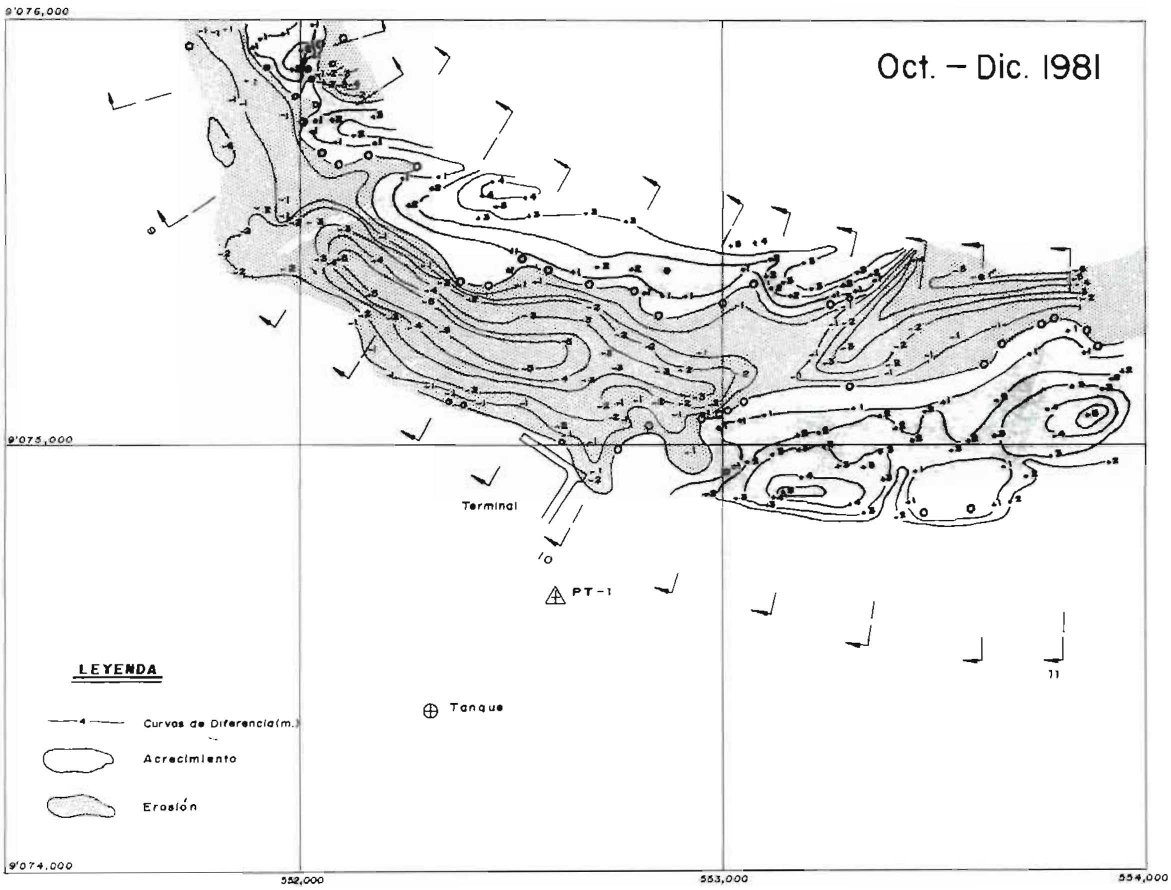

FIGURE 7(e) ACCRETION AND EROSION OCTOBER TO DECEMBER 1981

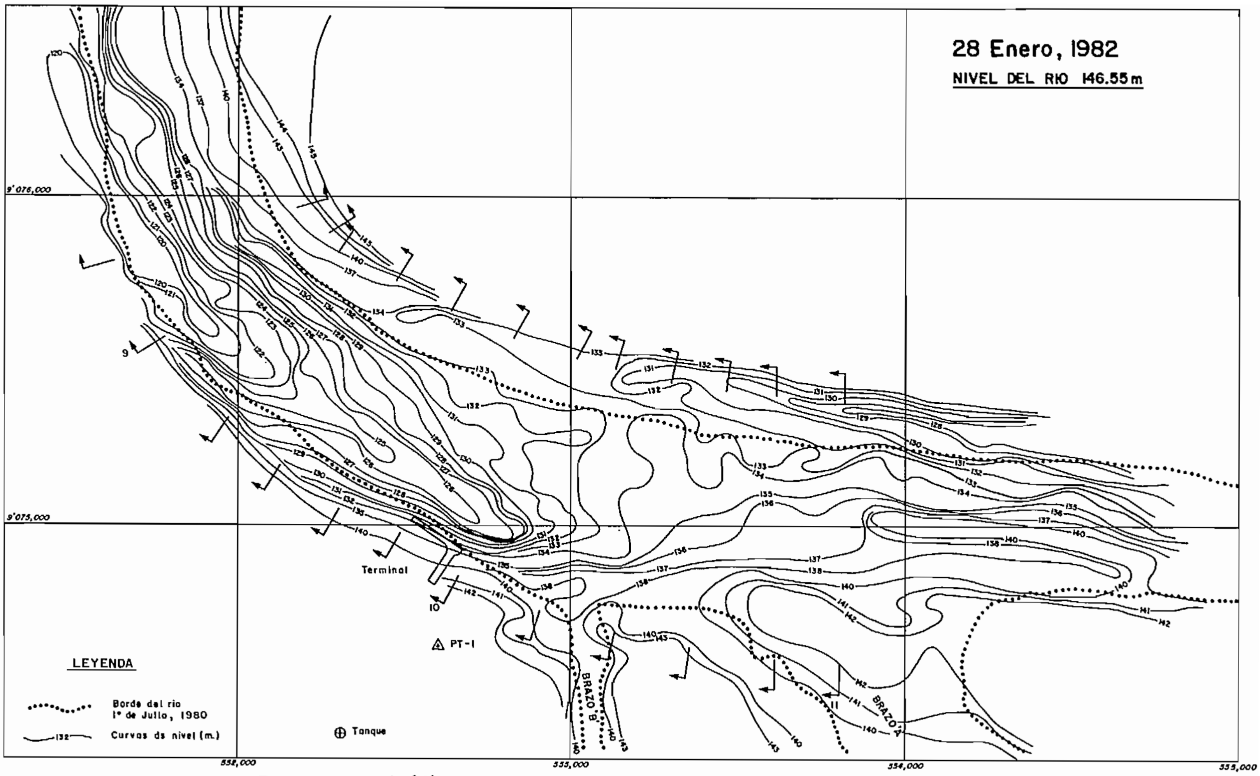

FIGURE 7(f) BATHYMETRY — JANUARY 1982

May to June 1982

In the May survey (Figure 7(j)) a 10-m deep zone approximately 100 m from the dock was noted. This zone, of about 200 m diameter, had side slopes of 1 in 10 and, according to the June comparison in Figure 5(k), acted as a sand trap with accumulations of up to 7 m. Although during this period the net movement of the river levels was in a falling stage, there was a 6-day period when the river rose nearly 3 m and probably contributed to some erosion on the right bank of the river. There was also erosion recorded in the areas of confluence with Channels A and 8. The sand bar had built up by about 2 m and migrated downstream.

June to August 1982

The river level was at this time approaching low water. Figure 7(l) shows a general accretion of 1 to 2 m, although close to the dock it appeared that the deep zone mentioned in the previous comparison filled in further with accretions of up to 6 m. The flows from Channels A and 8 appear to have been a dominant feature in producing a narrow passage of flow close to the left bank upstream of the dock, resulting in erosion for the second consecutive survey period. In the August survey, there appeared to be a second spit forming with the 134 to 138 m contours, producing gains in this area of up to 2 m.

August to September 1982

The bathymetry in Figure 7(m), obtained in early September 1982, confirms the sand spit discussed in the previous period. At this time, the river was at its lowest level and the advancing sand bar was clearly evident. The relatively stable condition for this period is clearly shown in Figure 7(n), with losses of only about 1 m being evident. There are isolated small "pockets" of accretion.

July 1980 - September 1982

In examining the net changes over the 2 years since the base survey of July 1980, dramatic differences emerge in not only the course of the river, as discussed in an earlier paragraph, but also in the elevations of the riverbed as shown in Figure 7(o). Maximum accretions of 15 m were found downstream at Section (a) and reducing in the upstream direction to gains of 2 or 3 m near the port. The bar, which is now at an elevation of between 137 and 139 m shows a general increase of approximately 6 m since 1980.

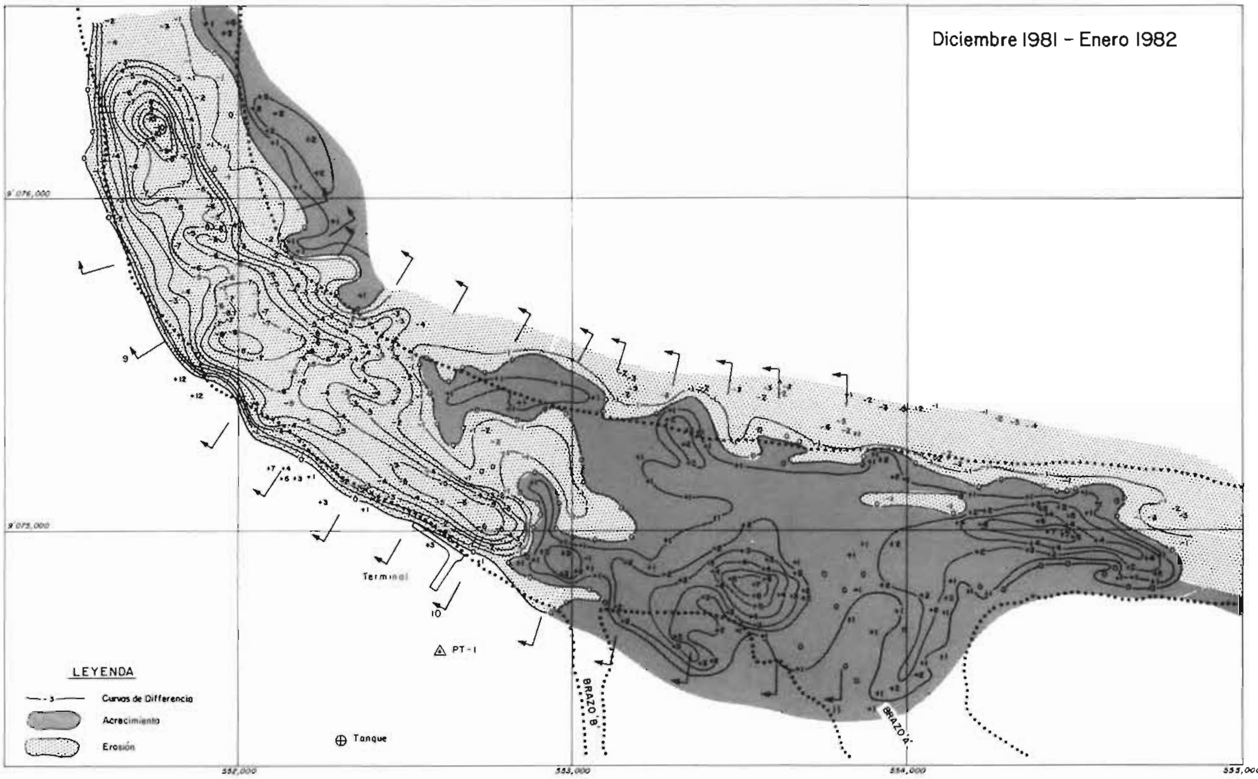

FIGURE 7(g) ACCRETION AND EROSION DECEMBER 1981 – JANUARY 1982

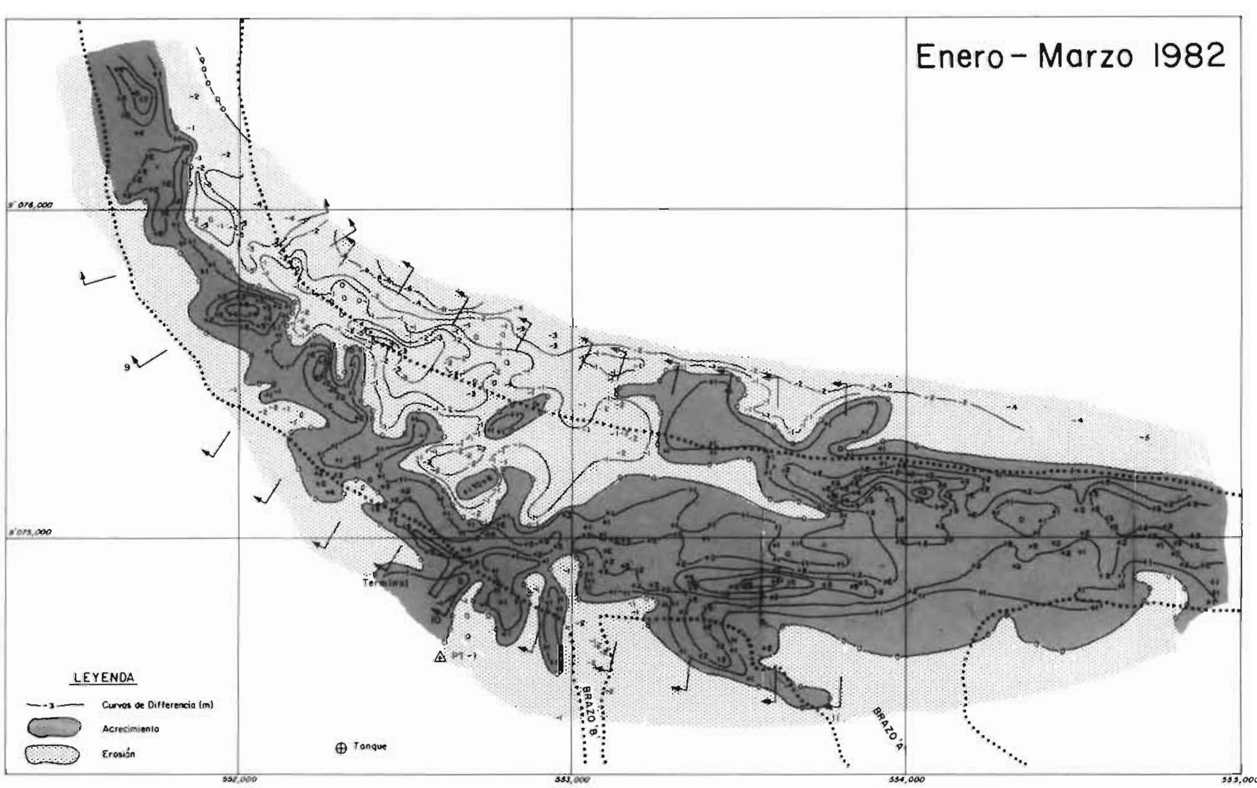

FIGURE 7(h) ACCRETION AND EROSION JANUARY TO MARCH 1982

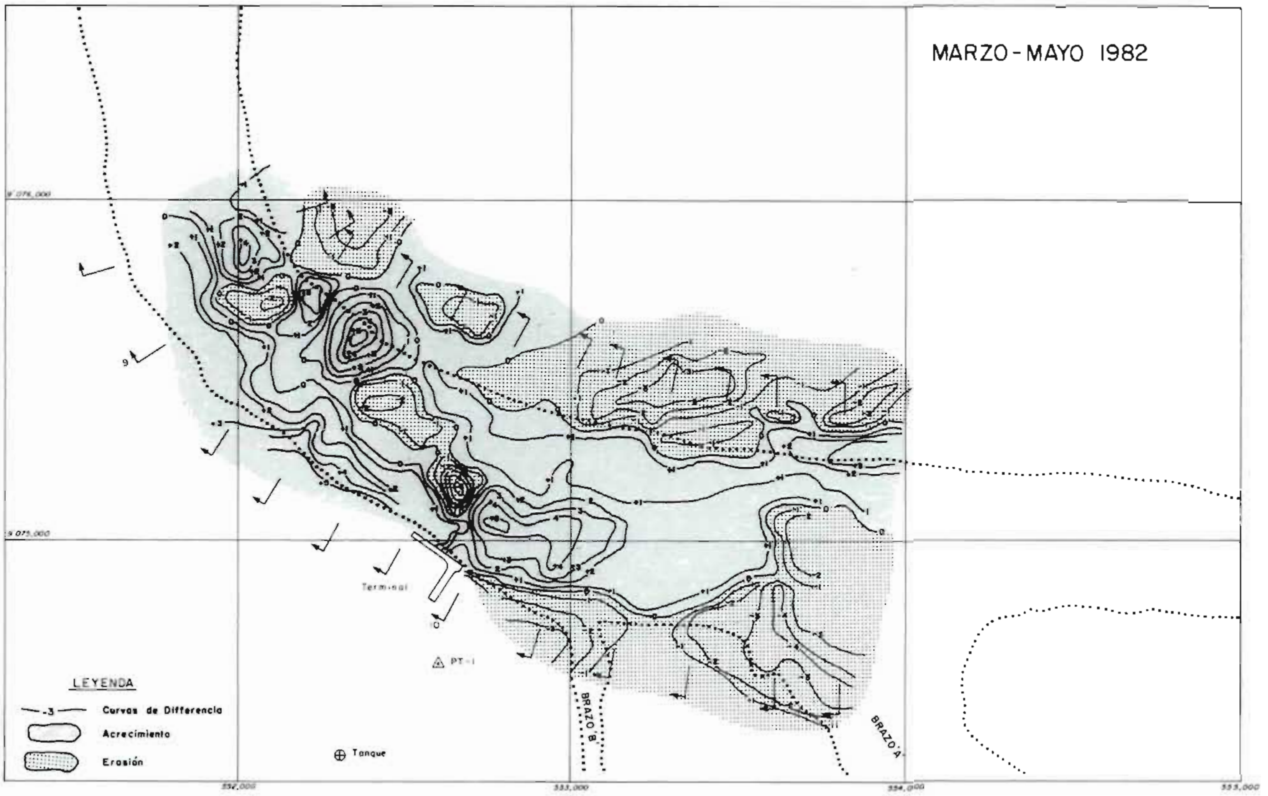

FIGURE 7(i) ACCRETION AND EROSION MARCH TO MAY 1982

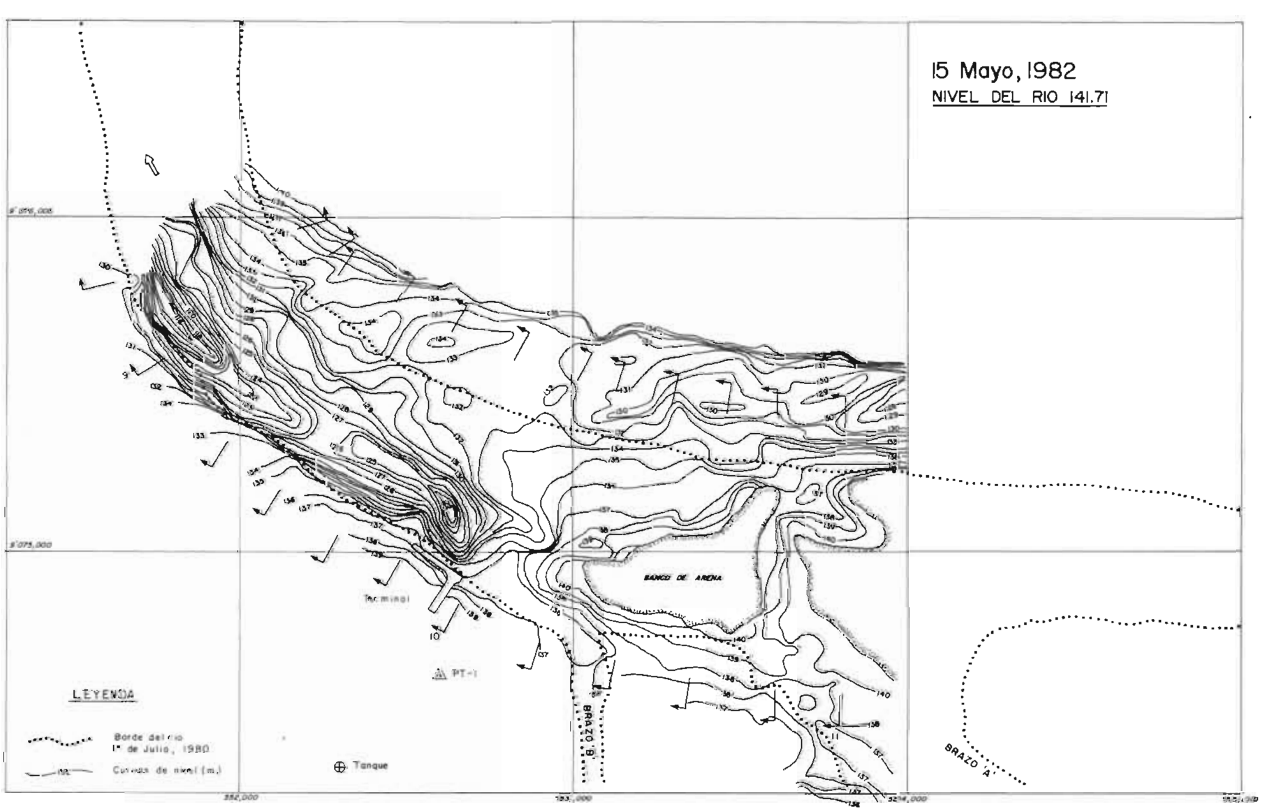

FIGURE 7(j) BATHYMETRY — MAY 1982

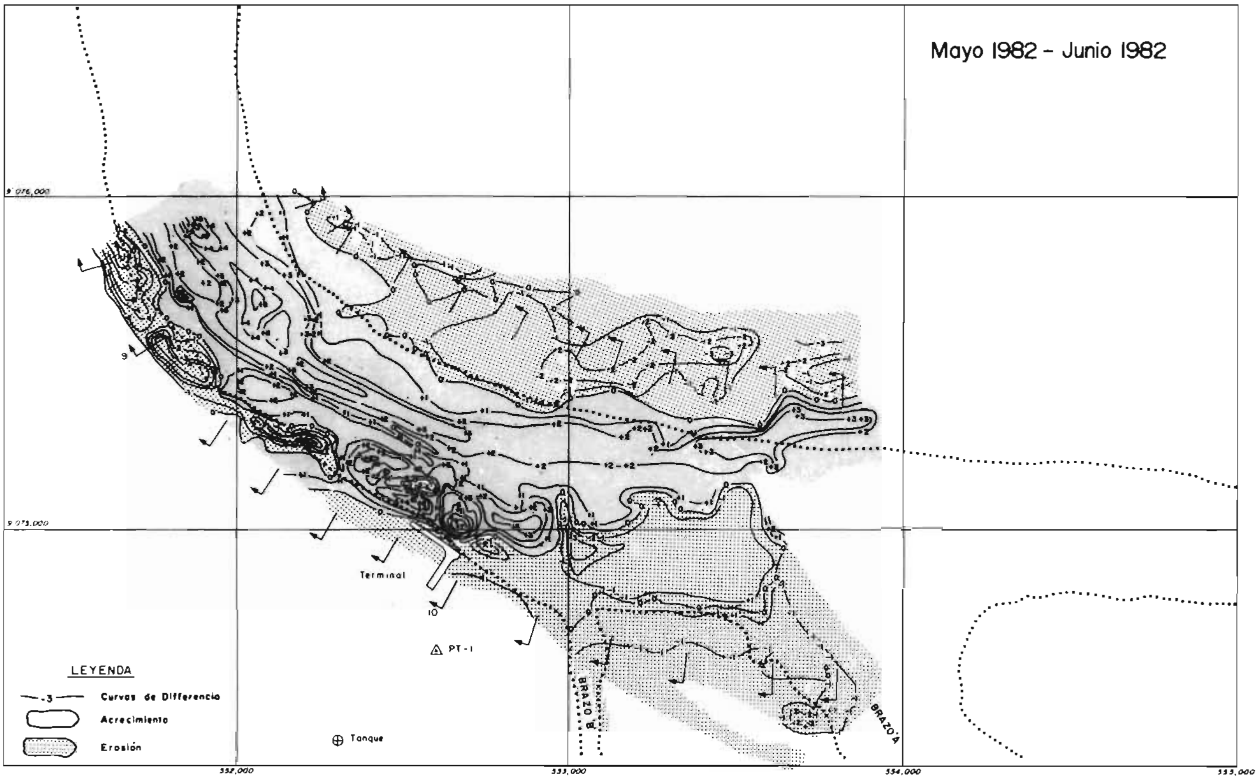

FIGURE 7(k) ACCRETION AND EROSION MAY TO JUNE 1982

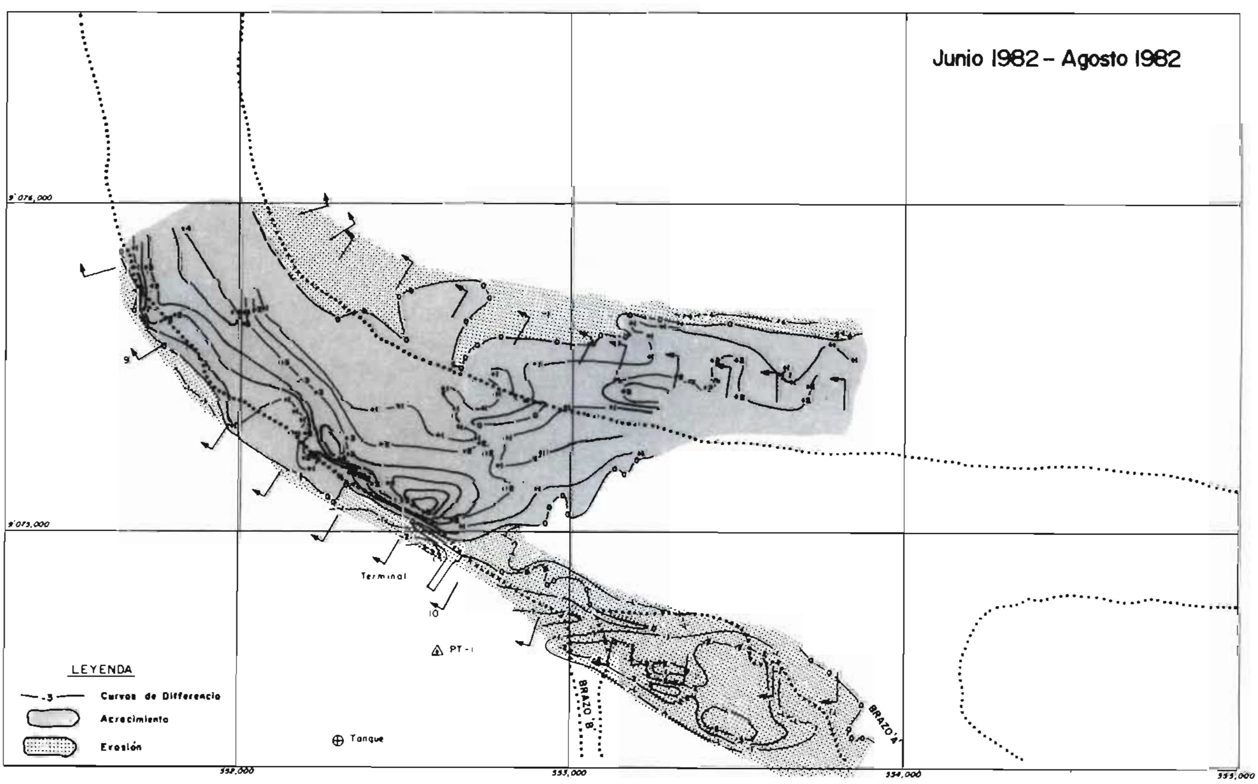

FIGURE 7(l) ACCRETION AND EROSION JUNE TO AUGUST 1982

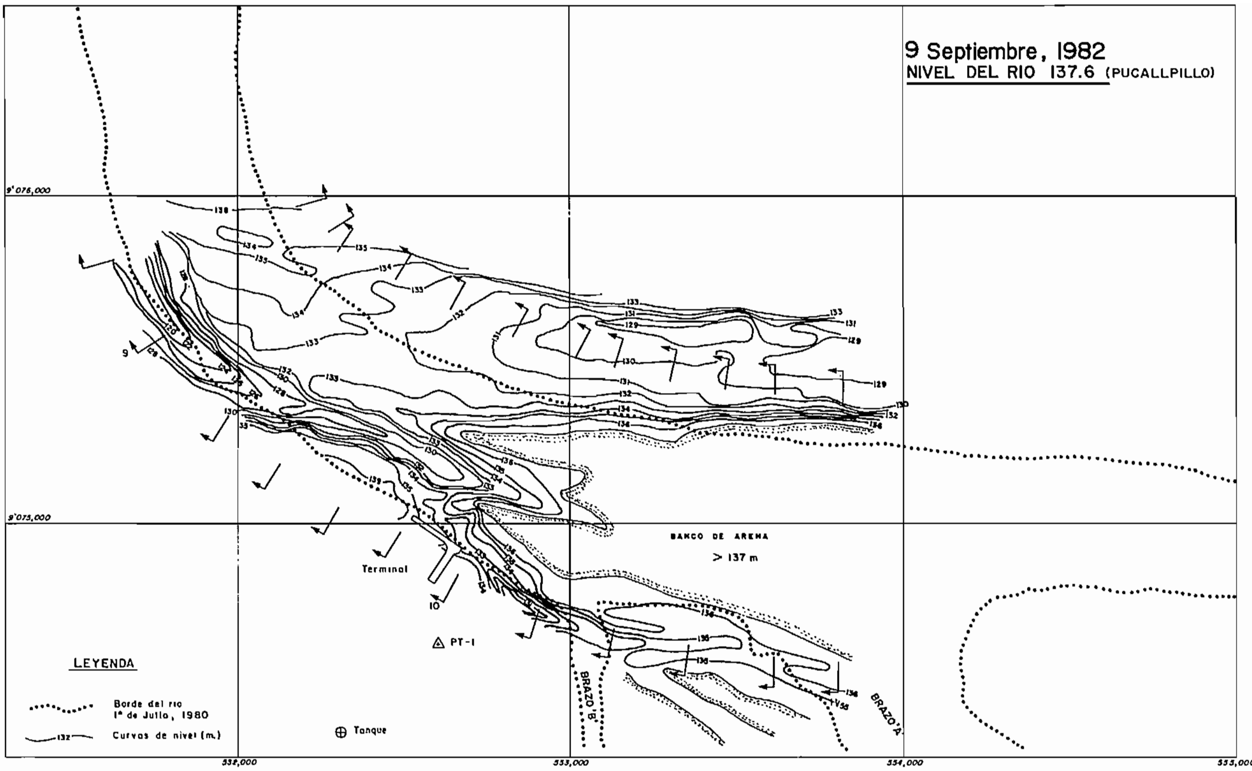

FIGURE 7(m) BATHYMETRY — SEPTEMBER 1982

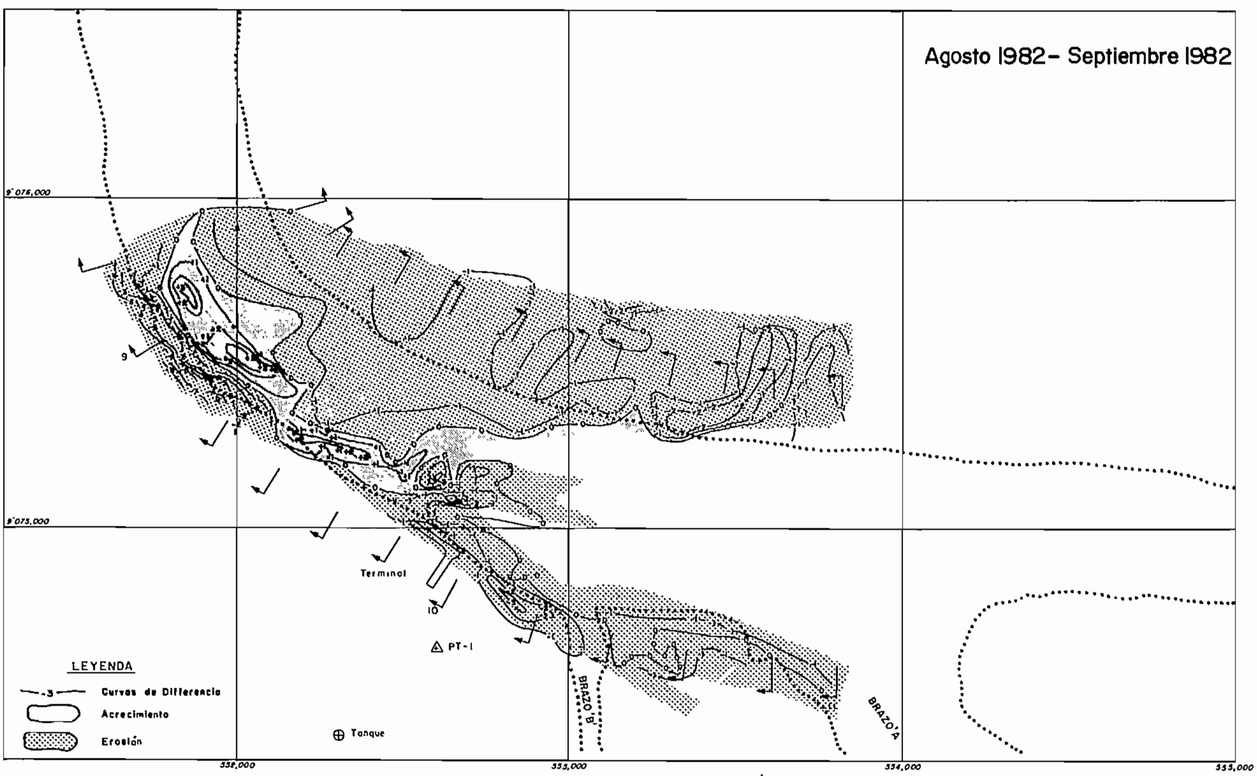

FIGURE 7(n) ACCRETION AND EROSION AUGUST TO SEPTEMBER 1982

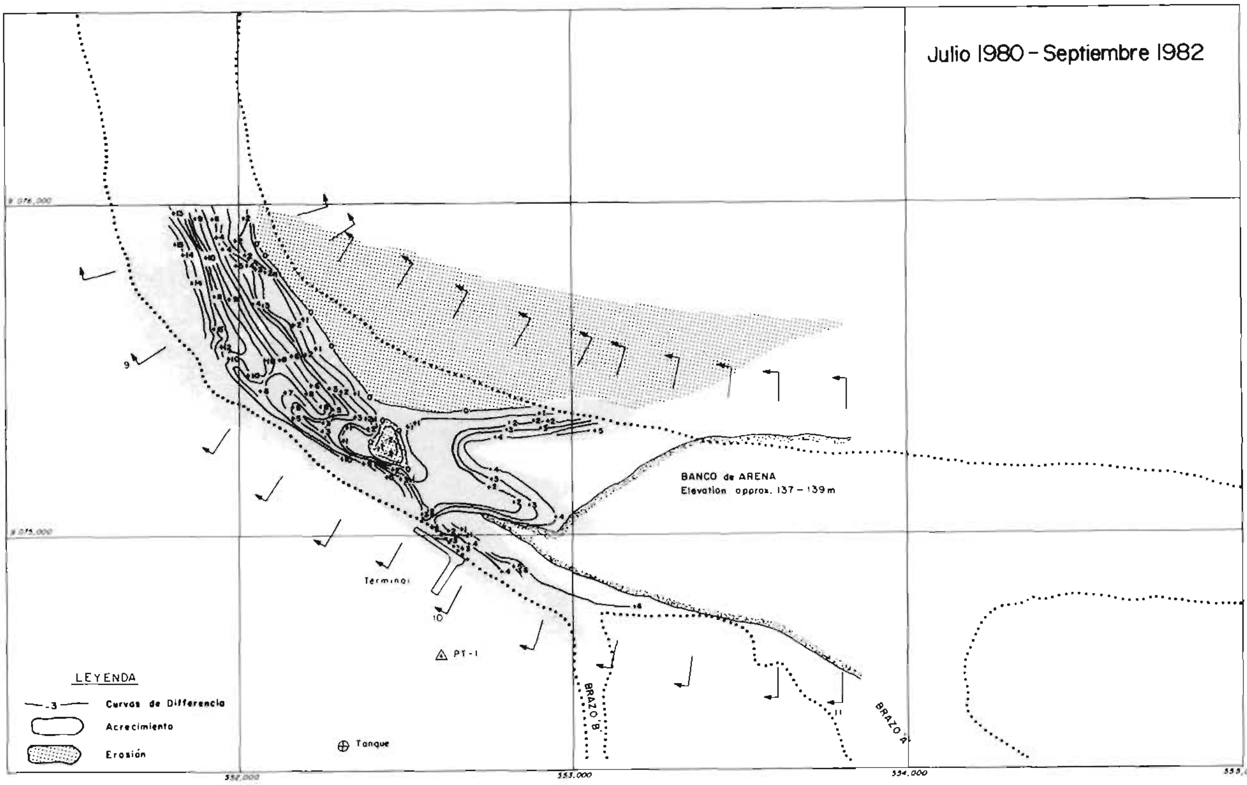

FIGURE 7(o) ACCRETION AND EROSION JULY 1980 TO SEPTEMBER 1982

Summary of Accretion/Erosion Maps

The following Table 3(a) summarizes each of the eleven periods examined and relates to the erosion and accretion locations with the corresponding river stage. For each of the survey periods a stage value has been derived from the product of an energy "index" based on river stage (1 to 3 from low to high water and 3 to 1 from high to low water) and the duration of the period between surveys (i.e., "dwell" at given stages).

Table 3(b) summarizes a step further, the information given in Table 3(a) and places in ascending order the "stage values" with rising and falling stage. Immediate response to this Table 3(b) is that there is evidence of correlation between stage and location of process and an attempt was made to strengthen the probability of correlation by using energy index (product of energy and severity of process) with stage and location.

Figure 8 shows the plot of energy index with stage value and shows very clearly the correlation between stage and the location of the process.

The analysis, although containing only eleven sets of data, strongly indicates that during low to rising stage, there is tendency for erosion to take place at the crossover bars, whereas on the high to falling stage, there is an emphasis on accretion to the crossover bars and erosion at the point bars. This is consistent with the general observations by Pierce and Elliott, who carried out studies on the lower Mississippi River in the USA. It appears, however, that Pierce and Elliott may have examined only high and low water and not the transition between the extremes. Included in this analysis on the River Ucayali, however, are two such periods, i.e., the low water period of August to October 1981 and the high water period of January to March 1981. The process in each of these two periods, is in complete agreement with Pierce and Elliott's findings.

TABLE 3(a)

ACCRETION/EROSION LOCATIONS AT EACH SURVEY PERIOD

				PROCESS			
				EROSION		ACCRETION	
Period	Stage Rising/ Falling	Energy Index	Stage Value (E)	Location	Severity Index	Location	Severity Index
Jul/80 - Nov/80	R	1-2	6	CB	1	G	3
Nov/80 - Jan/81	R	2-3	7	G	2	PB	1
Jan/81 - Aug/81	F	2	12	PB	1	G	3
Aug/81 - Oct/81	R	1-1	4	CB	2	PB	3
Oct/81 - Dec/81	R	2	5	CB	2	PB	2
Dec/81 - Jan/82	R	2-3	5	CB	3	PB	1
Jan/82 - Mar/82	R	3	6	PB	2	CB	2
Mar/82 - May/82	F	3-2	7	PB	1	CB	1
May/82 - Jun/82	F	2	2	PB	2	CB	2
Jun/82 - Aug/82	F	2-1	3	PB	1	CB	2
Aug/82 - Sep/82	F	1	1	PB	1	CB	1

CB = Crossover Bar

PB = Point Bar

G = General

Stage Value (E) = Energy Index x Duration

Severity of Process - 3 = Severe

2 = Moderate

1 = Mild

TABLE 3(b)

ACCRETION/EROSION LOCATIONS FOR STAGE AND ENERGY

		PROCESS					
		EROSION			ACCRETION		
Stage	Stage Value (E)	Location	Severity of Process	Energy Index	Location	Severity of Process	Energy Index
Low and Rising	4	CB	2	8	PB	3	12
Rising	5	CB	2	10	PB	2	8
Rising	5	CB	3	15	PB	1	4
Rising	6	CB	1	6	G	3	12
Rising and High	6	PB	2	12	CB	2	8
Rising	7	G	2	14	PB	1	4
Falling	1	PB	1	1	CB	1	1
High and Falling	2	PB	2	4	CB	2	4
Falling	3	PB	1	3	CB	2	6
Falling	7	PB	1	7	CB	1	7
High and Falling	12	PB	1	12	G	3	36

Energy Index = Stage value x Severity Index

INTRODUCTION TO THEORETICAL APPROACH

Regime Theory

Because the River Ucayali is a virgin river in the sense that there is virtually no morphological data available, it will require several more years of good quality measurements before attempting to correlate further hydraulic parameters with changes to the river regime. Nevertheless a comparison was made with some empirical formulae for meander geometry derived by Inglis after several years of regime studies on Indian rivers.

$$Lm = Cl\ (Qmax)^{1/2}$$

where on the Ucayali

Lm = meander length = 42,000 ft

Qmax, based on a stage of 148 m = 683,000 cfs which is approximately 20 percent above bank full

Cl = constant between 18 and 42

then $Cl = \frac{42000}{(683000)^{1/2}} = 50$ (maximum), since Q could be significantly higher)

and

$$Wm = Cw\ (Qmax)^{1/2}$$

where

Wm = meander width = 22,000 ft

Cw = a constant which is in the order of 0.5 Cl

then $Cw = \frac{22000}{(683000)^{1/2}} = 26.6 = 0.53\ Cl$

also

$$R = CrQ^{1/2}$$

where

R = meander radius = 4,800 ft

Cr = a constant of approximately 6

then $Cr = \frac{4800}{(683000)^{1/2}} = 5.8$

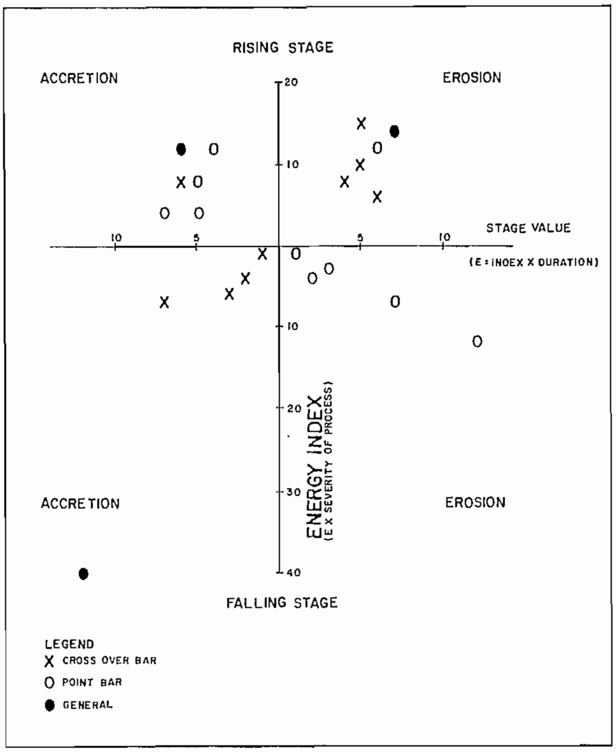

FIGURE 8 ENERGY INDEX VS STAGE VALUE

Sediment Transport

Sediment load in the River Ucayali undoubtedly is the dominant mechanism determining the behavior of the riverbed and its boundaries. This paper has described the qualitative results that occur and although quantitative knowledge of the sedimentation processes on the Ucayali are unknown at this time due to the lack of sufficient observations, a brief attempt was made in 1982 to compare a measured transport rate with a theoretical sediment load formula.

In January 1982, when the river was at its highest and therefore probably when the suspended sediment transport rate was at its maximum, suspended sediment samples were taken with a P.61 sampler in conjunction with velocity measurements using drogued floats. The resulting measured suspended load was approximately 0.45 x 10^6 t/day. To arrive at a calculated load, several formulae were used from studies carried out by du Boys for obtaining bed load and Albertson and Sarde to resolve the total sediment load, from which a calculated suspended sediment transport rate of about 1.5 x 10^6 t/d was determined.

It should be mentioned here that during 1976 and 1977, a US geological survey under the leadership of R. H. Meade carried out a sediment sampling program on the Lower Amazon from Iquitos, Peru, to the river's mouth. From their analysis, a suspended sediment transport rate of 1.7 x 10^6 t/d at Iquitos, some 1,000 km downstream of Pucallpa, was obtained.

CONCLUSIONS

The information gained from good quality bathymetry on the River Ucayali at Pucallpa has proved to be most valuable in defining the dramatic changes that can occur to the bend of a meandering river with a highly mobile bed. The meander at Pucallpa appears to be migrating northwards at an average rate of between 150 m and 200 m per year.

Despite the overall accretion in the port area at Pucallpa, as a consequence of a major thalweg migration northwards from the dock, there still appears to be an approach channel from downstream that is sufficiently deep for present requirements. The ability of the flow from Channels A and B to maintain a concentration of higher velocities near the dock through this channel, will be the key determinant of whether or not the sand bar developing from upstream can encroach on the immediate dock area.

The Peruvian government should be commended for initiating this important work in the Upper Amazon region and it is necessary for other countries concerned (namely Bolivia and Brazil) to realize now the need to obtain the hydrological information necessary to ensure future safe and economic river navigation and to locate and investigate specific areas which may inhibit efficient utilization of their river systems.

If other agencies are carrying out or intend to carry out similar studies in the region, then it would be fruitful to consider a mutual exchange of data.

ACKNOWLEDGEMENTS

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REPORT ON DMA'S PROTOTYPE GRAPHICS FROM ENHANCED LANDSAT IMAGERY FOR APPLICATION TO HYDROGRAPHIC CHARTING

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ABSTRACT

The Defence Mapping Agency (DMA) is currently developing prototype graphics from remotely sensed imagery for support to hydrographic survey planning and DMA's nautical chart maintenance program. The imagery for these prototypes is Landsat scenes that are enhanced by digital image processing techniques, or processed totally in an analog mode for quick response requirements. This paper discusses these processing approaches within the framework of the prototype efforts.

Landsat's multispectral scanner imagery in the Makassar Strait of Indonesia is computer enhanced to highlight hydrographic information such as shoals, uncover areas, land-water boundaries, and shallow water depth intervals. These enhancements are graphically presented in a variety of scales, formats, and color assignments representing three approaches to computer enhancements.

To produce quick response graphics, the analog approach to enhancement involves the use of a color additive viewer and multiscale projector/viewer for analysis of multispectral/multitemporal Landsat film. The prototype graphics using this approach were developed to support DMA's chart maintenance program, but could be used as a tool for survey planning in shallow waters.

RESUME

La DMA est à mettre au point un prototype de système graphique, à partir d'images obtenues par télédétection, qui sera utilisé pour la planification des levés hydrographiques et pour son programme de tenue à jour des cartes marines. Pour ce prototype, les scientifiques utilisent des images de Landsat, accentuées à l'aide de techniques de traitement numérique, ou traitées totalement en mode analogique pour obtenir rapidement des reproductions graphiques. L'auteur de la présente étude expose ces méthodes de traitement, dans le cadre des efforts déployés pour la mise au point du prototype.

Des images du détroit de Makassar (Indonésie), obtenues par balayage multispectral à partir d'un Landsat, sont accentuées par ordinateur de façon à mettre en relief des données hydrographiques comme les hauts-fonds, les zones découvrantes, les limites terre-eau et les intervalles bathymétriques dans les eaux peu profondes. Ces images accentuées sont présentées dans divers formats, échelles et agencements de couleurs, correspondant aux trois méthodes d'accentuation par ordinateur.

Pour obtenir rapidement des reproductions graphiques, on se sert, pour le mode d'accentuation analogique, d'un synthétiseur image/couleur et d'un projecteur à différentes échelles pour l'analyse des diapositives multispectrales/multitemporelles obtenues par Landsat. Le DMA a mis au point le système graphique utilisant cette méthode, pour son programme de tenue à jour des cartes, mais on pourrait aussi l'utiliser pour la planification des levés dans les eaux peu profondes.

INTRODUCTION

The Defence Mapping Agency (DMA) is charged with the responsibility of providing safe and adequate nautical chart coverage for all areas of the world outside the U.S. territorial waters. New vessels possessing greater speeds and deeper drafts demand more accurate and timely charts to support an increasing traffic volume in unsurveyed or poorly surveyed areas. Hydrographic survey data used to produce the DMA charts are collected by specially equipped survey vessels of the U.S. Naval Oceanographic Office (NAVOCEANO). At the present collection rates, survey ships will require hundreds of years to collect the needed data to produce current and accurate charts. In addition to the high cost of hydrographic surveying, the time from data collection to portrayal on a published, updated nautical chart is extensive. Electro-optical sensors such as the Landsat's multispectral scanner (MSS) can be used to augment the slow and expensive process of collecting hydrographic information; as well as for an analysis tool used in the chart compilation process, resulting in a nautical chart that is more responsive to the needs of the maritime community.

The Multispectral Scanner (MSS) onboard each of the Landsat 1, 2, and 3 systems contain detectors which are sensitive to a narrow portion of the electromagnetic radiation (EMR) spectrum. The wavelengths of the 4 bands on the MSS are as follows:

Band 4	0.5 - 0.6 micrometers
Band 5	0.6 - 0.7 micrometers
Band 6	0.7 - 0.8 micrometers
Band 7	0.8 - 1.1 micrometers

Portions of the solar light spectrum pass through a water column, reflect off a seafloor or shoal and return to a detector where it creates a voltage signal, which is then transformed into a digital value. Propagation of light through water depends upon environmental conditions such as water clarity and bottom reflectance, and on wavelength. For the MSS system, the portion of the EMR spectrum detected by band 4 penetrates the water column to a depth of 40 meters under ideal conditions. Band 5 can detect to about 8 meters, band 6 to 0.5 meter and band 7 (used for shoreline definition) has no subsurface detection capability.

A radiometric problem in the first 3 Landsat MSS systems is known as "striping". The six detectors for each band do not respond to the same ground stimulus with equal intensity. This results in a pattern which repeats every six scan lines of a band thus producing a striping effect in the resultant image. This striping is not uniform across the scene and is particularly troublesome in the most sensitive portions of the dynamic range of bands 4 and 5. Destriping algorithms have been developed that reduce, but do not remove, this MSS detector radiometric noise.

For several years, DMA and NAVOCEANO have been discussing the potential application of Landsat imagery to support the hydrographic survey program. In 1980, DMA launched a project to produce a set of graphics derived from enhanced Landsat imagery that could be used for presurvey planning or field survey operations. Portions of the southern Makassar Straits in Indonesia were selected for this project to acquire ground truth from an ongoing NAVOCEANO survey.

Three distinctly different approaches were pursued to enhance Landsat imagery for the extraction of hydrographic information:

1. Contract with Environmental Research Institute of Michigan (ERIM) to derive relative water depths,

2. Contract with Earth Satellite Corporation (Earthsat) to derive enhanced depth penetration and shoal outline graphics, and

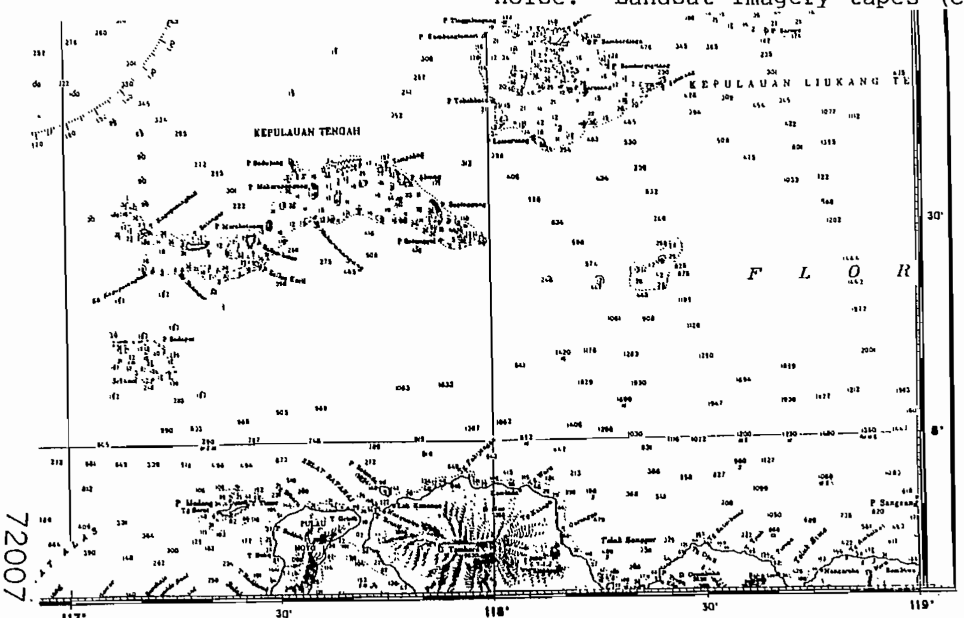
3. Inhouse processing on the Digital Image Processing System (DIPS) to create interpreted graphics.

All three processing approaches were completed in April 1982. During April-September 1982, DMA created a set of potential survey planning graphics from the combined set of enhanced Landsat graphics produced in each of the three approaches.

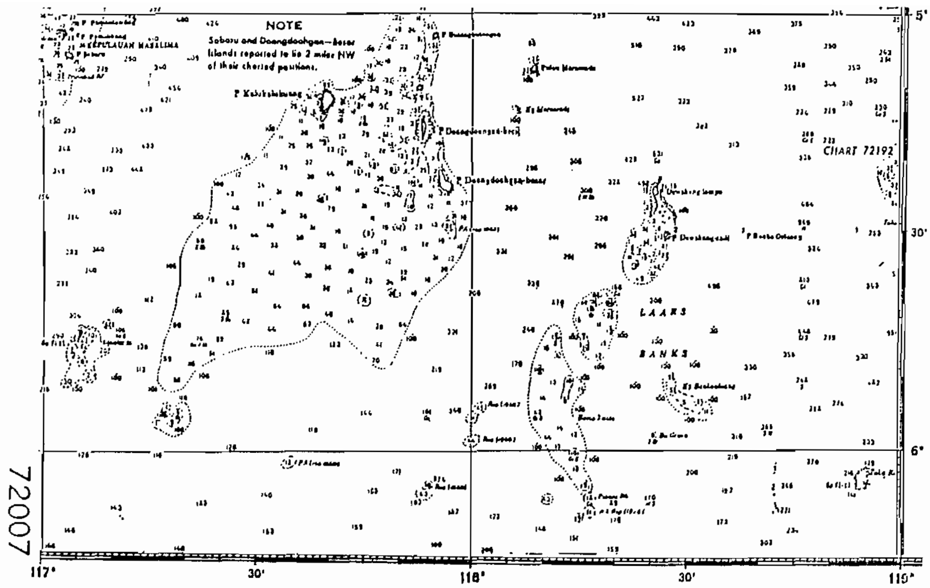
As surveying in the Makassar Straits is completed, ground truth will be used to refine the processing algorithms and sequence. The intent of this intial set of graphics is to provide a start-up processing capability which can be refined and improved as necesary.

DESCRIPTION OF PROTOTYPE AREA AND DATA SET

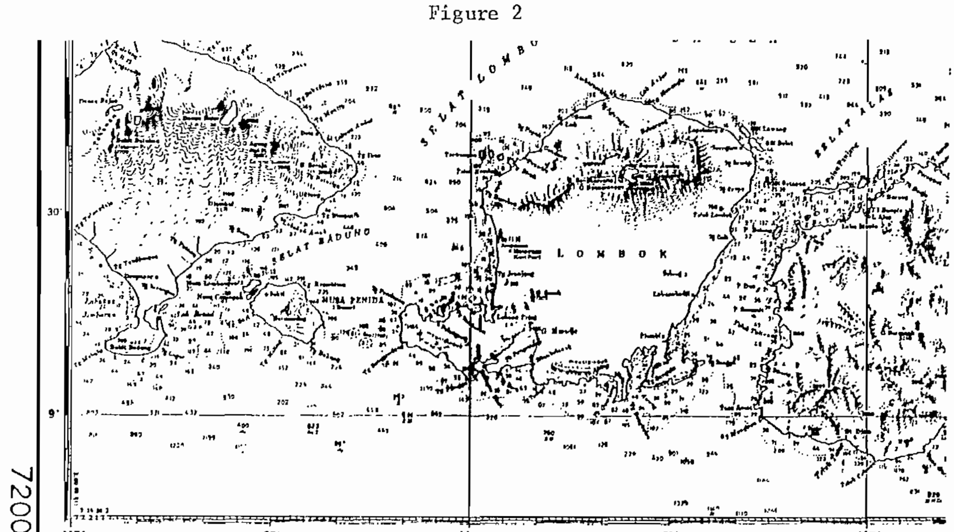
ERIM and Earthsat processed the identical areas labeled Sites A/B and Site C, figures 1 and 2. Five Landsat scenes (2 unique scene centers) were used and collected in 1972, 1973, and 1978. The earliest scenes had considerable system noise. Landsat imagery tapes (CCT's) and



Indonesia, Southern Part of Makassar Straits, Site A/B
Chart Scale - 1:750,000
Figure 1



Indonesia, Southern Part of Makassar Straits, Site C
Chart Scale - 1:750,000
Figure 2



Indonesia, Southern Part of Makassar Straits
Chart Scale - 1:750,000
Figure 3

film were provided for each scene. DMA Chart 72007 (at a scale of 1:750.000), and a DMA control manuscript (at a scale of 1:300,000), were the source documents used.

The area processed by DMA on the DIPS (figure 3), was a few degrees below sites A/B and C in the straits of Lombok. This area was mostly deep water with shallowing areas only near the major landforms of Bali and Lombok. DMA Charts 72222 (scale 1:200,000) and 72035 (scale 1:497,000) were used as the base documents. Only one Landsat image tape (dated 21 June 1973) was used although Landsat analog images were also obtained to provide some multitemporal analysis.

PROCESSING AND GRAPHICS PRODUCED ON THE DIPS

In 1978 DMA began developing a digital image processing system which included software to extract hydrographic information from remote sensing platforms such as landsat. The experience gained and the processing techniques developed in the analysis of Landsat imagery of coastal areas will serve as the foundation for the digital production support to the nautical chart compilation process.

The essential hardware components of the DIPS include the following:

COMTAL Image processing station (Vision 1)

- Dual screen 512 by 512 displays
- 3 planes each of 512 by 512 by 8 bit refresh memory (6.3 Megabits total)
- Trackball cursor, keyboard
- 4 overlay planes
- Firmware and image processor

- Plotters
  - Versatec
  - Applicon, Ink jet

-5 Tape drives (800/1600 BPI, 125 IPS)

Disk drives

- 2 DEC RA60
- 1 DEC RA81
- 1 DEC RP04

- Terminals
  - 2 DEC VT100
  - 1 Tektronix 4014
  - 1 LA36 Decwriter

- PDP 11/45 Minicomputer
  - 128K main core
  - floating point processor

The software components include:

- RSX 11M, Version 4.0 operating system
- Menu driven application software for controlling image processing operations
- Water depth algorithms

Of the many presentations developed on the DIPS, the most useful sets of graphics were those derived from pseudo color processing and from infrared imagery. Reference 2 provides a full description of the processing performed and scaled down versions of all the graphics produced. Pre-processing steps included:

a. Destriping (Constrained moving window average), and

b. Contrast enhancement (look up table to define subsurface detail and land/water interface)

Both presentations were geometrically corrected to a transverse mercator projection (UTM grid) 1:80,000 scale. Sixteen subscenes (512 by 512 pixel) of the Landsat scene were separately processed and plotted. The plots were photographically scaled to 1:200,000.

The graphics derived from infrared imagery were produced using bands 4, 5, and 7 which produce a color scheme of vegetation -red, culture - grey, water - blue. The pseudo color graphics were produced as a combination of bands 4 and 7 only. Band 4 was additionally enhanced by a technique known as "density slicing" in which pixel grey level ranges were classified according to the hydrographic, environmental, or image "noise" information they represented. These classes were color coded and combined with a land mask overlay developed from band 7.

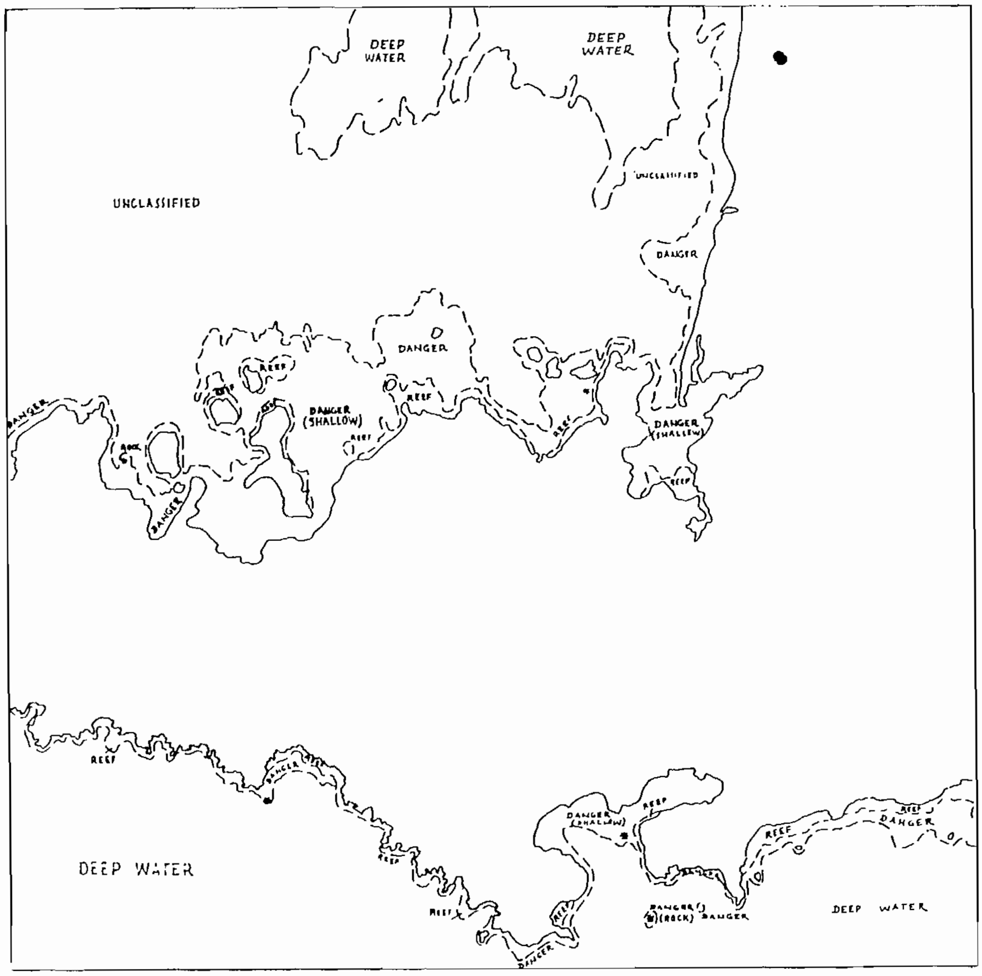
The pseudo color and infrared derived graphics were used to develop an interpreted graphic (figure 4). On this graphic, "deep water" is defined as areas where the depth is approximately 18 meters or greater. Subsurface hydrographic information depicted on this graphic is at depths less than 18 meters. This graphic will be a standard final product to be used by cartographers as a source in the chart compilation process. In Landsat scenes used to derive these graphics, environmental noise masked large areas so that no useful hydrographic information could be extracted. These areas are classified as "uninterpreted". This noise is in the form of clouds and surface turbidity. Also, system noise, mainly from the striping (or "banding") problem, was rather severe on this scene. The amount of hydrographic information extracted from this processing was reduced by a general lack of significant shallow water, reefs, shoaling areas and scene noise.

Over the next 2 years, additional hardware and software will be added to the DIPS. There remains several software processing limitations which must be addressed to make the most effective use of the DIPS. Reference 4 contains a detailed description of these limitations. It is the intention of DMA to eventually perform all image processing on the DIPS, rather than contracting out some of this work as in the Makassar project.

CONTRACT WITH ERIM

Since 1975 ERIM has been developing, under contract to DMA, techniques and algorithms for deriving shallow water depths from multispectral imagery. These algorithms have been transferred to DMA and installed on the DIPS.

The calculation of water depth is based on the exponential attenuation of light with increasing water depth. This attenuation factor is dependent on wavelength (Landsat's MSS 4 having the deepest penetration) and on numerous environmental conditions (water quality, bottom reflectance, etc.). Two adjacent bottom areas at the same depth but with distinctly different bottom types (grass versus sand) have different reflectances.



Overlay to Psuedo-Color Graphics

Figure 4

This results in different pixel grey shade values for these areas and subsequent difference in the depth calculations. In shallow water areas where both MSS 4 and 5 penetrate to the bottom, ratios of MSS 4 and 5 can be used to minimize the effects of changing bottom types. In deeper waters (greater than 5-7 meters), MSS 5 attenuates completely so that only MSS 4 is receiving any return signal. In this case, since the water depth equations makes the assumption that bottom types are uniform throughout, MSS 4 must be "modified" to account for these changing bottom reflectances. Areas of four different but uniform bottom types were estimated by DMA and used to compute an offset in the calculation of depth. In tidal areas where both bands 5 and 6 penetrated to the bottom, ratios of MSS 5 and 6 were also formed. Since all 4 Landsat bands contain noise, threshold values were determined for each band below which the signal return was judged to have attenuated.

The basic equations used in the depth calculations were as follows:

Single band (MSS 4) Method

$$V = Vs + (Vo)\, e^{-2KZ}$$

Ratio (MSS 4/MSS 5) Method

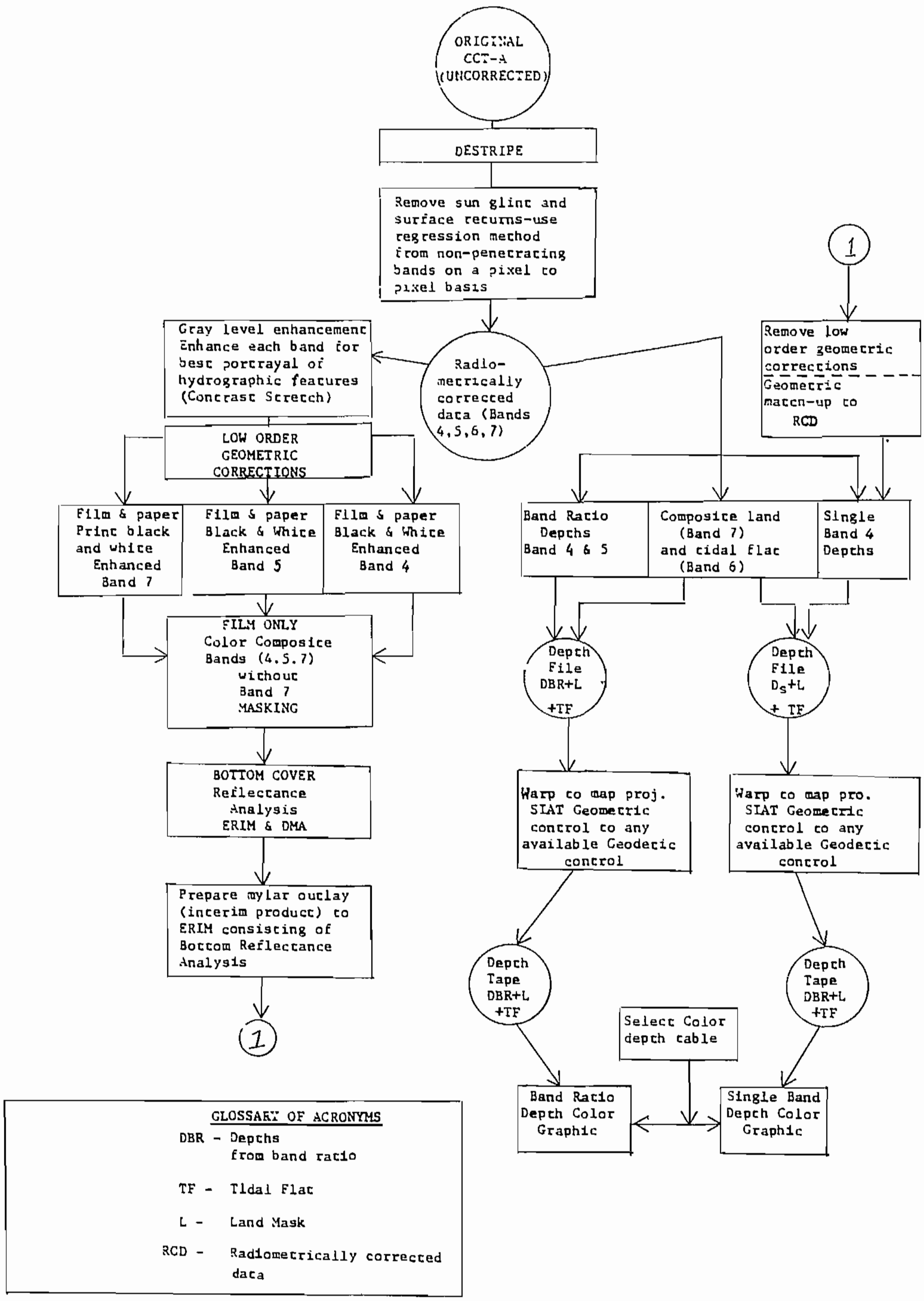
$$\frac{V(4) - Vs(4)}{V(5) - Vs(5)} = \frac{Vo(4)}{Vo(5)}\, e^{-2(K(5)-K(4))Z}$$

where V = obs. signal (in band 4 or 5)
K = water attenuation coefficent (for band 4 or 5)
Z = depth
Vs = deep water threshold signal

Vo is coefficient dependent on the solar irradiance at the surface, the bottom reflectance, the atmospheric transmission, and the sensor.

The processing sequence and the graphics to be produced by ERIM are described in figure 5. The graphics for each of two test sites included water depth prints and transparencies from 2 processes and displayed in three formats.

Each graphic is a composite of the single band MSS 4 and the two ratio methods (MSS 4/MSS 5 and MSS 5/MSS 6). When both bands MSS 4 and MSS 5 penetrated to the bottom, depths were computed only from the ratio of MSS 4/MSS 5. In the very



Processing Flow Diagram For ERIM Contract

Figure 5

shallow water areas (e.g., uncovers) where MSS 6 penetrated also, only the ratio of bands MSS 5/MSS 6 was used. In the deeper waters where only band 4 receives reflected energy from the bottom, graphics were developed for comparison using both MSS 4 modified and unmodified for changing bottom reflectance.

Each graphic is color coded for a depth range of 0.6 meter using a color "look up" table described in table 1. Scales of 1:167,000 and 1:300,000 were used for final output.

MSS 4/MSS 5 Ratio

Land	000
0.0 - 1.0	460
1.0 - 1.6	477
1.6 - 2.2	377
2.2 - 2.8	277
2.8 - 3.4	077
3.4 - 4.0	044
4.0 - 4.6	033
4.6 - 5.2	073

MSS 5/MSS 6 Ratio

Land	000
0.0 - 0.4	460
0.4 - 0.6	477
0.6 - 0.8	377

MSS 4 Alone

0.0 - 1.6	777
1.6 - 2.2	666
2.2 - 2.8	555
2.8 - 3.4	444
3.4 - 4.0	333
4.0 - 4.6	222
4.6 - 5.2	111
5.2 - 5.8	744
5.8 - 6.4	733
6.4 - 7.0	722
7.0 - 7.6	711
7.6 - 8.2	700
8.2 - 8.8	474
8.8 - 9.4	272
9.4 - 10.0	070
10.0 - 10.6	040
10.6 - 11.2	030
11.2 - 11.8	747
11.8 - 12.4	727
12.4 - 13.0	707
13.0 - 13.6	404
13.6 - 14.2	303
14.2 - 15.4	447
15.4 - 16.6	337
16.6 - 17.8	227
17.8 - 19.0	007
Deep Water	003

MSS 4 Modified

0.0 - 1.0	073
1.0 - 1.6	777
1.6 - 2.2	666
2.2 - 2.8	555
2.8 - 3.4	444
3.4 - 4.0	333
4.0 - 4.6	222
4.6 - 5.2	111
5.2 - 5.8	744
5.8 - 6.4	733
6.4 - 7.0	722
7.0 - 7.6	711
7.6 - 8.2	700
8.2 - 8.8	474
8.8 - 9.4	272
9.4 - 10.0	070
10.0 - 10.6	040
10.6 - 11.2	030
11.2 - 11.8	747
11.8 - 12.4	727
12.4 - 13.0	707
13.0 - 13.6	404
13.6 - 14.2	303
14.2 - 15.4	447
15.4 - 16.6	337
16.6 - 17.8	227
17.8 - 19.0	007
19.0 - 19.6	005
Deep Water	003

Color Depth Table

Table 1

Some details of the processing steps include:

a. Destriping

Using histogram normalization

b. Geometric Correction

The data was resampled to a 40 M by 40 M grid using a nearest neighbor technique. Resampling was done to a transverse mercator projection on a UTM grid. Control points were used to interactively adjust the Landsat ephemeris (roll, pitch, yaw, etc.).

c. Removal of Varying Surface And Haze Effects

The variation in band 7 above its threshold signal in deep water was used to determine sun glint, surface turbulence, etc., in bands 4, 5, and 6.

These graphics provided estimates of depth zones which were generalized and collapsed into fewer depth zones at DMA. This will be a standard product at DMA to be used in presurvey planning, survey operations, and as a source manuscript in the nautical chart compilation process.

CONTRACT WITH EARTH SATELLITE CORPORATION

The third approach was to enhance the imagery to maximize the extraction of hydrographic information from Landsat imagery. This was specified in a contract let to Earth Satellite Corporation in Bethesda, Maryland. The objective of this contract was to obtain a color enhanced mosaic of three Landsat scenes in the Makassar Straits. The graphics produced were at a scale of 1:300,000 on a transverse mercator projection and emphasized portrayal of the submerged features in the imagery.

The Earth Satellite Corporation performed all enhancements in a digital mode on their Grinnell image processing system, which contains the following components:

H/W - GMR 270 image processing subsystem
- 4 image channels
- 512 by 512 pixel refresh memory/channel
- 4 graphic overlay planes
- cursor controls (joysticks)
- Prime 750 minicomputer

S/W - GEOPIC
- menu driven interactive system
- Batch software

The description and sequence of processing steps performed were as follows:

a. Destriping

Performed radiometric recalibration to remove striping effects from the Landsat scene. This was done by a technique known as cumulative histogram matching in which a point by point connection is applied to each pixel value for each of the 6 Landsat detectors per spectral band.

b. Decorrelation

Band 4' = 0.9 * Band 4 - 0.1 * Band 5
Band 5' = 0.9 * Band 5 - 0.1 * Band 4

c. Geometric Correction

Correction for Landsat systematic errors
Cubic convolution sampling to UTM Grid

d. Contrast Stretch

e. Color Composite

Water area - decorrelated bands 4 and 5
Land area - band 7 and decorrelated bands 4 and 5

Three Landsat scenes were processed digitally in this sequence. Output of each scene was an Optronics plotted film image. These films were photographically mosaicked and photographed with a copy camera.

The final output product was a graphic which significantly improved the definition of shoaling areas in the scene. The color contrast between shallow water and deep water (completely attenuated light) areas was greatly enhanced permitting descrimination of shoals from environmental phenomena. This processing technique will become a standard enhancement for the DMA production system.

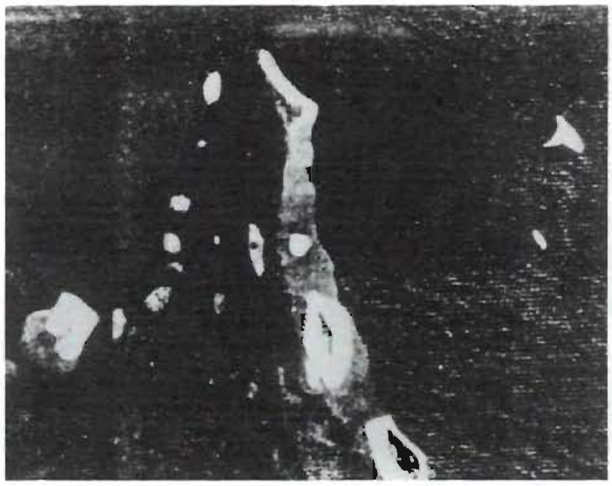
COMBINED GRAPHICS OBTAINED FROM THE THREE APPROACHES

All graphics produced by DMA's image processing system (DIPS) and by work performed under contract with ERIM and ESC were combined and generalized into 4 types of presentations:

- Enhanced shoals
- Interpreted overlays
- Residual overlays
- Color coded water depth

These presentation formats were determined to be most useful to DMA and NAVOCEANO in support of presurvey planning, survey operations, and they will be used as source documents in the chart compilation process. These graphics will be produced at the scale and projection of the base manuscript.

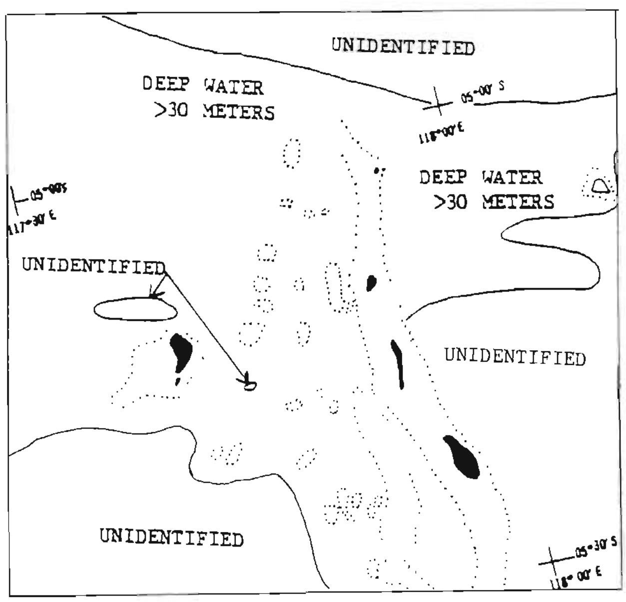
A. Enhanced Shoals: (figure 6) An enhanced Landsat graphic similar to that produced by the Earth Satellite Corporation that will depict shoals, reefs, and other submerged hazards. This graphic will supplement the "Interpreted Overlay" and the "Residual Overlay".



Makassar Strait
Original Landsat 1 Scene, July 1972
Composite of Bands 4, 5, 7

Figure 6

B. Interpreted Overlays: (figure 7) Overlays containing interpreted areas - shoals, reefs, hazards, deep water, etc. - derived from enhanced Landsat imagery. These overlays will also identify the limits of penetration (areas where depths are determined to be shallower than a determined value) as well as uninterpreted area due to cloud cover, haze, water turbidity, etc. The total area of the overlay will be labeled with descriptive identifiers.



Interpreted Graphic
Derived From Enhanced Landsat Image

Figure 7

C. <u>Residual Overlay:</u> (figure 8) This overlay will also be registered to the nautical chart. It will highlight only the differences between hydrographic information extracted from enhanced Landsat imagery and the existing nautical chart. As such, it will identify uncharted shoals, improperly charted soundings, and existence of hazards not identified on the chart.

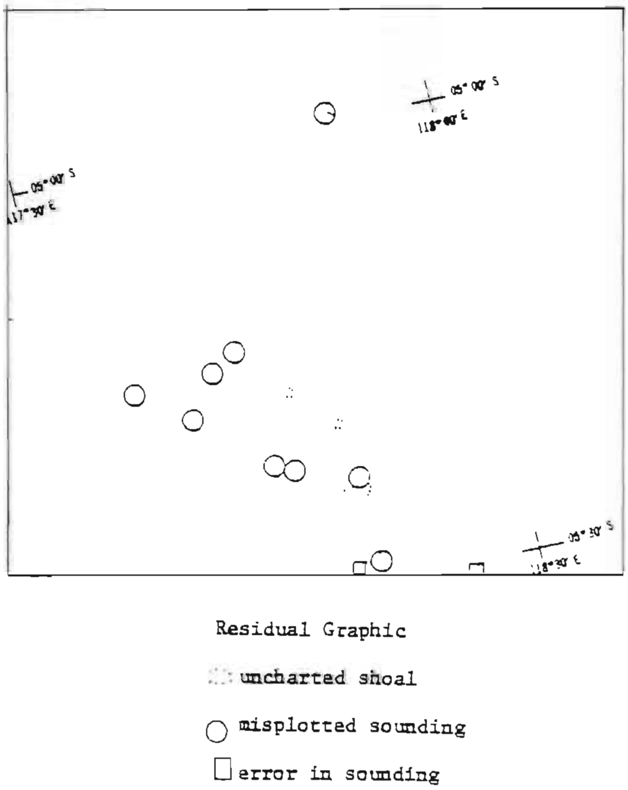
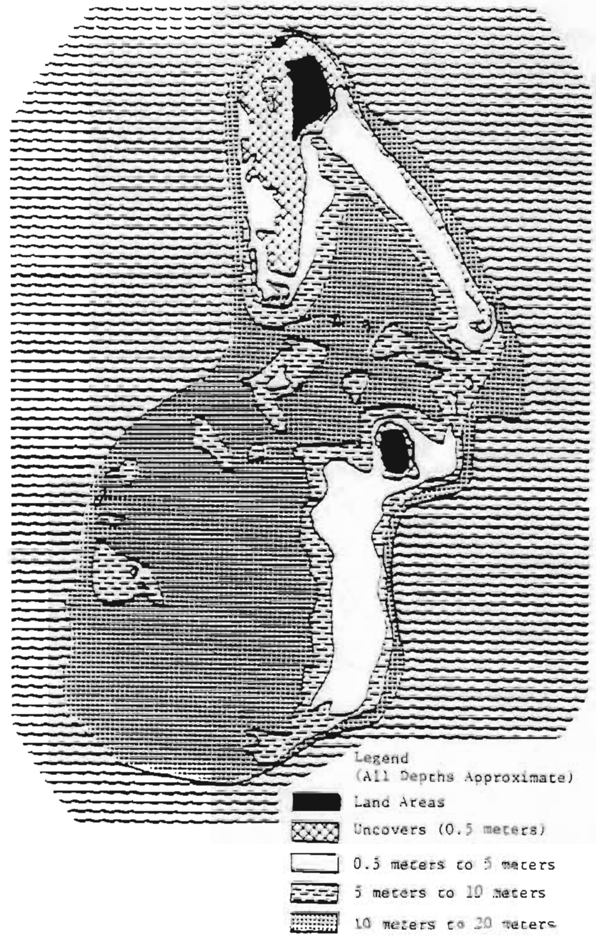


Figure 8

D. <u>Color Coded Water Depth:</u>(figure 9) These graphics will be developed at scales from 1:50,000 to 1:200,000. At these scales Landsat derived depth manuscripts will be used mainly when no other reliable data exists. This data will be depicted on the chart as position approximate (P.A.). The graphics will consist of zones of relative depths computed from an algorithm developed for DMA by ERIM. Constrasting colors will be assigned to each zone. A typical graphic will contain the following depth zones:

Land
Low tide (uncovers) to 5 meters
5 - 10 meters
10 - 20 meters
deep water, greater than 20 meters

This graphic will be developed only with digital processing and only when good quality landsat CCT's are available. A gridded overlay will be registered, along with this graphic, to the appropriate chart.



Relative Water Depth Graphic

Figure 9

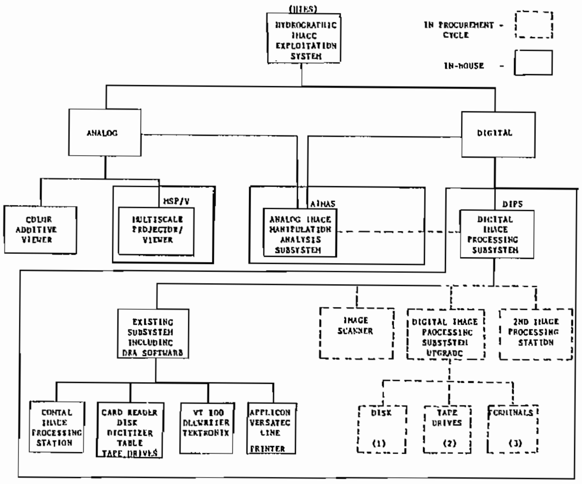
<u>DEVELOPMENT OF A PRODUCTION SYSTEM</u>

Production of graphics derived from Landsat imagery will be done on the Hydrographic Image Exploitation System (HIES), under development at DMA (figure 10). The analog subsystem of the HIES contains the following:

a. Color Additive Viewer (CAV)

This is used to superimpose 3 spectral bands through red, blue, and green color filters onto a common screen. Adjustments to color assignments and intensity can be made to enhance selected details in the combined image. Features of this system include:

- 5 channels
  70 mm film format for each channel
- individual potentiometers for each channel light
- X-Y and rotational controls
- 3X lens on each channel
- 4 filter options (red, blue, green, clear)



Hydrographic Image Exploitation System

Block Diagram

Figure 10

b. Multiscale Projection/Viewer (MSP/V)

This rear projection system provides a means for rapid comparison between film imagery and an existing chart or manuscript of the same area. Features of this system include:

- film formats supported (35 mm & 70 mm both roll & chip, 241 mm chip)
- backlighted, tiltable table from 0^{o} - 35^{o}
- rotation and magnification of film to match scale projection of chart mounted on table.
- enlargement from 2X to 82X
- metric accuracy to plus or minus 1 mm at chart scale

The analog/digital subsystem of the HIES is the Analog Image Manipulation and Analysis System (AIMAS) which is a LogE/ISI Views 200 System. Imagery can be scanned, digitized, enhanced, and output to film. This subsystem provides a means for rapid digital enhancement of analog Landsat imagery. Features include:

- vidicon Camera
- digitizing subsystem
- CRT display with refresh memory
- isometric projection subsystem
- Matrix camera subsystem

The digital subsystem of the HIES has already been described in section III.

Four presentations (section VI) developed from Landsat imagery will be end products of a production effort at DMA. However, as this program evolves, these graphics will expand and possibly change in format and content. As much processing as possible will be done at DMA on the HIES. However, some processing may be done under contractual arrangements until the HIES is fully developed. Routinely, these graphics will be developed from Landsat imagery using analog processes. However, where fine detail is needed and where Landsat computer compatible tapes (CCT's) are available, these graphics will be developed from digital processing which is more rigorous and accurate. In either case, the largest scale routinely supportable is 1:100,000. A summary of the three image processing modes to be used at DMA and an estimate of relative processing times are given in figure 11.

TABLE OF ESTIMATED RELATIVE PROCESSING PARAMETERS
IN THREE MODES

	Analog Mode				Analog/Digital Mode				Digital Mode			
	Deliverables				Deliverables				Deliverables			
	1	2	3	4	1	2	3	4	1	2	3	4
Preprocessing	Acquire imagery, analysis, quality, shallow water extent, film lab support.				Acquire imagery, analysis, quality, shallow water extent, film lab support.				Acquire CCT's, store on disk, determine data "clean up" needed.			
Process	2 hours				2 hours				16 hours			
Tube	1-10 days				1-10 days				2 weeks - 4 months			
Main Processing	CAV, MSP/V				CAV, MSP/V, AIMAS, Contract				AIMAS, DIPS, Contract			
Process	20 hrs	8 hrs	N/A	N/A	35 hrs	12 hrs	8 hrs	N/A	80 hrs*	16 hrs	50 hrs	50 hrs
Tube	4 days	2 days	N/A	N/A	7 days	3 days	2 days	N/A	4 wks	3 days	2 wks	2 wks
Quality	1	1	N/A	N/A	2	2	2	N/A	3	3	3	3

Processing based on
1 Landsat scene

Deliverables
1-Interpreted Overlay
2-Residual Overlay
3-Imagery (Earth Sat type)
4-Color Coded Water Depth

Quality (geometry, registration, level of detail)
3-Best
2-Good
1-Acceptable
*-Applicon plotter 1wk/scene
512 x 512 - 40/scene - 10 min plot, 40 min create tape

CAV - Color Additive Viewer
MSP/V - Multiscale Projector/Viewer
AIMAS - Automated Image Manipulation/Analysis System
DIPS - Digital Image Processing System

Figure 11

CONCLUSION

The major thrust of this project was to demonstrate Landsat imagery enhancement techniques available in a digital mode to extract hydrographic information in support of nautical charting and surveying operations. The combined set of graphics and the techniques used to create them should provide a firm framework for a standard set of processing parameters, enhancement techniques, and display formats to be developed for the production environment at DMA.

The thematic mapper (TM) in Landsat 4 should be significantly more useful for hydrographic applications. The spectral range and wavelength of the TM bands, which are better suited for shallow water feature detection than MSS, combined with the improved spatial resolution of Landsat 4 offer great promise to the DMA charting program.

The application of remote sensors, such as Landsat, airborne active/passive scanners and Synthetic Aperture Radar (SAR), to hydrographic data collection represents a new and promising generation of technology that can and must be exploited to improve navigational safety for ocean travelers.

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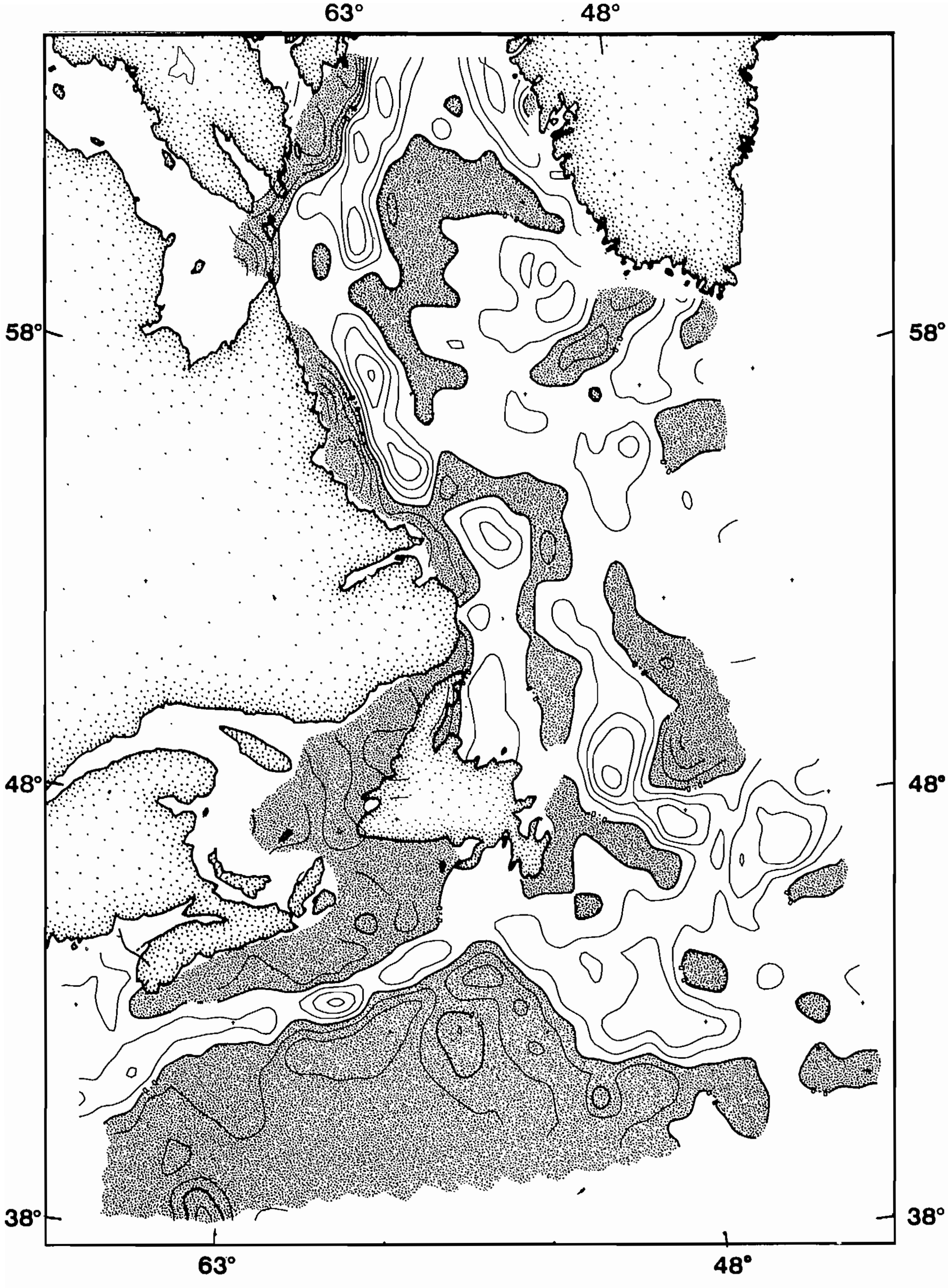

FIGURE 2. Compilation of the free-air gravity anomaly off the east coast of Canada. Constructed from sea-surface data collected during multiparameter survey cruises 1964-1982. Contour interval: 20 mgal. Negative areas are stippled.

instruments. Mobilization of these ships for survey use therefore required considerable planning and innovation, particularly in the design and construction of portable laboratory modules for the conversion of cargo holds into equipment and work spaces.

MANPOWER

Hydrographic and geophysical personnel collaborate extensively in the mobilization and execution of multiparameter surveys. Program planning is carried out jointly: hydrographic and geophysical priorities are considered, and the availability of resources to commit to specific projects is reviewed. In the field, geophysicists are outnumbered by hydrographers, who assume responsibility for the day to day running of the survey operation. This includes ship conning, the operation of navigation systems and most survey instrumentation, and routine data processing. Geophysicists are usually represented by a small staff charged with specialized tasks in maintenance, training, or the occasional operation of complex systems such as seismic reflection equipment.

NAVIGATION

Precise positioning is a prerequisite for the accurate definition of sea floor topography and marine potential fields. Point observations of water depth, gravity, and magnetics must therefore be accompanied by reliable determinations of the ship's coordinates on the surface of the earth. An additional requirement peculiar to the measurement of gravity at sea is to know the ship's course to within one half of a degree, and the speed to within one tenth of a knot. These parameters are required to calculate corrections for the Eotvos effect, which is an apparent change in gravity that is sensed by a measuring device installed in a moving vessel.

In the early years of the multiparameter survey program, ship positioning was accomplished largely through use of Low-Ambiguity Decca (Lambda) operating in the range-range mode. With a well calibrated chain, Lambda yielded positional accuracies in the order of 50-150 m, and ranges of up to 300 nautical miles were possible under good conditions. The Gulf of St. Lawrence, the Grand Banks of Newfoundland, and the South Labrador Sea were mapped with Lambda.

In 1974, the primary positioning method was switched from Lambda to a combination of Loran-C and the Navy Navigation Satellite System (NNSS). Loran-C is used in the rho-rho mode, which is a triangulation technique based on measured transmission times from two or more shore stations to the ship. Synchronization between the shore transmitters and the

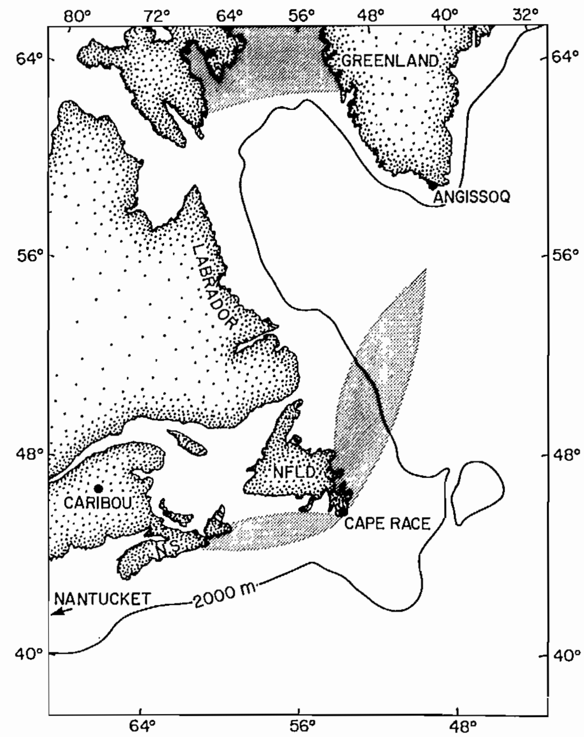

FIGURE 3. Loran-C coverage diagram. The shaded areas indicate where Loran-C signals are too weak for mapping operations, or where estimated positioning errors in the rho-rho mode exceed 200 m at the 68% confidence level. These constraints apply to the use of BIONAV in this region. Adapted from Grant, 1973.

seagoing receiver is maintained by a precise atomic clock aboard ship. This clock tends to drift, but drift rates can be derived from an analysis of NNSS fixes.

The entire procedure is automated in BIONAV, an integrated system that combines input from a variety of navigation sensors, including log and gyro, to produce the best possible fix (Wells and Grant, 1981). As a computer controlled system, BIONAV stores fixes in digital form and can display ship's positions in a variety of ways, depending on user needs. On multiparameter surveys, fixes are written to a video display once a minute; these are plotted manually every ten minutes by hydrographic watchkeepers who try to keep the ship on a pre-defined track, and who must exercise considerable care in calling for course and speed adjustments that have minimal effect on underway gravity measurements.

With the combined input of NNSS and the North Atlantic Loran-C chain, it is estimated that BIONAV can yield ship's positions to an accuracy of plus or minus 200 metres anywhere in most parts of the offshore area extending from the Bay of Fundy to Hudson Strait (Figure 3). From the northern part of the Labrador Sea

MULTIPARAMETER SURVEYS IN THE OFFSHORE: BROADENING THE DIMENSIONS OF HYDROGRAPHY.

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ABSTRACT

For nearly two decades, the Canadian Hydrographic Service has collaborated with elements of the Department of Energy, Mines and Resources in the conduct of multiparameter surveys in offshore waters. These surveys have expanded the hydrographer's traditional role of measuring water depth to include the measurement of marine gravity, magnetics and sediment thickness Combined operations have significantly enhanced our capacity to gather information with only a modest increase in cost. For instance, a typical ice-reinforced vessel equipped with echo sounder, navigation equipment, and computer facilities can cost upwards of $25,000 daily; the capacity for measuring gravity and magnetics can be added for as little as $2,000 per day.

Since the inception of the program, a total of 31 survey cruises have gathered hydrographic and geophysical data on nearly a half millon line kilometres. These data are published in a variety of forms, and contribute to studies that describe the history and characteristics of the submerged part of the Canadian landmass and of the adjacent sea floor.

Hydrographers and geophysicists will be collaborating for some time to come. Future plans for joint surveys call for the systematic densification of measurements south of Nova Scotia and Newfoundland; Baffin Bay will be mapped when adequate and affordable navigation systems are available. In addition, a major impact can be expected from the Draft Convention of the Law of the Sea, which will impose a need for extensive surveys aimed at defining offshore boundaries.

RÉSUMÉ

Depuis près de 20 ans, le Service hydrographique du Canada collabore avec des services du ministère de l'Energie, des Mines et des Ressources à la réalisation de levés multiparamétriques au large des côtes. Dans le cadre de ces levés, le rôle traditionnel de l'hydrographe a été élargi et il mesure non seulement la profondeur de l'eau, mais encore la pesanteur, le champ magnétique et l'épaisseur des sédiments. Moyennant une faible hausse des coûts, le Service est ainsi parvenu à augmenter considérablement sa capacité de collecte de données grâce à ce opérations combinées. Par exemple, un navire dont la coque a été renforcée pour navigeur dans les glaces et qui est équipé d'un écho-sondeur d'appareils de navigation et de matériel informatique peut coûter jusqu'à $25,000 par jour; pour un supplément d'à peine $2,000 par jour, on peut y ajouter un gravimètre et un magnétomètre.

Depuis le lancement du programme, un total de 31 expéditions ont permis de recueillir des données hydrographiques et géophysiques sur près d'un demi-million de kilomètres. Ces données sont publiées sous diverses formes et elles servent aux études qui décrivent l'histoire et les caractéristiques de la partie immergée du continent canadien et des fonds océaniques adjacents.

Les hydrographes et le géophysiciens vot poursuivre leur collaboration pendant quelque temps encore. Ils ont prévu d'effectuer conjointement des levés en vue d'accroître méthodiquement la densité des mesures au Sud de la Nouvelle-Ecosse et de Terre-Neuve; par ailleurs, la baie Baffin sera cartographiée lorsque des systèmes de navigation appropriés et abordables seront disponibles. En outre, on peut escompter que la préparation de la convention du droit de la mer aura de grandes répercussions pour ces activités, car il faudra réaliser des levés détaillés pour déterminer les frontières au large des côtes.

WHY COMBINED OPERATIONS?

At least four costly components are required in the mobilization of offshore hydrographic surveys:ships, people, navigation systems, and data gathering instrumentation. It is often feasible to increase the effectiveness of these expensive resources by applying them to the collection of auxiliary data, particularly when compatible measurement techniques are involved. Clearly, combined data gathering operations can be much cheaper than separate operations; of perhaps greater importance, they often provide an opportunity to do work that might otherwise never be contemplated.

A good illustration of the benefits of combined operations is the multiparameter survey program off the Canadian east coast. The objective of this project, begun in 1964 at the Bedford Institute of Oceanography (BIO), is the hydrographic and geophysical mapping of the continental shelves of Canada, and the adjacent deep-sea basins.

The project started out under purely hydrographic auspices, i.e. to provide better charts of the sea floor in regions of interest to Canada. However, it didn't take long for geophysicists at BIO to recognize that this undertaking represented an ideal opportunity to embark on a long-range program of measuring gravity and magnetics in the same regions.

Beginning with a small trial survey in the Bay of Fundy, hydrographers and geophysicists have been partners in a collaboration that has yielded some impressive results. To date, most of the region extending from the Gulf of Maine in the south to Davis Strait in the north has been surveyed at line spacings that range from twenty nautical miles down to one nautical mile (Figure 1). In all, some thirty-one cruises have collected bathymetric, gravimetric, and magnetic data over close to a half million line kilometres. This has resulted in the creation of an enormous data base that has many applications in studies of the sea floor and the oceanic crust (Figure 2).

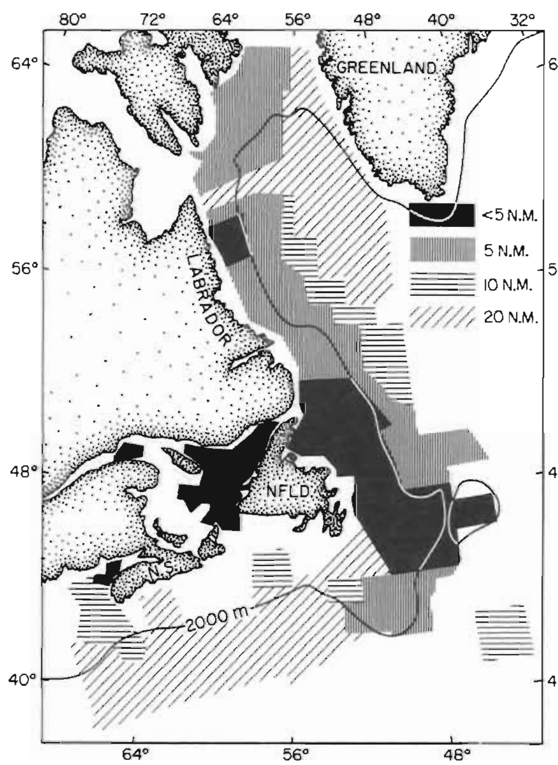

FIGURE 1. Extent and density of multiparameter survey coverage from 1964 to 1982. Data consist of bathymetry, magnetics, and gravity for the most part, with shallow seismic reflection in some areas.

Significantly, the geophysical measurements have been carried out at a fraction of the cost of doing them independently: the primary requirements were to equip hydrographic survey vessels with geophysical instrumentation, to train hydrographic personnel in the routine operation of this equipment, and to provide specialized staff to handle repair and maintenance.

A look at today's prices illustrates the economy of this approach. At BIO, it costs about twenty-five thousand dollars a day to operate a hydrographic survey vessel that is capable of extended cruises in remote and often ice-infested offshore areas. This pays for a ship that is staffed and equipped for accurate navigation and depth sounding. (The cost only covers the use of readily-available positioning systems, i.e. NNSS and Loran-C, and not of systems that have to be especially deployed for particular surveys.) The capacity to measure gravity and magnetics can be added simply, by providing extra equipment and support manpower costing in the order of two thousand dollars a day. Thus the vessel's capability as a survey platform has been enhanced by a factor of three, with an increase in cost of less than ten percent.

In terms of manpower utilization, the multiparameter survey program has been particularly effective because it has emphasized teamwork between people with complementary skills. The essence of hydrography is field work: the methodical, disciplined surveys that collect the data which go into the production of reliable charts. The thrust of geophysics, on the other hand, is interpretation: the reduction and analysis of data in order to extract information that confirms or refutes a theory. Working in concert, hydrographers and geophysicists have therefore brought specialized aptitudes to bear in their respective areas of expertise; the outcome has been a balanced effort that has made efficient use of human resources. Thus it has not been necessary to commit scarce manpower resources for the purposes of training and developing a cadre of specialist geophysical surveyors. Nor has it been necessary to divert hydrographic field expertise into the theoretical realms of geophysics.

SHIPS

A mix of Government-owned and chartered vessels have been deployed as survey platforms. Of the BIO fleet, the two ships that have been most used are CSS BAFFIN and CSS HUDSON. Both are icebreakers with displacements approaching 5000 tonnes. They can carry a scientific and survey complement of up to 25 (though in practice the usual survey team rarely approaches that size). A smaller BIO ship, the CSS DAWSON, has also been used on occasion; it displaces 2700 tonnes, and has room for a complement of 13.

During 1972-78, two smaller charter vessels were engaged: M/V MINNA and M/V MARTIN KARLSEN, owned by Karlsen Shipping of Halifax. Both were in the 2500-3000 tonne displacement range, with room for 12 to 15 survey personnel. Designed and constructed as ice-reinforced cargo vessels, these ships didn't feature ready-made and suitable space for drawing offices and laboratories. Nor did they provide much in the way of specialized facilities such as stable electrical power, antenna mounts, echo sounding transducers, and arrangements for towing through Davis Strait and into Baffin Bay, positioning accuracy is reduced significantly by factors that affect Loran-C performance: weak signals, skywave interference, and excessive landpath.

Satisfactory Loran-C coverage can be extended by the use of auxiliary transmitter stations installed temporarily at selected locations along the coast. In 1980 and 1981, Davis Strait was mapped with the aid of Accufix transmitters located at Saglek Bay and Brevoort Island. This approach yielded good results, but the mobilization and support of these sites were difficult and expensive undertakings. Moreover, the rigours of the northern climate took their toll: in 1980, a major two-ship operation in Davis Strait had to be cut short when the transmitter tower at Saglek collapsed on account of icing.

Short of establishing a string of expensive and vulnerable transmitters along the coast of Baffin Island, it is not clear yet how to achieve accurate positioning for surveys in Baffin Bay. It was thought at one time that the U.S. "Navstar" Global Positioning System (GPS) might eventually provide a navigational capability in the region, but full deployment is not expected until later in the decade. More importantly, it appears that non-military users may be denied access to the precise GPS code that is required for the calculation of accurate fixes.

SURVEY INSTRUMENTATION

Most of this instrumentation consists of standard products that are commercially available. Water depth is normally measured with a 12 kHz hull- or ram-mounted transducer connected to a transceiver and recorder. Total magnetic field is measured with a proton precession magnetometer connected to a sensor towed some 200 metres astern of the ship. Gravity data have for the most part been collected with Graf-Askania model GSS-2 or standard LaCoste and Romberg sea gravimeters.

On some cruises, sediment thickness has been mapped with the aid of a simple seismic reflection system consisting of an airgun, a single-channel hydrophone streamer, and a mix of associated equipment that has been built or bought. Hull-mounted or towed 3.5 kHz sounding systems have been operated on a trial basis on some surveys, to evaluate their potential for systematic mapping of shallow sediments. Sidescan sonar and the Huntec Deep Tow System have also been deployed on occasion.

SHIPBOARD DATA LOGGING AND PROCESSING

The upper part of Figure 4 shows the general flow of data through the different stages of acquisition and processing in the field.

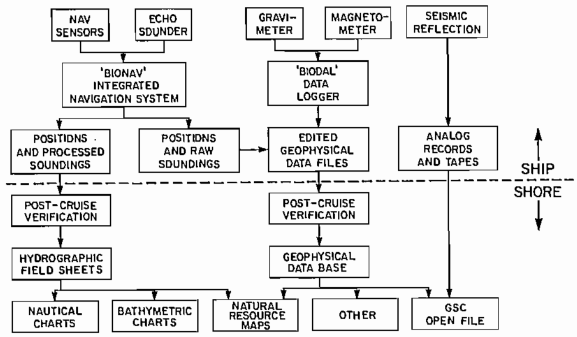

FIGURE 4. Generalized diagram showing the flow of multiparameter survey data aboard ship and ashore.

The primary logger for geophysical data is BIODAL - a hard-wired apparatus developed and constructed at BIO a few years ago. Its main purpose now is the recording of magnetometer and gravimeter output onto 9-track magnetic tape.

Bathymetric data are not now automatically logged in computer readable form, because of past difficulties in the real-time digitizing of deep soundings. Instead, the sounding display is scaled manually, and the readings are entered through the BIONAV keyboard for merging with the navigational data. Field trials are scheduled to investigate methods of further automating this process.

All basic survey data i.e. water depth, total magnetic field, and gravimeter output, are displayed and saved on strip chart records. Auxiliary seismic data are also displayed and saved on strip chart records, in addition to being recorded in analog form on magnetic tape.

Aboard ship, the bathymetric and potential field data are processed on a minicomputer. The processing serves three purposes: initial quality control, data display for verification and survey planning, and creation of digital files for archiving and further processing ashore.

Separate software packages are used to process hydrographic and geophysical data. The reasons for separate software are partly historical and partly practical: computer programs for hydrographic and geophysical processing have evolved independently and in modular fashion to perform specialized data handling tasks; they have been implemented to be equally applicable to single-purpose missions, i.e. surveys that are exclusively hydrographic or geophysical. Under these circumstances, we have not considered it particularly worthwhile to homogenize our data processing operations into one set of interlocking programs. However we are committed to the use of common software modules for all future applications development, particularly in the area of graphics display. We have also attempted to facilitate the exchange of common information such as fixes and soundings by specifying formats that make the data accessible to both sets of software.

For hydrographic purposes, bathymetric data are corrected in the field for sound velocity, transducer depth, and tide where appropriate. This is in keeping with the requirement to produce accurate charts for navigation and for the precise representation of seafloor topography.

Processing of potential field data at this stage consists of: conversion of gravimeter output to milligals, with correction for Eotvos effect; derivation of magnetic anomalies with reference to the International Geomagnetic Reference Field; and merging with raw bathymetric data. Corrections for gravimeter drift and magnetic diurnal variation are only applied during post-cruise processing, if applied at all.

The processed output for both bathymetric and potential field data consists of listings, profile plots, track plots, postings, and digital files on magnetic tape or disc.

POST-PROCESSING AND DISPOSITION OF DATA

When a survey cruise is over, data are brought ashore for final processing and merging with previously collected data. As outlined in the lower part of Figure 4, bathymetric and geophysical data are handled separately.

Hydrographic data are further verified for accuracy, and then are machine plotted to create final field sheets. These sheets are the primary input for the production of a variety of navigation and bathymetric charts. (Navigation charts are intended principally for mariners concerned with the plotting of routes and the safety of passage; bathymetric charts are intended for those interested in seafloor topography, such as fishermen, mining and oil companies, dredging contractors, pipeline and cable-laying engineers, etc.)

Geophysical data are turned over to personnel of the Atlantic Geoscience Centre (AGC) for similar verification, followed by entry to a computer-based archival/retrieval system. Data can then be extracted in a variety of forms, depending on the use to which it will be put, be it in-house scientific interpretation or public release: contour maps, profile plots, digital files, etc.

In reports on scientific investigations, the geophysical data most often appear as part of regional compilation maps (e.g. Haworth and MacIntyre, 1975; Keen and Hyndman, 1979; Srivastava, 1978).

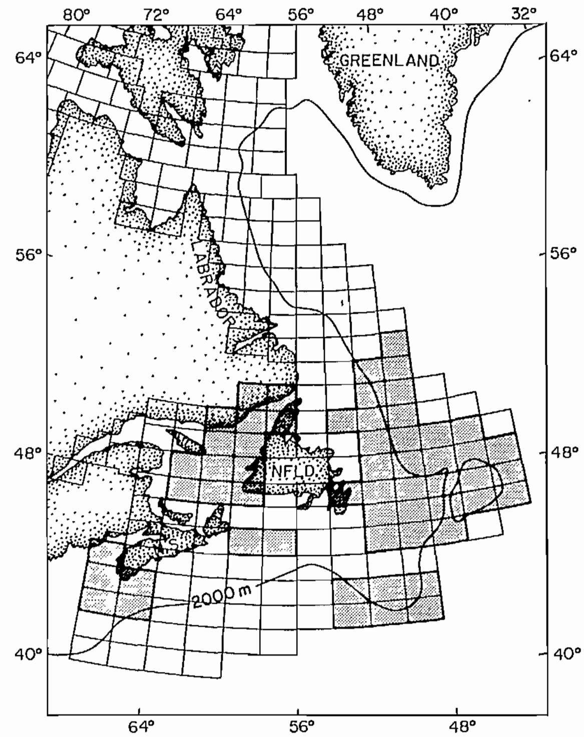

FIGURE 5. Arrangement of Natural Resource Maps off the Canadian East Coast. Shaded areas indicate where geophysical data have been published. Adapted from Canadian Hydrographic Service, 1981.

Data released directly to the public may appear in several different forms. Two formal map series - the Natural Resource Map (NRM) series and the National Earth Science Series (NESS) - portray bathymetry, gravity, and magnetics at scales of 1:250,000, 1:1,000,000, and 1:2,000,000. Bathymetric data are also represented in GEBCO sheets 5.04 and 5.08 at a scale of 1:10,000,000. Special compilations exist in a number of non-series maps produced at various scales (Canadian Hydrographic Service, 1981).

All of the above maps are published by various agencies of the Canadian Government. Preliminary contour maps that depict hydrographic or geophysical data are periodically released through the open files of the Geological Survey of Canada (e.g. Hunter, Shih, and Macnab, 1982). Depending on the purpose for which they were produced, these maps may not conform to the format and scale conventions of the formally-published maps.

Generally, geophysical data that have been made public in the form of contour maps are also released in the form of digital files on magnetic tape, so that users may apply their own processing techniques.

Figures 5 and 6 outline the areas for which geophysical data have been pub-

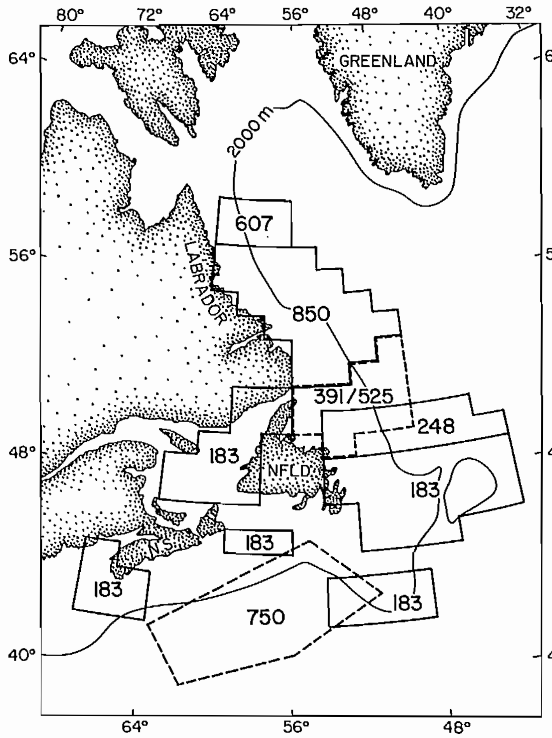

FIGURE 6. Areas covered by multiparameter survey data released through the Open File system of the Geological Survey of Canada.

lished as Natural Resource Maps or released through open file, respectively. Clearly, not all survey results have been released (compare with Figure 1). The biggest problem area is the Labrador Sea gravity data, which consist of numerous data sets collected over a long period of time on different datums. A major effort is underway to resolve the inconsistencies between different surveys through careful review and adjustment of all the data.

WHERE DO WE GO FROM HERE?

A look at Figure 1 shows that we need more detailed mapping to flesh out the regional surveys south of Newfoundland and Nova Scotia. Surveying in this area poses few logistical or environmental problems; the job will probably be finished over the next few years through a succession of cruises scheduled near the end of each year's field season.

Farther north, Baffin Bay is virtually unsurveyed to modern standards. As already mentioned, mapping in this region is not expected to get underway until a suitable - and affordable - navigation system is available.

A new slant on offshore surveying has been provided by the recently promulgated Draft Convention on the Law of the Sea. Article 76 of the Convention contains a definition of the "continental shelf" of a coastal state which, for purposes of the Convention, also encompasses the continental slope and rise. The seaward limits of this "continental shelf", and hence of the coastal state, are specified by geological and morphological parameters, e.g. thickness of sedimentary rocks and change in sea floor gradient.

The full implications of this Article have yet to unfold, and will probably require the efforts of a generation or so of maritime jurists to unravel. It is clear also that a lot of detailed mapping work will be necessary to justify territorial claims and to resolve contentious areas. We in Canada have already done some work. However, much remains to be done to attain the level of understanding that will be necessary to define our new offshore boundaries. The private sector will no doubt be called in to perform some of this work, because it will involve the use of resources (e.g. multi channel seismics, long-range side scan sonar) that are not presently available within Government circles. Even so, much of the burden of data validation and interpretation will land on the shoulders of hydrographers and geophysicists who have been involved in offshore multiparameter surveys.

Clearly, there is a lot of surveying left to do in the offshore. Hydrographers and geophysicists will no doubt continue to pool their skills and talents in the mapping of this large and important region.

ACKNOWLEDGEMENTS

A long-lasting and wide-ranging project such as the one described here must obviously draw on the contributions of many participants: the hydrographers who organize and run the surveys; the ships' captains and crews; the specialized support personnel at sea and ashore; and the cartographers who prepare quality maps for publication.

Darrell Beaver and Keh-Gong Shih provided the information used in creating Figures 1 and 2. Members of the BIO Drafting & Illustrations and Photography Sections produced the figures.

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AUTOMATION TODAY -
SCRATCHING THE TWENTY-ONE YEAR ITCH

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ABSTRACT

For twenty-one years the Canadian Hydrographic Service has used computers to collect or process hydrographic data. Early attempts to use computers in the field were not well accepted because logging methods were not dependable, sounding data contained errors, processing methods were slow and cumbersome, and equipment was large and heavy. Recent low-cost, mass-produced, small, easy-to-use computers have had an impact on automation from the space race to the automotive industry, from banking to weaving. Children use computers every day in schools, and a home computer is becoming less the exception and more the rule.

Still, for the hydrographer, the computer has often appeared to stand in the way of productivity. Experiences with early systems may have led to scepticism and a reluctance to try the next generation of hardware. Software processing techniques have been relatively stable, but after twenty-one years of trying, less than twenty per-cent of the hydrographic surveys being conducted in Canada today are automated. So why automate?

This paper attempts to analyze the rationale behind efforts to automate hydrographic data collecting and processing techniques, while taking a critical look at the existing automation scheme. Some thoughts on assimilating automated systems into present hydrographic field programs are offered.

RÉSUMÉ

Depuis déjà vingt-et-un ans, le Service hydrographique du Canada utilise l'ordinateur pour l'analyse des données hydrographiques. Les premières utilisations d'ordinateur sur le terrain ont été mal reçues parce que les méthodes d'acquisition n'étaient pas dignes de confiance, les données de profondeur contenaient des erreurs, les méthodes d'analyse des données étaient lentes et complexes, et l'équipement même était trop gros et lourd. Les quantités de petits ordinateurs récents, qui sont faciles à utiliser et qui coûtent peu, ont exercé une influence sur l'automation, de la course spatiale à l'industrie automobile, de l'industrie bancaire jusqu'au tissage. Les enfants se servent d'ordinateurs à l'école tous les jours, et l'ordinateur personnel devient de moins en moins l'exception mais plutôt chose courante.

Cependant, pour l'hydrographe, l'ordinateur semble souvent encombrer la productivité. Les vilaines expériences avec les premiers systèmes ont suscité un certain scepticisme et une répugnance à essayer les systèmes de la prochaine génération. Les techniques d'analyse des données hydrographiques ont été relativement stables, mais après vingt-et-un ans d'essais moins de vingt pour cent des levés hydrographiques sont automatisés au Canada. Pourquoi alors automatiser?

Cette communication tente d'analyser la justification des efforts déployés en vue de l'automation de la collecte et de l'analyse des données hydrographiques, tout en critiquant parfois les techniques présentes qui pourraient être améliorées. La communication traite également d'autres méthodes destinées à intégrer les systèmes automatisés dans les levés hydrographiques actuels.

INTRODUCTION

Nothing worthwhile is ever easy. From the moment someone has a vision to the moment that vision is brought to fruition, there is a long hard road to be travelled, involving many individuals and organizations, each with an idea or ideal that varies from the others to some degree. With luck and good planning the final product will incorporate all the good ideas, eliminate the bad ones, and be useful to those it was designed for in the first place.

Accepting a new idea does not come easy either. When a hydrographer knows a system works, and it has been refined over the years and developed into an art, then why rock the boat? In the year of our Hydrographic Service 3 B.C. (Before Computers), Gregorian calendar year 1959, there were still harbour authorities in some parts of North America that would not accept depths recorded on an echo sounder. Line and lead, they reasoned, were the only sure way to prove that the recorded depth was the true one. Old ways and old ideas die hard.

It is now, in the year of our Hydrographic Service, 22 A.D. (After Digital). Twenty-one years ago the Canadian Hydrographic Service first used a computer to plot depths. In those twenty-one years, there have been a lot of good men with good ideas, who worked long and hard to adapt the computer to hydrographic applications. The term automation was introduced. That scared some hydrographers because they thought it meant the computer was going to take over their jobs. What would mortal man be left with? Could he stand being slave to an electronic wizard and a row of blinking lights? It took a while before hydrographers realized that computer-assisted was a more appropriate term, and that these assistants were under his control, not the other way around.

Today, computers are part of everyday life. Sons and daughters use them at school and come home to show their parents how to program them. A computer prepares the bank statement and the charge card bill. Basic trades like weaving use computers to work out the warp and weave of intricate patterns that often took years for an artisan to design. A majority of hydrographers probably have a microchip strapped to their wrist. Nearly every piece of electronic gear that is purchased today has a microprocessor built in, from the stereo receivers and microwave ovens that sit on the shelf at home, to positioning systems, sounders and depth digitizers that are used at work. My motorcycle, about as basic a mode of motorized transport as there is, has two microchips. One monitors the head light, tail light, coolant level, battery level, gas level and oil pressure, and reports any malfunctions on a liquid crystal display. The other senses speed and steering axis rotation and duration, just so it can shut off the turn signal after completing a turn.

In a world where robotics have taken over the auto industry in Japan and space shuttle voyages are becoming an ordinary media event, why, for the average hydrographer, does the computer assistant appear to stand in the way of productivity?

THE COMPUTER

Early experiences with computers in the field began in 1962 when an automatic plotting system was used on board CSS BAFFIN. It was billed as the system to plot depth information directly onto a chart, but it had many problems and never made it to the production stage. The total system weighed 1 1/2 tons and the deck structure had to be reinforced to support it. In 1969, digital soundings were first recorded on board a survey launch and processed by computer back at base. A lot of work was done towards selecting depths from recorded data, for plotting at survey scale, so that the final product closely resembled the traditional field sheet. Problems with this system included its large size, its weight, its high power requirement and its undependable hardware characteristics. But the real drawback was that the hydrographer was never sure that, when he tried to process the recorded data, there would be any data there to process. Even so, the system was used successfully on production surveys, thanks to a few hard-working, single-minded hydrographers and electronics technicians, who's dedicated and stubborn attitude made the system work. However, it was never accepted as a viable alternative by most hydrographers.

A computer first made its way on board a Canadian survey launch in 1974, where it was used to filter depths and positions before they were recorded. It also checked to make sure the data were being recorded properly, and it provided a straight-line navigation and line-keeping capability. The equipment was still big and heavy and drew a lot of power. Cartridge tape recorders were not very dependable, but the system was used to log hydrographic data until 1981 and to process data until 1982.

In 1977 the first microprocessor was used to acquire data and provide straight-line navigation on board a survey launch. This reduced the size, weight and power requirements considerably and improved dependability significantly through solid-state technology. This system and systems like it are still being used today, even on manual surveys, for the line-keeping features alone. Hydrographers are beginning to accept the computer assistant, when it provides obvious and immediate benefits.

It was not until 1981 that a breakthrough in field recorders was made. Tape recorders have always worked fine on board the larger survey vessels where the environment is somewhat controlled, but have never been dependable on small survey launches where shock, vibration, temperature and humidity cause problems. In 1981, hydrographic data were recorded on prototype bubble memory recorders. Bubble memory is a solid-state, non-volatile, recording medium that costs more than tape, but is more dependable in two ways. The hardware is reliable because there are no moving parts, and data integrity is virtually guaranteed.

Field processors are getting physically smaller, with larger memories and larger data storage devices. They are also a lot easier to use than the early versions. Just turn them on, enter time and date, and the computer is ready to accept a command. This is a far cry from the system used in 1969. On that computer, a program had to be toggled in from front panel switches, so that a second program could be read in from paper tape. Finally, after reading a third set of instructions, control of the computer was possible through the keyboard. Often this process had to be tried two or three times before it worked properly. All this in only two racks full of equipment. Today, for a modest investment, all the power of a PDP-11, with a quarter megabyte of memory, eight interfaces and thirty-one megabytes of disc storage, is available in a video terminal and 5 1/4 inches of rack space.

THE SURVEYS

The surveys of any hydrographic organization are generally quite diversified. Large scale harbour plans, medium scale nearshore surveys and small scale offshore surveys are done in each region of the Canadian Hydrographic Service. Some factors may differ from region to region, such as depth, bottom roughness, tides, positioning needs or even ice cover, that make regional survey requirements unique. Survey vessels range from six metre open boats, to eleven metre launches, to ships thirty metres to one hundred metres in length.

For automation to be a reasonable alternative to present manual techniques of collecting and processing hydrographic data, an automated system must be useful on any survey. While automated systems may have been successful on board large survey vessels doing medium and small-scale offshore surveys, they have yet to demonstrate enough versatility to handle other regular jobs such as inshore surveys and large scale harbour surveys. Indeed, there was a time when it looked as though the survey might have been chosen to fit the automated equipment, when the reverse should always be the case. Logging and processing systems must be versatile enough to be useful on large scale surveys where one metre position accuracy and recorded fixes more often than once a second are imperative. The same system should be useful on small scale surveys where depths every second are not necessary, but positions from two positioning systems may be required.

There are different levels of automation to consider as well. Are hydrographers satisfied with producing a graphic product? Most of them are, and most cartographers prefer to use that graphic, the field sheet, to produce the chart. The graphic may contain shoreline, contours, bottom samples or even depths that are manually added to a sheet of computer-selected and computer-drawn soundings. This stage in the history of the field sheet serves a useful purpose. It introduces the hydrographer to computer logging and processing techniques, while allowing him to produce a product with which he is both familiar and secure. The challenge thirteen years ago was to use the computer to produce a document that a hydrographer could look at and say, 'Yes, the computer has produced a field sheet.' But this is not an end in itself, and it is not enough to stop there.

Only a small portion of the surveys have been automated over the last twenty-one years. In 1982 less than one-quarter of the hydrographic surveys in Canada used computer-assisted techniques.

THE RATIONALE

Some hydrographers see automation as a method of eliminating most, if not all, human participation. I can never see this taking place because there are many decisions that require the training and instinct of a hydrographer, and these decisions should not be left to a computer. There are many things a hydrographer can observe and note that a computer could never monitor, let alone record. One of the benefits of utilizing a computer for data acquisition, data filtering and line-keeping, is that it gives the hydrographer more time to look around him and devote his time to the other important aspects of the job.

This paper was originally titled 'Why Automate?', but it was changed because it could possibly be construed as having a negative connotation. Once hydrographers understand automation as the utilization of a computer assistant, then the question asked in the original title is important and the answers significant. What are the advantages of automation? First of all, just admitting that there are advantages does not mean that each attempt at automation will achieve the specified goals. Proponents cite accuracy, efficiency and quality as the basic improvements. Time and money are saved, and chart compilation is enhanced. Purported disadvantages of automated systems are that equipment may be expensive, equipment failures cost time, the final product as it stands today does not make the chart compilers task any easier and hydrographers seem to be doing just fine without automation. It would appear as if the better is the enemy of the good. Well, nobody said it was going to be easy.

The survey vessel must go out and collect data whether manual or computer-assisted techniques are used. So there does not appear to be an advantage to automation here. Or does there? The computer can help keep the vessel on-line and help reduce the need for interlines and restarting a line, it can help get the vessel to and from the survey area, it can collect and store depths and positions and it can check them to ensure they are valid. Clearly, there is an advantage to automation in improved efficiency. Accuracy is also improved. If each depth has a corresponding position, and data are recorded automatically, estimates of straight lines and constant speeds between fixes are no longer necessary.

What about cost? The equipment required to log digital depth and position data may cost upwards of 25,000 dollars per installation. Compared with the cost of depth sounders, positioning systems and survey vessels this is a small amount, but significant just the same. Processing systems may cost 50,000 dollars or more, but only one system is required for each survey. The potential saving in man-hours of scaling, reducing and inking soundings over the years is enormous. It is difficult to put a price tag on these improvements.

This may all seem repetitive. Other people besides myself have said it before. So the reader may wonder 'Why is he saying it all again?' Well, as long as people are still asking the questions, they need to be answered. One question I have neglected to pose is, 'Does automation reduce the number of personnel?' I think it has been shown that the number of personnel is not reduced significantly, no matter what the original design engineers may have told hydrographers. However, training needs, job duties, and work hours may be changing.

The arguments for and against automation indicate that the question 'Why automate?' is an important one. An even more important question, once the decision to automate is made, is 'How should a hydrographic organization go about it?'

It would be nice to buy an off-the-shelf system that has been debugged and proven by other hydrographic agencies. If there is no system available that satisfies the requirement, then it is a big task to put together a workable system. Defining the requirements of a system is a most important fundamental task, and it cannot be left to hardware engineers and software programmers. While they may develop the most unique, dependable and prettiest box in the world, unless the hydrographer wants it and needs it, the exercise has been futile. The hydrographer must have a direct hand in the design, development and implementation of any system he will be expected to use. If he feels he has a stake in it, he will work hard to make it a success.

THE FUTURE

Digitally recorded depth and position information is potentially useful for more than just making field sheets. Although the hydrographer will be the primary user, other mapping agencies, oil companies and construction engineers are all possible customers. The chart compiler will potentially reap the most benefit when he starts to integrate digitally recorded field data into the navigation chart. As hydrographers collect and process digital data they must have these customers in mind.

Computer-assisted cartography is a reality. Although it is possible to justify field loggers and processors because of efficiency increases, cost decreases and accuracy improvements, hydrographers must always be aware that the chart, not the field sheet, is the final product. Data collected and processed digitally in the field should be directly usable in the chart-making process.

As it stands today, the processed digital data are not useful to the cartographer. The data consist of files containing depths and their associated positions that, when plotted at survey scale, do not make a lot of sense until contours, shoreline, bottom samples and the rest are added to the plot manually. The cartographer cannot use this digital information directly. He uses a graphic document to compile his chart and then digitizes the compilation.

There are efforts underway to improve the situation, by producing a contour-format digital field sheet that can be used directly by the compiler in the chart-making process. This will not only make the vision of a totally digital field sheet a realistic one, but it will allow the cartographer to consider a new chart format using electronic video displays instead of a paper chart. The information needed to change the display format will be available from the digital contour field sheet, and will make adapting to the future that much easier. Once the needs of the cartographer have been met, accommodating the needs of other potential users should be easy.

CONCLUSIONS

Hydrography is a very special case. It is difficult for a big company to develop and volume-produce field logging and processing systems, with a full range of software routines, for a small hydrographic market. This means that hydrographic organizations may have to develop equipment and programs to meet a special need, in a field where only hydrographers have the expertise to say what it is that needs to be developed. That in itself is a 64,000 dollar question. To start with, in Canada alone there are four field offices, each dealing with different needs due to a variation of survey requirements. Compound that with the variety of equipment available to do essentially the same job; a multitude of computers, echo sounders, depth digitizers, data recorders, positioning systems and survey platforms. On top of this, there are slight philosophical differences that can mean different programming approaches to similar problems, resulting in a wide variety of programs and little control over how they work or what they do. Under these conditions a common approach is difficult. This is a part, but only a small part, of the reason hydrographers have not fully accepted the computer assistant.

Developing specialized equipment to meet a particular need is not difficult. It has been done many times with HAAPS, INDAPS, PHAS and HYNAV. All of these systems have had their successes and failures. Often the failures occurred because the hydrographer tried to use, or wanted to use, the equipment to do something it was not designed to do. There could be two reasons for this. Either the equipment was not designed properly to meet the needs of the user, or the needs have changed. Sometimes it is a combination of both.

Ten years ago there was a tendency to use the computer in an attempt to reproduce the manual product, and this often caused more problems than it solved. If the product was not exactly like the hand-produced item, it was rejected. Hardware and software designs were not always practical, partly because the state of the art equipment was too heavy and drew too much power to use in a small launch, and partly because the hydrographer had very little input into the design. As size and power requirements were reduced through advanced technology, systems became more practical for launch installations. Development engineers were also giving hydrographers the opportunity to participate in the design and implementation of equipment and software that was, after all, for their use. Attitudes towards data processing have changed as well. Hydrographers are no longer trying to duplicate exactly with a new technology what is done so well with existing technology. This has led to a major innovation, the contour-format field sheet, which will tie the digital field product directly into the chart-making process, and assist in making other innovative charting concepts a reality.

As time goes on, even successful products become outdated. With the electronics field advancing the way it is, there is no end in sight for hydrographic development. There are development stages, though. Even big companies have to stop developing and produce a marketable product, which may be old technology by the time it gets into the hands of the consumer. It will, however, satisfy an existing need and new systems will be developed in time to meet future demands. Development sections should not worry about producing new equipment every time a new product advancement is announced. A lot of time must be spent in support of existing systems, including training, documentation and field trips to repair hardware or software and to offer advice or guidance.

Management must actively, openly and enthusiastically support development efforts. In particular, the use of automated systems on production surveys should be encouraged as much as possible. While automated equipment may not work perfectly the first time it is used in a production environment, it should not interfer with production. Hardware and software should already have undergone field tests prior to implementation. The hydrographer should understand exactly what the software is doing, and he must be confident it is doing the job he wants it to do. Software may be sophisticated, but it should be easy to modify and simple to use.

Change is one of the most destabilizing elements of life, and automation is one of the most feared words. Failure to properly take into account the human factor involved in implementing and using new technology adversely affects productivity. Hydrographers should be encouraged to help make decisions concerning this implementation. As the technology is demystified, fears are reduced and the chances of acceptance and success are increased.

For twenty-one years the Canadian Hydrographic Service has been scratching the surface of automation, an itch that will not go away. Hydrographers have to face the fact that the computer age is upon them. There is going to be some adjustment necessary, but it should be as painless and productive as possible.

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DR. DORSEY'S ELECTRONIC LEAD LINE - - THE U.S. COAST AND GEODETIC SURVEY'S HYDROGRAPHIC SURVEY ECHO SOUNDER DEVELOPMENT 1924-1939

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ABSTRACT

The development of the hydrographic survey echo sounder by the U.S. Coast and Geodetic Survey (USC&GS) was the outgrowth of antisubmarine warfare technology developed during World War I. Today, the echo sounder is the backbone of hydrographic survey operations worldwide. This paper is based on a long-forgotten file spanning the years from 1924 to 1939, and the official journals and documents of the USC&GS. Excerpts from the file are often humorous and historically enlightening. The technology involved is for the most part primative by today's standards and is described briefly in that context. A most significant aspect is the cooperative relationship between industry and government which achieved the objective with minimal paperwork, specifications, and contract squabbles. Oh, for the good old days.

RÉSUMÉ

La mise au point, par la U.S. Coast and Geodetic Survey (USC&GS), de l'écho-sondeur pour les levés hydrographiques fut l'un des aboutissements des recherches menées pendant la Première Guerre mondiale, dans le domaine de la lutte anti-sous-marine. Aujourd'hui, l'écho-sondeur est, dans le monde entier, l'instrument de base pour ce qui est des levés hydrographiques. La présente étude s'inspire d'un dossier, depuis longtemps oublié, sur la USC&GS, des années 1924 à 1939. Les techniques elles-mêmes sont demeurées primitives, pour la plupart, et elles y sont décrites brièvement. L'aspect le plus important est probablement la collaboration entre l'industrie et la gouvernement, qui a permis d'atteindre l'objectif avec un minimum de paperasserie, de spécifications et de querelles au sujet des contrats. C'est en somme une rétrospective nostalgiques.

INTRODUCTION

Wars have a way of accelerating the process of technological breakthrough, applications, and development. It is a period when risk is endemic and the risk taker has much to gain. Hydrography is one of the fields that has seen the benefits of just such periods.

Prior to World War I, physicists from several countries were proposing underwater echo ranging as a means of averting disasters such as the TITANIC's collision with an iceberg in April 1912. Notable among these was Richardson, a British physicist, who proposed a method for emitting a sonic beam from a ship for the detection of icebergs. Richardson and the others were hindered, however, by the lack of a satisfactory sonic transmitter. The war and the German U-Boat threat brought forth just such a device in Langevin's invention of a piezo-electric oscilator. Difficulties were encountered with horizontal ranging, many aspects of which have not been fully resolved to this day. Vertical depth soundings were a simpler matter, however, and certainly of greater interest to the hydrographer at the time.

This new technology greatly interested the U.S. Coast and Geodetic Survey (USC&GS) in the early 1920's for it offered a means of improving accuracy, coverage, and above all, production in the execution of hydrographic surveys. Although pole and lead line soundings could be obtained underway with a reasonable degree of accuracy and efficiency, deep-sea wire soundings were slow and laborious at best. USC&GS operations entailed an increasing amount of sounding work beyond 100- fathom depths, particularly off Alaska, Hawaii, and the Philippine Islands. These areas required the lowering of a deep-sea sounding lead on a piano wire. Wire soundings could take hours, and would result in questionable depths along with even more questionable positions. The Survey's first use of an echo sounder was a U.S. Navy Sonic Depth Finder operated during a trip from Norfolk, Virginia, to San Diego, California, by the USC&GS Ship GUIDE in 1923. Although the Navy echo sounder was considered inadequate for hydrographic surveys, there was sufficient interest in the technique to consider the purchase of a unit which could be modified to support survey operations. Thus, on October 31, 1924, the Survey issued a Request for Proposal for a "sounding apparatus for use in ocean surveying in depths of 15 to 1,000 fathoms". The successful bidder on November 14, 1924, was Submarine Signal Corporation of Boston, Massachusetts. The price was $7,245 including installation.

THE SUBMARINE SIGNAL FATHOMETER

The contract called for a 90-day delivery, but it would be over a year before the first "apparatus" was accepted. The first Submarine Signal Fathometer was installed on the USC&GS Steamer LYDONIA in 1925. Two other units were ordered that year for the SURVEYOR and DISCOVERER (not to be confused with present vessels by that name). During that period, a number of modifications and improvements were made which were incorporated into the later production models. The added costs of the development were borne by the manufacturer, partly, it may be assumed, because of reduced manufacturing costs of the production models and the prospects of future sales, and partly by Captain W. E. Parker's acceptance letter of December 15, 1925, which cautioned that "any departure from the original contract creates a situation which it may be difficult to explain to the Comptroller General."

The flurry of correspondence in the spring of 1926 indicated that development of the Fathometer was just beginning. A host of gremlins were at work in the initial unit, with repeated failures centered around the governor. They were progressively attributed to a fault relay, the rheostat, or the circuitry. Shunts, condensers, rewiring, and shielding collectively solved the reliability problem but not the persistent 12- and 25-fathom stray soundings being reported. Needless to say, beam forming and side lobe suppression were not at a high stage of development at this time.

This first Fathometer used an oscillator as a sound source and a separate valve mounted through-hull hydrophone receiver. Soundings were read by means of a light flash in a neon tube mounted on a circular scale. In May 1926, Submarine Signal developed a tank-mounted hydrophone internal to the hull and water flooded. This unit, which reduced hull noise and stray soundings, was installed on all three vessels then equipped with Fathometers.

Dr. Dorsey Employed

The Survey was not totally satisfied with the Fathometer's performance but was very impressed with its potential. A decision was made to increase the in-house capability to continue development. It should be noted that Radio Acoustic Ranging was under development for position fixing during this same period, thus underwater acoustics was of considerable interest. The search for a senior electrical engineer to head the development effort led to the appointment of Dr. Herbert Grove Dorsey, under whose patent Submarine Signal manufactured the Fathometer.

Dr. Dorsey was initially approached in June 1926 with a description of the task and a mention that some amount of sea time would be involved. Dr. Dorsey replied that he had applied to the Naval Research Laboratory (NRL) for a position which entailed little or no sea duty as he was prone to seasickness but would take the offered position for $500 per month. After some haggling, Dr. Dorsey was appointed on September 15, 1926, at $5,200 per annum although he pointed out in his reports and correspondence for sometime thereafter that the position at NRL was $5,400 per annum. Thus began 13 years of development culminating in a recording echo sounder which would be the Survey's workhorse for nearly a quarter of a century.

THE DORSEY FATHOMETER

Dr. Dorsey began his work in earnest, often dealing directly with peers at Submarine Signal. Although the hierarchy at both the Survey and the company was obviously delighted with the progress being made, in January 1927 the Survey pointed out to Submarine Signal that the Government could not take responsibility for the various pieces of equipment which Dr. Dorsey was testing on the LYDONIA but would be happy to continue the testing. Submarine Signal replied that they were equally pleased with the results, pointing out that they were not concerned with liability and had used the loan agreement simply for accounting purposes. Thus, having both gone on record, about liability and loss, the bureau and the company unofficially encouraged the arrangement. Development proceeded at a healthy pace with soundings obtained reliably to 1,500 fathoms and frequently to 2,600 fathoms, well beyond the original specification of 1,000 fathoms. Although Submarine Signal and Dr. Dorsey continued to refine the original Fathometer, the real development effort was being directed at a shoal-water unit to be used in obtaining soundings under 100 fathoms for inshore work.

Striker Type Fathometer

Initial work on the shoal water instrument centered around a sound source created by a mechanical striker. Development progressed from ship personnel rhythmically beating the hull with a hammer to the construction of an electro-mechanical striker. The ships NATOMA and RANGER were outfitted with the first manufactured units in the summer of 1928. The deepest soundings obtained were less than 55 fathoms and reliable soundings were generally obtained only in less than 35 fathoms.

Dorsey Fathometer

In the Survey's in-house development of a shoal water echo sounder, two major changes were made to previous techniques. First was the replacement of the governor with a tuning fork to drive and control a synchronous motor. The second change was the use of a magnetostrictive transducer to replace the oscillator and hydrophone. Fabricated in-house, the Dorsey Fathometer prototype was field tested during 1934. These tests were extremely successful, giving reliable depths to 150 fathoms. Since Submarine Signal held the rights to basic patents on several of the features of the prototype, a contract was issued for them to place the prototype in production. The contract was approved by the Secretary of Commerce in February 1935 after receiving the review from his solicitor who advised that he thought the sole source could be justified although he hesitated "to predict the reaction of the Comptroller General." Thus, with this standard legal advice, production of the Dorsey Fathometer began.

THE SHOAL WATER DEPTH RECORDER

By 1938 the Survey had 14 years of experience with echo sounding. As a matter of fact, these instruments had been so thoroughly accepted in the field as to prompt the Acting Director of the Survey to state that, "These (Fathometers) are giving such good results in precision depth measurements that some of the Commanding Officers feel that they cannot do hydrographic surveying without one." The hydrographer in the field wanted to lay aside his lead line and pole (although both remain today) and the Commanding Officer wanted a permanent record so that he could check the work of his launch parties. The Dorsey Fathometer, although very reliable, had two drawbacks. It was not portable for use in launches and it did not provide a permanent graphic record. Thus, in December 1938 a set of detailed specifications were developed for a "portable automatic-recording depth sounder for use in hydrographic surveying, which is capable of producing clear, accurate, legible, and permanent records of depth when operated in a motor launch or other small boat...." The specifications described operating conditions, transducer type, beam or cone width, sounding intervals, depth range, paper size, interval and scale marks; power limitations, etc. In other words, all of the features we now expect in an echo sounder short of digitizing were incorporated in the specifications. Invitations to bid were sent to five companies, three in the United States, one in England and one in Canada. After some negotiation, the successful bidder was again Submarine Signal.

The portable recording echo sounder developed under the contract was tested and accepted in November 1939. Designated the 808 Fathometer, it had a range of 2 feet to 160 fathoms, easily meeting the 3-foot to 90-fathom specification. The 808 was the standard shoal water echo sounder for the Survey from its introduction in 1940 until phased out in the mid-1960's.

HISTORICAL NOTES

The file on which much of this paper is based contains some noteworthy historical items such as international interest in the United States development of the echo sounder, the debate over what sound velocity echo sounders should be calibrated for, communications, and Government contracting.

International Developments

The London "Journal of Commerce" in its March 12, 1928, issue noted United States developments in echo sounding and encouraged widespread use for merchant vessels. The article concluded that, "The power of taking very rapid soundings is of great service in checking position, and it is to be hoped that our own marketers will soon be able to satisfy the most careful shipowners," and complimented the USC&GS in stating, "The U.S. surveying service deserves the very highest credit for...the experiments and the full reports that they are publishing for the benefit of the seafaring world."

Submarine Signal Fathometers were successfully used on several European survey vessels from 1929 to 1931. The Danish Royal Navy conducted Fathometer surveys off Iceland and Greenland with great success during 1929. The German Navy Ship EUROPA was equipped in 1930. The Norwegian Naval Vessel NANSEN not only reported success in Arctic surveying but the use of the Fathometer as a navigation tool to resolve disparate radio bearings on return to home port in heavy fog.

Sound Velocity Standard

During this period of acceptance of the echo sounder as a survey tool by international hydrographers, the issue was raised as to what standard should be used for sound velocity in seawater. The debate was not as disparate as one might assume given the possibilities. USC&GS maintained that it should be 800 fathoms per second which would mean that nearly all corrections to echo soundings would be additive, thus reducing the chance of blunders. The Germans maintained that 1,500 meters per second was more nearly the average for open ocean surveys and thus more nearly correct for Naval and merchant vessels which did not make corrections. More likely, the debate involved a metric issue and the ease of using a round number, as one can readily see that 800 fathoms per second is approximately 1,463 meters per second and 1,500 meters per second is approximately 820 fathoms per second. The Survey has used both 800 fathoms per second and 820 fathoms per second at various times and has used both during some model changes in echo sounders. The latest instruments being purchased are calibrated for 800 fathoms per second (4,800 feet per second), and 1,500 meters per second depending on the sounding units selected.

Communications and Contracting

Throughout this 15-year period, the files show that difficulties were being reported and resolved by correspondence between Washington, D.C., and Boston, Massachusetts, dated 1 to 3 days apart. This is almost impossible today even using Rapidfax equipment or express delivery. Today, one could hardly get a letter approved overnight, let alone delivered.

Contracting is the other area which has become more complex and its evolution is seen in the files over the 15-year period. The 1924 proposal was one page. The 1935 Dorsey Fathometer was to be built by copying the Government-provided prototype. The 1938 specifications for the 808 Fathometer were three pages and the acceptance test report was two pages. The DSF6000N dual beam echo sounder, being built by Raytheon Ocean Systems Company for the National Oceanic and Atmospheric Administration and presently undergoing acceptance testing and evaluation, has specifications nearly an inch thick, and test and evaluation reports will undoubtedly run into volumes. I leave to the reader the question of whether some things have really improved.

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UNE APPROCHE MÉTHODOLOGIQUE AUX RECHERCHES SUR LA CONCEPTION GRAPHIQUE DES CARTES MARINES

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RÉSUMÉ

Le besoin d'améliorer la représentation graphique de la carte marine a récemment été identifié. L'addition cumulative de données diverses et l'encombrement visuel résultant sont des exemples typiques de problèmes nécessitant des études au niveau de la représentation. Comme le démontrent certaines recherches menées sur les carte aériennes, le choix de solutions graphiques appropriées permet une meilleure communication des diverses informations nécessaires à la navigation. Des recherches sur l'encodage graphique devraient ainsi permettre d'optimiser le transfert de l'information du cartographe aux navigateurs et autres usagers. La théorie de la communication cartographique fournit un cadre bien structuré pour entreprendre de telles recherches.

Dans le passé, la conception de la carte marine reposait sur les impressions personnelles et l'expérience du cartographe. Ces méthodes de recherche indirectes manquent malheureusement d'objectivité. Il est préférable de rechercher des méthodes plus fiables et d'adopter une approche basée sur l'évaluation objective. Ainsi, l'efficacité de la représentation graphique proposée devrait être testée systématiquement en consultant un certain nombre de sujets.

L'adoption d'un cadre méthodologique qui suit de près les étapes successives de la démarche scientifique aide alors à justifier les choix du cartographe marin. Ce dernier doit désormais se préoccuper de questions telles que la perception visuelle du lecteur et les conditions d'utilisation de la carte marine.

ABSTRACT

The need for improved nautical chart design has recently been identified. Cumulative addition of various data and the resulting visual clutter are examples of actual problems calling for studies in this field. As has been demonstrated in studies of aeronautical charting, effective communication of navigational information can be achieved through the choice of appropriate graphic solutions. Research on effective graphic encoding should permit optimization of information transfer from the cartographer to the navigator and other users. Cartographic communication theory can provide an organized framework to initiate studies on improved chart encoding.

In the past, cartographers' personal impressions and experience have led the way in nautical chart design. Such indirect research methods were lacking in objectivity. Better ways must now be sought and an approach relying on objective chart evaluation should lead the way. Thus, practical measurement of the reliability of proposed chart designs must be achieved through systematic testing with subjects. The normal chart use conditions are then investigated and simulated to measure the perceptual reactions of the users on specific problems needing investigation. Adoption of an adequate methodology, hence, following closely the successive steps of scientific experimentation, can also bring the marine cartographer to the realm of scientific research.

INTRODUCTION

Au cours des décennies le Service hydrographique du Canada a progressivement amélioré la qualité graphique de la carte marine. Le produit actuellement diffusé est d'une facture très soignée. Les améliorations se sont succédées au cours des années, jusqu'à l'adoption des normes adoptées pour la "Carte Nouvelle". Le calibre du dessin et de l'impression classe notre production dans un groupe de file au niveau mondial. Parallèlement, les recherches plus récentes sur l'usage de la cartographie assistée par ordinateur vont bon train. Le système en usage a graduellement été rendu meilleur, et les développements anticipés pour un futur à moyen terme permettent un optimisme justifié.

Il faut cependant mentionner que les recherches sur l'efficacité de la carte marine en tant qu'instrument de communication sont plutôt rares. Le Canada n'accuse pourtant pas de retard sur les autres pays; cette lacune semble généralisée à l'échelle mondiale. Hormis une thèse sur la représentation ponctuelle des mesures de profondeur (Stanley, 1973), ce n'est qu'en 1982 qu'une étude préliminaire sur l'efficacité de la carte marine était publiée (Castner and McGrath, 1982). Le centenaire du Service hydrographique du Canada incite à marquer un temps d'arrêt afin de réfléchir aux réalisations cartographiques du passé et à prévoir le futur. L'utilité des recherches relatives à l'évaluation de la carte marine devrait nous motiver à porter celles-ci au tableau des activités à promouvoir au cours des prochaines années.

LA CARTE MARINE: INSTRUMENT DE COMMUNICATION DE L'INFORMATION

Le cartographe chercheur est toujours en quête d'approches susceptibles de l'aider à comprendre comment l'utilisateur exploite l'information de ses cartes. Le but ultime est évidemment d'en améliorer l'efficacité. La théorie de la communication semble offrir un cadre approprié pour organiser les efforts consacrés à cette fin.

La fonction de la carte marine est de fournir au navigateur l'information nécessaire à la navigation d'un point à un autre en toute sécurité. La transmission efficace de cette information déterminera le degré de succès de cette activité. L'intérêt actuellement suscité par les études de communication cartographique croît constamment. C'est le schéma de la communication de l'information d'abord mis au point par Shannon et Weaver qui inspira par la suite les nombreuses tentatives de création d'un modèle cartographique (Shannon and Weaver, 1949). La version proposée à la figure 1 intègre les principales caractéristiques des modèles que nous avons analysé.

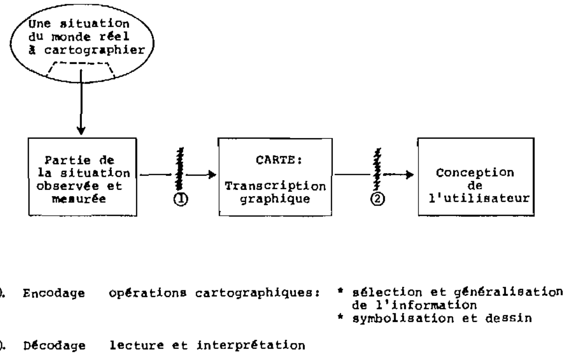

FIGURE 1. Un modèle général de communication cartographique.

Le point de départ du schéma est une situation précise du monde réel: une portion de la mer en région côtière serait un exemple approprié. L'information à transmettre est relevée et transmise au navigateur au moyen de la carte marine. Les opérations d'encodage et de décodage de l'information agissent comme des filtres causant une réduction ou perte d'information à mesure qu'on se déplace vers la droite du modèle. Il faut donc minimiser cette perte en mettant au point des méthodes de représentation (codage) appropriées au type de carte considéré.

Il n'existe pas de symbole graphique unique pour traduire visuellement une caractéristique ou une variante donnée de la carte marine. Conséquemment, l'auteur hésite souvent entre plusieurs solutions. Celui-ci peut sortir de l'impasse en mesurant soigneusement l'efficacité respective de chaque design envisagé. Cette procédure est plus valable qu'une décision basée sur le choix personnel de l'auteur.

Le modèle de communication cartographique aide à comprendre les mécanismes de transfert de l'information au moyen de cartes. Il fournit aussi une approche épistémologique appropriée aux recherches sur l'efficacité de la carte marine. Les préoccupations qu'il a généré au cours de la dernière décennie soulignent la nécessité d'adopter des stratégies de recherche plus méthodiques pour la conception des cartes. Il devient ainsi pertinent d'analyser les types de recherche actuellement répandus en cartographie.

TYPOLOGIE DES RECHERCHES EN CONCEPTION CARTOGRAPHIQUE

Le cartographe peut emprunter diverses approches afin de mener à terme une recherche de conception cartographique. La classification de Robinson (1977) repose sur deux grandes catégories. L'approche indirecte est très subjective alors que l'approche directe montre la plupart du temps un souci pour des choix basés sur l'objectivité, mettant de côté les goûts personnels et les choix arbitraires du chercheur.

L'approche indirecte

L'approche indirecte est caractérisée par l'absence d'interaction avec les utilisateurs de la carte. On ne vérifie pas si le produit final est efficace. La "conception empirique" est la mise au point de solutions graphiques basées sur les opinions personnelles, l'expérience et le bagage théorique du cartographe. Celui-ci ne peut fournir aucune preuve de la validité de la solution retenue. Cette procédure parfois qualifiée d'essai et erreur a été la pratique générale au Service hydrographique du Canada jusqu'à présent. C'est aussi de très loin la plus commune et la moins objective en conception cartographique.

Des idées nouvelles viennent parfois des "adaptations de découvertes d'autres disciplines". Les résultats d'expériences ou les principes élaborés dans d'autres disciplines sont appliqués au design de la carte. Ces recherches n'ayant pas été menées dans un contexte cartographique, il est souvent hasardeux d'en étendre les conclusions à la conception de la carte. Celle-ci est une image complexe dont le lecteur a des préoccupations souvent différentes de celles qui prévalent dans les expériences de ces disciplines connexes (colorimétrie, psychologie, etc.). Les concepteurs de cartes marines ne semblent pas avoir puisé de ce côté. Bien que potentiellement utile, cette procédure devient valable si de nouvelles mesures sont prises en reproduisant l'expérience en contexte cartographique selon une approche plus directe.

L'approche directe

Les recherches menées selon l'approche directe sont basées sur une consultation des utilisateurs en vue de justifier les choix effectués au niveau de la représentation cartographique. Déjà plus objectif que les recherches indirectes précédemment exposées, le "recensement des réactions des utilisateurs" analyse les opinions d'une clientèle envers un produit. Axées sur les catégories d'information de la carte plutôt que sur la symbolisation, ce type de recherche est souvent biaisé par les conventions en place et les convictions personnelles du lecteur. De telles recherches ont été menées par le Service hydrographique du Canada dans le passé (Smith, 1976). Constituant un premier pas vers le désir de consulter l'usager, ces recherches ne mesurent pas l'efficacité réelle de la carte. L'effort était louable car les conclusions ne sont plus basées que sur les seules idées du cartographe. Il faut néanmoins aller plus loin et franchir un autre pas vers l'objectivité en évitant ce simple vote.

Les trois types de recherche suivants répondent à cet objectif. Ils sont basés sur la mesure de performances de lecteurs lors d'une utilisation simulée de la carte. C'est la façon la plus objective de procéder à une véritable étude de communication cartographique et les futurs efforts d'évaluation de la carte marine devraient s'en inspirer. La "recherche psychophysique", la "recherche cognitive" et la "recherche orientée vers les tâches de lecture" ne sont pas encore répandues dans les bureaux de cartographie gouvernementaux.

La "recherche orientée vers les tâches de lecture" se penche sur la façon dont le lecteur aborde visuellement les éléments de la carte. Le problème est de savoir comment et avec quelle efficacité le navigateur utilise la carte. Quelles sont les stratégies de lecture adoptees par l'utilisateur? Dans un deuxième temps, avec quel succès exécute-t-il ces tâches? Le laps de temps requis pour exécuter ces opérations visuelles et la précision avec laquelle l'information est extraite permettent de répondre à cette dernière question. La "recherche psychophysique" étudie les relations stimulus-réaction. Quelle est la perception engendrée par un symbole cartographique donné? Finalement, la "recherche cognitive" devrait être ajoutée à la classification de Robinson. Dépassant le premier temps de lecture et la perception visuelle, ce type d'étude tente d'expliquer comment le lecteur acquiert, emmagasine, mémorise, organise et utilise ensuite l'information brute acquise à partir des éléments graphiques de la carte. Les mécanismes cognitifs vont ainsi beaucoup plus loin que le simple input sensoriel étudié dans les recherches psychophysiques. Ils incluent la réflexion ainsi que l'élaboration d'images mentales ou de répartitions spatiales. Leur étude peut aider à mieux comprendre la carte et en faciliter la conception.

Le cartographe-hydrographe devrait dorénavant exploiter le potentiel de l'approche directe et surtout des trois derniers champs de recherche précédemment exposés. La carte marine peut certainement bénéficier d'un programme fondé sur ces trois types de recherche. Ceux-ci reposent non seulement sur une consultation objective des navigateurs mais s'inscrivent aussi dans un cadre méthodologique bien plus scientifique que les travaux de conception cartographique antérieurs des services hydrographiques nationaux.

ADOPTION D'UN CADRE MÉTHODOLOGIQUE ET PROPOSITION D'UN CHEMINEMENT POUR LES RECHERCHES SUR LA CONCEPTION GRAPHIQUE DE LA CARTE MARINE

L'étude des cartes au travers des trois méthodes qui nous intéressent peut conduire à une évaluation sérieuse de l'efficacité des solutions graphiques envisagées. Suite à la formulation des hypothèses de la recherche, le cartographe reproduit expérimentalement certaines conditions de la carte. Il recueille des données sur les performances et la perception des sujets de l'échantillon qu'il a constitué pour la circonstance. Les statistiques recueillies dans les études de communication cartographique sont analysées de façon descriptive, graphique ou mathématique. Dans ce dernier cas, les méthodes statistiques permettent de vérifier si les résultats de l'expérience sont significatifs. En d'autre mots, est-il possible de généraliser les conclusions de cette seule expérience avec une marge de sécurité scientifiquement acceptable?

Cette suite d'opérations suit de très près les étapes de la démarche scientifique. Une approche méthodologique semblable renforce la valeur accordée aux conclusions et aux recommandations qui émanent de la recherche. On peut dorénavant mettre de côté les études menées à tâtonnement. Un cadre méthodologique solide permet toujours de sauver du temps et de structurer logiquement le déroulement d'un projet de recherche.

La cartographie thématique a souvent fait recours à cette approche. Plus récemment, la carte aéronautique a aussi emprunté cette voie avec des résultats intéressants (Hopkin and Taylor, 1979). Servant toutes deux à la navigation, la carte aéronautique et la carte marine ont des points communs. Il est temps de tirer le meilleur parti de la méthode scientifique et de s'en inspirer pour établir une stratégie de recherche valable pour la cartographie marine. Le cheminement suivant semble tenir compte de l'ensemble des préoccupations mentionnées jusqu'ici:

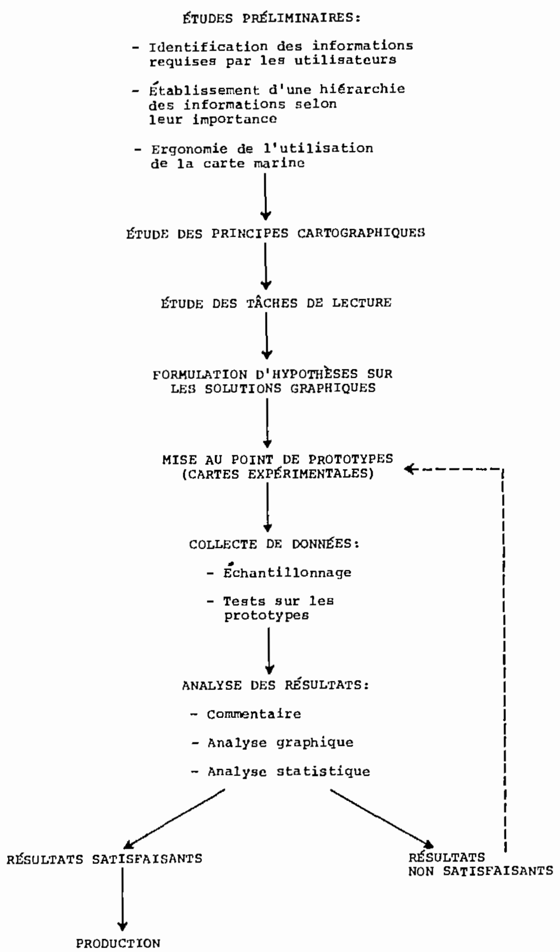

FIGURE 2. Un cheminement adaptable aux recherches sur la conception graphique de la carte marine.

UN EXEMPLE PRATIQUE DE RECHERCHE EN CONCEPTION CARTOGRAPHIQUE: LA REPRÉSENTATION DU FOND MARIN

Que sait-on de l'efficacité des cartes marines modernes? Peut-on affirmer que leur design en général et les symboles conventionnels sont adéquats? Il est évident que les cartes Loran-C sont très chargées et la recherche de solutions à ce problème épineux revêt un intérêt spécial. Il en va de même pour de nombreux autres aspects de la carte marine. Kerr et Anderson (1982) ont suggéré que sa présentation actuelle est un amalgame de ce que les cartographes pensent être les meilleurs éléments des cartes de divers pays. Aucune forme d'évaluation cartographique ne peut cependant confirmer ces choix. Les concepteurs de cartes marines n'ont probablement pas exploité le potentiel des découvertes et des principes cartographiques. Il faut encourager de futurs efforts dans cette voie. Les directives de l'Organisation Hydrographique Internationale en matière de standardisation de symboles ont des répercussions sur les cartes de mombreux pays. Cet organisme devrait aborder objectivement les recommandations que lui soumettront les cartographes-chercheurs dans le futur.

Il faut des efforts considérables pour parvenir à un design cartographique valable. Afin de simplifier la tâche, le chercheur doit étudier les composantes de la carte séparément ou par sous-groupes. Toutefois, il faut mener chaque étude dans le contexte global de la carte marine en insérant les symboles considérés dans l'image d'ensemble de la carte. Les prochaines lignes montrent comment on pourrait éventuellement examiner un aspect particulier de la carte marine selon l'approche proposée précédemment.

Plusieurs méthodes permettent de représenter graphiquement le fond marin. On dénombre entre autres: les sondes ponctuelles, les isobathes, l'estompage, les teintes hypsométriques et la méthode de Tanaka qui combine l'isoligne et l'estompage. La question étant de savoir laquelle de ces méthodes est la plus efficace dans un contexte de navigation, une évaluation comparative s'impose. Afin de déterminer laquelle des cinq méthodes citées convient le mieux à la carte marine, le chercheur pourrait soumettre les cinq versions de la carte à certains tests. On pourrait poser certaines questions à des sujets et enregistrer la précision et la rapidité des réponses. Les questions doivent évidemment se rapprocher des tâches ou activités visuelles qui prévalent lors d'une utilisation normale de la carte.

Le navigateur cherche-t-il à visualiser la morphologie du fond marin ou plutôt à déterminer des profondeurs relatives ou absolues? Les travaux de Phillips et al. (1975) montrent que l'efficacité des méthodes de représentation adaptables au relief sous-marin varie selon les objectifs de lecture du navigateur. Les résultats qu'ils ont obtenus suggèrent que les teintes hypsométriques conviennent à la visualisation globale des formes du terrain. Cette même méthode donne de piètres résultats pour la perception des altitudes absolues. La représentation digitale (cotes d'altitude) convient alors davantage. Ces remarques montrent non seulement comment on pourrait exécuter des expériences semblables dans le contexte de la carte marine, mais aussi la pertinence des études sur les tâches de lecture et l'utilisation de la carte marine. Une identification rigoureuse des tâches visuelles fournit des indices pour le choix de la méthode de représentation. Ainsi, Castner et McGrath suggèrent avec raison de poursuivre plus loin leurs travaux sur les activités et les tâches visuelles relatives à la carte marine.

La recherche de Phillips et al. peut nous inspirer considérablement. Leurs découvertes amènent de nombreux indices sur la perception du relief terrestre. Cependant, d'autres recherches s'imposent en raison des particularités de la carte marine. Une étude similaire pourrait indiquer si notre conception de la carte marine est adéquate ou non. La version actuelle de la carte canadienne combine trois types de représentation: sondes, isobathes et teintes hypsométriques. La réalité est souvent plus complexe que l'évaluation indépendante de chacune de ces méthodes de représentation. La recherche expérimentale doit tenir compte de l'interaction visuelle de ces symboles. Ces dernières considérations confirment le besoin de tester diverses combinaisons de symboles afin de déterminer la meilleure. Les recherches de Phillips et al. nous montrent que les fonctions multiples de la carte marine (variété d'utilisateurs) impliquent nécessairement l'usage simultané de plus d'un type de symbole pour la représentation du relief marin.

L'introduction de la nouvelle présentation de la carte marine canadienne remonte maintenant à quelques années. La "Carte Nouvelle" amenait alors des changements liés à la représentation du fond marin. La densité des sondes diminuait au profit d'un nombre accrue d'isobathes. Les promoteurs de ce changement ne vérifièrent pas vraiment si l'innovation était "pour le meilleur ou pour le pire". Des travaux menés selon le cadre methodologique dont nous avons discuté permettraient de justifier plus adéquatement de futurs changements dans la symbolisation.

CONCLUSION

L'exemple de la représentation du fond marin n'est qu'un des nombreux aspects de la carte qui pourraient bénéficier de recherches de conception graphique. On peut citer le choix des symboles figuratifs, la taille des symboles ponctuels, la disposition du lettrage, la représentation des réseaux Loran-C en relation avec l'encombrement visuel de la carte, etc. La qualité du produit final peut gagner énormément en efficacité. Il s'agit maintenant d'établir un programme de recherche basé sur certaines priorités. Ainsi, la structure d'ensemble de la représentation devrait être examinée avant les symboles ponctuels dont la fréquence d'utilisation varie d'un feuillet à l'autre.

La carte marine est l'aboutissement des opérations hydrographiques. C'est aussi l'instrument qui nous permet d'acheminer à l'utilisateur la plupart des informations dont il aura besoin pour la navigation. Considérant les ressources monétaires et les efforts investis chaque année dans les missions hydrographiques et la production cartographique, les recherches sur l'efficacité de le la carte semblent pertinentes. La carte est le seul lien de communication entre le cartographe qui a compilé les données initiales et le lecteur. Notre devoir est de développer la meilleure version possible de ce chaînon stratégique et il serait regrettable de perpétuer un produit dont on ne connaît pas l'efficacité.

La recherche cartographique a certainement ses limites mais il faut tirer le meilleur parti des découvertes qui peuvent en résulter. La présentation des séries cartographiques gouvernementales change rarement. Cette inertie est parfois mentionnée en milieu académique. Il est vrai que la modification des normes cartographiques d'une série d'envergure ne se fait pas du jour au lendemain. Quelques problèmes et coûts supplémentaires peuvent en découler. Cependant, d'éventuelles améliorations ne peuvent indéfiniment être remises à plus tard. Le Service hydrographique du Canada a déjà fait preuve de flexibilité en ce sens lors de la création de la "Carte Nouvelle". Il semble donc possible de donner suite aux découvertes que pourrait prochainement amener un programme de recherche bien structuré.

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TIDE MEASUREMENT BY ACOUSTIC TELEMETRY
PART 1: THE BOTTOM UNIT

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ABSTRACT

This paper describes the ocean bottom unit of an underwater acoustic telemetry system designed primarily to address the problems of tidal data gathering. The problems of tidal data collection are highlighted and the objectives of the acoustic telemetry system are stated. A shallow water environmental model is used to obtain accurate estimates of parameters such as propagation loss, band level noise, frequency dispersion, and time dispersion. The environmental model in conjunction with in situ measurements dictate the guidelines used in the system design. A breakdown of the bottom unit into subsystems is given and each subsystem is described. The results of tests performed on the system on June 12 and 13, 1982, in Bedford Basin, Dartmouth, Nova Scotia, are summarized. Finally, other potential applications of the system are mentioned.

RÉSUMÉ

Le présent document décrit l'unité de fond d'un système sous-marin de télémétrie acoustique conçu principalement pour régler les problèmes de la collecte des données sur les marées. Ces problèmes sont décrits et les objectifs du système de télémétrie acoustique sont établis. Nous utilisons un modèle du milieu d'eaux peu profondes en vue d'obtenir une estimation précise de paramètres comme l'affaiblissement de propagation, le niveau du bruit de la bande, la dispersion des fréquences et la dispersion dans le temps. Nous nous sommes servis du modèle au milieu et de mesures prises sur place pour établir les lignes directrices utilisées pour la conception du système. Nous décomposons l'unité de fond en sous-systèmes et décrivons chaque sous-système. Les résultats des tests effectués sur le système les 12 et 13 juin 1982 dans le bassin Bedford à Dartmouth (Nouvelle-Écosse) sont résumés. Enfin, nous mentionnons d'autres applications éventuelles du système.

INTRODUCTION

Tidal measurement is an integral part of the process of charting the oceans. Traditionally, the tide has been measured along the shore with simple recording instruments and the data obtained has been used to correct the measured water depth to the low water datum. In practice, this method does not provide reliable data when the shoreline is gently sloping or when the tidal range is large. Moreover, the collection of good tidal data in harsh environments is difficult because of problems caused by the weather, ice, and surf. Such problems plague shore-mounted recording instruments. Development of an ocean bottom-mounted tide gauge at the Bedford Institute of Oceanography (BIO), about six years ago partially solved these problems. The gauge provided reasonable accuracy in depth measurements and could be moored at a number of locations in the ocean, making it possible to obtain information about tides in off-shore areas. Sea trials indicated that the concept was a viable one, but that the next prototype system should possess a higher data rate and a lower error rate, in addition to certain features deemed useful.

For this reason, a Concordia University research group specializing in acoustic signal processing was asked to design an electronic telemetering device that could be used to reliably transmit the tidal data gathered by the gauge to a ship within the vicinity of the mooring. The success of this task required a good knowledge of the fading dispersive nature of the acoustic communications channel, especially for shallow water areas of the ocean.

OBJECTIVES OF THE SYSTEM

The acoustic telemetry system design was implemented with the following general requirements in mind:

(1) To access data produced by moored instruments.
(2) To operate in shallow water environments where severe multipath conditions exist.
(3) To transmit encoded data at a rate of at least 32 bits/sec.
(4) To achieve bit error rates of between 10^{-4} and 10^{-5} or better.
(5) To communicate effectively over ranges of 1 km or more during sea state 5 weather conditions and relative ship-bottom unit motion of at least ±6 knots.
(6) To consume little standby power so that ordinary batteries could be used as the power source for the bottom unit of the system for deployment periods in excess of 1 year.

OVERVIEW OF THE OPERATION OF THE SYSTEM

The telemetry system consists of an ocean bottom unit and a deck unit placed on board a survey ship. This arrangement is illustrated in Figure 1. The bottom unit is connected to a tide gauge via an interrupt-driven interface. It is moored on the ocean floor and left to collect data for a predetermined period of time. The data collected is conditioned and stored in a microcomputer memory. At present, the memory can accommodate 512 16-bit words. A time tag is affixed to every third data word to enable the correct time sequence to be reconstructed on receipt of the data.

The survey ship carrying the deck unit comes within the vicinity of the mooring site and signals the bottom unit by transmitting an interrogation command which the command receiver of the bottom unit recognizes. The interrogation command consists of a 250 ms encoded tone burst which contains 5 tones spaced 400 Hz apart in a 2048 Hz bandwidth around 8192 Hz. The tones are down-converted, filtered, and rectified in the command receiver and diversity combined to form a detection statistic which is tested against a threshold.

When the threshold is exceeded, the bottom unit transmits an encoded synchronization preamble to the deck unit. This is followed by transmission of the actual tidal information.

ENVIRONMENTAL STUDY

The design of the system was carried out in accordance with the sonar equations. These equations are based on the equality between signal level and noise level when some processor function such as a detection decision is being evaluated. They provide the necessary relationship among the system parameters and the major environmental parameters such as transmission loss and ambient noise. In a one-way communication link the sonar equation of relevance is given by,

$$(S/N)_R = L_s + (N_{DI})_R - T_L - L_N \qquad (1)$$

where $(S/N)_R$ is the signal-to-noise ratio at the receiver, $(N_{DI})_R$ is the directivity index of the receiver, T_L is the transmission loss, and L_N is the band level noise.

Reliable communications in the ocean depends largely on the accuracy with which the environmental parameters such as transmission loss, band level noise, frequency, and time dispersion can be estimated. In estimating transmission loss and band level noise, a shallow water environmental model was used and calculations were carried out at two frequencies, 7 and 16 kHz; six sea states, ssϕ-ss5; and three different temperatures, -10°C, 0°C, and +10°C. The frequency and time dispersion estimates were derived from sound velocity profile studies of six shallow water locations off the Canadian east coast. The results of the environmental studies provided the guidelines for the design of the telemetry system. They predicted the following:

(1) The worst case transmission loss at a range of 1 km would be 59.95 dB. Such a loss would occur at a temperature of -10°C on a muddy ocean bottom during ss5 weather conditions.
(2) The band level noise at 7 kHz during ss5 in the open ocean would be -35 dB.
(3) Frequency dispersion (doppler spread B) would be approximately 4 Hz at a range of 1 km
(4) Time dispersion (multipath spread L) would be approximately 100 ms at a range of 1 km

Based on the frequency and time dispersion estimates of 4 Hz and 100 ms, respectively; actual data; and on practical considerations from an implementation point-of-view, the optimum transmit pulse duration (T_p) was set at 125 ms. The deck unit receiver frequency resolution was then calculated as $(B + \frac{1}{T_p}) = 12$ Hz and the total received tonal duration was established to be $(T_p+L)=225$ ms. As a result, a 125 ms dead time between transmissions was allowed for multipath decay. The environmental study indicated that the system should transmit at 7 kHz with a bandwidth of 2 kHz, based on the modulation scheme chosen, since for a given transmitter power and directivity index, the signal-to-noise ratio was better at 7 kHz than at 16 kHz Consequently, the transmission band was established as 8192 Hz ±2 kHz. Data encoding and 5-fold frequency diversity were used to combat fading which could occur because of the dispersive nature of the medium. It was also recommended that the ship on which the deck unit is placed should observe a vehicle-current axial velocity of less than 6 knots and a horizontal range approximation of about 1 km, when interrogation of the bottom unit is attempted.

Description of the Bottom Unit

A functional block schematic diagram of the bottom unit of the telemetry system is shown in Figure 2. The unit is divided into three subsystems. They are:

(1) The command receiver subsystem.
(2) The microcomputer and data gathering subsystem.
(3) The frequency synthesizer subsystem.

THE COMMAND RECEIVER SUBSYSTEM

The command receiver is that portion of the telemetry system which deals with the processing of incoming information so as to recognize the interrogation command issued by the deck unit. The command receiver is designed to operate with a probability of false alarm $P_{FA} = 10^{-8}$ and a probability of correct decision $P_{CD} = .99$. This implies that only 1 in every 100 interrogation attempts would not be recognized and only 1 false alarm would occur in every 289 days of operation. These are important considerations because of the severe power constraint imposed on the operation of the system.

A block schematic diagram of the command receiver is illustrated in Figure 3. Its operation is as follows. The five incoming interrogation command tonals are received by the transducer and then passed to the pre-amplifier which consists of a matching network amplifier and a bandpass filter centred on 8192 Hz and having a bandwidth of 2048 Hz. The tonals are mixed with a 7168 Hz reference signal and the difference frequencies are amplified and passed through a bank of five bandpass filters each 40 Hz wide and centred at each of the five down-converted frequencies. Further amplification is applied followed by envelope detection. The output of the detectors are sampled and multiplexed into an 8-bit A/D converter. The samples are then transferred to the RCA CDP 1802 microprocessor subsystem where the signal processing continues, by performing the following functions:

(a) Formation of the long term average (LTA) of the noise energy on each of the five diversity channels over K(125)ms periods. The LTA noise estimate for the ith channel is given as,

$$\hat{N}_i(n\Delta) = \frac{1}{K} \sum_{\ell=n-K}^{n} \hat{E}_i(\ell\Delta)$$

where Δ is the sampling period and is equal to 125 ms. The LTA is done as a "sliding-window" average. The integer $K = 480$.

(b) Production of a weighting rule for each channel by normalizing the STA estimate by the LTA estimate. The weighting rule is given as,

$$\gamma_i(n\Delta) = \hat{E}_i(n\Delta)/\hat{N}(n\Delta)$$

The weighting rule is similar to automatic gain control circuitry, and used in lieu of it.

(c) Frequency diversity combining by summing the normalized outputs of all 5 diversity channels every 125 ms to partially form the detection statistic. The summation is given as,

$$\gamma(n\Delta) = \sum_{i=1}^{5} \gamma_i(n\Delta)$$

(d) Temporal combining by summing two consecutive values produced through frequency combining to form the detection statistic, denoted by,

$$\gamma = \gamma(n\Delta) + \gamma((n-1)\Delta)$$

(e) Testing γ against a threshold Λ. If the threshold is exceeded, the microcomputer instructs the frequency synthesizer subsystem to commence data transmission.

Data Gathering Subsystem

The data gathering subsystem consists of the gauge interface unit and the microcomputer. The microcomputer is comprised of the RCA CDP 1802 microprocessor, a 262144 Hz clock, and 3 k-bytes of memory. Its functions are:
(1) To store data received and conditioned by the gauge interface unit.
(2) To complete the signal processing functions of the command receiver.
(3) To do the data encoding function of the synthesizer subsystem.
(4) To control the entire functioning of the bottom unit.

FREQUENCY SYNTHESIZER SUBSYSTEM

The frequency synthesizer is that portion of the bottom unit that converts the digital data stored in memory into tonals and prepares these tonals for transmission.

The synthesizer uses a dense MFSK modulation scheme in which $M=4$ and the number of frequency diversity channels, $D=5$. In this scheme each 16 bit data word is conveyed using a subset of 40 tones from a set of 160. Four pilot tones are interleaved between the 5 diversity channels to make 44 tones overall. The pilot tones are used by the deck unit for doppler and synchronization corrections. The tones are created digitally using the accumulator overflow technique of frequency synthesis [1]. Quadrature outputs are produced, with all 44 in-phase and quadrature components independently summed to form two composite waveforms. Summation of this large number of tones requires that their phases be randomized in order to minimize the peak-to-average ratio of the composite waveform. This is accomplished by using a quadratic phase set to initialize the phases of the tones. The tones are created in the range of ±1 kHz and up-converted to the band 7168 Hz to 9216 Hz through modulation with an 8192 Hz carrier. The tones are then windowed, power amplified, and transmitted.

Performance predictions indicate that for a bit error rate of 1.25×10^{-5}, reliable communication between the bottom and deck units over a range of 1 km during ss5, could be maintained with an amplifier output power of between .72 to 7.2 watts. Thus, the output of the power amplifier was made variable in fixed steps over the range .25 to 6 watts.

SEA TEST

The system was tested on June 12 and 13 1982 in the Bedford Basin, Dartmouth, Nova Scotia. The results indicated that even though the test conditions were far from ideal the system performed very well. Error-free transmission was obtained at a range as far as 1.5 km with 6 watts of power. In instances when errors did occur, there seemed to be quite plausible explanations. A summary of test results is given in [3].

CONCLUSION

The acoustic telemetry system described was designed primarily to address the problems of tidal data gathering in the ocean. Its flexibility and potential, however, allow it to be marketed in a much broader sense. It can be viewed as a telemetry communication system capable of collecting and telemetering any type of data that can be easily converted to electrical signals. To accomplish this would require only the redesign of the gauge interface unit to suit the interface requirements of the new system. In this respect, the system can be used for many other applications such as:
(1) Pollution monitoring in the ocean, lakes, rivers, and water supplies.
(2) Water level monitoring in water supplies.
(3) Control of underwater submersibles in ocean bottom resource mining and oil rig drilling maintenance.
(4) Military surveillance.

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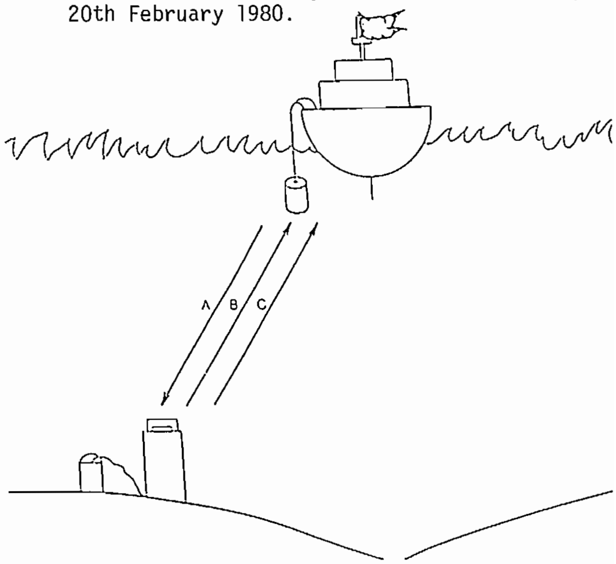

Figure 1. Interrogation arrangement between the bottom and deck units.

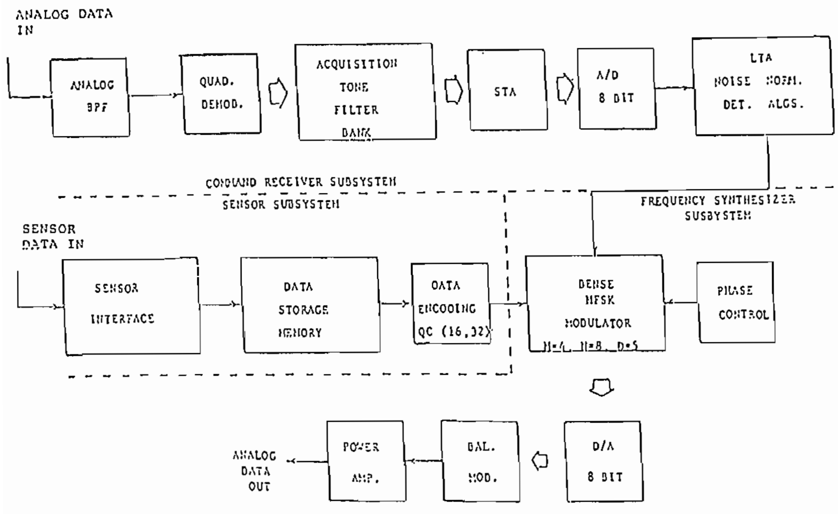

Figure 2. Functional block schematic diagram of the bottom unit of the acoustic telemetry system.

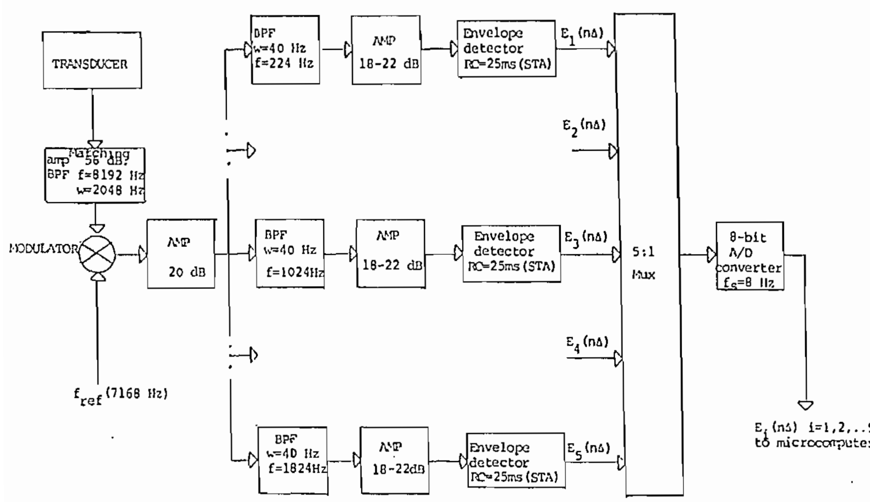

Figure 3. Block schematic diagram of command receiver.

TIDE MEASURMENT BY ACOUSTIC TELEMETRY
PART II: THE DECK UNIT

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ABSTRACT

This paper describes the receiver of an acoustic telemetry System. It begins with a brief description of the dispersion problems associated with underwater communication, followed by a detailed explanation of the hardware developed to overcome these problems. The hardware description includes a detailed look at the Fast Fourier Transform processor and the time synchroniser. Software algorithms for doppler shift estimation doppler shift correction, time estimation, tone demodulation, and error correction are described. Finally, some test results obtained in Bedford Basin, Halifax, are presented.

RESUME

Le présent document décrit le récepteur d'un système de télémétrie acoustique. Il commence par une brève description des problèmes de dispersion liés à la communication sous-marine, qui est suivie d'une explication détaillée du matériel mis au point pour régler ces problèmes. La description du matériel comprend un examen approfondi du processeur Fast Fourier Transform et du synchronisateur temporel. Nous décrivons des algorithmes de logiciel pour l'estimation de la variation de fréquence (effet Doppler), la correction de la variation de fréquence, l'estimation du temps, la démodulation des tonalités et la correction des erreurs. Pour terminer, certains résultats des tests effectués dans le bassin Bedford, à Halifax, sont présentés.

INTRODUCTION

A significant disadvantage of measuring tides with bottom-mounted tide gauges is that tidal information can be obtained only upon recovery of the instrument at the completion of the survey. This disadvantage may be overcome by the use of a bottom-mounted tide gauge which can transmit to the survey ship, on demand, the tidal information gathered over a period ranging from days to several weeks. A device of this type allows the hydrographer to maintain an up-to-date account of corrected soundings and greatly expedites the progress of a hydrographic survey, especially in the Arctic. To this end, a prototype acoustic telemetry-system has been developed and tested by Concordia University for the Bedford Institute of Oceanography 1,2 . The system consists of two parts: The bottom-mounted unit which collects tidal data and transmits it to the Deck Unit upon request, and the Deck Unit, described in this paper, which is responsible for receiving and demodulating the information transmitted from the Bottom Unit, while correcting for frequency and temporal dispersion of the underwater environment.

THE ACOUSTIC ENVIRONMENT

The sea is far from the ideal sound-propagation medium. Sound waves, apart from being concepted by noise, also suffer from time and frequency dispersion. Time dispersion or multipath is due to reflections of rays by the surface and bottom before reaching the receiver. Sound signals transmitted take different paths, and as a result, arrive at different instants at the receiver. Since higher order rays make steeper angles with the boundary surfaces, they travel longer distances and suffer greater attenuation, however, their energy is relatively weak and can be neglected. The time difference in multipath arrival relative to direct path arrival is computed for an average sound speed of 1478.3m /s and shown in Table (1) 1,2 .

From Table 1 we see that the worst case dispersion, occurring when both the transmitter and receiver are at a relatively shallow depth is on the order of 30-100ms. Intensity fluctuation of the various paths may be as much as 20 dB.

A second form of dispersion, frequency dispersion, is caused by reflection from the ocean surface. Grazing angles of 3^{o} and 6^{o} were felt to be reasonable values for low order multipaths, considering placement of the transmitter and receiver. The frequency dispersion caused by reflection from the ocean surface was calculated using the Bifrequency Function. Table 2 shows the results of frequency spread calculations at two frequencies of 7 kHz and 17 kHz and three sea states (SS). A linear spreading mechanism was assumed with a surface spectrum width of 0.2 Hz 1,2 .

Since there was considerably less frequency spread (3 Hz vs 6.8 Hz) for the lower frequency carrier, the transmitter was designed with a carrier of 8192 Hz and a carrier frequency-to-bandwidth ratio of 4.

The two parameters, doppler spread B and multipath spread L, determine the communication tonal transmit time duration and the receiver frequency resolution. Thus, if a tone of length ω_p with a bandwidth of ω_p were transmitted it would be received as a signal of length (Tp+L) and bandwidth (ω_p+B). The estimates of doppler spread B and multipath spread L at 7 kHz are taken to be 4 Hz and 100 ms, respectively. The optimum pulse duration Tp is set at 125 ms. Thus, at the receiver, a frequency resolution of (B+1/Tp) or 12 Hz is required. The duration of the received tone would, however, be (Tp+L) seconds or approximately 225 ms. The transmitter tones are spaced 12 Hz apart with 125 ms dead time following each 125 ms transmission.

HARDWARE DESCRIPTION

The analog and digital hardware employed to receive and demodulate the tidal data is shown in Figure 2. An 8086 16-bit microprocessor provides all the control and processing required. A 512-point comples FFT processor is used to demodulate the MFSK tones to bits. Time synchronization is provided by the synchroniser module. Other hardware consists of data storage memory, analog hardware in the preprocessor for automatic gain control (AGC), and a voltage controlled oscillator (VCO) for doppler correction as shown in Figure 2.

TIME SYNCHRONIZER

Tidal data is coded into tones before it is transmitted by the bottom unit. These tones which represent 16 bits of data are transmitted for 125 ms followed by 125 ms of dead time (no transmission), to provide word frame synchronization and to allow for multipath decay. Interleaved at frequencies ±1020 Hz and ±216 Hz from the carrier, four pilot tones are transmitted. See Figure 3.

The hardware for the time synchronization consists of a mixer for frequency translation, four bandpass filters, four rectifier-integrators and an 8-bit A/D converter. See Figure 4.

For frequency translation the incoming signal is multiplied with the 6144 Hz local carrier; this process moves the pilot tones to 1028 Hz, 1832 Hz, 2264 Hz and 3068 Hz. To achieve some immunity from doppler shift and the adjacent data tones, the bandpass filters used to capture the pilot tones were designed with a bandwidth of 36 Hz, since the maximum doppler shift envisaged was ±16 Hz and the nearest data tone was located 24 Hz away. Chebyshev filters were chosen for their high roll-off and relative simplicity in design. The outputs of the filters are then rectified and integrated for 125 ms. The outputs of all the integrators are summed and then sampled and converted at the rate of 256 Hz by the A/D converter. See Figure 5.

The 8-bit data is then differentiated using a 7-point finite impulse response (FIR) filter; the acquisition timing marker is derived from the differentiator output after appropriate threshold tests are applied. A Chebyshev-derived 7-point filter, with coefficients truncated to 8-bits and internal arithmetic carried out to 16-bits achieved an accuracy of ±5 ms ±3 . The algorithm used in the software implementation is shown in Figure 6. Threshold tests are performed both on the differentiator output and on the amplitude of the input into the differentiator, before any time estimate is made. Furthermore, to provide some noise immunity, both thresholds must be exceeded for five successive times before the start of the next data batch is predicted.

A 256 Hz clock serves as the main time base for the synchronizer. This clock, which is derived from the CPU master clock, provides interrupts to the CPU every 1/256 second. The CPU then samples the diversity combined output and implements the 7-point Chebyshev differentiator algorithm. Since transmission from the bottom unit lasts 125 ms followed by 125 ms of dead time, the transmission-to-transmission cycle is 250 ms. During this period, the CPU is interrupted 64 times, therefore the time base for the synchonizer is 64. When the thresholds have been satisfied, the CPU corrects the time base to some predetermined value which is corrected for the total delay of the synchronizer.

DEMODULATION OF TIDAL DATA

In the dense incoherent MFSK system employed in the bottom unit, the number of m-ary alternatives M=4, there are N=8 m-ary symbols/baud for a total of 16 bits/baud, and the system uses D=5-fold frequency diversity; thus, 40 data tones are transmitted per baud; interleaved in the band are 4-pilot tones used for time synchronization. As described above, the synchronizer provides the time markers for the start of the data batch sampling for the Fast Fourier Transform (FFT) processor. The FFT processor then forms the 160 (MxNxD) narrow band filters needed for the MFSK tone detection.

Once the start of the data batch has been determined, the CPU samples the data at 3072 Hz a period of 160 ms, resulting in 512 complex samples. For the FFT algorithm, a constant geometry decimation in frequency radix - 2 method was selected. The hardware for the FFT processor is described in the next section.

FFT PROCESSOR

The FFT processor employed in this unit operates as a stand-alone system, only relying on the CPU for input data and start commands. In this way, the CPU is free to continue processing data from the previous batch or calculate the start of the next batch. The FFT hardware employed a high speed arthimetic logic unit (ALU) and a TRW TDC 1010J 16-bit multiply-accumulator for the FFT butterfly calculations. The coefficients necessary were stored in EPROM tables which were made available by the address indexing circuitry. The whole FFT process is controlled by a microprogram which is resident in PROM memory, thus facilitating changes. Two 1 K x 16 buffers were used to provide temporary storage of data during the FFT process. Some pipelining is employed to increase the speed of the calculation. However, in order to keep the implementation simple, most operations occur sequentially. The time taken for a 512 point complex FFT is 30 ms.

The 512 narrow band bins of the FFT are 6 Hz wide. However, the tones transmitted from the bottom unit are 8 Hz wide and 12 Hz apart. The medium, however, adds another 4 Hz to the width of the tones due to doppler spread. Therefore, after the FFT has produced the 6 Hz wide bins, energy from the adjacent bins must be added to the centre bin. Once bin combination is accomplished, linear detection is performed to demodulate the signal. At this point the five diversity bands are lined up and summed. This reduces the original 160 bins to 32 bins. Every four consecutive bins are compared to ascertain the weight of each of the two bits in the 16 bit data word. See Figure 7. The 6 Hz to 12 Hz bin combination, the linear detection, diversity combination, and tone-to-bit conversion are all implemented in software by the CPU.

DOPPLER CORRECTION

The pilot tones used for time synchronization are also detected by the FFT processor, as they fall into the FFT band which is ±1536 Hz. The pilot tones as noted earlier are located 24 Hz away from the nearest data tones. See Figure 3. For doppler correction, the pilot tone bins and the two bins on either side of them are examined for the energy they contain. First, diversity combination is performed by adding the four pilot tone bins and the adjacent bins. The resulting three bins are then compared with templates stored in tables to determine the frequency shift that has occurred. Nineteen templates corresponding to 0 Hz and 2 Hz doppler shifts are stored in EPROM. The CPU makes a comparison with each of these templates and the combined pilot tone bins to determine the closeness of fit. Once a template has been chosen, the CPU issues a command to changes the VCO, thus correcting the doppler shift. Changes are affected only once every two batches to maintain the same correction for both the data word and the codeword.

AUTOMATIC GAIN CONTROL

The gain of the programmable amplifier used in the preprocessor is set by the CPU. Initial gain is decided upon by the CPU depending on the noise in the environment. A maximum of 62 dB gain change is possible. To determine the amount of gain required, the CPU examines the amplitude output of the synchronizer. Gain is controlled by two algorithms in software. One, the fast-attack algorithm, reduces the gain in steps of 6 dB to prevent saturation. The other algorithm, called the slow attack, ajusts the gain ±2 dB, also optimizing the gain to keep the signal in the top quarter of the 8 bit A/D convertor. The algorithm includes safeguards to protect against extreme changes, but when such conditions occur, as in the case of too low or too high a signal, a warning light informs the operator.

ERROR CORRECTION

Tidal data transmitted from the bottom unit is encoded before transmission. Each 16 bit data transmission is followed by 16 bits of code information. A quasi-cyclic, rate 1/2 code is employed. This code has the ability to correct for 3 errors in every 32 bit transmission. Decoding in the deck unit is performed off-line. After the transmission is complete, the 8086 CPU performs the decoding algorithm and notes those occasions where error correction was inadequate.

OUTPUT INTERFACE

The system comes equipped with an RS232 serial line with baud rates from 150 to 9600. Once requested by the operator, the CPU provides all the decoded data and also lists an uncorrected table data, in addition to also providing data concerning doppler correction, gain correction, and time estimation.

CONCLUSION

The acoustic telemetry system was tested in Bedford Basin, on July 12th and 13th, 1982. The basin, having closed boundaries and a muddy bottom, introduced severe multipath and attenuation of the signal. Despite these conditions, error-free transmission was achieved at distances up to 1.5 km. Industrial and shipping noise was much higher and did cause some errors. These were corrected for the most part, except in some extreme cases.

The concepts designed into the equipment readily lend themselves to applications other than hydrographic surveying and oceanography. Because of the high data quality possible, the system can be adapted to a number of civil and military uses. These include the control of seafloor instruments associated with oil exploration and extraction, submarine cable performance monitoring, pollution or water quality monitoring, and the control of submersible vehicles used in ocean exploration and defense.

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TABLE 1. WORST CASE TIME DISPERSION (S = SURFACE REFLECTION, B = BOTTOM REFLECTION). R_n = PROPAGATION DISTANCE. ΔR_n = PROPAGATION LENGTH DIFFERENCES · Q_N = GRAZING ANGLES.

Multipath order n	Description	R_n(Km)	ΔR_n(m)	$\Delta\tau_n$(ms)	θ_n(deg)
0	direct path	1.8288	0	0	0
1	S	1.8291	0.3	0.2	1
2	S-B	1.8654	36.6	24.8	11
3	S-B-S	1.8745	45.7	30.9	12
4	S-B-S-B	1.9660	137.2	92.8	22
-1	B	1.8593	30.5	20.6	10
-2	B-S	1.8654	36.6	24.8	11
-3	B-S-B	1.9658	137.0	92.7	21
-4	B-S-B-S	1.9660	137.2	92.8	22

TABLE 2. FREQUENCY DISPERSION (Hz).

f(KHz)	SS 2-3, $\theta = 3^\circ$	SS 4, $\theta = 6^\circ$
7	0.9	3.0
16	1.9	6.8

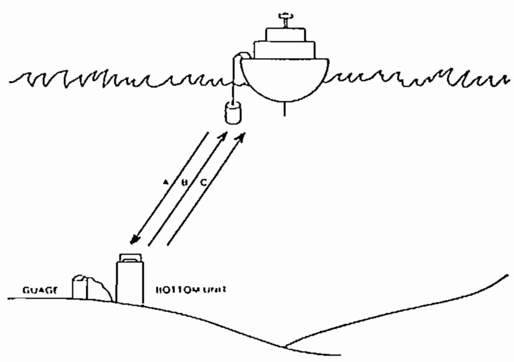

Fig. 1. Acoustic telemetry system communications protocols.

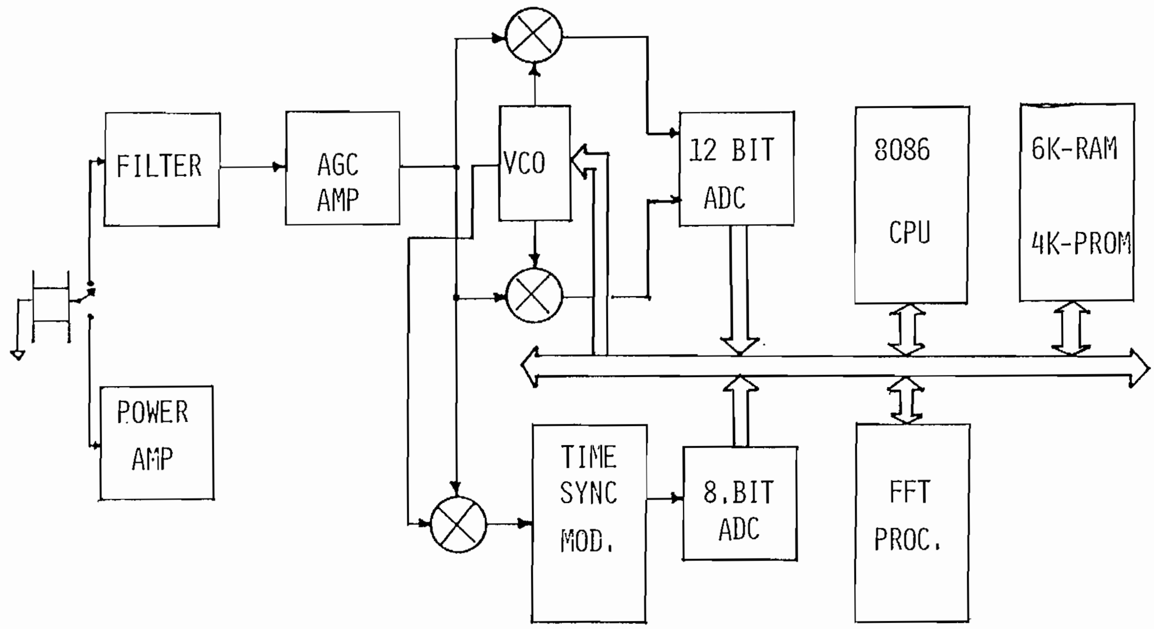

FIG. 2: BLOCK DIAGRAM DECK UNIT

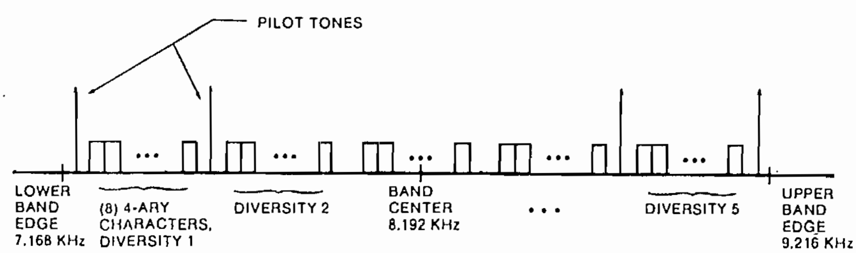

FIG.3: PILOT TONE AND DATA SPECTRAL ALLOCATIONS

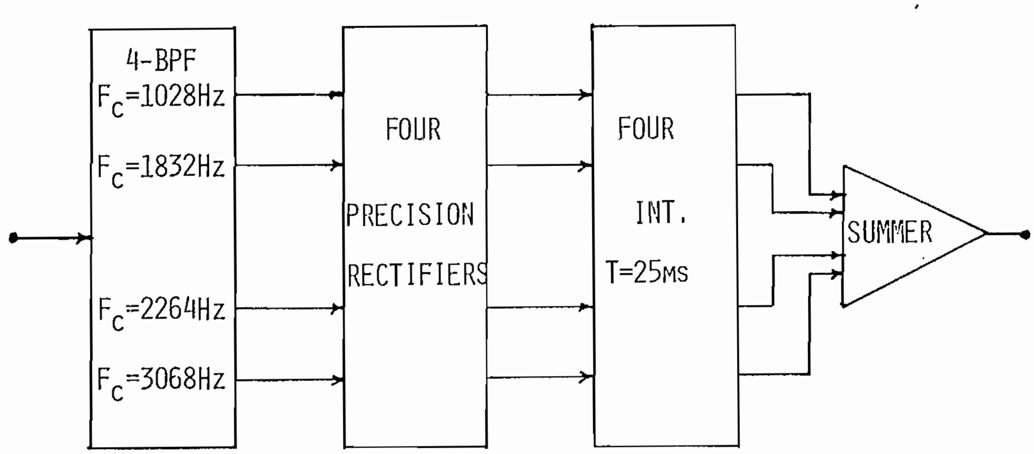

FIG.4: BLOCK DIAGRAM TIME SYNCHRONIZER

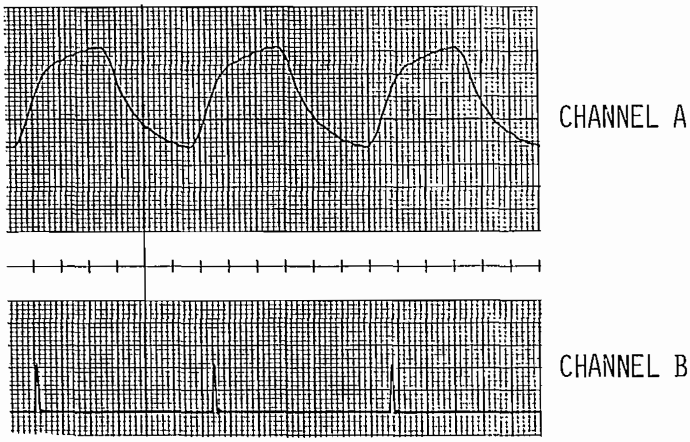

FIG.5: CHANNEL A: PILOT TONE DIVERSITY COMBINER OUTPUT WAVEFORM.
CHANNEL B: TIMING MARKER INDICATING BAUD ONSET TIME.

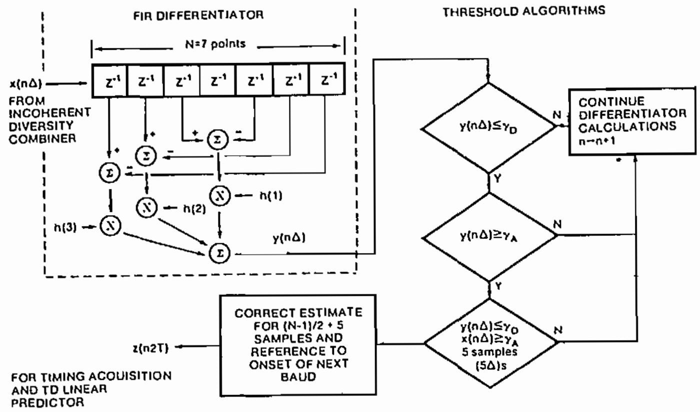

FIG.6: DIGITAL FIR DIFFERENTIATOR AND THRESHOLD ALGORITHMS.
z^{-1} DENOTES UNIT DELAY, $\Delta = 2\pi/\omega_S$, T IS BAUD TIME DURATION
$\gamma_D(<0)$ IS DIFFERENTIATOR OUTPUT THRESHOLD. $\gamma_A(>0)$ IS DIVERSITY COMBINER OUTPUT THRESHOLD.

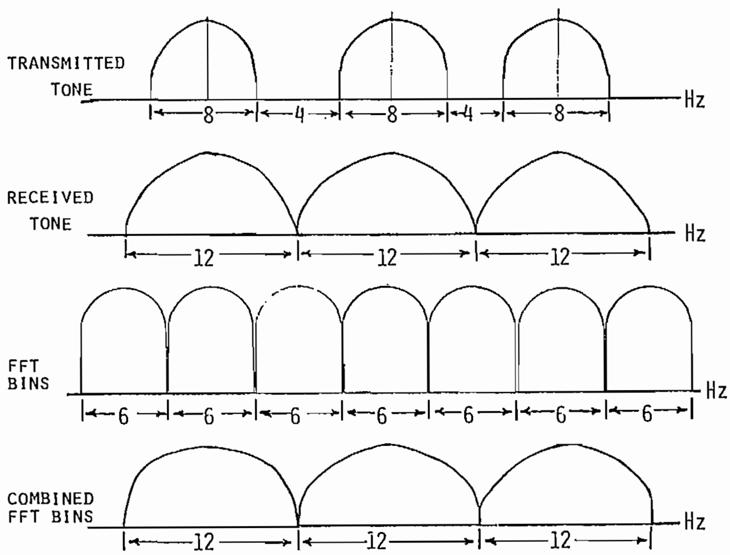

FIG. 7: SPECTRAL RESOLUTION (Hz)

COMMON DATUM CHARTS OF THE MALACCA AND SINGAPORE STRAITS

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ABSTRACT

The Malacca and Singapore Straits provide an important route for maritime traffic. On the existing nautical charts, however, discrepancies have been found in geographical positions due to the different geodetic systems being used on the Peninsular Malaysia-Singapore side and the Indonesian side of the Straits.

In 1977, Indonesia, Japan, Malaysia and Singapore agreed to produce jointly charts of the Straits based on a common datum point to eliminate such discrepancies. The project comprised Phase I and Phase II. In Phase I from 1977 to 1979, three sheets of the Common Datum Charts, two on a scale of 1:50,000 and one on 1:75,000 were produced to cover the Singapore Strait. In Phase II from 1980 to 1982, three other sheets each on a scale of 1:200,000 covering both of the Straits were produced by utilizing the results of a satellite geodetic survey carried out by a joint team.

RÉSUMÉ

Les détroits de Malacca et de Singapour sont situés sur une importante route de navigation. Cependant, on a découvert des lacunes dans les positions géographiques sur les cartes marines existantes, en raison des différents systèmes géodésiques utilisés entre la partie des détroits que longe la presqu'île malaise et celle que longe l'Indonésie.

En 1977, des experts de l'Indonésie, du Japon, de la Malaisie et de Singapour convenaient de produire des cartes des deux détroits en adoptant un élément de base cummun pour combler ces lacunes. Ce projet comportait deux phases. Au cours de la Phase I, de 1977 à 1979, trois feuilles des cartes à zéro commun, soit deux à l'échelle de 1/50 000 et une au 1/75 000, ont été réalisées pour englober le détroit de Singapour. Durant la Phase II, de 1980 à 1982, une équipe conjointe a préparé trois autres feuilles sur les deux détroits, chacune à l'échelle de 1/200 000, en ayant recours aux résultats obtenu d'un levé géodésique par satellite.

BACKGROUND

The Straits of Malacca and Singapore provide an important shipping route connecting Europe and the Middle East with the Far East. The recent increase both in size of tankers and in volume of maritime traffic has caused the necessity of reviewing nautical charts in use and introducing traffic separation schemes in the Straits. The nautical charts were mainly produced from the surveys before World War II.

At the 4th Session of the IMCO Sub-committee on Safety of Navigation in 1967, Japan and Singapore submitted a proposal to establish traffic separation schemes in the Straits. This proposal was, however, rejected as it was considered necessary to carry out a precise hydrographic survey and to provide more aids to navigation there before establishing such schemes.

Under such circumstances, Japan proposed, in 1968, a precise hydrographic survey be carried out in the Straits jointly with Indonesia, Malaysia and Singapore. This project was accepted by the three coastal countries, and in 1969, a preliminary survey was conducted in the Straits, which was followed by a series of joint hydrographic surveys from 1970 to 1975.

Based on the results of these surveys, the existing nautical charts have been duly corrected. However, the topographic features including coastlines, landmarks, etc., charted on those nautical charts are those surveyed independently on different geodetic datums. The charts with such topographic information have caused inconsistency in ship's position fixing in case of using landmarks on both shores of the Straits. Accordingly, it has become a serious concern to produce nautical charts that will eliminate such discrepancies, not only to meet navigational requirements but also to establish IMCO's routing.

Such being the case, representatives of the four countries met in Tokyo from 22 to 26 March, 1977, and agreed to produce jointly a series of charts (Common Datum Charts or CDC) based upon a common datum point to rectify such discrepancy. In April 1977, Memoranda of Understanding were signed between Japan and each of the coastal countries, and thus the project started.

CHARACTERISTICS OF CDC

The CDC itself is not a nautical chart but is a master sheet of a nautical chart to be published by each participating country. The purpose of the project was to produce such master sheets. Accordingly, updating of the CDC will be made by each country by means of updating its nautical chart produced from the CDC.

GEODETIC SYSTEMS ALONG THE STRAITS

The relative discrepancy of topographic features on the existing charts between the Peninsular Malaysia-Singapore side and the Indonesian side is derived from the different geodetic systems based on which respective topographic feature representations are made, as shown in Fig.1.

Namely, the Peninsular Malaysia-Singapore side is covered by the Revised Kertau Datum while the islands of Indonesia facing the Singapore Strait are covered by the Bangka Datum and on the east coast of Sumatera are scattered only such control points independently fixed by astronomical observations.

Therefore, it is necessary to clarify the following geodetic relationships for production of the CDC based on WGS-72 using the Fundamental Point at Pulau Pisang as common datum point as mentioned in the Memorandum of Procedure which will be described later.

- For charts covering the Singapore Strait:

  The relationship between the common datum point (WGS-72) and the Revised Kertau Datum or the Bangka Datum.

- For chart covering the Malacca Strait:

  The relationship between the common datum point (WGS-72) and the Revised Kertau Datum or each of control points at the astronomical observation spots.

Fortunately, the coordinate values of the common datum point on WGS-72 as well as the relationship between the common datum point and the Revised Kertau and the Bangka Datums are already known. Hence, production of the CDC covering the Singapore Strait can be made by compilation of existing source materials.

In case of the CDC covering the Malacca Strait, on the other hand, the relationship between the common datum point and each of the control points on the east coast of Sumatera are unknown so that it is first necessary to clarify such relationship.

OVERALL PLANNING FOR PHASE I AND PHASE II

For executing the production work, a technical meeting was held in Singapore from 10 to 12 May 1977 to work out specifications of CDC and the working

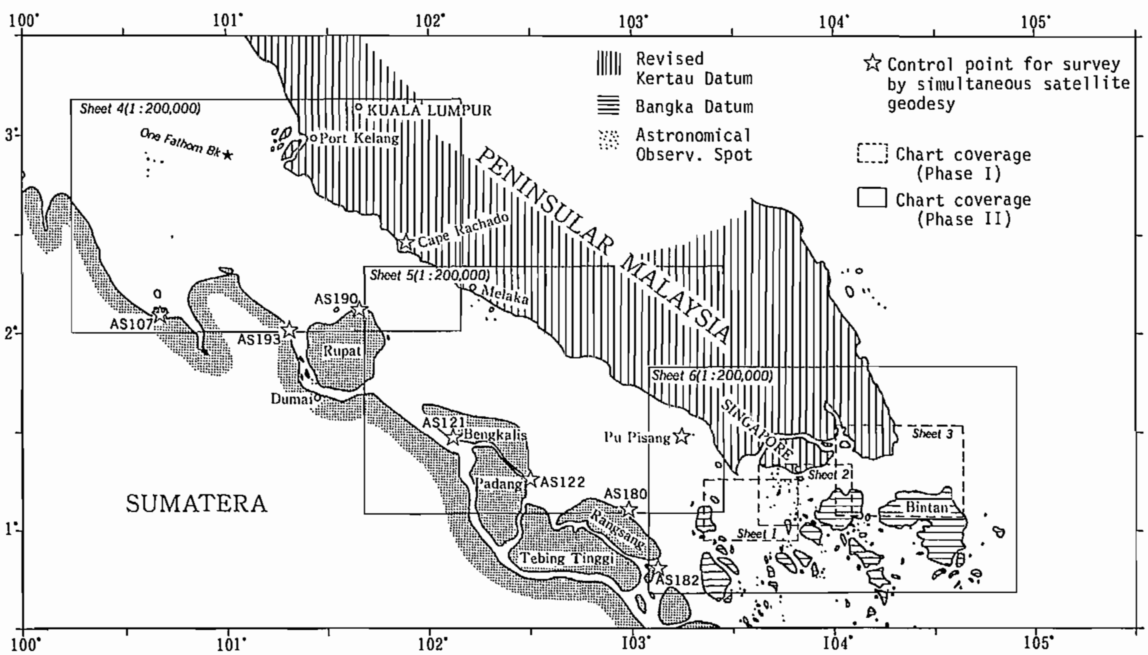


Fig. 1.

schedule. At the meeting, Memorandum of Procedure (MOP) was prepared and signed by the representatives of the four countries.

According to the MOP, it was defined that the joint work would be carried out to produce the CDC covering the area from the eastern entrance of the Singapore Strait to the northern entrance of the Malacca Strait. In Phase I, the main items of work were: to collect and verify all the source materials required for the whole objective area, to produce three sheets of CDC covering the Singapore Strait (two on a scale of 1:50,000 and one on 1:75,000), and to carry out reconnaissance for execution of the work in the subsequent phase.

For execution of the work in Phase II, another technical meeting was held in Kuala Lumpur from 17 to 19 June 1980, and MOP was prepared and signed. According to this MOP, the principal work to be done were the satellite geodetic survey for connecting the astronomical observation spots on the east coast of Sumatera with the common datum point, and production of three sheets of CDC (each on a scale of 1:200,000) covering the Malacca and Singapore Straits.

WORK OF PHASE I

Principal specifications of the CDC and work carried out in Phase I are described below.

Principal specifications of CDC in Phase I

- Common datum point : Fundamental Point at Pulau Pisang with transit satellite derived coordinates 01°28'08".1158N, 103°15'22".6890E as its geodetic coordinates.
- Spheroid to be used : World Geodetic System 1972 (WGS-72) with a= 6,378,135.00m and f=1/298.26.
- Scale and coverage (see Fig.1) :

  Sheet 1

  Scale 1:50,000
  Coverage 00°57.8'N-- 01°16.5'N
  103°21.0'E--103°47.0'E

  Sheet 2

  Scale 1:50,000
  Coverage 01°02.0'N-- 01°20.0'N
  103°36.0'E--104°03.0'E

  Sheet 3

  Scale 1:75,000
  Coverage 01°04.0'N-- 01°32.0'N
  103°58.0'E--104°37.0'E
- Standard parallel : 01°15'.
- Language : English.
- Unit of measurement : Metric system.
- Projection : Mercator.
- Symbols and abbreviations : In accordance with the Standard Symbols and Abbreviations adopted by the IHO. For those symbols and abbreviations on the IHO Standard List for which no technical resolutions has been adopted, those appearing in Japanese Chart No.6011 would be used.
- Colour : In four colours.

Production of CDC in Phase I

Collection of source materials

Each participating country collected all its national and foreign source materials as much as possible and sent them to the Hydrographic Department of Japan. These source materials were then sorted out according to the locality to facilitate the ensuing work. Additional source materials were furnished mainly from Singapore at later stages of the work.

Verification of source materials and preparation of detailed specifications

Technical personnel of the four countries met in Tokyo from 10 to 30 March 1978 and verified and graded all source materials, and prepared detailed specifications for production of CDC. The collected source materials included some of old dated ones originated from the U.K. and the Netherlands. All the source materials were graded according to their dates of survey, geodetic datums and accuracies. Then, planning sheets for the CDC were prepared on which those source materials to be used were indicated.

Detailed specifications not included in the MOP were discussed, and a manual and a standard list for symbols and abbreviations for the production of CDC were prepared.

Discussions were also made on how to adjust the geographical coordinates on CDC of Phase I. It was agreed that a convenient method would be to apply the difference of geographical coordinates of the Fundamental Point at Pulau Pisang in WGS-72 and the Revised Kertau or Bangka Datum (Fig.2) by parallel shifting, which was confirmed to offer no problem cartographically.

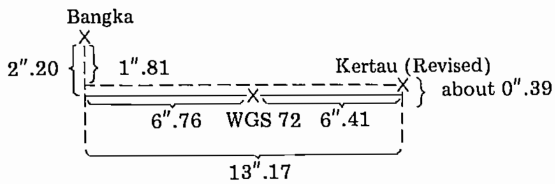


Fig.2. Relationship between geodetic datums at Fundamental point (Pulau Pisang).

Chart compilation

The joint team of the four countries met in Tokyo from 4 July to 29 November 1978, to carry out the compilation of the CDC. The objective of this work was to compile a number of smooth sheets and other source materials into compilation manuscripts which contain instructions for drawing detailed items on the CDC. Some technical problems encountered during the course of compilation, i.e. conversion method of fathoms into metres, limits of bathymetric representation, etc. which were not covered by the manual, were solved jointly by discussion.

The titles of the three sheets of CDC in Phase I were as follows:

- Sheet 1: Singapore Strait - Western Portion
- Sheet 2: Singapore Strait - Central Portion
- Sheet 3: Singapore Strait - Eastern Portion

Investigation of landmarks

The investigation was to check and update the compilation manuscripts by collating the charted landmarks such as conspicuous trees, towers, lighthouses and other topographic features with the actual ones in the field.

The field work was carried out by the joint team of four countries using the Indonesian survey vessel KRI JALANIDHI from 8 to 28 January 1979. Based on the findings, the compilation manuscripts were duly amended by the joint team in Singapore upon completion of the field work.

Reconnaissance for subsequent phase

In the subsequent phase, it was planned to produce CDC covering the Malacca Strait. In this case, it was necessary to connect, as stated before, the common datum point and the control points fixed by astronomical observations on the east coast of Sumatera. Since these control points were established a long time ago, it was necessary to confirm whether these points are in existence and is it possible to carry out satellite geodesy nearby those stations or not.

The reconnaissance was carried out in succession to the investigation of landmarks above, from 23 January to 21 February 1979, by a joint team of the four countries using Indonesian survey vessel KRI JALANIDHI. As the result, eight out of 11 control point marker stones were confirmed existent, and accordingly it was concluded that the satellite geodetic survey would be feasible at these control points.

Preparation of repromats

The joint team of the four countries carried out the work in Tokyo from 10 April to 10 August 1979, to prepare and proofread repromats of the CDC according to the compilation manuscripts. Three different sheets were prepared for the original manuscripts of each CDC, either by drawing manually or by sticking up phototypeset letters and symbols.

Finalization of repromats

The representatives of the four participating countries met in Tokyo from 19 to 21 September 1979, and finalized the repromats of Sheets 1, 2 and 3 of the CDC and the report on the work thereof.

WORK OF PHASE II

Principal specifications of CDC in Phase II

The common datum point, spheroid to be used, language, unit of measurement, projection, symbols and abbreviations and the number of colours to be used were the same as those in Phase I.

- Scale and coverage (see Fig.1) :

Sheet 4

Scale 1:200,000
Coverage 02°00'N-- 03°12'N
100°25'E--102°10'E

Sheet 5

Scale 1:200,000
Coverage 01°06'N-- 02°18'N
101°42'E--103°27'E

Sheet 6

Scale 1:200,000
Coverage 00°40'N-- 01°50'N
103°05'E--104°50'E

- Standard parallel : 02°00'.

Production of CDC in Phase II

Satellite geodetic survey

Out of ten marker stones of control points, i.e. eight confirmed in existence during Phase I and two in Phase II, seven were selected as indispensable ones for construction of the CDC. Satellite geodetic survey was jointly carried out at these seven control points as well as at Cape Rachado lighthouse in Peninsular Malaysia and at Pulau Pisang (Fig.1).

The survey was carried out by the joint team of four countries for 107 days from 25 August to 9 December 1980. Continuous satellite observation of Doppler shifts at the Fundamental Point at Pulau Pisang and simultaneous observation at each of control points in turn were carried out with NNSS receivers of the same type.

The number of passes received at the common datum point was 252 and that at each observation station was around 40. Based on these observations, geodetic coordinates of each control point on WGS-72 were obtained by the Translocation Method (Fig.3, Table 1). To support the survey team in the field, Indonesian survey vessel KRI BURUJULASAD and Singapore survey vessel M.V. MATA IKAN were used.

The final data processing and preparation of the survey report were carried out in Jakarta from 19 to 25 April 1981.

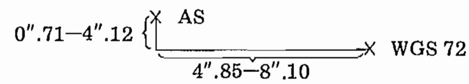


Fig.3. Relationship between Bessel 1841 and WGS-72 (astronomical observation spots).

Chart compilation

The chart compilation was carried out by the joint team of four countries in Tokyo from 25 May to 23 August 1981 in the same way as in Phase I.

The adjustment of geographical coordinates on CDC in Phase II was made as follows:

As for the smooth sheets and land maps based on the Revised Kertau or Bangka Datum, the relationship in Fig.2 was applied to all over the area covered by the CDC as in the Phase I, and the geographical coordinates were shifted parallelly.

As for the smooth sheets and land maps based on the astronomical observation control points, their geographical coordinates were shifted parallelly according to the relationship shown in Table 1.

Thus, the charts based on WGS-72 were constructed. It was also confirmed that such parallel shifting would offer no problem cartographically.

Table 1. Coordinates on Bessel 1841 and WGS-72.

Station name	AS No.	Astronomical	WGS 72	Correction
Tg. Medang	AS 190	02° 07' 06".50N	02° 07' 05".789N	-0".71
		101° 38' 40".19E	101° 38' 46".704E	+6".51
Muara Kubu	AS 107	02° 04' 12".40N	02° 04' 08".279N	-4".12
		100° 38' 19".29E	100° 38' 25".779E	+6".49
Tg. Ketam	AS 193	02° 00' 01".80N	(02° 00' 01".653N)	(-0".15)
		101° 19' 08".59E	(101° 19' 14".188E)	(+5".60)
Bengkalis	AS 121	01° 27' 57".20N	01° 27' 55".488N	-1".71
		102° 06' 37".89E	102° 06' 42".736E	+4".85
Tg. Sekudi	AS 122	01° 15' 36".00N	01° 15' 33".723N	-2".28
		102° 29' 30".19E	102° 29' 35".969E	+5".78
Tg. Kedabu	AS 180	01° 05' 38".10N	01° 05' 34".810N	-3".29
		102° 58' 15".99E	102° 58' 24".087E	+8".10
Tg. Bakau	AS 182	00° 49' 44".50N	00° 49' 40".650N	-3".85
		103° 06' 39".59E	103° 06' 45".149E	+5".56

Note: The values in ( ) were obtained by Point Positioning.

The titles of the three sheets of CDC in Phase II were decided as follows:

- Sheet 4: Malacca Strait - One Fathom Bank to Tanjung Keling
- Sheet 5: Malacca Strait - Tanjung Keling to Western Entrance of Singapore Strait
- Sheet 6: Singapore Strait

Investigation of landmarks

With the same purpose and method as in Phase I, the investigation was carried out by using the Malaysian vessel M.V. PEDOMAN from 19 September to 18 October 1981. Corrections to compilation manuscripts were made in Singapore as in the same way in Phase I.

Preparation of repromats

The work was carried out in Tokyo from 5 January to 31 March 1982 as in the same way in Phase I.

Finalization of repromats

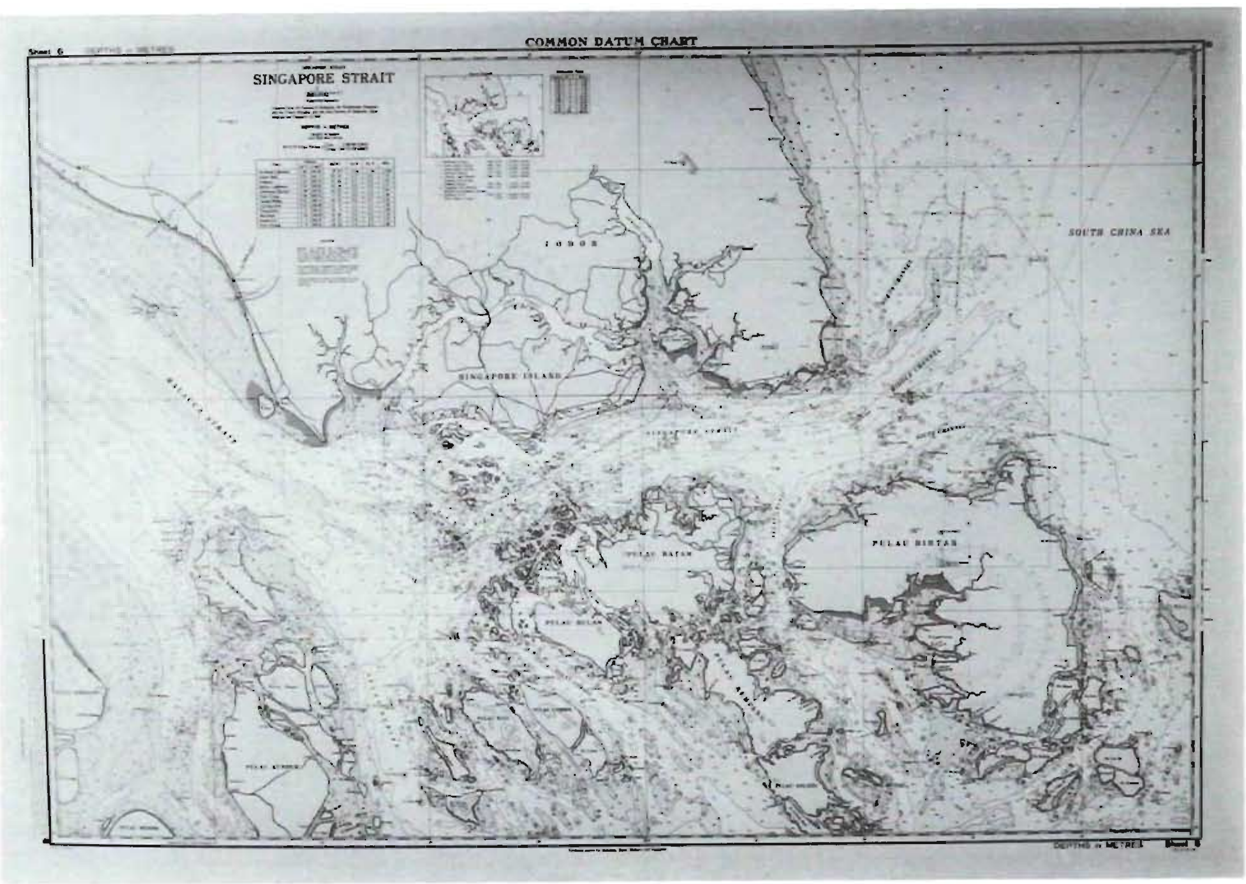
The representatives of four participating countries met in Tokyo from 25 to 27 May 1982, and finalized the repromats of Sheets 4, 5 and 6 of the CDC and the report on the work thereof.

CONCLUSION

After completion of the whole work in Phase I, Japan published charts Nos.751, 750 and 749 based on CDC Sheets 1, 2 and 3, respectively, in February 1980. The chart representation was so modified as to become in line with the Japanese chart style.

Similarly, after completion of Phase II, Japanese charts Nos.621, 622A and 622B were published in September 1982, based on CDC Sheets 4, 5 and 6, respectively.

Thus, the Common Datum Charts of the Straits of Malacca and Singapore will be maintained up-to-date in the form of nautical charts published by the participating countries.



Common Datum Chart Sheet 6

THE ELECTRONIC CHART

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T.V. Evangelatos

Canadian Hydrographic Service

(For presentation at the Canadian Hydrographic Service Centennial Conference, Ottawa, 6-8 April 1983)

The Electronic Chart

ABSTRACT

The Canadian Hydrographic Service began its involvement in collecting and processing digital hydrographic data in the late 60's. During the intervening years the Service has been actively involved in the development, testing and implementation of digital data acquisition systems for the recording and processing of hydrographic data and the processing of digital data in the chart production process. So far the orientation of the overall process has remained towards the eventual production of the conventional nautical chart. The value of the digital data itself for the maintenance of the charts and possibly its eventual use on the bridge was of course recognized.

Today the technological push is towards the increase of microprocessor technology in the instrumentation packages. Electronic positioning systems facilitate computer processing for real time navigation information. Display technology, particularly video displays now make possible the graphic presentation of data stored within a digital database. Coincidentally marine traffic is increasing and the costs of marine disasters are escalating. Therefore it is reasonable to assume that there will be a demand to integrate positioning and collision avoidance radars with navigational information contained on the nautical chart. This paper will review this technology and consider the future role of information contained on the nautical chart as it will be used in the electronic systems on the bridge.

La carte électronique

Sommaire

Le Service hydrographique du Canada a commencé à recueillir et à traiter des données hydrographiques numériques à la fin des années 1960. Depuis lors, le Service a participé activement à l'élaboration, à l'essai et à la mise en place de systèmes d'acquisition des données numériques qui permettent d'enregistrer et de traiter les données hydrographiques et de traiter les données numériques aux fins de la production des cartes. Jusqu'ici, le processus global est resté axé sur la production de la carte marine classique. Bien entendu, on a reconnu la valeur des données numériques pour la mise à jour des cartes et, en fin de compte, pour un usage probable sur la passerelle.

Aujourd'hui, le progrès technique se traduit par une utilisation de plus en plus grande du microprocesseur dans les groupes d'instruments. Les systèmes de positionnement électroniques facilitent le traitement informatique des données aux fins de l'obtention de renseignements sur la navigation en temps réel. La technique d'affichage, notamment l'écran vidéo, permet maintenant de représenter graphiquement les données emmagasinées dans une case de données numériques. Dans le même temps, le tratic maritime ne cesse d'augmenter de même que le coût des catastrophes maritimes. Par conséquent, nous pouvons supposer à juste titre que les navigateurs demanderont à ce que les données relatives aux radars de positionnement et anti-abordage soient intégrées aux renseignements sur la navigation fournis par la carte marine. Dans le présent document, nous examinons cette technique et envisageons le rôle futur des données fournies par la carte marine dans la mesure où elles seront utilisées dans les systèmes électroniques sur la passerelle.

PREFACE - A Navigation Day-Dream

Imagine the scene on the bridge shortly after the year 2000. Newfoundland and the federal government have recently reached agreement on offshore resource ownership, and the tanker, "Concord Yemani", light out of Bahrein, is crossing the Grand Banks en route to Come-By-Chance. At 2200 that night the second mate is on the bridge getting the consolidated Notices to Mariners for the Atlantic coast by telex from St. John's radio; he records them on a discette which he loads into the Electronic Chart Storage Controller, and thus automatically updates the chart data in storage. The Captain comes out of his sea cabin, and notes that on the real time chart video display there is a strobe flashing on the Virgin Rocks, with a warning that on the present course and speed made good the ship will pass within 2 miles of the 30 m contour in 18 minutes time. The mate on watch assures him he is keeping an eye on this while he manoeuvres to clear a group of draggers, and as has become quite a habit with him, he again comments on how useful it is to have the NAVSTAR/LORAN driven electronic chart look after position plotting, leaving him free to concentrate on avoiding collision. The Captain is satisfied, and goes to the auxiliary video display and calls for the ephemeris to display tomorrow's time of sunrise and sun's true bearing (for a gyro check), followed by tides for the day computed from harmonic constituents included in his Atlantic coast chart disc. He also checks "S.D." for details of reporting and traffic regulations for Come-By-Chance. Then he calls up the Chart at 1:5,000,000 and zooms the scale until Placentia Bay fills the screen. He superimposes fishing areas in green and traffic control zones in purple, then erases them to have a clearer look at the depths. As he scans over the chart up to Come-By-Chance, enlarging the scale as he goes, he finds he cannot go above 1:24,000 for the outer approaches as that was the scale of the original survey. The Captain uses the "track-plan" routine to put on his courses for the next day. He selects a 10m keel clearance and 5 cables lateral clearance; flashing danger strobes come up on a couple of points where these are not satisfied. Once he is happy with his planned track he transfers it to the chart controller so that it will appear on the real time plot when the ship reaches that area.

As the ship rounds Cape St. Mary's next morning and approaches Argentia traffic control, the mate on watch superimposes the digital radar output in green on the chart video display, and by radar joystick he matches the radar coastline to the chart coastline, thus removing a small residual ASF correction in the Loran-C that is driving the ship position. He confirms at a glance that there are no islands three miles ahead up the coast, so these radar echoes must be fishing boats. As the ship nears Argentia they pick up the shore radar re-broadcast, and superimpose that video image on the chart in orange to keep track of other ships in the vicinity not yet on their own radar. At the same time the captain puts the "track profile" on the auxiliary display; this shows a graph of the under-keel clearance along his planned track, with the ship's sounder graph superimposed.

An hour later, in preparation for berthing at the loading dolphins, the Captain locks on the differential Loran-C monitor for maximum accuracy with respect to the dock, and switches the real time display to docking mode. At a scale of 1:1,000, (no soundings) this shows the ship 15 cm long, making it easy to judge her orientation and distance from her berth.

Mr. Smallwood is first aboard the ship when the gangway goes down.

<u>THE ELECTRONIC CHART IS COMING</u> as we celebrate the 100th Anniversary of the Canadian Hydrographic Service and look back to the beginning of the Service and the ways and means used to collect data and present it to the mariner; it is equally of interest and of value to look ahead to where we are going. The nautical chart has evolved from a map showing the shoreline and prominent features and depths along navigation tracks, to the depth contour, more shoreline information, and then the cultural features as settlements developed. Today, the nautical chart is a comprehensive document showing not only detailed depth contours, the shoreline and the foreshore information, but also considerable additional navigational aid information which may be relevant to navigation, notes about the tides and currents, harbour information, etc. As the chart has evolved it has become more cluttered with information; consequently the challenge to the cartographer is to show more and more and more information on a document which is limited in scale and size. This necessarily means that at some point information has to be dropped to make space for other higher priority information. It means that colours need to be used, symbols need to be developed to graphically show more information in a small space, and that eventually special purpose charts are required. Charts for offshore navigation, recreational charts, fisheries charts are examples.

On the bridge of a ship the nautical chart today is an important document for navigation, for recording the tracks of the ship, and to carry the additional notes that a mariner or fisherman may add to his chart relevant to his particular mission. The nautical chart as it is now will continue to be used for many years into the future. We are not suggesting that the nautical chart will cease to exist in the near future. However, it does have limitations, and current technical developments can possibly be applied to mitigate these.

Television today is an important form of information transfer, and along with television a whole array of new developments are occurring showing the direction of the future in terms of using the electronic technology to show visual information. For example, you do not go very far today without seeing an arcade with video games. Well, there are other applications, less profitable perhaps but nevertheless more practical, of the same video technology. For example, Ford Motor Company is now demonstrating a video map which is placed in the car and keeps track of the car's position relative to the map and shows the driver where he is within the streets of the city. Texas Instruments have developed simulators and are in the process of developing equipment for the video display of digital terrain models of the earth so that the pilot in the cockpit, if he loses his view of the ground, has a digital version of the terrain shown to him on the video display within the cockpit.

A year ago we field tested a Japanese video plotter attached to a Loran-C receiver onboard C.S.S.. "Dawson". It had a 30 cm screen, and displayed the ship's track from Loran-C on mercator projection at any scale from 1:10,000 to 1:1,000,000 adjustable instantly by zoom control. Way points entered in the Loran-C receiver microprocessor were displayed on the plotter, and the operator could tag points on the plot by various symbols positioned by a cursor. The plotter stored several hours of track in its own memories, and these could be backed off onto a casette recorder to be stored for replaying onto the plotter at a later date. The most impressive demonstration of its usefulness came when the release of a seabed transponder failed, and the ship had to drag for the mooring. The ship's track when laying the transponder and its 600 m ground line was replayed onto the plotter at 1:10,000 scale, and with this it was childs' play to con the ship in dragging for the ground line and when that parted, successfully grappling the mooring itself. It was successful because the Captain had an immediate, continuous, complete record of the ship's track, without plotting a single fix. He had plenty of time to manoeuvre the ship, keep an eye on the work on deck, and watch the radar for other traffic, because he did not have to dive for the plotting sheet every minute to update the ship's position.

The concept of a video chart is not a new idea. Some years ago Sperry (Tiblin 1977) added chart information to collision avoidance radar. The U.S. Coast Guard are evaluating video charts now. (Puckett H. 1978, Erickson 1982). Companies such as Texas Instruments and Navigation Sciences Inc., of Washington D.C. have done contract and in-house research on electronic charting (figure 1.)

What is the electronic chart? Is there a firm definition of the electronic chart at this time? No, it is too early to see what the end product will be. The term is used for discussion purposes only. At its most elementary level it could be envisioned to be that information which is used on a video display where the Loran-C position and the radar are integrated and some shoreline information is added to the display, possibly also containing navigational way points. At its most comprehensive level, it can be envisioned as a digital data base of the bathymetry, other navigational information, shoreline, sailing directions, nautical publications and Notice to Mariners with a data manipulation system that has the ability to zoom in or specific information, select certain information, integrate computations from several sensors, compare measured depths to the depths in the digital data base or project and identify possible hazards, etc. Its development will depend on the pace of technological advances, on the introduction of Navstar GPS as a universal, precise navaid, and on shipowners and legislators being convinced that it will make navigation safer and more efficient. In this paper we would like to show how the electronic chart can help the mariner and to discuss the impact of advancing technology on the electronic chart. We do this with the idea of generating discussion rather than laying down a cut and dried program.

<u>FEATURES OF THE ELECTRONIC CHART</u> No one supposes the Electronic Chart will simply arrive in 1990, fully developed and with every imaginable feature. Instead it will evolve from the present limited starts, and at anytime, different versions will have as much variety in features as there are in automobiles. However there are some basic features which will be common to all electronic charts, and we will consider those after making a general comparison with paper charts.

In concept at least, the electronic chart has advantages over paper charts. One is flexibility - the ability to move from one part of the ocean to another by slewing a joystick, or automatically following the ship, and to zoom the scale by press-button control. Perhaps the most important is the ability to display the ship's position on the chart, and to maintain a continuous plot with the full accuracy of whatever navaids are being used. The navigator can see at a glance where he is, without putting his head over the chart table and plotting a fix, and he will be able to compare the radar directly with Loran-C/Decca/Navstar G.P.S., and so solve positioning inconsistencies. Another difference is that the video display can be animated, to put a red flasher on a navigation hazard; to show a pulsing blue wave on a tide rip; to show the track of bergs and growlers. It can be programmed to display notes at appropriate times; for example that "strong tidal streams occurs three hours after high water i.e. at 1997/03/0400Z".

The video display also has drawbacks. The resolution is not as good as on paper (but it is arguable that the display should be kept bold and uncluttered so that it can be assimilated quickly). All chartwork at present done by pencil and parallel rule will have to be done electronically on the display (but that should cause the new generation no trouble). If a component fails you lose the chart (but you can also lose radar and the ship's steering gear). Perhaps the greatest problem will be that flexibility has an inevitable twin-complexity; it will be vitally important to make the electronic chart user-friendly, and to have some international set of uniform standards and procedures.

The electronic chart system comprises a great many features. Here are some of them, starting with the video display:

The Video Display of the Chart The projection can be a choice. The computer will generate rhumb lines or great circles, so Mercator or Gnomonic are not essential.

The scale can be varied from very small (which requires that the computer generalize the data) to very large. However the scale of the original survey must not be exceeded, or if there is good reason to exceed it, this fact must be flagged, perhaps by pecking or blurring the lines. Evidently the data base for such a chart has to cover the area of the smallest scale chart and yet have the detail of the largest scale - a formidable problem in data storage and manipulation.

Because the resolution is less than that of the paper chart, less data can be displayed and some selection will be necessary. But critical features such as shoreline and conspicuous objects, shoals, critical depth contours, fixed and floating aids, power cables in anchorages, etc., must always be shown.

Optional data should be available on demand. A minimum set for a complete electronic chart is everything on the paper chart, grouped under classifications such as "depth contour," "type of bottom", "tides and currents", "traffic control", etc. Other features not always on the paper chart, such as "special fishery information", "main shipping routes", "distribution of icebergs for the month of June", could be added for display one at a time.

Survey data recorded on NAD 27 datum should be transformed to WGS '72, if necessary by the electronic chart itself.

Displaying the Ship's Position Video plotters are already driven from TRANSIT SATNAV plus log and gyro, or by LORAN-C, etc. The continuous track they generate is a great advance over occasional hand-plotted positions in detecting gross errors, or the effect of currents, etc.

To equal the accuracy of the paper chart, Loran-C fixes must be corrected for land - path errors.

A visual fix by cross bearings (or range and bearing) could be plotted by putting a cursor onto the object and entering the range and bearing on the control panel; this would display a range arc and bearing LOP on the video.

It is fundamentally important that the electronic chart is integrated with the radar display, preferably by superimposing a digitized radar image (with brightness control) on the chart video. This will help to identify radar targets, especially when the shoreline is low or masked by sea ice, and will distinguish between radar echoes from buoys and from other ships. By joystick control, the radar image (and the ship's position that goes with it) can then be moved to correspond with the shoreline, thus eliminating residual errors in the radio navaid, which will thereafter serve to keep the radar on the target by dead-reckoning the ship along the track. The OOW can check at a glance that this is in fact happening.

Making Chart Corrections The basic chart data must be on a protected, read only, memory; this will be revised when major changes occur, just as a paper chart is reprinted. Automatic chart corrections will be applied from a temporary correction memory which the mariner replaces each time he obtains a fresh set of corrections.

Planning a Passage Instead of using a pencil, parallel ruler, dividers, and a whole chart folio, the mariner will plan a passage by first zooming down to a scale small enough to show both the port of departure and the destination, and run the track cursor along the proposed passage in order to read out total distance and given speed, the time on passage. Then he will increase scale and re-frame the chart to cover the first leg of the voyage and put a cursor at each end of the first leg. The computer will draw a line between, and in a sophisticated model chart, it will flash any hazards within a selected distance of the track. After displaying and checking auxiliary information such as tidal streams and fishing vessel concentrations for that time of year, the mariner presses "hour" to generate ticks at one hour intervals along track, and then "store", which records the track on the passage discette, which can then be filed until the ship sails. Once that route has been proved satisfactory, the passage discette can be re-used indefinitely.

Ephemerides In a sophisticated model, navigation programs can be selected from a wide range, and an annual ephemeris tape will update sight reduction calculations; compute time and the sun's true bearing at sunrise and sunset; compute tides from stored tidal constituents; etc. Similar programs will provide magnetic variation; Omega diurnal correction; geoid height for Transit Satnav corrections; geographic datum transformation, etc.

Track Record In addition to a continuous record of ship's position, the electronic chart logger could record the scale used and class of information being displayed at any time, plus a digitised radar picture at intervals. Stored in a sealed unit "black box" this would be a more reliable record than a pencil track on a paper chart plus pencil entries in the ship's log.

The Hardware Technology The hardware that could be used to build an electronic chart is more or less available now. The cost of the hardware alone is probably still too high to make such systems attractive to many users. The cost of developing general purpose software is also very high at this time, but with current and predicted reduction in hardware prices of over 20% per year, it should not take very long for the cost of the hardware components to reach a reasonable level. The foundation of the software is being laid through the construction of special purpose systems and from the progress being made in computer-assisted cartography and hydrography.

The major components of the electronic chart as currently visualized are:

- Microprocessor central processing unit (CPU)
- Data storage medium
- Electronic display
- Radar and positioning systems

Microprocessors Today's low-cost computer is typically an 8 bit microprocessor with a capability of executing around 1/2 million instructions per second. Such a chip sells for about $5.00. Chips that can run up to 10 times faster are now available at slightly higher cost. By 1985 it is predicted that the 8 bit microprocessor will have been supplanted by the 16 bit chip or 32 bit. The major obstacle in moving to the larger chip is not the extra cost of the hardware but the very large variety of existing and relatively inexpensive (often free) software for the 8 bit units. Current 32 bit microprocessor chips range from $400 up and we expect the electronic charts will be based on this technology. Of course to the cost of the chip must be added memory and hardware to control the various peripherals and perform other functions; the cost of the chip is only a small part of the overall computer system cost.

Memory The striking decrease in cost of the hardware for storing digital data over the past decade has been a significant factor in creating the microprocessor revolution. For some types of memory storage the costs have dropped by a factor of 100 and this trend is expected to continue for the forseeable future.

The electronic chart will employ different types of storage. These are illustrated in Figure 1. The primary memory, packaged with the CPU, consists of a main memory and a cache. Main memory will contain the program and data currently being processed. Faster memory costs more, and the use of a high speed cache memory between the slower and cheaper main memory and the CPU is a way of speeding things up in an economical fashion. As memory gets faster and cheaper, the cache may not be required. At present primary memory is constructed from semi-conductor arrays which are still too expensive for storage of very large amounts of data; this creates the need for the secondary, mass storage, memory.

The mass storage memory could probably be a magnetic disc, but in the future the optical disc may be more attractive due to its greater capacity. It may be feasible to store all the hydrographic charts of Canada on one 30 cm diameter disc!

Auxiliary or archival memory is used for data that is not accessed very often. It must be reliable and relatively low cost. Although magnetic tape is typically used, this medium might not be suitable for shipboard use. A potential application of the archived memory might be to automatically log the vessel's track and any other important activity that can be monitored. In the event of an accident or other mishap the record would be available for analysis.

Electronic Displays The specification, design and selection of the display and the operator's console will be a crucial element in the design of the electronic chart. A high resolution colour display is mandatory for a general purpose system, although single colour, medium resolution displays may be adequate for special purpose systems. High resolution means at least 1000 line elements in each axis. Our work in computer-assisted cartography suggests a minimum dimension of 40cm square. With current technology these requirements can only be met with a cathode-ray tube (CRT) type of display. Liquid crystal and plasma displays are being developed but it will be some time before they can compete with the CRT in terms of size and resolution.

Liquid crystal and plasma displays are flat, operate at lower voltages, consume less power and are more compact than the CRT display.

Radar The mariner's first reaction upon hearing about the proposed electronic chart is that it must show the radar information. Two choices exist: attempt to overlay the radar "picture" on the electronic chart display, or alternately add the chart data to radar display; the latter would require a major redesign of the radar system, and therefore it is felt that the first method would be easier and less costly.

Two techniques to add the radar information to the electronic chart display have been suggested. The radar returns could be digitized, processed to match the scale of the electronic chart display and then added to the display. The second technique would use a scan converter to convert the radar picture to a raster display, which would also be scanned and added to the electronic chart display. Both of these approaches require investigation.

THE CHS TECHNOLOGY BASE In the 1950's the CHS introduced electronic navigation and positioning to the field surveys and in the 1960's the computer was added to the field survey operations. From those meagre beginnings the use of the computer has increased to where today it is used extensively for survey computations, data logging, processing and plotting. The result is an ever increasing accumulation of digital hydrographic data.

In the late 1960's, automated plotting was introduced in CHS chart production to handle the mathematical functions such as navigation lattices, borders and grids for the nautical chart. The digitizing was developed so that graphic data could be converted into computer compatible form. The equipment that the CHS now has is flexible, interactive and is effectively used for chart production. The introduction of interactive graphics in the late '70's was an important innovation in the chart production process because this put into the hands of the cartographer the same decision-making power that he had before in compiling the charts manually. Interactive chart compilation is possible provided the cartographer has available to him the data in digital form to work with. One of the holdbacks in this process is that most of the hydrographic data base required for chart production is still in graphic form.

Today we see the automated logging of digital hydrographic field surveys where the position and depth and time are recorded and processed and the field sheet automatically plotted in the field. Currently the software is being developed to handle the automated contouring of the digital hydrographic data. Charts are compiled and the compiled information is digitized, interactively edited, and automatically drawn so that the colour negatives used in the chart printing processes now are automatically drawn on high resolution plotters such as the Gerber 32 and the Kongsburg plotters. The Canadian Hydrographic Service is in the process of developing a digital hydrographic data base and a digital chart data base as a result of these ongoing production processes. The question to be addressed is whether these data bases will be appropriate for the customer who doesn't want the hard copy version of the data, but the digital data itself for an integrated navigation system on the bridge.

The data base used for the electronic chart may just be a cataloguing system which simply accesses digital versions of our existing charts with their overlapping scales and limited coverage. But since the electronic chart will be more flexible than the paper chart, both in scale and in selecting certain classes of data, it is capable of containing much more information than the paper chart does. In principle it is possible to provide a completely general data base, conceivably containing all available hydrographic information. Whether this is practical is another matter. The choice between a paper chart oriented system and a general system is an important question since many years will be needed to build up the digital data base.

It is not the CHS's responsibility to research and develop the electronic chart for use by mariners. However, if we are to have a data base which will meet the needs of the future, we need lead time to begin its development and to bring it into place when the technology becomes available for the mariner. Therefore, there are certain areas in which we will conduct research, in order to give direction to our data base development. We need to know what will be required of the data base. We need to develop the procedures for selection and generalizing the data. We need to know what kind of symbols will be used on a video display; they will not necessarily be the same symbols used on the traditional nautical chart. We need to plan the production, maintenance and distribution of the digital chart data base. Although we do not see the electronic chart coming into full use for many years, we recognize that it is important to start to plan for it today.

Hydrographers and cartographers have only begun to use and be comfortable with computerized systems. The expertise and experience established in applying automation to hydrography and cartography will be an asset in the development of the electronic chart. We will be conducting a study to review the state of the art at determining what is happening in other offices and companies around the world, in developing and applying the technology. We will also be conducting pilot projects to provide more specific information relevant to the development and specification of the data base. A prototype electronic chart is now being planned to simulate the use of a commercial electronic chart. The objectives of this project are to develop:

1. data base specifications
2. minimum standards for the use of the hydrographic data base
3. standard video symbols and conventions

INTERNATIONAL IMPLICATIONS As versions of the electronic chart evolve over the next decade, the world's hydrographic offices will face new situations, and some new challenges. Their chart production monopoly, based on selling charts as a government service at less than cost, will disappear as industry begins to produce electronic charts. Industry will ask for a logically organised, complete, data base. If there are no guidelines, each manufacturer will make his own selection of which chart features should be shown, and his own selection of which chart features should not be shown, and his own choice of colours to identify them and symbols to portray them. In an extreme example he may eliminate everything except the shoreline, and blow up a 1:50,000 scale survey to a 1:5,000 scale display.

Issues that the world hydrographic offices need to recognize include base format; minimum standards for the use of hydrographic data; colour code conventions for various features; and standard symbols. These matters cannot be finally settled until electronic charts have been produced and used, and even then regulations that are too strict are undesirable as they tend to stifle development. But general guidelines need to be established before bad practices become entrenched, and difficult to undo. The air industry is ahead on this, with, for example, specifications for a computer readable IFR cockpit display (ARINC 1980). We cannot establish standards before we know a fair amount about how an electronic chart will work.

CONCLUSION The present generation of hydrographers and cartographers have participated in the development of hydrography and cartography from a manual operation using optical and mechanical instruments to one that which today makes extensive use of electronic and computer technology. Like other information sciences it has and still is experiencing a technological and information explosion. It is inevitable that the limits of scale and size of the nautical chart will be overcome by computerized information bases. The studies and seminars over the past year are only a beginning, but we hope they will stimulate ideas and further work in this new and exciting frontier of hydrography.

MEMORY HIERARCHY

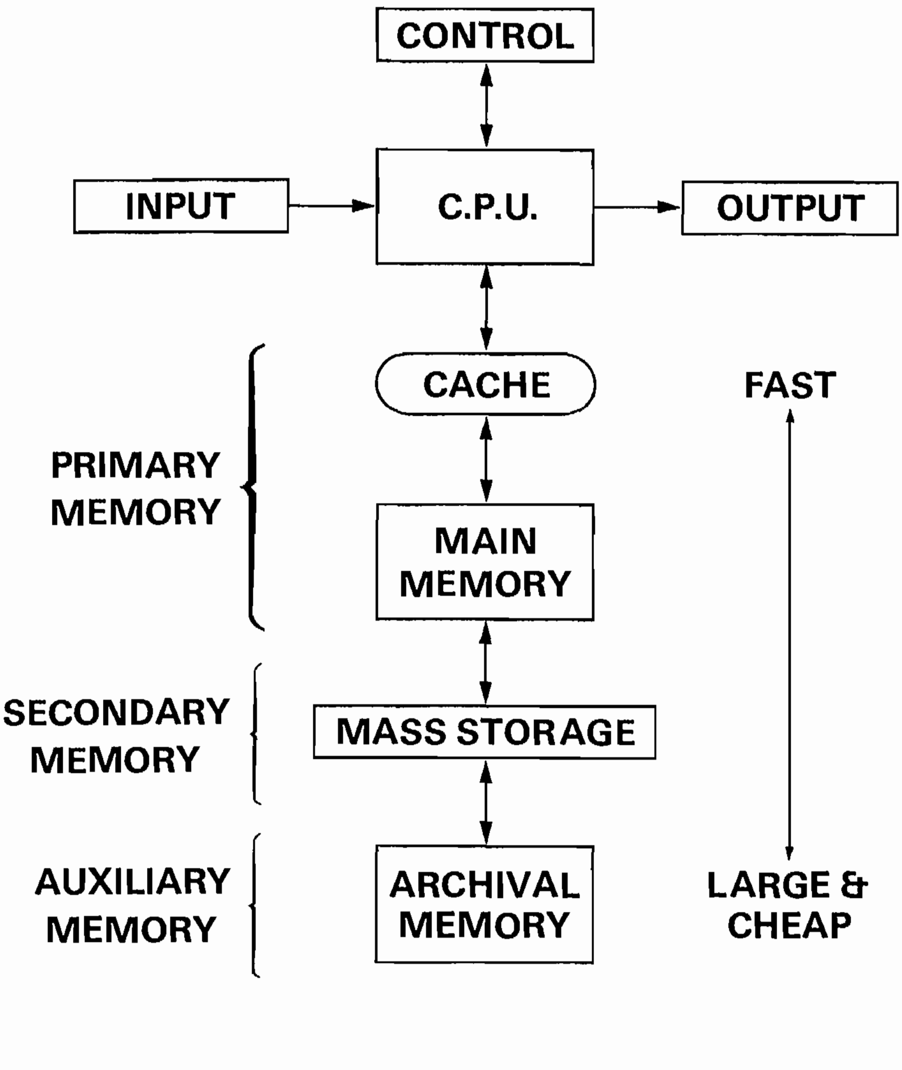

Figure 1

THE USE OF LORAN-C IN THE CANADIAN FISHING FLEET

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ABSTRACT

Since its production, LORAN-C has played an increasingly important role within the Canadian fishing fleet. Four different economic factors have been responsible for this changing role: diminishing catches, and more effective sonar systems. The number of fishing vessels using LORAN-C is estimated, based on licensing data available on the Canadian fleet. Equivalent estimates are made for the U.S. fishing fleet. Features now available on the newest LORAN-C receivers provide a hint of what can be expected in integrated navigation systems in the future. The constraints affecting the amount that vessel owners would be willing to invest in upgrading their LORAN-C systems is outlined. Finally, the possible impact this may have on the Canadian Hydrographic Service is discussed.

RÉSUMÉ

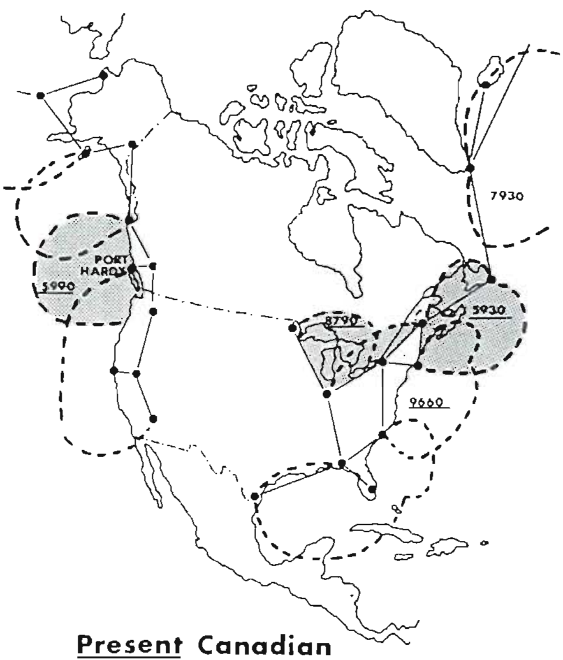
Depuis sa création, le réseau Loran C joue un rôle de plus en plus important au sein de la flotille de pêche canadienne. Cette évolution est due à quatre facteurs économiques différents; la baisse du prix des récepteurs, la hausse du côut d'exploitation et du prix d'achat des bateaux, la baisse des prises et l'apparition, sur le marché, de systêmes sonar moins chers et plus efficaces. L'auteur de la présente étude évalue le nombre de bateaux de pêche utilisant le réseau Loran C, sur la base des données relatives à la délivrance des permis aux pêcheurs canadiens et fournit des estimations équivalentes pour la flottille de pêche des États-Unis. Les caractéristiques des récepteurs Loran C les plus récents donnent une idée de ce qu'on peut attendre des systêmes de navigation intégrés, dans un proche avenir. L'auteur examine la répercussion possible de ces perfectionnements pour les cadres SHC (numériques ou autres). L'auteur termine en s'efforçant de préciser le maximum des montants que les propriétaires de bateaux seraient disposés à investir pour moderniser leurs systêmes Loran C.

INTRODUCTION

LORAN-C is provided for users in Canadian Hydrographic Waters through a cooperative arrangement between the U.S. Coast Guard and the Canadian Coast Guard (who operate the transmitters), and the Canadian Hydrographic Service (who provides calibrated LORAN-C lattices on Canadian Hydrographic charts).

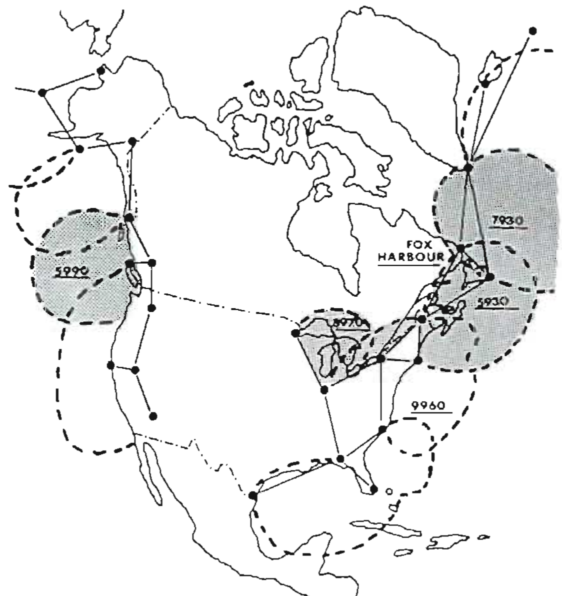
Figure 1 shows the present LORAN-C coverage in Canadian waters. On the west coast the 5990 chain was commissioned in August 1977, with the Port Hardy transmitter being added in November 1980. On the east coast the 9960 chain (which provides good coverage in the Bay of Fundy and the southern half of the Scotia Shelf) was commissioned in September 1978. The 5930 chain (which extended good coverage over the Bay of Fundy, all of Scotia Shelf, Cabot Strait and most of the Gulf of St. Lawrence) was commissioned in April 1980. Some coverage south of Greenland is presently available from the 7930 chain. A new transmitter at Fox Harbour, Labrador, scheduled to be operational within the next few years, will be used to extend the coverage of the 9960 chain, and to form a new Labrador Sea chain (with Cape Race and Angissoq), which together will extend LORAN-C coverage over all of the Gulf of St. Lawrence, The Grand Banks of Newfoundland, and north over much of the Labrador Sea, as shown in Figure 2.

Who are the users of LORAN-C in Canadian waters? In this paper we look at one class of user - the fisherman. We have taken two approaches. First we develop a user profile, based on Canadian fishing fleet statistics, and place this in a North American context by considering U.S. fishing fleet statistics as well. Secondly, we look at LORAN-C receivers, and enhancements to them which may occur in the near future. Based on these two considerations we suggest some implications for the role of the Canadian Hydrographic Service in providing appropriate LORAN-C information to its users.



Present Canadian LORAN-C Coverage

FIG 1



Future Canadian LORAN-C Coverage

FIG 2

THE CANADIAN COMMERCIAL FISHING FLEET

In Canada, data on our fleet of fishing vessels is available from Transport Canada, and from the regional licensing boards of the Department of Fisheries and Oceans.

Transport Canada produces an annual inventory of all registered vessels in Canada, called the List of Shipping (MOT, 1982). This inventory is divided into two categories: fishing vessels, and others. The data include the name of the ship, the owner, the port of registry, the type of ship, it's length, gross tons, and net tons. Gross tonnage is defined as the capacity in cubic feet of the space within the hull and the enclosed space above deck available for cargo, stores, fuel, passengers and crew, all divided by 100, where 100 cubic feet is defined as equal to 1 gross ton. Net tons are defined as gross tonnage less the space consumed by crew and machinery.

Files on annual fishing vessel licenses are maintained by the Newfoundland [Russel, 1982], Scotia Fundy [Jones, 1982], Quebec [Berube, 1982], and British Columbia [Hsu, 1982; Carson, 1982] regional licensing boards of the Department of Fisheries and Oceans. A copy of the licensing form is shown in the appendix. The Newfoundland, Scotia Fundy, and Quebec files are being maintained annually, whereas since 1979 the British Columbia files have not been maintained for every element on the form. It is from these files that our profile of the distribution of electronic equipment on the vessels was derived.

Table 1 shows a distribution of vessels by province for Atlantic Canada, by tonnage and by electronic equipment on board for 1979-1980. This indicates that of the 33,530 vessels found in the Atlantic fleet, LORAN-C was the third most used electronic device, superseded only by depth recorders and RADAR. For British Columbia this breakdown of electronic equipment by tonnage is not available--only the totals for all tonnage. These values are shown in brackets at the bottom of Table 2. However, from discussions with staff from the B.C. fisheries region [Carson, 1982], it is reasonable to use the Scotia Fundy region as a model to estimate the breakdown of electronic

ABLE 1 Electronic Equipment Atlantic Canada Fleet.

Region	Gross Tonnage	No. of Vessels	Depth Recorder	RADAR	LORAN	DECCA	Auto Pilot	SONAR	Direction Finder
N'fld (1980)	0- 9	18,197	292	67	9	13	4	24	33
	10- 25	1,034	770	628	69	61	36	77	53
	26- 49	267	171	177	59	36	42	40	23
	50- 99	89	82	85	47	24	47	41	30
	100-149	8	6	8	5	5	3	4	3
	150+	89	88	89	83	88	52	13	12
Scotia Fundy (1980)	0- 9	6,700	1,796	331	79	15	30	24	116
	10- 25	3,680	3,063	1,569	818	40	193	94	225
	26- 49	372	397	426	374	37	184	33	17
	50- 99	203	258	291	251	88	139	39	22
	100-149	56	68	78	67	38	48	9	7
	150+	172	241	279	270	149	160	67	35
Quebec (1979)	0- 9	2,254	325	72	1	1	-	2	-
	10- 25	259	220	125	10	2	2	9	-
	26- 49	84	81	77	50	1	-	-	4
	50- 99	40	37	39	24	2	3	2	2
	100-149	17	17	17	14	4	8	1	2
	150+	9	9	9	9	7	5	6	-
Summary for Atlantic Canada									
	0- 9	27,151	2,413	470	89	29	34	50	149
	10- 25	4,973	4,053	2,322	897	103	231	180	278
	26- 49	723	649	680	483	74	226	73	44
	50- 99	332	377	415	322	114	189	82	54
	100-149	81	91	103	66	47	59	14	12
	150+	270	338	377	362	244	217	86	47
Totals		33,530	7,921	4,367	2,239	611	959	485	584

Sources: Newfoundland data: Russel [1982]
Scotia Fundy data: Jones [1982]
Quebec data: Berube [1982]

equipment by tonnage on commercial fishing vessels in B.C. The B.C. fleet is considered to be more modernized and the estimates should therefore be slightly low. This is verified by comparing the totals so estimated with the known totals shown on Table 2. Here again, LORAN-C is ranked third most important after depth recorders and RADAR, but the proportion of electronic equipment to the size of the fleet is much higher.

TABLE 2 Estimated Registered Commercial Fishing Vessels in B.C. (1979) by Tonnage, Electronic Equipment.

Gross Tons	# Vessels	Depth Recorder	RADAR	LORAN	Auto Pilot	SONAR	DF
0- 9	4,458	1,195	220	53	20	16	77
10- 24	2,400	1,998	1,023	533	126	61	147
25- 49	483	515	566	485	239	43	29
50- 99	261	332	374	323	179	50	28
100-149	82	99	114	98	70	13	10
150+	49	68	79	77	46	19	10
Estimated Totals	7,733	4,207	2,376	1,560	680	202	301
Known Totals	7,733	(5,809)	(3,655)	(1,923)	(2,709)	(295)	(544)

Source: Hsu [1982] and Carson [1982].

Table 3 and Figure 3 describe the entire Canadian fishing fleet using the estimated values for B.C. and the known data for the Atlantic region indicating that nearly 10% of the ships recorded use LORAN-C. Table 4 breaks down the distribution of electronic equipment as a percentage of the number of vessels by tonnage categories.

TABLE 3 Canadian Commercial Fishing Vessels 1979-1980 by Tonnage and Electronic Equipment.

Gross Tons	# Vessels	Depth Recorder	RADAR	LORAN	DECCA	Auto Pilot	SONAR	DF
0- 9	31,609	3,508	690	142	39	54	66	226
10- 25	7,373	6,051	3,345	1,430	129	357	196	425
26- 49	1,206	1,164	1,186	968	122	465	116	73
50- 99	593	709	789	645	227	368	132	82
100-149	163	190	217	184	101	129	27	22
150+	319	406	456	435	286	263	105	57
Totals	42,263	12,028	6,683	3,808	904	1,636	642	885

Source: Derived from Tables 1 and 2.

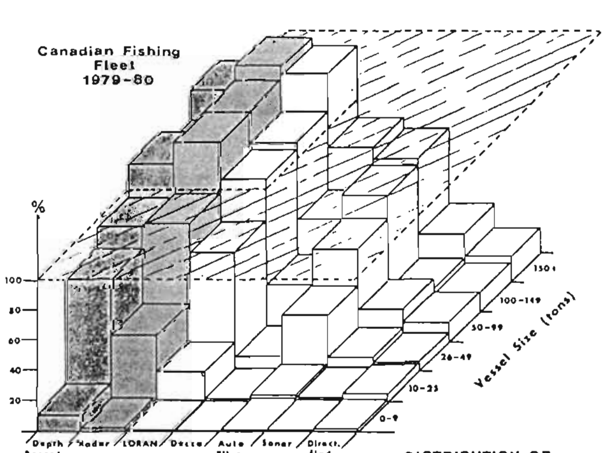


FIG 3 DISTRIBUTION OF ELECTRONIC EQUIPMENT BY TONNAGE

It is obvious from Table 4 that vessels over 25 tons gross have a substantial amount of navigational equipment on board. It also appears evident that some vessels must have more than one piece of the same equipment.

TABLE 4 Percentage of Onboard Electronic Equipment on Canadian Fishing Vessels.

Gross Tons	Depth Recorder	RADAR	LORAN	DECCA	Auto Pilot	SONAR	DF
0- 9	11.1	2.2	0.4	0.1	0.2	0.2	0.7
10- 25	82.1	45.4	19.4	1.8	4.8	2.7	5.8
26- 49	96.5	98.3	80.3	10.1	38.6	9.6	6.1
50- 99	119.6*	133.0*	108.8*	38.3	62.1	22.3	13.8
100-149	116.6*	133.1*	112.9*	62.0	79.1	16.6	13.5
150+	127.3*	143.0*	137.6*	89.7	82.4	32.9	17.9

NOTE: * indicates duplication of equipment.

Source: Derived from Table 3.

To test the validity of these statistics, we conducted our own selective assessment of electronic equipment used in Atlantic Canada. We discussed the reporting mechanisms with the staff of the Scotia Fundy Licensing Board [Russel, 1982] and discovered that equipment added to an already registered vessel might not show in the statistics. As a result we conducted some equipment surveys of our own at several randomly selected harbours in the Scotia Fundy region. We found that the proportion of vessels carrying each type of equipment was always higher than the official statistics indicated. Since we were primarily concerned with LORAN-C use, we concentrated on verifying those statistics. Our sampling indicates that in the 10 to 50 ton category the frequency of LORAN-C use is about twice that shown in the available records. This would imply that there are up to 6800 LORAN-C receivers in use in the Canadian commercial fishery or up to 16% of all vessels are equipped with at least one receiver. If we omit vessels less than 10 tons, then up to 62% of the remainder of the fleet uses LORAN-C. These estimates are based on 1979 statistics. While the fleet expanded by about 3% per year between 1974 and 1979 (see Table 5), LORAN-C use increased by more than that (e.g., by 13% from 1979 to 1980). This indicates an incomplete market penetration of LORAN-C receivers, even considering the Canadian LORAN-C coverage improvements of 1977, 1978 and 1980.

.BLE 5 Canadian Fisheries Number of Vessels by Tonnage (for those Provinces Reporting by Tonnage).

GROSS TONNAGE	1973	1974	1975	1976	1978	1979	1980
10	29,640	28,851	31,151	29,758	29,777	25,008	25,520
10- 25	4,255	4,411	4,551	4,610	6,314	4,606	5,054
26- 49	859	928	974	942	981	523	574
50- 99	377	415	431	415	480	264	287
100-149	124	143	137	114	140	58	66
150-499	273	289	292	273	259	225	222
500+	-	-	-	-	35	32	38

Source: Canadian Fisheries Annual Statistical Review 1973-1980 (e.g., DFO [1980]).

THE UNITED STATES FISHING FLEET

Since LORAN-C has been available longer and more uniformly in the U.S. than in Canada, it is useful to place these Canadian statistics in a continental context. Statistical data on the U.S. fishing fleet is far more difficult to acquire than that for Canada, due to a different management regime. The National Marine Fisheries Service (NMFS) of the National Oceanic and Atmospheric Administration (NOAA) compiles various statistical reviews (e.g., NMFS [1974]; NMFS [1981]). The number of registered fishing vessels is not determined on an annual basis. The last year for which an inventory was made was 1976. Since that period, only estimates are available. These estimates are based on accurate knowledge of the number of vessels operating within conservation zones, augmented by selected surveys at key harbours. These are probably the best estimates of operating commercial fishing vessels and will always be less than the number of registered fishing vessels reflected by U.S. Coast Guard (USCG) data, as some of the vessels in the USCG register are no longer operating.

TABLE 6 Fishery Statistics of United States NOAA Summary of Operating Units 1974, Tonnage by Area.

NET TONNAGE	NEW ENG.	MIDDLE ATLANTIC	CHESA-PEAKE	SOUTH ATLANTIC	GULF	PACIFIC	GREAT LAKES	TOTAL
5- 9	28	37	1,258	222	261	1,177	29	3,012
10- 29	224	167	486	464	1,534	3,707	171	6,753
30- 49	154	97	42	383	614	935	38	2,263
50- 99	176	108	47	414	1,543	491	2	2,781
100-149	84	34	24	29	615	121	-	907
150+	65	17	41	11	113	273	-	520
Total	731	460	1,898	1,523	4,680	6,704	240	16,236

New England = ME, NH, MA, RI, CT.
Middle Atlantic = NY, NJ, DE.
Chesapeake Bay = MD, VA.
South Atlantic = NC, SC, GA, FL (east coast).
Gulf = FL (west coast), AL, MS, LA, TX.
Pacific = WA, OR, CA, AK.
Great Lakes = NY, MN, WI, MI, IL, IN, OH, NO.

Source: NMFS [1974].

TABLE 7 Registered Fishing Vessels in the United States as Shown on USCG Files 1980.

Length (ft)	No. of Vessels
0- 29	5,171
30- 44	16,062
45- 64	6,618
65- 99	4,165
100-149	377
150+	265
Total	32,658

Source: Crawford [1983].

TABLE 8 Registered Fishing Vessels in the United States as Shown on USCG Files 1970-1979.

Year	Total No. Registered Vessels
1970	19,589
1971	20,263
1972	20,632
1973	20,140
1974	23,442
1975	24,150
1976	24,965
1977	26,374
1978	28,434
1979	30,567

Source: Crawford [1983].

Table 6 shows the distribution of fishing vessels by region for 1974 [NMFS, 1974]. The number of vessels registered with the Coast Guard for 1980 by length is shown in Table 7, and the total vessels for the years 1970 to 1980 in Table 8 [Crawford, 1983]. It must be noted that in the U.S., only vessels over 5 net tons are catalogued by the USCG and the NMFS. The NMFS estimates that in 1981, 18,900 vessels over 5 net tons were actively involved in commercial fishing, and that 92,800 motor boats under 5 net tons were also operating [NMFS, 1981].

A tabulation of the vessels indicating the use of electronic equipment is unavailable. However an estimate based on an economic planning study [Dick, 1982] shows 25,980 vessels involved in commercial fishing, of which 16,700 are estimated to carry LORAN-C (see Table 9 and Figure 4). This agrees closely with the upper limit estimates made above for Canadian vessels over 10 tons (62%).

TABLE 9 Marine Users of Radionavigation Systems (U.S. Owned Vessels, 1980).

Type of Operation	LORAN	TRANSIT LORAN	TRANSIT	OMEGA TRANSIT LORAN
Recreation/sport fishing	115,000	-	-	-
Commercial fishing	16,700	-	300	-
Oil (crew, supply, tow)	1,400	-	-	-
Passenger	1,100	-	-	-
Other	600	-	-	-
Freighter/tanker GT 1600 ton	-	1,000	-	-
Other	-	200	-	-
Research/training	-	-	-	200
Totals	134,800	1,200	300	200

Source: Dick [1982].

Presuming the estimates and extrapolations we have made so far are all correct, the commercial fishing sector in 1980 represented (see Figure 5)

(a) approximately 10,000 vessels over 10 tons in Canada,
(b) approximately 20,000 vessels over 10 tons in the United States,
(c) a total of 23,500 LORAN-C users for the U.S. and those Canadian regions presently covered by LORAN-C,
(d) a growth of about 13% (3000 new units) in LORAN-C users per year.

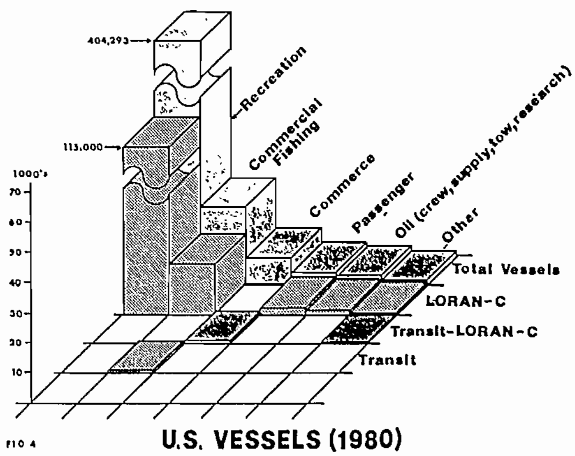


FIG 4 U.S. VESSELS (1980)

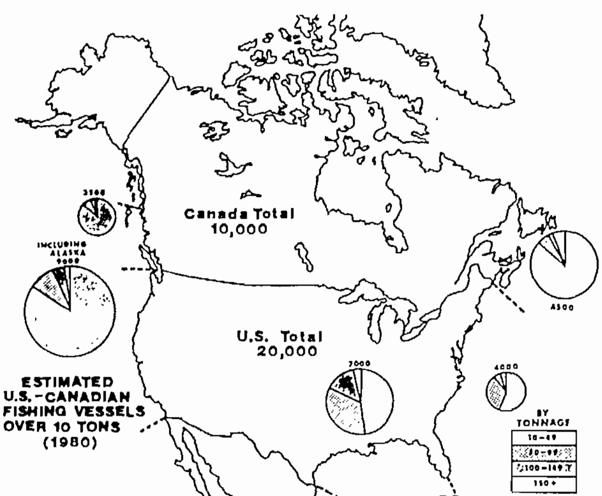


FIG 5

VESSEL COSTS vs LORAN-C COSTS

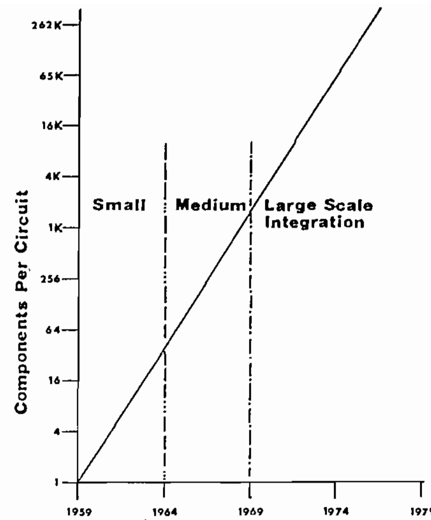
In common with most commercial activities where manpower and energy are significant cost factors, the cost of ship construction, maintenance, and operation has increased annually at greater than the rate of inflation (see Table 10).

TABLE 10 Average Value of Canadian Fishing Vessels per Vessels by Tonnage ($1000).

Gross Tonnage	1973	1974	1975	1976	1978	1979	1980	Average Annual % Change
10	2.0	3.1	2.9	3.3	4.8	2.6	3.0	7.3
10- 25	16.0	25.9	25.3	28.2	30.3	19.1	24.3	7.4
26- 49	39.7	66.8	68.9	76.2	100.5	76.6	98.7	21.2
50- 99	72.0	117.8	130.0	151.2	199.9	191.6	261.4	37.6
100-149	145.2	183.1	198.0	224.7	319.7	324.2	418.9	26.9
150-499	464.0	524.5	533.9	575.6	799.1	1086.2	1114.4	20.0
500+	-	-	-	-	2340.0	2776.7	3305.3	20.6
Average								20.1

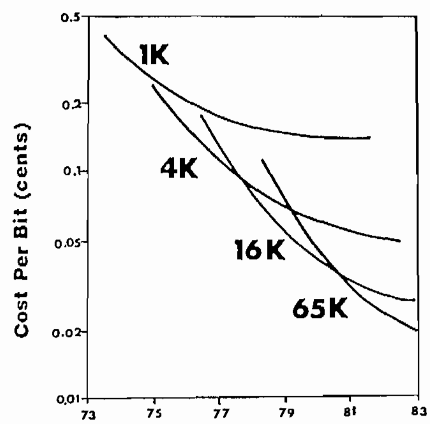
Source: Canadian Fisheries Annual Statistical Review 1973-1980 (e.g., DFO [1980]).

In contrast, the microelectronics revolution is resulting in drastic reductions in manufacturing costs, as well as major improvements in the reliability and capability of electronic equipment. Figures 6 and 7 show two aspects of this microelectronics revolution (component density and memory cost) which illustrate just how much improvement has been realized over the past decade. It is likely that these improvements will continue at a similar rate for some years yet. There is a time lag between the development of a denser chip, for example, and its implementation in commercial equipment, such as a LORAN-C receiver. Therefore even the microelectronic advances made today will take some years to percolate down to the shelves of the marine electronics supplier.



Number Of Components Per Circuit In Computer Memories. AFTER NOYCE (1977)

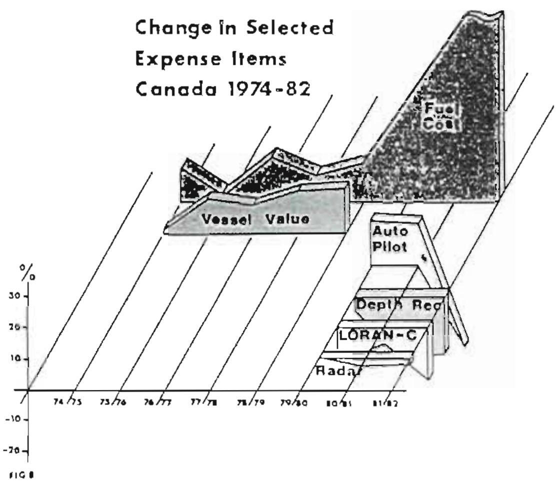
FIG 6



Cost Per Bit Of Computer Memory
AFTER NOYCE (1977)

FIG 7

These two tendencies mean that ship replacement and operating costs will continue to rise, while the cost, reliability and capability (see next section) of onboard electronic equipment, such as LORAN-C receivers, will continue to improve. Hence such electronics will represent a smaller fraction of the total vessel equipment and operating costs. Figure 8 is a plot of the annual percentage change of vessel value (defined as in DFO [1980], <u>not</u> including fishing gear), operating costs and selected electronic equipment costs. The cost of navigational equipment (i.e., LORAN and RADAR) is seen to have decreased while all the other items increased. This difference should become accentuated as the microelectronics revolution continues.



CURRENT AND FUTURE LORAN-C RECEIVERS

Until 1980 most LORAN-C receivers provided just time difference (TD) measurements. Since then newer models have offered additional capabilities, such as coordinate conversion from TD measurements to latitude and longitude, a clock giving date and time, limited waypoint navigation, such as range and bearing to destination. Currently it is also possible to add either a paper or video course plotter to some LORAN receivers. A few provide the option for cassette storage of the navigation data (time and position), and options are available for integrating LORAN-C systems with autopilot and sonar systems. Current typical prices for such LORAN-C systems are shown below.

LORAN-C receiver	$ 2,400
Receiver with coordinate conversion	3,700
Receiver, coordinate converter and paper plotter	8,200
Receiver, coordinate converter and video plotter	12,000
Receiver, coordinate converter, video plotter and cassette recorder	14,000

As the effects of the microelectronics revolution permeate through to enhance LORAN-C equipment we can expect these costs to come down, and improved capabilities to emerge. For example, during 1983 at least one prototype system should become operational, which integrates a differential LORAN-C receiver, an electronic chart, and RADAR, with the LORAN-C track, the chart, and the RADAR return all superimposed on the same video plotter [Rogoff, 1983]. (The impact of electronic charts is discussed by Anderson and Eaton [1983].) Another example is the limitation of currently available coordinate converters to adequately model the LORAN-C overland phaselag (additional secondary factor, or ASF). The advent of more powerful, lower cost microprocessors with larger cheaper memories will make it possible to incorporate better ASF modelling in receivers with coordinate converters. One possible future trend could be toward integrated bridge systems in which all electronic equipment on board is integrated into a unified system. If the cost trends seen in Figures 6, 7 and 8 continue, eventually such integrated systems may become common in new fishing vessel construction and in vessel equipment upgrading programes.

Another issue concerning the future of LORAN-C is its relationship to the adoption of GPS as the prime navigational system for the future. The Dick [1982] radionavigation economic planning model suggests that if LORAN-C is dismantled in favour of the Global Positioning System (GPS), then the total user navigation equipment costs (purchase plus operating) over the 25 year period from 1980 to 2005 will be 22% higher than if LORAN-C is kept operating, even after GPS is available. Presumably, this information will not be ignored by current LORAN-C users and will have to be considered by both the U.S. and Canadian governments during the GPS/LORAN-C decision process.

CANADIAN FISHERIES MARKET FOR LORAN-C

We have seen that in regions where LORAN-C has been available for a number of years, about 60% of the fishing vessels over 10 tons used it in 1980. Presumably this percentage will tend toward 100% (or beyond, as some vessels carry more than one set) as LORAN-C costs decline and capabilities increase. New markets should develop as the new Fox Harbour transmitter extends LORAN-C coverage, and as users begin to replace their early, simpler receivers with new enhanced models. However, let us look at the factors influencing the Canadian fisherman's decision on whether to purchase LORAN-C, and with what enhancements.

The possible advantages to the fisherman of LORAN-C and its enhancements are increased catches, and reduced costs. The Canadian fishing industry is a regulated one, and is likely to continue as such [Kirby, 1983]. In such an environment, regulated catch quotas, not navigational performance, is the limiting factor on productivity. Two ways in which LORAN-C may reduce costs are through reduced fuel consumption due to better navigation (mainly to and from the fishing ground), and lower insurance premiums, if insurance companies can be convinced that LORAN-C (probably with several of the above enhancements) can reduce the risk of collision and groundings. This latter factor may in the end turn out to be the most influential one.

IMPACT ON THE CANADIAN HYDROGRAPHIC SERVICE

We have shown that LORAN-C use is becoming widespread within the Canadian fishing fleet, and have suggested that LORAN-C receivers with enhancements, such as coordinate conversion, waypoint navigation, video plotting, track storage, electronic charts, and integration with other sensors, will become less expensive, increasingly reliable, and more widely available.

We conclude by suggesting some implications for the Canadian Hydrographic Service of the widespread use of such enhanced LORAN-C receivers. We will avoid consideration of the profound changes which may result from the use of electronic charts, as they are considered elsewhere (Anderson and Eaton, 1983).

If we speculate that the day may come when every vessel carrying LORAN-C will have a coordinate converter with a good ASF predictor, what then will be the role of LORAN-C lattices on CHS charts? The present role of primary coordination from TD readings may then be replaced by calibration of the receiver coordinate converter. What changes might this imply as to the nature of lattices?

Once a significant portion of the fishing fleet uses LORAN-C receivers enhanced with track recorders, and interfaced to sonar systems, it then becomes possible to collect and use the combined sonar and navigational data gathered on such vessels, for improved evaluation of existing fish stocks. This could add greatly to the fish stock data base, which would be of advantage to both commercial fishermen as well as to government population dynamics groups concened with fisheries management. Questions of trust and reliability between the sectors would have to be addressed, but this is consistent with the recent emphasis placed on the necessity for cooperation between government and commercial fisheries interests (Kirby, 1983). While not directly involved in such population studies, it may be that the CHS would play an interface role, concerned with assessment of the quality of the navigational data involved.

ACKNOWLEDGEMENT

This work was supported in part by a strategic grant from the Natural Sciences and Engineering Research Council of Canada. We wish to thank Zeth Berube, Dick Carson, Jack Crawford, Mike Ellingwood, Tim Hsu, Chuck Jones, Mort Rogoff and Ray Russel for their advice and cooperation.

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Government of Canada — Gouvernement du Canada
Fisheries and Oceans — Pêches et Océans

$20 FEE DROIT

1982 COMMERCIAL FISHING VESSEL REGISTRATION APPLICATION

DEMANDE D'IMMATRICULATION D'UN BATEAU DE PÊCHE COMMERCIALE 1982

PART A – VESSEL/OWNER IDENTIFICATION: — **PARTIE A – IDENTIFICATION DU BATEAU/PROPRIÉTAIRE:**

Please indicate which of the two official languages you want to receive correspondence in
Veuillez indiquer dans laquelle des deux langues officielles vous préférez qu'on vous écrive
☐ English / Anglais ☐ French / Français

1. Commercial Fishing Vessel (CFV) No. / Nº de bateau de pêche commercial (BPC)
2. Vessel Name / Nom de bateau
3. Social Insurance No of Owner / Nº d'assurance sociale du propriétaire
4. FAMILY NAME OF OWNER / NOM DU PROPRIÉTAIRE — GIVEN NAMES / PRÉNOMS
5. MAILING ADDRESS/ADRESSE POSTALE

Postal Code / Code postal

PART B – VESSEL STATISTICS: — **PARTIE B – STATISTIQUES DU BATEAU:** — Office use only / Réservé à l'usage du bureau

6. Home Port / Port d'attache
7. Usual Port of Landing / Port habituel de débarquement
8. Usual Number in Crew / Nombre habituel de membres déquipage
9. Year Built / Année de construction
10. Where Built - Country/Province / Lieu de construction (pays ou province)

11. Hull / Coque: Wood / Bois ☐ Steel / Acier ☐ Aluminum / Aluminum ☐ Fiberglass / Fibre de verre ☐ Other / Autre ☐
12. Refrigeration / Refrigératière: RSW / EMR ☐ Spray / Pulvérisation ☐ Plate / Plaque ☐ Ice / Glace ☐ None / Néant ☐
13. Propulsion: Gas Marine / Moteur marin à essence ☐ Diesel Marine / Moteur marin diesel ☐ Outboard / Hors-bord ☐ Converted Car / Moteur d'automobile ☐ Row or Sail / Avirons ou voiles ☐

14. Electronic Equipment (Show number of each) / Appareils electronique (Indiquer le nombre de chacun): Radio Telephone / Radio-téléphone ☐ Depth Recorder / Sondeur acoustique ☐ Decca ☐ Radar ☐ Loran ☐ Sonar ☐ Auto Pilot / Pilote automatique ☐ Direction Finder / Radiogoniomètre ☐ Other (Specify) / Autre (Préciser) ☐

15. For Trawlers and Draggers / Chalutage et dragage: Side / Par le côté ☐ Stern / Par l'arrière ☐ Type of Trawl Gear / Type de chalut

16. Propeller Type / Helice: Fixed / Fixé ☐ Variable Pitch / Pas variable ☐
17. Engine Horse Power (B.H.P.) / Puissance du moteur (P.R.F.)

18. Ministry of Transport Registration Number / Nº d'immatriculation du Ministère des Transports
19. Radio Call Letters / Indicatif radio

20. Gross Tons / Jauge brute
21. Registered Net Tons / Jauge nette officielle
22. Length Overall / Longueur hors tout

23. Total weight of fish (in pounds) your vessel will carry when full / Quantité totale de poisson (en livres) que peut transporter votre bateau lorsqu'il contient un plein chargement

24. For vessels 35' and over hold capacity (length X width X height) in cubic feet / Réservé aux bateau 35' et plus - capacité de cale (longueur X largeur X hauteur) en pieds cubes

25. How much is your vessel worth, including auxiliary boats but not fishing gear / A combien évaluez-vous votre bateau, en incluant les embarcations auxiliaires, mais non les engins de pêche

26. How much was your vessel worth, including auxiliary boats but not fishing gear, when you purchased it / Quelle était la valeur de votre bateau en incluant les embarcations auxiliaires mais non les engins de pêche, quand vous l'avez acheté

27. NAFO areas usually fished / Région de l'OPANO habituellement pêchées

PLEASE ENCLOSE CORRECT FEE ($20); MAKE CHEQUE OR MONEY ORDER PAYABLE TO: RECEIVER GENERAL FOR CANADA AND MAIL TO

PRIÈRE DE JOINDRE LA SOMME APPROPRIÉE POUR PAYER LE DROIT À ACQUITTER; VEUILLEZ FAIRE UN CHÈQUE OU UN MANDAT À L'ORDRE DU RECEVEUR GÉNÉRAL DU CANADA ET LE FAIRE PARVENIR AU

REGIONAL DIRECTOR GENERAL
GOVERNMENT OF CANADA
FISHERIES AND OCEANS
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HALIFAX, N.S. B3J 2S7
ATTN: LICENSING UNIT

DIRECTEUR GÉNÉRAL RÉGIONAL
GOUVERNEMENT DU CANADA
PÊCHES ET OCÉANS
B.P. 550
HALIFAX (N.-É.) B3J 2S7
À L'ATTENTION DE LA SOUS-SECTION DES PERMIS

I HEREBY CERTIFY THAT THE INFORMATION GIVEN IN THIS APPLICATION IS TRUE, CORRECT AND COMPLETE IN EVERY RESPECT.

J'ATTESTE QUE LES RENSEIGNEMENTS QUI FIGURENT DANS LA PRÉSENTE DEMANDE SONT VÉRIDIQUES, CORRECTS ET COMPLETS SOUS TOUS LES RAPPORTS.

Signature — Date

FP 1471

AUTOMATION OF THE DMA LIST OF LIGHTS AND RADIO NAVIGATIONAL AIDS PUBLICATIONS

By:

Morris F. Glenn
Navigation Department
Hydrographic/Topographic Center
Defense Mapping Agency
Washington, D.C. 20315

ABSTRACT

The Defence Mapping Agency (DMA) has completed the software development required to automate the compilation, publication and maintenance of seven volumes of the DMA List of Lights and two volumes of the DMA Radio Navigational Aids. This paper provides a detailed overview of the software subsystem necessary to load, process and publish the List of Lights and Radio Aid data on the Automated Notice to Mariners System (ANMS) computer. The List of Lights software will share all of the ANMS hardware and communications capabilities. It will provide remote query capabilities for mariners at sea, digital data transmission potential for computer applications and, most important, the potential to produce an up-to-date edition of any annual volume at any time.

RÉSUMÉ

La Defense Mapping Agency (DMA) a terminé l'élaboration d'un logiciel qui permettra d'automatiser la compilation, la publication et la tenue à jour de sept livres des feux et de deux volumes des aides radios à la navigation de la DMA. Le présent document fournit un examen descriptif du sous-système de logiciel utilisé pour charger, traiter et publier le livre des feux et les données sur les aides radios à l'aide de l'ordinateur pour le système automatisé d'Avis aux navigateurs (Automated Notice to Mariners System - ANMS). Le logiciel pour le livre des feux partagera toutes les capacités de matériel et de communication de l'ANMS. Il permettra d'effectuer à distance des demandes d'information pour les navigateurs en mer, de transmettre des données numériques pour des applications informatiques et, plus important encore, de fournir à tout moment une édition à jour de tout volume annuel.

INTRODUCTION

The Defence Mapping Agency (DMA) has completed the software development required to automate the compilation, publication and maintenance of seven volumes of the DMA List of Lights and two volumes of the DMA Radio Navigational Aids. The List of Lights has been published by the United States Government since 1871 and the Radio Aids since 1925. Presently, both of these publications are completely produced by the use of manual methods and files. Each of these publications has a long history of service to the fleet and is considered an important navigational aid for all mariners. The statutory basis for these publications can be found in the U.S. Code, Title 10, Section 2791 (Public Law 97.295, Oct. 12, 1982) and Title 44, Section 1336.

Corrections to the List of Lights and Radio Aids, which are published in the weekly Notice to Mariners, were the initial data set scheduled for inclusion in the Automated Notice to Mariners System (ANMS). Once the weekly corrections were automated, the additional software required to automate the annual List of Lights and Radio Aids data and produce them on the ANMS was minimal. Therefore, the entire manual production operation was included in the initial software development project. Inclusion of the entire manual production process on the ANMS computer was a very cost effective project allowing a new flexibility which has never been possible before. The ANMS computer will provide remote query capabilities for mariners at sea, digital data transmission potential for computer applications, and most important, the potential to produce an up-to-date edition of any annual volume at any time.

This brief paper is outlined and arranged in such a manner as to support an overview of the List of Lights automation project. Since computers have become ubiquitous in modern navigation, no attempt has been made to define usage of the most commonly used computer terms. This concept was succinctly presented by O. L. Martin in his paper entitled "Automation of DMA Nautical Information Products" presented at a symposium called "Man and Navigation:An International Congress" (Sussex, Brighton, England, Sept. 10-14, 1979). If there was ever a doubt that computers had become an integral part of DMA's support for mariners, Mr. Martin's illuminating presentation removed it and further defined DMA's future navigational automation goals. The combined materials in his paper have also helped to narrow the penumbra which had been allowed to grow in prior years between the separate fields of computers and navigation. Today, the merger of computers and navigation is obvious in practical application aboard ship and in all of its supportive adjuncts.

THE AUTOMATED NOTICE TO MARINERS SYSTEM

There are several published articles which will provide readers with details concerning the ANMS hardware specifications and the capabilities of the initial Chart Corrections Subsystem. In particular, refer to a paper by Morris F. Glenn presented at the 12th. International Hydrographic Symposium in Monaco, France in April, 1982 entitled "Chart Corrections via Global Communications." This paper and several others are reprinted in a DMA Navigation Department pamphlet entitled "Automated Notice to Mariners System" dated 5 March, 1982. (Available from DMA upon application).

The present ANMS hardware is a combination of three commercially available systems: Prime 400 computer and peripherals, Imlac PDS-4 intelligent terminals and peripherals, and a Photon Pacesetter Mark III typesetting machine. The intelligent terminals provide the man/machine interface to load data into the ANMS computer controlled and managed files. Intelligent terminals were selected for several reasons. The ANMS data entry procedure required the availibility of several different screen character sets of varying font sizes and types with several data entry screen templates, a capability to plot hard copy of the information which is shown on the screen display, and a simplified data entry procedure which could be aided by pre-programmed computer function keys. The Prime computer is the heart of the ANMS and manages all data files, data processing and data communications (See Figure 1). It also creates the print tape in a special format to drive a Photon typesetter. The resultant hard copy is formatted into sequential pages which are camera-ready for making press plates. Once the data base is built, or corrected via an Imlac terminal, the computer can generate a whole volume of List of Lights information within minutes and the contents will be completely up-to-date. The three hardware units are combined to form a powerful publications management system collectively called the ANMS.

Although the hardware is of importance, one might say that the real heart of the ANMS is the specially developed applications software. The Chart Corrections Subsystem software took over four years to develop and it consists of about 45 individual programs. They operate under the Prime system software, PRIMOS, and are written in COBAL. A further complicating factor is that the applications software had to be developed to allow data entry on an intelligent terminal (written in assembly language). The data entry software is also divided between the Prime Computer disk file and Imlac fixed disk storage (respectively identified as PSEE and ISEE). Each Imlac terminal has a 10 mb. disk storage capacity (5mb. fixed and 5mb. removable). This allows the specially designed Imlac software to be stored on-line and a number of character sets to be stored for output upon a printer/plotter (Versatec 1200A). The intelligent terminal is connected to the Prime computer via a 9600 baud line and is in continuous communications with the ANMS data files which are stored on the Prime Disk.

The Broadcast Warning Subsystem was the second software system to be installed on the ANMS. The first Daily Memorandum produced by the Navigation Department completely on the ANMS computer was No. 20 of February 1, 1982. The Broadcast Warning Subsystem shares the overall design concept of the Chart Corrections Subsystem (i.e., data is loaded to Prime disk files via the Imlac terminal and a print tape is created by the computer to drive the Photon typesetter). Additionally, the data base containing all active broadcast warnings is maintained by the Prime System and query software allows access over global communications links in the same manner as chart corrections.

When the List of Lights Subsystem is added to the Prime computer, the demand upon all peripherals as well upon the CPU will be extensive. The Prime now supports up to 64 interactive time shared users, but unfortunately, as the numbers of on-line users increases, the response time for all users will decrease. Another major system consideration, in view of the importance of meeting extremely strict Navigation Department daily and weekly production schedules, is to insure the existence of some reasonable back-up capability. Although there are many important reasons to maximize response time (i.e., remote users may be paying long distance communications rates for their connect time and data entry personnel need rapid response time to effectively utilize the Imlac terminals), the most important system planning consideration is to provide a back-up production capability for vital

DMA publications and ANMS master data files.

The solution to the overall system problem of improving response time, providing production back-up, and back-up for on-line files, is to network the present ANMS CPU with a second CPU (this item is in the DMA 1984 equipment procurement program). This final hardware acquisition, which is planned to complete the ANMS hardware configuration, will provide two CPU's operating in a computer network to share on-line data files, split processing workload, and provide essentially a complete back-up capability for all system hardware, files and software. In addition to copies of all master files (resident on a separate disk device), this configuration will make it immaterial which disk contains the master file (a benefit of a networked system). If one CPU becomes inoperative, the second CPU can be used to complete the query or data processing task. Even if the on-line disk is disabled, the task can be easily completed by use of back-up files.

Presently, the ANMS automation plan assumes a two processor environment which will allocate the data processing tasks as follows: the present CPU will handle routine production input/output, manage on-line Chart Corrections, support Broadcast Warnings and List of Lights weekly workfiles and automatically schedule ancillary tasks to support production; the second CPU will handle remote data base queries that can be generated from anywhere on the globe on a 24-hour basis. The second CPU will also handle all batch processing necessary to produce:

A. Annual volumes of List of Lights

B. Periodic Summary of Corrections Volumes

C. Daily back-up of work files

D. Periodic back-up of master files

E. New navigation publications which are planned for addition to ANMS

F. Future projects such as processing graphics.

The increased computer capability is not considered an optional feature when so many important and highly time oriented publications are involved. Banks, airlines and other business establishments have pioneered the redundancy concept of computer operations and this capability is now offered by most modern computer manufacturers. Also, by use of widespread international standards such as the CCITT X.25 which supports computer to computer or computer to terminal communications via packet switching software, computers marketed by many vendors may be connected into a single computer network. This is an important design concept when one considers the global nature and impact of the Chart Corrections, Broadcast Warnings and List of Lights data. In addition to a worldwide geographic distribution of users, DMA has numerous cooperative agreements with U.S. agencies and foreign governments for the exchange of hydrographic data. Without such exchanges, DMA would be unable to produce its navigational publications in a timely, accurate and comprehensive manner. Conceptually, the new hardware configuration of the ANMS advances the time when computers will perform a major role in the exchange and dissemination of international hydrographic information.

LIST OF LIGHTS AND RADIO AIDS DATA

DMA has been tasked with producing List of Lights and Radio Aids publications on a worldwide basis, except for the continental United States (CONUS). In CONUS, the U.S. Coast Guard produces the Light Lists, however DMA publishes the weekly corrections to the Coast Guard's Light Lists in the Notice to Mariners. Presently, there are about 59,000 lights and 3,000 radio aids listed and the weekly Notice to Mariners contains an average or about 80 information changes to these aids.

Each volume of DMA's List of Lights (Pub. numbers 110 thru 116) covers a particular geographic area of the world. Each volume contains a written description (in columnar form) of lighted navigational aids and fog signals (except secondary buoys) in use throughout the world (except CONUS). Storm signals, signal stations and radio aids operated in conjunction with light stations are also included in these volumes. These seven volumes are the only complete single source of identifying information for navigational aids during day and night or inclement weather published in the United States. Cartographic chart symbols and light legends located on nautical charts are not sufficient to describe the ranges, shapes, colors, light characteristics, structure, height of the light above water, sectors, stand-by or emergency apparatus, seasonal notes, fog signal characteristics/appliances or other text oriented details which are necessary for "all weather" identification. The radio navigational aids are presently published in DMA Pubs. 117A and 117B. After this automation effort is complete, the numbered radio aids will be removed from these volumes and merged geographically in the new automated volumes of the List of Lights. The remaining text in the two Radio Aids publications will be combined into a single volume published occasionally. Thus, the resultant volumes of List of Lights will provide mariners with a comprehensive sequential guide to navigational aids.

MANUAL COMPILATION METHODS

DMA's List of Lights data are now stored and produced by use of specially designed photo-list cards (which are not to be confused with the machine readable IBM type card format). The cards are filed in the order of their respective geographic area. A Marine Information Specialist (MIS) evaluates all new light and radio aid information and determines the appropriate disposition of this new data by considering:

A. Source of the information

B. Consistency with existing information

C. Impact upon shipping

D. Degree of urgency

E. International commitments

F. Relevant operational requirements

Depending upon the reliability of the source and importance assigned to dissemination of a reported change in the status of a light, a correction will be written for publication in the Weekly Notice to Mariners. Upon receipt of the Notice to Mariners, the mariner will apply the correction to his copy of the List of Lights. The photo-list cards used to print these corrections will also be used to physically replace the former data card in the appropriate file drawer for subsequent inclusion in the next printing of the annual volume. Noncritical or editorial corrections are not published in the weekly Notice. These are processed and applied only to the file copy of photo-list cards. The new information will appear in the next annual volume.

The present manual production process utilizes several outdated, Vari-typer Model 900 machines. These machines allow the operator to select a choice of fonts and type sizes for use in each field of the photo-list card. The resultant line-of-type produces a clean, sharp image which is used as camera ready copy. For generating the annual publication, a manual paging process is required to count and arrange the large file of cards into a publication format. This is a long and tedious task because the color coded cards, arranged in a vertical overlapping manner, must be positioned for photographing exactly as their content would appear in the final volume of the List of Lights. In other words, even a blank line must be manually input by use of a "spacer card" and every line accounted for by use of a counting device to ensure exact page lay out. The addition or deletion of a light thus substantially affects the card file, and each new printing of an annual volume requires a manual readjustment of the entire file system before paging. The advantages and savings involved in automating such a repetitive manual procedure were obvious from the beginning of the ANMS.

LIST OF LIGHTS AUTOMATION PLAN

In addition to automating the processing and publication system just described, the new digital List of Lights data base was planned so that it could provide many new capabilites for maintaining, extracting and disseminating data pertaining to lights and radio aids. Automation also includes the capability to utilize new digital techniques and to incorporate U.S. Navy communications systems as they become availible. This supports future ANMS goals to interface the system with all new global communications systems and new international hydrographic reporting methods which may be developed (between national hydrographic offices and major shipping companies).

The List of Lights Subsystem was essentially modeled after the original Chart Corrections Subsystem of the ANMS. As noted earlier in relation to the development of the Broadcast Warning Subsystem, the initial software effort was in the nature of a research and development effort, because there were no other comparable systems available which DMA could use to develop specific designs. In addition to the existing Chart Corrections Subsystem software, all ANMS start-up hardware was already installed and its operational capability was well established and clearly demonstrated.

Thus, the design constraints around which the List of Lights was developed compared to most other software efforts, was exceedingly specific. Fortunately, the need for a phased development plan which allowed the addition of other publications to the system was anticipated during the original ANMS system design. Therefore, all hardware and software specifications were written accordingly. For example, the Screen Entry Editor (SEE) for the Imlac intelligent terminal was written in modules which could be easily changed to reconfigure the screen template (format). Since Chart Corrections data were only the first of several data sets to be automated on the ANMS, use of the software to allow input of data for other publications was an important stepping stone in ANMS development. Even though the fields, fonts and type of text to be input were subject to change, the operational parameters required to load the other publications were presumed to remain the same.

The List of Lights has been divided into three separate areas for discussion purposes in this paper: Weekly Production Cycle, Annual Production Cycle, and Communications Capabilities. The List of Lights Subsystem is referred to as LOLS in this text for purposes of brevity.

DESCRIPTION OF WEEKLY PRODUCTION CYCLE

The production sequence begins when a Marine Information Specialist (MIS) sends a printed form containing the text of light/radio aid change information to the ANMS to promulgate a change in the data on the Light Master file. The operator utilizes one of the Imlac data entry terminals and the LOLS data entry program. First, the LOLS data entry program requires the operator to load the light/radio aid number and then it searches the Daily Work file and Light Master file for a record of any prior entries for this number. The program will display any available information on the screen within the proper fields of the LOLS screen entry template. If the number entered by the operator represents a new entry, all fields must be loaded with the required data in order to complete the data entry. If data is returned for an existing light, only the fields which are to be changed must be entered. Once the data is entered, the operator strikes the "Store Key" and the data is written to the daily work file (completing the data entry operation).

After the operator has entered a new light or correction into the file via the Data Entry Program, the "Clear Text" Mode is executed and a copy of the data set in its published form is displayed on the screen. The "Plot Key" is then hit to output hard copy on the Versatec to serve as the editor's proof copy (hard copy which can be attached to the data entry card). The MIS edits the input data and, if it has been properly loaded, the MIS will initial the proof plot. The edit initials are a vital record in this part of the entire processing procedure and are loaded into the data base. Input which does not have an entry in the field for editor's initials will be omitted from all subsequent processing and publication. Only edited data published because of the important uses to which the List of Lights data is subjected. If the editor's verification reveals that a change or correction to the original input transaction is needed, the entire data entry process will be repeated (from input of light/radio aid number onward to modify the items in error).

Once each week, depending upon the official "cut-off" date of the weekly Notice to Mariners, the Weekly Print Processor (hereafter referred to as a Proc) is executed. This is a control mechanism which is written to call and execute a series of software programs. It allows the operator to start a complicated ANMS computer operation, and except for mounting tapes, the operator is free to perform other tasks. The Proc consists of the following:

A. Daily Work File Backup. A file copy is written as a safety precaution.

B. Weekly Photocomposition. A Photon print tape is created which contains a series of typesetting commands necessary to drive a Photon Typesetter and data to be typeset. The computer also paginates the data, lines up the data, inserts the necessary column and page heading, inserts applicable footnotes, controls line length and page length, and if necessary, applies the logic for line splitting and other accounting steps necessary to maintain continuity within a multi-page, printed publication.

C. Master/History Files Update. The master file is updated to reflect all changes in the Weekly Work File. If there is an existing light/radio aid record on the master file, one more processing step is performed. The "old" master file record must be moved to the history file to keep an accurate historical record. This allows the complete history of all automated light/radio aids to be automatically researched by the computer.

D. Master File Backup. This provides a separate copy of the master file in case of loss by man made disasters or "electronic gnomes".

Each of the above programs may be invoked separately in order to handle unexpected occurrences and/or error conditions. The Weekly Proc will first ask the operator for publication information such as the Notice Number and Year pertaining to this weekly run (as NN/YY). The weekly program also checks for editor's initials, as noted earlier, before any data from the Daily Workfile will be processed further.

ANNUAL PRODUCTION CYCLE

The Annual Production Cycle runs under the control of the Annual Proc, or the operator may elect to run separately any individual program which is normally under control of the Annual Proc. Since the computer time for an annual volume of the List of Lights will be much longer than the computer time for the weekly notice, a check point procedure is utilized to allow the operator to restart the incomplete part of a long computer run in case a failure or problem is experienced in a program. This saves a great amount of CPU time when recovery procedures do not involve rerunning the entire program. The operation of the print program is the same as that previously described for the Weekly Print run, except that an Index Print file is created. The Index Print is a simultaneous operation and is written temporarily to disk during the Annual Print run. The disk file contains the name of the light/radio aid on the Master File (stored in front of the "Key Ended" symbol which the operator entered into the name and location field of the data line). For the Index, along with the name, a page number and a light number is also recorded. The Index entries for sub headings will not only print the name of the geographic area as it will appear, but also the number of the first aid to follow it. The index print program is then invoked by the Proc and this file is checked against a "See Proper Name" file to insure that proper reference is made to each light. The "See Proper Name" file is a sequential file stored on disk and is sorted with the Index Print file to show general names. The output is printed and recorded on a Photon tape.

Next, the U.S. International Cross Reference Program is run (independent of Annual Print Run). Two Photon tapes are output: one to print the U.S. - vs - International Light Number conversion table, and a second tape to print the International - vs - U.S. Light Number table. Processing sequence is not important, hence both of these tables may be run at any time.

COMMUNICATION CAPABILITIES

The initial query capabilities of the List of Lights software for public use have been limited to two queries. The Query by Heading is the most extensive data base search tool available providing access to all light/radio aid entries under a particular heading in the annual volumes (i.e. by heading, sub-heading, or, light name). The query by number of a light/radio aid is obviously the fastest method as the computer search will be much more specific. At present, the automation plan will allow remote users to query for the latest light/radio aid information for up to 10 numbered aids. Programs are:

A. Query by Heading (Enter program LQMO2). The program then prompts the user to input the required data specifics.

B. Light/Radio Aid Query (Enter program LQMO1). Entries will be the volume number of Annual List of Lights of requested light(s) and then numbers of Light/Radio Aids needed. Other queries may be added to the LOLS software if a need is demonstrated by a significant number of remote ANMS Users for more information. Changes may also be made to achieve a more efficient query procedure. Long distance communications are expensive and most users will want to maximize their use of the LOLS query system. The query system is <u>not</u> envisioned as a substitute for the annual volumes. It is meant to serve as an additional computer navigational tool for mariners to ascertain the latest changes to the lights/radio aids on DMA charts. In many cases, there are several particular light/radio aids upon which mariners place reliance for safe ship navigation. The specific procedure to facilitate a remote query will be published in the next edition of the Automated Notice to Mariners Communications Users Manual (present edition is May 1982). A System Users Identification Number may be obtained from this office by submission of a written request at any time.

SUMMARY

The automation of the List of Lights has involved more than computer specialists and programmers. There has been an intensive effort to include Marine Information Specialists to insure the user orientation of the final software. Readers familiar with the present format in the Radio Navigational Aid publications can appreciate the magnitude of the task to reformat information into the eight columns which are utilized in the annual List of Lights. This requires the continuing participation of Maritime Safety Division personnel during the initial data base loading phase. During this same time period, operators will be loading the annual volumes of the List of Lights on a multiple shift basis. They will be using a specially tailored data entry program because of a lack of a weekly notice number, year or other ancillary files to interact with (i.e. history file, etc.) which will be associated with the "initial input" as taken directly from the annual volumes. Also, multiple light numbers will be loaded, exactly as they appear in the printed volumes; however, after the master file is loaded, the need for this software option will be infrequent and changes to the Light Master file will usually be processed one at a time.

The goals of the List of Lights Automation effort which we have developed in this paper can be summarized as follows:

A. To automate the production and publication of the corrections to the annual List of Lights as well as production of the annual volumes of these publications.

B. To merge the List of Lights with radio aids into one publication, which will provide mariners with the most complete navigation listing of sequential aids of its type available.

C. To provide mariners with an on-line data base of the most up-to-date light/radio aid information via global communications links.

D. To provide rapid digital data management tools to replace antiquated Vari-type equipment, extensive space consuming manual files and slow manual publications set-up methods.

The software developed by this effort is a major advance toward DMA's long-term goal of achieving a totally automated weekly Notice to Mariners. Although it builds upon earlier software, the new List of Lights software will make the remaining automation steps easier and less costly so we must give some credit to the synergistic effect of each of our completed ANMS Phases. Phase Three will complete the text oriented, data entry capabilities. Research and development efforts which are planned but are not now programmed, will address graphics. List of Lights automation adds two very important publications to the ANMS and its impact will extend beyond the actual DMA List of Lights publications themselves. The resultant automated subsystem will be a model for later automation efforts concerning other national List of Lights publications which are now produced by every major maritime nation in the world.

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Sabina L. Wu
- Project Manager

Barbara D. Napjus
- Associate Programmer

Other IITRI personnel have been associated with software development and their work has also been of importance in the delivery of a fully operational software system. Mr. V. Edward Leudtke of the General Services Administration was instrumental in the development of the initial system design. Mr. Steve Choy of the Harry Diamond Laboratory wrote the initial Screen Entry Editor (SEE) software.

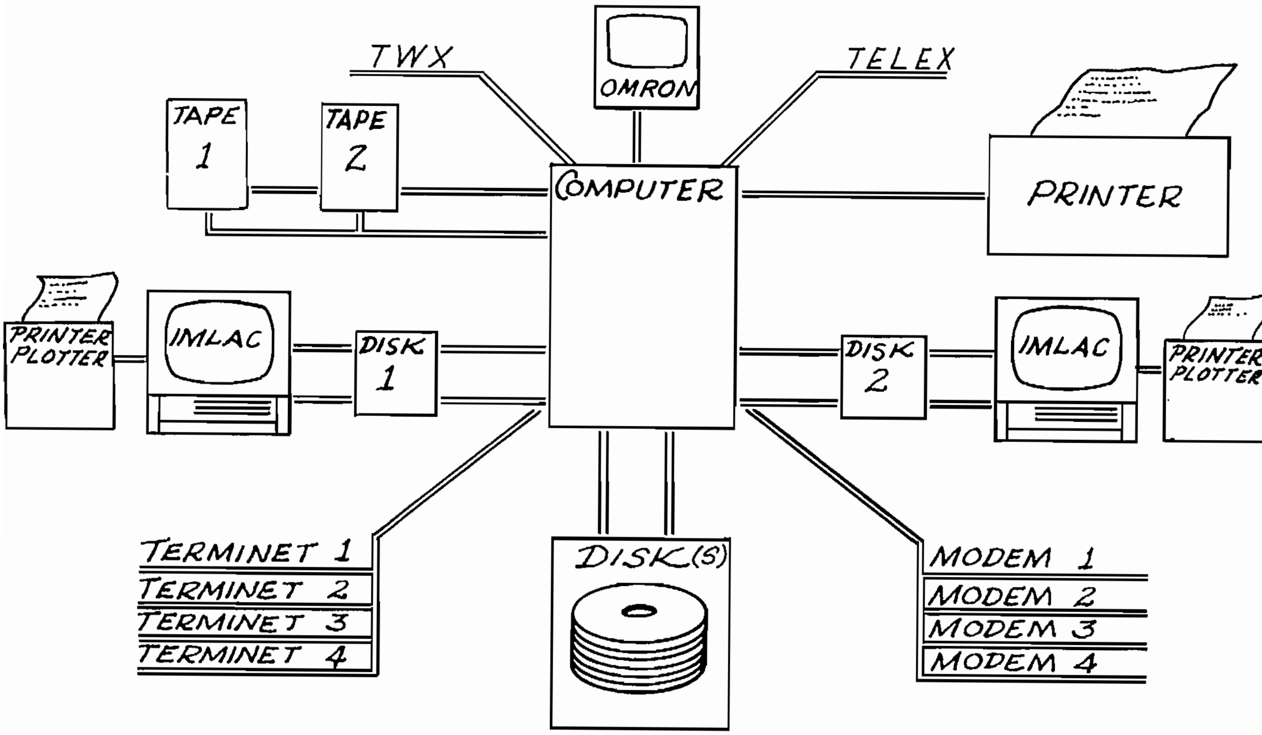


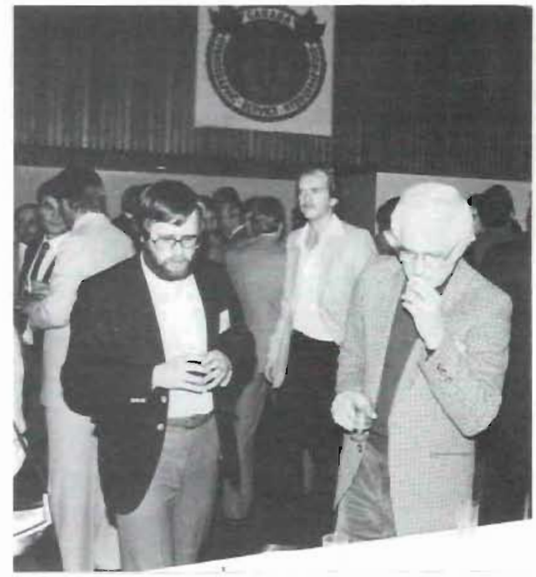
FIGURE 1. FUNCTIONAL DIAGRAM OF AUTOMATED NOTICE TO MARINERS SYSTEM. (NOTE: LIST OF LIGHTS DATA ARE LOADED VIA ONE OF THE TWO IMLAC TERMINALS. ALL DATA ARE STORED ON DISK FILES UNDER THE CONTROL OF THE PRIME 400 COMPUTER. A MAGNETIC TAPE IS OUTPUT TO DRIVE A TYPESETTING MACHINE FOR PRINTING THE WEEKLY CORRECTIONS AND ANNUAL VOLUMES. PROOF PLOTS ARE OUTPUT ON TWO PRINTER/PLOTTERS ATTACHED TO THE IMLAC DATA IMPUT STATIONS OR ON A HIGH SPEED LINE PRINTER CONTROLLED BY THE COMPUTER. TWX, TELEX AND A VARIETY OF MODEMS ALLOW REMOTE ACCESS TO THE LIST OF LIGHTS DATA FILES.)

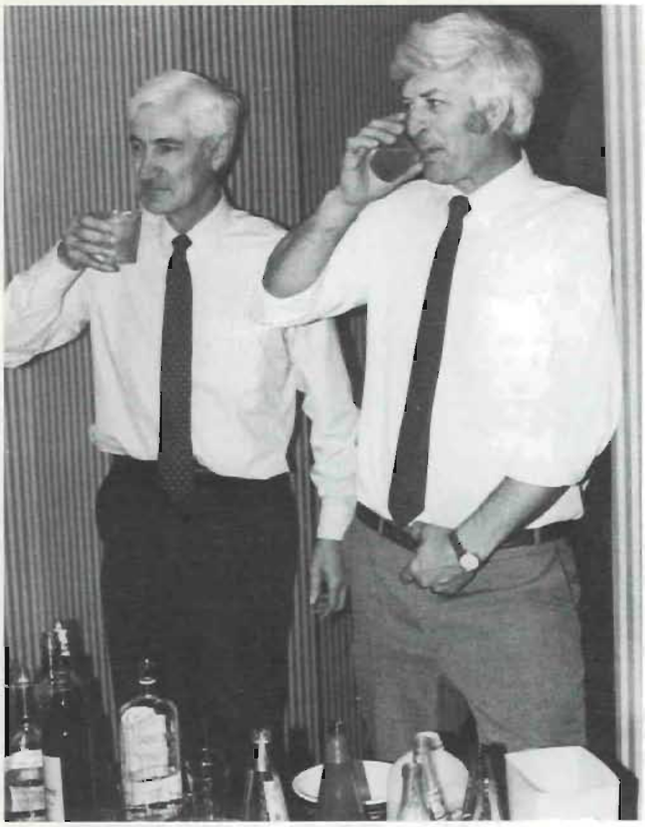
CONFERENCE PHOTOGRAPHY

PHOTOGRAPHIES DE LA CONFÉRENCE


MONITEQ


Marinav









"FROM LEADLINE TO
LASER"
1883
1983
"DE LA LIGNE DE SONDE
AU LASER"

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