BATHYMETRIC ATLAS of the COLUMBIA RIVER ESTUARY

Columbia River Estuary Data Development Program

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of the
COLUMBIA RIVER ESTUARY

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November, 1983

Acknowledgements

This atlas is based on 1982 bathymetric surveys conducted by the U.S. Army Corps of Engineers and on earlier surveys by the U.S. Coast and Geodetic Survey (now the National Ocean Survey, a division of the National Oceanic and Atmospheric Administration). The 1868, 1935, 1958 and 1982 bathymetric and differencing maps were produced by Northwest Cartography, Inc. under contracts with the Columbia River Estuary Data Development Program (CREDDP) and the U.S. Army Corps of Engineers.

The continued interest, participation and support of CREDDP by the U.S. Army Corps of Engineers Portland District is gratefully acknowledged.

Preface

The Columbia River Estuary Data Development Program

This document is one of a set of publications and other materials produced by the Columbia River Estuary Data Development Program (CREDDP). CREDDP has two purposes: to increase understanding of the ecology of the Columbia River Estuary and to provide information useful in making land and water use decisions. The program was initiated by local governments and citizens who saw a need for a better information base for use in managing natural resources and in planning development. In response to these concerns, the Governors of the states of Oregon and Washington requested in 1974 that the Pacific Northwest River Basins Commission (PNRBC) undertake an interdisciplinary ecological study of the estuary. At approximately the same time, local governments and port districts formed the Columbia River Estuary Study Taskforce (CREST) to develop a regional management plan for the estuary.

PNRBC produced a Plan of Study for a six-year, $6.2 million program which was authorized by the U.S. Congress in October 1978. For the next three years PNRBC administered CREDDP and $3.3 million was appropriated for the program. However, PNRBC was abolished as of October 1981, leaving CREDDP in abeyance. At that point, much of the field work had been carried out, but most of the data were not yet analyzed and few of the planned publications had been completed. To avoid wasting the effort that had already been expended, in December 1981 Congress included $1.5 million in the U.S. Water Resources Council (WRC) budget for the orderly completion of CREDDP. The WRC contracted with CREST to evaluate the status of the program and prepare a revised Plan of Study, which was submitted to the WRC in July 1982. In September, after a hiatus of almost one year, CREDDP work was resumed when a cooperative agreement was signed by CREST and the WRC to administer the restructured program and oversee its completion by June 1984. With the dissolution of the WRC in October 1982, the National Oceanic and Atmospheric Administration (NOAA) assumed the role of the WRC as the federal representative in this cooperative agreement.

CREDDP was designed to meet the needs of those groups who were expected to be the principal users of the information being developed. One such group consists of local government officials, planning commissions, CREST, state and federal agencies, permit applicants, and others involved in planning and permitting activities. The other major anticipated user group includes research scientists and educational institutions. For planning purposes, an understanding of the ecology of the estuary is particularly important, and CREDDP has been designed with this in mind. Ecological research focuses on the linkages among different elements in the food web and the influence on the food web of such physical processes as currents, sediment transport and salinity intrusion. Such an ecosystem view of the estuary is necessary to predict the effects of estuarine alterations on natural resources.

Research was divided into thirteen projects, called work units. Three work units, Emergent Plant Primary Production, Benthic Primary Production, and Water Column Primary Production, focused on the plant life which, through photosynthesis and uptake of chemical nutrients, forms the base of the estuarine food web. The goals of these work units were to describe and map the productivity and biomass patterns of the estuary's primary producers and to describe the relationship of physical factors to primary producers and their productivity levels.

The higher trophic levels in the estuarine food web were the focus of seven CREDDP work units: Zooplankton and Larval Fish, Benthic Infauna, Epibenthic Organisms, Fish, Avifauna, Wildlife, and Marine Mammals. The goals of these work units were to describe and map the abundance patterns of the invertebrate and vertebrate species and to describe these species' relationships to relevant physical factors.

The other three work units, Sedimentation and Shoaling, Currents, and Simulation, dealt with physical processes. The work unit goals were to characterize and map bottom sediment distribution, to characterize sediment transport, to determine the causes of bathymetric change, and to determine and model circulation patterns, vertical mixing and salinity patterns.

Each of these thirteen work units produced a final published report. (The Fish work unit produced two reports, one presenting research data, the other an ecological interpretation of the data.) In addition, all the work unit results are integrated in a comprehensive synthesis entitled *The Dynamics of the Columbia River Estuarine Ecosystem*, the purpose of which is to develop a description of the estuary at the ecosystem level of organization. In this document, the physical setting and processes of the estuary are described first. Next, a conceptual model of biological processes is presented, with particular attention to the connections among the components studied by the work units. This model provides the basis for a discussion of relationships between physical and biological processes and among the functional groups of organisms in the estuary. Finally, the estuary is divided into regions according to physical criteria, and selected biological and physical characteristics of the habitat types within each region are described. Historical changes in physical processes are also discussed, as are the ecological consequences of such changes.

Much of the raw data developed by the work units is collected in a magnetic tape archive established by CREDDP at the U.S. Army Corps of Engineers North Pacific Division Data Processing Center in Portland, Oregon. These data files, which are structured for convenient user access, are described in an *Index to CREDDP Data*. The index also describes and locates several data sets which were not adaptable to computer storage.

The work unit reports, the synthesis, and the data archive are intended primarily for scientists and for resource managers with a scientific background. However, to fulfill its purposes, CREDDP has developed a set of related materials designed to be useful to a wide range of people.

Guide to the Use of CREDDP Information is an introduction to the estuarine ecosystem for citizens, local government officials, and those planners and other professionals whose training is in fields other than the estuary-related sciences. It highlights the principal findings of the program and demonstrates how this information can be used to assess the consequences of alterations in the estuary. A summary of planning, permitting and mitigation procedures is included.

Two atlases are among the program's publications. Color maps of the distribution and abundance patterns identified by the work units are presented in *The Columbia River Estuary: Atlas of Physical and Biological Characteristics,* which includes an explanatory text. A separate *Bathymetric Atlas of the Columbia River Estuary* contains color bathymetric contour maps of three surveys dating from 1935 to 1982 and includes differencing maps illustrating the changes between surveys. CREDDP has also produced unbound maps of the estuary designed to be useful to resource managers, planners and citizens. These black-and-white maps illustrate the most recent (1982) bathymetric data as contours and show intertidal vegetation types as well as important cultural features. They are available in four segments at a scale of 1:50,000 and in nine segments at 1:12,000.

Two historical analyses have been produced. *Changes in Columbia River Estuary Habitat Types over the Past Century* compares information on the extent and distribution of swamps, marshes, flats, and various water depth regimes a hundred years ago with corresponding recent information and discusses the causes and significance of the changes measured. *Columbia's Gateway* is a two-volume set of which the first volume is a cultural history of the estuary to 1920 in narrative form with accompanying photographs. The second volume is an unbound, boxed set of maps including 39 reproductions of maps originally published between 1792 and 1915 and six original maps illustrating aspects of the estuary's cultural history.

A two-volume *Literature Survey of the Columbia River Estuary* (1980) is also available. Organized according to the same categories as the work units, Volume I provides a summary overview of the literature available before CREDDP, while Volume II is a complete annotated bibliography.

All of these materials are described more completely in *Abstracts of Major CREDDP Publications*. This document serves as a quick reference for determining whether and where any particular kind of information can be located among the program's publications and archives. In addition to the abstracts, it includes an annotated bibliography of all annual and interim CREDDP reports, certain CREST documents and maps, and other related materials.

To order any of the above documents or to obtain further information about CREDDP, its publications or its archives, write to CREST, P.O. Box 175, Astoria, Oregon 97103, or call (503) 325-0435.

The Cover

Dramatic hydrographic changes at the mouth of the Columbia River are shown by the two maps reproduced on the front cover. On the left is a portion of a survey conducted in 1841 by the U.S. Exploring Expedition under the command of Charles Wilkes. The map is one of several from the expedition that were originally produced by copperplate engraving. It shows depth soundings in fathoms in open water and in feet over the stippled shoal areas. On the right is a portion of a base map produced in 1983 by Northwest Cartography, Inc., for the Columbia River Estuary Data Development Program. It displays bathymetric contours derived from U.S. Army Corps of Engineers surveys conducted in 1982. The contour values are in feet.

The two maps are reproduced here at approximately the same scale (1:40,000). That they show approximately the same area can be seen by the position of Baker(s) Bay and Pt. Adams, the only features named in common on the two maps. Much of the evolution of East and West Sand Island and Clatsop Spit, which were non-existent in 1841, is shown in Segment 2 (1868/1935) of the Bathymetric Differencing Series on page 5 of this atlas.

Introduction

This *Bathymetric Atlas of the Columbia River Estuary* is a collection of maps from several hydrographic studies undertaken by Northwest Cartography, Inc., between 1979 and 1982 for the Columbia River Estuary Data Development Program (CREDDP), the U.S. Army Corps of Engineers Portland District, and the Corps' Waterways Experiment Station (WES). Its purpose is to provide an overview of sediment accretion and erosion patterns within the estuary and to facilitate interpretation of the slow, large-scale changes in the estuary floor. It reproduces three of the five bathymetric contour map series produced during these studies and contains three bathymetric differencing contour map series produced for this atlas.

The maps displayed in this atlas are referenced 1868, 1935, 1958 and 1982. These maps make use of data from the following four series of hydrographic surveys:

1868 — surveys made by the U.S. Coast and Geodetic Survey within the period 1867-1873, which predates most human alterations;

1935 — surveys made by the U.S. Coast and Geodetic Survey within the period 1926-1937, which follows the period of jetty building but coincides with major changes in pile dikes and channel alignment;

1958 — surveys made by the U.S. Coast and Geodetic Survey within the period 1949-1958, which predates major flow regulations and deepening of the navigation channel in the estuary from 35 to 40 feet but follows the deepening of the entrance to 48 feet; and

1982 — surveys made by the U.S. Army Corps of Engineers within the period 1979-1982, which represent current conditions.

The bathymetric contour maps in this atlas illustrate the latter three survey series. The differencing maps illustrate the changes that occurred between each successive pair of surveys.

The above mentioned series of hydrographic surveys included preliminary "boat" sheets, edited "smooth" sheets, and the more formally displayed but site specific "condition" surveys. The primary difficulty in using any historical series of hydrographic surveys to develop bathymetric differences and calculate variations in sediment is the non-uniformity of the surveys. There are cartographic inconsistencies within the hydrographic surveys such as tidal datum, geodetic control and planimetric development of the shoreline. These anomalies can be dealt with adequately. The troublesome inconsistency which remains is intrinsic to the nature of hydrographic surveying and it may be simply stated that the survey vessel does not repeat its survey track lines in identical locations from survey year to survey year. Thus a comparison of survey data that spans a period of years (and in the case of the Columbia River Estuary a period of 115 years) would involve a series of differently organized arrays of point data. Organizing these data into a system for analytic processing was a major goal within the framework of these studies.

In addition to compiling contour maps, Northwest Cartography has produced a digital bathymetry index for locating and recalling specific subarea data; has calculated sediment volume changes in 6528 grid cells that cover the estuary; has calculated net changes in grid cell surface area and depth regime; and has tabulated bathymetry and bathymetric differences in a series of five books with over 2200 tabular files. A series of index maps at the back of this atlas identifies the source documents used. By contacting the organization responsible for the publication of this atlas, arrangements to use the larger scale maps and the numeric outputs just described may be made.

Bathymetric Contour Map Series

Most hydrographic data are obtained and processed as point data. Bathymetric contour maps are interpretations made from such point data. Previous to these studies, no bathymetric contour maps existed for the Columbia River Estuary at a level of detail and organization suitable for scientific and management applications. The goals of the bathymetric contour mapping series were to:

- collect historic and contemporary source data;
- review data for quality and coverage, and document the best data on index maps (found at the back of this atlas); and
- produce five contour mapping series which would portray the bathymetric configuration of the estuary in (*circa*) 1868, 1935, 1958, 1975 and 1982.

The selection of the surveys to be used in these studies was based on identifying surveys which had good coverage and a dense sampling and which were done at times that would make them useful for analyzing the effects of human alterations. In the interpretation of contour lines, Northwest Cartography has attempted to be consistent with the National Ocean Survey's work by conservatively placing the contour line on the deep side of the soundings. The production of the various bathymetric contour mapping series on the seven base map segments was accomplished using standard cartographic methods and did not involve the computerization of data. Contour intervals of 0, 6, 12, 18, 24, 30, 42, 60, and 80 feet were selected. These maps were originally produced at scales of 1:20,000 and 1:40,000. Those reproduced here have been photographically reduced to a scale of 1:60,000.

Bathymetric Differencing Contour Map Series

The purpose of the differencing studies was to map and quantify changes in the estuary floor as erosion or accretion contours. If we could fix our view upon a single point (x,y) within the estuary and record its depth (z) observed there at different intervals of time, we would then have a record of change to the floor at that one point. However, the approximately 650,000 points that were sampled and analyzed to produce the data represented by these differencing maps did not in general represent repeated occupations of the same site.

The methodology used to create the bathymetric differencing series was developed by Northwest Cartography as an application of transect sampling which we did not find documented elsewhere.[1] As mentioned in the introduction, the intrinsic disorganization of hydrographic point data presents the primary difficulty in the processing of hydrographic data. In order to organize the point data into a regular grid of data from the original sounding lines without sacrificing the variability of sample density, Northwest Cartography first conducted a transect analysis. The transect grid (15 seconds of latitude by 15 seconds of longitude) was overlaid onto the hydrographic survey sheets, and depth values were recorded along the transects and at the grid cell centers. These values were digitized along the transects anywhere a sounding value was within the tolerance range of the transect, or where an interpreted contour line (available from the newly developed bathymetric contour series maps) intersected the transects. This placed all depth (z) values for a given survey year onto common transect (x,y) axes.

However, the z values were still irregularly spaced along the x,y axes. In order to difference the z values from year to year, another level of organization was introduced. The transect grid cell was divided into eight equally spaced increments along each of its two x and two y cell sides. A computer program was written which assigned an integer z value to each of the eight steps based upon its proximity to a known (digitized) hydrographic value. Steps that occurred between two digitized z values were assigned a computed integer z value which was derived from the technique of linear interpolation between the two surrounding digitized z values. Upon completion of this z value ordering and assignment, each survey year had eight z values along each 15 second x,y transect grid, and also had a z value at each cell center. The transects were then displayed as profiles on a computer terminal screen to correct digitizing errors or to flag illogical depth values for further review and editing.

The bathymetric differencing computer programs then generated a file of bathymetric changes between any two survey years compared. This difference file was then output on a line plotter which plotted regularly spaced difference values along the plotted transect grid. A computer program was used to group bathymetric differences into contour groups that represented consistent ranges of bathymetric difference. Final contouring at ± 6-foot intervals was performed manually. The bathymetric differencing maps found within this atlas were produced after final contouring with standard cartographic methods. In these maps, areas of sediment change are shown with hypsometric tints; progressively greater values of accretion are shown in darkening shades of orange, and progressively greater values of erosion are shown in deepening shades of blue.

Source Documents Used

The U.S. Coast and Geodetic Survey (USCGS) has been responsible for the preparation of nautical charts in the U.S. since the early nineteenth century. This agency was later renamed the National Ocean Survey (NOS) and presently operates as a division of the National Oceanic and Atmospheric Administration (NOAA).

Two kinds of source documents are used to make nautical charts. These are the topographic surveys ("T-sheets") and hydrographic surveys ("H-sheets"). The topographic surveys are the authority for the development of the shoreline (high water line) and all information landward of the high water line. The hydrographic surveys are the authority for all data below the plane of high water. Descriptive reports which accompany hydrographic surveys were prepared for all surveys since 1887, but are not generally available for surveys prior to the 1920's. These descriptive reports often contain information needed to resolve vertical and horizontal control problems in the surveys and may help explain anomalous data.

The determination of historical shorelines is a formidable problem. Because in-water changes were deemed more important to the hydrographic studies undertaken in the Columbia River Estuary than exact shoreline position, a decision was made to use the NOS/NOAA H-sheets but not the T-sheets. The expense of obtaining and using the T-sheets for historical surveys and contemporary surveys (there are 33 large scale NOS planimetric T-sheets needed to cover the estuary for the 1958 survey alone) was judged to outweigh the benefits of using them.

Display Base Map

To produce understandable bathymetric contour and differencing maps, it is necessary to have a base map showing the shoreline and major geographic features on which to present the contours and differences. Of the current map products available, the 1:40,000 scale nautical charts published by NOS/NOAA appeared to be the best for display of the bathymetric data. The two nautical charts which cover the study area are #18521 (50th Edition) and #18523 (38th Edition). These charts were prepared using both an H-sheet and a T-sheet. The shoreline and survey control features shown on the topographic survey were obtained by photogrammetric techniques and are intended to satisfy national map accuracy standards.

Alterations to these nautical charts were necessary to adapt them to project needs: a full one-minute latitude/longitude graticule was added, the existing bathymetry was deleted to provide for the display of the bathymetric data being developed, and the study area was divided into seven base map segments.

Recent studies of biological and physical data for CREDDP eventually prompted the development by Northwest Cartography of a new photogrammetrically controlled base map series for the estuary. The new base maps appear as the display base in *The Columbia River Estuary: Atlas of Physical and Biological Characteristics* (CREDDP 1984). The maps in this atlas were, however, developed prior to the new base maps.

Since the purpose of these maps was to show bathymetric contours and change rather than to document shoreline positions or changes, it was not considered necessary to adjust the base map shoreline for the earlier maps. Because these maps show historical bathymetric contours superimposed on the modern shoreline, contour lines sometimes appear crossing shorelines and zero lines sometimes appear in midwater.

Considerations For Users

For many legal and scientific purposes, the shoreline (high water line) and the low water line (mean lower low water — MLLW) are of considerable importance. These datum levels are at the upper and lower limits of traditional hydrographic and planimetric surveying techniques, respectively. Difficulties in their determination may, therefore, be expected.

The charted shoreline or high water line is not a datum level carried from a tide gauge by spirit level. It is a representation of what a surveyor saw on the ground and interpreted as being the high water line. The departure from the datum level in marshes, where the shoreline is actually a vegetation line, may be quite large. The shoreline represented on hydrographic surveys (H-sheets) is not usually authoritative; it may be only a sketch or tracing from the topographic survey sheet (T-sheet). Authoritative shoreline determination requires the use of the T-sheets which were not, for reasons stated earlier, available for use in these studies.

As for MLLW, experience suggests that the MLLW on hydrographic surveys can be accepted as approximately correct where supported by soundings below and above MLLW. Elsewhere, it should be treated with some skepticism. The degree of accuracy is probably sufficient for scientific work where the emphasis is placed on large-scale changes affecting the estuary as a whole. A detailed study, scientific or legal, of a specific area may require greater accuracy. The accuracy and interpretation of U.S. Coast and Geodetic Survey maps is treated more fully in Shalowitz (1964).[2]

There are a number of sources of error in the base maps and hydrographic surveys used, and the subsequent overlaying of the bathymetric and difference data. Briefly, these are:

- differences in the projection type between the nautical charts used for the base maps (Mercator) and the hydrographic surveys (polyconic);
- generalization of shoreline portrayal on the 1:40,000 NOS nautical charts used for the base maps;
- differences over time in the latitude/longitude graticule, deriving from the 1927 North American Datum shift and from other causes;
- errors in positioning soundings on the survey sheets;
- distortion caused by photographic reproduction of the original charts and surveys (now on microfilm);
- inadequate sounding density to resolve complex bathymetry;
- lack of documented shore station control on early surveys and nautical charts; and
- errors caused by interpolation or other miscellaneous factors.

The procedure that was used in positioning and overlaying hydrographic surveys onto the base maps was to match the latitude/longitude graticule first, the shore control stations second, and "stable" shorelines third. The latitude/longitude graticule has been changed several times on many older surveys; shoreline control stations are lost or only approximately duplicated at a couple of points from survey to survey; and the most stable shorelines change somewhat.

It is Northwest Cartography's opinion that, for the Columbia River Estuary study, the placement of the shoreline and bathymetry is reliable to within 0.1 inch, or 167 feet at a scale of 1:20,000. The shoreline match is generally better than this for most surveys, and larger misalignments occur only in spot locations. Most changes in the shoreline that are of interest in the present project (e.g., up to several miles of shoreline migration at Clatsop Spit) are considerably larger than the errors. The maps displayed in this atlas, despite small errors inherent in their source data, have been processed uniformly and this uniformity allows for a generally accurate portrayal of the net change in bathymetry within the estuary.

There are also a number of distinct sources of error affecting the correctness of the depth values. Briefly, these are:

- changes in the definition of the tidal datum level to which soundings are referenced;
- natural changes in sea level over time;
- errors inherent in the use of the lead line for soundings in strong currents or rough water;
- errors introduced by rounding off of soundings;
- errors in the reduction of soundings to tidal datum;
- improper sampling of a sand wave field because of inadequate sounding density; and
- other miscellaneous errors associated with computer and cartographic processing.

The first and fifth causes mentioned above are probably the most important in the Columbia River Estuary. Because of the large variations in freshwater inflow, tidal elevations in the Columbia River are subject to large seasonal fluctuations that increase upriver and become important above about River Mile 23. Columbia River Datum (CRD), the sounding reference level presently used, was defined in 1912 but has since been revised. The relationship of older soundings to CRD cannot be determined. Examination of survey sheets, descriptive reports, and NOS tidal data suggest that errors due to this cause do not exceed a few tenths of a foot at River Mile 23, but could be as large as one to two feet at River Mile 50. Without a much larger historical data base, these discrepancies cannot be resolved. The calculated historical changes are, however, considerably larger than one to two feet in most areas.

Sand waves up to six feet have been observed, and the sounding density is often inadequate to resolve them completely. The errors can usually be edited out of a contour map by smoothing the contours. Spot errors of three to five feet in the difference maps will occasionally result. In summary, it is likely that systematic errors resulting from historical changes in datum level range from negligible, below River Mile 20, to as much as one or two feet at the upper limit of the study area. Since the contour interval is six feet, the errors do not interfere with the use of the maps for most purposes, but may bias estimates of volume changes caused by accretion and erosion in the upriver part of the study area. Random errors are largely eliminated in the contouring process.

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[1] D.A. Jay and R.B. Harvey, unpublished manuscript, 1981.

[2] *Shore and Sea Boundaries* Vol. II, Publication 10-1, U.S. Department of Commerce, Coast and Geodetic Survey, pp. 1-352.

HISTORIC BATHYMETRY SERIES
COLUMBIA RIVER ESTUARY
SEGMENT 1

Mouth and Approaches

LEGEND

- Shoreline to 12'
- 12' to 24'
- 24' to 42'
- 42' to 80'
- > 80'
- Limit of data coverage (1982 series only)
- Land area (NOAA charts #18521 and #18523 shorelines)

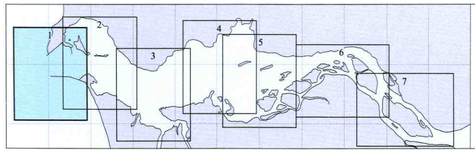
Bathymetric data compiled by Northwest Cartography from hydrographic surveys (smooth sheets, condition surveys) provided by the Coast and Geodetic Survey, the National Ocean Survey and the U.S. Army Corps of Engineers. Bathymetric contours are in feet relative to Mean Lower Low Water. Land area shown is derived from NOAA nautical chart shorelines, chart #18521, 50th Edition and chart #18523, 38th Edition.

0 1 2 3 Mi

0 1 2 3 4 5 Km

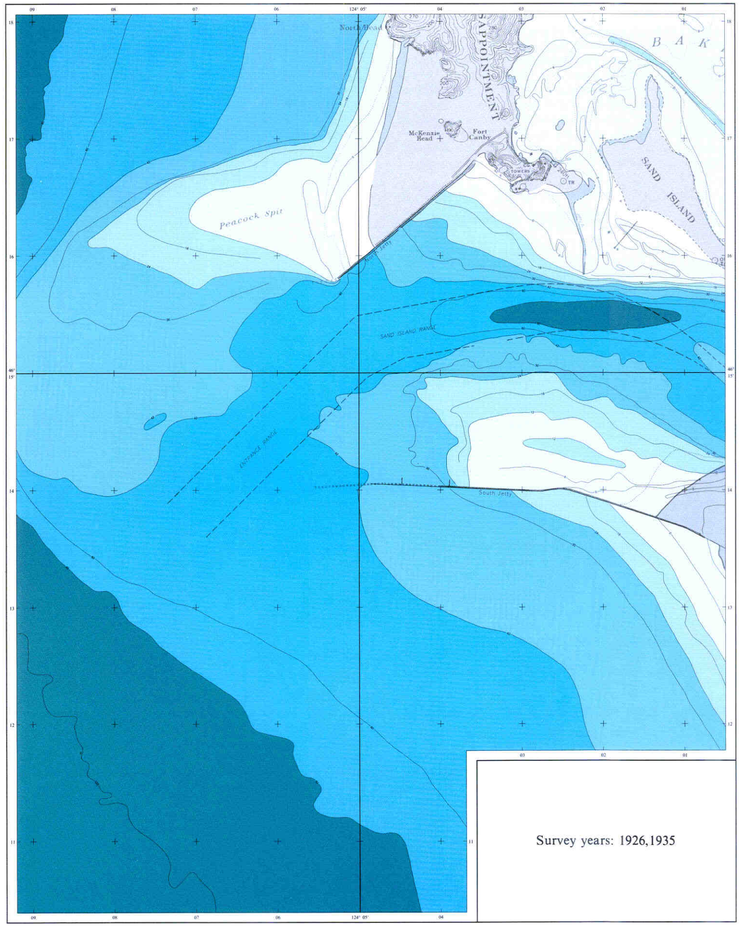
Scale: 1:60,000

INDEX TO MAP SERIES SEGMENTS

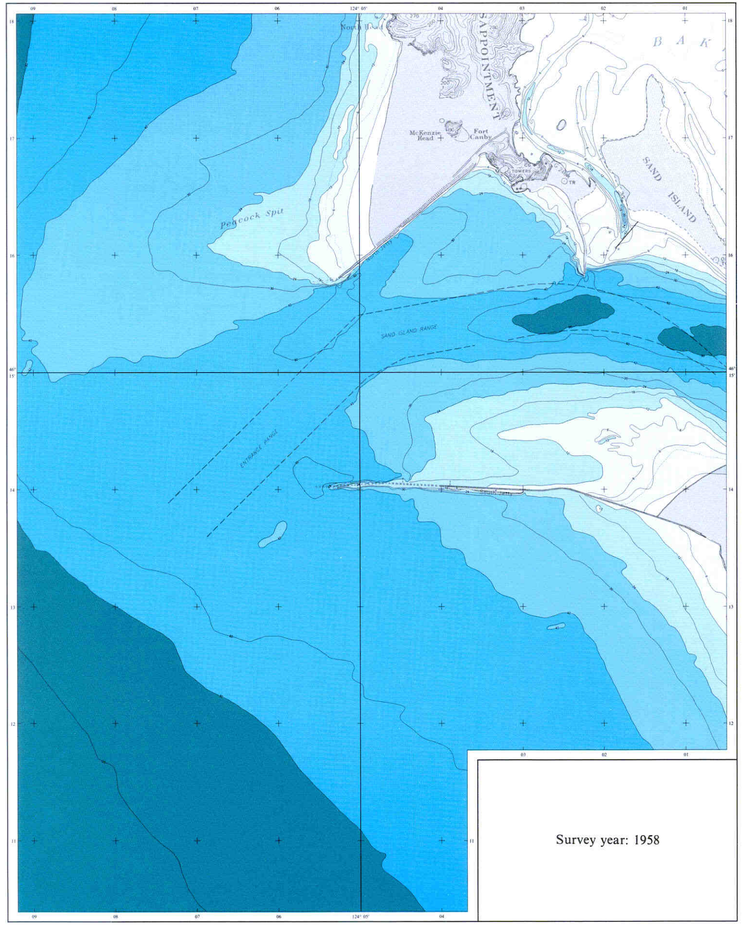


Map series was originally developed in 1980 by Northwest Cartography, Inc. for the Columbia River Estuary Data Development Program. Additional work done by Northwest Cartography in 1982 for the U.S. Army Corps of Engineers. The base map was photographically produced from NOAA nautical charts #18521, 50th Edition and #18523, 38th Edition.

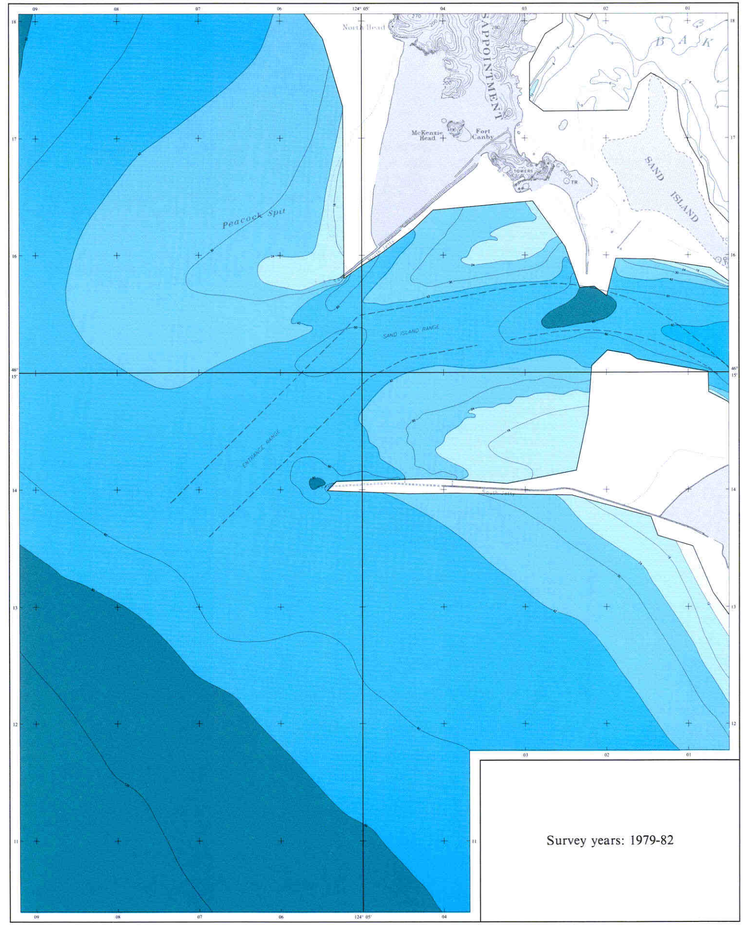
1935



1958



1982



BATHYMETRIC DIFFERENCING SERIES
COLUMBIA RIVER ESTUARY
SEGMENT 1
Mouth and Approaches

LEGEND

ACCRETION	EROSION
0' to 6'	0' to -6'
6' to 12'	-6' to -12'
12' to 24'	-12' to -24'
>24'	<-24'

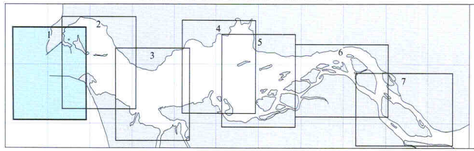
Limit of data coverage (1958/1982 series only)

Bathymetric differencing data developed by Northwest Cartography, Inc. utilizing a computer comparison of bathymetric data between hydrographic survey years. Contours representing historical depth changes are shown in feet (positive values = accretion, negative values = erosion).

0 1 2 3 Mi
0 1 2 3 4 5 Km

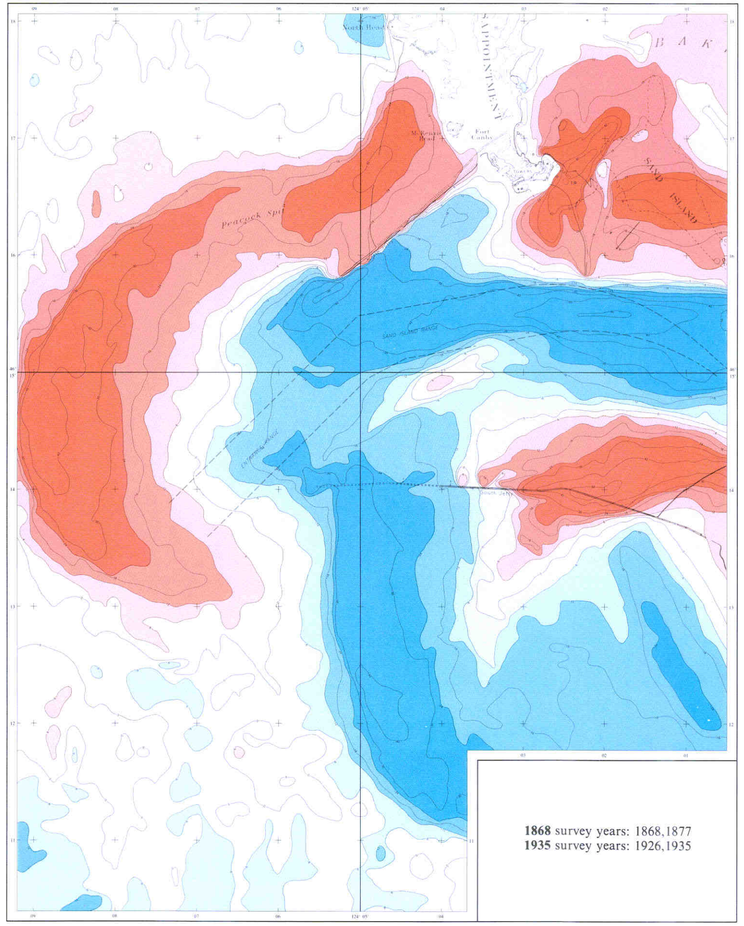
Scale: 1:60,000

INDEX TO MAP SERIES SEGMENTS



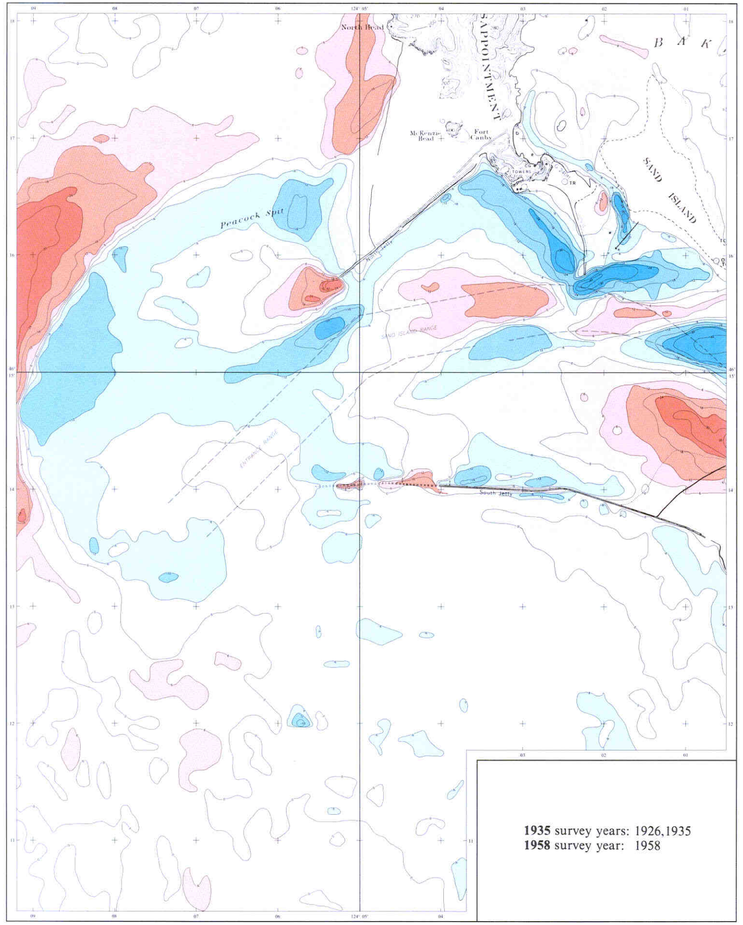
Map series was originally developed in 1980 by Northwest Cartography, Inc. for the Columbia River Estuary Data Development Program. Additional work done by Northwest Cartography in 1982 for the U.S. Army Corps of Engineers. The base map was photographically produced from NOAA nautical charts #18521, 50th Edition and #18523, 38th Edition.

1868/1935



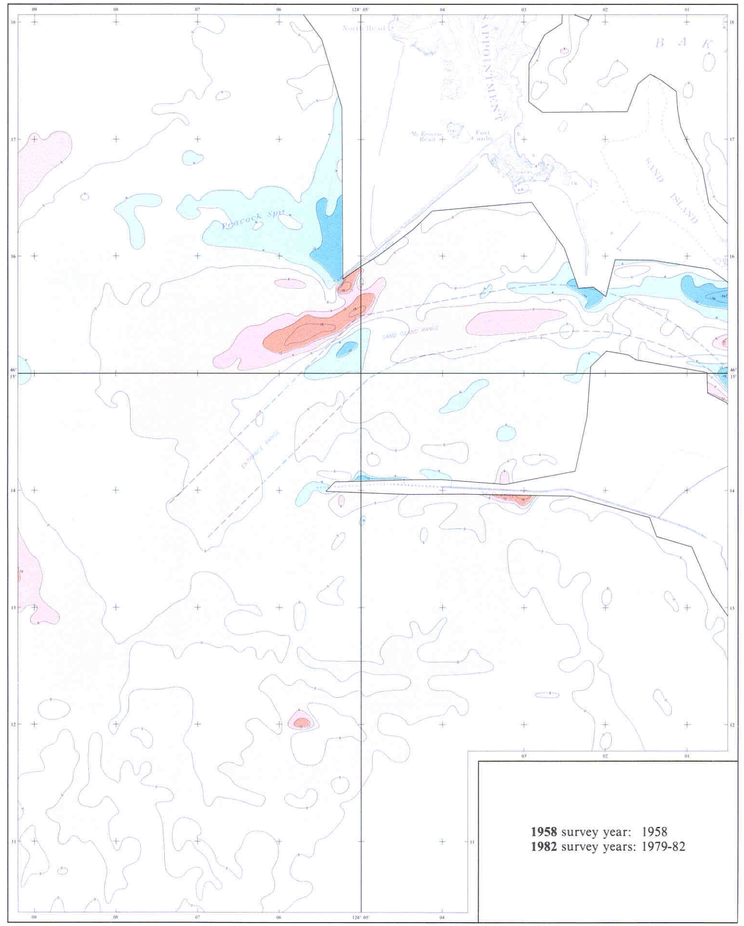
1868 survey years: 1868,1877
1935 survey years: 1926,1935

1935/1958



1935 survey years: 1926,1935
1958 survey year: 1958

1958/1982



1958 survey year: 1958
1982 survey years: 1979-82

HISTORIC BATHYMETRY SERIES
COLUMBIA RIVER ESTUARY
SEGMENT 2

Baker Bay and Clatsop Spit

LEGEND

- Shoreline to 12'
- 12' to 24'
- 24' to 42'
- 42' to 80'
- > 80'
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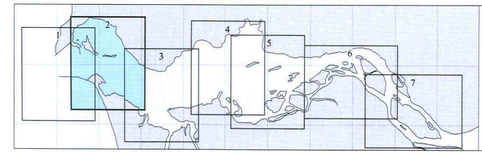
0 1 2 3 4 5 Km

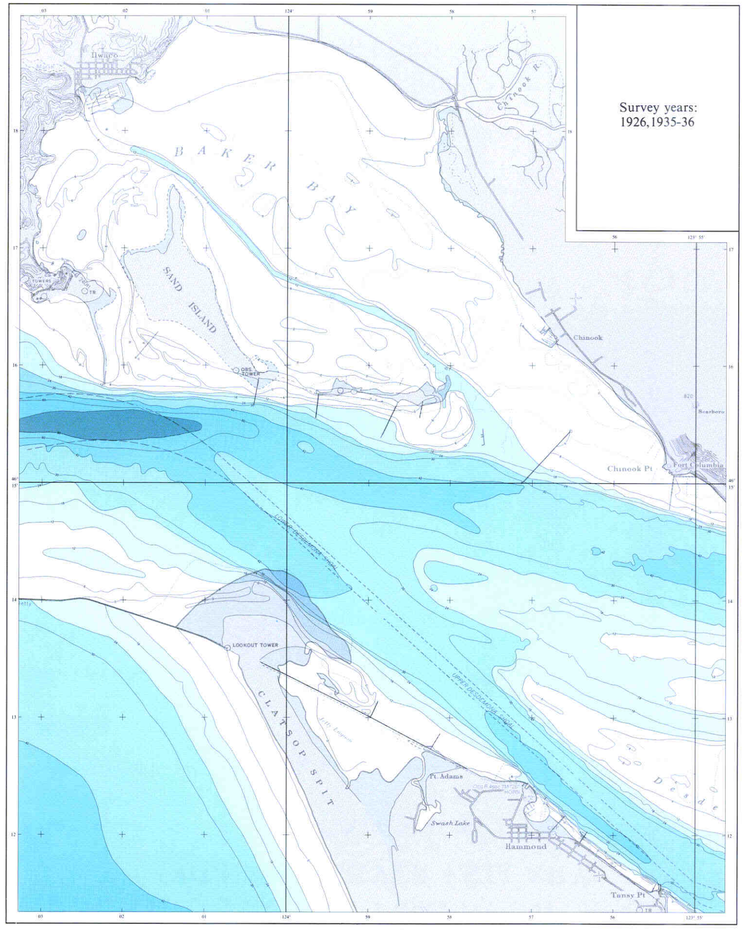
Scale: 1:60,000

INDEX TO MAP SERIES SEGMENTS

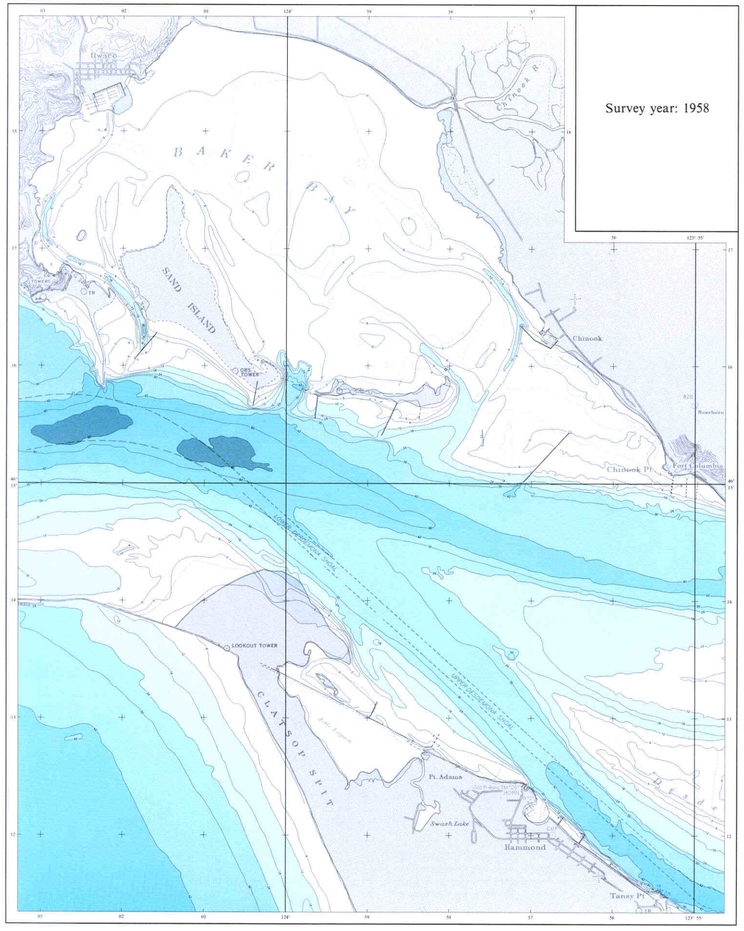


Map series was originally developed in 1980 by Northwest Cartography, Inc. for the Columbia River Estuary Data Development Program. Additional work done by Northwest Cartography in 1982 for the U.S. Army Corps of Engineers. The base map was photographically produced from NOAA nautical charts #18521, 50th Edition and #18523, 38th Edition.

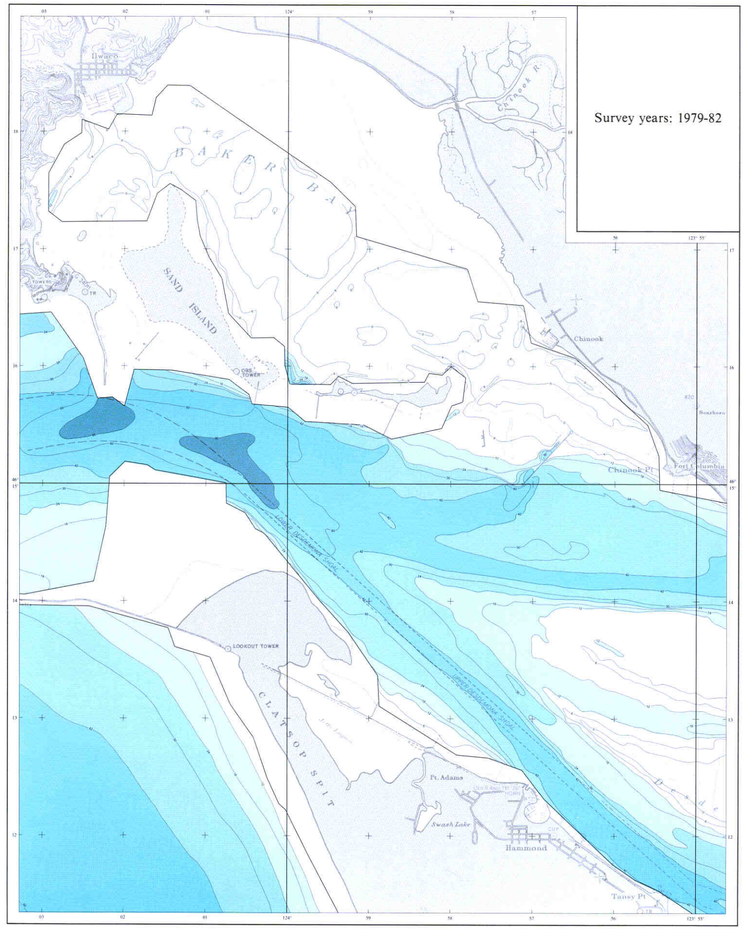
1935



1958



1982



BATHYMETRIC DIFFERENCING SERIES
COLUMBIA RIVER ESTUARY
SEGMENT 2

Baker Bay and Clatsop Spit

LEGEND

ACCRETION	EROSION
0' to 6'	0' to -6'
6' to 12'	-6' to -12'
12' to 24'	-12' to -24'
>24'	<-24'

Limit of data coverage (1958/1982 series only)

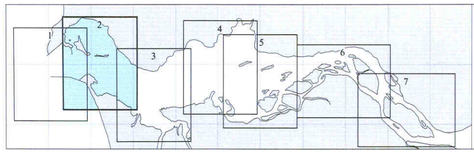
Bathymetric differencing data developed by Northwest Cartography, Inc. utilizing a computer comparison of bathymetric data between hydrographic survey years. Contours representing historical depth changes are shown in feet (positive values = accretion, negative values = erosion).

0 1 2 3 Mi

0 1 2 3 4 5 Km

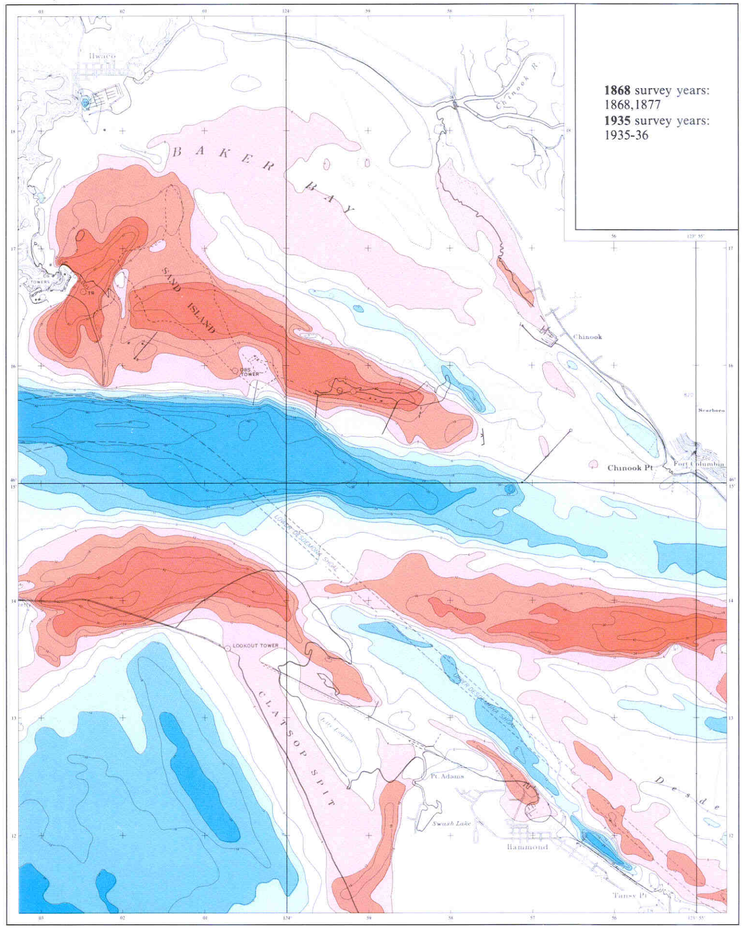
Scale: 1:60,000

INDEX TO MAP SERIES SEGMENTS

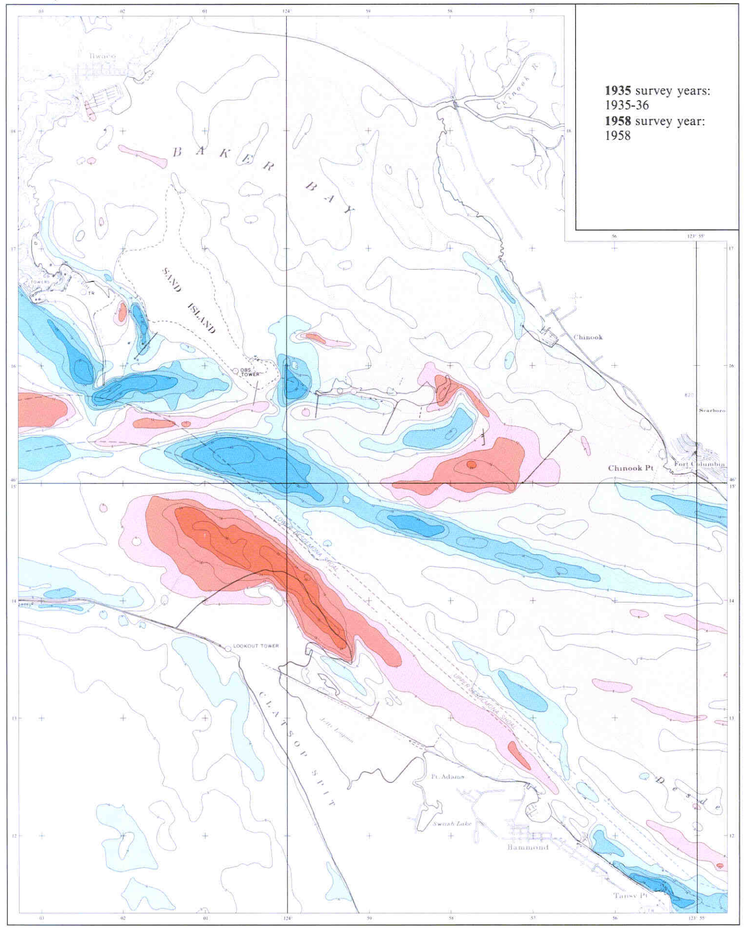


Map series was originally developed in 1980 by Northwest Cartography, Inc. for the Columbia River Estuary Data Development Program. Additional work done by Northwest Cartography in 1982 for the U.S. Army Corps of Engineers. The base map was photographically produced from NOAA nautical charts #18521, 50th Edition and #18523, 38th Edition.

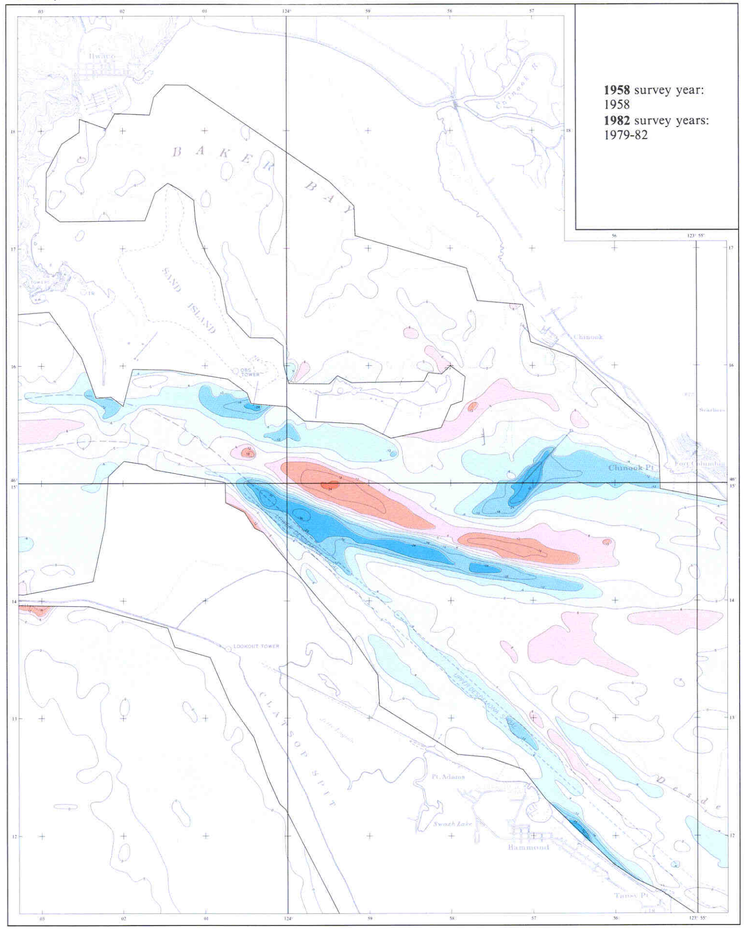
1868/1935



1935/1958



1958/1982



BATHYMETRIC DIFFERENCING SERIES
COLUMBIA RIVER ESTUARY
SEGMENT 2
Baker Bay and Clatsop Spit

LEGEND

ACCRETION	EROSION
0' to 6'	0' to -6'
6' to 12'	-6' to -12'
12' to 24'	-12' to -24'
>24'	< -24'

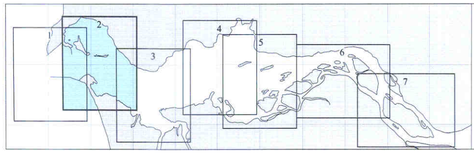
Limit of data coverage (1958/1982 series only)

Bathymetric differencing data developed by Northwest Cartography, Inc. utilizing a computer comparison of bathymetric data between hydrographic survey years. Contours representing historical depth changes are shown in feet (positive values = accretion, negative values = erosion).

0 1 2 3 Mi
0 1 2 3 4 5 Km

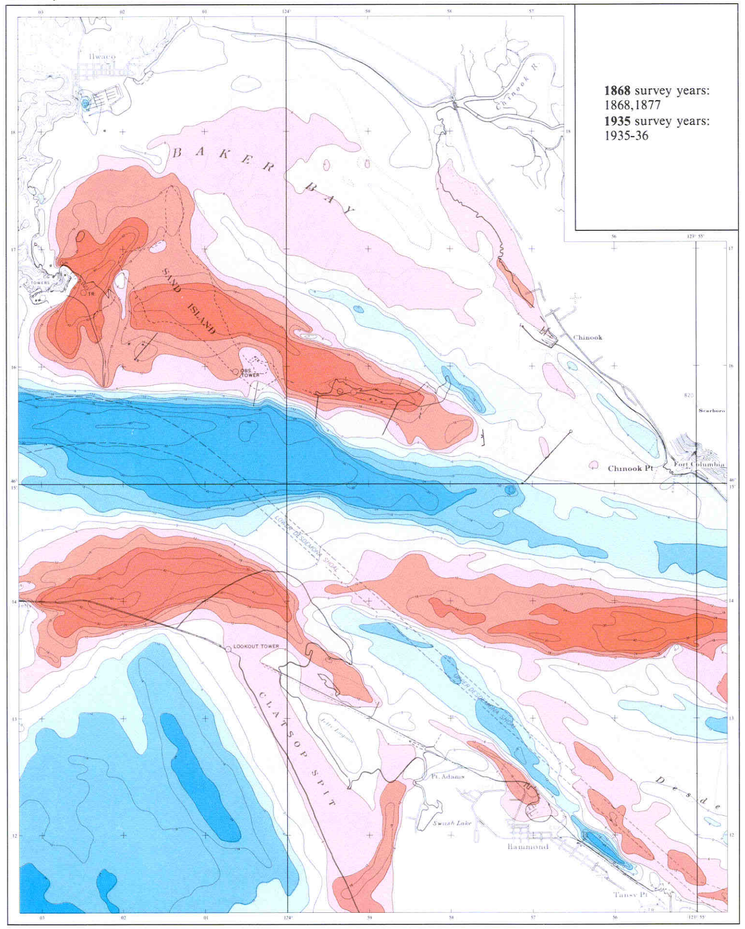
Scale: 1:60,000

INDEX TO MAP SERIES SEGMENTS

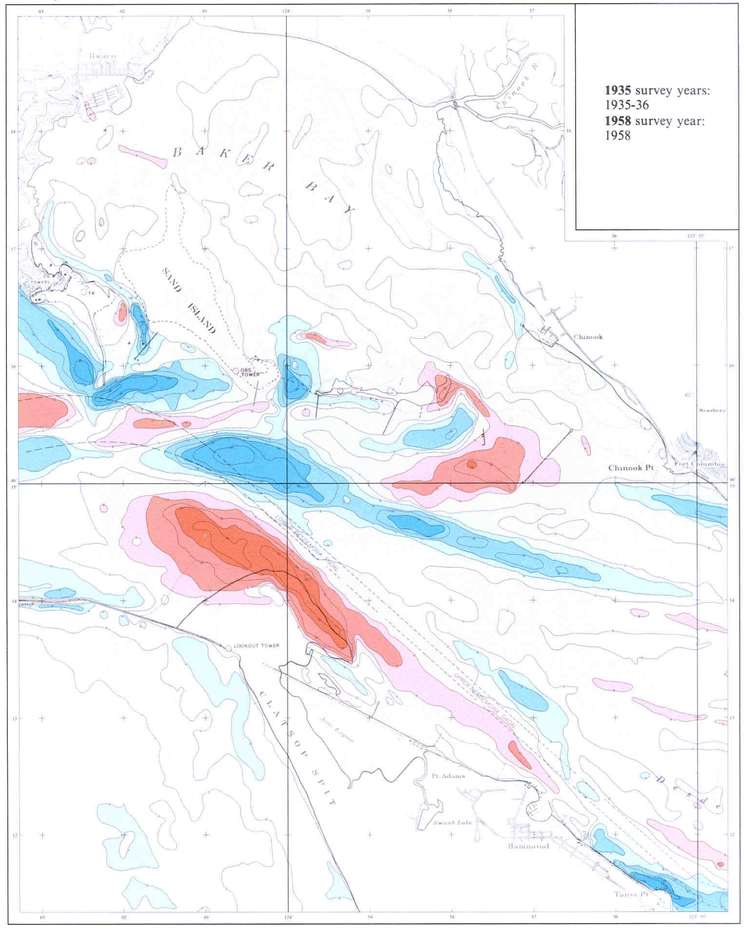


Map series was originally developed in 1980 by Northwest Cartography, Inc. for the Columbia River Estuary Data Development Program. Additional work done by Northwest Cartography in 1982 for the U.S. Army Corps of Engineers. The base map was photographically produced from NOAA nautical charts #18521, 50th Edition and #18523, 38th Edition.

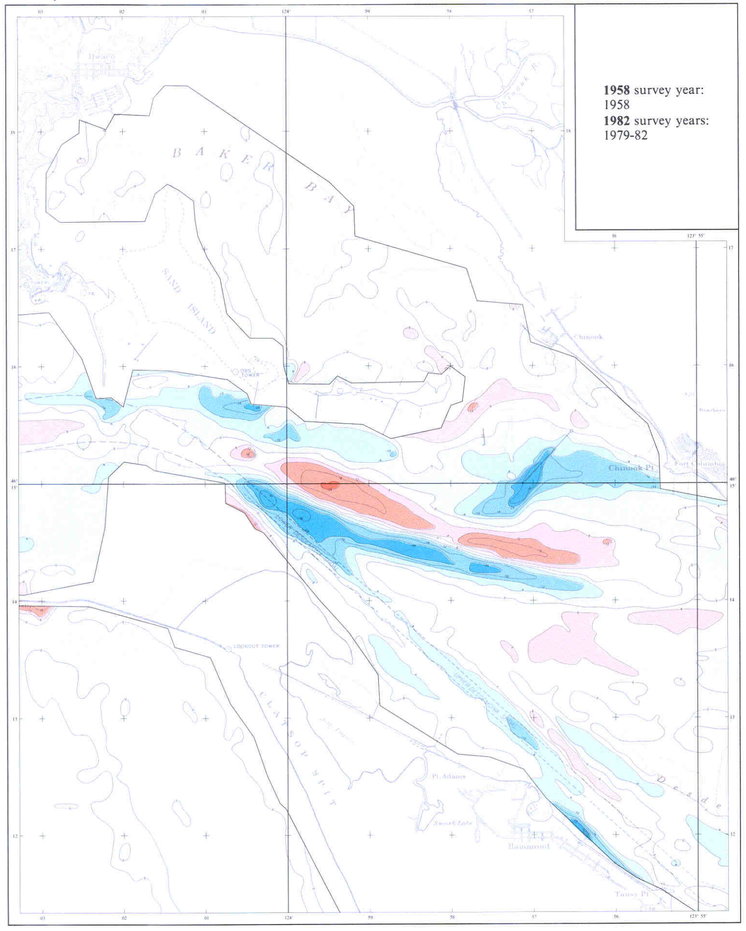
1868/1935



1935/1958



1958/1982



BATHYMETRIC DIFFERENCING SERIES
COLUMBIA RIVER ESTUARY
SEGMENT 3
Desdemona Sands and Youngs Bay

LEGEND

ACCRETION	EROSION
0' to 6'	0' to -6'
6' to 12'	-6' to -12'
12' to 24'	-12' to -24'
> 24'	< -24'

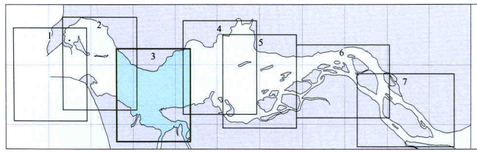
Limit of data coverage (1958/1982 series only)

Bathymetric differencing data developed by Northwest Cartography, Inc. utilizing a computer comparison of bathymetric data between hydrographic survey years. Contours representing historical depth changes are shown in feet (positive values = accretion, negative values = erosion).

0 1 2 3 Mi
0 1 2 3 4 5 Km

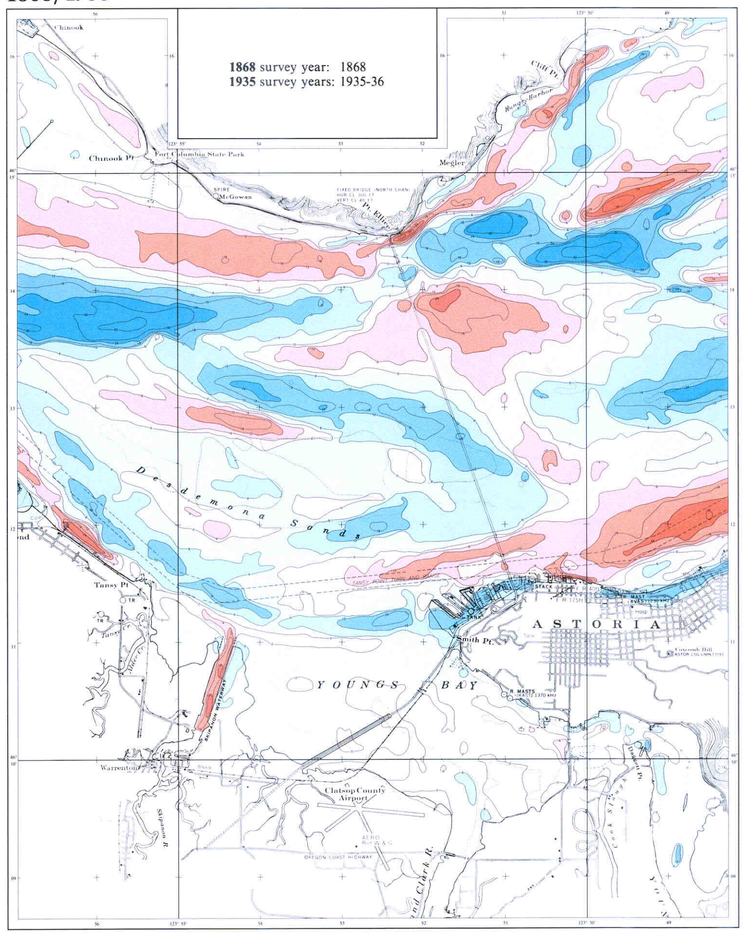
Scale: 1:60,000

INDEX TO MAP SERIES SEGMENTS

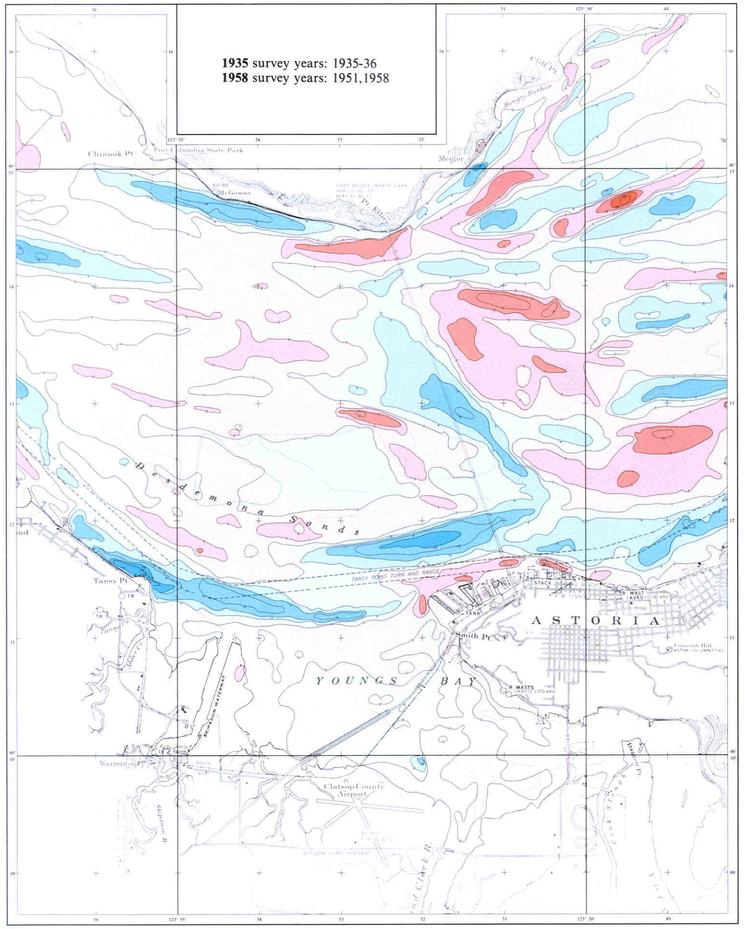


Map series was originally developed in 1980 by Northwest Cartography, Inc. for the Columbia River Estuary Data Development Program. Additional work done by Northwest Cartography in 1982 for the U.S. Army Corps of Engineers. The base map was photographically produced from NOAA nautical charts #18521, 50th Edition and #18523, 38th Edition.

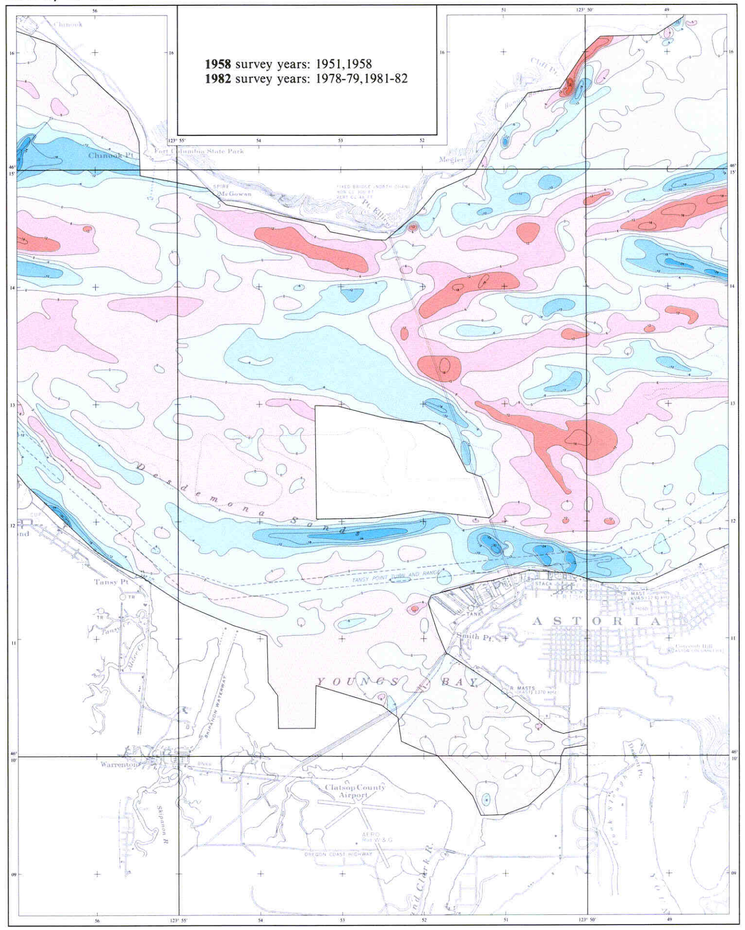
1868/1935



1935/1958



1958/1982



HISTORIC BATHYMETRY SERIES
COLUMBIA RIVER ESTUARY
SEGMENT 4
Tongue Point and Grays Bay

LEGEND

- Shoreline to 12′
- 12′ to 24′
- 24′ to 42′
- 42′ to 80′
- > 80′
- Limit of data coverage (1982 series only)
- Land area (NOAA charts #18521 and #18523 shorelines)

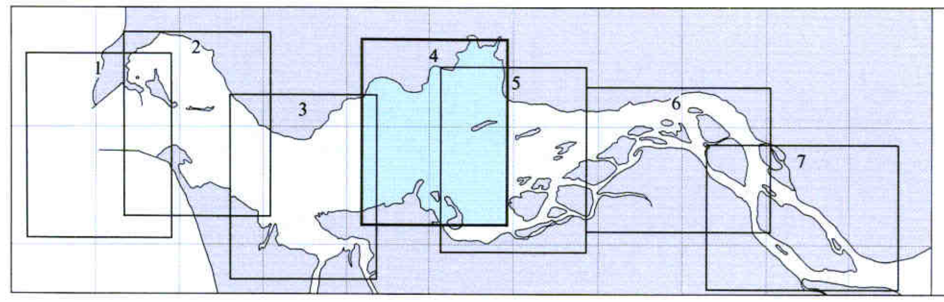
Bathymetric data compiled by Northwest Cartography from hydrographic surveys (smooth sheets, condition surveys) provided by the Coast and Geodetic Survey, the National Ocean Survey and the U.S. Army Corps of Engineers. Bathymetric contours are in feet relative to Mean Lower Low Water. Land area shown is derived from NOAA nautical chart shorelines, chart #18521, 50th Edition and chart #18523, 38th Edition.

0 1 2 3 Mi

0 1 2 3 4 5 Km

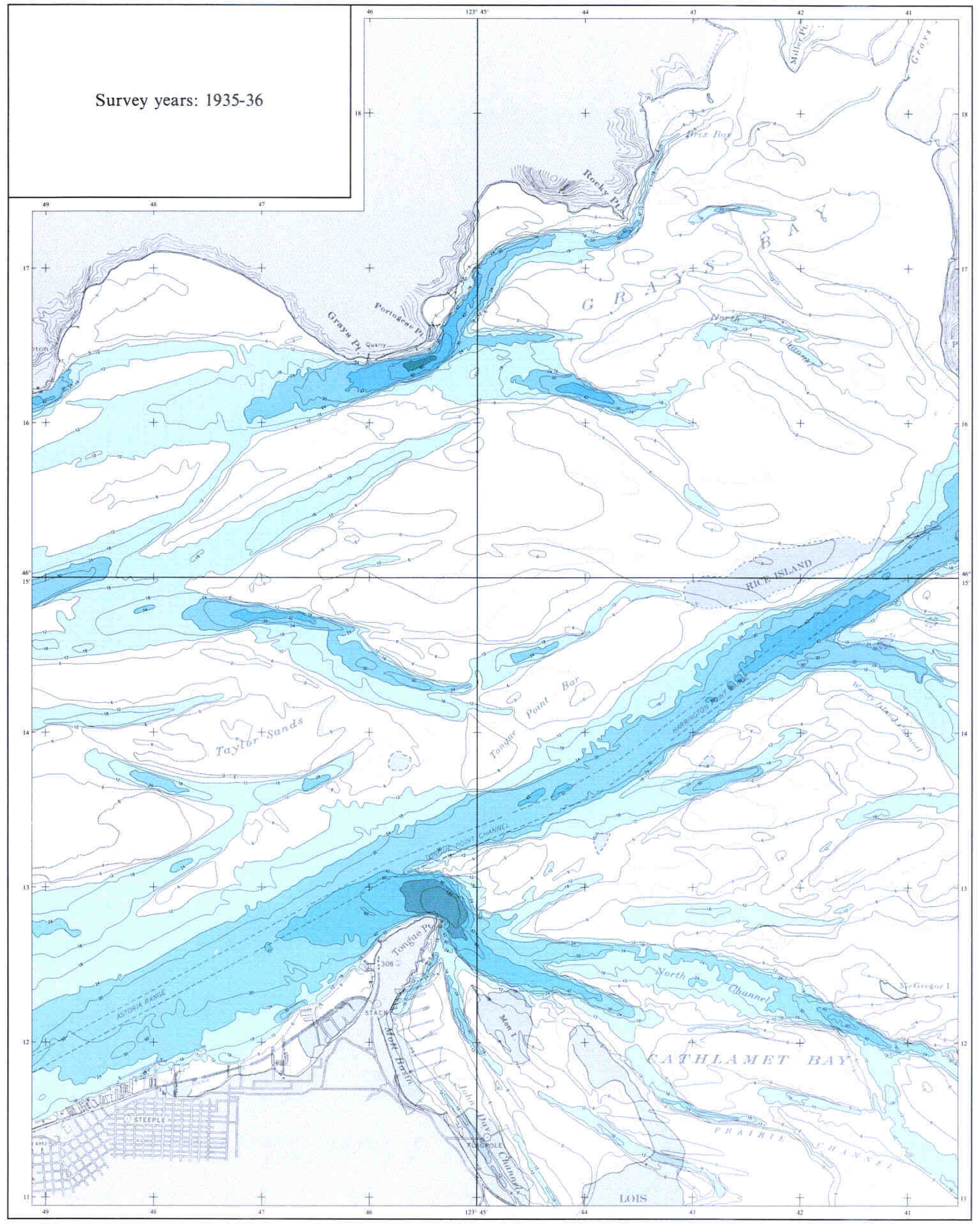
Scale: 1:60,000

INDEX TO MAP SERIES SEGMENTS

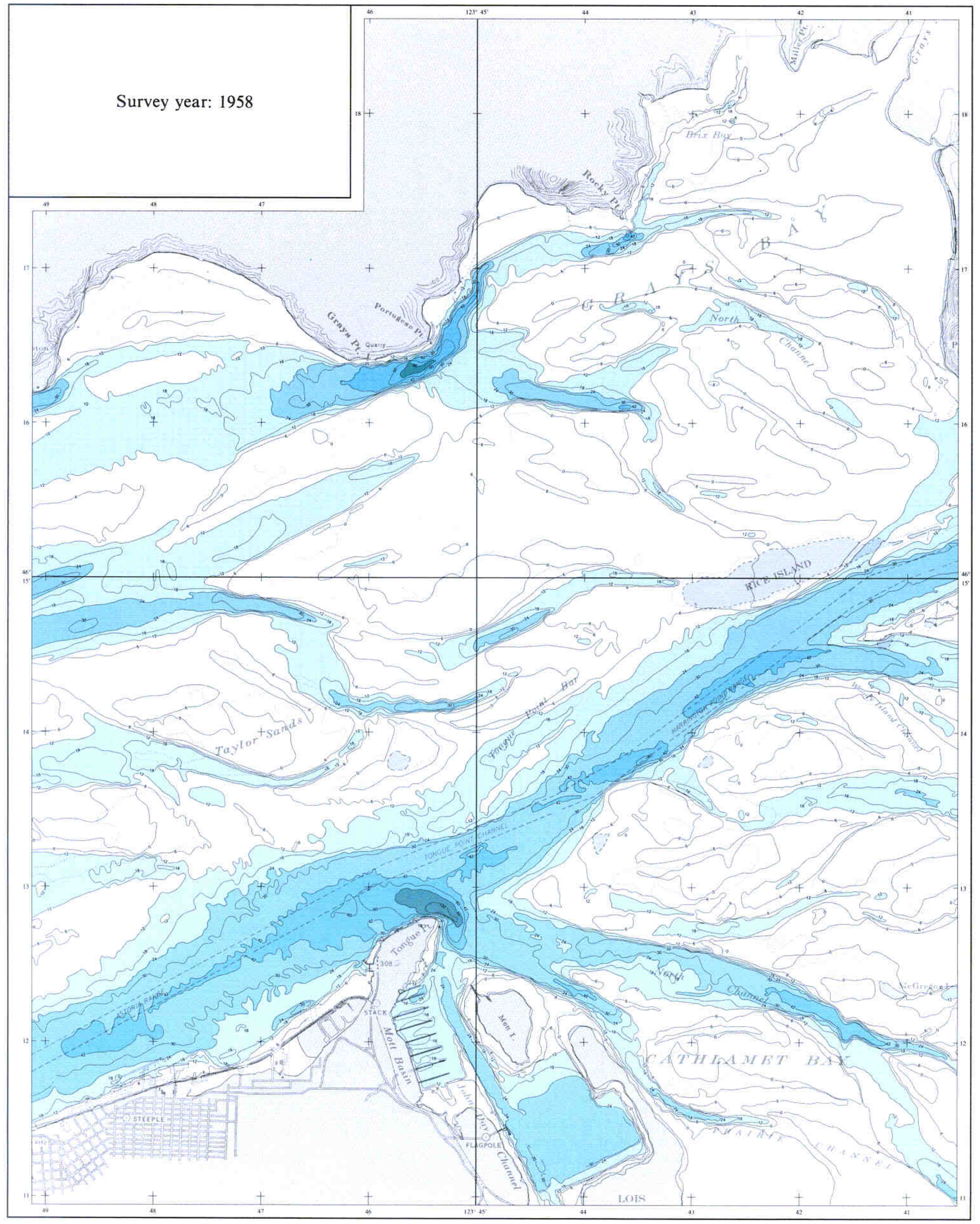


Map series was originally developed in 1980 by Northwest Cartography, Inc. for the Columbia River Estuary Data Development Program. Additional work done by Northwest Cartography in 1982 for the U.S. Army Corps of Engineers. The base map was photographically produced from NOAA nautical charts #18521, 50th Edition and #18523, 38th Edition.

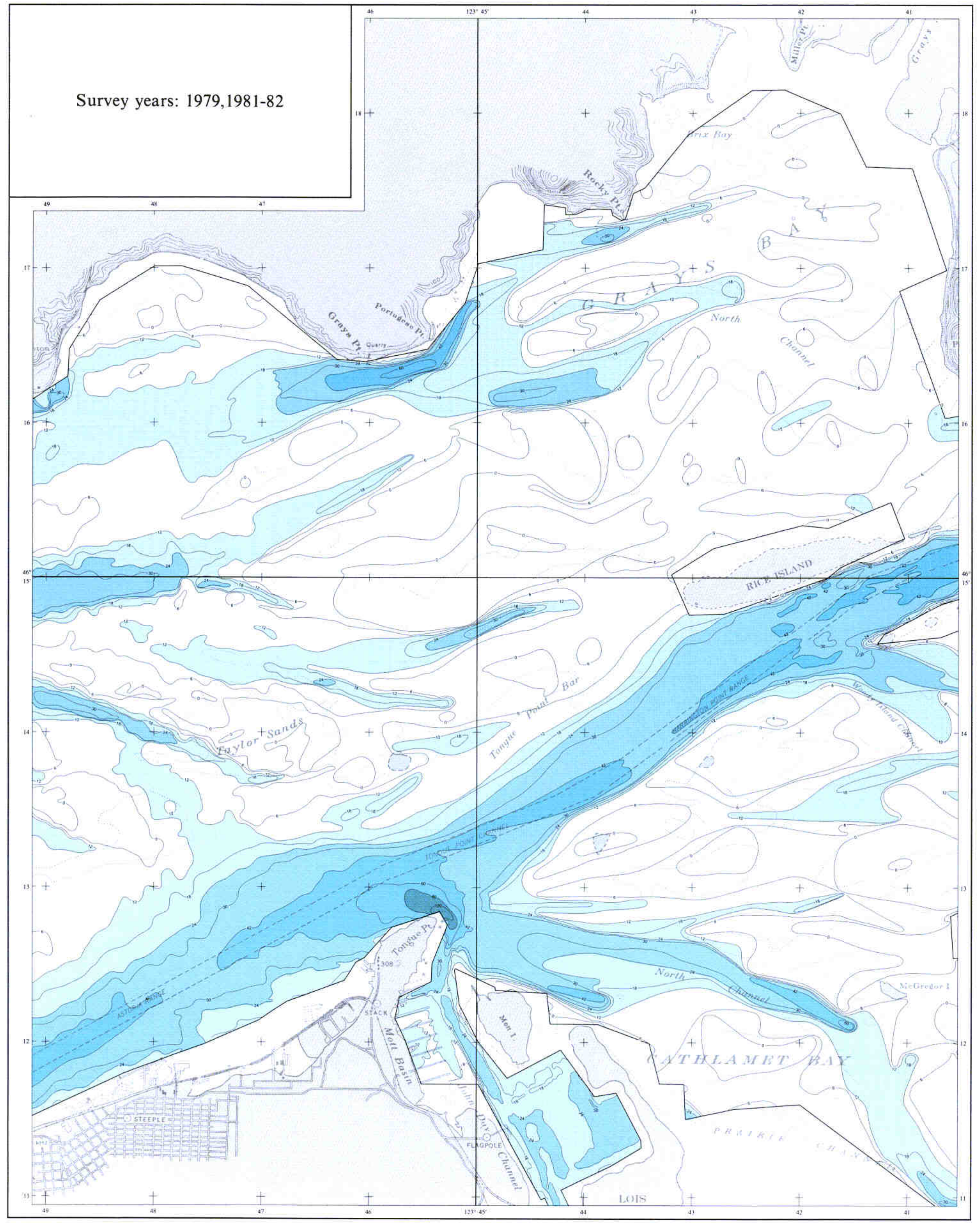
1935



1958



1982



BATHYMETRIC DIFFERENCING SERIES
COLUMBIA RIVER ESTUARY
SEGMENT 4

Tongue Point and Grays Bay

LEGEND

ACCRETION	EROSION
0' to 6'	0' to -6'
6' to 12'	-6' to -12'
12' to 24'	-12' to -24'
>24'	<-24'

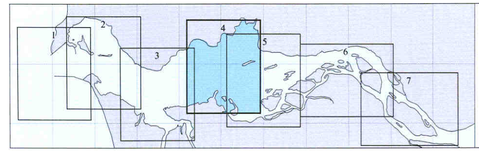
Limit of data coverage (1958/1982 series only)

Bathymetric differencing data developed by Northwest Cartography, Inc. utilizing a computer comparison of bathymetric data between hydrographic survey years. Contours representing historical depth changes are shown in feet (positive values = accretion, negative values = erosion).

0 1 2 3 Mi
0 1 2 3 4 5 Km

Scale: 1:60,000

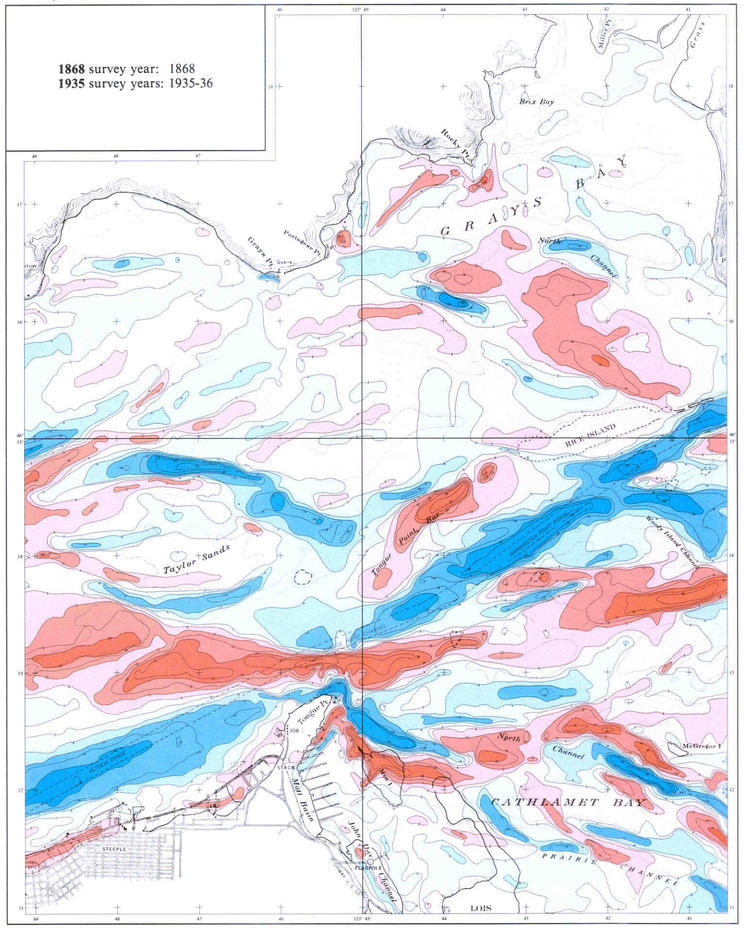
INDEX TO MAP SERIES SEGMENTS



Map series was originally developed in 1980 by Northwest Cartography, Inc. for the Columbia River Estuary Data Development Program. Additional work done by Northwest Cartography in 1982 for the U.S. Army Corps of Engineers. The base map was photographically produced from NOAA nautical charts #18521, 50th Edition and #18523, 38th Edition.

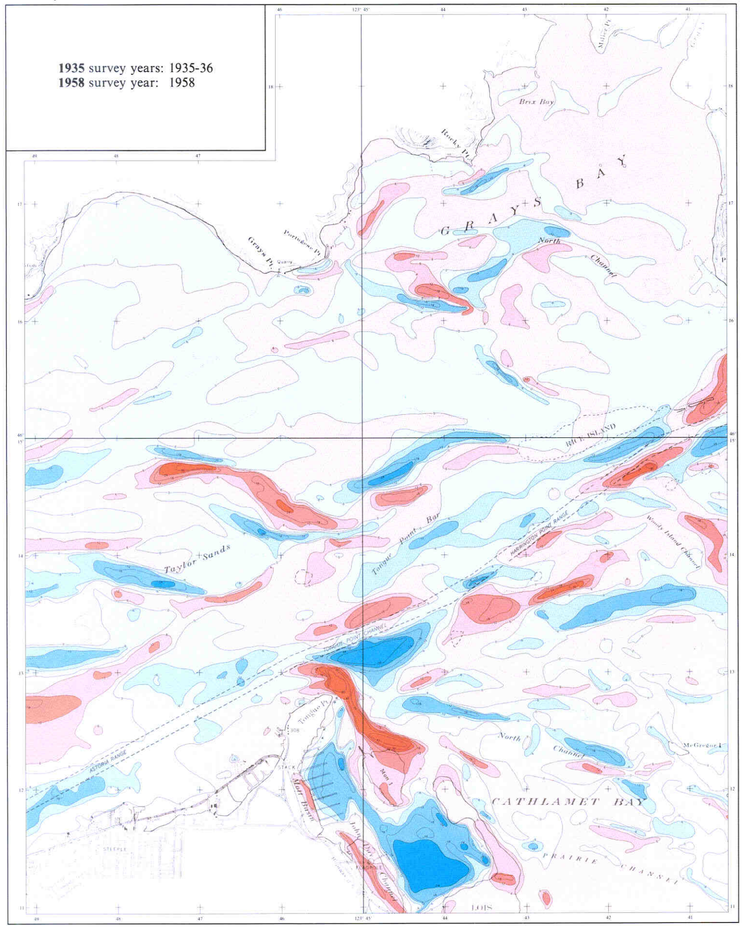
1868/1935

1868 survey year: 1868
1935 survey years: 1935-36



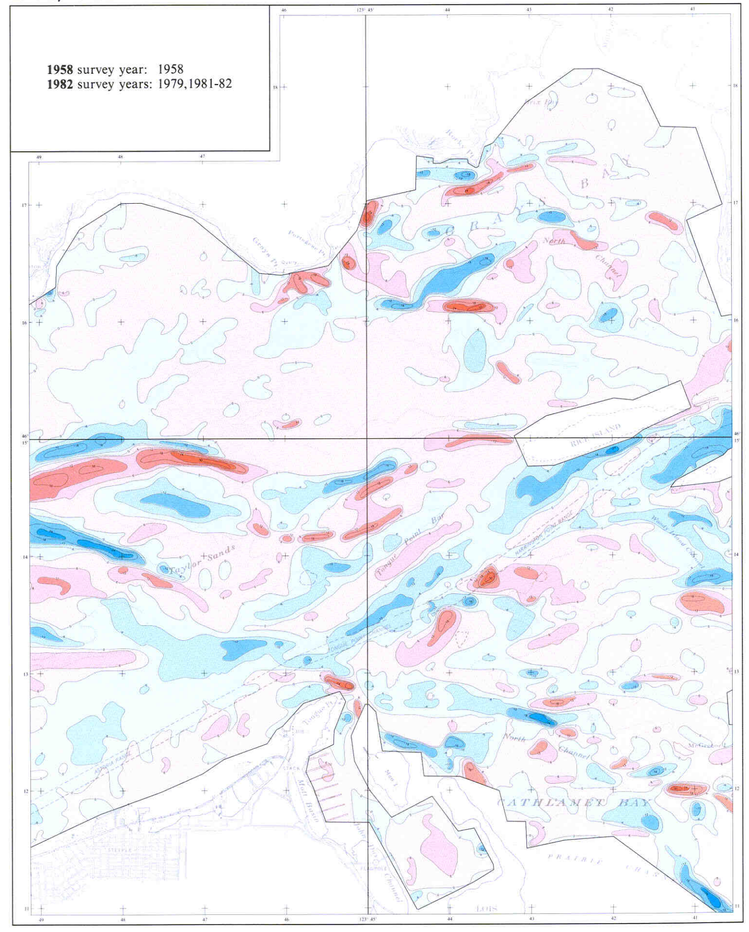
1935/1958

1935 survey years: 1935-36
1958 survey year: 1958



1958/1982

1958 survey year: 1958
1982 survey years: 1979,1981-82



HISTORIC BATHYMETRY SERIES
COLUMBIA RIVER ESTUARY
SEGMENT 5

Cathlamet Bay and Miller Sands

LEGEND

- Shoreline to 12'
- 12' to 24'
- 24' to 42'
- 42' to 80'
- > 80'
- Limit of data coverage (1982 series only)
- Land area (NOAA charts #18521 and #18523 shorelines)

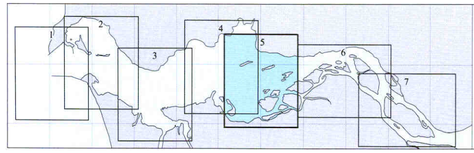
Bathymetric data compiled by Northwest Cartography from hydrographic surveys (smooth sheets, condition surveys) provided by the Coast and Geodetic Survey, the National Ocean Survey and the U.S. Army Corps of Engineers. Bathymetric contours are in feet relative to Mean Lower Low Water. Land area shown is derived from NOAA nautical chart shorelines, chart #18521, 50th Edition and chart #18523, 38th Edition.

0 1 2 3 Mi

0 1 2 3 4 5 Km

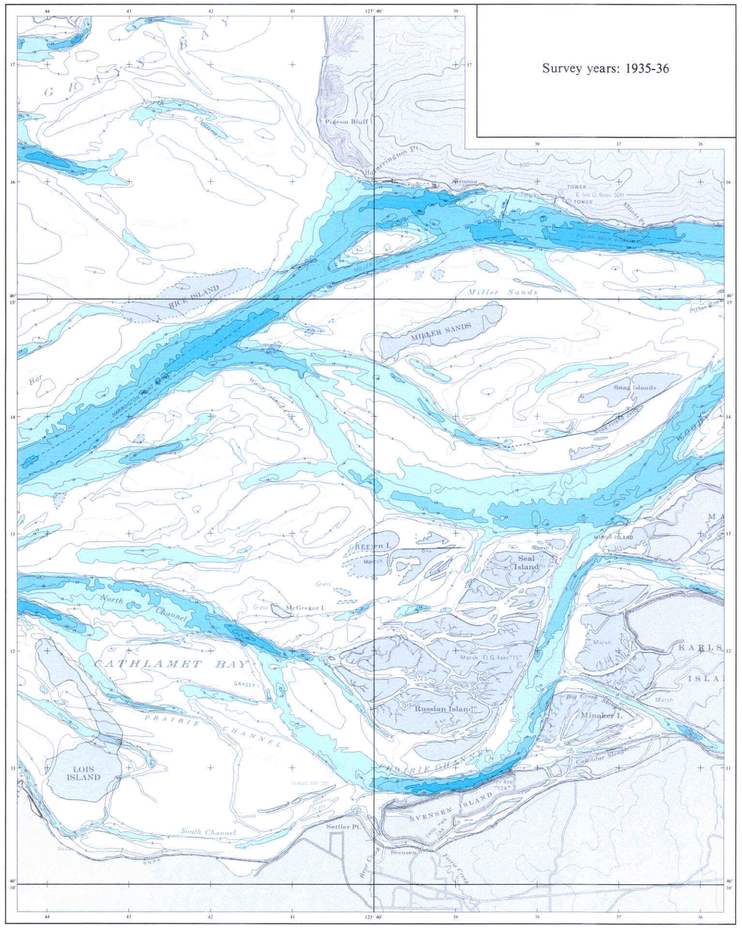
Scale: 1:60,000

INDEX TO MAP SERIES SEGMENTS

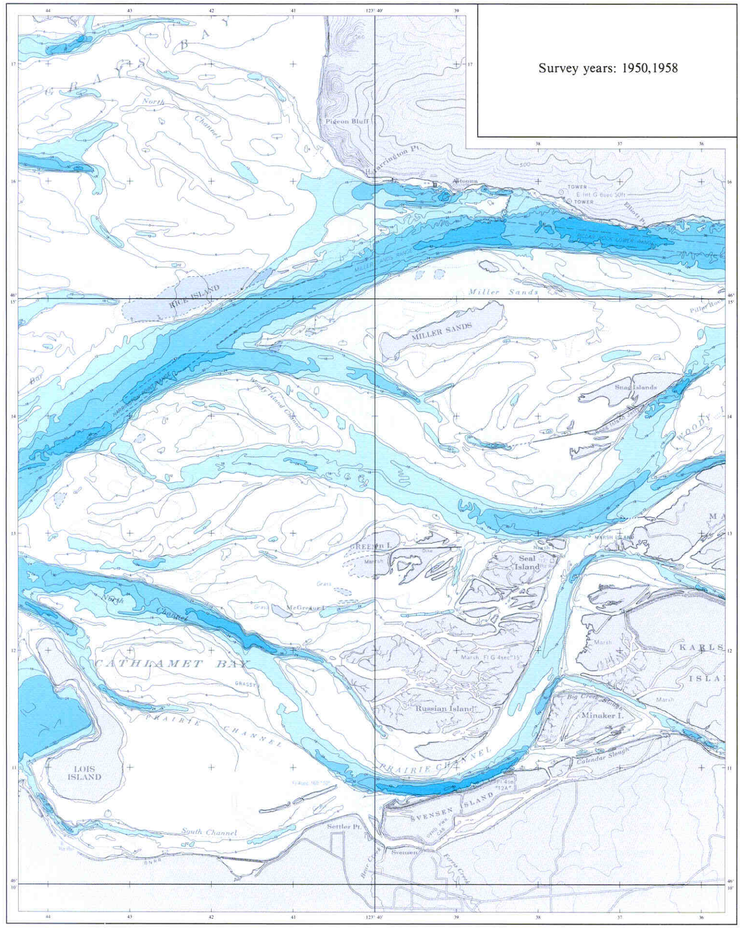


Map series was originally developed in 1980 by Northwest Cartography, Inc. for the Columbia River Estuary Data Development Program. Additional work done by Northwest Cartography in 1982 for the U.S. Army Corps of Engineers. The base map was photographically produced from NOAA nautical charts #18521, 50th Edition and #18523, 38th Edition.

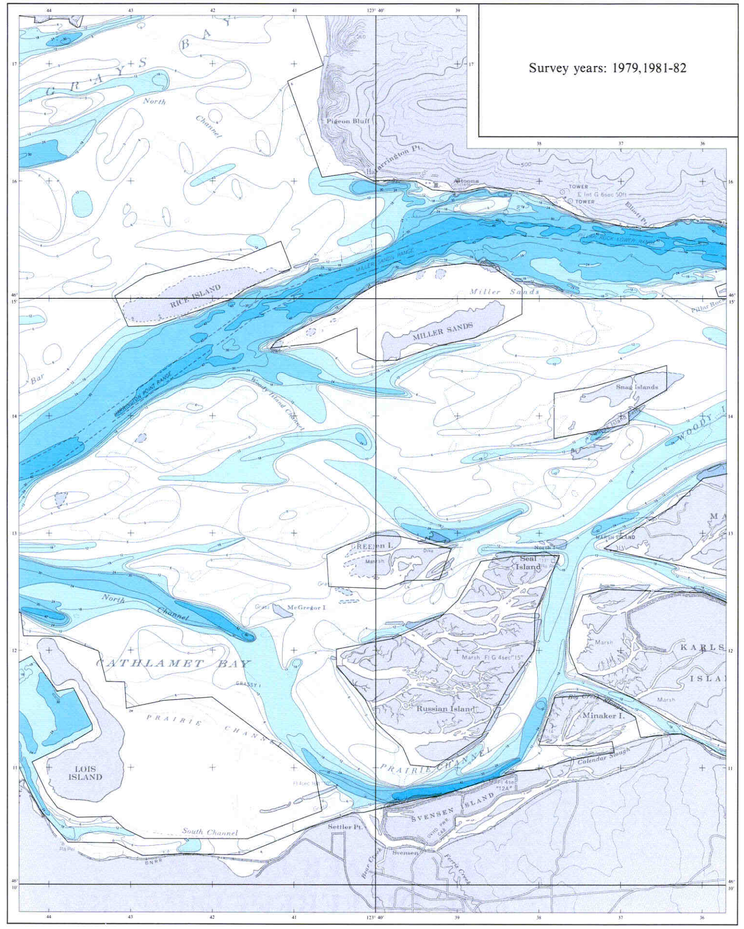
1935



1958



1982



BATHYMETRIC DIFFERENCING SERIES
COLUMBIA RIVER ESTUARY
SEGMENT 5

Cathlamet Bay and Miller Sands

LEGEND

ACCRETION	EROSION
0' to 6'	0' to -6'
6' to 12'	-6' to -12'
12' to 24'	-12' to -24'
>24'	<-24'

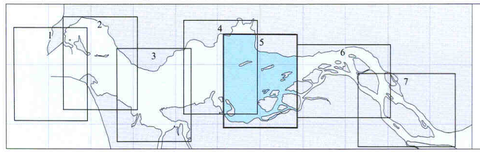
Limit of data coverage (1958/1982 series only)

Bathymetric differencing data developed by Northwest Cartography, Inc. utilizing a computer comparison of bathymetric data between hydrographic survey years. Contours representing historical depth changes are shown in feet (positive values = accretion, negative values = erosion).

0 1 2 3 Mi
0 1 2 3 4 5 Km

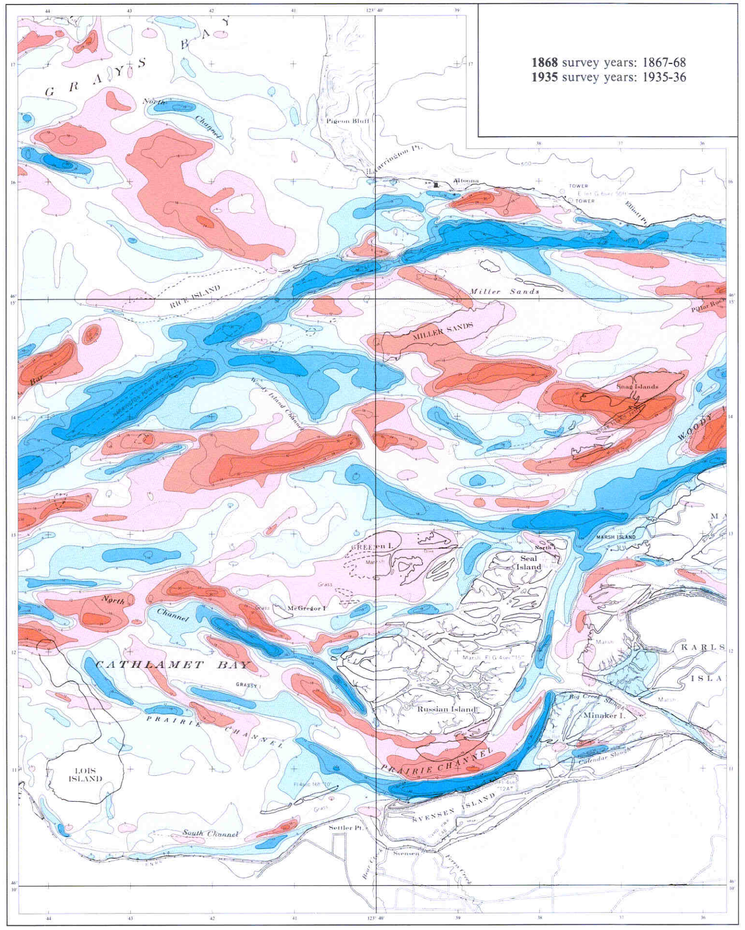
Scale: 1:60,000

INDEX TO MAP SERIES SEGMENTS

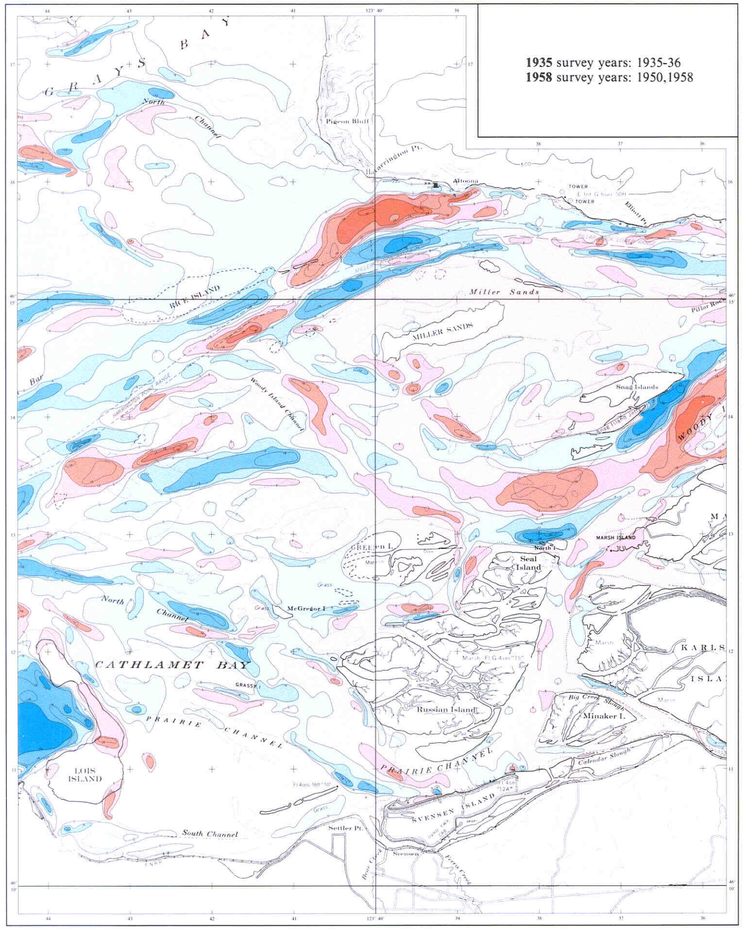


Map series was originally developed in 1980 by Northwest Cartography, Inc. for the Columbia River Estuary Data Development Program. Additional work done by Northwest Cartography in 1982 for the U.S. Army Corps of Engineers. The base map was photographically produced from NOAA nautical charts #18521, 50th Edition and #18523, 38th Edition.

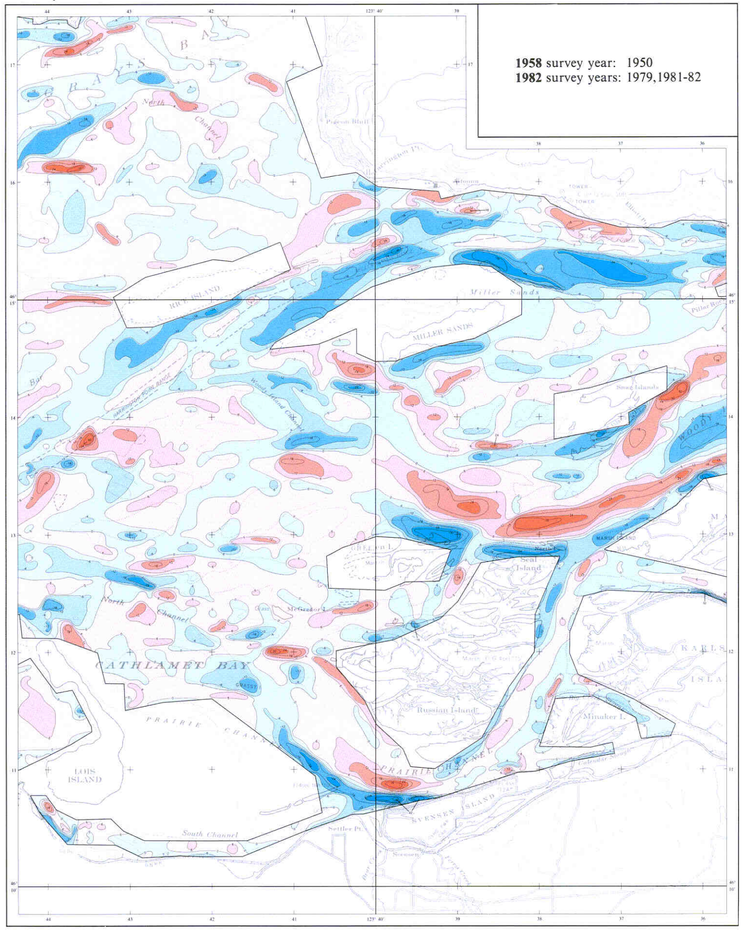
1868/1935



1935/1958



1958/1982



HISTORIC BATHYMETRY SERIES
COLUMBIA RIVER ESTUARY
SEGMENT 6

Jim Crow Sands to Tenasillahe Island

LEGEND

- Shoreline to 12'
- 12' to 24'
- 24' to 42'
- 42' to 80'
- >80'
- Limit of data coverage (1982 series only)
- Land area (NOAA charts #18521 and #18523 shorelines)

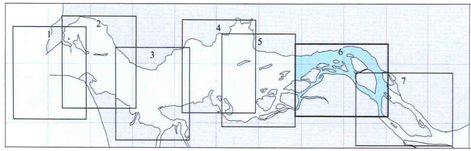
Bathymetric data compiled by Northwest Cartography from hydrographic surveys (smooth sheets, condition surveys) provided by the Coast and Geodetic Survey, the National Ocean Survey and the U.S. Army Corps of Engineers. Bathymetric contours are in feet relative to Mean Lower Low Water. Land area shown is derived from NOAA nautical chart shorelines, chart #18521, 50th Edition and chart #18523, 38th Edition.

0 1 2 3 Mi

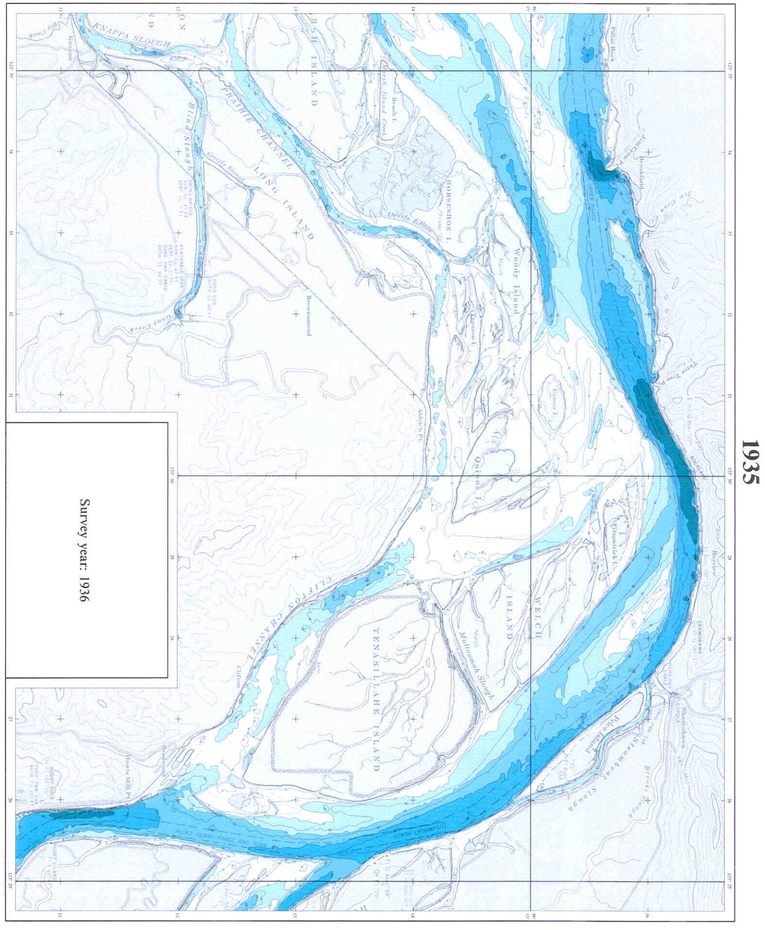
0 1 2 3 4 5 Km

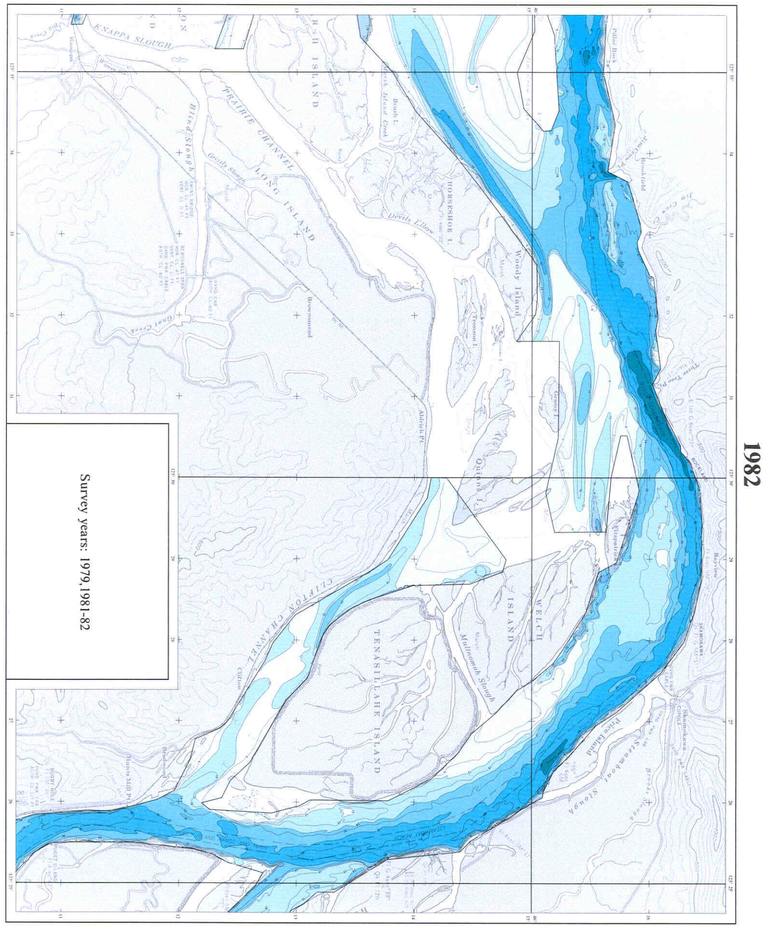
Scale: 1:60,000

INDEX TO MAP SERIES SEGMENTS



Map series was originally developed in 1980 by Northwest Cartography, Inc. for the Columbia River Estuary Data Development Program. Additional work done by Northwest Cartography in 1982 for the U.S. Army Corps of Engineers. The base map was photographically produced from NOAA nautical charts #18521, 50th Edition and #18523, 38th Edition.





BATHYMETRIC DIFFERENCING SERIES
COLUMBIA RIVER ESTUARY
SEGMENT 6

Jim Crow Sands to Tenasillahe Island

LEGEND

ACCRETION	EROSION
0′ to 6′	0′ to -6′
6′ to 12′	-6′ to -12′
12′ to 24′	-12′ to -24′
>24′	<-24′

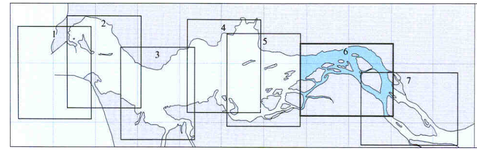
Limit of data coverage (1958/1982 series only)

Bathymetric differencing data developed by Northwest Cartography, Inc. utilizing a computer comparison of bathymetric data between hydrographic survey years. Contours representing historical depth changes are shown in feet (positive values = accretion, negative values = erosion).

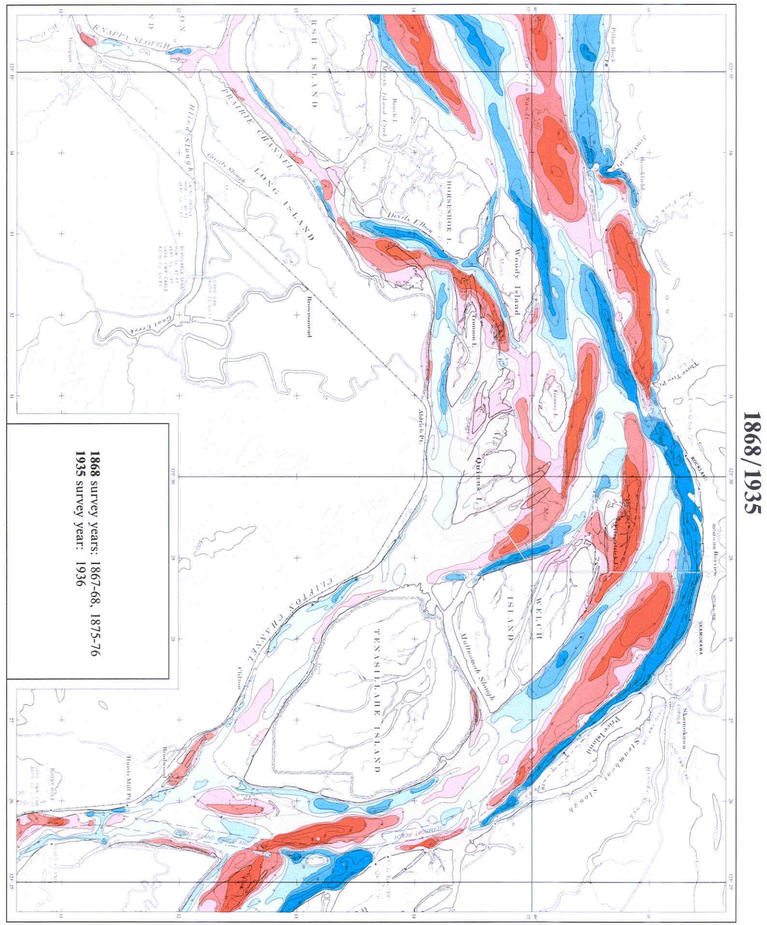
0 1 2 3 Mi
0 1 2 3 4 5 Km

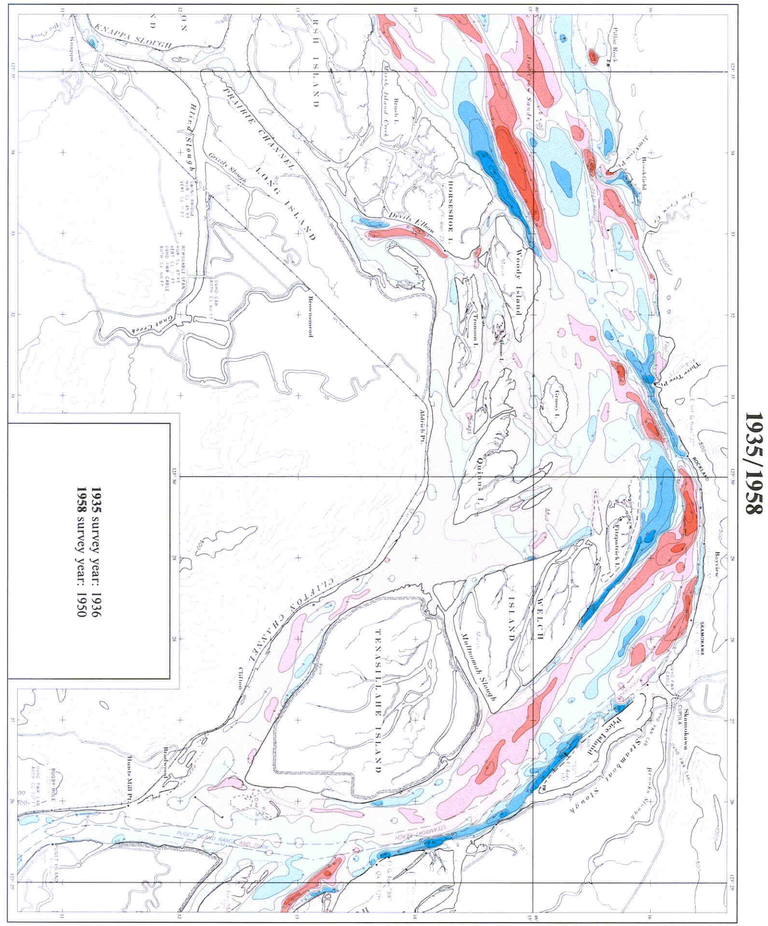
Scale: 1:60,000

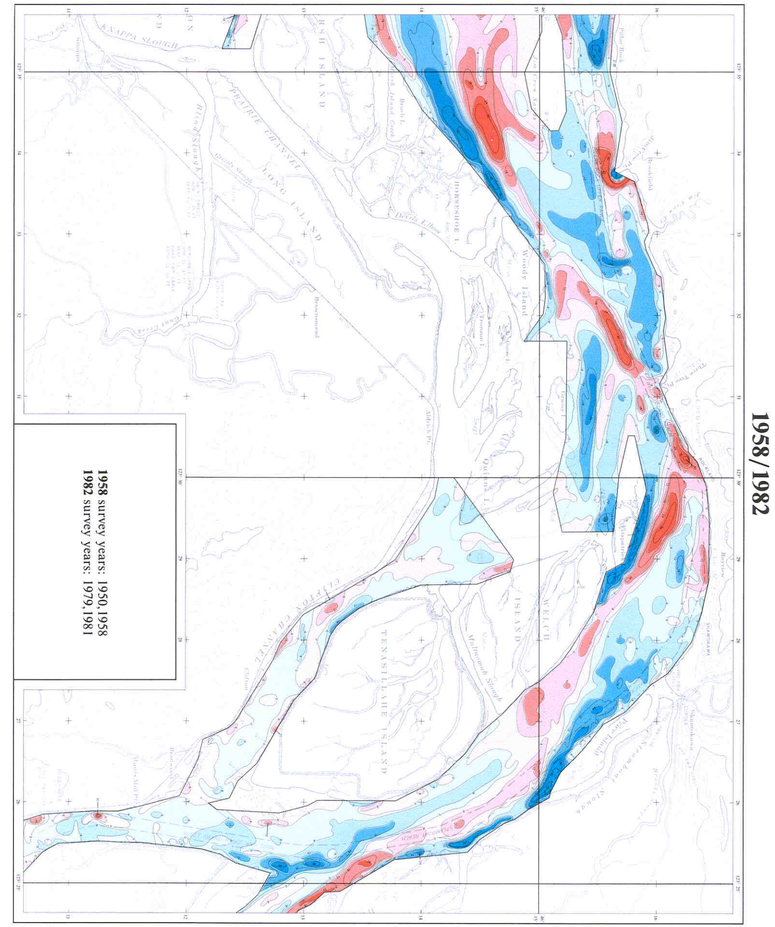
INDEX TO MAP SERIES SEGMENTS



Map series was originally developed in 1980 by Northwest Cartography, Inc. for the Columbia River Estuary Data Development Program. Additional work done by Northwest Cartography in 1982 for the U.S. Army Corps of Engineers. The base map was photographically produced from NOAA nautical charts #18521, 50th Edition and #18523, 38th Edition.







HISTORIC BATHYMETRY SERIES
COLUMBIA RIVER ESTUARY
SEGMENT 7

Puget Island

LEGEND

- Shoreline to 12'
- 12' to 24'
- 24' to 42'
- 42' to 80'
- > 80'
- Limit of data coverage (1982 series only)
- Land area (NOAA charts #18521 and #18523 shorelines)

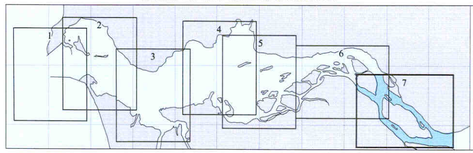
Bathymetric data compiled by Northwest Cartography from hydrographic surveys (smooth sheets, condition surveys) provided by the Coast and Geodetic Survey, the National Ocean Survey and the U.S. Army Corps of Engineers. Bathymetric contours are in feet relative to Mean Lower Low Water. Land area shown is derived from NOAA nautical chart shorelines, chart #18521, 50th Edition and chart #18523, 38th Edition.

0 1 2 3 Mi

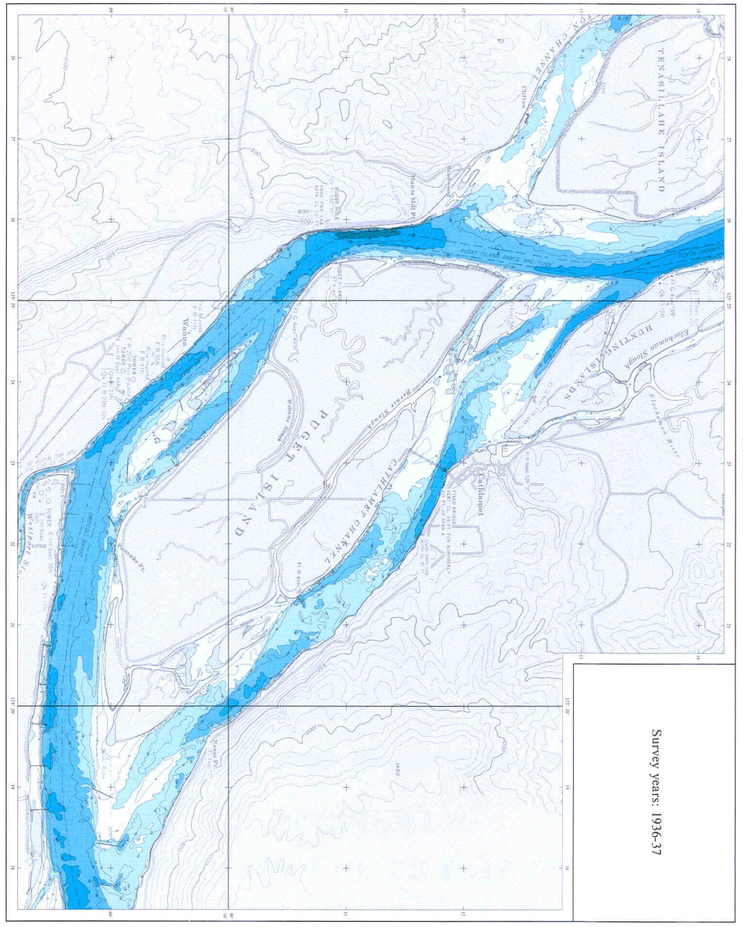
0 1 2 3 4 5 Km

Scale: 1:60,000

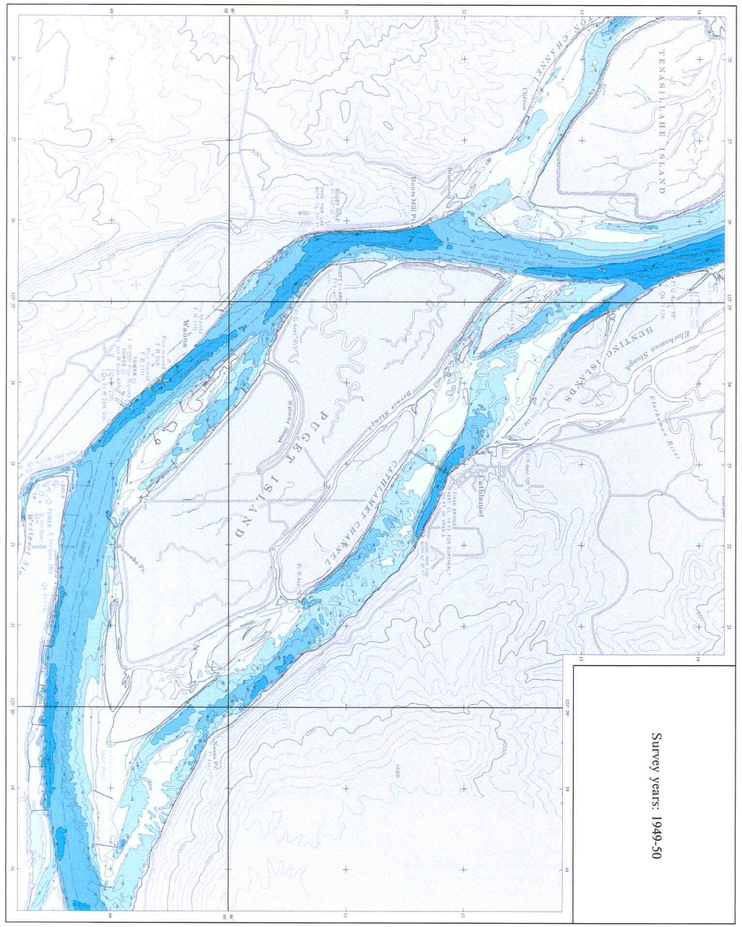
INDEX TO MAP SERIES SEGMENTS



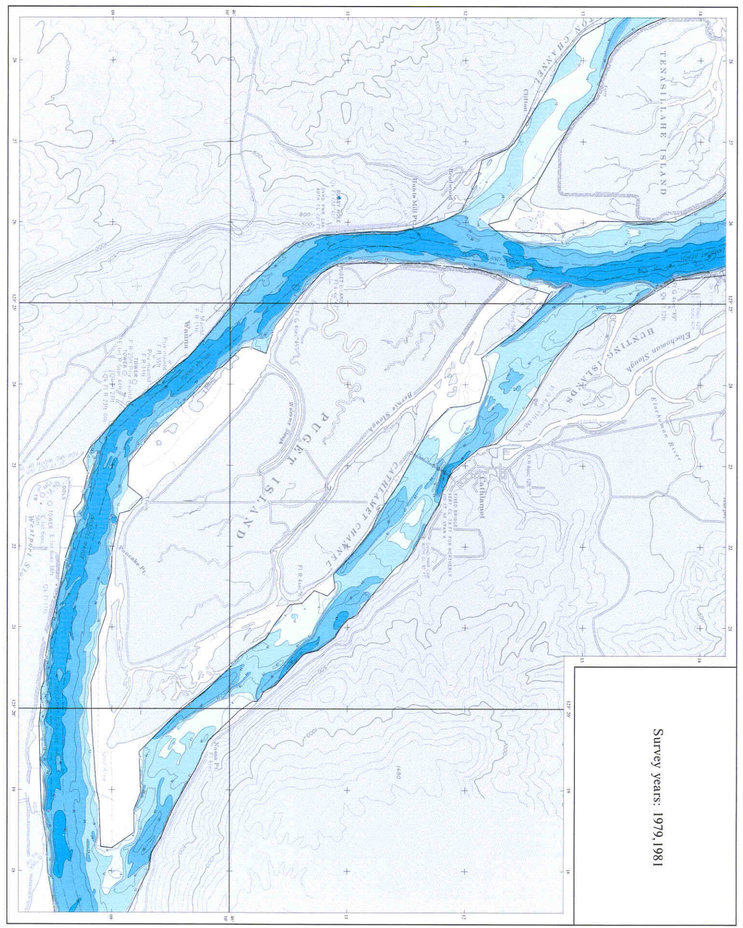
Map series was originally developed in 1980 by Northwest Cartography, Inc. for the Columbia River Estuary Data Development Program. Additional work done by Northwest Cartography in 1982 for the U.S. Army Corps of Engineers. The base map was photographically produced from NOAA nautical charts #18521, 50th Edition and #18523, 38th Edition.



1935



1958



1982

BATHYMETRIC DIFFERENCING SERIES
COLUMBIA RIVER ESTUARY
SEGMENT 7

Puget Island

LEGEND

ACCRETION	EROSION
0' to 6'	0' to -6'
6' to 12'	-6' to -12'
12' to 24'	-12' to -24'
>24'	< -24'

— Limit of data coverage (1958/1982 series only)

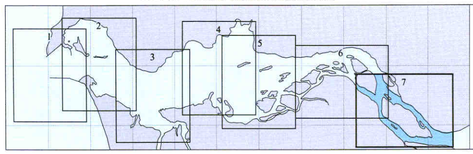
Bathymetric differencing data developed by Northwest Cartography, Inc. utilizing a computer comparison of bathymetric data between hydrographic survey years. Contours representing historical depth changes are shown in feet (positive values = accretion, negative values = erosion).

0 1 2 3 Mi

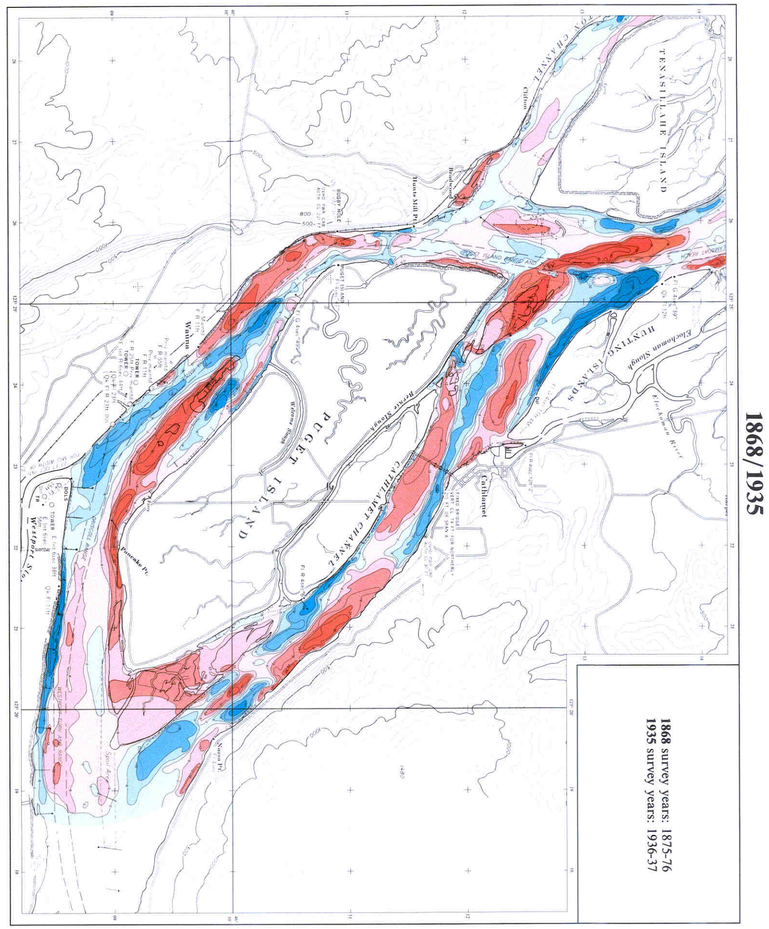
0 1 2 3 4 5 Km

Scale: 1:60,000

INDEX TO MAP SERIES SEGMENTS

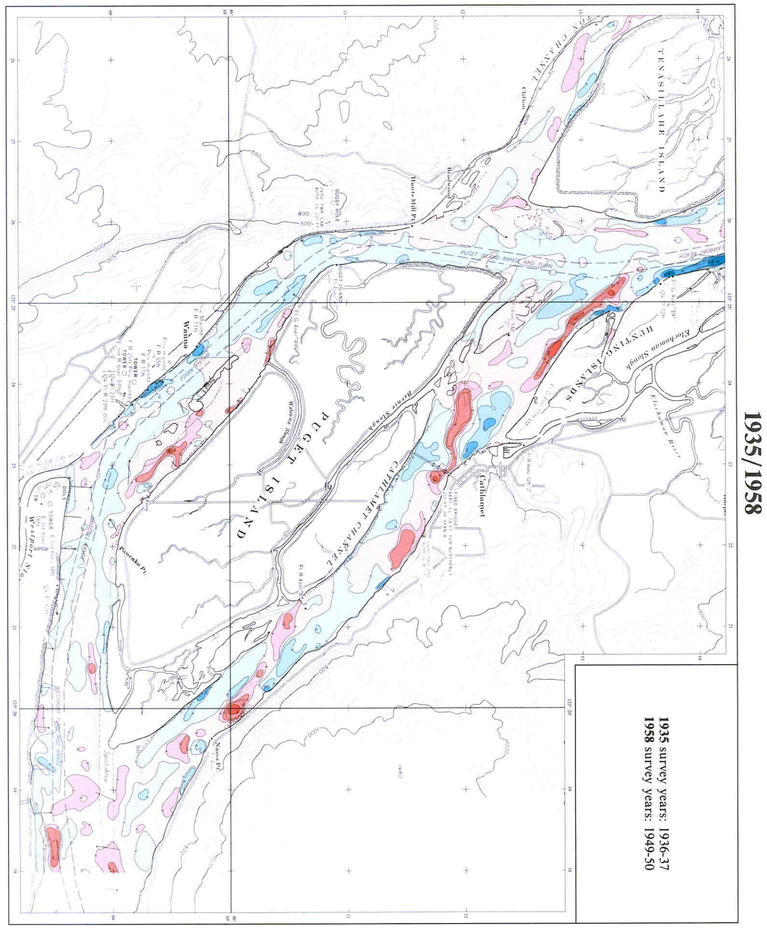


Map series was originally developed in 1980 by Northwest Cartography, Inc. for the Columbia River Estuary Data Development Program. Additional work done by Northwest Cartography in 1982 for the U.S. Army Corps of Engineers. The base map was photographically produced from NOAA nautical charts #18521, 50th Edition and #18523, 38th Edition.



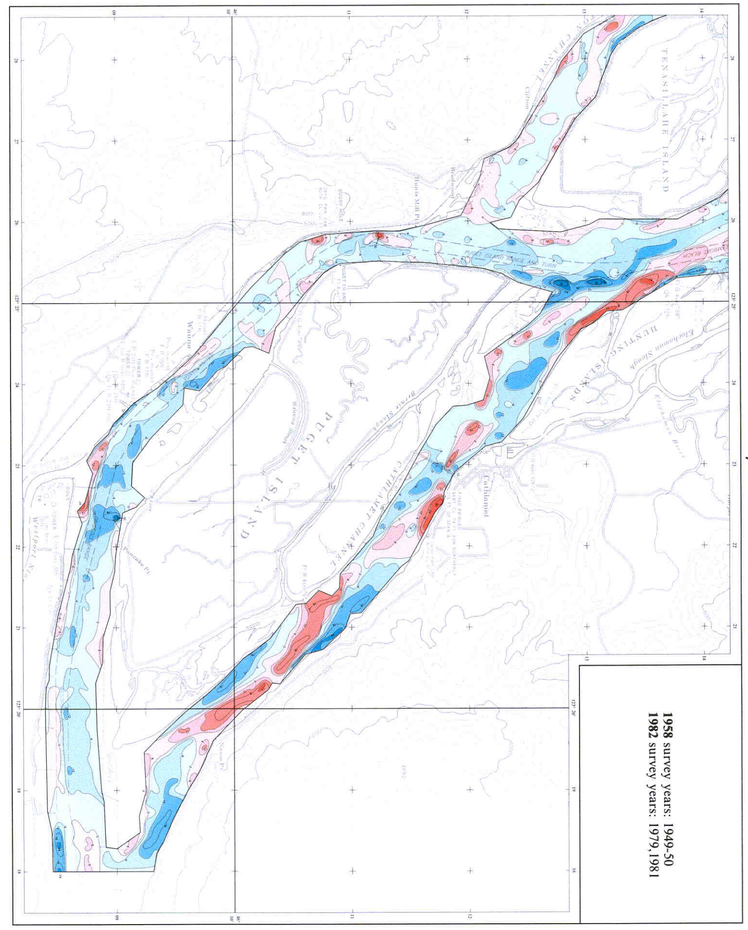
1868/1935

1868 survey years: 1875-76
1935 survey years: 1936-37



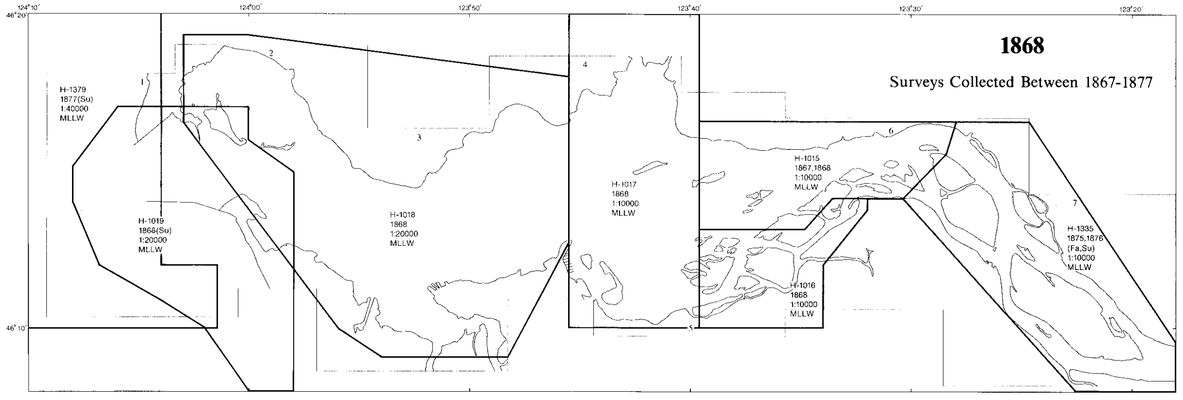
1935/1958

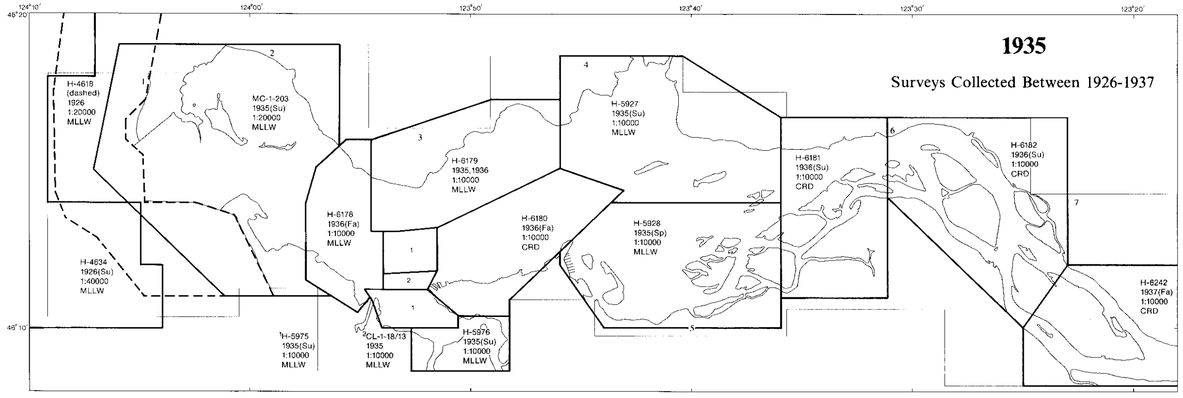
1935 survey years: 1936-37
1958 survey years: 1949-50

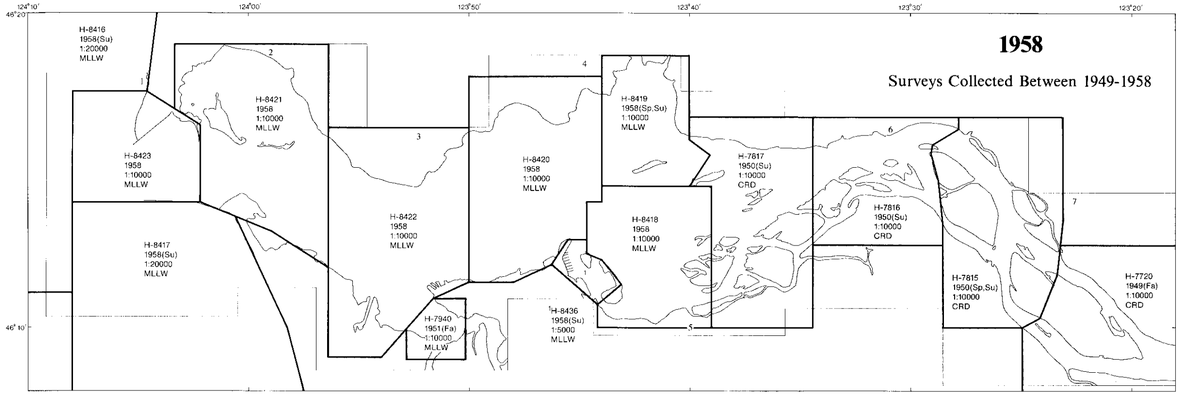


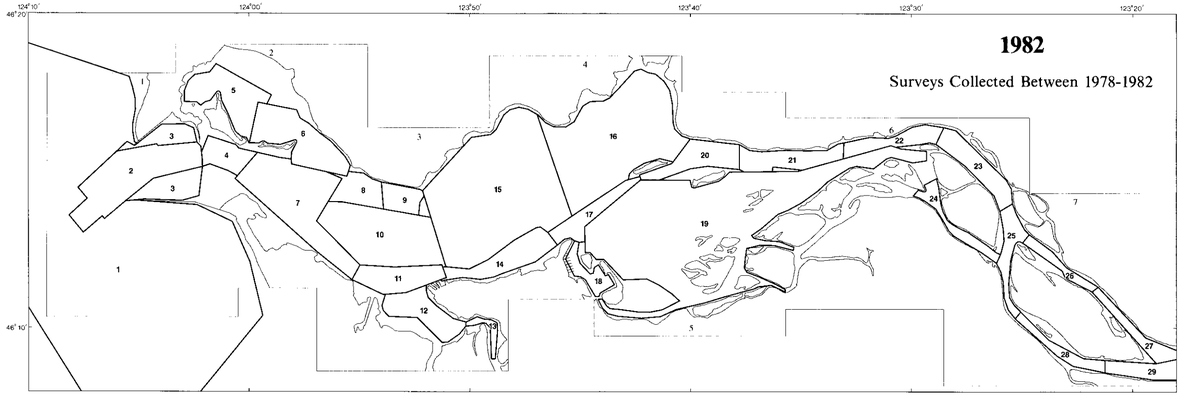
1958/1982

1958 survey years: 1949-50
1982 survey years: 1979,1981









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3: MC-1-515 3/79 1:10000
4: CL-5-201 6/79 1:10000
5: CL-2-233 2/82 1:5000
6: CL-2-232 2/82 1:5000
7: CL-5-218 4/81 1:10000
8: CL-5-202 6/79 1:10000
9: CL-5-194 12/78 1:10000
10: CL-5-216 2/81 1:10000
11: CL-9-162 6/81 1:5000
12: CL-11-54 5/81 1:5000
13: CL-11-55 10/81 1:5000
14: CL-14-139 6/81 1:5000
15: Upper Sands 1/82 1:10000
16: Taylor Sands 1/82 1:10000
17: CL-18-224 6/81 1:5000
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19: Cathlamet Bay 6/82 1:10000
20: CL-21-178 9/81 1:5000
21: CL-26-162 10/81 1:5000
22: CL-28-131 10/81 1:5000
23: CL-33-146 11/81 1:5000
24: Clifton Channel 12/81 1:20000
25: CL-36-137 11/81 1:5000
26: CL-37-28 3/79 1:5000
27: CL-37-29 3/79 1:5000
28: CL-40-152 11/81 1:5000
29: CL-44-142 11/81 1:5000

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