2. SEGMENTATION OF GALVESTON BAY

The present project is concerned with two aspects of the Galveston Bay environment, water quality and sediment quality. These are so closely related as to be considered together as a single variable, labeled here "water quality." In order to carry out a trends analysis on the bay, the aggregation of an enormous amount of data is necessary, which in turn requires some sort of analytical segmentation. The specific strategies of water-quality segmentation are considered here, preliminary to the formulation of criteria and delineation of segments in Galveston Bay for this purpose.

2.1 Purposes of Segmentation

Segmentation refers to the subdivision of an estuary into regions, and represents a compromise between the resolution of physical detail in the natural system, and the expediency of dealing with a small number of geographical units. Any segmentation system therefore entails a coarse level of spatial aggregation. The question is how coarse a resolution can the objective of the analysis tolerate, and therefore how small can the number of defined segments be.

There are two broad objectives for imposing a segmentation system on an estuary: administrative and analytical. The administrative objective refers to administration of laws and regulations. Therefore, part of the criteria for an administrative segmentation is an alignment of segment boundaries with jurisdictional boundaries, which can include:

State boundaries
county and district boundaries
state tract boundaries
geographical boundaries

For a large watercourse like Galveston Bay, the segment boundaries can also reflect efficient access to the region for inspection or enforcement purposes. Therefore proximity to marinas and boat docks, or to highways and bridge crossings can form part of the criteria for segmentation.

The second broad objective of segmentation, *viz.* analytical, refers to the aggregation and analysis of data of some sort from the subregions of the bay. This segmentation is related to the nature of the data (or, equivalently, the objective of the analysis). Economic or demographic analyses will require different spatial aggregation, hence different segmentations, than, say, geological or climatological analyses. It must be emphasized that the imposition of a system of segmentation is a compromise between some minimum level of spatial resolution (which carries with it a statistical level of confidence) and a minimum number of spatial units for analysis.

The definition of segments for an estuary becomes especially complex when the property of interest, say distribution of an organism in the bay, is dependent upon another variable, say water quality, which has its own spatial variability. Further, a segmentation system may in fact reflect both broad objectives listed above. The regulation of shellfish harvesting and the regulation of water quality, for example, have both an administrative objective, which may subject the segmentation to criteria of political boundaries and field-operations efficiency, and an analytical objective, which may require delineation of spatial variability of the target parameters.

One of the earliest, and therefore best-known, approaches to segmentation of an estuary for water quality purposes is that of Bostick Ketchum (1951a,b), who subdivided the estuary into segments of length equal to the tidal excursion. His segmentation is hydrographic in principle [i.e. governed by criteria (1) and (2) in the following section], and is based upon two fundamental postulates: (i) advection by the tidal current is the dominating transport, (ii) mixing is complete over each segment during each tidal cycle. On closer consideration, it will be seen that these two postulates conflict, in that to the extent that one is satisfied the other is violated. Of course, Ketchum's segmentation was devised to support *computational* analysis, which frequently imposes some rather strong conditions on the segmentation. Urban (1966) applied the Ketchum method to Galveston Bay, and devised a computational segmentation suitable for large-scale physical exchange analysis.

The most prominent example of segmentation for computational purposes is the gridding of a numerical model. Such segmentations basically observe the same philosophy stated above, in that a computational segmentation is a compromise between the need for a fine resolution of physical and water quality detail, and the need for as few a number of segments as possible in order to minimize computational overhead. However, the computational scheme imposes conditions of its own. For instance, the actual location of physical boundaries is altered to conform to the position of computational elements. For a finite-difference grid, such as that developed for Galveston Bay by the Galveston Bay Project (Ward and Espey, 1971, TDWR, 1981), the segments are square regions one-nautical-mile on a side. A finite-element model repairs this geographical distortion to some extent (e.g., Klein and Ward, 1991), but still replaces the shoreline with straight-line segments. Further, in either type of numerical grid, the concentration of constituents is taken to be homogeneous within segments. (Actually, the mathematics of mass budgeting may assume some spatial distribution across a segment, linear in low-order finite-difference models, and linear or parabolic in finite-element models, but when the model is applied to real data, e.g. in validation, the data are generally averaged across the segment.) In general, however, a computational segmentation observes different criteria and is not as effective a schema for the analysis and depiction of water quality data as a segmentation expressly formulated for this purpose.

The General Land Office, and several other state agencies, employ the state tract system for segmentation. This is an example of a segmentation system that is purely administrative, and in which the constraints of operational surveying completely determine segment boundaries. The Texas State Department of Health employs a rather gross segmentation of the bays for monitoring and regulating shellfish harvesting. The segments generally correspond to large geographical subdivisions of the bay (e.g. Clear Lake and Trinity Bay) and have little correspondence to hydrographic or water quality features of the system. Again, it is a system devised for its administrative benefits, rather than analysis of water quality.

The most important administrative water-quality segmentation system is, of course, that of the Texas Water Commission. The Galveston Bay system, including the tributaries, is presently subdivided into about 40 segments. The TWC WQ Segments (also referred to as Classified Segments or Designated Segments) represent one of those instances of a segmentation system that reflects both objectives named above, i.e. it is used both for regulation and for analysis. In the regulation arena, the Water Quality Segments are the basis for setting water quality standards, hence underlie discharge permitting, compliance enforcement, and administrative actions. In the analytical arena, the Water Quality Segments are the basis for establishing monitoring stations and determining ambient water quality. The rationale for TWC WQ segmentation is a combination of geography, tradition and politics.

The requirements of the GBNEP Work Statement is that status-and-trends analyses be carried out for each of the Texas Water Commission Water Quality Segments presently in use in the Galveston Bay system. However, to secure the objectives of this project, it is necessary to perform analyses on a finer spatial scale than possible with the TWC segments. Therefore, we have devised a system of "Hydrographic Segmentation" for Galveston Bay to form the basis for detailed analysis. The criteria underlying the formulation of this (or, in general, any) analytical segmentation are developed below, prior to presentation of the segmentation schema itself.

2.2 Principles of Water Quality Segmentation

Just as different data collection programs have different objectives which inform the procedures and methodologies, so also are the sampling areas and sampling stations in general different from one agency to the next. Yet in many areas of the bay, *to within a certain level of confidence* (in the statistical sense), there is no difference between measurements taken at one position and those from another, perhaps even several kilometers removed. From the standpoint of identifying temporal trends in water quality and in characterizing regional water quality within the system, it is desirable to aggregate sampling stations from different programs. (Indeed, even within the same program, the same sampling station is not occupied precisely from one sampling run to the next.) With different data sets so aggregated, a sufficiently extended and dense set of data may be created to allow statistical characterization of these specific water quality regions.

Aggregation of data should be based upon the determination of regions of homogeneity (within some statistical threshold), and zones or loci of sharp gradients in properties. The former should correspond to the interior regions of segments and the latter to boundaries between segments. In order to minimize errors introduced by this aggregation, and to maximize its physical significance, the areas in which sampling stations are to be aggregated must be carefully delineated. This delineation should take into account transports, bathymetry, waste sources (where appropriate), inflows, and in general the distribution of physicochemical features which will either homogenize the parameter (to define the region encompassed by a water quality segment) or create steep gradients (to define the boundary between segments). It is useful to formalize these notions as specific criteria of segmentation, both to guide the specification of segments for the bay, and as a means of evaluating the suitability of existing agency segmentation systems.

Since water quality is a property of the fluid medium, one of the determinants of water quality is the pattern of transport within the estuary system. Therefore, variables which must be included in the definition of water quality segments are morphology and hydrography, *viz.*:

(1) Morphology: constraints on, or barriers to, flow and exchange:

(1.1) Physiography should comprise the principal boundaries of segments wherever the fluid zone intersects emergent landforms or shorelines. Moreover, when no other conditions are constraining, the segment boundary should be placed between readily identifiable landmarks.

(1.2) Submerged reefs and shoals should form a boundary between segments, even when substantial flow over the shoal occurs, because the presence of the shoal will affect detention and circulation both upcurrent and downcurrent.

(1.3) Channels frequently differ in water quality from the open, shallow bay, and can act as a preferential conduit for flow. Therefore a channel should be included well within the interior of a segment, or be itself an independent segment, but should not be near the boundary of a segment. Because channels are well-marked by navigation aids, there is frequently a spatial bias of sampling in channels, which should be considered in defining segments that contain channels.

(1.4) Inlets typically are zones of strong currents. When the inlet is of limited spatial extent, e.g. Rollover Pass or the mouth of San Jacinto Bay, it is best to separate the zones on either side of an inlet as different segments with the inlet serving as the boundary. When the inlet has considerable spatial extent (or is the site of an extensive base of observations), such as Bolivar Roads or San Luis Pass, the inlet zone should be delineated and identified as a separate segment. For tidal inlets, the bar structure offers a convenient boundary for the inlet segment, consonant with (1.2).

(2) Hydrography:

(2.1) Horizontal gradients in water density, as indicated by temperature and salinity, should be used to define segment distributions, with the zone of shallow (or zero) horizontal gradient lying within the segment interior, and the zone of steep gradient lying on the boundary. Because of the extreme variability of salinity, this definition may have to apply to average or long-term distributions.

(2.2) Any zones of systematic density stratification should be segregated from those of zero or unsystematic stratification. As with (2.1), because of the extreme variability of salinity, this may be a condition to apply to long-term mean density distributions.

(2.3) Current structure, especially current shears, should be employed, when the data are available, to define circulation patterns; generally segment boundaries should lie either parallel to or orthogonal to current trajectories, and should not be oblique.

(2.4) Tidal variation in an estuary can affect water mass retention and water-quality differences, particularly dramatic changes in tidal range, and conversions from progressive- to standing-wave properties.

(2.5) Tidal current trajectories are a special case of (2.3) that become especially important in defining segments which contain or are adjacent to inlets or tidal conduits. The deflection of tidal currents by the Texas City Dike is an excellent example.

(2.6) Fetch under dominant wind regimes can govern regions of the bay which are well-mixed and those that are not, due to the importance of wind-driven waves in effecting mixing. A subtler effect may be the generation of large-scale wind-driven gyres, but on the Texas coast definitive data on these forms of circulation are lacking.

(2.7) Turbulence derived from bed roughness is an important source of mixing and dispersion, and therefore can be important in delineating areas of differing mixing intensities. To the extent that information exists on bedforms, this should be incorporated into the segment definition.

(2.8) Inflows are a prominent source of systematic (throughflow) currents, and under sufficiently high flows can lead to extensive water-mass replacement. Segment boundaries should therefore take into account the normal region of influence (i.e., the outflow plume) from a point inflow. For large-scale inflows, such as the Trinity

River, this is obviously a feature that will vary with river hydrograph, and at times encompass all of Trinity Bay or even Galveston Bay, so some judgement may be required. Another type of inflow to consider is the large-volume discharge from an outfall, e.g. the cooling water return of a power plant.

While these hydrographic principles can be articulated, the fact is that the data base upon which these kinds of decisions must rely is usually lacking. Indeed, many of the hydrographic judgements must revert to morphological considerations.

Water quality is in fact a suite of parameters, each of which is subject to its own complex of sources and sinks, and kinetic processes. To a varying degree, however, transport processes underlie all of these, so the hydrographic properties enumerated above form a set of minimal criteria for segmentation. In addition, water quality segmentation must also reflect the following properties specific to water quality constituents:

(3) Water quality:

(3.1) Regions of homogeneity are one of the most important factors in the definition of segments. Ideally, a segment should encompass a region which is largely homogeneous in water quality. At the same time, water quality parameters in the real world are extremely variable and rarely homogeneous (the term implying a certain threshold of statistical variability which is deemed acceptable). Segment definition is based first upon relative differences in water quality—some regions having a greater tendency toward homogeneity than others—and second upon the kinds of transport and mixing processes that would tend to promote homogeneity.

(3.2) Regions of steep gradients, in contrast, should be the defining property for a boundary between segments. As with (3.1), this is a relative measure which may be frequently belied by data, depending upon external conditions, and must be supplemented by identifying the kinds of transport and mixing processes that would tend to promote steep gradients.

(3.3) Proximity to loads should be considered in defining water quality segments, since this would entail a large-scale difference in water quality that is superposed upon whatever ambient mixing processes are operative.

(3.4) Systematic degradation of a region of the bay, as exhibited directly in trends of water quality or indirectly in anthropogenic influences, is sufficient reason to segregate an area as a specific segment. Reaches of the Houston Ship Channel, and some of the lateral bays of the San Jacinto River are good examples. This criterion is also related to

(3.3), in that proximity to new discharges may be sufficiently compelling to anticipate degradation of water quality.

(3.5) Finally, any region in which there is a systematic trend toward degradation, even though the water quality indicators may still lie within the normal or "healthy" range may be beneficially monitored by being defined as a separate segment. This is a more subtle differentiation of the same philosophy expressed in (3.4).

Ideally, a separate segmentation would be defined for each water-quality parameter, e.g. dissolved oxygen, sediment mercury, BOD, but such an approach would be manifestly unworkable, therefore the definition of segments needs to consider the principal water quality parameters taken collectively.

The application of criteria (1), (2), and (3) without further constraints would result in a veritable plethora of segments. From the opposite direction, we wish to minimize the number of segments in order to: (i) maximize the number of data points per segment, hence the statistical strength of the conclusions, (ii) improve the conceptual value of the analysis, by presenting the results for as few, large segments of the bay as possible (a reflection of the poor ability of the human mind to assimilate numerous facts simultaneously, requiring some degree of pre-digestion). There is an additional practical criterion lurking here, *viz.* to decrease the effort of analysis, which will proceed on a segment-by-segment basis and therefore is proportional to the number of such segments, but this is probably subsumed within (ii). This criterion can be expressed as follows:

(4) Maximal spatial aggregation:

(4.1) Definition of segments should be cognizant of the conceptual value of organizing the system into a small number of quasi-autonomous regions. Further, the boundaries of these regions should correspond to natural physiographic boundaries and be defined by well-established, easily determined landmarks or landforms.

(4.2) Dimension of a segment should take into account the minimum number of data points within the segment required to characterize a spatially representative value. This would be based upon the distribution of historical sampling stations in the region and typical variability in water quality.

(4.3) Dimension of a segment should also consider the minimum number of data points over time needed to resolve principal temporal variability, and the available period of record at the established monitoring stations.

(4.4) One element of establishing acceptable spatial dimensions is the intrinsic variability at a given point in water quality versus variability across the segment area.

(4.5) The segmentation scheme should be comprised of non-overlapping segments, so that every point in the watercourse falls within a unique segment.

These criteria could be expressed quantitatively in terms of measurement variance at a point in a given area of the bay. The key measures would be the intrinsic variability in a water quality measurement (due to "noise" in the basic measurement, inaccuracies in sample procedures including station location, and variance contributed by external controls, e.g. wind, currents, spatial variability of the parameter field), the spatial region over which a point measurement is "representative" given its intrinsic variability and the large-scale gradients in that area of the bay, and a pre-determined desired level of confidence in the aggregated data.

Criterion (4.1) appears different in character from the other three, in that it is more qualitative and can be applied from a purely morphological viewpoint, while (4.2)-(4.4) have a strong statistical flavor, and would require a fair data base for their application. Implicit in (4.1) is the concept of areal scale of depiction, which is not an absolute measure but is, rather, at least partially determined by the objectives of the analysis in which the segmentation is to be employed. For some purposes, a rather gross segmentation might appear satisfactory. The extreme example would be analyzing bay-wide parameters, in which the entire bay is regarded, in effect, as one segment. This sort of analysis is done, for example, when bay-wide water budgets are carried, in tidal prism analyses, and in computing bay-wide salinities (cf. the annual reports on bay salinities of the Texas Parks and Wildlife Department). Upon closer analysis, however, these "global" depictions of the bay really amount to accepting a rather large statistical variance in the answers. (Some users of such a gross approach may, of course, be unaware of the enthymeme.) The key point is that the intended spatial scale of the analysis, determined by the objectives of the analysis, in effect imposes a level of statistical variance—a confidence level—on the results.

Criterion (4.5) is not required by the statistical methods of data analysis. Indeed, for scientific purposes, it could make sense to have overlapping segments, with sampling stations counted among the aggregated data for more than one region. On the other hand, by requiring disjoint segments, it then becomes possible to carry out a census of data availability, and to avoid problems of weighting of measurements, due to the same measurement being counted in more than one aggregation. Further, the administrative function of segmentation would be greatly complicated by overlapping segment definitions.

The definiteness of these criteria is somewhat meretricious, in that the information base for their quantitative application is not extant. This is especially true for the statistical measures underlying (4). For most parameters, these measures are *ab initio* unknown and in any event relatively spongy, varying with intended purpose of the analysis and the cultural bias of the investigator, and varying over time. However, their enumeration serves the good purpose of providing an objective set of criteria that can be applied intuitively, and on the basis of gross characteristics of the bay and past experience with data from the bay. Further, they form a basis for iteratively evaluating and revising a candidate segmentation. Indeed, any system of segmentation is seen to be ultimately iterative: as data are acquired, and as the bay changes, the system of segmentation will have to be revised. This has been the experience already with the TWC WQ Segments.

Because these criteria are rather intuitive, the present TWC WQ Segmentation more or less conforms to them. However, there are some anomalies, which, even at this stage of formulation, these criteria can be used to identify. For example, the south boundary of Segment 2432 is placed to include the GIWW within Chocolate Bay, a zone in which we would expect systematic water quality differences from the open shallow bay characteristic of the remainder of this Segment, and in violation of criteria (1.3) and (3.2) above. Another example is the inclusion of the region from Redfish Bar to the Causeway in Segment 2439, despite the prominent geomorphological barrier of the Texas City Dike, in violation of criterion (1.1) above.

The criterion listed above of proximity to loads (3.3) poses a particular problem. This would imply that a separate segment be defined encompassing the outfall of every discharge to the bay (or, better, separate segments be defined for each hydrodynamic zone of the effluent plume, from the initial mixing to the far-field). Since the objective of analysis is "ambient" water quality on an aggregated spatial scale, we leave it implicit that the near-field zone of a major discharge is to be considered *excluded* from the segment into which it discharges. This is consonant with the practice of ambient water-quality monitoring, in which the establishment of stations avoids the immediate area of outfalls. On the other hand, monitoring for compliance/enforcement may in fact require that stations be occupied squarely in the outfall plume. In sorting through the available station data within a given segment, which (it will be recalled) is drawn from many programs with differing objectives, those stations within the near-field influence of an outfall must be identified and excluded. (Of course, if one wished to study the behavior of a specific outfall plume, then these stations would be precisely the ones to retain and analyze, but that is not our present objective.)

Note that this criterion does not exclude the influence of a discharge on the far-field water quality. Indeed, in many sections of the bay where there are large-volume discharges, such as power-plant returns, or a concentration of smaller discharges in a restricted area (the Upper Houston Ship Channel is an immediate example), the definition of segments must explicitly recognize and include those effects.

The notion of a scale of analysis emerged in the formulation of criteria. This aspect of segmentation cannot be overemphasized. Underlying any segmentation scheme is a dominant spatial scale of analysis, which carries with it an associated level of confidence one is willing to accept in the aggregation of samples over a region of the estuary. For someone studying the variation of water quality in Galveston Bay on a scale of tens of kilometres, it is appropriate to depict Chocolate Bay as one or two segments. Another researcher with the different purpose of studying the kinetics of a constituent within Chocolate Bay itself would find this scale of representation much too coarse, and would employ a much more refined spatial segmentation. Either level of segmentation would be inappropriate and unworkable for the other's purpose. (Note that the use of field data from a network of stations implicitly assumes a segmentation, in that each sampling station is presumed to represent water quality over some extended area in which the station is located.)

2.3 Project Segmentations of Galveston Bay

2.3.1 Numerical Schema of Segments

Not only must we define a system of segmentation for analysis of water quality, we must devise a means by which this segmentation may be imposed in automatic data processing. That is, there must be a computational means for determining into which segment a sampling station from any past program would fall. The method adopted here is to define each segment as the union of quadrilaterals encompassing the portion of the watercourse defined to lie within that segment. The corners of each quadrilateral are given by latitude/longitude pairs, and an algorithm was developed which determines whether a given station, specified by its latitude-longitude coordinates, lies within the quadrilateral. We note that (1) these quadrilaterals are not parallelograms, but can be any four-sided figure distorted as necessary to conform to the shape of the watercourse, (2) only the watercourse is considered to be within the segment, even though the quadrilateral may cover substantial land area as well, (3) a series of quadrilaterals taken together can better approximate complicated geometry. The last is the reason that a conjunction of such quadrilaterals is used. Because many segments have complex shapes, a single quadrilateral was not practical, as it would frequently overlap adjacent quadrilaterals.

Figure 2-1 shows an example of the depiction of segments by quadrilaterals. This figure displays Clear Lake and part of its watershed. The main body is one segment and is adequately depicted by a single quadrilateral, as indicated. Segment 1101 is Clear Creek from its mouth at Clear Lake to above FM 528, and is encompassed by two quadrilaterals. Segment 1113, Armand Bayou, extends northward from Clear Lake, and is defined by two elongated quadrilaterals. The key sides of these quadrilaterals are those that intersect the watercourse at the boundaries of the segments. Placement of the other corners is arbitrary and is adjusted to optimize the fit. Trinity Bay, Segment 2422, is represented by three quadrilaterals, as shown in Fig. 2-2. (The reader may have noted that these two examples are TWC Water Quality Segments.)

In addition to providing a quantitative mechanism for processing large data bases, the quadrilateral depiction of segments has another benefit: it is a means of precisely and quantitatively defining the boundaries of a segment. The nearly universal practice of using small-scale maps to depict segment locations is a continuing problem, especially in open waterbodies where there is no obvious morphological boundary, as these maps are subject to drafting and printing

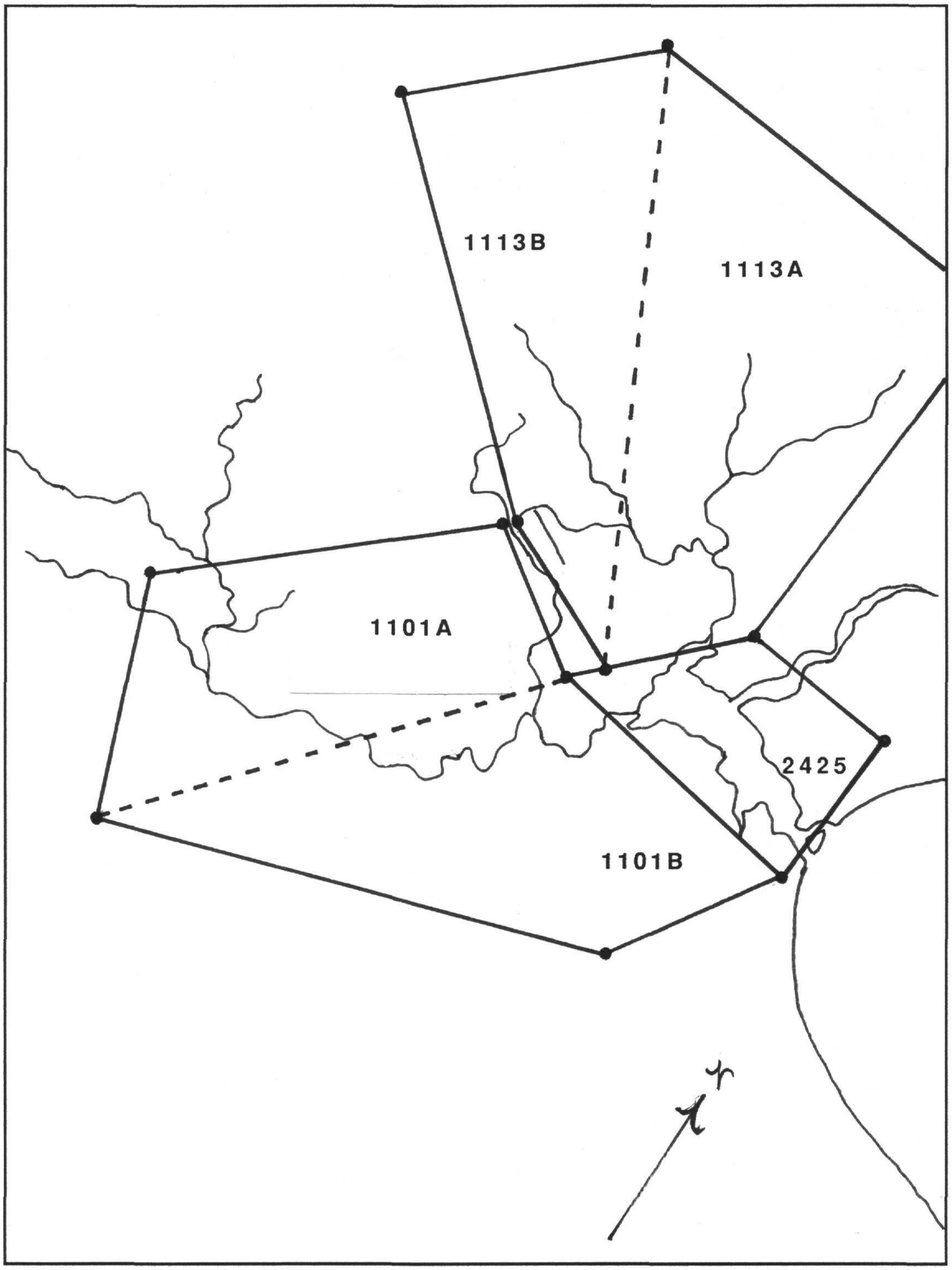

Fig. 2-1 Quadrilateral definition of TWC segments in Clear Lake area

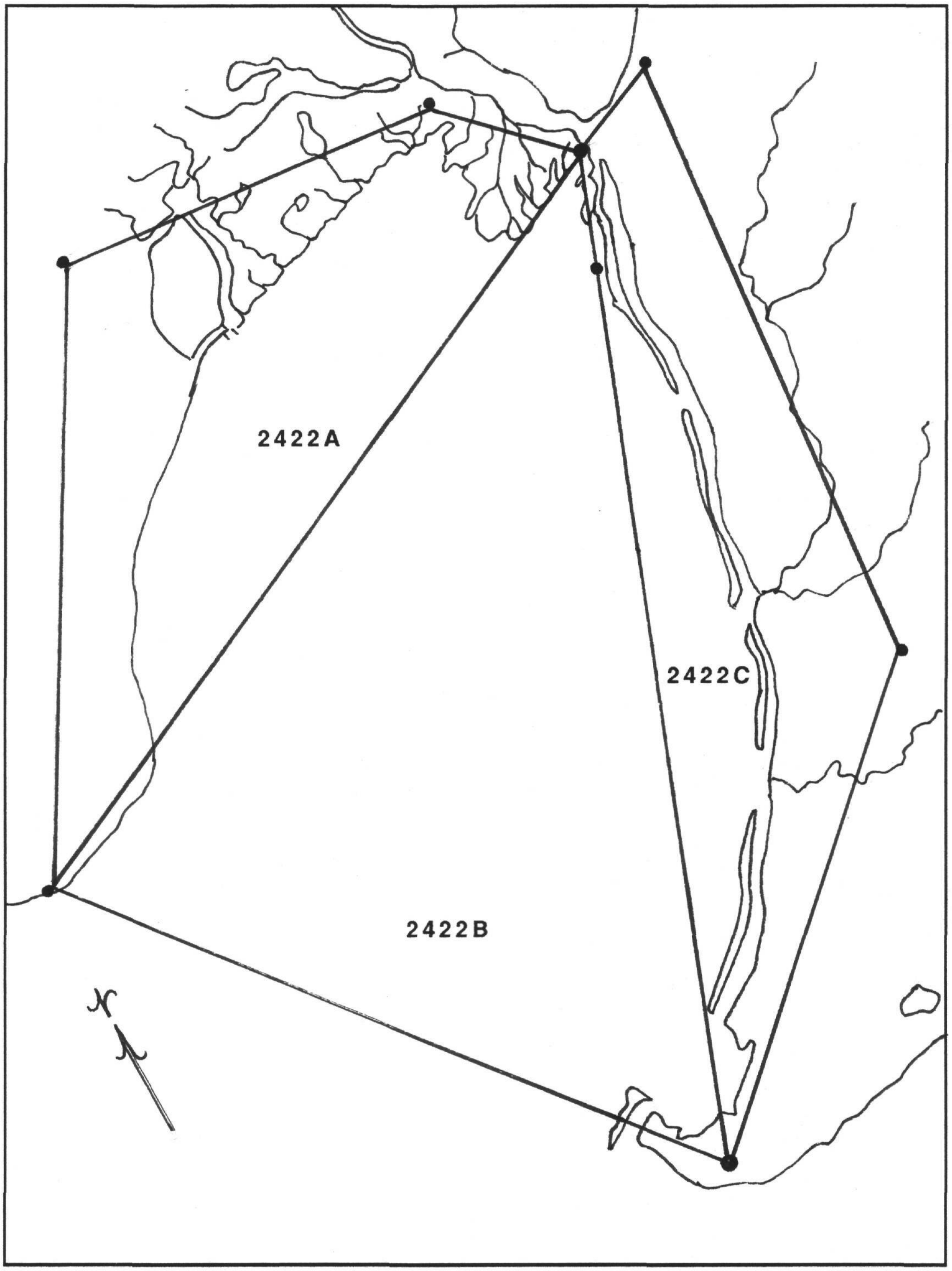

Fig. 2-2 Quadrilateral definition of Trinity Bay (TWC Segment 2422)

errors, and introduce uncertainty in the precise location of boundaries. With a quadrilateral-based definition, the quadrilateral corners can be specified to whatever accuracy is needed, and become an unequivocal means of communicating segment boundaries. While in this report, we will display maps of the hydrographical segments employed, it should be understood that these are graphic vehicles only, and the segments themselves are precisely defined by the applicable quadrilaterals.

2.3.2 Texas Water Commission Water Quality Segments

As noted earlier, the Texas Water Commission system of segmentation forms the basis for water management in the state. The Galveston Bay system is represented in this system by thirty-seven (37) segments, nineteen (19) in the open bays plus eighteen (18) in the tributaries. These are summarized in Table 2-1. Those in immediate proximity to Galveston Bay are depicted on Figs. 2-3 and 2-4. The boundaries for the open-bay segments are not well-defined and are established qualitatively (i.e., by approximate location on crude maps, e.g. TWC, 1990). Thus far, this has not presented an administrative problem, because most of the routine monitoring stations are placed well in the interior of these segments. ("All," we were advised by TWC staff at the outset of the project, but several of the Statewide Monitoring Network stations proved to be on or in close proximity to segment boundaries. A few are even located in the wrong segment.) Further, there are several undesignated tributaries that are taken to be part of the segment into which they conflow, especially along the upper Houston Ship Channel (for example, Greens Bayou). There are three quasi-segments attached to Galveston Bay, *viz.* 0900, 1000, and 1100. These are not well-defined geographical areas, but rather pigeonholes for miscellaneous stations, such as the minor tributaries to the Houston Ship Channel, Goose Creek, discharge canals, and the small lakes on the north shore of West Bay.

The quadrilaterals used to define the TWC Water Quality Segments are given in Table A-4 in the Appendix.

2.3.3 Hydrographic Segmentation

It was necessary to formulate a segmentation system suitable for use in this project. The primary purpose of the segmentation is analytical, i.e., for data aggregation by area of the bay, to support statistical and trend analyses. For the establishment of general levels and trends in water quality, the spatial resolution needed to be on the order of 5-10 kilometres, except when hydrographic properties demand a smaller scale. From a practical standpoint, application of the principles enumerated in Section 2.2 meant basing the segmentation largely upon the hydrographic criteria (1) and (2) of Section 2.2, along with the data management criteria (4). This segmentation considered the criteria (3) to the extent that experience and data on specific water quality variables permitted. At first, we endeavored to structure the hydrographic segmentation so that it can be easily aggregated into the TWC WQ Segments, but as the process developed it proved to be better to make the hydrographic segmentation independent of the

TABLE 2-1

Present TWC Water Quality Segments in Galveston Bay System

Basin	*Segment Number*	*Segment Name*
Bays and Estuaries		
	2421	Upper Galveston Bay
	2422	Trinity Bay
	2423	East Bay
	2424	West Bay
	2425	Clear Lake
	2426	Tabbs Bay
	2427	San Jacinto Bay
	2428	Black Duck Bay
	2429	Scott Bay
	2430	Burnett Bay
	2431	Moses Lake
	2432	Chocolate Bay
	2433	Bastrop Bay/Oyster Lake
	2434	Christmas Bay
	2435	Drum Bay
	2436	Barbours Cut
	2437	Texas City Ship Channel
	2438	Bayport Channel
	2439	Lower Galveston Bay
Trinity River		
	0801	Trinity River Tidal
	0802	Trinity River below Lake Livingston
Trinity-San Jacinto Coastal		
	0900	
	0901	Cedar Bayou Tidal
	0902	Cedar Bayou Above Tidal

TABLE 2-1
(continued)

Basin	Segment Number	Segment Name
San Jacinto River		
	1000	
	1001	San Jacinto River Tidal
	1005	Houston Ship Channel/San Jacinto River
	1006	Houston Ship Channel
	1007	Houston Ship Channel/Buffalo Bayou
	1013	Buffalo Bayou Tidal
	1014	Buffalo Bayou Above Tidal
San Jacinto-Brazos Coastal		
	1100	
	1101	Clear Creek Tidal
	1102	Clear Creek Above Tidal
	1103	Dickinson Bayou Tidal
	1104	Dickinson Bayou Above Tidal
	1105	Bastrop Bayou Tidal
	1107	Chocolate Bayou Tidal
	1108	Chocolate Bayou Above Tidal
	1113	Armand Bayou Tidal

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Figure 2-3

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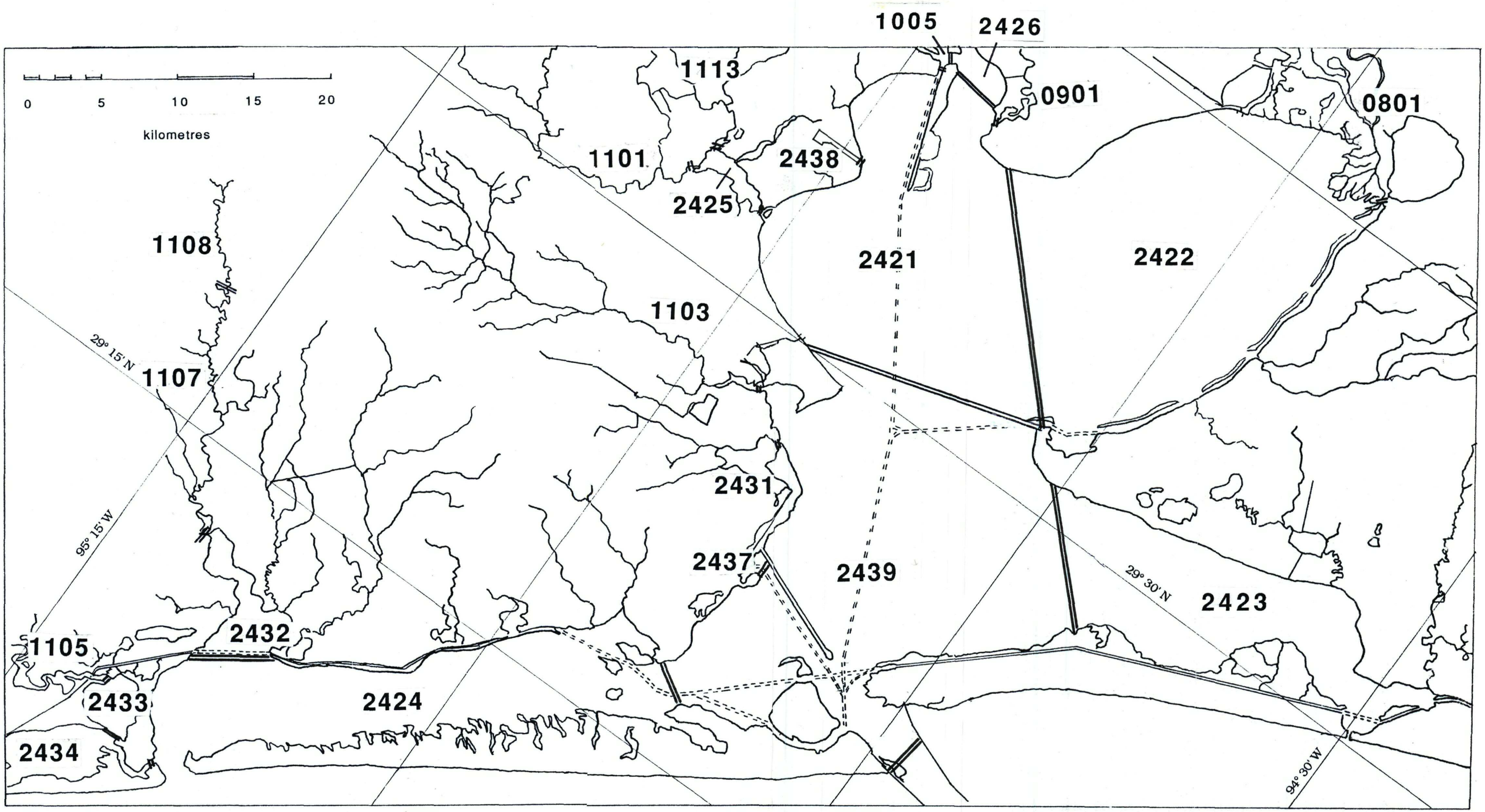

Fig. 2-3 - TWC Water Quality Segments for Galveston Bay

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Figure 2-4

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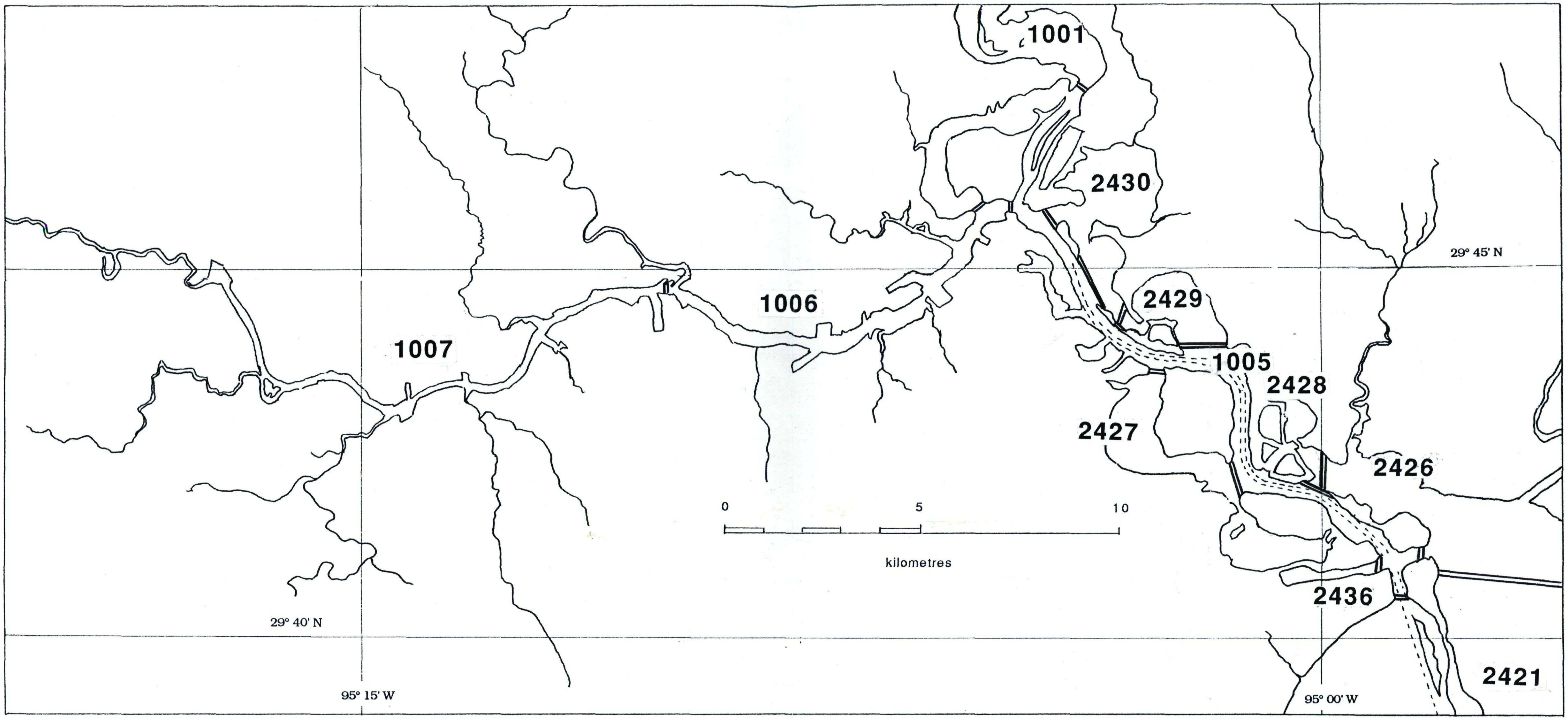

Fig. 2-4 - TWC Water Quality Segments for Houston Ship Channel

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TWC water quality segments. Whenever possible, the boundaries of the hydrographic segments were taken to coincide with the larger TWC Segment, though there are many exceptions.

The final hydrographic segmentation is depicted in Fig. 2-5 for the main body of Galveston Bay, in Fig. 2-6 for the adjacent Gulf of Mexico, and in Fig. 2-7 for the Houston Ship Channel. Those segments lying upstream from the areas shown on Figs. 2-5 and 2-7 were considered too remote from the Galveston Bay system to be included in the present analysis (though they are considered in the TWC segment analysis). It will be noted that generally the hydrographic segments (HS) of Figs. 2-5 through 2-7 are considerably smaller than those of the Texas Water Commission, so a finer level of spatial analysis is permitted, especially in the open bay areas. The quadrilaterals precisely defining the locations of these hydrographic segments are given in Table A-5 of the Appendix.

These hydrographic segments formed the fundamental organizational units for the water quality and sediment data in the present project. Some particular features of this segmentation warrant mention. The Houston Ship Channel in the open bay occupies its own segments, a narrow strip of approximately 1 km width centered on the dredged channel. Similarly, the Texas City Channel and prominent reaches of the GIWW are also embedded within narrow segments. This is due to the peculiar hydrodynamics of salinity intrusion and increased tidal response dictated by the deeper water, and also due to the isolating effect of dredge disposal areas on the lateral boundaries of these channels. Two rather odd-appearing segments, T3 and G6, enclose the returns from major power plants. The orientation of the segments in Trinity Bay track the typical plume of runoff from the river. The boundaries of several of the segments are dictated by reefs or other bathymetric features. For example, G32 is bounded on the east and north by Hannas Reef, W10 is bounded on the west by Karankawa Reef, and G14, G27 and G30 encompass the complicated mid-bay reef and shoal complex of Red Fish Bar. Segment T7 is the Trinity marsh below the old Wallisville Levee, and T13 encompasses the active distributaries of the modern channel of the Trinity River.

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Figure 2-5

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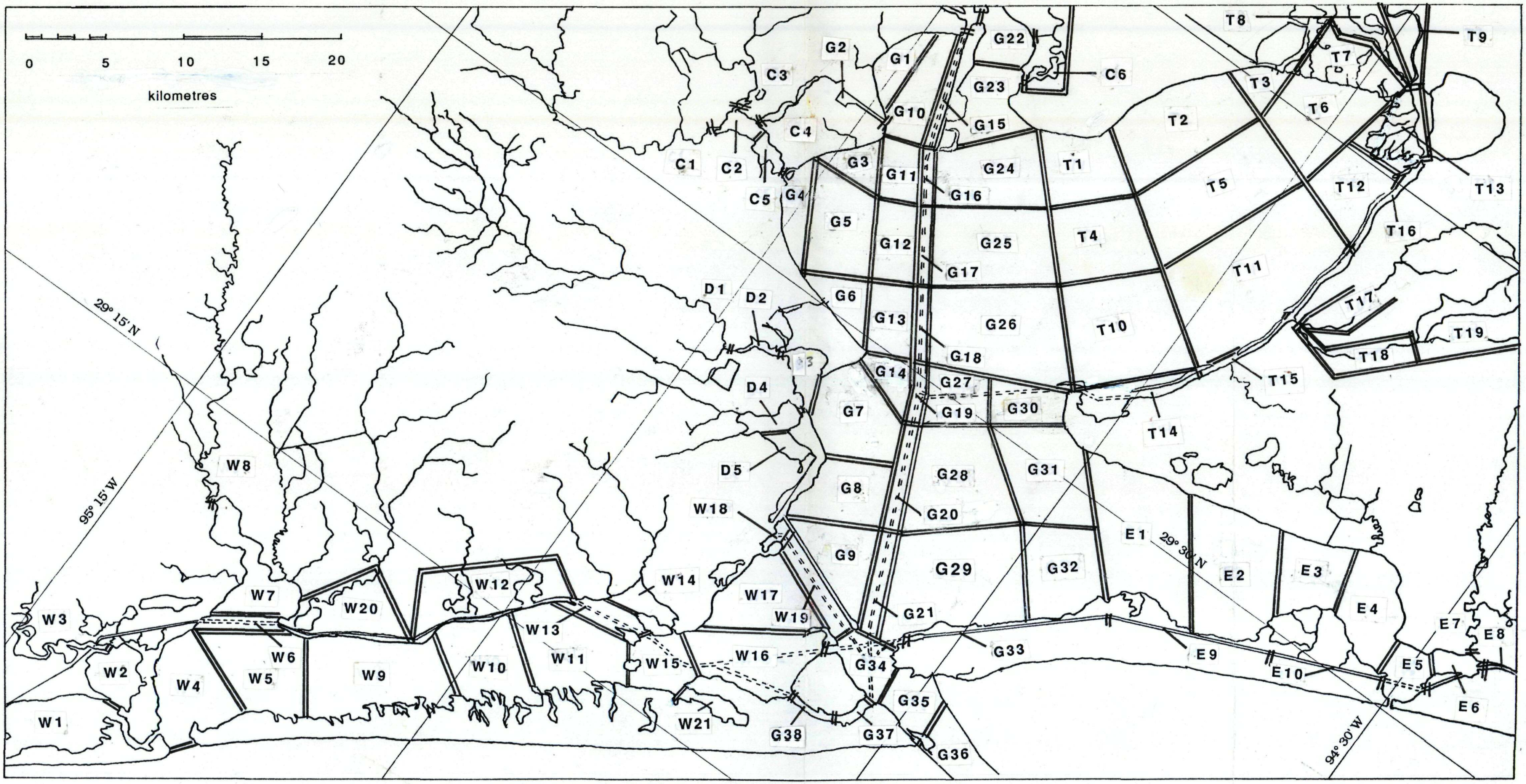

Fig. 2-5 - Hydrographic segmentation for Galveston Bay

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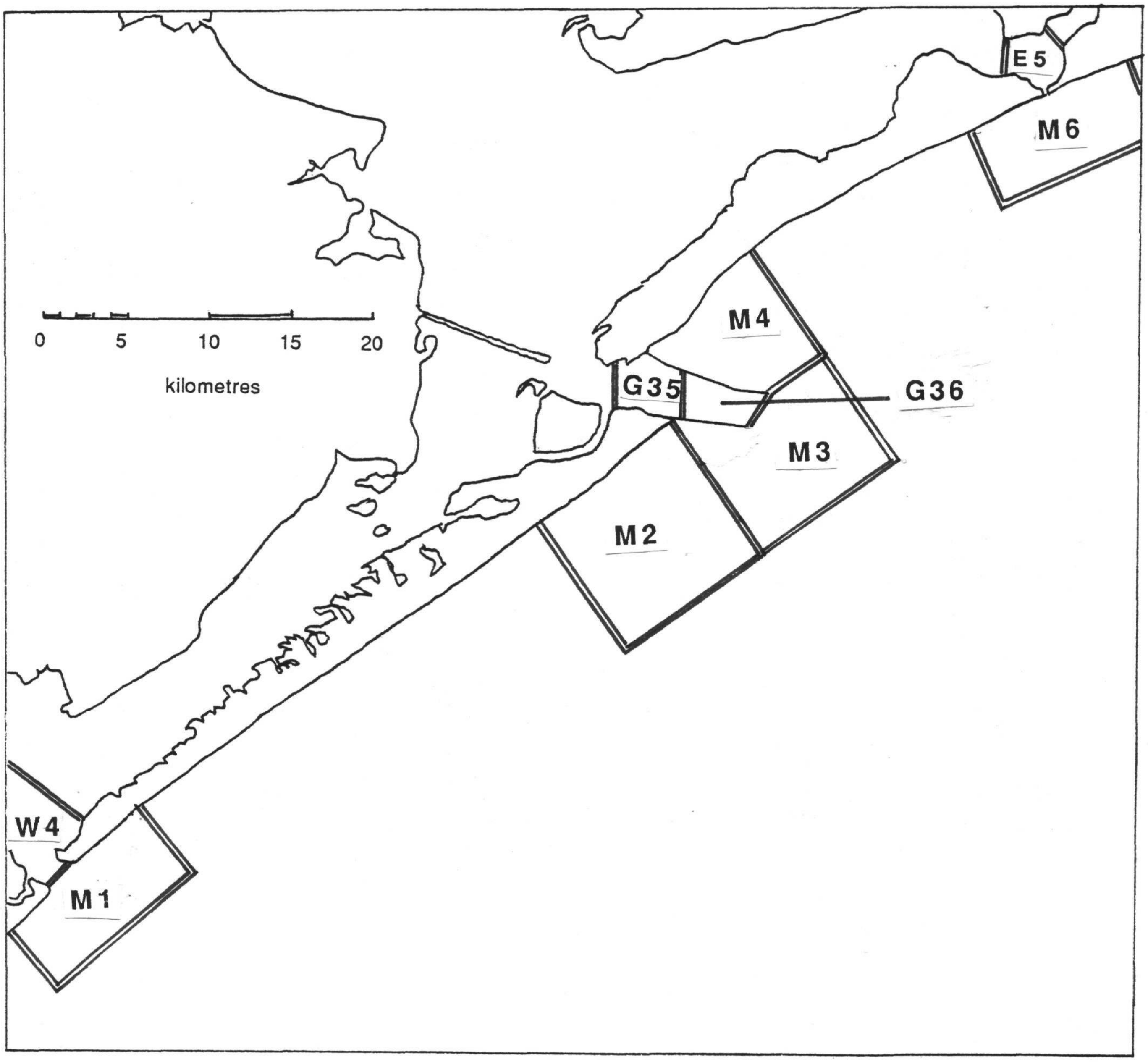

Fig. 2-6 - Hydrographic segmentation for Gulf of Mexico nearshore

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Figure 2-7
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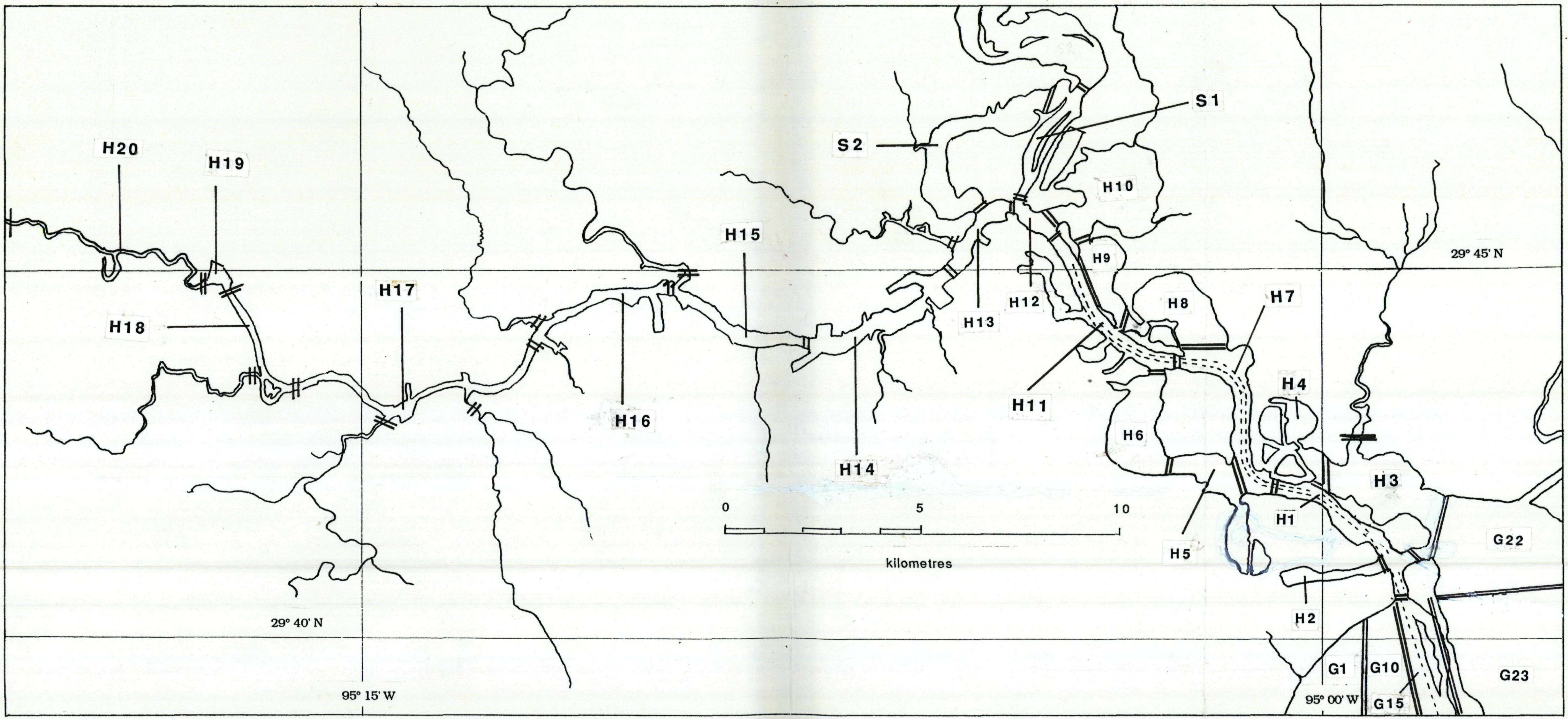

Fig. 2-7 - Hydrographic segmentation for Houston Ship Channel

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