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Land Use/Land Cover Changes in Mainland Coastal Mississippi, 1950s to 1992

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PURPOSE OF STUDY

This research project was initiated in 1992 to document recent changes in land use/land cover categories of the mainland portion of the Mississippi coastal zone. The purposes of the study are: a) to provide a cartographic and quantitative baseline within which specific regions of land loss, particularly wetland loss, could be identified, b) to document temporal variability in land cover changes, especially in Mississippi's coastal wetlands, and c) to provide a starting point for further scientific inquiries into the geomorphic processes contributing to or affected by recent changes in Mississippi's wetlands and adjacent coastal uplands.

ACKNOWLEDGMENTS

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Many people assisted the authors in the preparation of this report, and special thanks go to S. Cragin Knox, Director of the Office of Geology and State Geologist for Mississippi for encouraging this project and continuing to forge strong links between state government and academia. Jack S. Moody, Director, and Stephen M. Oivanki of the Energy and Coastal Geology Division of the Office of Geology provided endless professional assistance and support.

Many others assisted the principal authors in providing, interpreting, and computerizing the voluminous data used in this study. Karen M. Wicker of Coastal Environments, Inc., Baton Rouge, Louisiana was not only the lead author of the initial 1980 U. S. Fish and Wildlife Service report which summarized 1950s-1970s changes in land cover categories of coastal Louisiana and Mississippi, but she generously provided unpublished data from the original interpretations. The finalized data generated were provided in computer tape format by Larry Handley of the National Biological Survey, National Wetlands Research Center, Lafayette, Louisiana. Interpretation of the 1990s aerial imagery was completed with most able assistance by Leslie Sontag (formerly) of the MSU Department of Geosciences and Michele D. Meyer-Arendt, freelance photo interpreter and cartographer. Philip White of the Mississippi Office of Geology was largely responsible for the pain-staking digitizing of the data. Although many others assisted in the process leading to completion of this project, the final "quality-control" rested in the hands of the principal authors, and any errors or mistakes herein must be blamed solely on them.

INTRODUCTION: ARE COASTAL WETLANDS ENDANGERED?

The value of wetlands

Wetlands are considered to be among the most valuable ecosystems on earth. Found at the land-water ecotone, and defined in part on the basis of at least seasonal inundation of standing water, wetlands play important roles in cleansing polluted water, absorbing storm wave energy, and recharging groundwater. Wetlands are also among the greatest biomass-producing environments on earth (Mitsch and Gosselink, 1986). Their increasing recreational and commercial value in terms of fish and wildlife production is recognized by scientists, policy-makers, and the general public (Costanza and Farber, 1985; Houck, 1983; and Turner, 1977). Over the last two or three decades, a myriad of legislative acts, land use regulations, and management plans has been enacted to preserve this valuable ecosystem from succumbing to destruction as a result of agricultural expansion, petroleum exploitation, urban/industrial construction, tourism development, and human tampering with natural (i.e. biologic, geologic, hydrologic, and atmospheric) processes.

Geologic foundations of wetlands

Wetlands may be defined by either geologic or biotic parameters, and in public usage it is usually the latter that receives most attention. Geologically, wetlands are a transitional category between dry land and open water. Soil-forming processes characterize the sedimentary substrate in wetland environments in spite of regular, and often lengthy, periods of inundation. Wetlands play a major role in sediment budgets, especially in terms of interrelationships between terrestrial and aquatic environments. Because of the unique geomorphic setting of wetlands, a similarly unique set of vegetation tends to colonize it. And because it is easier to identify and map the visible vegetation than the soil or the substrate, the term "wetlands" has become associated with the biotic instead of the geologic factors. Field identification manuals cite vegetative species as indicators of wetlands (e.g. Wetlands Training Institute, Inc., 1989). Because of the biological productivity of wetlands, most of the scientific, governmental, and popular literature on wetlands also falls under "biology" instead of "geology".

The geologic importance of wetlands is increasingly being recognized, especially relative to hydrologic and sediment flux processes in fluvial and coastal environments. The U. S. Army Corps of Engineers presently uses a hydrogeomorphic classification of wetlands to assess functions and assign values to the variety of wetlands found in the United States and its dependencies (Brinson, 1993).

Concerns over wetland loss

The loss of wetlands, by both human and natural processes, has been receiving much attention in recent years. Although the shrinking acreage of wetlands in the United States has been noted since the turn of the century, especially by duck hunters, not until a U. S. Fish and Wildlife (USFWS) report was released in 1980 was the severity recognized (Wicker, 1980). This report, which summarized a mapping project in which land cover maps (in ecological terms, habitat maps) of the mid-1950s were compared with similar maps of the late-1980s for a region encompassing southeast Louisiana and coastal Mississippi (Wicker et al., 1980). The first interpretation of the data generated indicated that southeast Louisiana was losing wetlands at an astounding rate of about 40 square miles per year (Gagliano et al., 1981). Since the initial study was released, numerous follow-up studies have been conducted at various levels ranging from local to international. An overall trend of wetland loss has been documented for the United States, and both human-induced and natural processes have been blamed (Gosselink and Baumann, 1980; Meyer-Arendt, 1987a; Mitsch and Gosselink, 1986; Tiner, 1984; Turner and Cahoon, 1987; and Williams, 1990b). In view of recent evidence of sea level rise, perhaps induced by a trend of overall global warming, concerns about corollary accelerated wetland losses have increased (Burrage, 1991; Day and Templet, 1989; Hoffman et al., 1983; Meyer-Arendt, 1990; Otvos, 1991; and Titus, 1988).

Whereas the concern over wetland losses has received considerable attention nationally and internationally, little attention has been paid to the coastal wetlands of Mississippi. It has been the aim of this project to analyze the Mississippi portion of the original USFWS study (Wicker, 1980) and update it to the 1990s. The identification of patterns and processes of wetland changes, as well as overall land-water changes, in coastal Mississippi not only documents recent trends but provides a baseline data set useful for further geologic, geographic, hydrologic, biologic and other investigations.

Types of wetlands

To accurately define, identify, and classify wetlands have been major problems for much of this century. Since wetlands form part of a continuous gradient between dry land and water, to assign an upper and lower limit to this ecotone is somewhat arbitrary (Mitsch and Gosselink, 1986). Geologists and soils scientists classify wetlands on the basis of sediment characteristics; hydrologists look at levels or periods of inundation; and biologists, botanists, and ecologists may define wetlands on the basis of prevailing species. The U. S. Fish and Wildlife Service defined wetlands as:

"...lands transitional between terrestrial and aquatic systems where the water table is usually at or near the surface or the land is covered by shallow water.... Wetlands must have one or more of the following three attributes: 1) at least periodically, the land supports predominantly hydrophytes, 2) the substrate is predominantly undrained hydric soil, and 3) the substrate is non-soil and is saturated with water or covered by shallow water at some time during the growing season of each year"(Cowardin et al., 1979).

No matter what the general definition of wetlands may be, one can delineate numerous subtypes, which are known by dozens of vernacular terms and found in a variety of environments. In terms of vegetation, forested wetlands (swamps) are distinguished from grassy, non-forested wetlands (marshes). In terms of broad geographic distribution, we can distinguish fresh-water inland wetlands from coastal wetlands (or tidal wetlands), which are subject to tidal influence and range from fresh to saline in terms of salinity (Figure 1 and Table 1 are included as examples of wetland topologies).

In this study, the focus has been upon coastal wetlands, particularly non-forested tidal wetlands (marshes) which have been most vulnerable to deterioration as a result of both human-induced and natural processes. As with wetlands in general, the coastal wetlands ecotone is actually quite complex in terms of vegetative habitats (Figure 2). Based upon geomorphology, at least six major types of tidal marshes have been identified (Figure 3).

Origin and maintenance of coastal wetlands

Coastal wetlands of the world have developed in regions of low gradients, fine-grained sediments, and low wave energy. Such geomorphic zones include estuaries, lagoons, drowned river valleys, deltas, and exposed coasts sheltered by reefs, barrier islands, or a wide shallow foreshore. Excessive energy in the water (normally wave energy, but also tidal or longshore current energy) will preclude the establishment of wetland vegetation.

Low-elevation coastal wetlands (usually less than 5 ft above sea level in microtidal regimes) may be described by the two sets of processes that account for sediment transport and deposition. Marine-dominated marshes are found in sites subject to sedimentation as a result of tidal or wave action while still protected from erosive wave energy. Examples of such sites include

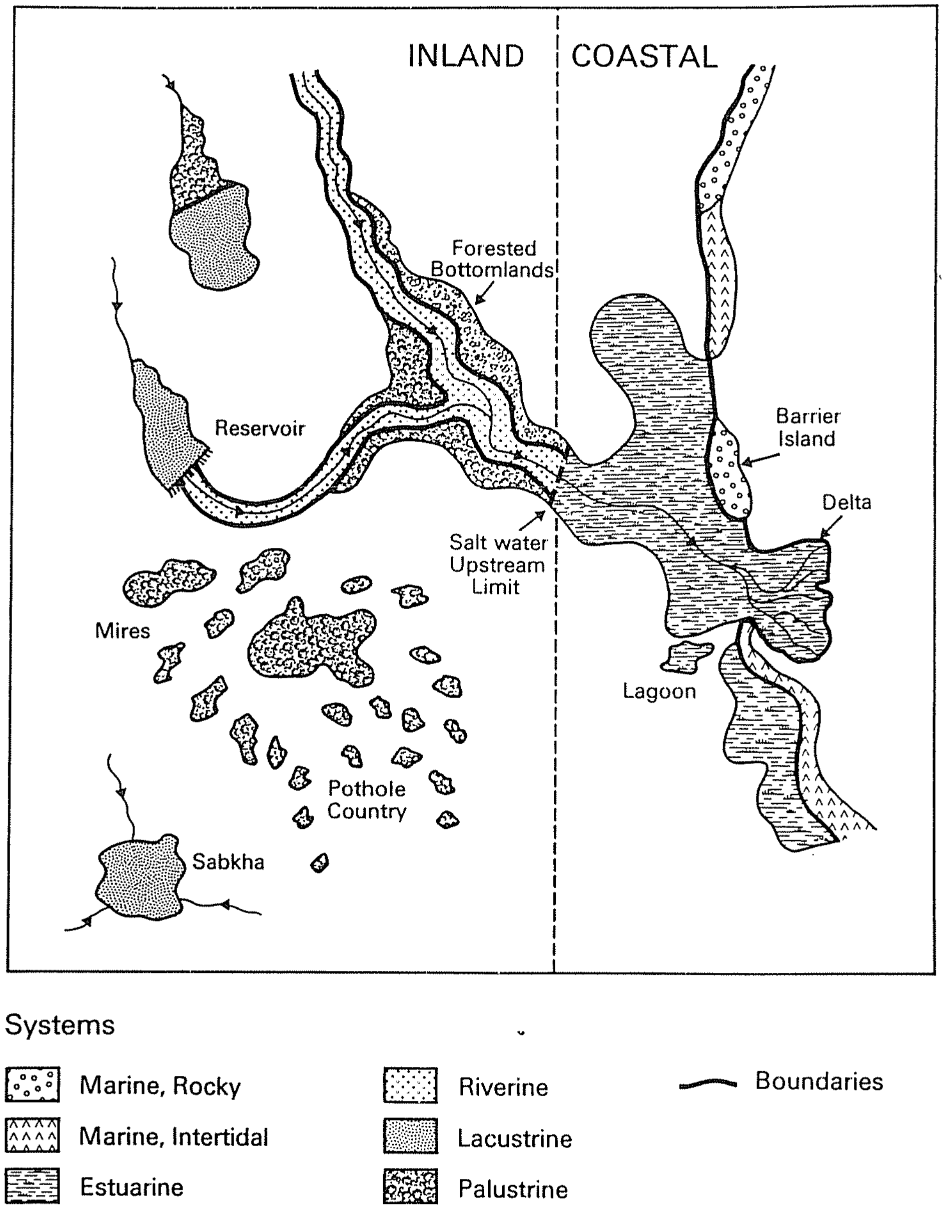

Figure 1. A variety of wetland types. (Williams, 1990a; after Tiner, 1984)

System	Location	Water regime	Water chemistry[a]	Vegetation type
Coastal wetlands				
Marine	Open coast	Supratidal	Euhaline-mixohaline	Shrub wetland
		Intertidal	Euhaline	Salt marsh, mangrove
		Subtidal	Euhaline	Sea grass, algae
Estuarine	Coastal sabkha	Supratidal	Hyperhaline-mixohaline	Algae, barren sabkha
	Estuaries deltas	Supratidal	Mixohaline-fresh	Brackish-freshwater marsh, shrub wetland
	lagoons	Intertidal	Euhaline-mixohaline	Salt marsh, mangrove
		Subtidal	Euhaline	Sea grass, algae
Interior wetlands				
Riverine	River channels	Perennial	Fresh	Aquatics, algae
		Intermittent		Aquatics, emergent wetland
		Ephemeral		Aquatics, emergent wetland
	Flood plains	Ephemeral or stagnant	Fresh	Emergent wetland, shrub and forest wetland
Lacustrine	Lakes lake deltas	Perennial >2 m deep	Fresh limnetic	Aquatics, algae
		Perennial-intermittent <2 m deep	Fresh littoral	Aquatics, emergent wetland, shrub/forest wetland
	Sabkhas	Ephemeral	Hypersaline-mixosaline	Algae, barren sabkha, some phreatophytes
Palustrine	Ponds	Perennial	Fresh littoral	Aquatics, algae
	Turloughs	Intermittent	Fresh	Aquatics, emergent wetland
	Lowland mires	High water tables	Fresh	Aquatics, *Sphagnum* moss, bog plants,
	Upland mires	Perennial to ephemeral surface water		emergent wetland, shrub wetland, forest wetland

[a]Halinity refers to ocean-derived salts and salinity to land-derived salts The prefixes are defined in terms of parts per thousand salts as follows hyper >40‰, eu 30–40‰ mixo 0 5–30‰ (brackish), fresh <0 5‰

Table 1. Classification of wetlands by system, location, water properties, and vegetation. (Orme, 1990)

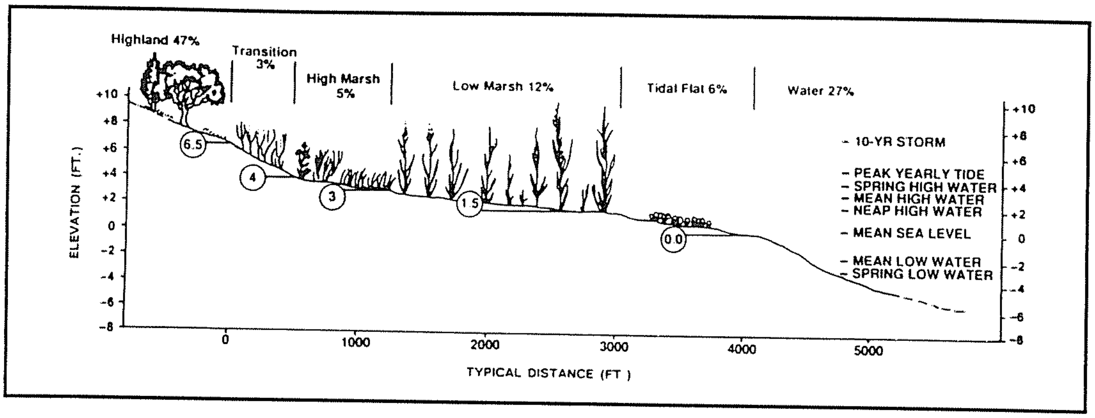

Figure 2. Vegetative sub-environments in relation to water level parameters in a typical southeastern USA coastal wetland ecotone. (Kana et al., 1988, based on studies in South Carolina)

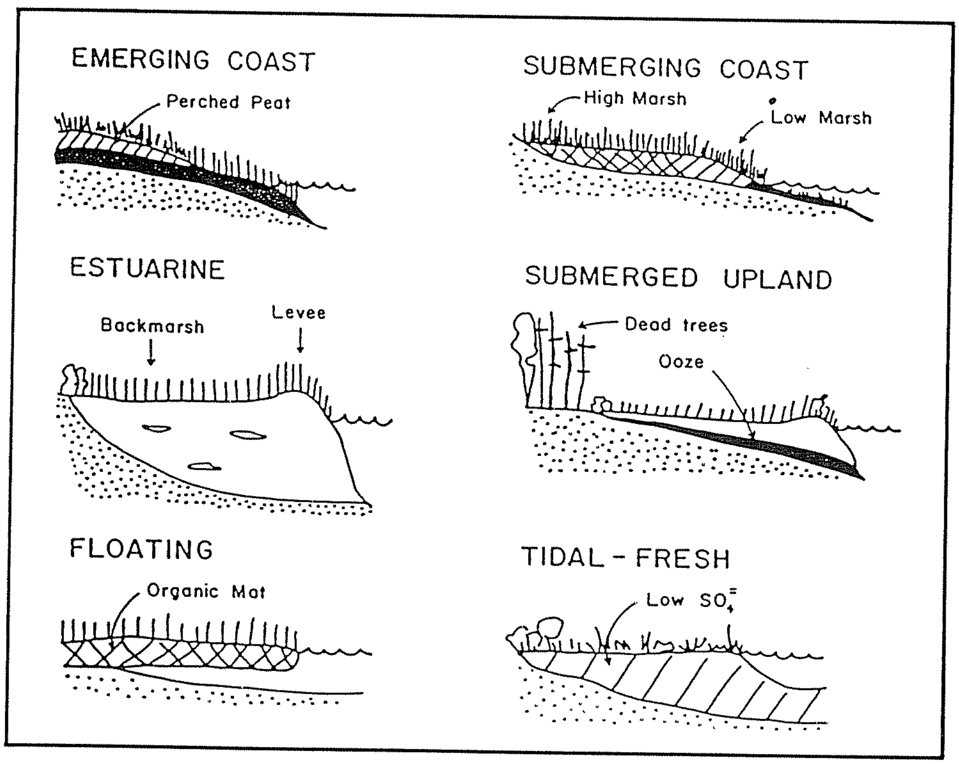

Figure 3. Six major tidal marsh types. (Stevenson et al., 1986)

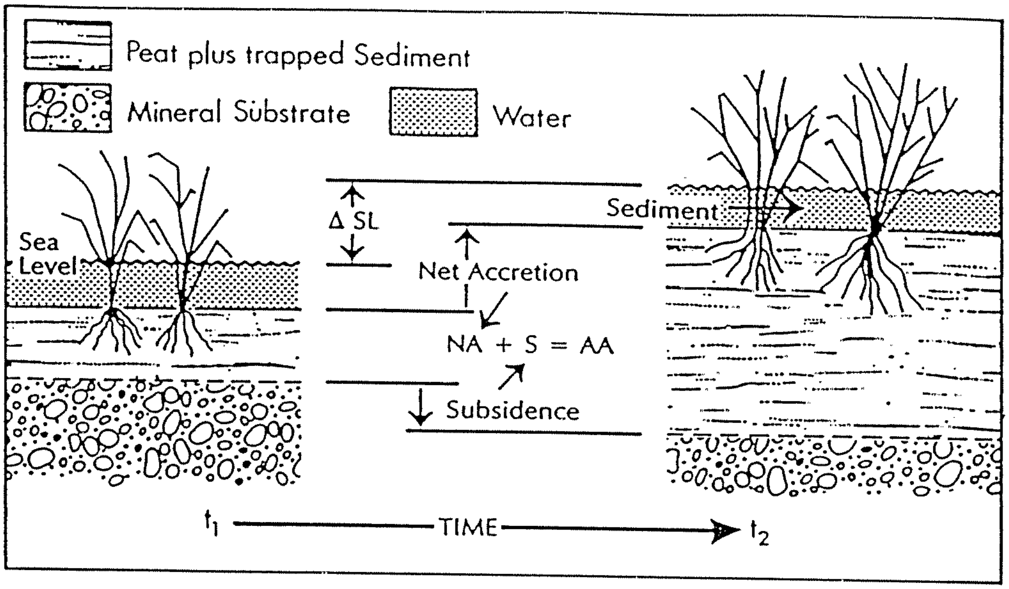

Figure 4. Factors affecting marsh maintenance. (Walker et al., 1987; after DeLaune and Smith, 1984)

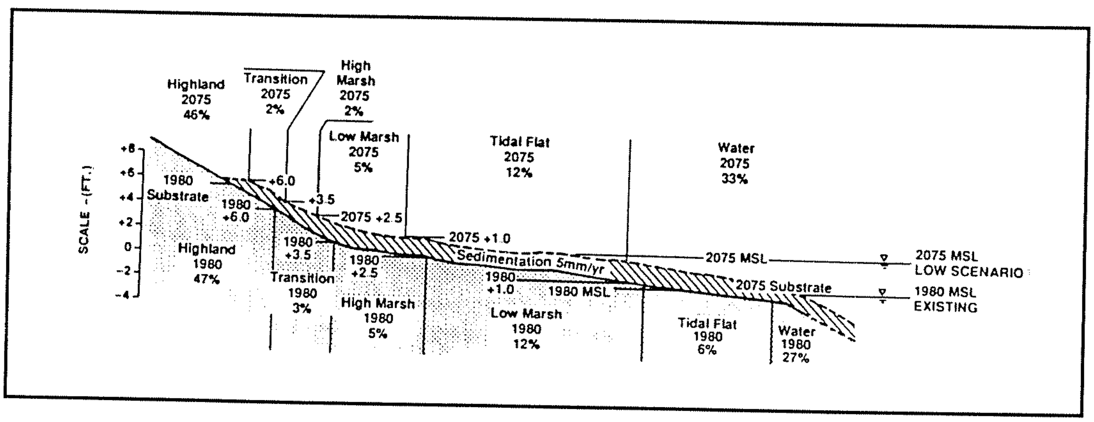

Figure 5 Shift in wetlands zonation along a shoreline profile. (based upon a projection of 40-cm sea level rise by 2075 by Kana et al., 1988)

the lee of beach spits, offshore bars, or barrier islands as well as along the margins of protected bays (Mitsch and Gosselink, 1986). The second, and most important in terms of overall areal extent, wetland-creating process is fluvial/deltaic sedimentation. During periods of peak discharge, streams and rivers carrying large sediment loads will deposit the sediments into floodplains within entrenched stream valleys, into protected bays and estuaries, or onto shallow continental shelves. Where levels of erosive wave or tidal action are relatively low, as in estuaries or along exposed coasts with low wave energy regimes, the deposited sediments form a gradual-sloping (i.e. low gradient and relatively wide) land-water ecotone suitable to wetland development.

Although wetlands prevailed during most phases of geologic history (their legacy transformed into our present hydro-carboniferous resources, including oil, gas, and coal), present-day coastal wetlands are Holocene in age and specifically traced to the waning of the Flandrian transgression about 5000 years ago (Orme, 1990). After the last glacial maximum about 18,000 years ago, the sea began to rise eustatically from a level perhaps 300-400 ft lower than present. Between 15,000 and 7,000 or so years ago, the high rate of sea level rise (0.4 in/yr, or 1.0 cm/yr) precluded any significant shallow-water sedimentary deposition and vegetative colonization thereof. Most wetland formation dates to around 5,000 years ago when rates of post-glacial sea level rise slowed to less than 0.1 in/yr (0.2 cm/yr) (Nummedal, 1983).

Coastal wetland stability

Under natural conditions, the stability of marsh wetlands is dependent upon the interaction of two categories of processes: relative sea level rise and marsh accretion. Excessive rates of the former, coupled with low rates of the latter, will restrict regenerative ability and lead to wetland deterioration.

Relative sea level rise is a generalized term that includes both processes of land submergence (subsidence) and processes of water level rise. Since the effect of both processes is a lowering of land surface relative to water levels, it is often difficult to separate the relative magnitudes of each, and thus the term has become adopted. The terms "relative subsidence" and "apparent sea level rise" have also made their way into the literature.

Marsh accretion, specifically vertical marsh accretion, refers to various mechanisms of sedimentation by which the marsh surface builds upward (Figure 4). Sedimentation in marshes may be divided into (in situ) organic sedimentation, in which decay of organic matter builds up the marsh surface, and inorganic sedimentation, whereby mineral sediments are introduced to the marsh by fluvial or marine processes. Fluvial sedimentation is usually in the form of overbank sedimentation wherein river-borne sediments are released into marshes as a result of seasonal flooding and overtopping of natural levees, and also river-mouth (or deltaic) sedimentation whereby sediments drop out as the hydraulic energy diminishes at the mouth of the river. Marine sedimentation is most often in the form of tidal action redistributing sediments to marshes or storm-triggered wave action dispersing sediments into marshes.

For given rises in relative sea level, coastal marshes may remain viable if sufficient rates of vertical marsh accretion can be maintained. So far, most coastal wetlands of the East and Gulf Coasts of the U.S. have managed to keep pace with eustatic sea level rise (Stevenson et al., 1986). However, studies of wetlands within the Mississippi River deltaic plain of southeast Louisiana have shown where processes of subsidence constitute a much higher component (perhaps 85%) of local relative sea level rise and marsh accretion rates have not kept pace (Baumann and DeLaune, 1982; Boesch, 1982; Boesch et al., 1983; Day and Templet, 1989; DeLaune et al., 1983; Mendelssohn and McKee, 1987; and Turner and Cahoon, 1987). The deficit has been most severe in more inland fresh-to-brackish marshes which have historically depended upon overbank flooding from the Mississippi River and its former distributaries to supply mineral sediments (Templet and Meyer-Arendt, 1988).

Marshes closer to the Gulf of Mexico are characterized by both a higher salinity regime as well as a higher tidal regime. As a result, these saline marshes are subject to greater marine sedimentation because of this higher tidal energy, and thus they have experienced less of an accretion deficit. This trend has been noted not only in Louisiana (Templet and Meyer-Arendt, 1988), but also at Sapelo Island, Georgia (Carter, 1988). The amount of external sediment influx and corollary relative stability of saline marshes (at least with respect to the accretion deficit) is reflected in the ratio of inorganic-to-organic matter, especially when compared to more inland fresher marshes. One can conclude that the influx of fluvial sediments is more important in the fresh-to-brackish marshes in terms of maintaining sufficiently high rates of vertical accretion.

Impacts of future sea level rise on coastal wetlands

Because of the high rates of wetland submergence in the Mississippi River deltaic plain of southeast Louisiana (a result more of land submergence rather than sea level rising), this wetland environment serves as an excellent example of what can be expected throughout the world's coastal wetlands in the wake of accelerating eustatic sea level rise (Day and Templet, 1989). The mechanisms of wetland loss identified in Louisiana since serious studies first began in the early 1980s may well become replicated on global levels if accelerated sea level rise rates are realized.

Analysis of tide-gauge records and sea level rise projections calculated on the basis of global warming rates (Hoffman et al., 1983) infer that, under worst-case scenarios, sea level will rise at a rate equal to or exceeding that of the Holocene transgression (about 0.4 in/yr, or 1.0 cm/yr). Models indicate that, even if marshes keep pace with such high rates (i.e. no marsh accretion deficit develops), the land-water ecotone will become narrower as sea level rises onto the steeper slopes of coastal Pleistocene uplands (Figure 5). Furthermore, the extensive urban development along the shoreline of the USA (particularly along the low-gradient southeastern U.S. coast) will preclude the strip of fringing tidal wetlands from relocating upslope (Figure 6). Unless processes of sedimentation resume or become re-established if sea level reaches a new relative equilibrium, wetlands will not reappear along developed coasts.

Analysis of 100 years of records from the Biloxi, Mississippi tide gauge reveals that relative sea level has increased 0.6 feet (20 cm)--an average rate of 0.07 in/yr, or 0.18 cm/yr (Burdin, 1991). Although these rates are much below those of the Holocene transgression, predictions of future rises in these rates has caused concern among coastal Mississippi scientists and policy-makers (Burrage, 1991; and Otvos, 1991). These concerns are over both acceleration of wetland loss and shoreline erosion, as well as potential impacts upon the human occupants and development infrastructure in the Mississippi coastal zone.

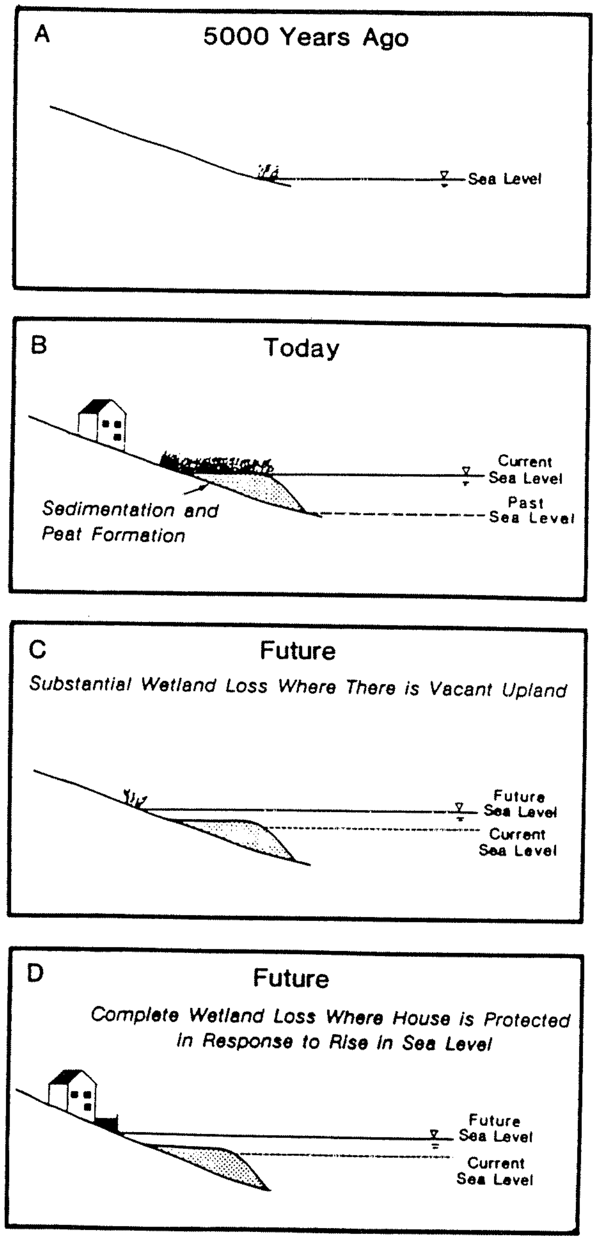

Figure 6. Past, present, and future scenarios of coastal wetland formation. Since the slowing of rates of sea level rise (A), wetlands have developed along low-gradient shoreline (B). If sea level rise rates again increase, the zone of coastal wetlands will shrink under natural conditions (C) or even disappear where human modification is extensive (D). (Titus, 1988)

MISSISSIPPI'S COASTAL WETLANDS

Distribution of wetlands

Coastal wetlands are found throughout the various micro-environments of coastal Mississippi that meet the conditions for wetland formation discussed previously. These micro-environments include the lower reaches and deltas of streams emptying into Mississippi Sound and adjacent bays, low-energy shore environments of estuarine bays and Mississippi Sound, and lee shores of the offshore barrier islands. Mainland coastal Mississippi, the focus of the present study, may be described in terms of four drainage systems: the Pearl River, St. Louis Bay, Biloxi Bay, and the Pascagoula River (Figure 7). The Pearl and the Pascagoula Rivers, as well as smaller tributaries, downcut their respective valleys during lower sea level stands, and these valleys became drowned at the end of the Flandrian transgression. Since that time, extensive sedimentation has filled in most of the valleys and resulted in land progradation out into the open water. These sediments have provided the foundation for wetland growth.

In addition to the fluvio-deltaic wetlands of the lower Pearl River, the Pearl River drainage basin also includes the extensive marshes of southern Hancock County. These coastal marshes may have accreted either directly from sediments contributed via previous active delta lobes of the Mississippi River or indirectly as a result of wave-sheltering by Mississippi River sediments deposited in a previous eastern (St. Bernard) delta. Holocene beach ridges, still quite prominent in the region, also contributed to wave sheltering which allowed wetlands to develop.

Mississippi's two semi-enclosed estuarine bays are St. Louis Bay and Biloxi Bay (including Back Bay of Biloxi). The Jourdan River, Bayou La Croix, Wolf River, and several smaller bayous contribute sediments to St. Louis Bay, and both fluvio-deltaic and bay-fringing marsh wetlands abound. The coastal flatwoods "uplands" are barely higher than many of the marshes in this area. The Biloxi River, Tchoutacabouffa River, Bernard Bayou, and a few smaller bayous empty into the Back Bay of Biloxi, and several bayous empty into Davis Bay, an "arm" of Biloxi Bay south of Ocean Springs. As evidenced by all of Mississippi's coastal streams, there is a zonation inland from salt marsh (downstream) to fresh marsh and cypress swamp (upstream) (Eleuterius, 1973). This

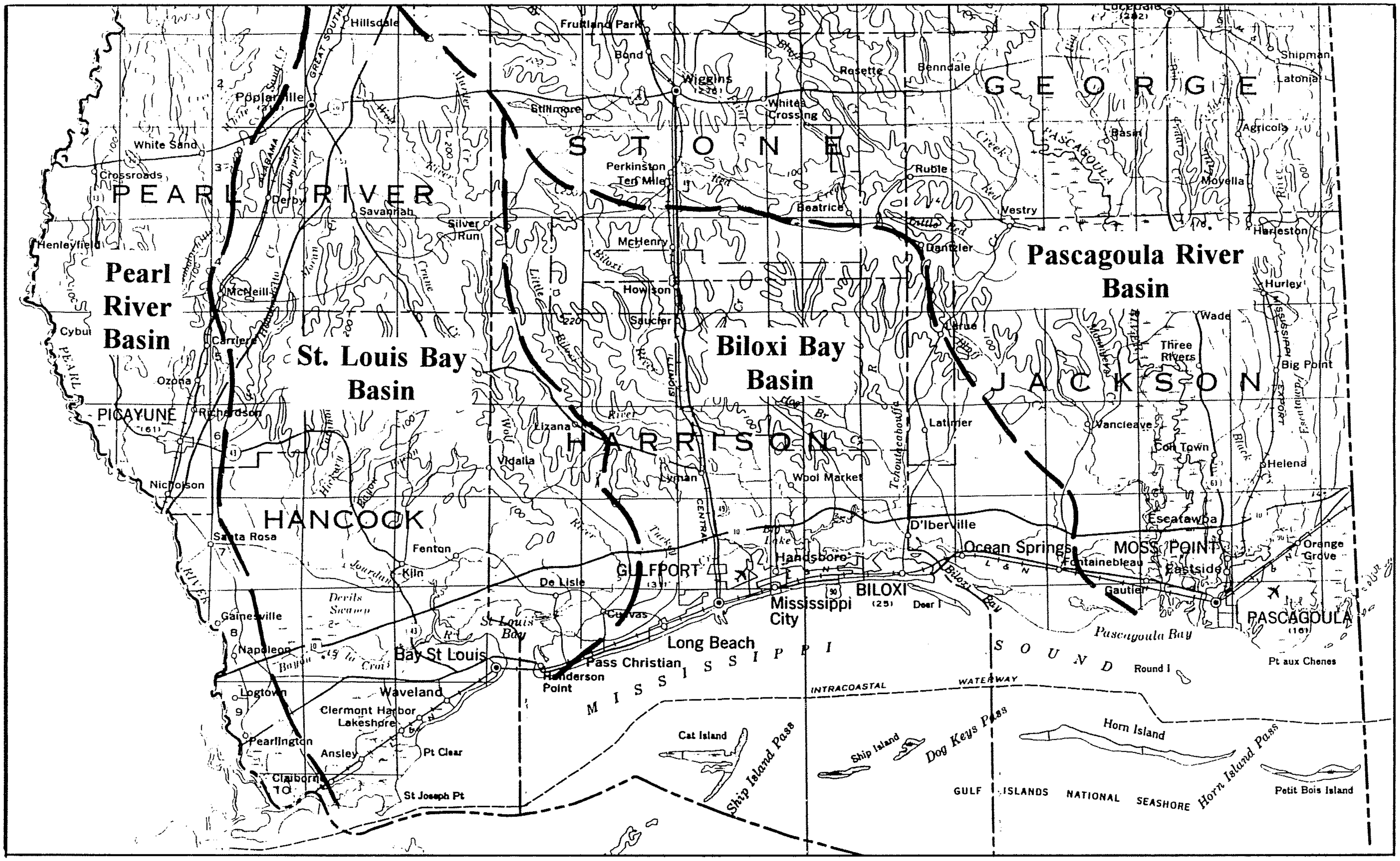

Figure 7. Mississippi Gulf Coast drainage basins.

gradation is a combined function of gradient (higher elevations upstream) and degree of tidal influence. Fluvio-deltaic tidal marshes are found in abundance at the head of Back Bay of Biloxi, and small fringing marshes as well as several marsh islands are found throughout the bay system.

The expansive marshes of the lower Pascagoula River (dimensions of about 4 miles by 7 miles) have also resulted from high rates of sedimentation in the late Holocene as well as the modern period. Extensive dredging related to industrial development in the Pascagoula area has modified much of the natural delta, but some wetlands have evolved on some of the dredge spoil islands there. Wetlands also extend up most of the lower tributaries of the Pascagoula River. Extensive marshes are also found east of the city of Pascagoula to beyond the Alabama state line, and their genesis is traced to fluvio-deltaic sedimentation via a former channel of the Escatawpa River (a present tributary of the Pascagoula) coupled with wave sheltering by the delta front (the former Grand Batture Islands) and the offshore barrier islands (Meyer-Arendt and Kramer, 1991).

Previous studies of land cover changes in wetland areas

Numerous studies with varying degrees of detail have been conducted in Mississippi's coastal wetlands and adjacent environments. For purposes of this study, only a few previous studies have attempted to summarize changes in land use and land cover. The following are synopses of such studies which are antecedent to the present study.

Eleuterius' marsh inventory of 1973

Over two decades ago, botanist L. N. Eleuterius produced what has endured as the comprehensive overview paper on coastal marshes in Mississippi (Eleuterius, 1973). This study was conducted in anticipation of passage of a state Wetlands Protection Act, which was a key component of the Mississippi Coastal Program, which, in turn, was developed in response to passage of the federal Coastal Zone Management Act of 1972 (Graber, 1986). Many scientists, including Eleuterius, were alarmed at the amount of industrialization and urbanization taking place in and adjacent to the coastal wetlands. Eleuterius (1973) described the human impacts upon the marshes of Mississippi as follows:

> Approximately 1,000 acres of marshland was filled in Mississippi prior to 1930. This conservative figure takes into account both residential and industrial beach developments around cities such as Biloxi, Pascagoula, Ocean Springs, Bay St. Louis and Waveland. Highway 90, which runs along the Mississippi Coast, traversed many marsh areas. Small roads along the beach covered or cut off many marsh areas, which were drained and in many cases have been filled in.
>
> Since 1930 approximately 8,170 acres have been filled for industrial and suburban developments. Eighty-five acres of marsh have been used as garbage dumps. The general location and acreage filled by hydraulic dredge or garbage is shown [Table 5 of Eleuterius, 1973]. There is a projected plan for south Mississippi to fill an additional 26,963 acres for industry prior to 1990. The increase in population associated with the projected industrial growth of this area will intensify pressure on waterfront property. Premium prices for such real estate will undoubtedly encourage more housing developments along, and probably in, the privately owned housing development fills or the further use of the marshes as garbage dumps. Construction of channels, marinas, public and private docks and deepening and bulkheading of channels will probably increase.
>
> There is also a proposal to destroy completely Deer Island marsh habitat by bulkheading and filling all the way out to the four-foot depth contour interval.--Eleuterius, 1973

In 1973, the Wetlands Protection Law was passed, and practically all of the grandiose plans for wetlands reclamation ground to a halt. Although wetlands removal still occurs, the regulatory process has become quite elaborate, and extensive mitigation actions must be undertaken. From 1973 until 1994, the lead agency in the permitting process in Mississippi has been the Bureau of Marine Resources, Mississippi Department of Wildlife, Fisheries, and Parks, headquartered in Biloxi (Graber, 1986). In July 1994, this office was restructured as the Mississippi Department of Marine Resources.

The USFWS habitat study of 1980

Intended as part of the National Wetlands Inventory, a U. S. Fish and Wildlife Service project to map the coastal wetlands of Louisiana and Mississippi was initiated in 1978 (Wicker, 1980). Black-and-white aerial photographs of the mid-1950s and the latest color-infrared high-altitude photography (mostly 1978) were manually interpreted according to a hierarchical classification scheme devised by Cowardin et al. (1979) to evaluate land cover/ land use in terms of "habitat" potential for flora and fauna. The senior author of this report served as a mapping/data analysis supervisor on that project.

The extent of coastal wetland losses along the central Gulf Coast first became apparent as the two sets of habitat maps were quantitatively analyzed (Gagliano et al., 1981). The data showed a reduction in land area of 413,000 acres (11.3% of an original 3,646,000 acres) in southeast Louisiana alone. South Louisiana, which contains over 40% of the nation's coastal wetlands, quickly became the focus of much public and legislative attention (Alexander et al., 1986). In comparison to Louisiana's loss of about 650 square miles of land between 1955 and 1978, the overall land loss calculated for coastal Mississippi, over 9 square miles (6,055 acres) in approximately the same period, seemed trivial (Table 2). The proportion of coastal zone land lost also appeared to be much lower than in Louisiana, in part because the ex-officio Mississippi coastal zone boundary used in the study (all habitats below the 15-ft contour) contains much non-wetland habitat. The pine flatwoods which naturally occupy the zone between the 5-ft and 15-ft contours have become prime sites for urban development over the past several decades.

Closer inspection of the habitat data revealed that, exclusive of the offshore barrier islands, Mississippi's mainland tidal marsh acreage of 69,130 acres in the 1950s (dates of photography ranged from the early 1950s to the late 1950s) had dwindled to 64,089 acres by 1978 (Figure 8). This loss of 5,041 acres (nearly 8 sq. mi.) amounted to a 7.3% loss, a rate approximately 65% that of the deltaic plain of Louisiana (Gagliano et al., 1981). A 1973 estimate of 64,805 acres of mainland marshes (based on 1968 planimetering of the then most recent topographical quads) seemed to indicate that most of the loss took place prior to

Category	Total coastal MS (acres)	Mainland: this study (acres)	Mainland: non-study area (acres)	Barrier islands (acres)
Total land area, 1950s	301,279	215,279	77,272	8,728
Total land area, 1970s	295,224	211,046	76,928	7,250
Land loss (land to water)	6,055	4,233	344	1,478
Total marsh area, 1950s	72,722	68,015	1,115	3,592
Total marsh area, 1970s	67,233	62,917	1,171	3,145
Marsh loss	5,489	5,098	+55	447
Total developed area,1950s	16,118	15,357	761	0
Total developed area,1970s	42,994	41,333	1,660	0
Gain in developed area	26,876	25,976	899	0

(Note: values are uncorrected)

Table 2. Summary of USFWS habitat analysis for Mississippi. (after Wicker, 1980)

implementation of the state Wetland Protection Law of 1973 (Eleuterius, 1973).

Meyer-Arendt's estuarine bay study of 1988

Perhaps because of the small amount of wetland loss and implementation of the Wetlands Protection Law of 1973, concerns with wetland losses in Mississippi remained low throughout the 1980s. With the exceptions of a summary report (Meyer-Arendt, 1988) and a computer-generated map of 1978 coastal habitats of Mississippi and Alabama (USFWS, 1984), little interest in the Mississippi habitat data was shown. Because of a variety of problems including poor quality and unacceptance by the National Wetlands Inventory, the USFWS National Coastal Ecosystems Team updated the habitat data based on newer January 1982/January 1983 color-infrared, 1:58,000-scale NHAP (National High Altitude Photography of the U. S. Geological Survey) aerial photographs. This reinterpretation was not completed until 1988-1989. A 1987 status report on wetlands in Mississippi suggested that the acreage of tidal wetlands was actually increasing (Eleuterius, 1987).

Because of this paucity of knowledge about processes and patterns of wetland changes in coastal Mississippi, a follow-up (to the USFWS report) pilot project--funded by the Mississippi State University Office of Research--was conducted in 1988 (Meyer-Arendt, 1989). The purposes of the study were:

1) to verify the accuracy of the USFWS habitat data,
2) to update the habitat measurements in the regions of St. Louis Bay and Biloxi Bay to the 1980s,
3) to document the relative role of each of the major identifiable processes of wetland change, including urbanization, within the 1950s-1980s period,
4) to assess the impact of the 1973 Wetlands Protection Law upon both the major agents of change as well as upon rates of wetlands change,
5) to make the wetland change information available to the public and the scientific community, and
6) to evaluate the need for expanding such a geographic analysis to the remainder to Mississippi's marshes.

The estuarine marshes were selected for the pilot study because of their proximity to the major urban areas of coastal Mississippi.

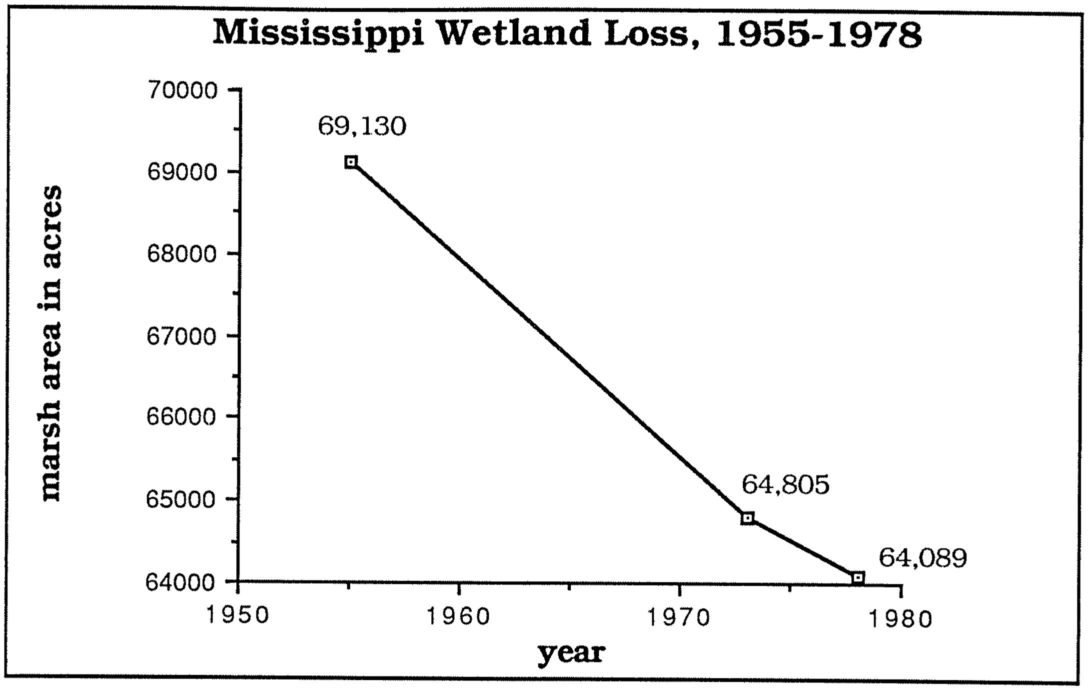

Figure 8. Change in acreage of mainland coastal wetlands in Mississippi, 1955-1978. (data from Eleuterius, 1973 and Wicker, 1980)

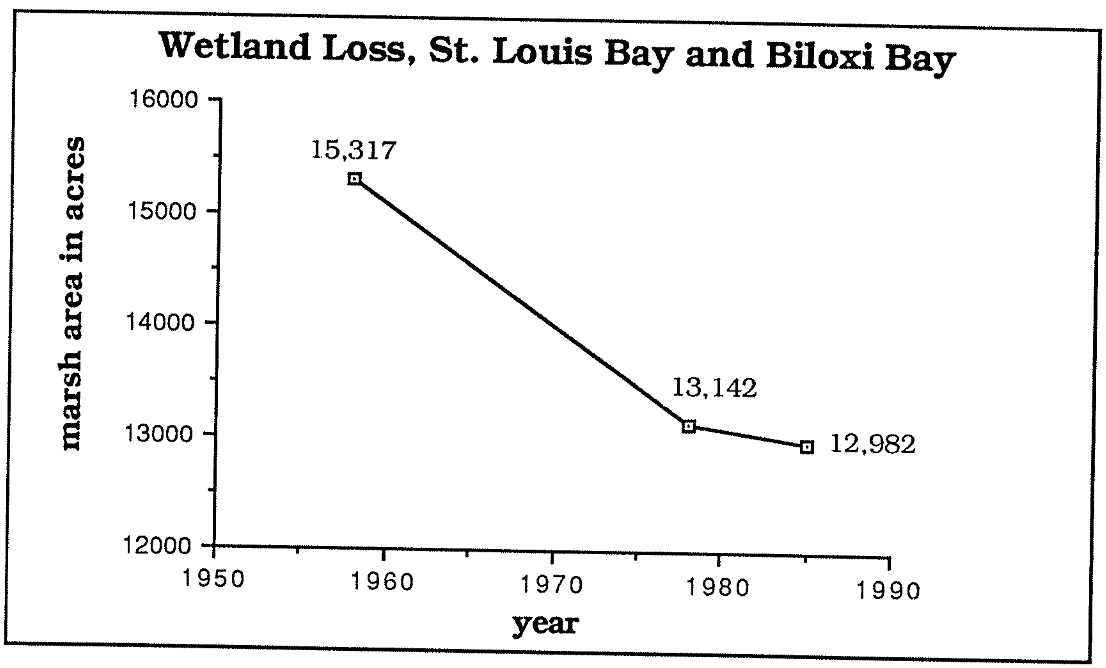

Figure 9. Change in acreage of estuarine wetlands in Mississippi, 1950s-1985. (Meyer-Arendt, 1989)

The data derived from the pilot study yielded results that both confirmed existing knowledge and also identified problems with existing studies. Of the USFWS habitat maps, the 1950s interpretations varied most in accuracy, in part because of poor quality black-and-white aerial photography. Marsh acreage for the 1950s may have been overestimated by 2 to 2.5%.

Of an overall recalculated 1950s marsh area of 15,317 acres within the study area, a total of 2390 acres were "lost", i.e. converted to another non-wetland habitat, by 1985 (Figure 9). Over 1400 acres of this loss (almost 60% of the total) occurred as a direct result of urbanization, mostly via dredge-and-fill activity associated with recreational subdivisions. Although the Bay St. Louis area was the primary locus of this activity, urban infringement upon wetlands was found throughout the study area. About 620 acres (over 25% of the loss) were converted into open water. Much of this was associated with the dredging of fill for the foundations of Interstate 10, but marina construction and residential canal dredging were also significant agents of land-to-water conversion. Natural land loss processes such as shoreline erosion or interior ponding, widespread throughout coastal Louisiana, were relatively insignificant. Also, over 370 acres of marsh wetlands became sites of spoil disposal. Because of the retention dikes and continued elevation increases due to periodic spoil disposal, most of these spoil disposal sites eventually became functional uplands in terms of vegetation and wildlife habitat. Some of the disposal sites did, however, become partially colonized by marsh vegetation.

In contrast to the loss of 2390 acres, a total of 55 acres of marsh wetlands were gained during this 1956-1985 period, chiefly as a result of deltaic sedimentation, as at the mouth of the Wolf River north of Pass Christian. Accounting for the gain, the net marsh loss in 30 years was 2335 acres--or 15.2% of the 1950s total wetland area, a rate higher than southeast Louisiana and about double the average for the total wetland area of Mississippi.

In contrast to the 1950s interpretations, the 1978 data exhibited a higher degree of interpretative accuracy that was most likely a reflection of the higher quality aerial photography used. The USFWS study listed a total of 13,142 acres of marsh within the study area for 1978, and the present study generated a figure of 12,982 acres. Assuming a relative accuracy for the 1978 data, wetland losses between 1978 and 1985 amounted to only 160 acres at the very most, or slightly over 1% loss over a period of 7 years. That "loss" may well have been within the estimated margin of error because of the difficulty of accurately mapping the small habitats, even at the 1:24,000 scale.

With minor exceptions, the Wetlands Protection Law of 1973 appeared to have been successful in sharply curtailing rates of human-induced wetland losses in the vicinity of St. Louis Bay and Biloxi Bay (including Back Bay). Examples of marsh losses between 1978 and 1985 included: a) wave erosion of abandoned fingerfill lots near the junction of Bayou La Croix and the Jourdan River, b) erosion of dredge-and-fill sites along Bernard Bayou, and c) loss of wetlands because of isolated cases of canal-dredging and spoil disposal. Highway construction across the lower Wolf River also appeared to have impacted wetlands by means of hydrologic modification and water impoundment (Meyer-Arendt, 1989).

OBJECTIVES AND METHODOLOGY

Objectives

To achieve the three aims outlined earlier: 1) to provide a cartographic and quantitative baseline of land use/land cover to identify areas of land loss in coastal Mississippi, 2) to document temporal variability in land cover changes, and 3) to provide a starting point for further scientific inquiry, the Mississippi Office of Geology in 1992 began to build a database of land and water categories as part of the Year 2 program of the USGS-funded Mississippi Coastal Geology and Regional Marine Study project. To complete the database (as well as to build upon the previously described studies), computer tapes of the earlier (mid-1950s, late 1970s, and 1982) habitat data generated for (and by) the U. S. Fish and Wildlife Service were acquired. To assess whether trends identified in the earlier studies continued into the present, a third set of land cover maps was deemed essential. Color-infrared imagery from 1991/1992 was acquired from the U. S. Army Corps of Engineers (Mobile District) to provide the most up-to-date baseline data (Table 3).

Table 3. Imagery acquired for the 1991-1992 data set used in the present study.

COE file #	roll #	date of image	flight line	exposure #s	total # of prints
SAM-20	888	20 Jan 1992	FL 1	1-21	21
SAM-20	888	20 Jan 1992	FL 2	24-42	19
SAM-20	888	20 Jan 1992	FL 3	46-65	20
SAM-20	888	20 Jan 1992	FL 4	69-73, 80-81	7
SAM-20	888	20 Jan 1992	FL 5	91-94	4
SAM-20	888	20 Jan 1992	FL 7	141-163	23
SAM-20	888	20 Jan 1992	FL 8	168-194	27
SAM-20	892	20 Jan 1992	FL 9	203-224, 227-229	25
SAM-20	892	20 Jan 1992	FL 10	247-255	9
SAM-20	892	20 Jan 1992	FL 11	284-289	6
SAM-20	892	20 Jan 1992	FL 12	319	1
SAM-21	880	20 Aug 1991	11	130-136	7
SAM-21	881	20 Sept 1991	12	272-278	7
SAM-21	886	26 Nov 1991	13	415-420	6
SAM-21	886	26 Nov 1991	21	462-469	8
SAM-21	886	26 Nov 1991	12	428-435	8
TOTAL					**198**

Note: This imagery was literally "hot off the press" as this project began. The few shortcomings--including a) no barrier island coverage, including Round Island and a thin sliver of Little Pt. Clear in Hancock County, and b) a gap in coverage north of Hwy 90/I-10 in Jackson County near the Alabama border--were more than offset by quality and up-to-dateness of the imagery.

Table 3. Imagery acquired for the 1991-1992 data set.

The Study Area

Although the official Mississippi Coastal Zone includes all of Hancock, Harrison, and Jackson Counties (Graber, 1986), it was decided to use the initial USFWS criterion, i.e. the 15-ft contour, in the generation of the 1990s land cover data set. This would facilitate comparative analysis between the three sets, and, in addition, all of the wetland changes and most of any other land-water changes would have taken place below the 15-ft contour.

Although the USFWS study (Wicker, 1980) included 38 topographical quadrangles wholly or partly within Mississippi, this study reduced the numbers of quadrangles by half to 19 (Figure 10). The upper tier of quadrangles (including four close to the Pearl River) were omitted because: 1) little wetland acreage is found there, 2) the existent wetlands there, distant from strong tidal and wave influence, appeared to be relatively stable through all years, and 3) the 1991-1992 coverage did not include much of this region. Likewise, the barrier islands were omitted for various reasons, including: 1) wetland acreage is relatively small, 2) most land loss on the islands resulted from beach erosion, 3) island land cover changes are monitored by the U. S. National Park Service which administers the Gulf Islands National Seashore to which all but Cat Island belong, and 4) the 1991-1992 coverage did not include much of this region. There were several additional gaps in the aerial photo coverage (refer to Table 3). Most of these gaps were in areas where few wetlands existed, such as in the northern portions of the Pascagoula North and Kreole quadrangles. In other areas, such as Round Island and the southernmost point of Little Pt. Clear (in Hancock County), the Office of Geology had photos or survey data from approximately the same period, and thus interpretation was completed in those critical areas.

Land Cover Classification and Mapping

Many classification systems have been devised over the years to delineate land use/land cover categories, especially wetlands. The U. S. Geological Survey produces land use/land cover overlays for many topographical quadrangles of varying scales, and a broad hierarchical classification system developed in the early 1970s (Anderson et al., 1976) has become a standard for geographic mapping (Meyer-Arendt and Wicker, 1981). More specific interpretation of wetland categories has led to several

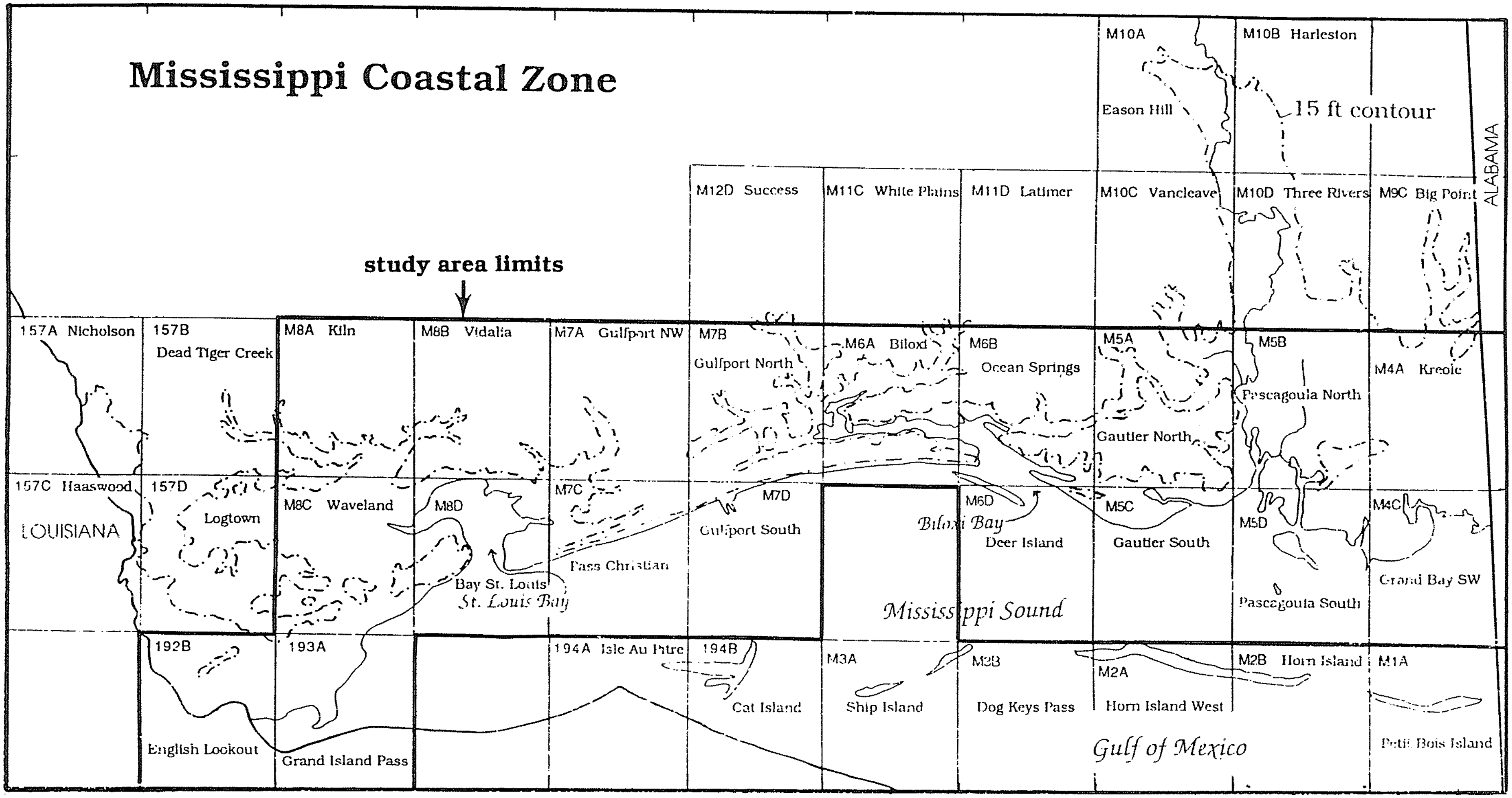

Figure 10. Limits of the study area. (Names and coded rectangles correspond to topographic quadrangle sheets used in the 1980 USFWS study)

"habitat"-oriented classification schemes by biologists and ecologists. The newest one by Cowardin et al. (1979), in which over 200 categories are used and habitats as small as one acre are delineated, has now become the standard in that discipline (Figure 11). More recently, government agencies such as the U. S. Army Corps of Engineers which are also charged with identifying wetlands, have begun to use to broader "hydrogeomorphic" classification system which places greater emphasis upon geomorphic location aspects, functions, and values (Brinson, 1993). (Readers are advised to consult the aforementioned sources to learn more details regarding the evolution of classification schemes.)

The 1950s and 1970s USFWS habitat maps were produced, in slightly modified format, in accordance with the hierarchical classification system developed by Cowardin et al. (1979) (Meyer-Arendt and Wicker, 1981; Wicker, 1980). This level of detail was and is of great importance to biologists and wildlife and fisheries managers who need to be aware of potential and actual carrying capacity levels for various species.

Since geoscientists are less concerned with specific habitats of species and more concerned with land area, sediments, and sediment budgets, a more general land cover classification was determined to be optimal for this study. Since the earlier data sets were based upon the detailed Cowardin classification system, it was decided to hierarchically "collapse" the 200+ categories into a more manageable number. This step not only facilitated interpretation of the 1991-92 aerial photographs, but it made comparison with the previous data simpler. In addition, the use of a loose Cowardin framework left open the possibility of filling in the detailed categories at a later date if demand were created and/or sources of funding were made available.

Precedent for simplification of the Cowardin system had already been set by geologists. Geologic mapping of portions of the Louisiana coastal zone by the Louisiana Geological Survey in 1989 and 1990 had been based upon a Cowardin classification reduced from 200+ categories to 16.

The present land cover classification system consists of a total of seven categories: water, marsh, forest, agriculture, developed, dredged spoil, and beach, plus a "not applicable" (n/a) category for land cover outside of the study area yet within the

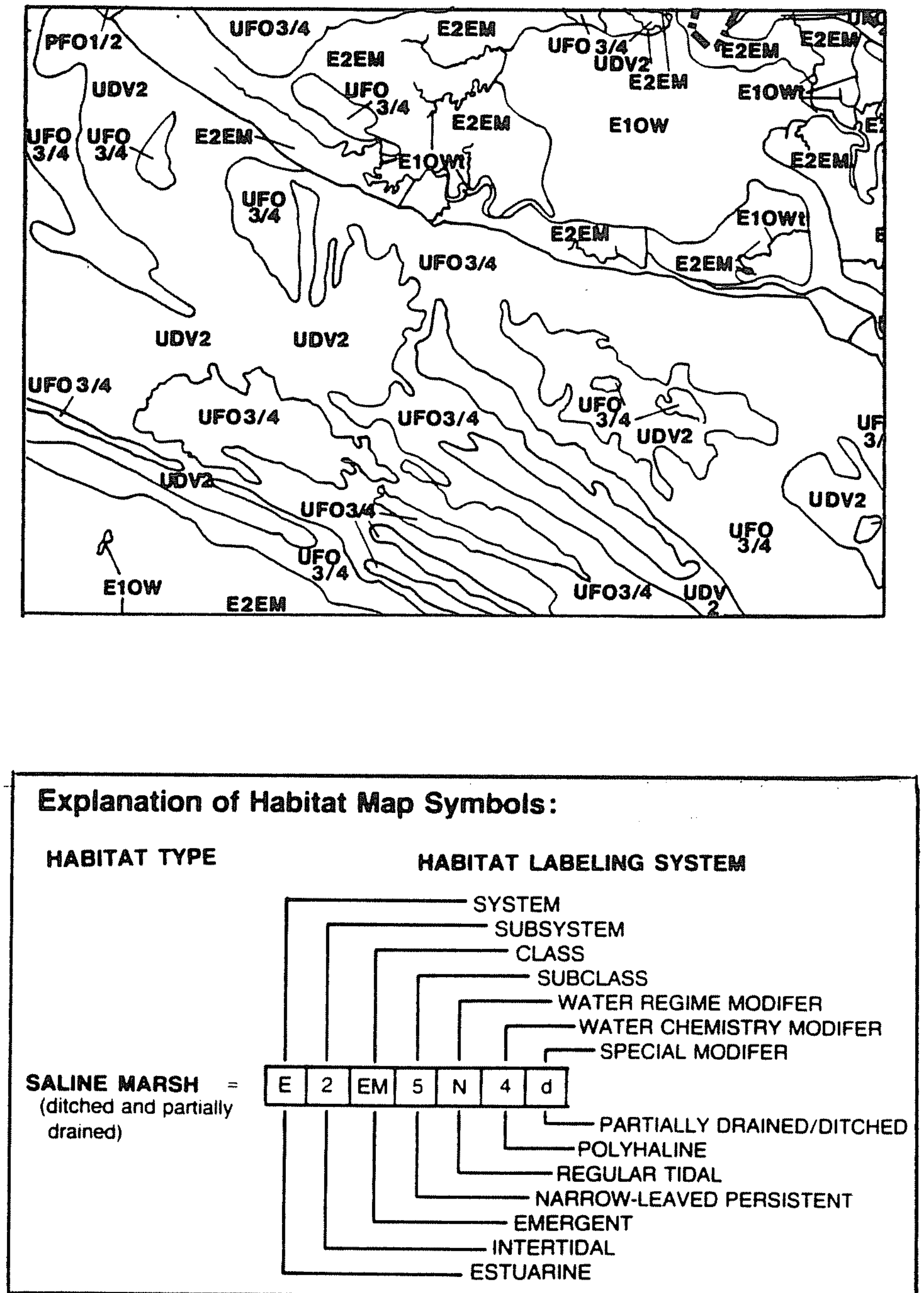

Figure 11. Example of the Cowardin classification system.

respective topographic quadrangles (i.e. above the 15-foot contour). Water includes all categories of water bodies, irregardless of size, flow regime, floating vegetation cover, degree of human modification, or salinity levels. Low-water exposed mudflats, submerged reefs, and artificial structures built out into water (such as groins) are also included in the water category. Marsh includes all grassy wetlands, irregardless of salinity or degree of modification by humans. Forest includes all forms of tree cover regardless of height, ranging from oak-pine uplands to bottomland hardwoods to bald cypress swamps. Although swamps are technically wetlands, the few swamps in the Mississippi coastal zone remained relatively consistent throughout the years and were thus not singled out for detailed analysis. Scrub/shrub vegetation, not normally regarded as "forest", is nonetheless includes as such here. If tree cover on pasture lands consisted of dispersed single trees (not clumps) and constituted less than about 15% cover, no forest category is delineated. Similarly, if a residential subdivision contains many trees, there is a good chance that no forest category would be broken out.

Spoil consists of dredged material that has been disposed of subaerially. It may be barren or lightly colonized by upland or wetland vegetation (depending on elevation and drainage characteristics). If a category of land cover, such as forest or development, is now found at a site where once much dredge spoil was deposited, than that category is used in place of the spoil category. Agriculture includes both cropland (row crops or tree crops) as well as pasture land. Some of Mississippi's coastal savannas consist of "open pine forest" (perhaps even less than 15% tree cover), and the open grassland is used for seasonal grazing of cattle. This would qualify as "agriculture" under the present classification.

The "developed" category includes all forms of structural development, from light residential to heavy industrial. If a subdivision has been platted in a coastal pine forest, and streets and utilities have been laid out, then the "developed" category should be used (even if the subdivision is not yet been filled in with homes). Beach includes the various types of sand beach. In Mississippi, the sand beach classification is applied mostly to the wide, artificial beaches found in all three coastal counties. Natural beaches, many of them less than 10 ft in width, were often difficult to map at the 1:24,000 scale because of the thinness of the category. These categories are a simplification of, and compatible with, both the Cowardin et al. (1979) and the collapsed Cowardin classification system used by the Louisiana Geological Survey (Appendix A).

The 7-category classification was used for two major reasons: 1) for purposes of identifying broad changes in land and water categories, the task of wetlands mapping for coastal Mississippi was greatly simplified, and 2) the mapping project could build upon the previous study of estuarine wetlands in Mississippi conducted by this investigator (Meyer-Arendt, 1989). It was decided, however, to use more than just categories of land and water, because to identify causes of wetland loss in coastal Mississippi, surrounding land cover changes may provide clues as to the reasons behind the wetland loss.

The mapping of the overlays entailed preparing stable base maps from the respective U. S. Geological Survey topographical quadrangles. Longitude/latitude, the 15-ft contour, and various control points such as highway intersections and stable waterways such as tidal channels and bayous were mapped onto the overlays. The color infrared aerial photography (see Table 3), 1991-1992 imagery in 9x9, 'distortion-free', 1:24,000 format acquired from the U. S. Army Corps of Engineers, Mobile District, was used to interpret the various land cover categories. By using the control points derived from the topographic maps, the 1992 map interpretations were formatted (i.e. distortions manually smoothed within large-scale, less than 1 sq. mi., blocks) to the stable base overlays. Borders were matched between quadrangles, and blueline copies of the 1950s and 1970s USFWS habitat maps were consulted to ensure a general consistency between years. The final overlays were prepared upon stable Mylar-acetate film and delivered to the Mississippi Office of Geology in Jackson for digitizing and entry into the computer database.

DATA ENTRY AND DATABASE MANIPULATION

Fish and Wildlife Service digital data of 1956, 1978, and 1982

Computer tapes containing the earlier habitat data generated by the U. S. Fish and Wildlife Service were processed on a Sun Sparcstation 2 and managed with ARC/Info, a Geographic Information

System (GIS) software. GIS was used because of its ability to combine graphics and database records. Drawing and drafting programs do not allow for analytical data crunching, and database programs do not map the data. GIS stores the area of a polygon in a record, and those records can then be queried, totaled, or highlighted on the computer screen as graphics.

The tapes contained three different files per 7.5-minute quadrangle: a graphics file, a major/minor code file, and a text attribute file. The major/minor files contained identification numbers linking the text attribute and graphics files. The attribute files contained major/minor codes and the Cowardin classification codes. The land use description names that were based on the seven collapsed Cowardin categories (water, beach, marsh, etc.) were added to the attribute files. A list of the Cowardin codes with the Office of Geology categories written next to the codes was used for this task. Data from 1978 and 1982 contained habitat codes that were not on the Cowardin list, so the USFWS sent a upland legend for those missing codes. The upland categories were not necessarily above the 15 foot contour interval, for example, Ingalls Shipyard that sits next to the water was coded as UU (Upland Urban). After all the Cowardin and upland codes were translated to the seven categories, the attributes were combined with the graphics files.

Using a simple ARC/Info command , *dissolve*, the polygons with the Cowardin categories were collapsed to resemble the seven land use categories. For instance, if there were two polygons next to each other with the Cowardin codes UFO and PFO41B, but the land use codes classified them both forest, the *dissolve* command deletes the line separating the 2 polygons and creates one large polygon. A 0.1 meter tolerance was used in editing the topology. This tolerance allows the lines to move just enough to close line breaks. Since a pencil line on a digitizer is more than a few meters wide, the 0.1 meter tolerance was determined to be reasonable.

1992 Interpretation Data

Mylar acetate was used for the 1992 interpretation because it is transparent enough to overlay, and yet stable enough not to expand or shrink in large amounts due to varying temperatures and humidity like paper prints. Most of the digitizing of the 1992 data was done in AutoCAD, the rest was done in ARC/Info. The Mylar sheets with the manually drawn (penciled) 1992 interpreted land use categories were pulled tight and taped to a large digitizer. The digitizer was calibrated for the Universal Transverse Mercator (UTM) coordinate system using four coordinate points. The transformation type was set to *affine* and the root mean square (rms) error was about ten meters as a result of the transformation. UTM was used instead of latitude and longitude (Geographic Reference System) because it appears on USGS topographic quadrangles and is a map projection, whereas the Geographic Reference System is not.

The exact coordinates of the quadrangle borders were used, so that if the lines on the Mylar did not end at the correct geographical border of the quadrangle, they were trimmed or extended. This insured that when the quadrangles were assembled as a mosaic they would fit together without gaps or overlaps. The lines were sketched in AutoCAD at an increment interval of 20 meters, i.e., a curve would be made up of 20 meter-long straight lines. Twenty meters is a small enough increment to capture detail and yet large enough to keep the drawing files' size manageable. Pen plots at 1:24000 were made to check for errors or missing lines. County lines were digitized on a separate data layer for later processing.

Database development

The finished AutoCAD drawings were transferred to ARC/Info with at least a four decimal place accuracy. The topology was cleaned up, i.e., dangling lines were connected and erroneous polygons deleted. The most time-consuming process was the adding of label points to the polygons and typing the habitat/land-use name that was recorded on the Mylar for each polygon. Since the barrier islands were not part of the study area, all of the Horn Island polygons were classified as water in the Gautier South quadrangle.

On some quadrangles the extent of interpreted land-use categories was different for the three time periods. The Kreole quadrangle, for example, had only the Mississippi portion interpreted in 1956; but in 1978 the entire quadrangle was interpreted; and in 1992 there was no photo coverage for the top part of the quadrangle. In such cases the final comparison maps were done with only data which was contiguous for all three time periods.

The 15-foot contour interpretation was found to be inconsistent for the three time periods studied due to varying interpretation methods over time as well as different interpreters for the three data sets. To correct this and to insure that comparable land-use area comparisons could be made between the data sets, the 1992 15-foot contour interpretation was superposed on the prior data. Where the 15-foot contour outline extended beyond the 1992 outline on an earlier data set, then the extension was added to all data sets. The final 15-foot contour outline thus contained a maximum-area composite of all the data sets. Where there was an obvious man-made elevation change, such as Singing River Island on the Pascagoula South quadrangle, the 1992 15-foot contour was not superposed on other data sets.

Polygon comparison and statistics

After all of the quadrangles were processed with correct attributes for each polygon, each data set was compared in Arc/Info with the corresponding data set for each of the other time periods. Two types of data tables were generated for each quadrangle: 1. a table containing the total area for each category per time period, and 2. a table listing each category area change for each time period. Quantitatively, the data generated for each topographic quadrangle for each of the years were displayed by several means, including total acreage values per land cover category and also type of change between time periods (e.g. amount of agriculture that became "developed" between 1956 and 1982). These data, which are quite extensive and kept on file at the Mississippi Office of Geology, were then collapsed into a spreadsheet from which patterns of change could be more easily discerned (Appendix B).

Additional tables were generated by breaking out the category totals in tables 1 and 2 by county. To separate quadrangles that spanned two counties, an attribute called a federal information processing standard (fips) county identification number was added to the database. Arc/Info separated the area totals according to the fips number for each county.

Printing/graphic output

All of the quadrangles were printed at a scale of 1:31680 (2" = 1 mi.) on a Tektronix Phaser III PXi color printer on 11" x 17" sheets. Color maps allowed easy visual comparison between time periods to spot obvious coding and polygon joining mistakes. Some of the polygons were so large and extensive that ARC/Info was unable to apply color fill. These large polygons were broken into smaller pieces for printing purposes. The cartographic data are in the form of land cover maps for each of the three time periods used (Appendix C). Because of dimensions and printer page-size limitations, the topographic sheets were divided into "top" and "bottom" portions. If one of these portions contained only water or a small area of upper tributaries where change was insignificant, then those maps were not included. Also, no 1982 data were received from the USFWS for the Kiln and Vidalia quadrangles of Hancock County. No maps for those dates are thus included, and 1978 data (from Wicker, 1980) were used in the quantitative analysis.

RESULTS AND DISCUSSION

Land cover changes in coastal Mississippi, 1950s to 1992

Analysis of the data (Appendix B) and the maps (Appendix C) reveals that many significant changes in land cover and land use have taken place since the 1950s on the mainland of coastal Mississippi. There has been a decrease in total land area within the study area of 2,670 acres, down from 194,746 acres (Figure 12). Over 8,500 acres of marsh was lost during the same period, a reduction of 13% of the 67,000 acres measured in the 1950s. Only about one quarter of this acreage (2,300 acres) is attributed to direct conversion of marsh to water, an area roughly equal to the total amount of land lost. Most of the marsh-to-water conversion is accounted for by shore erosion and marsh deterioration, but canalization is also a factor. Nearly 40% of the marsh loss is directly related to replacement by developed land, which seems to imply that "human processes" play a greater role than natural processes in wetland loss. The developed land use category tripled from 14,000 acres in the 1950s (7% of the total area) to nearly 43,000 acres in 1992 (22% of the total area). This rate of development is, of course, a great underestimate of the overall amount of industrial and residential development that has taken place in Mississippi's coastal counties because only land below the 15-ft contour was examined within this study. By far the greatest amount of development has been in former forest or agricultural lands above 15 ft in elevation.

The most significant aspects of the data are the documentation of the (apparent) extent of land lost, especially wetland loss, in coastal Mississippi. In addition, the data show that while overall rates of land loss have decreased slightly in the later interval (late 1970s/early 1980s to 1992), rates of wetland loss appear to have increased since 1978. Closer analysis of the individual topographic quadrangles reveals that such apparent increases reflect inaccuracies in photo interpretation and mapping, especially of several quadrangles (notably the Waveland quadrangle) which were remapped in 1982 by the USFWS. Although there were inaccuracies and inconsistencies noted, especially in the 1950s, 1970s, and 1982 data, at least overall generalizations regarding changes in land cover and land use can be made. In addition to recognition of patterns for the entire coastal study area, more detailed observations can be made on a county and even a topographical quadrangle basis (refer to Appendix B).

Overall patterns by county

Closer inspection of the land loss and marsh loss data reveals some variability among Mississippi's three coastal counties (Figures 13 and 14). Values of marsh loss are much higher than those of total land loss in all three counties, which reflects the high incidence of conversion of marsh to other uses throughout coastal Mississippi.

Conversion of marsh to water and marsh to development appear to be leading reasons for marsh loss in coastal Mississippi, but again there exists much variability among the counties (Figure 15). Replacement of marsh with developed land use and with water accounts for almost 96% of all marsh loss in Hancock County, whereas in Jackson County development and conversion to water account for less than 47% of marsh loss. Although this is partly explained by inaccuracies in interpretation and mapping of the low-quality 1950s air photos, and a corollary overestimation of marsh area in that time period, it also reflects the impact of natural aggradation of sediments within the Pascagoula River alluvial valley and subsequent conversion of marsh to forest as

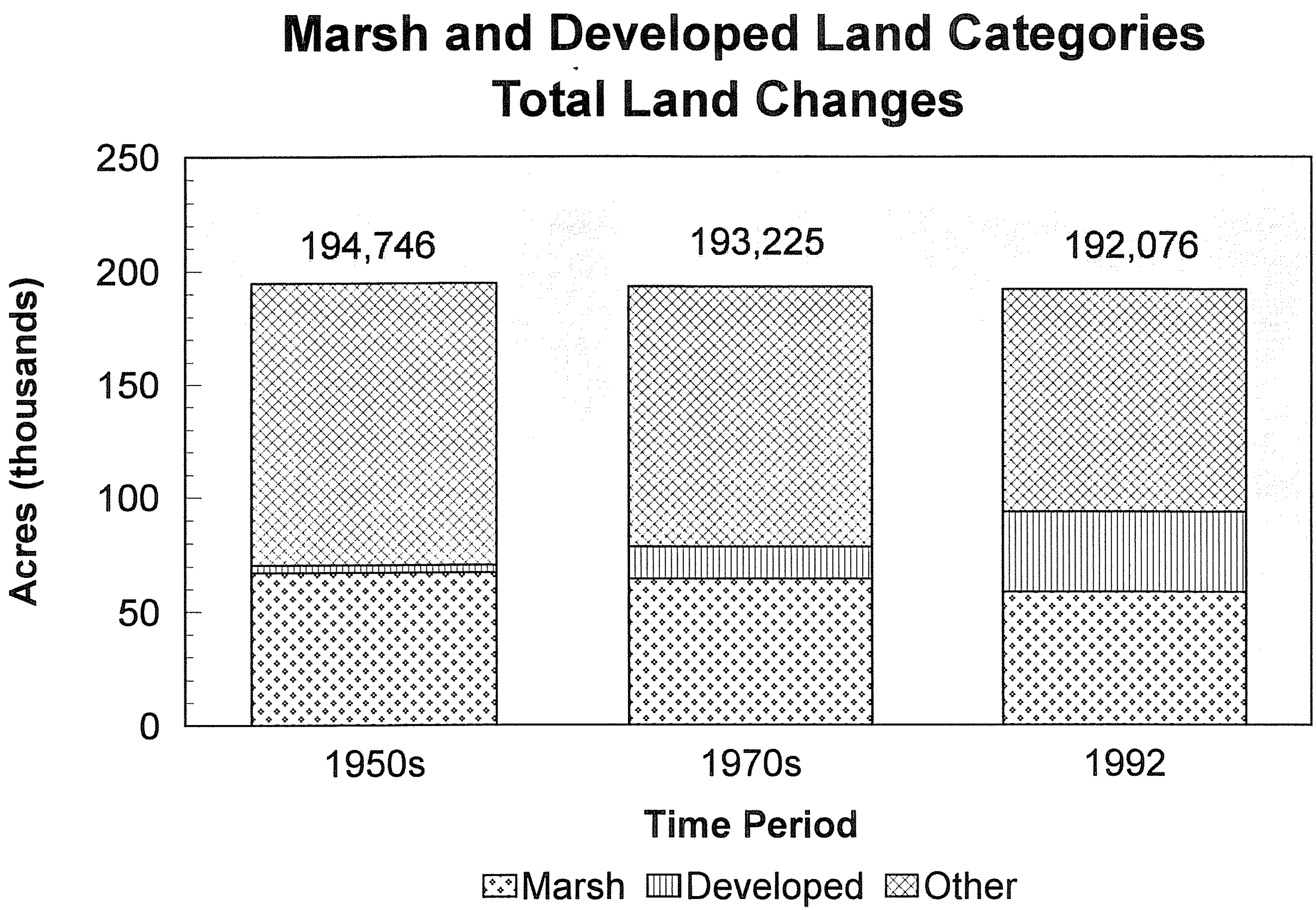

Figure 12. Summary of overall changes in total land area, developed land, and marsh in coastal Mississippi, 1950s-1992.

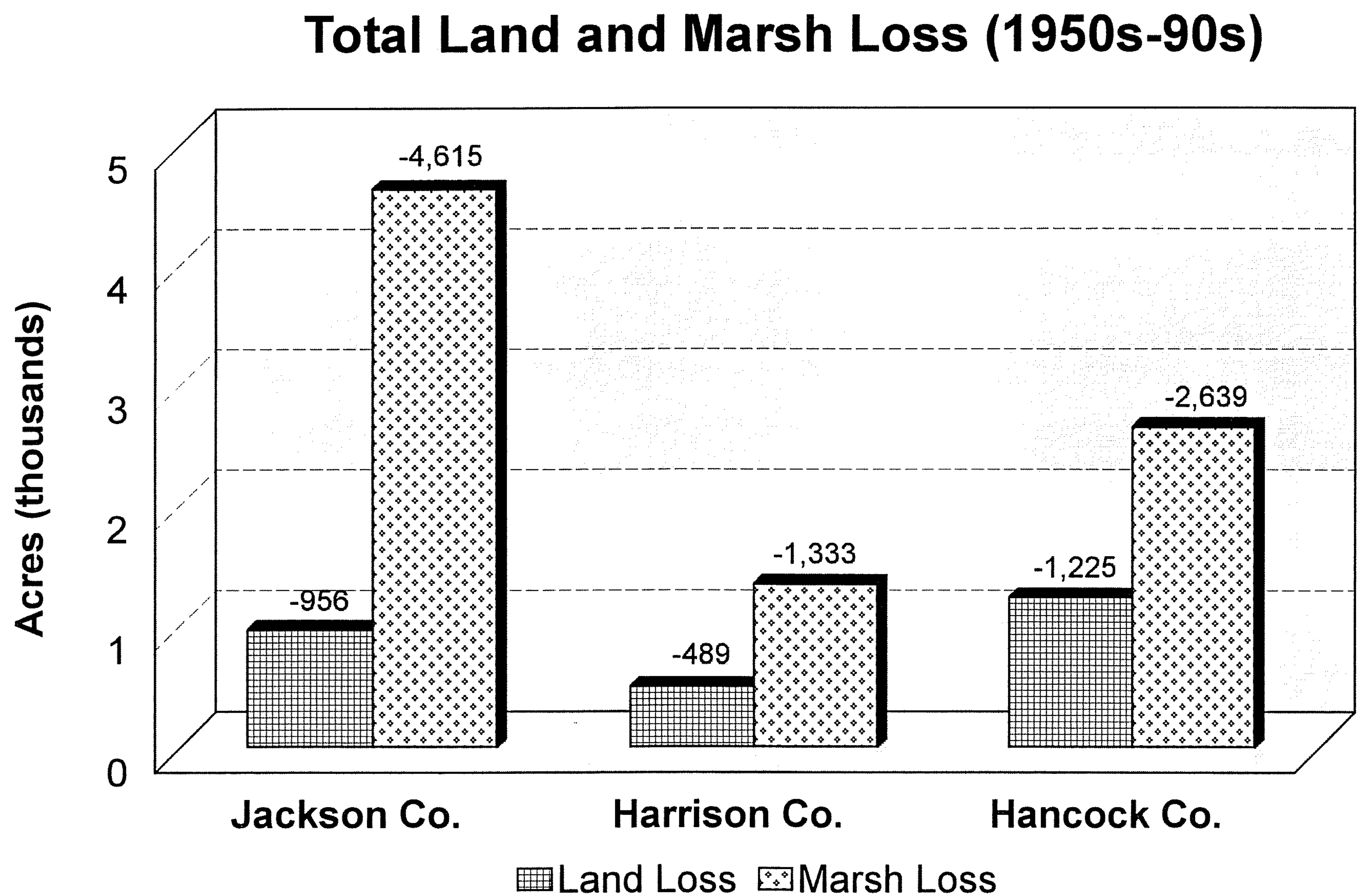

Figure 13. Overall land loss and marsh loss by county in coastal Mississippi, 1950s-1992.

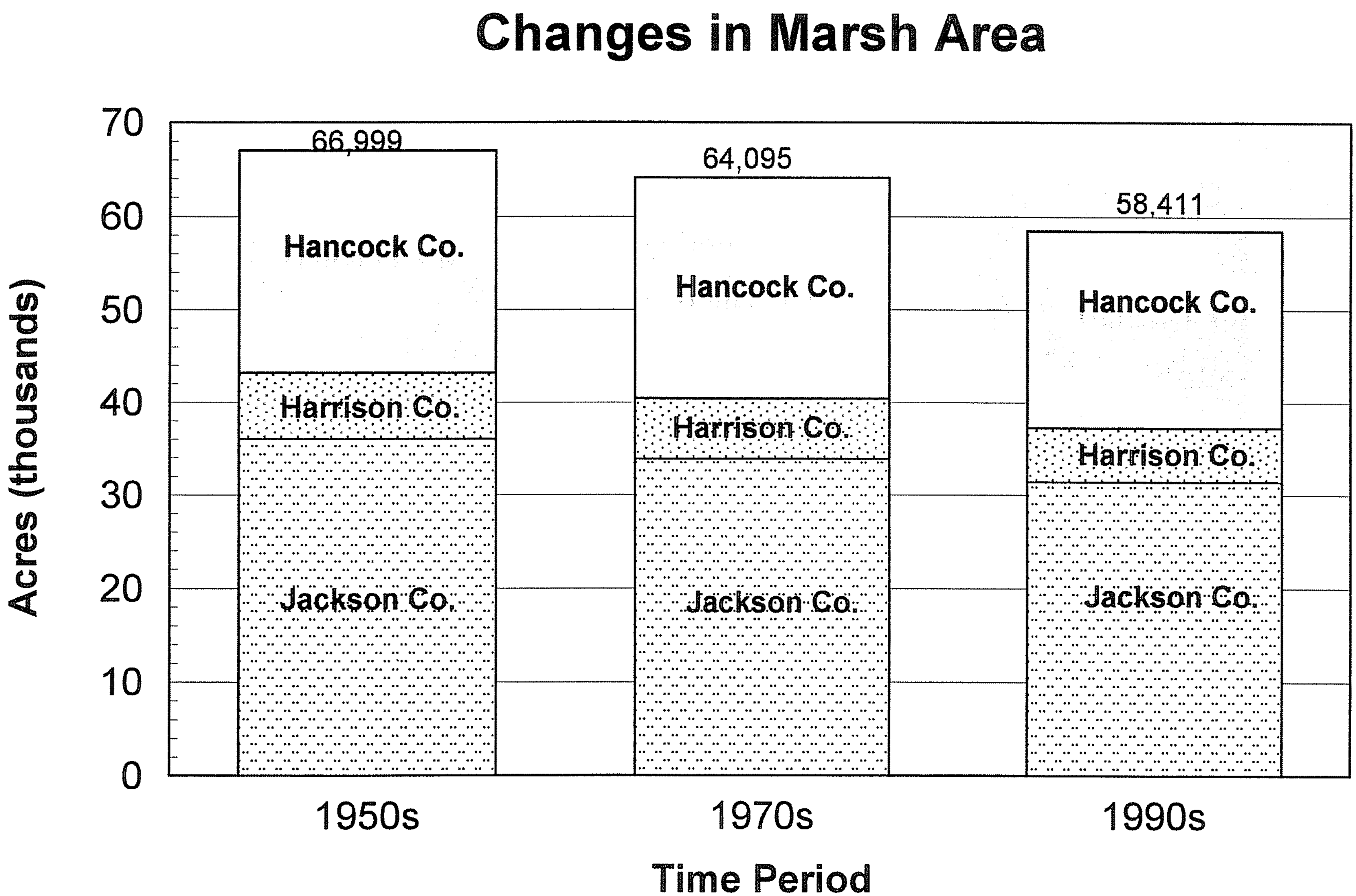

Figure 14. Changes in marsh area, by total and by county in coastal Mississippi, 1950s-1992.

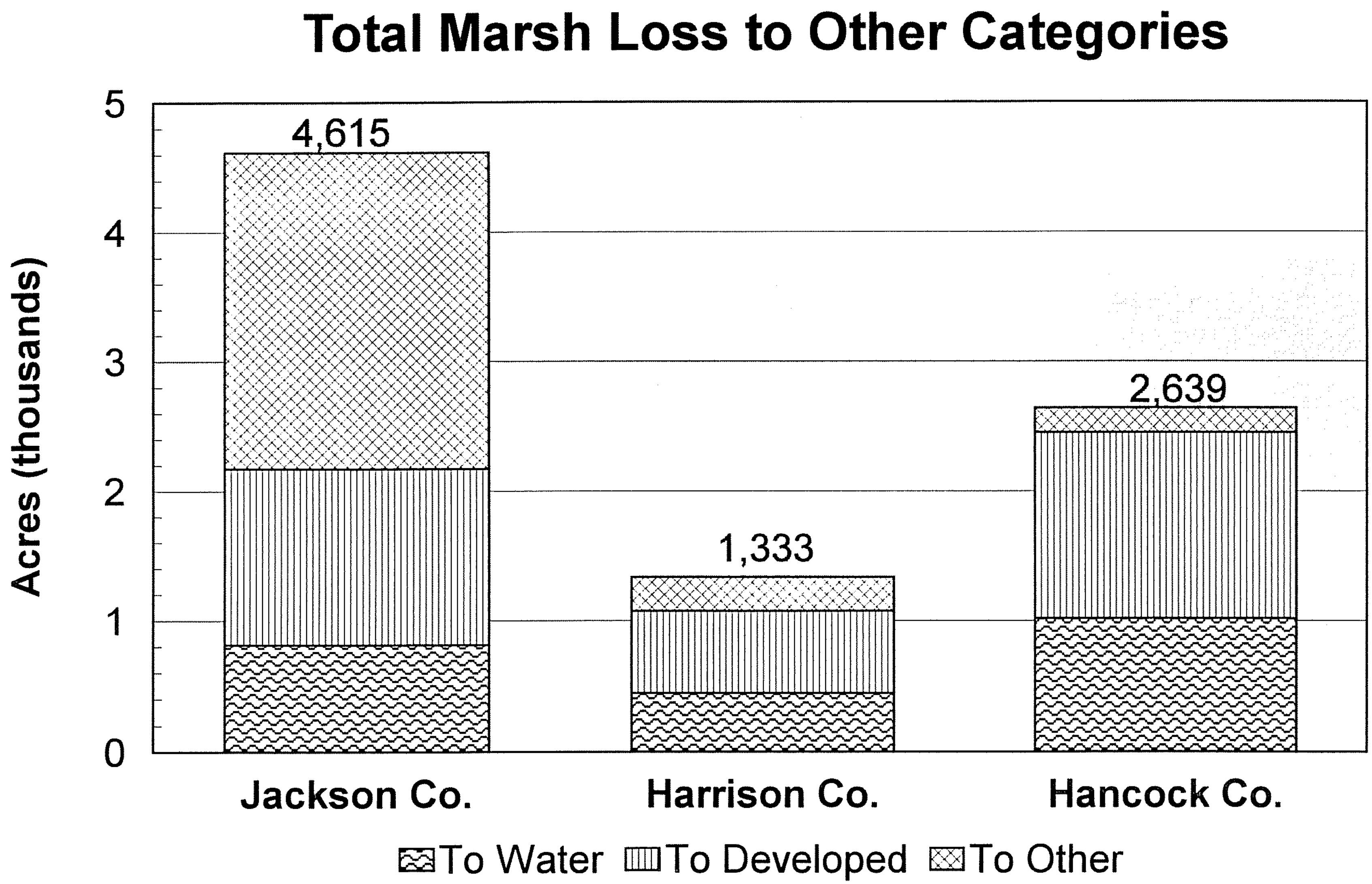

Figure 15. Total area of marsh lost by county in coastal Mississippi, 1950s-1992.

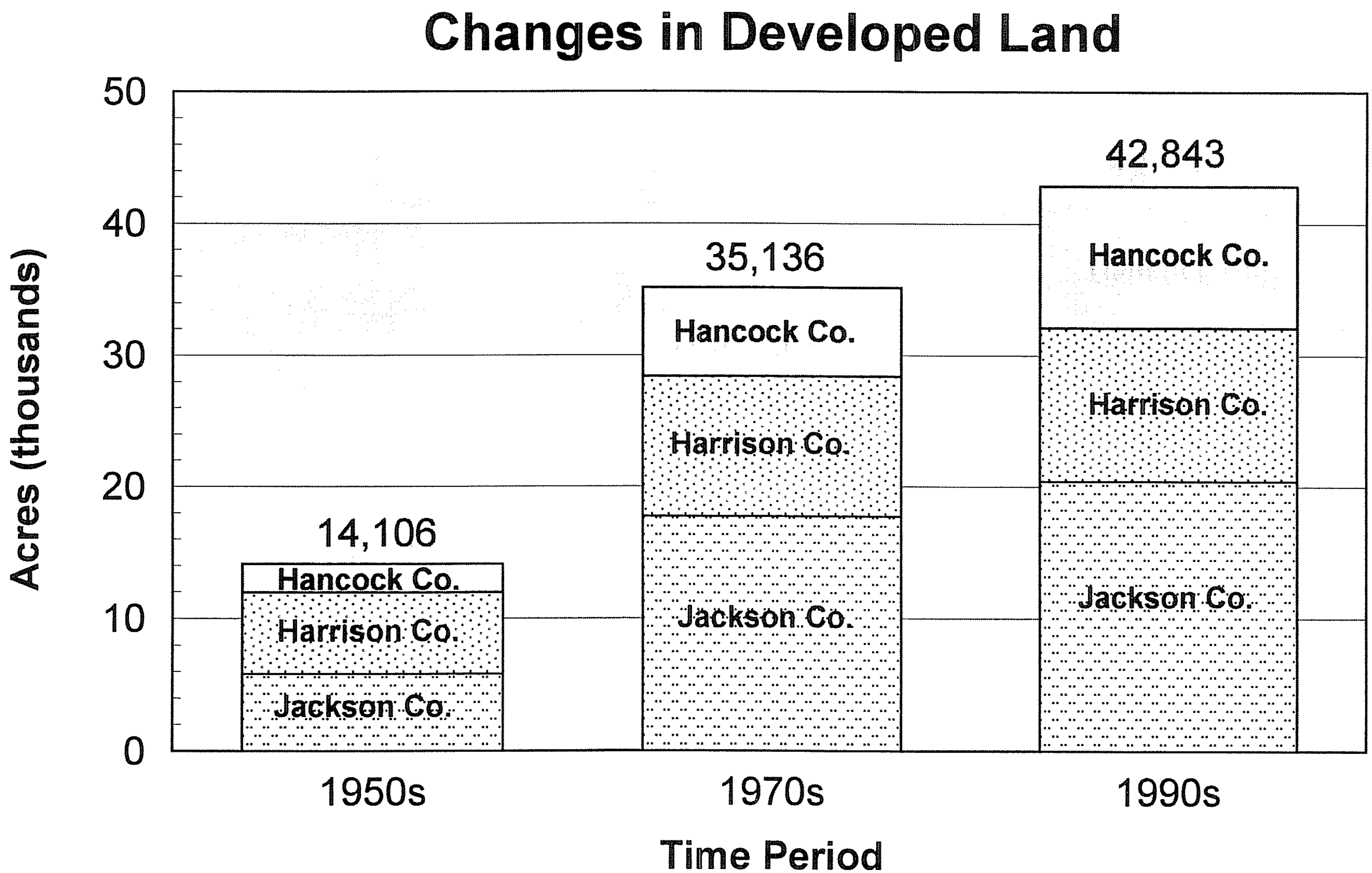

Figure 16. Changes in developed land, by county and by total, in coastal Mississippi, 1950s-1992.

wetland species of trees (such as bald cypress) colonized increasingly better-drained soil. Although the relative role of conversion of marsh to developed land varies among the counties, a trend of overall increase in developed land is seen in all three counties (Figure 16). The lower rate of increase in Harrison County (slightly less than doubling) as compared to the other two counties may be explained by the historically higher degree of urbanization and industrialization of Harrison County. Previously vacant or agricultural sections of Hancock and Jackson Counties are increasingly subject to processes of suburbanization as the local economies remain strong (most recently fueled by legalized casino gaming).

Overall patterns by topographic quadrangle

More specific trends of land cover and land use changes in coastal Mississippi can be identified by detailed analysis of each of the 19 topographic quadrangles included in the study. Such analysis includes examination of both quadrangle-wide patterns as well as patterns within the respective quadrangles. Throughout the following discussion, readers are advised to consult the respective topographic quadrangles (in Appendix C) as well as the summary data (in Appendix B). More detailed data, especially regarding the various changes in land cover categories between the various years, are available from the Mississippi Office of Geology.

Total land area change.

In terms of changes in total land area between the 1950s and 1992, several geographic patterns can be easily recognized (Figure 17). Although most of the quads exhibit stability in terms of overall land change, both the far eastern and the far western topographic quads display great fluctuations.

Severe land loss (over 400 acres) is restricted to two quadrangles, Grand Island Pass and Grand Bay SW, both of which are somewhat similar in terms of land cover. The data and land cover maps reveal that natural processes of shore erosion and marsh deterioration, whereby marsh breaks up and is replaced by open water, are the main reasons for the high land loss.

Moderate land loss has taken place in the Waveland, Gautier South, and Pascagoula North quadrangles. In Waveland, the creation

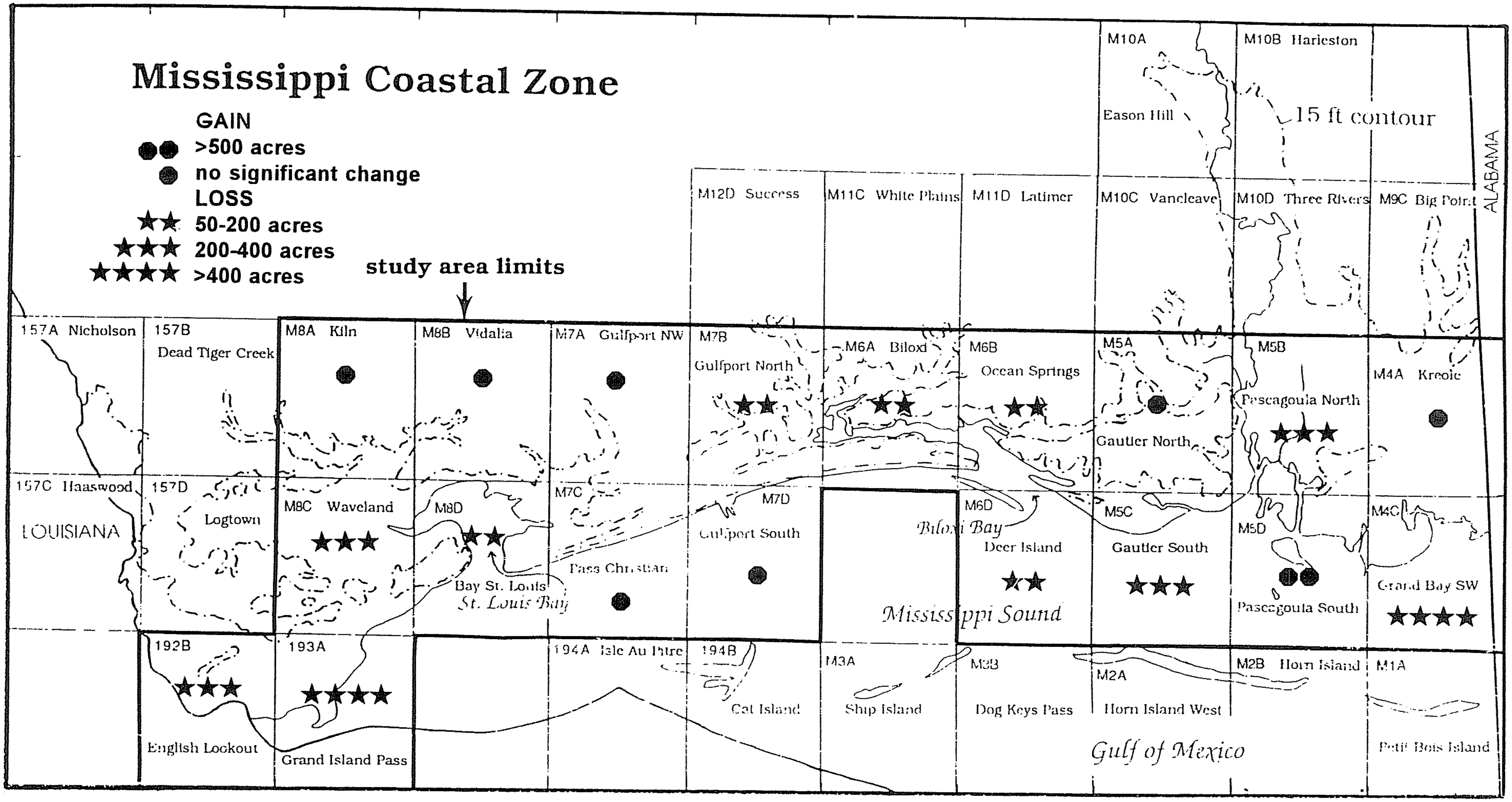

Figure 17. Change in total land area by topographic quadrangle in coastal Mississippi, 1950s-1992.

of numerous impoundments (reservoirs) as a by-product of suburbanization is the chief reason for this land-to-water conversion. Shore erosion and marsh deterioration play greater roles in Gautier South and Pascagoula North.

Insignificant or low rates of overall land loss characterize 12 of the 19 quads. The minimal land loss that did occur is attributed to a combination of shore erosion, marsh deterioration, and canalization.

The only quadrangle showing land gain is Pascagoula South, where a net gain of nearly 600 acres was measured. Some of this gain is attributed to marsh gain resulting from both natural sedimentation and also colonization of subaerial dredge spoil deposits; but a greater part is attributed to spoil deposition and development thereon. This development includes industrial development in Pascagoula and lower Bayou Casotte and the establishment of the U. S. Navy homeport on Singing River Island, an island created by repeated deposition of dredge spoil.

Total marsh area change.

A map of changes in total marsh area between the 1950s and 1992 similarly shows great variability among the topographic quadrangle sheets (Figure 18). Further examination of the individual sheets reveals even greater variability in reasons for trends that surficially appear to be similar.

The greatest loss of marsh is recorded on the Waveland, Kreole, and Grand Bay SW quadrangles. In Waveland, most of the loss is explained by residential development in marsh environments. To a much smaller degree, natural process of shore erosion and marsh deterioration and overestimation of marsh area in the 1950s account for the marsh loss. In Grand Bay SW, the marsh loss has resulted from a combination of shore erosion and marsh deterioration, and accounts for practically all of the land loss noted for this quadrangle. On the other hand, the marsh loss documented for the Kreole quadrangle is not real. Low sparse pine savanna and pasture lands were erroneously interpreted as marsh for the 1950s and 1970s, in part because of the difficulty in separating these land cover categories on black-and-white imagery. On the higher-quality 1992 color-infrared imagery, it was much

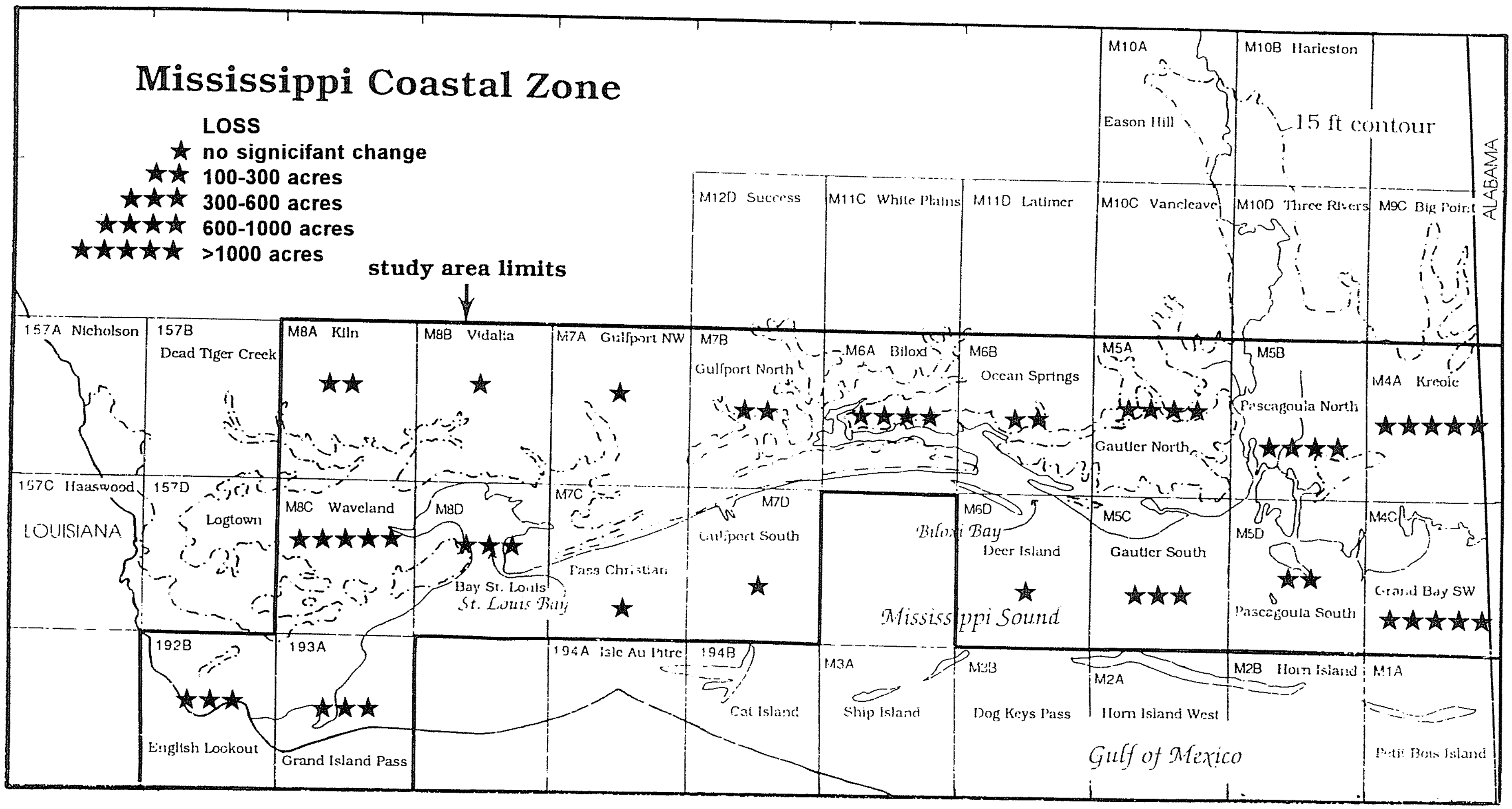

Figure 18. Change in total marsh area by topographic quadrangle in coastal Mississippi, 1950s-1992.

easier to distinguish the categories more accurately. Thus, there has probably been very little change in land cover in this portion of the Mississippi coastal zone. As on the Waveland quadrangle, much of the pine savanna was alternately interpreted as pasture lands (agriculture) and forest.

As discussed previously, this points to the difficulty of interpreting a multi-use category in which cattle graze in open woodlands. Another factor which may play a role is logging. Many of the coastal pine forests were clearcut in the 1930s and 1940s, and much of the pine savanna was probably still quite sparse in terms of tree cover at the time of the 1950s imagery. Regrowth by the time of the 1970s and 1992 imagery may account for the greater forest cover identified in those time periods.

The second tier of quadrangles experiencing high rates of marsh loss, perhaps best described as "moderately severe", includes Biloxi, Gautier North, and Pascagoula North. In Biloxi and Gautier, marsh loss is explained by, in roughly equal proportions, marsh deterioration and conversion to open water, conversion to development, and overestimation of the 1950s marsh acreage. In Pascagoula North, aggradation of alluvial valley sediments has led to swamp forest replacing fresh marshes in the northern part of the quadrangle. Also, much dredge-and-fill caused loss of marsh along the I-10 corridor and along the lower Escatawpa River where rates of commercial, industrial, and residential development have been high.

Moderate rates of marsh loss, ranging from 300 to 600 acres over the total time span, are found in the English Lookout, Grand Island Pass, Bay St. Louis, and Gautier South quadrangles. The first two quadrangles contain vast acreage of the Hancock County coastal marshes, and both shoreline erosion and marsh deterioration account for the moderate rate of marsh-to-water conversion noted there. The marsh loss in Bay St. Louis reflects marsh-to-development conversion, quite similar to the adjacent Waveland quadrangle. Development in marsh areas was also noted in Gautier South, but, for the most part, the apparent marsh loss has resulted from gross overestimation of marsh area in the 1950s (and also in the 1970s) data set.

Low rates of marsh loss were recorded for the Kiln, Gulfport North, Ocean Springs, and Pascagoula South topographic quadrangles.

For the Kiln quadrangle, marsh area was overestimated in the 1950s (and the 1970s), and the change was actually much less. Conversion to developed land accounted for most of the marsh loss in Gulfport North, Ocean Springs, and Pascagoula South. Shore erosion and marsh deterioration was also important in Ocean Springs and Gulfport North, especially in the Bernard Bayou area of the latter quadrangle.

The remainder of the quadrangles--Vidalia, Gulfport NW, Pass Christian, Gulfport South, and Deer Island--displayed little change in marsh acreage. The first two quads contain mostly upper tributary marshes which remained stable and not subject to development pressures, and Gulfport South contained no marshes at all. In Pass Christian, marsh area was underestimated for the 1950s, and it thus appears that marshes have increased between the 1950s and 1990s. However, the 1982 data seem to be more reliable, and a small amount of marsh loss (perhaps 90 acres) is inferred. Somewhat surprising is the relative stability shown on the Deer Island quad, where both Deer Island and the Pointe aux Chênes part of the island of Belle Fontaine lie exposed to the wave action of Mississippi Sound.

Change in total developed area.

The final land cover category examined in terms of regional variability in patterns and quadrangle-level trends was development, and, as might have been expected, there was considerable geographic variation (see Figure 19). The highest rates of development were related to industrial development in the Pascagoula and Gulfport urban areas and also suburbanization throughout the region from Bay St. Louis to Pascagoula. Lowest rates of development were found in both the older established urban centers as well as in quadrangles covered by extensive marsh and water. The focus on changes in total developed area was stimulated by a widespread belief that loss of land, and especially loss of marsh land, was directly correlated with degree of urbanization and commercial/industrial development.

Waveland and the Pascagoula North and Pascagoula South quadrangles exhibited the highest degree of development (over 2500 acres total) within the designated study area over the 1950s-to-1992 period. Development in the Waveland area was mostly

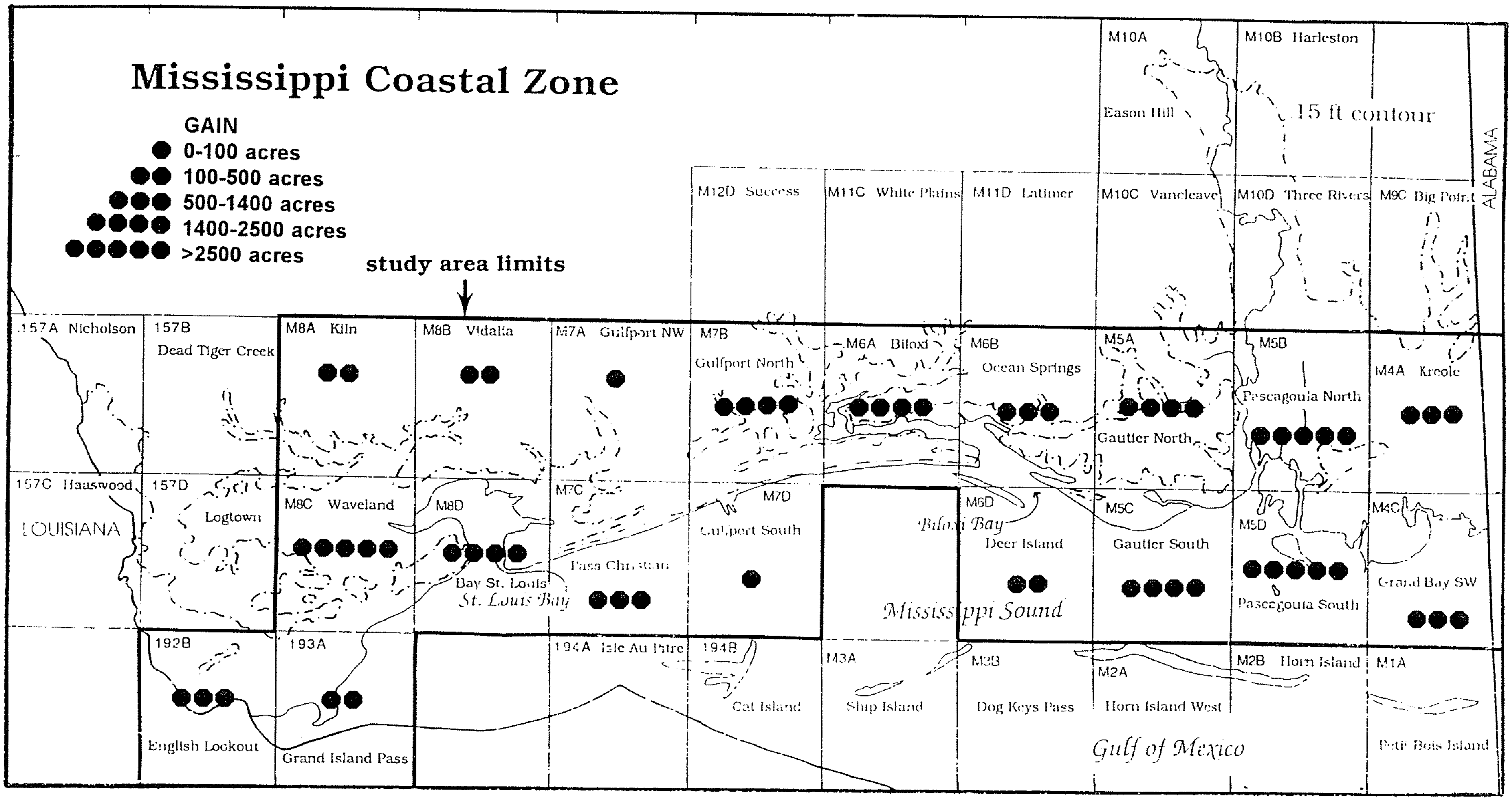

Figure 19. Change in total developed area by topographic quadrangle in coastal Mississippi, 1950s-1992.

related to recreational urbanization (i.e. summer home subdivisions), but development in the Pascagoula area was mostly industrial (i.e. ship-building, U. S. military, and pulp mill). In all cases, marsh wetlands were affected by the high rates of development over the study period. The high rates of development are still going on in the mid-1990s, and industrial expansion continues in Pascagoula, while casino gaming has stimulated residential expansion in Harrison and Hancock Counties, including the Waveland quadrangle.

High rates of development, between 1400 and 2500 acres over the period of study, were recorded for the Bay St. Louis, Gulfport North, Biloxi, and the Gautier North and South quadrangles. This development is all mostly in the form of extensive suburbanization stimulated by healthy local economies.

Moderate rates of development were noted in Ocean Springs and Pass Christian as well as in three quadrangles that contain extensive marsh wetlands. Ocean Springs and Pass Christian experienced much suburbanization and also limited commercial and industrial development. However, commercial/industrial development played a greater role in the rise of the developed land use category in English Lookout, Kreole, and Grand Bay SW. The English Lookout quad contains Port Bienville, a rapidly expanding shipping and industrial center in southwest Mississippi. Via a canal dredged to the Pearl River, there is direct weekly freighter service from Port Bienville to Mexico and other Latin American ports. A huge Chevron refinery complex accounts for the extensive development noted on the Grand Bay SW quadrangle, and commercial development in Kreole and greater Moss Point is evident on the Kreole quad.

Low or even extremely low rates of development were restricted to topographic quadrangles in which much of the land portion of the quadrangles had already been quite developed in the 1950s (notably Gulfport South), to quads that contained small acreage of upper tributary valleys in which development pressures had not yet been felt (such as Kiln and Vidalia), or to coastal quadrangles in which either little land existed for development and/or the land was ill-suited for widespread development. This latter category includes the Grand Island Pass and the Deer Island quads.

Limitations of the study

The interpretation of land cover categories was often subjective, and it was realized that inconsistencies in mapping over three time periods could lead to faulty results. Whereas the 1992 data set produced under this study was generated by only three photo-interpreters (and monitored closely by the senior author), the 1950s and 1970s data were generated by two dozen or more workers, many of them undergraduate college students (Wicker, 1980). In addition, the USFWS replaced the 1978 data with newer 1982 data for much of the Mississippi coastal area (the photo-interpretation was conducted in-house at the USFWS facility located in Slidell, Louisiana), and numerous inaccuracies were found. Errors identified led to several decisions being made for the 1990s interpretation. Problems included the following:

1) The 15-ft contour (the defacto Mississippi Coastal Zone boundary) was overgeneralized or omitted, in part because some portions of the Mississippi coast were only mapped at the 1:62,500 scale--where the contour interval was 10 ft--at the time of the initial study. Because of more accurate maps available for the newest set of overlays, it was decided to map the 1992 data with the highest accuracy possible.

2) Because the study area boundary did vary between the three sets of data, only portions of the study area common to all three data sets could be compared in a meaningful manner. In other words, for the final presentation of cartographic data as well as for the generation of the final quantitative data, the "study area" comprised that portion of the topographic quadrangle for which data had been generated for each of the three time periods. Because only small portions of some topographic quadrangles were thus able to be mapped, this limited the utility of the maps in identifying trends for certain land cover categories within a small area.

3) The position of the land-water interface varied somewhat between the years because of differing water elevations at the times the sets of photography were taken. Most of the 1950s photographs were taken during low water stages, whereas most of the 1970s, 1980s, and 1990s photos were at high water stages. As a consequence, categories such as beach appeared as different widths (if at all) in successive years. Upon first glance, it would seem

that the beaches were quite dynamic in terms of expansions and contractions, whereas in fact the beaches have remained fairly consistent throughout the years. This distortion also applies to the broader categories of "land" and "water", and land cover changes from the 1950s to the 1970s often exhibit a higher degree of land loss than actually occurred. As a general observation, the beach area (as well as overall land area) for the 1950s data set tended to be overestimated in terms of areal extent.

4) Much of the sparsely wooded pine savanna, especially prevalent in Hancock and Jackson Counties, was alternately identified as agriculture or forest. As discussed in a previous section, this was especially noticeable on the Waveland and Kreole quadrangles, where such distinctions were difficult to make on the basis of black-and-while aerial photography. This, of course, inhibits the usefulness of the land cover maps to accurately document such changes in land cover.

5) Similarly, there appears to have been much overestimation of marsh area in the first two data sets. This overestimation was determined during the course of mapping the 1990s land cover categories and carefully comparing interpretations with the earlier ones. The overestimation of marsh appeared to be rather uniform throughout coastal Mississippi for the 1950s, and somewhat less so and more quadrangle-specific for the late 1970s and 1982 data sets. Interestingly, the late 1970s value of marsh area is almost identical to an estimate of marsh area made by Eleuterius (1973). This overestimation of marsh area tends to inflate the amount of marsh lost throughout the successive intervals. In some cases, such as the Waveland quadrangle, the 1950s marsh values were slightly inflated and the 1982 marsh values were grossly inflated. When compared with the relatively accurate marsh values derived for 1992, an apparent trend of high marsh loss betweeen 1982 and 1992 results (see Appendix B). In fact, a previous study of the same area conducted by the senior author indicated that most of the marsh conversion took place prior to passage of the Mississippi Wetlands Protection Act of 1973 (Meyer-Arendt, 1989). It is beyond the scope of this report to change maps and quantitative data generated as part of previous studies (such as Wicker, 1980 and the unpublished 1982 data of the USFWS), and the reader is advised to carefully examine the values and distribution of marsh displayed on the earlier data sets.

6) Distortion also appeared to be a major problem in some of the 1950s and 1970s interpretations. Although the interpreted overlays were supposed fitted to stable-base topographic maps by matching up known fixed points such as highways or stream intersections, this "fitting" was conducted manually and thus subject to human error. Lack of an adequate number of control points resulted in a high degree of shifting of land areas and waterbodies. This was most noticeable in the English Lookout and Grand Island Pass quadrangles, where bayous and islands (including Grand Island island) appear to have shifted considerably over the years, and the Mississippi-Louisiana boundary appears to intersect the Hancock County coastline. In terms of data values, distortion did not seem to present a major problem as much as it did in terms of visualization and overlay potential.

Value of the present study and implications for the future

In spite of some of the shortcomings outlined in the previous sections, this study represents a first effort at understanding basic changes in land cover and land use categories of the lower elevations of the Mississippi Coastal Zone, with special emphasis upon changes in wetlands. The maps and data show that 13% of Mississippi's wetlands have disappeared since the 1950s. Even if we assume a hypothetical 2,000-acre overestimation of marshes for the 1950s, Mississippi would still exhibit a 10% marsh loss rate, a value similar to that recorded for Louisiana's Mississippi River deltaic plain (Gagliano et al., 1981). Unfortunately, the mid-point data (1978/1982) was not sufficiently accurate to determine exactly how marsh loss rates have changed from the first time period to the second. It is clear, however, that marshes have disappeared between 1978/1982 and 1992 as a combined result of natural and human processes.

As Mississippi's wetlands continue to be subject to the pressures of waterfront development and rising sea level, loss of these valuable resources will continue also. Since the legalization of dockside casino gaming in Harrison and Hancock Counties in 1992, over a dozen casino complexes has opened (Meyer-Arendt and Abusalih, 1994; Meyer-Arendt et al., 1994). Not only have wetland losses accompanied construction of some of the existing casinos, but remaining available sites are increasing in back bay settings where even greater marsh destruction could occur. Although the granting of permits is usually done only if wetland impacts are "mitigated" (i.e. offset by wetland protection or creation elsewhere in the general area), the potential for significant adverse environmental impacts remains high.

This study is valuable both in terms of documenting present conditions and also in terms of establishing starting points for future analyses. One, the study documents general changes in land cover categories which could be delineated to a finer degree (e.g. according to the Cowardin et al., 1979 classification) to examine changes in more detail, especially in regard to ecological habitats. Two, it supplies a baseline from which future changes in land cover and land use may be mapped. Three, the study provides an overview of trends, and spatial variations of trends, of land cover and land use changes in coastal Mississippi. This identification of spatial trends provides geoscientists with starting points for future research into more specific topics of geologic concern. Such topics might include: 1) monitoring subaqueous redistribution of former marsh substrate sediments, 2) doucmenting changes in sedimentation processes resulting from land cover changes, e.g. deltaic deposition in marshless environments and impacts of reduced agricultural cover upon sediment loads in streams, 3) modeling higher storm surge levels in accordance with documented rates of marsh deterioration, or 4) measuring and modeling increases in tidal prism and tidal hydraulic energy based upon marsh loss scenarios. The list can easily go on. The Mississippi coastal zone is a very dynamic environment as a result of both natural and human-induced processes. It is important that the dynamic processes are well understand for both scientific and planning purposes, and this study represents an effort at providing such an understanding.

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APPENDIX A

LAND COVER CLASSIFICATION CODES

land cover category	Cowardin code	LGS code	LGS description
water	E10W	1	water (natural)
water	L10W	1	water (natural)
water	POW	1	water (natural)
water	R2OW	1	water (natural)
water	E1OW	1	water (natural)
water	L1OWV	1	water (natural)
water	POWH	1	water (natural)
water	R4OW	1	water (natural)
water	E1OWL	1	water (natural)
water	L2OW	1	water (natural)
water	POWV	1	water (natural)
water	E1OWt	1	water (natural)
water	M1OW	1	water (natural)
water	R1OW	1	water (natural)
water	E1OWT	1	water (natural)
water	M1OWL	1	water (natural)
water	RIOWV	1	water (natural)
water	EIOWH	2	water (artificial)
water	L2OWX	2	water (artificial)
water	R1OWVX	2	water (artificial)
water	E1OWO	2	water (artificial)
water	POW1O	2	water (artificial)
water	R1OWX	2	water (artificial)
water	POWO	2	water (artificial)
water	R2OWO	2	water (artificial)
water	L2OWH	2	water (artificial)
water	POWX	2	water (artificial)
water	R2OWX	2	water (artificial)
water	L2OWO	2	water (artificial)
water	R1OWO	2	water (artificial)
water	E1AB5	13	aquatic veg. (floating)
water	E1AB5H	13	aquatic veg. (floating)
water	E1AB5L	13	aquatic veg. (floating)
water	E1AB5O	13	aquatic veg. (floating)
water	E1AB5X	13	aquatic veg. (floating)
water	L2AB45	13	aquatic veg. (floating)
water	L2AB45H	13	aquatic veg. (floating)
water	L2AB4V	13	aquatic veg. (floating)
water	L2AB5	13	aquatic veg. (floating)
water	L2AB5H	13	aquatic veg. (floating)
water	L2AB5X	13	aquatic veg. (floating)
water	PAB4	13	aquatic veg. (floating)
water	PAB4V	13	aquatic veg. (floating)
water	PAB5	13	aquatic veg. (floating)
water	PAB5H	13	aquatic veg. (floating)
water	PAB5X	13	aquatic veg. (floating)
water	R1AB5V	13	aquatic veg. (floating)
water	R1AB5	13	aquatic veg. (floating)
water	R1AB50	13	aquatic veg. (floating)
water	R1AB5V	13	aquatic veg. (floating)
water	R1AB5X	13	aquatic veg. (floating)
water	R2AB5	13	aquatic veg. (floating)
water	R2AB50	13	aquatic veg. (floating)

Cowardin = Cowardin et al., 1979; LGS = LA Geological Survey

water	R2AB5X	13	aquatic veg. (floating)
water	E1AB	13	aquatic veg. (submerged)
water	E1AB12	13	aquatic veg. (submerged)
water	E1AB2	13	aquatic veg. (submerged)
water	E1AB20	13	aquatic veg. (submerged)
water	L2AB1	13	aquatic veg. (submerged)
water	L2AB12	13	aquatic veg. (submerged)
water	L2AB2	13	aquatic veg. (submerged)
water	L2AB2H	13	aquatic veg. (submerged)
water	L2AB25	13	aquatic veg. (submerged)
water	L2AB25H	13	aquatic veg. (submerged)
water	R1AB2	13	aquatic veg. (submerged)
water	PAB2	13	aquatic veg. (submerged)
water	PAB2X	13	aquatic veg. (submerged)
water	PAB25	13	aquatic veg. (submerged)
water	R1AB2	13	aquatic veg. (submerged)
water	R1AB20	13	aquatic veg. (submerged)
water	R2AB2X	13	aquatic veg. (submerged)
water	R1AB25	13	aquatic veg. (submerged)
water	E2AB	13	aquatic veg. (submerged)
water	L2AB	13	aquatic veg. (submerged)
water	PAB	13	aquatic veg. (submerged)
water	R1AB	13	aquatic veg. (submerged)
water	R1ABO	13	aquatic veg. (submerged)
water	E1RS2R	14	inert
water	E1UB2	14	inert
water	E2FR2	14	inert
water	E2RF	14	inert
water	E2RF2	14	inert
water	E2RS2R	14	inert
water	E2UB34	14	inert
water	L2UBV	14	inert
water	M1UB2	14	inert
water	PUB4V	14	inert
water	PUBV	14	inert
water	R1BB2	14	inert
water	R1RS2R	14	inert
water	E2FL	14	inert (flats)
water	E2FL2	14	inert (flats)
water	E2FL23	14	inert (flats)
water	E2FL24	14	inert (flats)
water	E2FL3	14	inert (flats)
water	E2FL34	14	inert (flats)
water	E2FL34H	14	inert (flats)
water	E2FL3H	14	inert (flats)
water	E2FL5	14	inert (flats)
water	L2FL3	14	inert (flats)
water	L2FL34	14	inert (flats)
water	L2FL34H	14	inert (flats)
water	L2FL5	14	inert (flats)
water	PFL2	14	inert (flats)
water	PFL3	14	inert (flats)
water	PFL34	14	inert (flats)
water	PFL5	14	inert (flats)

Cowardin = Cowardin et al., 1979; LGS = LA Geological Survey

water	R1FL	14	inert (flats)
water	R1FL3	14	inert (flats)
water	R1FL5	14	inert (flats)
marsh	PEM	3	fresh marsh
marsh	PEM5	3	fresh marsh
marsh	PEMIN	3	fresh marsh
marsh	PEMD	3	fresh marsh
marsh	PEM1NS	3	fresh marsh
marsh	PEMM	3	fresh marsh
marsh	PEMIT	3	fresh marsh
marsh	PEMW	3	fresh marsh
marsh	PEM1TPH	3	fresh marsh
marsh	E2EM5P6	4	intermediate marsh
marsh	E2EM5P6D	4	intermediate marsh
marsh	E2EM5P6M	4	intermediate marsh
marsh	E2EM5P6W	4	intermediate marsh
marsh	E2EM5P	5	brackish marsh
marsh	E2EM5P5	5	brackish marsh
marsh	E2EM5P5D	5	brackish marsh
marsh	E2EM5P5M	5	brackish marsh
marsh	E2EM5P5W	5	brackish marsh
marsh	E2EM5D4	6	saline marsh
marsh	E2EM5N4	6	saline marsh
marsh	E2EM5N4D	6	saline marsh
marsh	E2EM5P4	6	saline marsh
marsh	E2EM5P4D	6	saline marsh
marsh	E2EM	4	non-fresh marsh
marsh	E2EMD	4	non-fresh marsh
marsh	E2EMM	4	non-fresh marsh
forest	UFO1	7	forest (upland)
forest	UFO13W	7	forest (upland)
forest	UFO4	7	forest (upland)
forest	UFO12	7	forest (upland)
forest	UFO1S	7	forest (upland)
forest	UFO13	7	forest (upland)
forest	UFO3	7	forest (upland)
forest	UFO1/3	7	forest (upland)
forest	UFO34	7	forest (upland)
forest	UFO134	7	forest (upland)
forest	UFO34S	7	forest (upland)
forest	PFO123	7	forest (bottomland hardwoods)
forest	PFO34	7	forest (bottomland hardwoods)
forest	PFO13	7	forest (bottomland hardwoods)
forest	PFO5	7	forest (bottomland hardwoods)
forest	PFO132	7	forest (bottomland hardwoods)
forest	PFO134	7	forest (bottomland hardwoods)
forest	PFO13C	7	forest (bottomland hardwoods)
forest	PFO	8	swamp
forest	PFO24	8	swamp
forest	PFO1	8	swamp
forest	PFO1R	8	swamp
forest	PFO12	8	swamp
forest	PFO1/2	8	swamp
forest	E2SS2	9	scrub/shrub

Cowardin = Cowardin et al., 1979; LGS = LA Geological Survey

forest	PSS13	9	scrub/shrub
forest	USS13	9	scrub/shrub
forest	E2SS3	9	scrub/shrub
forest	PSS2	9	scrub/shrub
forest	USS1/3	9	scrub/shrub
forest	PSS1	9	scrub/shrub
forest	PSS3	9	scrub/shrub
forest	USS134	9	scrub/shrub
forest	PSS12	9	scrub/shrub
forest	USS	9	scrub/shrub
forest	PSS123	9	scrub/shrub
forest	USS1	9	scrub/shrub
spoil (dredged)	E2EM5P6S	4	intermediate marsh
spoil (dredged)	E2EM5N4S	6	saline marsh
spoil (dredged)	PSS1R	10	scrub/shrub (spoil)
spoil (dredged)	PSS1S	10	scrub/shrub (spoil)
spoil (dredged)	USS13S	10	scrub/shrub (spoil)
spoil (dredged)	USS1S	10	scrub/shrub (spoil)
spoil (dredged)	USS1S3S	10	scrub/shrub (spoil)
spoil (dredged)	UD3V	14	inert
spoil (dredged)	UDV3	14	inert
agriculture	UDV2	11	agriculture/pasture
agriculture	UDV21	11	agriculture/pasture
agriculture	UDV2E	11	agriculture/pasture
agriculture	UDV2O	11	agriculture/pasture
agriculture	UGRP	11	agriculture/pasture
developed	PDV	12	developed
developed	UN1	12	developed
developed	UDV	12	developed
developed	UDV1	12	developed
developed	UDV1O	12	developed
developed	UDV1R	12	developed
beach	E2BB2	15	beach
beach	E2BB34	15	beach
beach	M2BB2	15	beach
beach	M2BB2S	15	beach
beach	R2BB2	15	beach

Cowardin = Cowardin et al., 1979; LGS = LA Geological Survey

WATER REGIME MODIFERS

NONTIDAL

A temporary
B saturated
C seasonal
D seasonal/well-drained
E seasonal/saturated
F semipermanent
G intermittently exposed
H permanent
J intermittently flooded

NONTIDAL COMBINED

Z intermittently exposed/permanent (G. H above)
W intermittently flooded/temporary (J. A above)
Y saturated semipermanent/ all seasonals (B. C. D. E. F above)

TIDAL

L subtidal
M irregularly exposed
N regular
P irregular
R seasonal
S temporary
T semipermanent
V permanent

NONTIDAL AND TIDAL

U unknown
K artificial

WATER CHEMISTRY MODIFERS

COASTAL HALINITY MODIFER

1 hyperhaline
2 euhaline
3 mixohaline (brackish)
4 polyhaline
5 mesohaline
6 oligohaline
— fresh

INLAND SALINITY MODIFER

7 hypersaline
8 eusaline
9 mixosaline
— fresh

pH FRESH WATER MODIFER

a acid
t circumneutral
l alkaline

OTHER MODIFIERS

SPECIAL MODIFERS

b beaver
d partially drained/ditched
f farmed
e reclaimed wetland
h diked/impounded
r artificial
s spoil
x excavated
o oil/gas/mineral
t tidal
p beach

SOIL MODIFERS

g organic
n mineral

HABITAT MAP SYMBOLS

SYSTEM AND SUBSYSTEM

***SYSTEM**
*subsystem

M MARINE
1 subtidal
2 intertidal

E ESTUARINE
1 subtidal
2 intertidal

P PALUSTRINE
— no subsystem

R RIVERINE
1 tidal
2 lower perennial
3 upper perennial
4 intermittent

L LACUSTRINE
1 limnetic
2 littoral

U UPLAND
— no subsystem

CLASS AND SUBCLASS

***CLASS**
*subclass

AB AQUATIC BED
1 submergent algal
2 submergent vascular
3 submergent moss
4 floating-leaved
5 floating
6 unknown submergent
7 unknown surface

BB BEACH/BAR
1 cobble/gravel
2 sand/shell

EM EMERGENT
1 persistent
2 nonpersistent
3 narrow-leaved nonpersistent
4 broad-leaved nonpersistent
5 narrow-leaved persistent
6 broad-leaved persistent

FL FLAT
1 cobble/gravel
2 sand/shell
3 mud
4 organic
5 vegetated pioneer
6 vegetated non-pioneer

FO FORESTED
1 broad-leaved deciduous
2 needle-leaved deciduous
3 broad-leaved evergreen
4 needle-leaved evergreen
5 dead
6 deciduous
7 evergreen

OW OPEN WATER
unknown bottom

RF REEF
1 coral
2 mollusc
3 worm

RS ROCKY SHORE
1 bedrock
2 boulder
3 vegetated non-pioneer

SB STREAM BED
1 cobble/gravel
2 sand
3 mud
4 organic

SS SCRUB/SHRUB
1 broad-leaved deciduous
2 needle-leaved deciduous
3 broad-leaved evergreen
4 needle-leaved evergreen
5 dead
6 deciduous
7 evergreen

UB UNCONSOLIDATED BOTTOM
1 cobble/gravel
2 sand
3 mud
4 organic

DV DEVELOPED
1 urban/residential/commercial/industrial
2 agriculture/pasture/modified grasslands
3 unvegetated land/spoil/disposal sites

GR GRASSLANDS

APPENDIX B

MAINLAND COASTAL MISSISSIPPI LAND COVER CHANGE SPREAD SHEET

1950s - 1990s

			Exact Dates of Photography			Interval Between Dates of Photography (years)		
County	**Code #***	**Topographic Quad**	**50s**	**70s/80s**	**90s**	**50s-70s**	**70s-90s**	**50s-90s**
JACKSON	M4A	Kreole	1953	1976	1992	23	16	39
JACKSON	M4C	Grand Bay SW	1953	1976	1992	23	16	39
JACKSON	M5A	Gautier North	1953	1976	1992	23	16	39
JACKSON	M5B	Pascagoula North	1952	1976	1992	24	16	40
JACKSON	M5C	Gautier South	1951	1976	1992	25	16	41
JACKSON	M5D	Pascagoula South	1952	1976	1992	24	16	40
JACKSON	M6A	Biloxi	1951	1982	1992	31	10	41
JACKSON	M6B	Ocean Springs	1952	1976	1992	24	16	40
JACKSON	M6D	Deer Island	1952	1978	1992	26	14	40
JACKSON COUNTY TOTAL (or average)			**1952.1**	**1976.9**	**1992**	**24.8**	**15.1**	**39.9**
HARRISON	M6A	Biloxi	1951	1982	1992	31	10	41
HARRISON	M6B	Ocean Springs	1952	1976	1992	24	16	40
HARRISON	M6D	Deer Island	1952	1978	1992	26	14	40
HARRISON	M7A	Gulfport NW	1958	1982	1992	24	10	34
HARRISON	M7B	Gulfport North	1958	1982	1992	24	10	34
HARRISON	M7C	Pass Christian	1958	1982	1992	24	10	34
HARRISON	M7D	Gulfport South	1958	1982	1992	24	10	34
HARRISON	M8B	Vidalia	1958	1978	1992	20	14	34
HARRISON	M8D	Bay St. Louis	1958	1982	1992	24	10	34
HARRISON COUNTY TOTAL (or average)			**1955.9**	**1980.4**	**1992**	**24.6**	**11.6**	**36.1**
HANCOCK	M8A	Kiln	1958	1978	1992	20	14	34
HANCOCK	M8B	Vidalia	1958	1978	1992	20	14	34
HANCOCK	M8C	Waveland	1958	1982	1992	24	10	34
HANCOCK	M8D	Bay St. Louis	1958	1982	1992	24	10	34
HANCOCK	192B	English Lookout	1956	1982	1992	26	10	36
HANCOCK	193A	Grand Island Pass	1956	1982	1992	26	10	36
HANCOCK COUNTY TOTAL (or average)			**1957.3**	**1980.7**	**1992**	**23.3**	**11.3**	**34.7**
GRAND TOTAL (or average)			**1955**	**1979.2**	**1992**	**24.2**	**12.8**	**37**

*Codes from USFWS report [Wicker, 1980]

Note: for Vidalia and Kiln quads, 1978 data are from Wicker, 1980.

		Total Land Area within Study Area (acres)			Change in Land Area, By Interval (acres)		
County	**Topographic Quad**	**50s land**	**70s land**	**90s land**	**50s-70s**	**70s-90s**	**50s-90s**
JACKSON	Kreole	23,019	22,892	23,009	-127	117	-10
JACKSON	Grand Bay SW	9,296	8,549	8,322	-747	-228	-974
JACKSON	Gautier North	10,377	10,347	10,361	-30	14	-16
JACKSON	Pascagoula North	29,326	28,855	29,084	-471	229	-242
JACKSON	Gautier South	5,645	5,551	5,401	-94	-150	-244
JACKSON	Pascagoula South	7,170	7,912	7,733	743	-180	563
JACKSON	Biloxi	620	642	632	22	-10	11
JACKSON	Ocean Springs	5,253	5,353	5,251	100	-102	-2
JACKSON	Deer Island	885	882	843	-2	-40	-42
JACKSON COUNTY TOTAL		**91,591**	**90,985**	**90,635**	**-606**	**-350**	**-956**
HARRISON	Biloxi	8,969	8,904	8,870	-65	-34	-99
HARRISON	Ocean Springs	969	915	920	-54	5	-49
HARRISON	Deer Island	345	354	307	9	-47	-38
HARRISON	Gulfport NW	2,711	2,800	2,685	89	-115	-26
HARRISON	Gulfport North	8,384	8,414	8,198	30	-216	-186
HARRISON	Pass Christian	5,034	5,172	5,039	138	-134	4
HARRISON	Gulfport South	467	514	458	47	-56	-9
HARRISON	Vidalia	961	983	947	22	-36	-14
HARRISON	Bay St. Louis	6,279	6,174	6,206	-104	32	-73
HARRISON COUNTY TOTAL		**34,119**	**34,230**	**33,630**	**111**	**-600**	**-489**
HANCOCK	Kiln	5,971	5,983	5,983	12	0	12
HANCOCK	Vidalia	752	777	790	24	14	38
HANCOCK	Waveland	32,009	31,618	31,688	-391	70	-321
HANCOCK	Bay St. Louis	4,088	4,094	4,054	6	-40	-34
HANCOCK	English Lookout	15,308	14,951	14,954	-357	3	-354
HANCOCK	Grand Island Pass	10,907	10,587	10,341	-321	-245	-566
HANCOCK COUNTY TOTAL		**69,036**	**68,010**	**67,811**	**-1026**	**-199**	**-1255**
GRAND TOTAL		194,746	193,225	192,076	-1521	-1149	-2670

Note: for Vidalia and Kiln quads, 1978 data are from Wicker, 1980.

		Total Developed Land Within Study Area (acres)			Change in Developed Land, by Interval (acres)		
County	**Topographic Quad**	**50s dev.**	**70s Dev.**	**90s Dev.**	**50s-70s**	**70s-90s**	**50s-90s**
JACKSON	Kreole	1,108	2,362	2,132	1255	-231	1024
JACKSON	Grand Bay SW	129	903	1,212	773	309	1082
JACKSON	Gautier North	99	1,489	1,857	1390	368	1758
JACKSON	Pascagoula North	1,746	5,189	6,572	3443	1383	4826
JACKSON	Gautier South	32	850	1,634	818	784	1602
JACKSON	Pascagoula South	2,197	4,816	5,153	2619	337	2956
JACKSON	Biloxi	323	328	324	5	-4	1
JACKSON	Ocean Springs	177	1,588	1,307	1411	-282	1129
JACKSON	Deer Island	0	166	179	166	13	179
JACKSON COUNTY TOTAL		**5,811**	**17,691**	**20,369**	**11880**	**2678**	**14558**
HARRISON	Biloxi	1,669	3,235	3,139	1566	-97	1469
HARRISON	Ocean Springs	618	672	675	54	4	58
HARRISON	Deer Island	0	0	0	0	0	0
HARRISON	Gulfport NW	138	106	148	-32	42	10
HARRISON	Gulfport North	663	2,881	2,944	2218	63	2281
HARRISON	Pass Christian	1,132	1,337	1,775	205	439	644
HARRISON	Gulfport South	308	380	319	73	-62	11
HARRISON	Vidalia	1	117	148	116	30	146
HARRISON	Bay St. Louis	1,584	1,969	2,564	385	595	981
HARRISON COUNTY TOTAL		**6,112**	**10,697**	**11,711**	**4585**	**1014**	**5599**
HANCOCK	Kiln	59	495	543	436	48	484
HANCOCK	Vidalia	0	23	113	23	90	113
HANCOCK	Waveland	871	4,648	7,422	3777	2774	6551
HANCOCK	Bay St. Louis	934	1,253	1,454	319	202	520
HANCOCK	English Lookout	241	123	978	-118	855	737
HANCOCK	Grand Island Pass	77	206	252	129	46	175
HANCOCK COUNTY TOTAL		**2,182**	**6,748**	**10,763**	**4566**	**4015**	**8581**
GRAND TOTAL		**14,106**	**35,136**	**42,843**	**21031**	**7707**	**28738**

Note: for Vidalia and Kiln quads, 1978 data are from Wicker, 1980.

		Total Marsh within Study Area (acres)			Change in Marsh Area, by Interval (acres)			Marsh to Water (acres) 1950s-1990s	Marsh to Developed (acres) 1950s-1990s
County	**Topographic Quad**	**50s Marsh**	**70s Marsh**	**90s Marsh**	**50s-70s**	**70s-90s**	**50s-90s**	**Marsh - Water**	**Marsh - Developed**
JACKSON	Kreole	5,927	5,493	4,621	-433	-872	-1305	11	54
JACKSON	Grand Bay SW	6,934	6,403	5,837	-532	-566	-1097	797	127
JACKSON	Gautier North	3,128	2,891	2,500	-237	-391	-628	4	334
JACKSON	Pascagoula North	13,542	12,426	12,652	-1116	266	-890	207	384
JACKSON	Gautier South	2,281	2,197	1,964	-84	-232	-317	84	91
JACKSON	Pascagoula South	1,592	1,835	1,360	243	-475	-232	-312	274
JACKSON	Biloxi	40	42	18	3	-24	-22	-3	19
JACKSON	Ocean Springs	2,136	2,112	2,031	-24	-81	-105	15	67
JACKSON	Deer Island	424	467	405	42	-61	-19	9	13
JACKSON COUNTY TOTAL		**36,005**	**33,867**	**31,389**	**-2138**	**-2477**	**-4615**	**812**	**1362**
HARRISON	Biloxi	2,271	1,755	1,620	-516	-135	-651	210	247
HARRISON	Ocean Springs	161	63	64	-98	0	-97	-11	119
HARRISON	Deer Island	246	271	263	25	-9	16	-3	0
HARRISON	Gulfport NW	422	371	403	-50	31	-19	7	-1
HARRISON	Gulfport North	1,125	1,056	885	-69	-171	-240	160	117
HARRISON	Pass Christian	819	993	902	174	-91	83	-9	9
HARRISON	Gulfport South	0	0	0	0	0	0	0	0
HARRISON	Vidalia	46	56	35	901	-912	-10	0	0
HARRISON	Bay St. Louis	2,079	1,961	1,664	-118	-297	-415	90	132
HARRISON COUNTY TOTAL		**7,168**	**6,527**	**5,836**	**250**	**-1582**	**-1333**	**444**	**624**
HANCOCK	Kiln	815	805	682	-10	-123	-133	15	20
HANCOCK	Vidalia	25	18	6	-8	-11	-19	0	0
HANCOCK	Waveland	4,802	4,680	3,077	-122	-1603	-1724	183	1145
HANCOCK	Bay St. Louis	1,205	1,291	1,097	86	-194	-108	-1	35
HANCOCK	English Lookout	9,159	8,795	8,823	-363	28	-335	293	165
HANCOCK	Grand Island Pass	7,820	8,113	7,500	293	-613	-320	524	76
HANCOCK COUNTY TOTAL		**23,826**	**23,702**	**21,186**	**-124**	**-2515**	**-2639**	**1014**	**1441**
GRAND TOTAL		**66,999**	**64,095**	**58,411**	**-2012**	**-6575**	**-8587**	**2,270**	**3,427**

Note: for Vidalia and Kiln quads, 1978 data are from Wicker, 1980

APPENDIX C

MAINLAND COASTAL MISSISSIPPI LAND COVER CHANGE MAPS

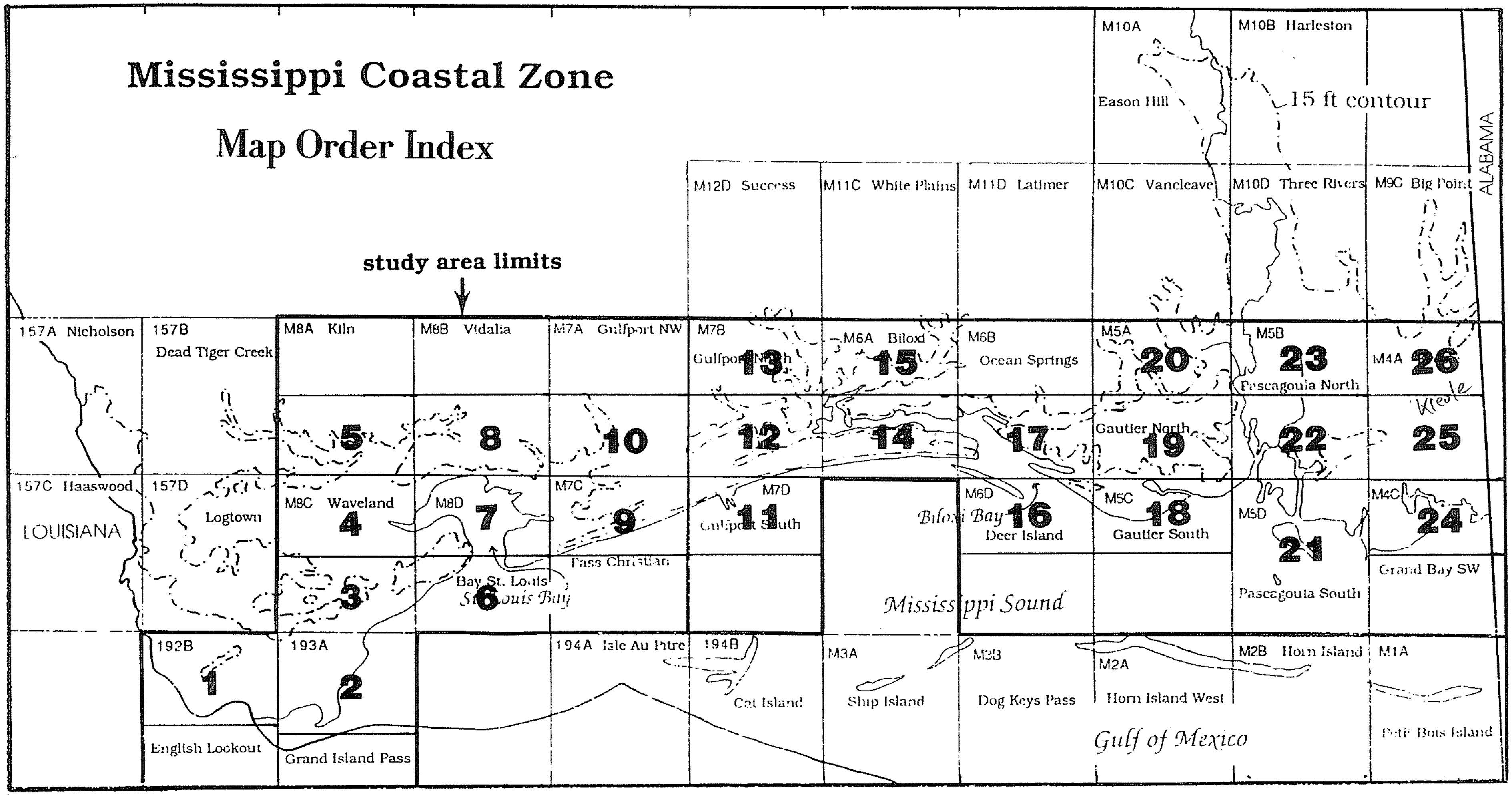
1950s - 1990s

Quadrangle maps are arranged in order from west to east.

See index map.

Mississippi Coastal Zone

Map Order Index



LEGEND

MARSH

FOREST

AGRICULTURE

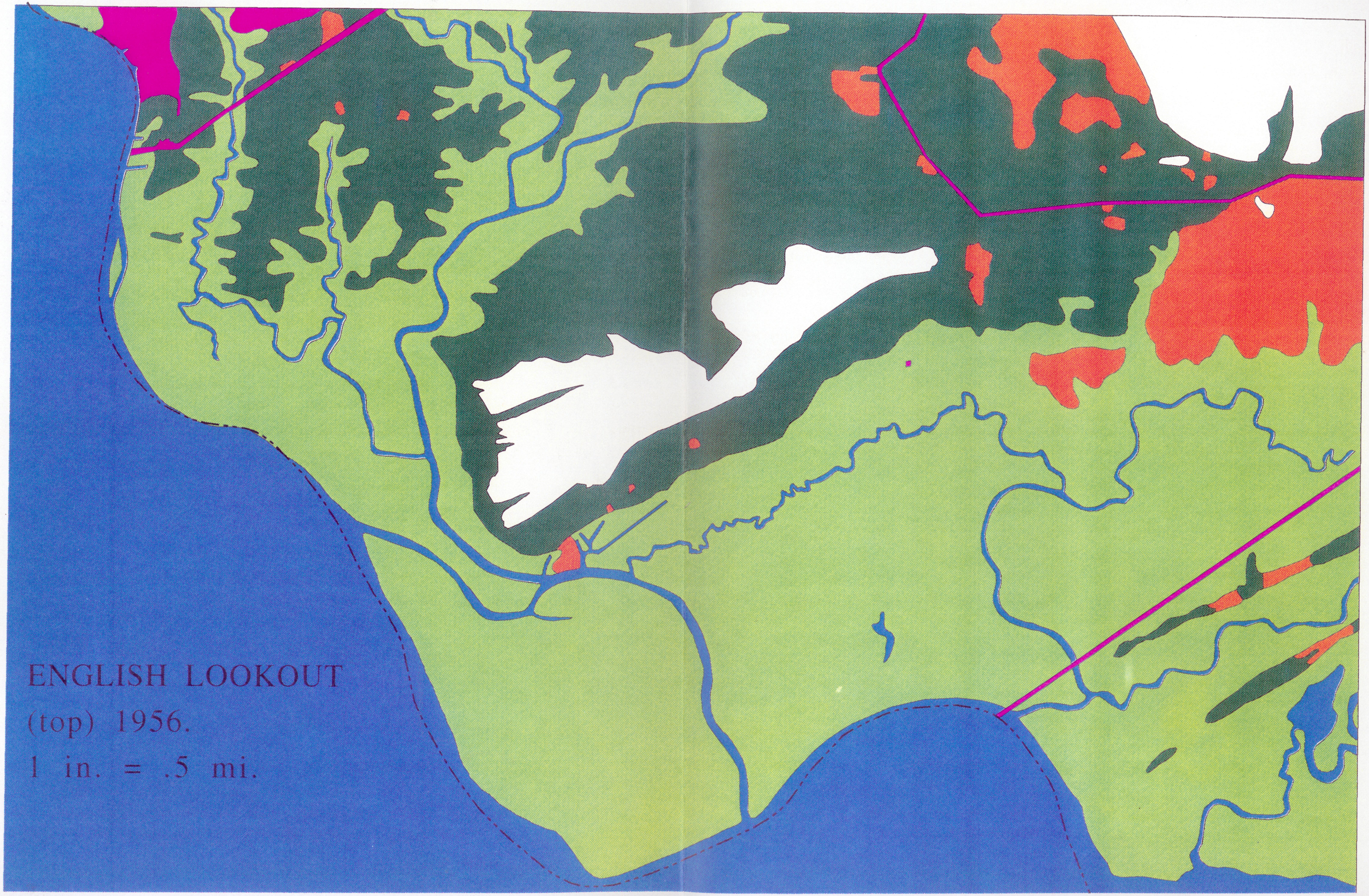
DEVELOPED

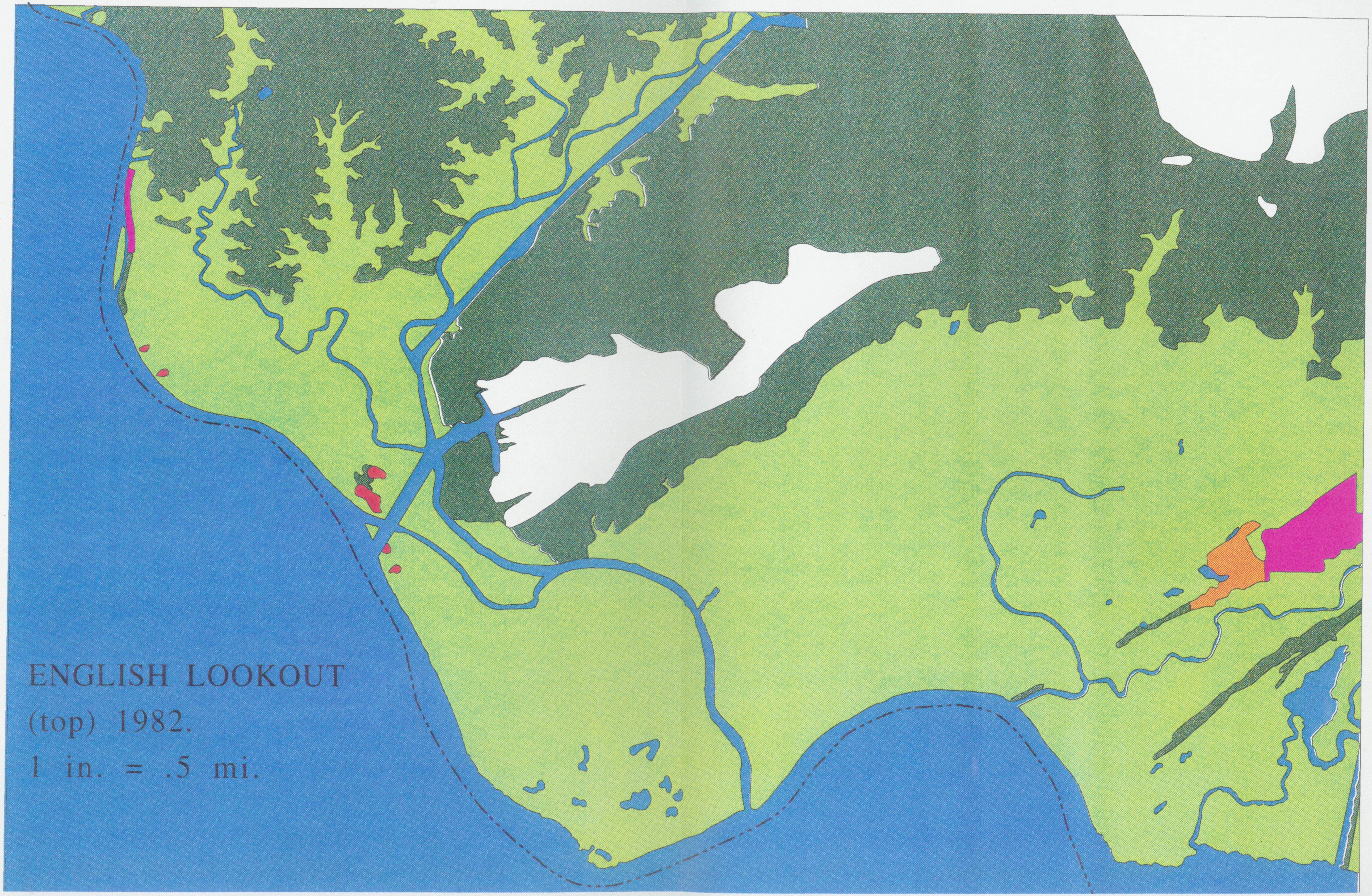
SPOIL

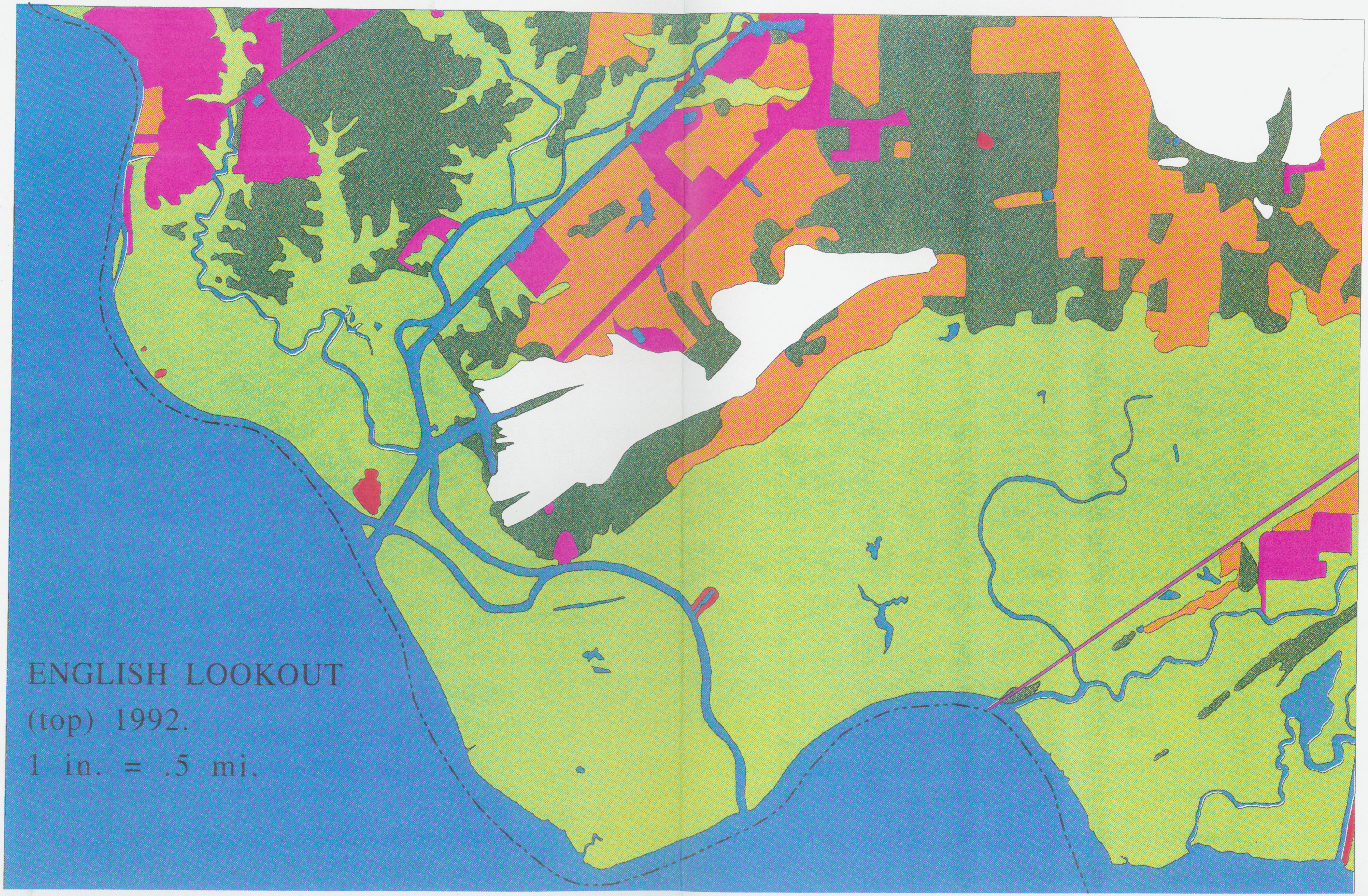
BEACH

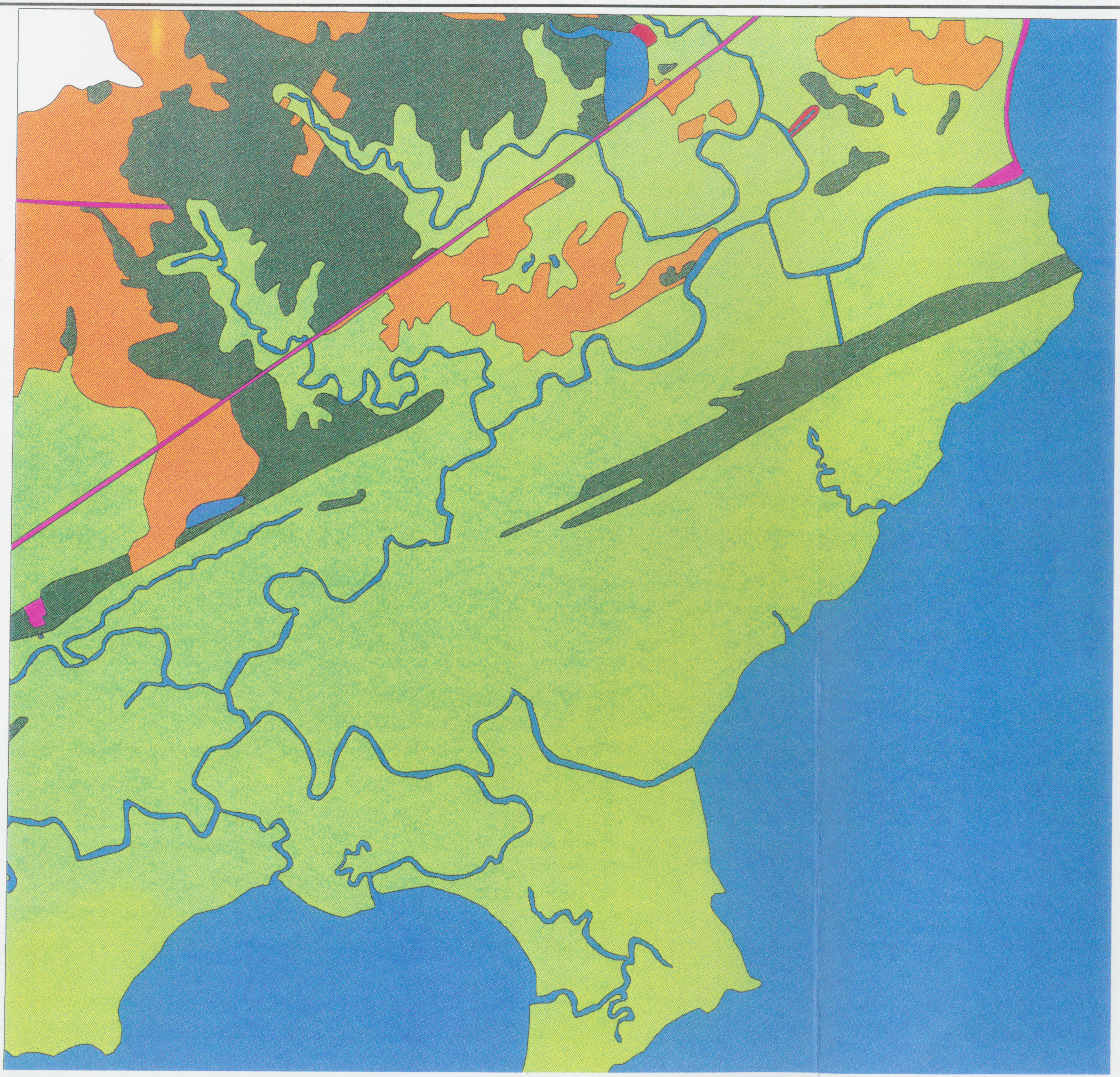
WATER

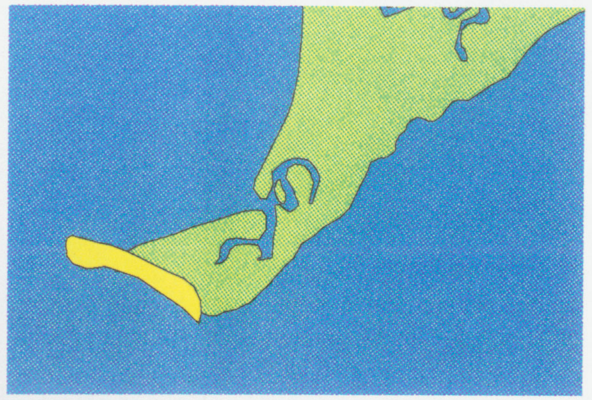
NOT APPLICABLE –
ABOVE 15 FT. CONTOUR


ENGLISH LOOKOUT
(top) 1956.
1 in. = .5 mi.

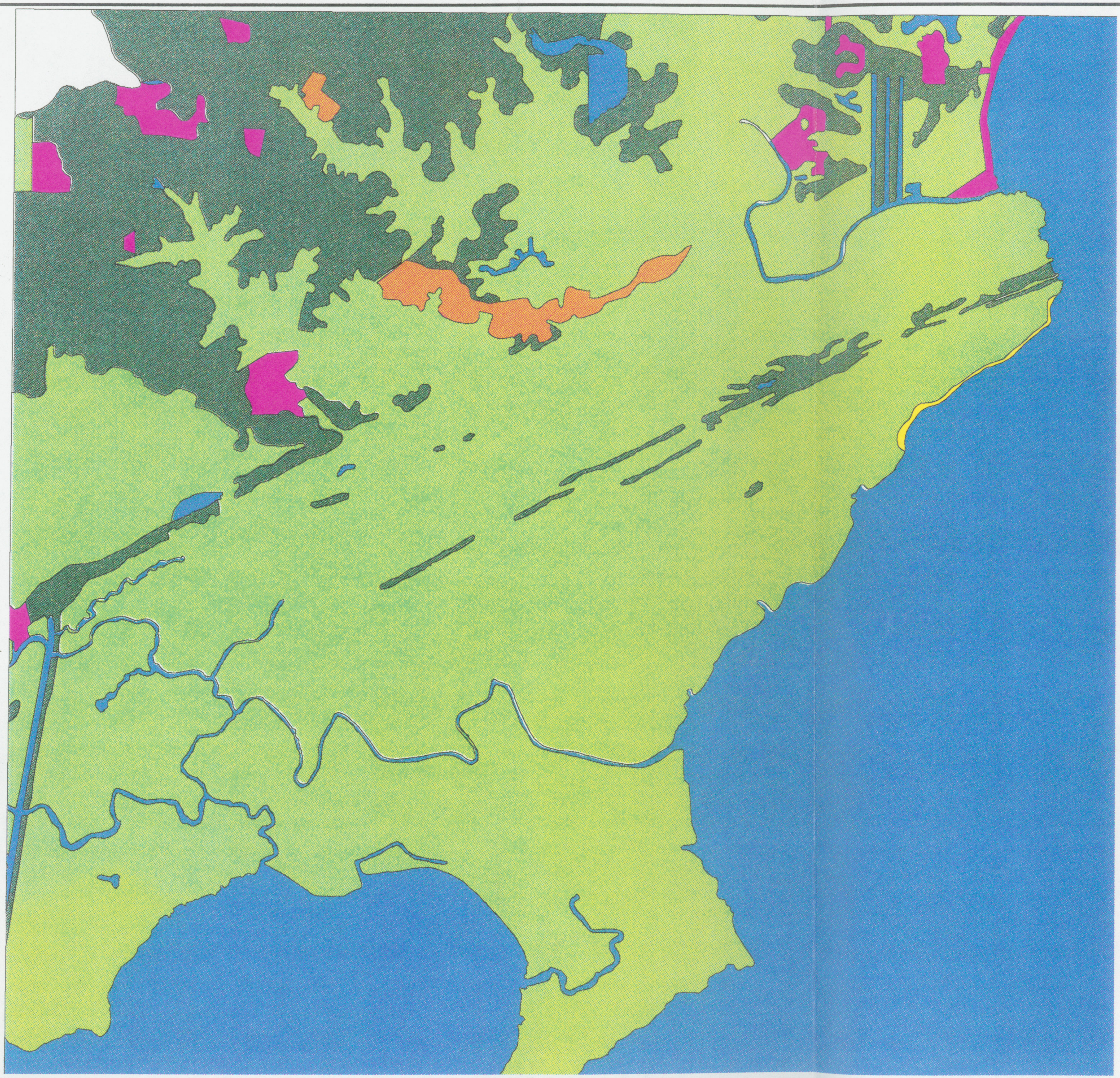

ENGLISH LOOKOUT
(top) 1982.
1 in. = .5 mi.

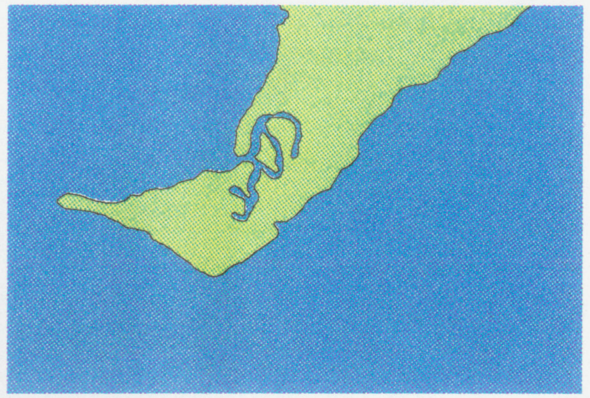

ENGLISH LOOKOUT
(top) 1992.
1 in. = .5 mi.



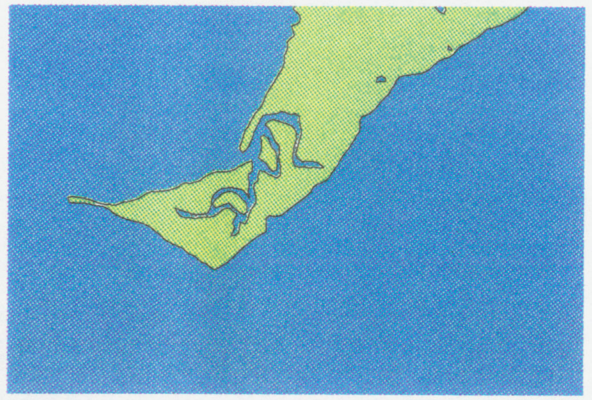


GRAND ISLAND PASS
(top) 1956.
1 in. = .5 mi.



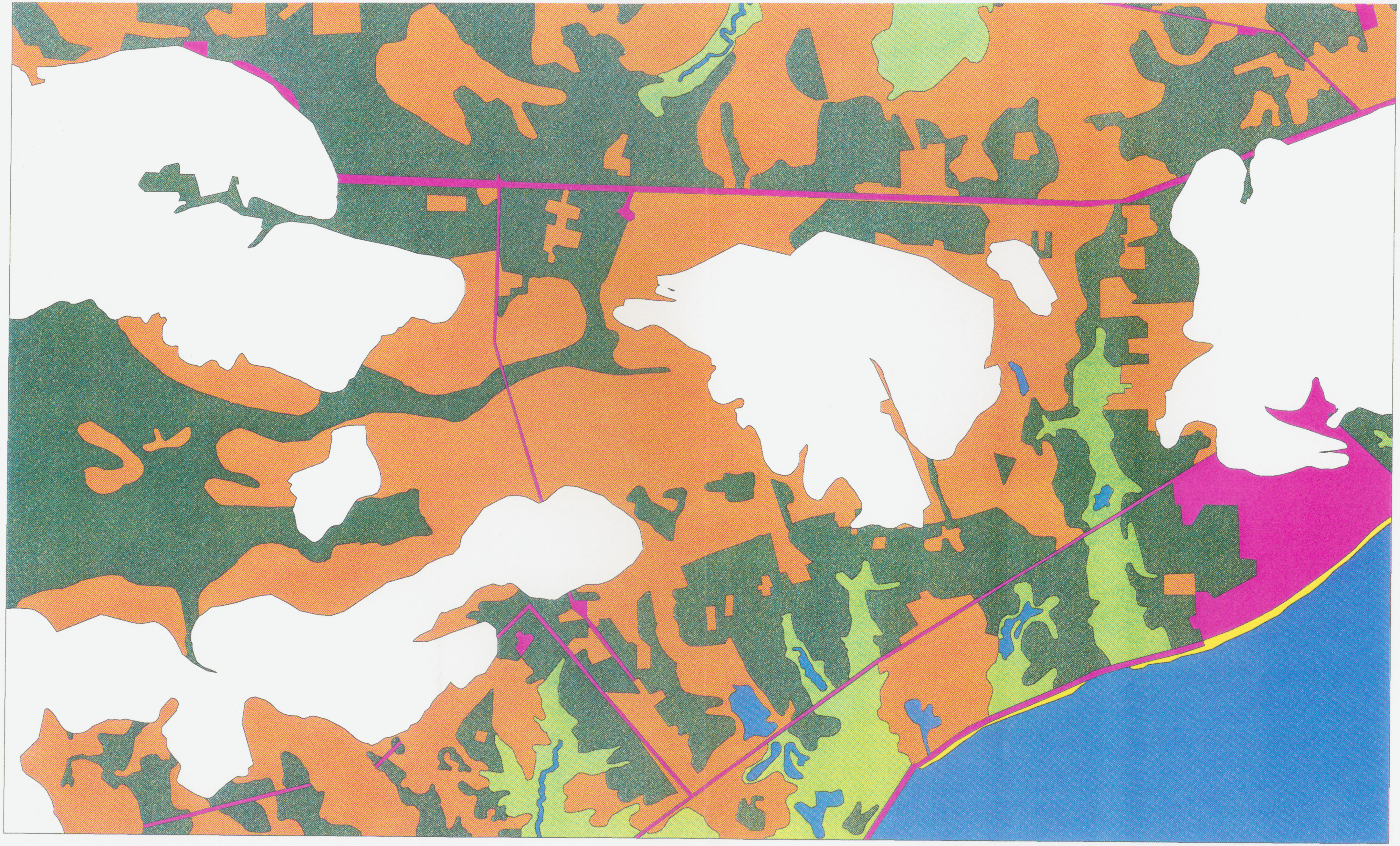


GRAND ISLAND PASS
(top) 1982.
1 in. = .5 mi.



GRAND ISLAND PASS
(top) 1992.
1 in. = .5 mi.

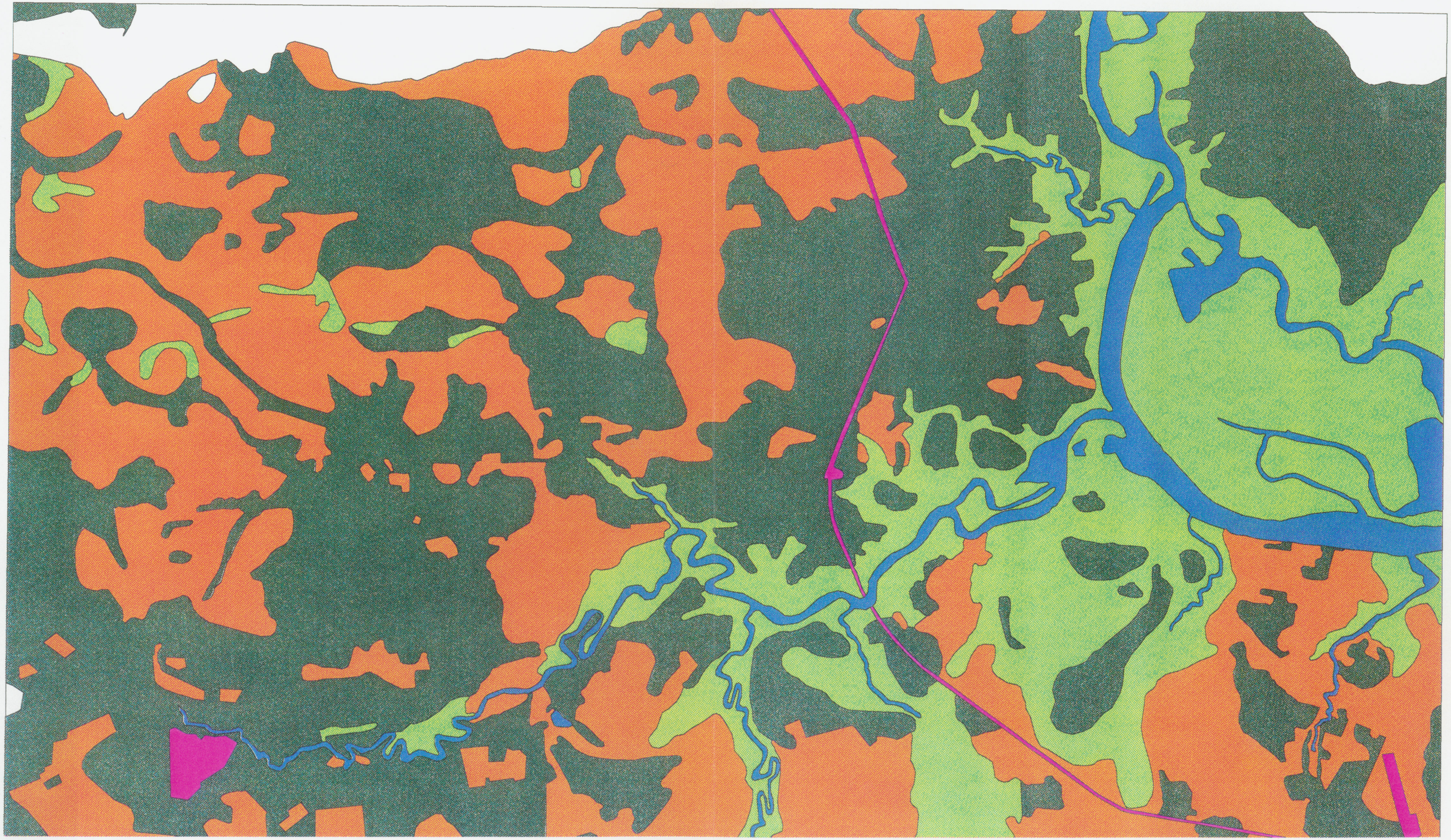
WAVELAND (bottom), 1956. 1 in. = .5 mi.



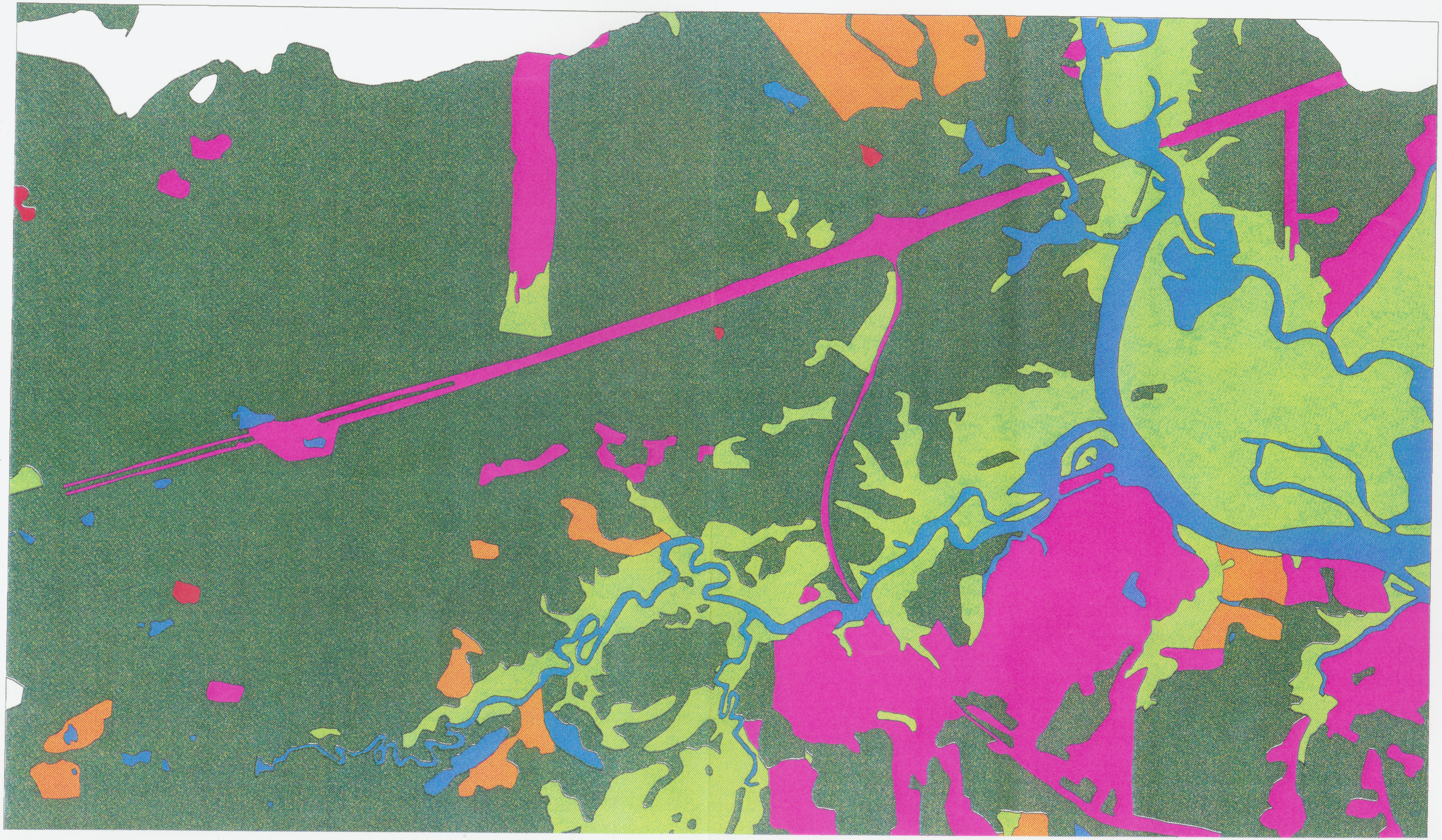
WAVELAND (bottom), 1982. 1 in. = .5 mi.

WAVELAND (bottom), 1992. 1 in. = .5 mi.

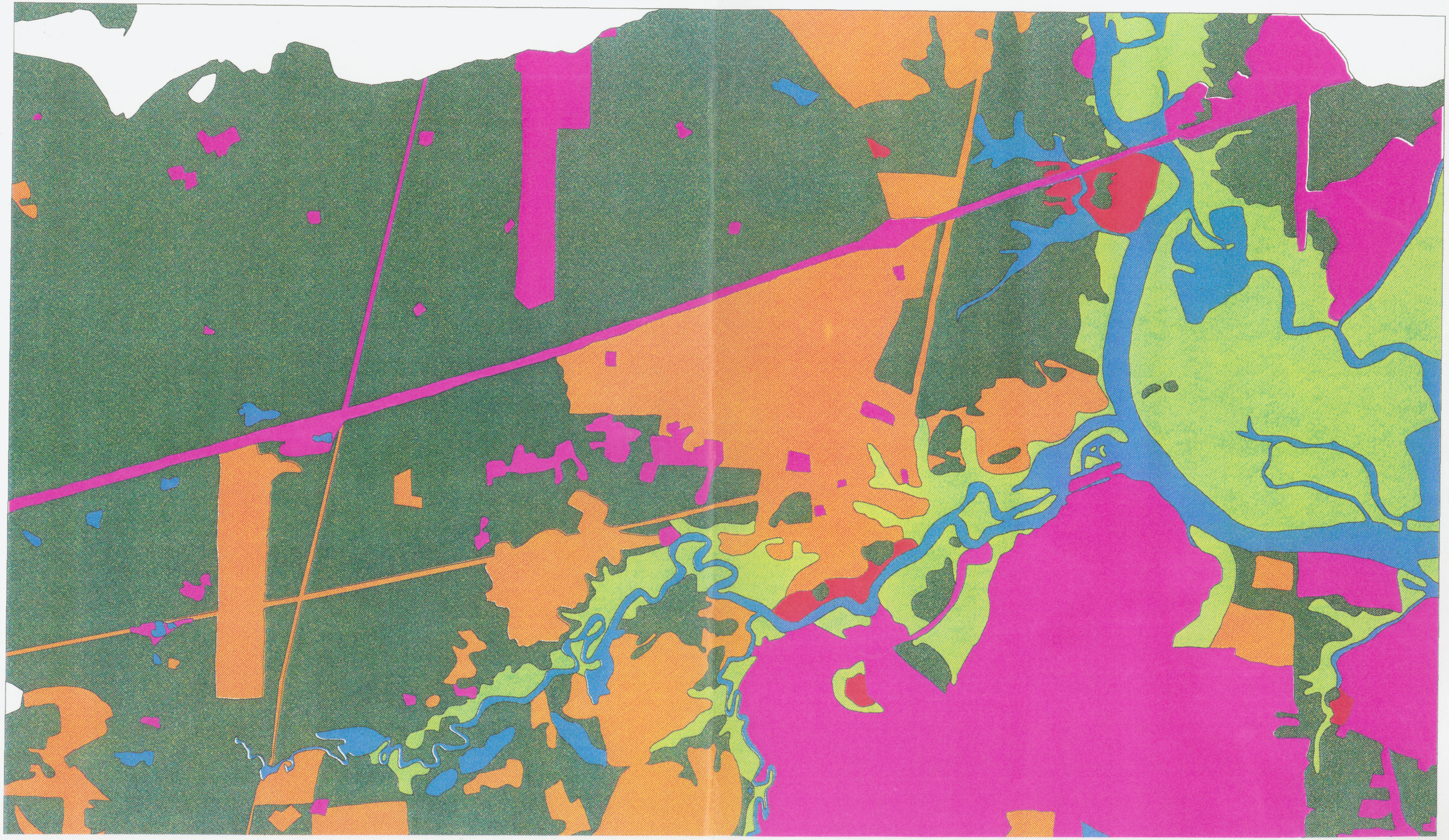
WAVELAND (top), 1956. 1 in. = .5 mi.



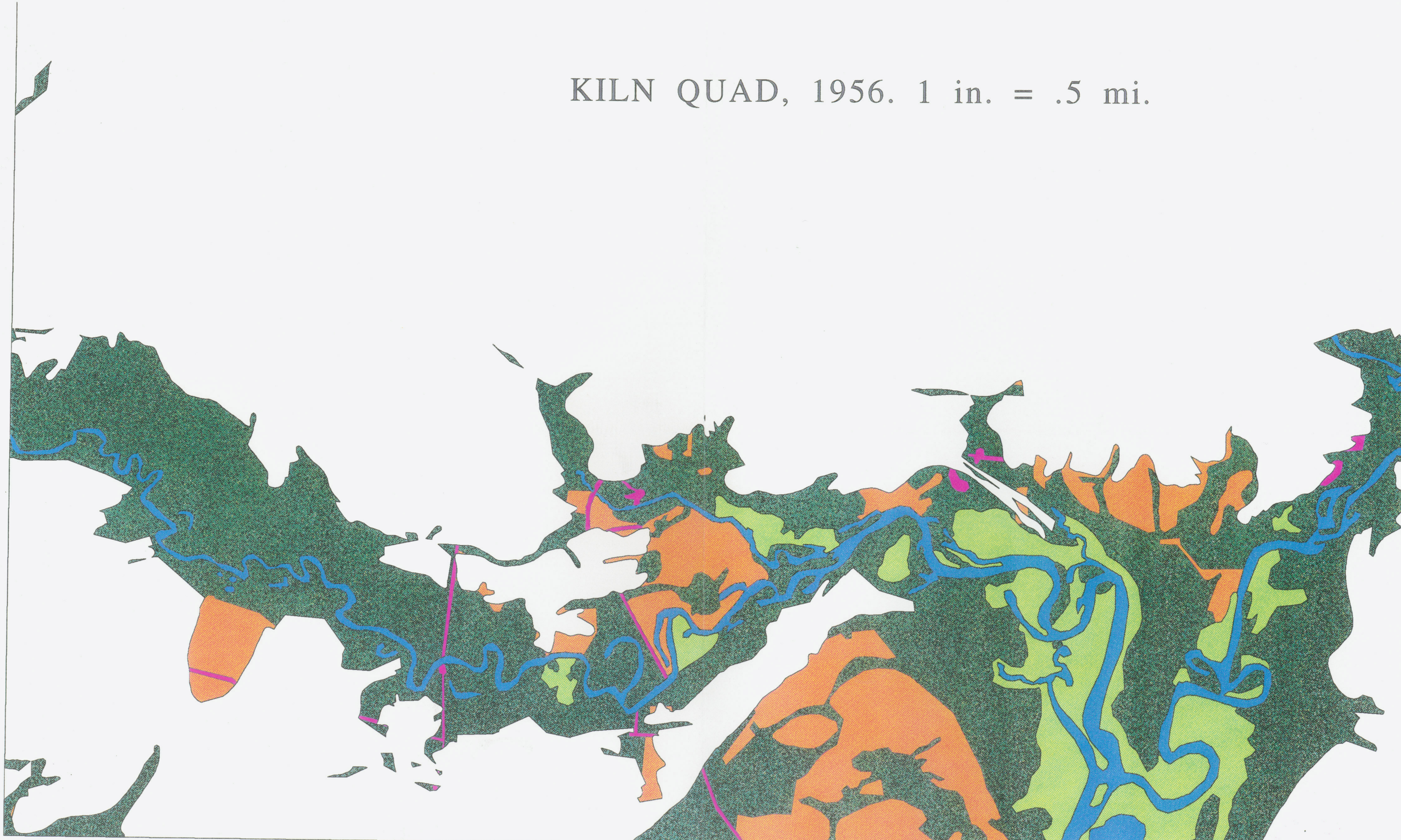
WAVELAND (top), 1982. 1 in. = .5 mi.



WAVELAND (top), 1992. 1 in. = .5 mi.



KILN QUAD, 1956. 1 in. = .5 mi.



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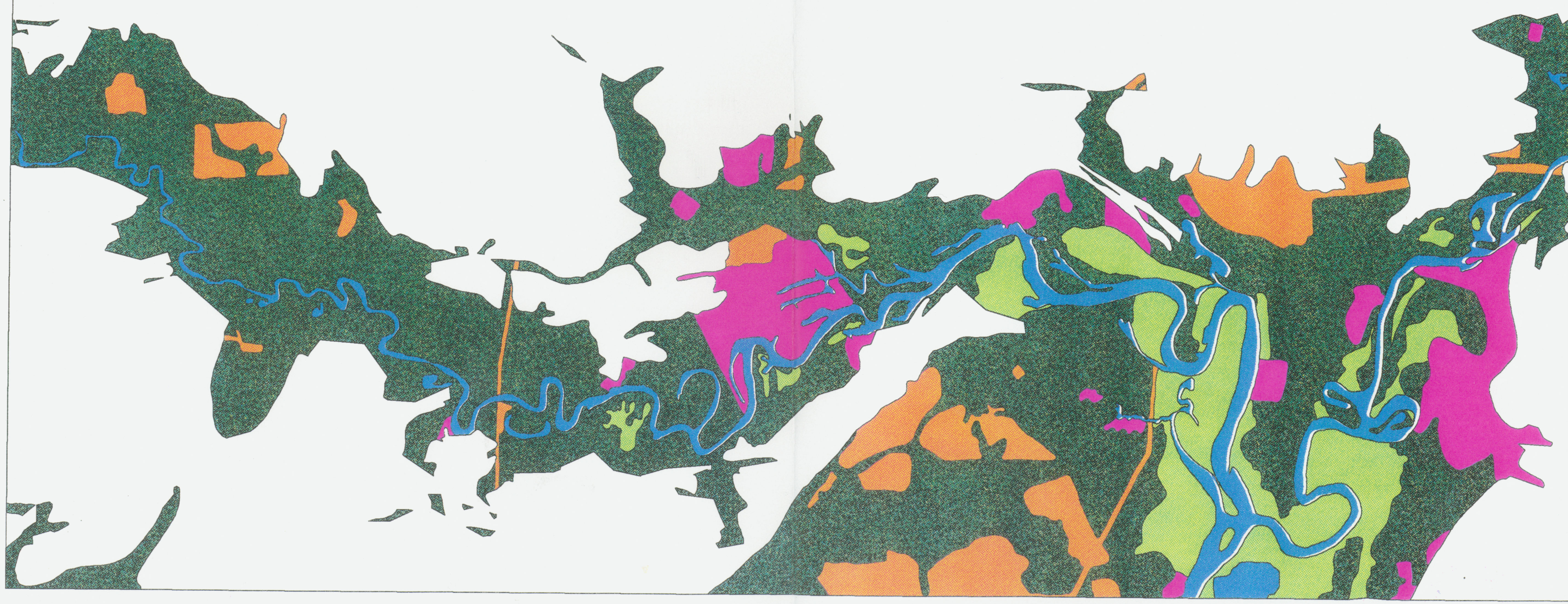
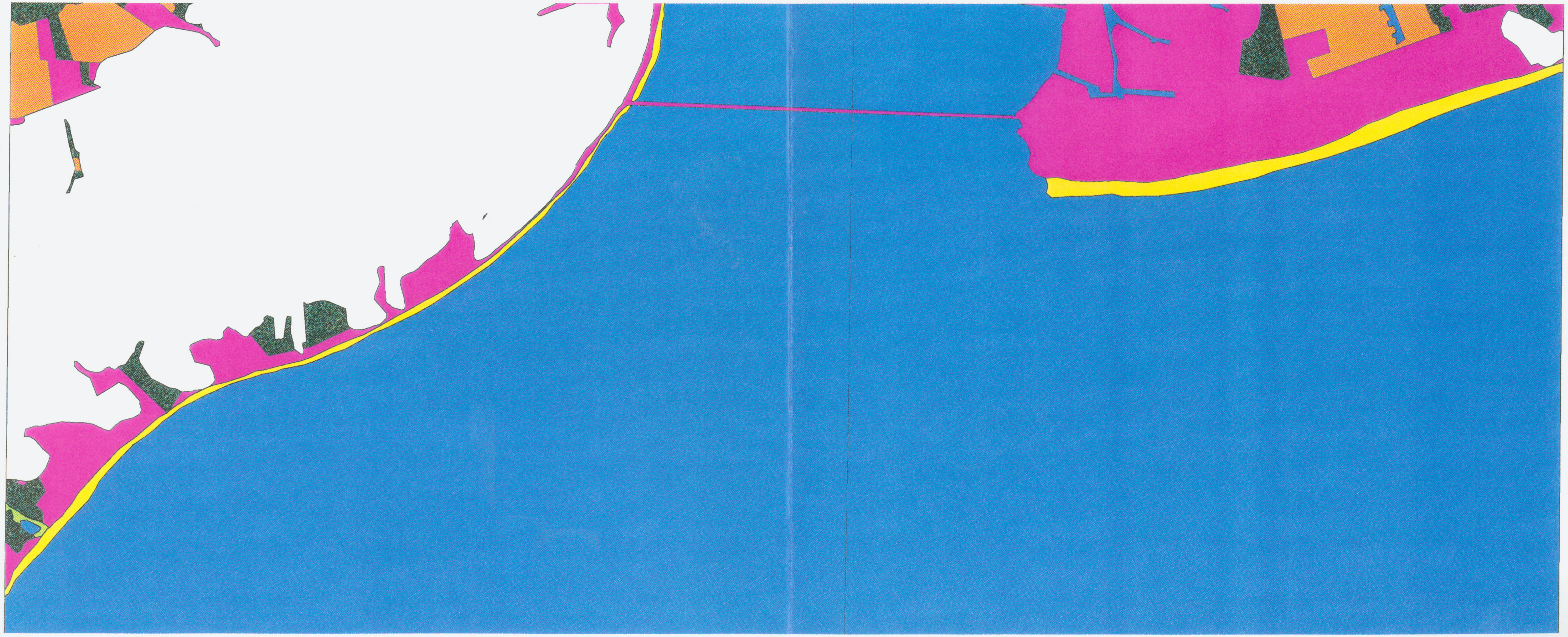
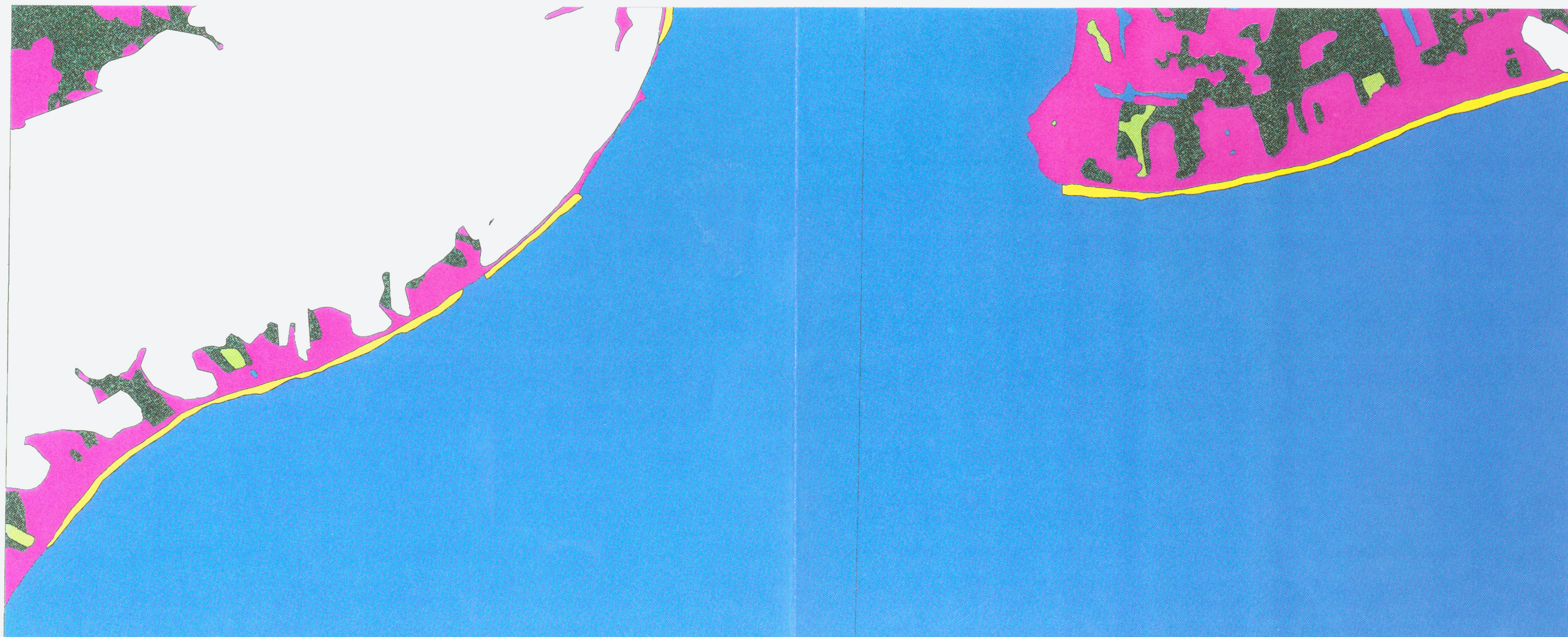


BAY ST. LOUIS QUAD (bottom), 1956. 1 in. = .5 mi.



BAY ST. LOUIS QUAD (bottom), 1982. 1 in. = .5 mi.



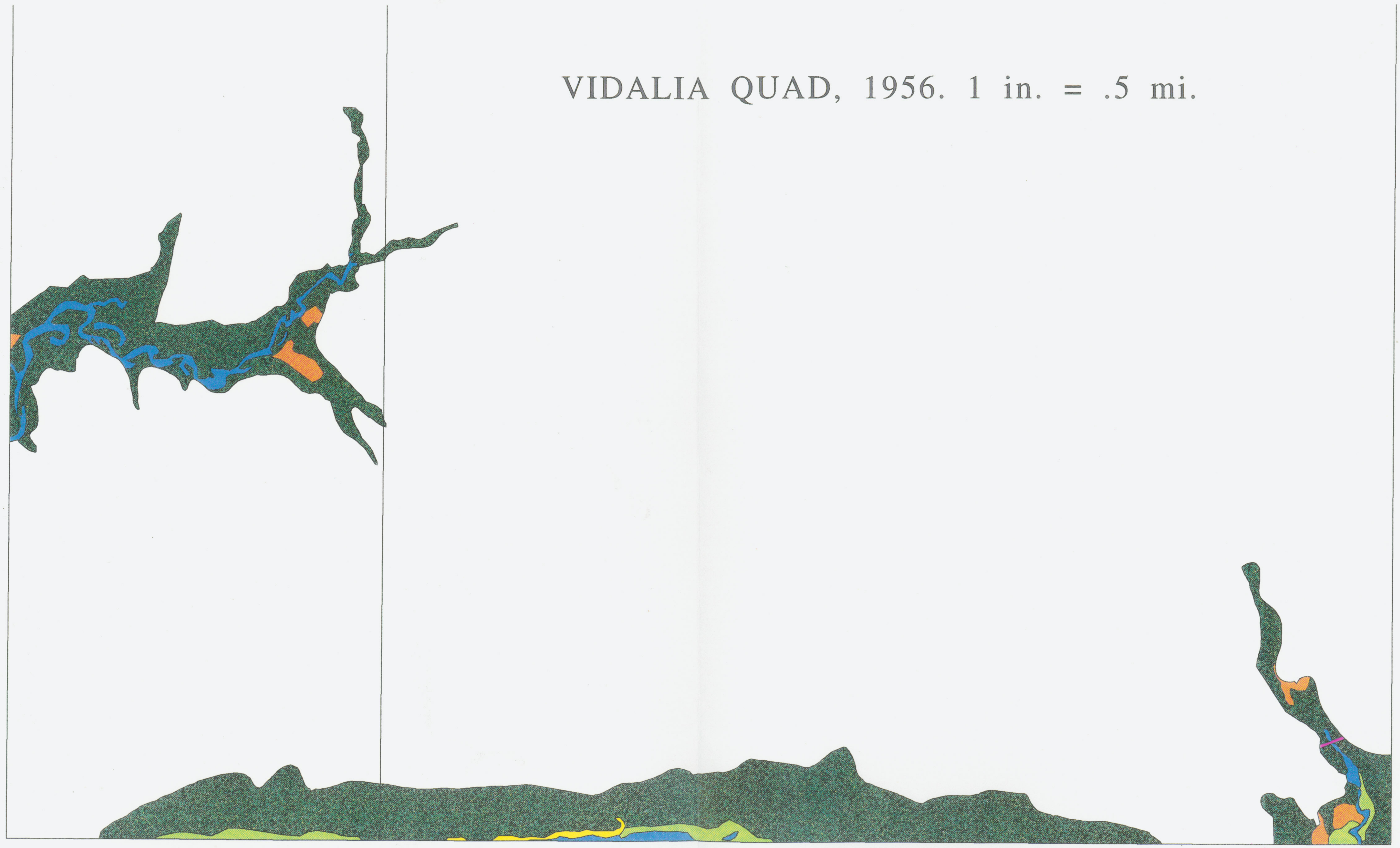
BAY ST. LOUIS QUAD (bottom), 1992. 1 in. = .5 mi.

BAY ST. LOUIS QUAD (top), 1956. 1 in. = .5 mi.

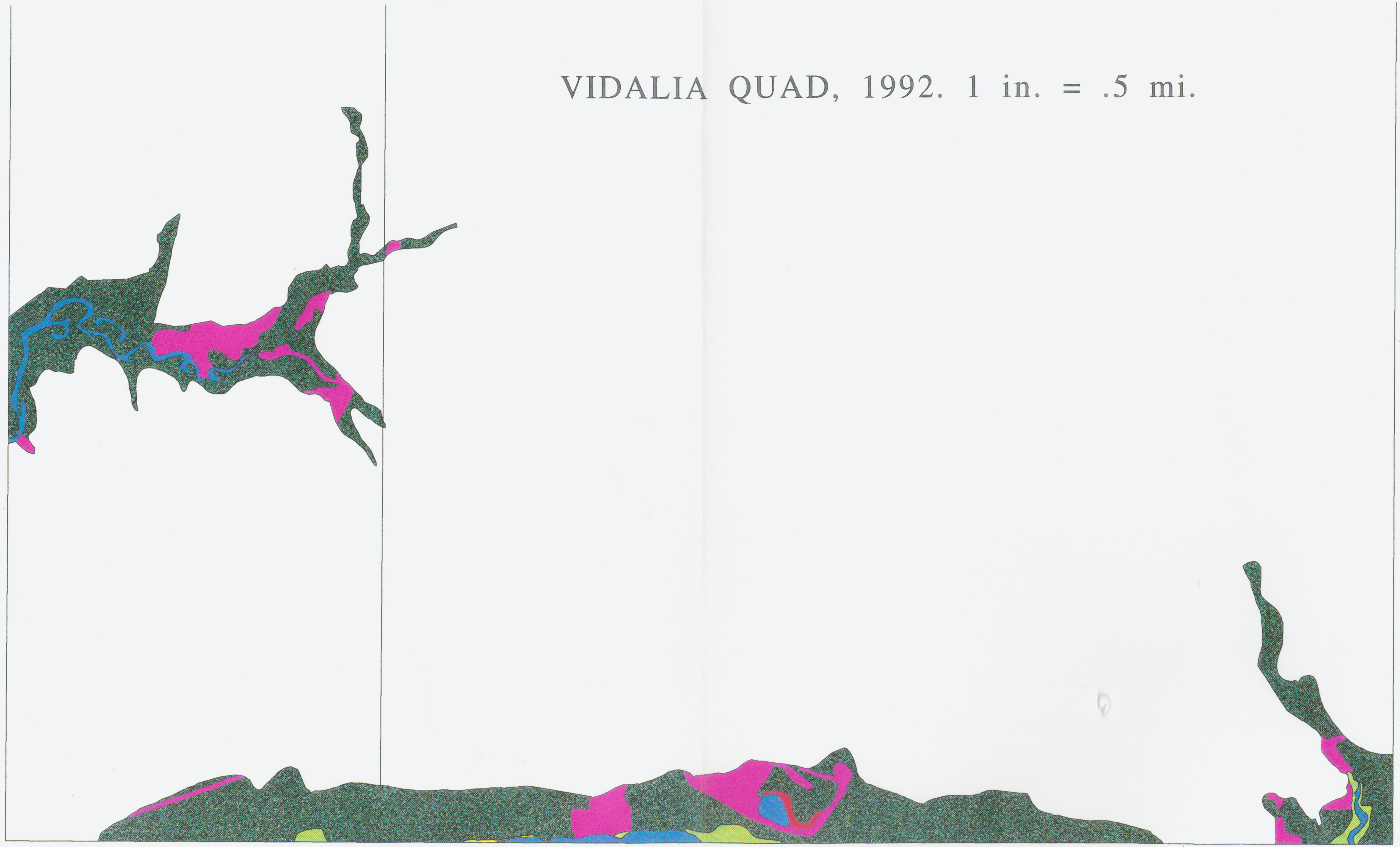
BAY ST. LOUIS QUAD (top), 1982. 1 in. = .5 mi.

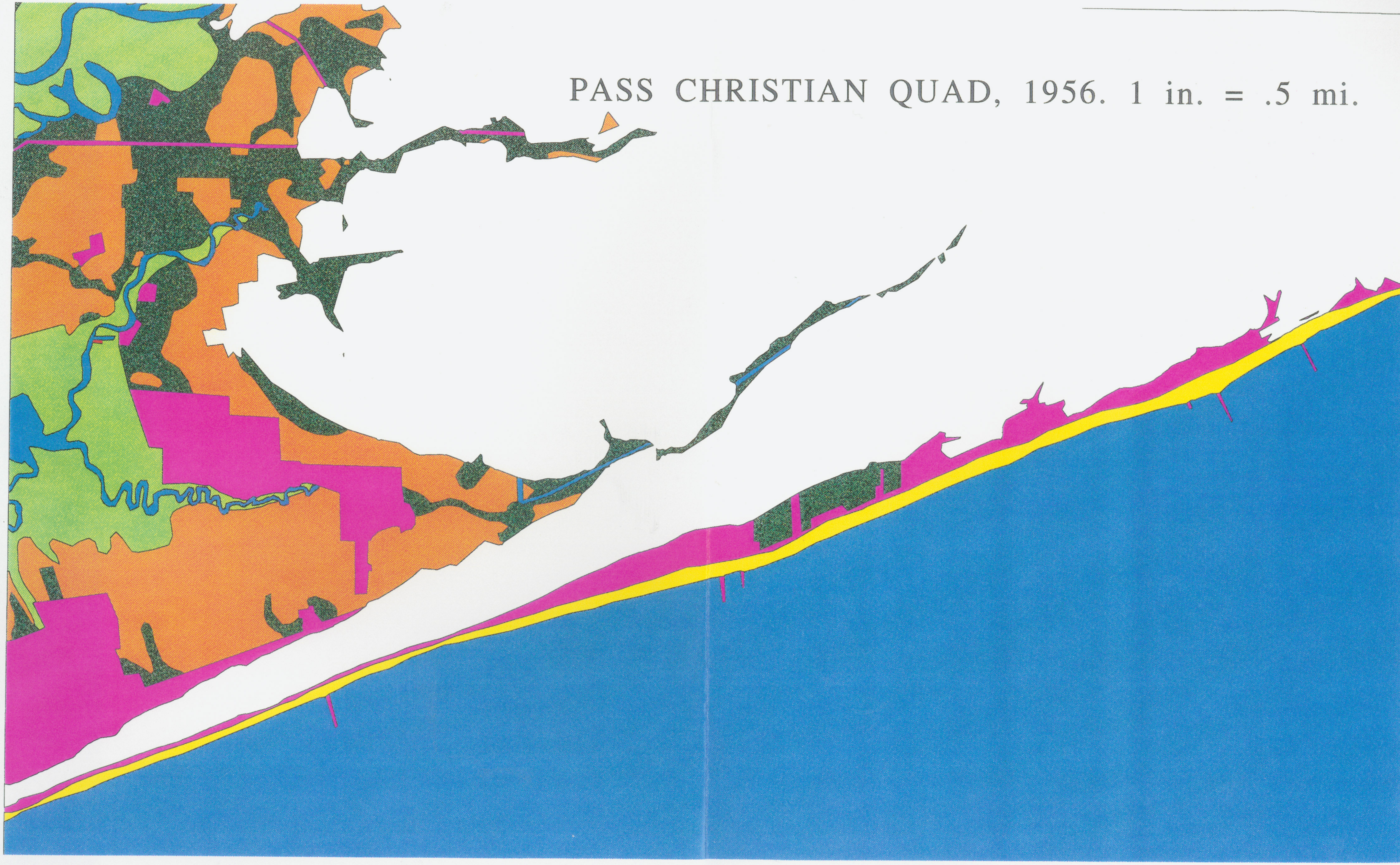
BAY ST. LOUIS QUAD (top), 1992. 1 in. = .5 mi.

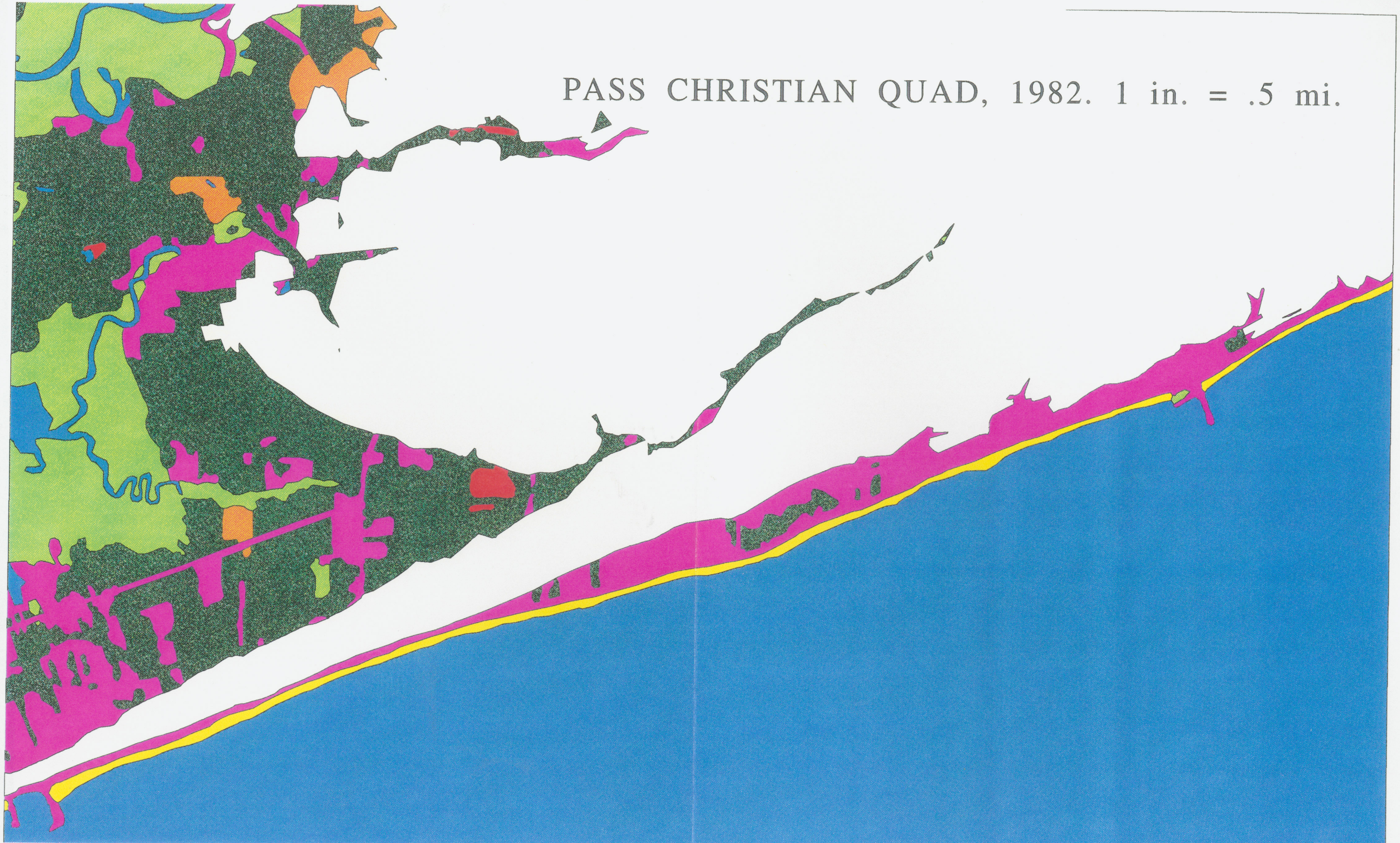
VIDALIA QUAD, 1956. 1 in. = .5 mi.

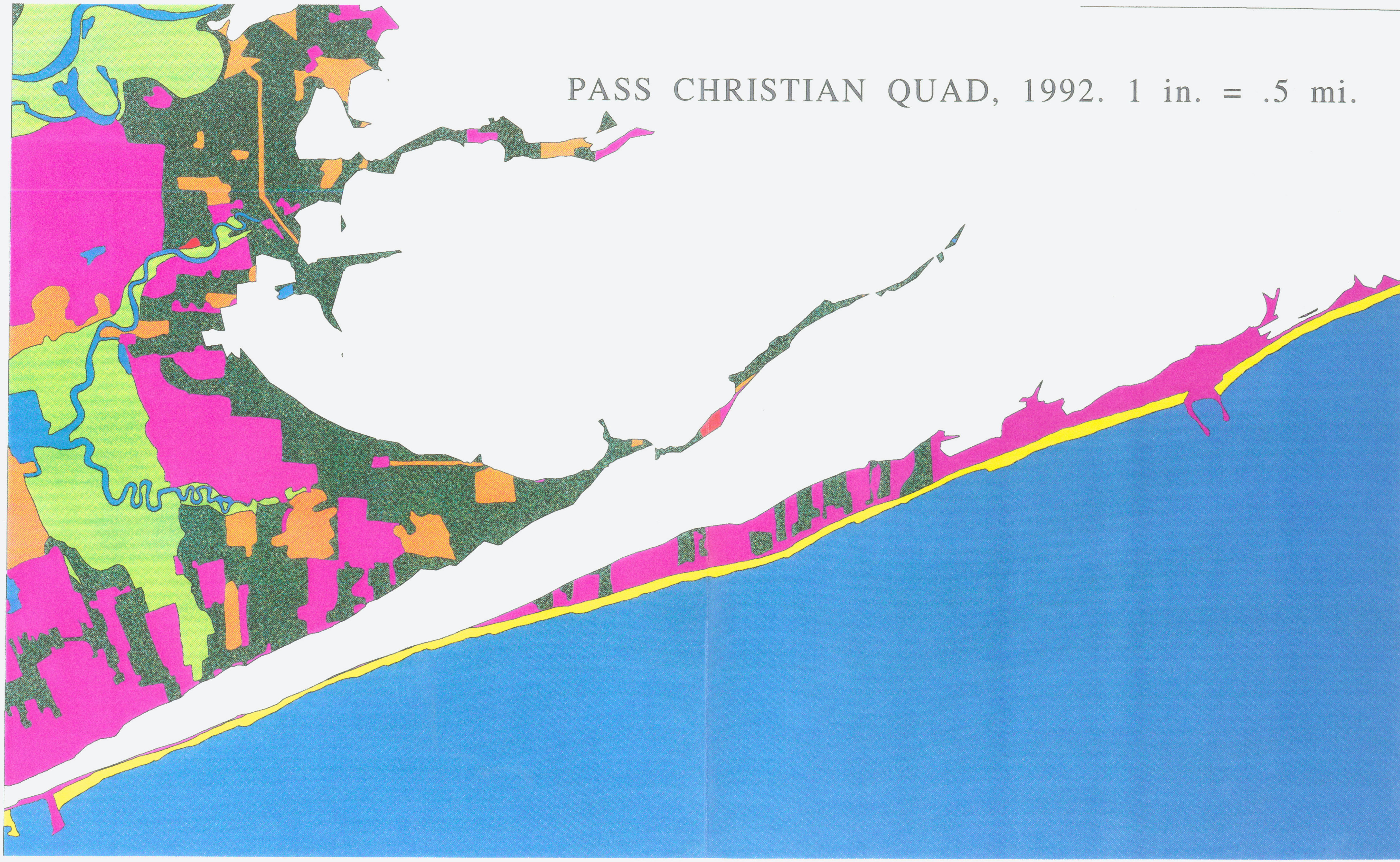


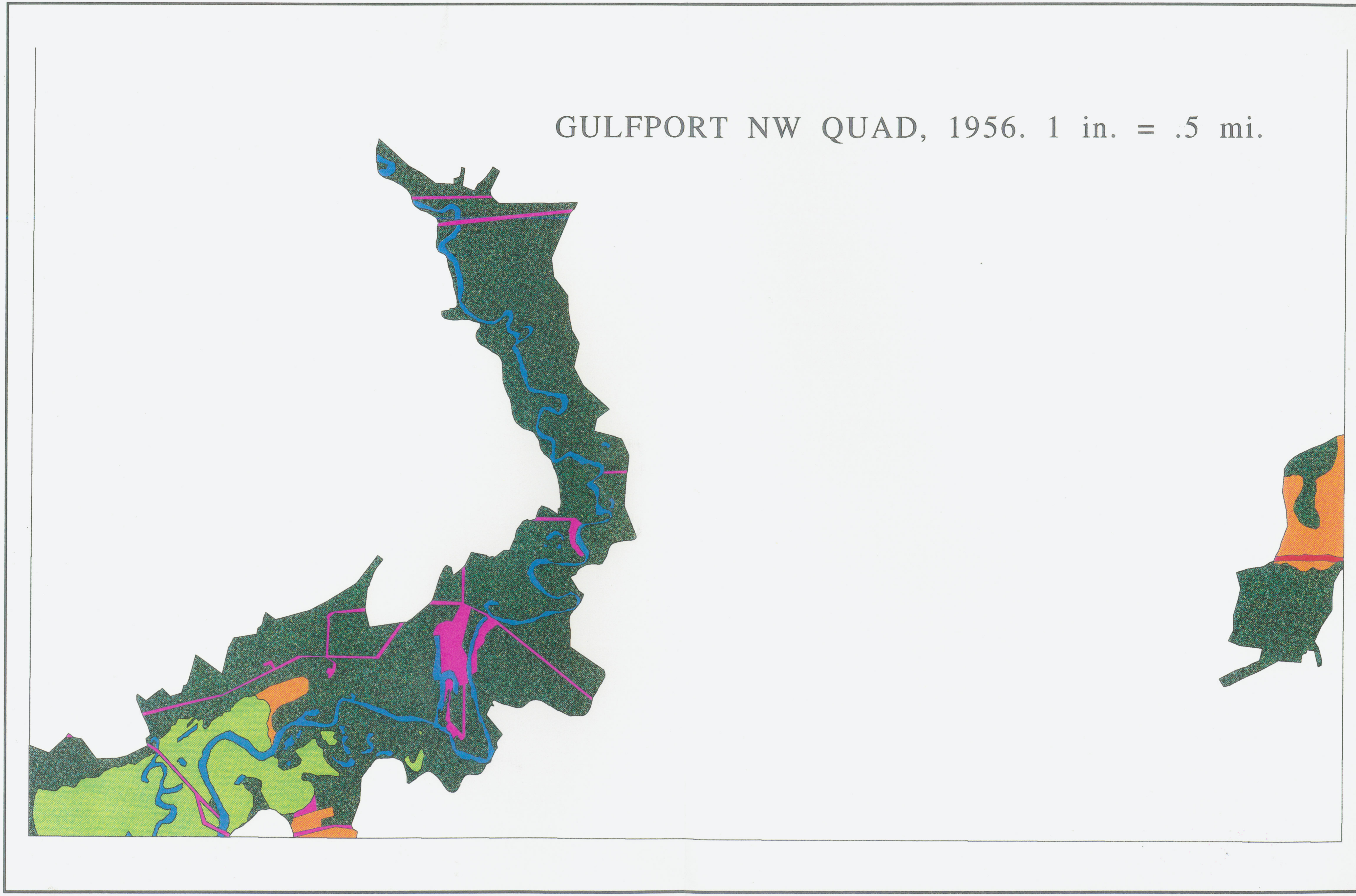
VIDALIA QUAD, 1992. 1 in. = .5 mi.



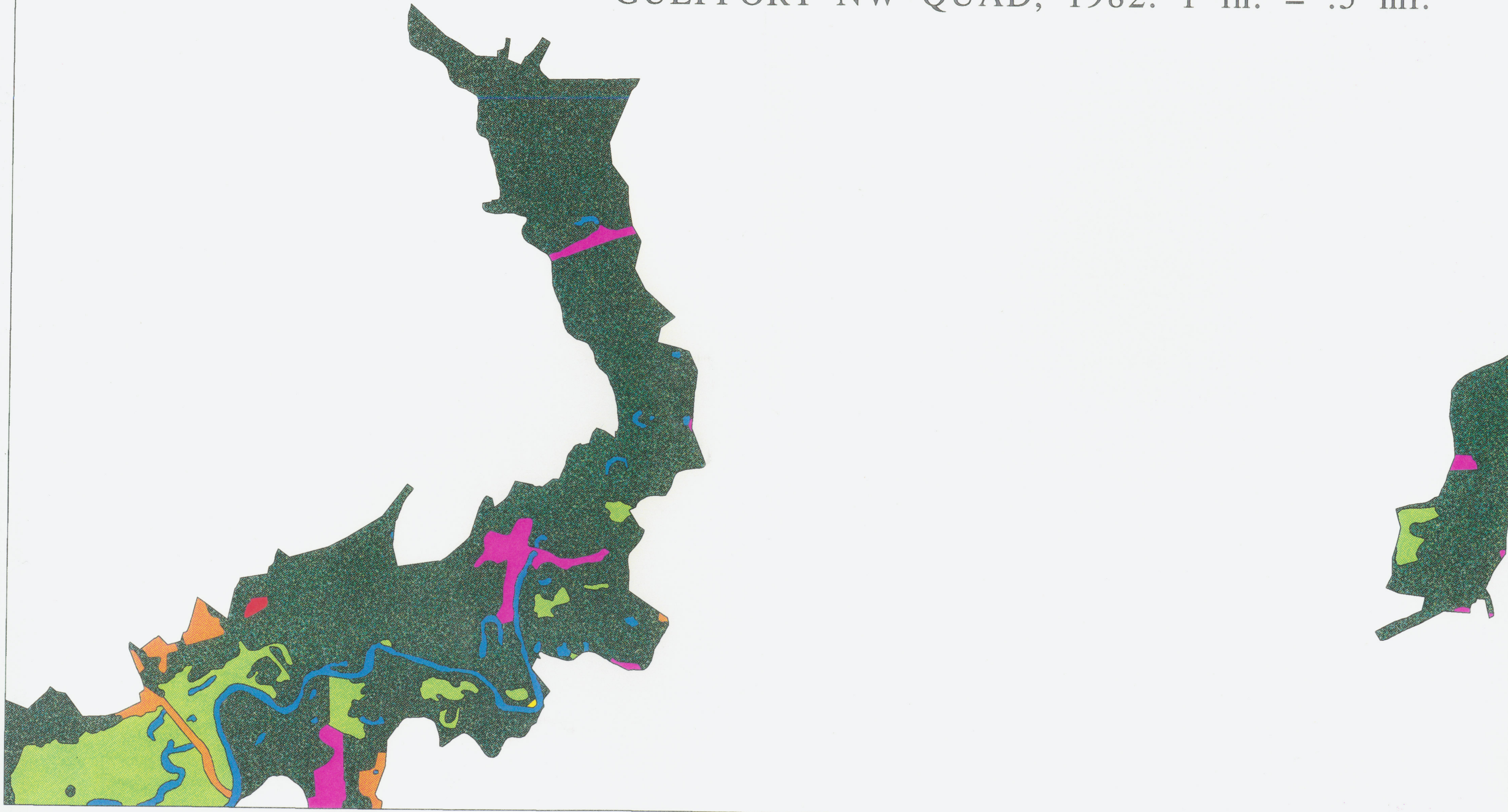

PASS CHRISTIAN QUAD, 1956. 1 in. = .5 mi.


PASS CHRISTIAN QUAD, 1982. 1 in. = .5 mi.


PASS CHRISTIAN QUAD, 1992. 1 in. = .5 mi.

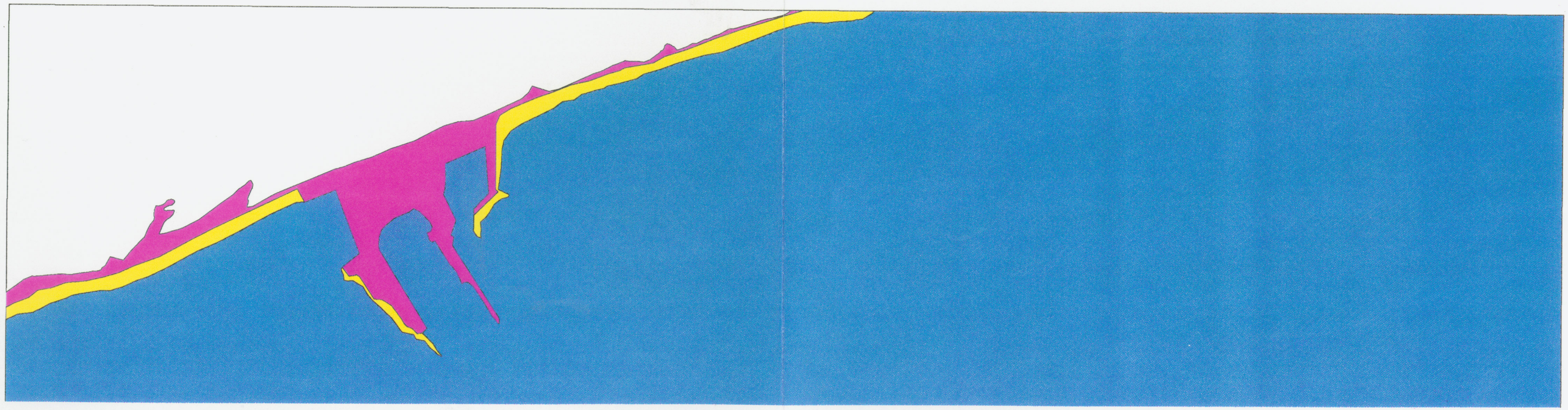

GULFPORT NW QUAD, 1956. 1 in. = .5 mi.

GULFPORT NW QUAD, 1982. 1 in. = .5 mi.



GULFPORT NW QUAD, 1992. 1 in. = .5 mi.

GULFPORT SOUTH QUAD, 1956. 1 in. = .5 mi.



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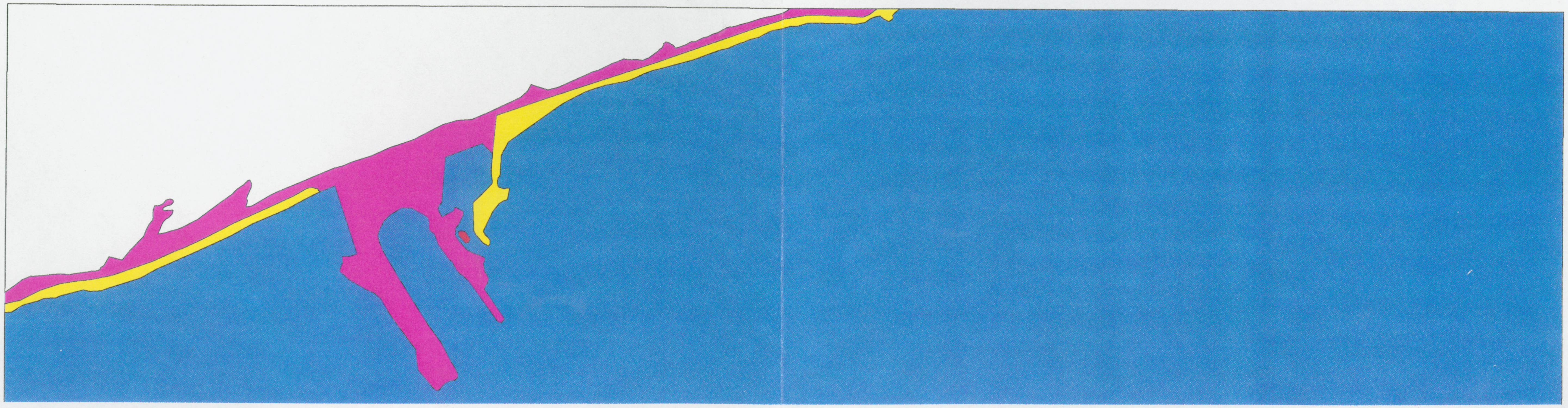
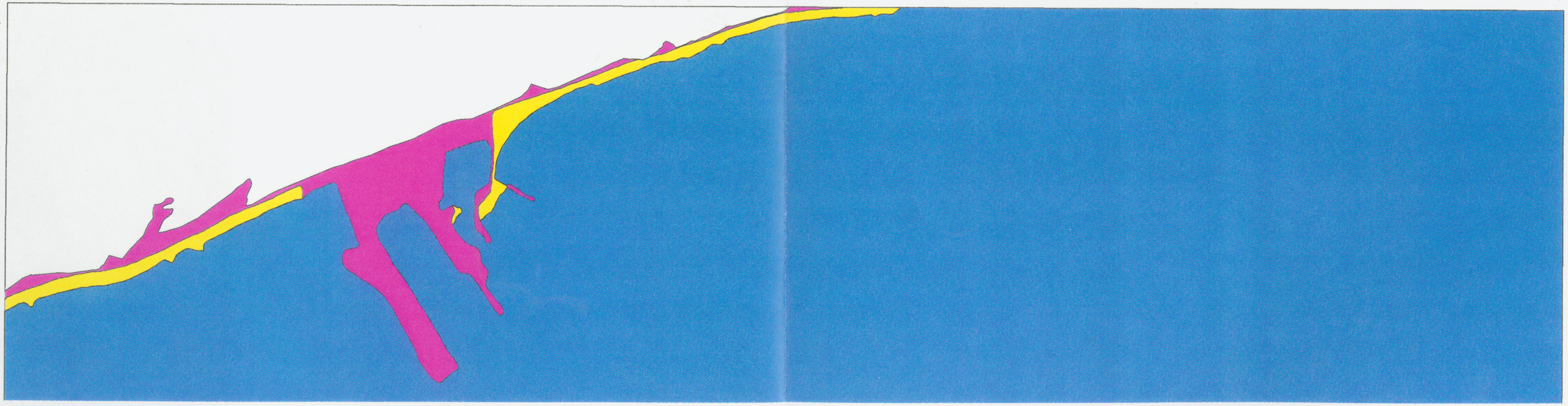
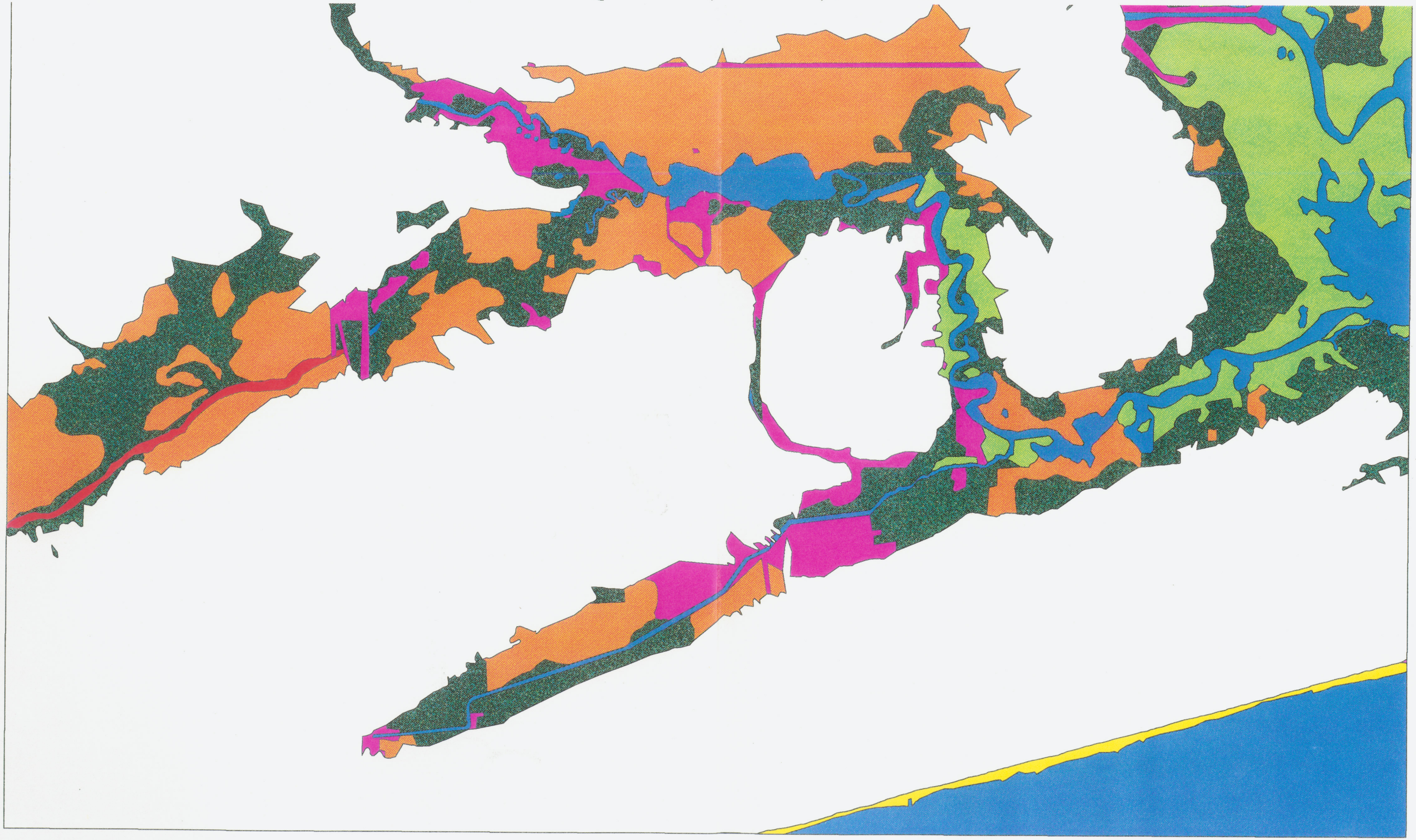


GULFPORT SOUTH QUAD, 1992. 1 in. = .5 mi.



GULFPORT NORTH QUAD (bottom), 1956. 1 in. = .5 mi.



GULFPORT NORTH QUAD (bottom), 1982. 1 in. = .5 mi.

GULFPORT NORTH QUAD (bottom), 1992. 1 in. = .5 mi.

GULFPORT NORTH QUAD (top), 1956. 1 in. = .5 mi.

GULFPORT NORTH QUAD (top), 1982. 1 in. = .5 mi.

GULFPORT NORTH QUAD (top), 1992. 1 in. = .5 mi.

BILOXI QUAD (bottom), 1956. 1 in. = .5 mi.

BILOXI QUAD (bottom), 1982. 1 in. = .5 mi.

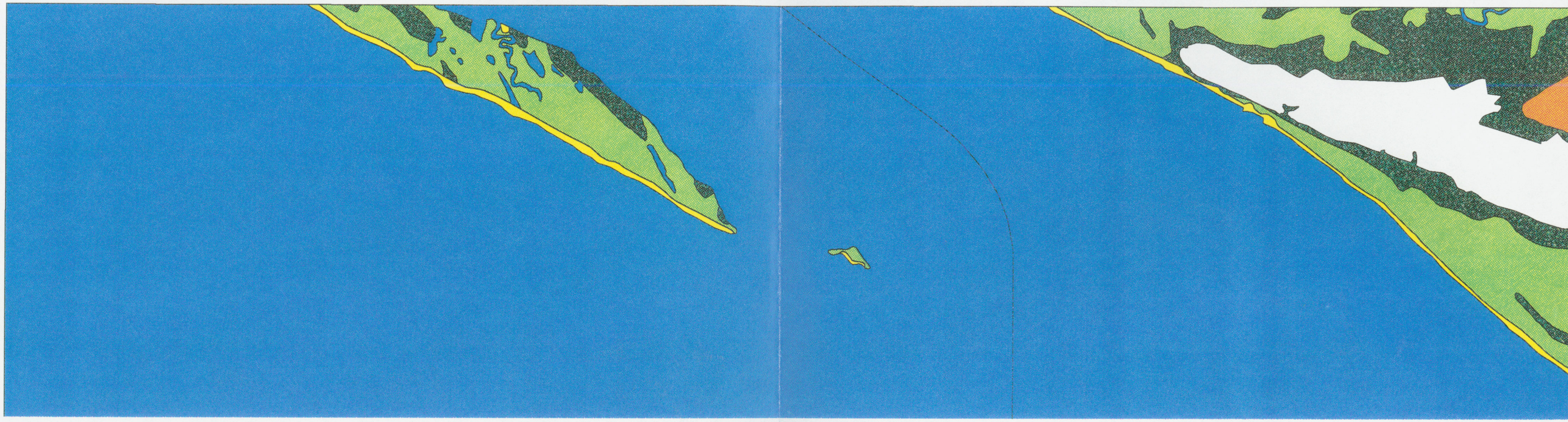
BILOXI QUAD (bottom), 1992. 1 in. = .5 mi.

BILOXI QUAD (top), 1956. 1 in. = .5 mi.

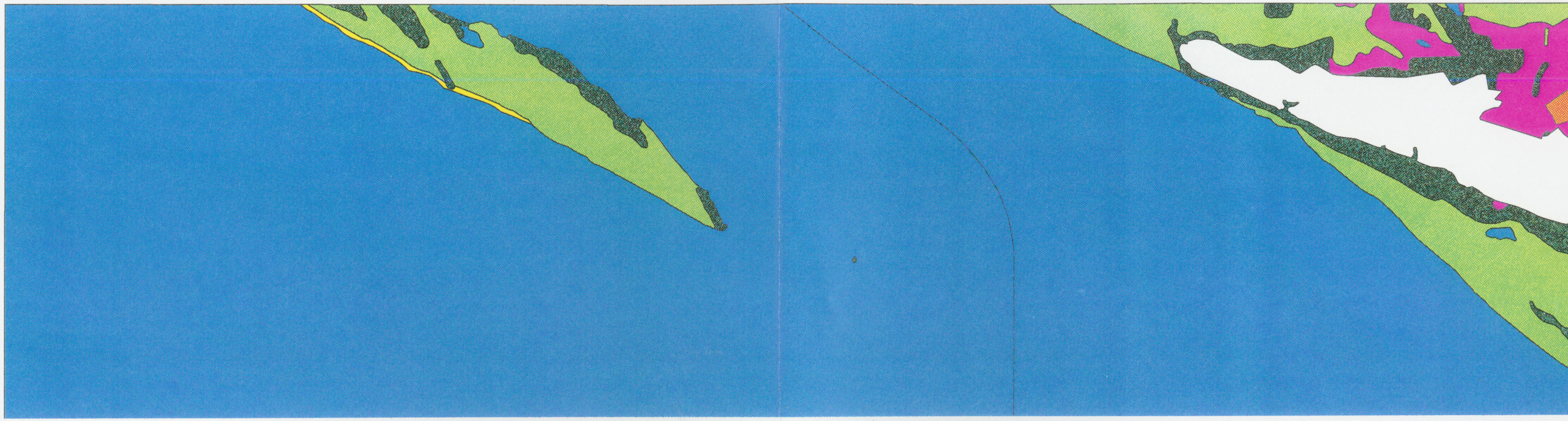
BILOXI QUAD (top), 1982. 1 in. = .5 mi.

BILOXI QUAD (top), 1992. 1 in. = .5 mi.

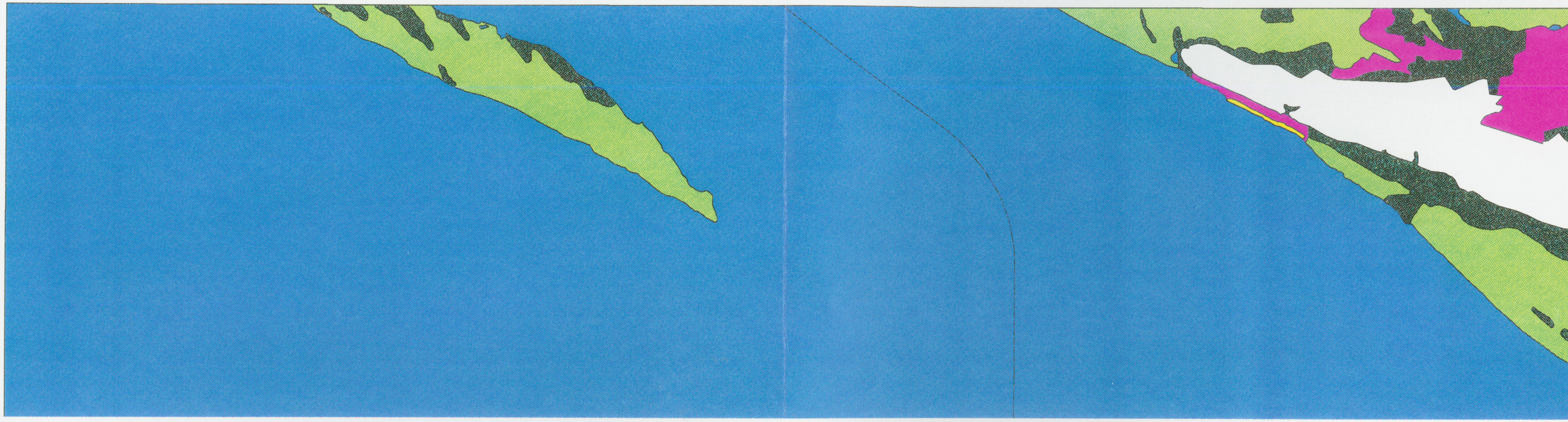
DEER ISLAND QUAD, 1956. 1 in. = .5 mi.

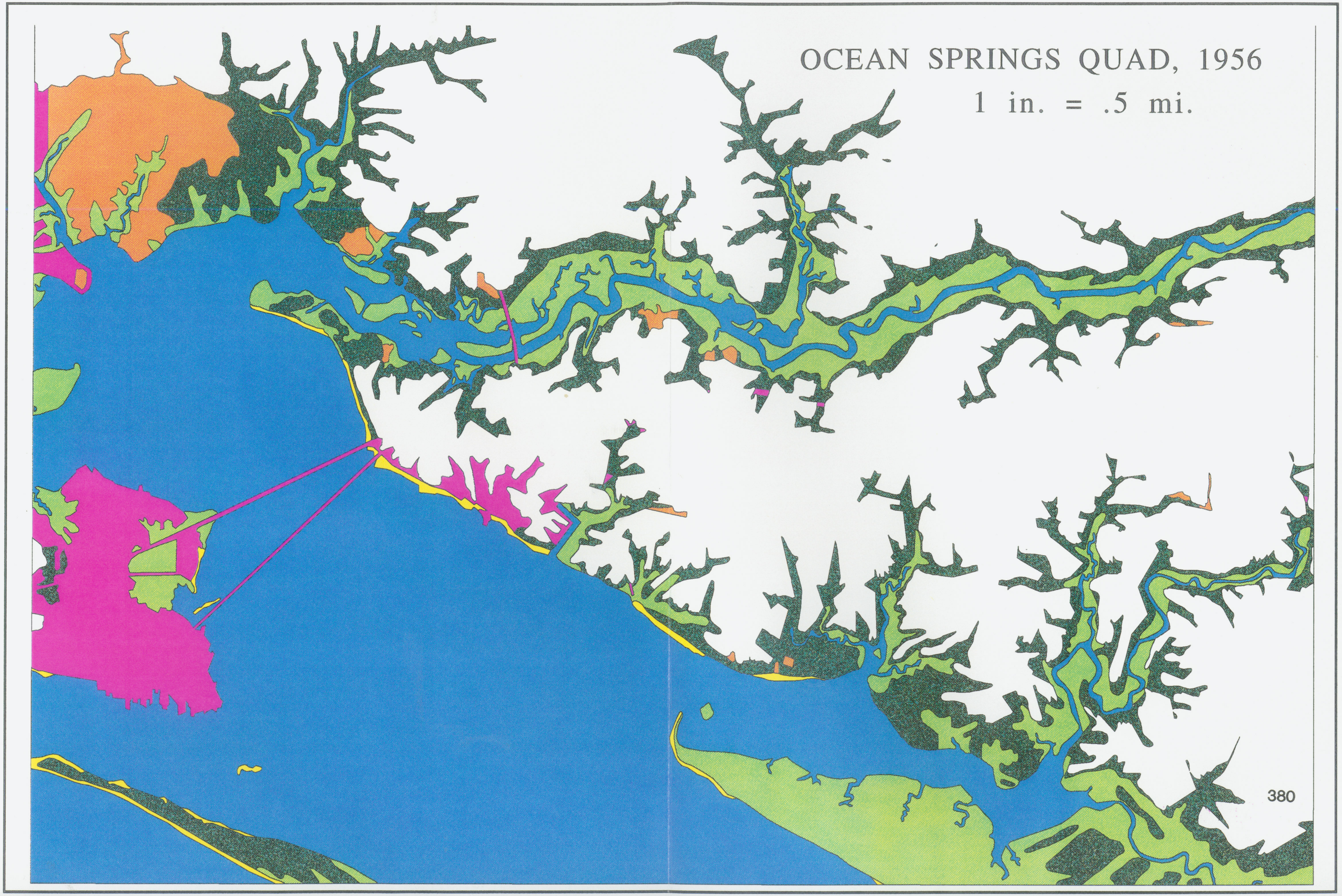


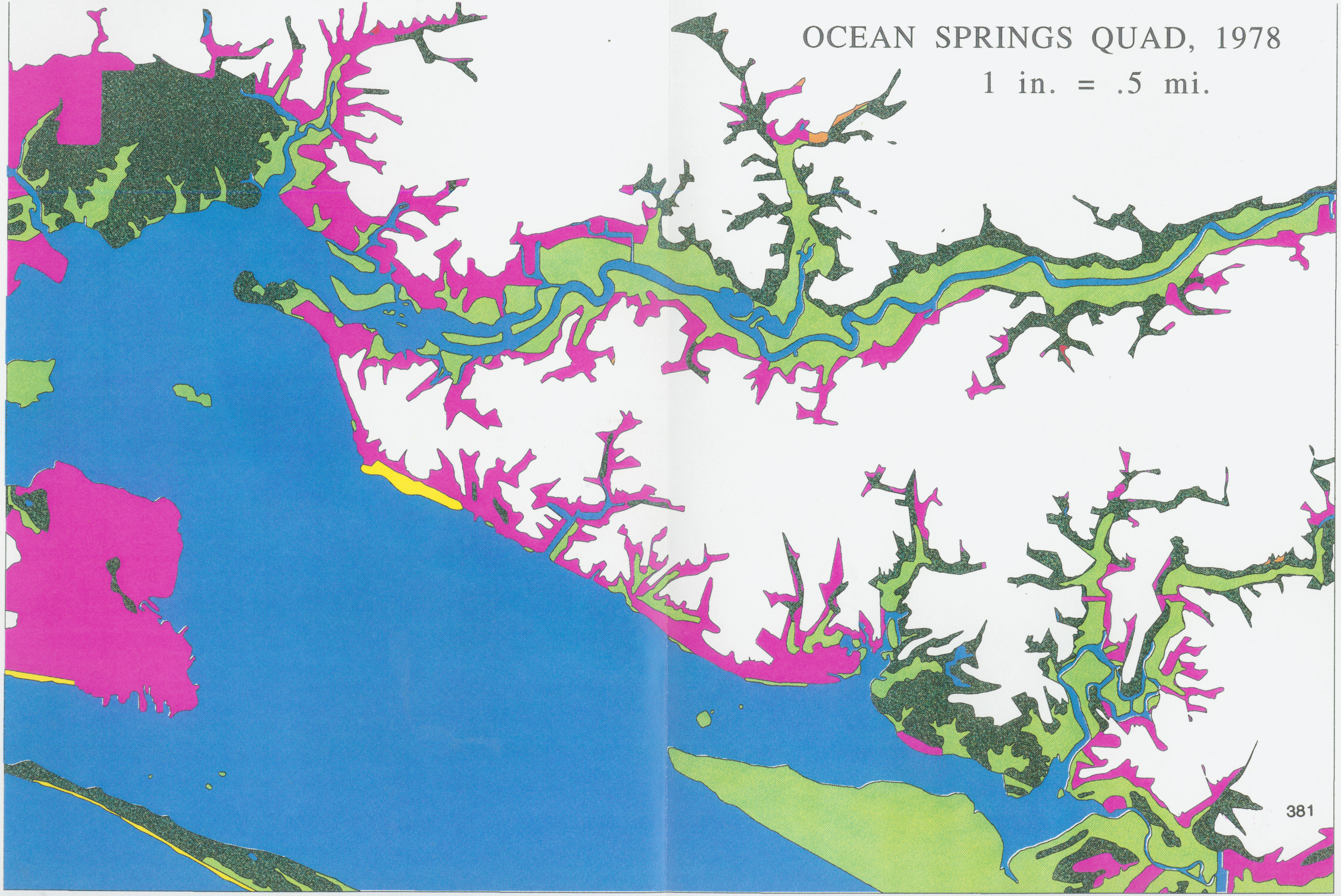
DEER ISLAND QUAD, 1978. 1 in. = .5 mi.



DEER ISLAND QUAD, 1992. 1 in. = .5 mi.

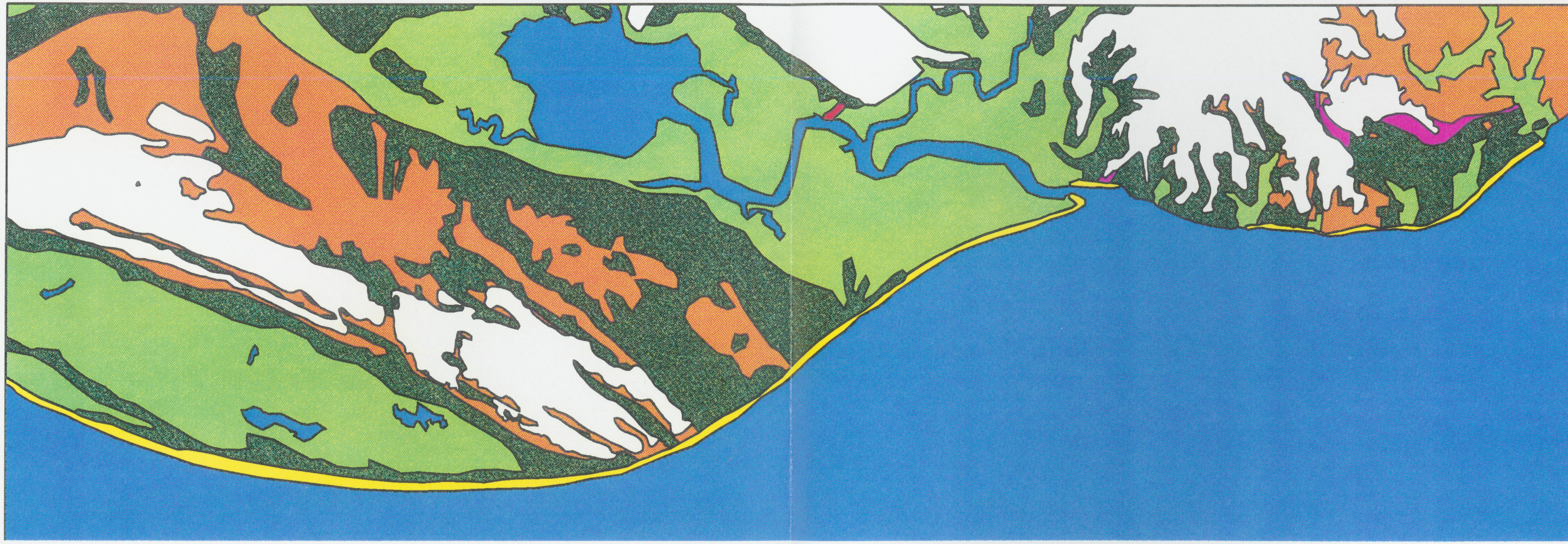



OCEAN SPRINGS QUAD, 1956
1 in. = .5 mi.

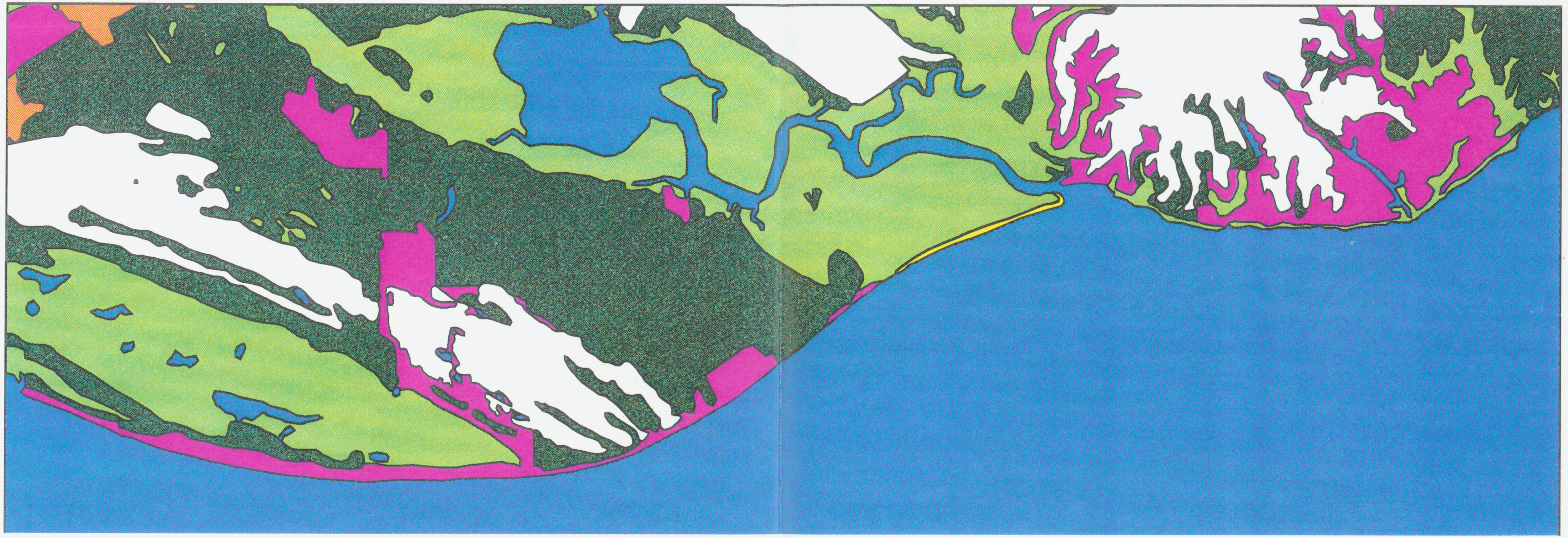

OCEAN SPRINGS QUAD, 1978
1 in. = .5 mi.


OCEAN SPRINGS QUAD, 1992
1 in. = .5 mi.

GAUTIER SOUTH QUAD, 1956. 1 in. = .5 mi.



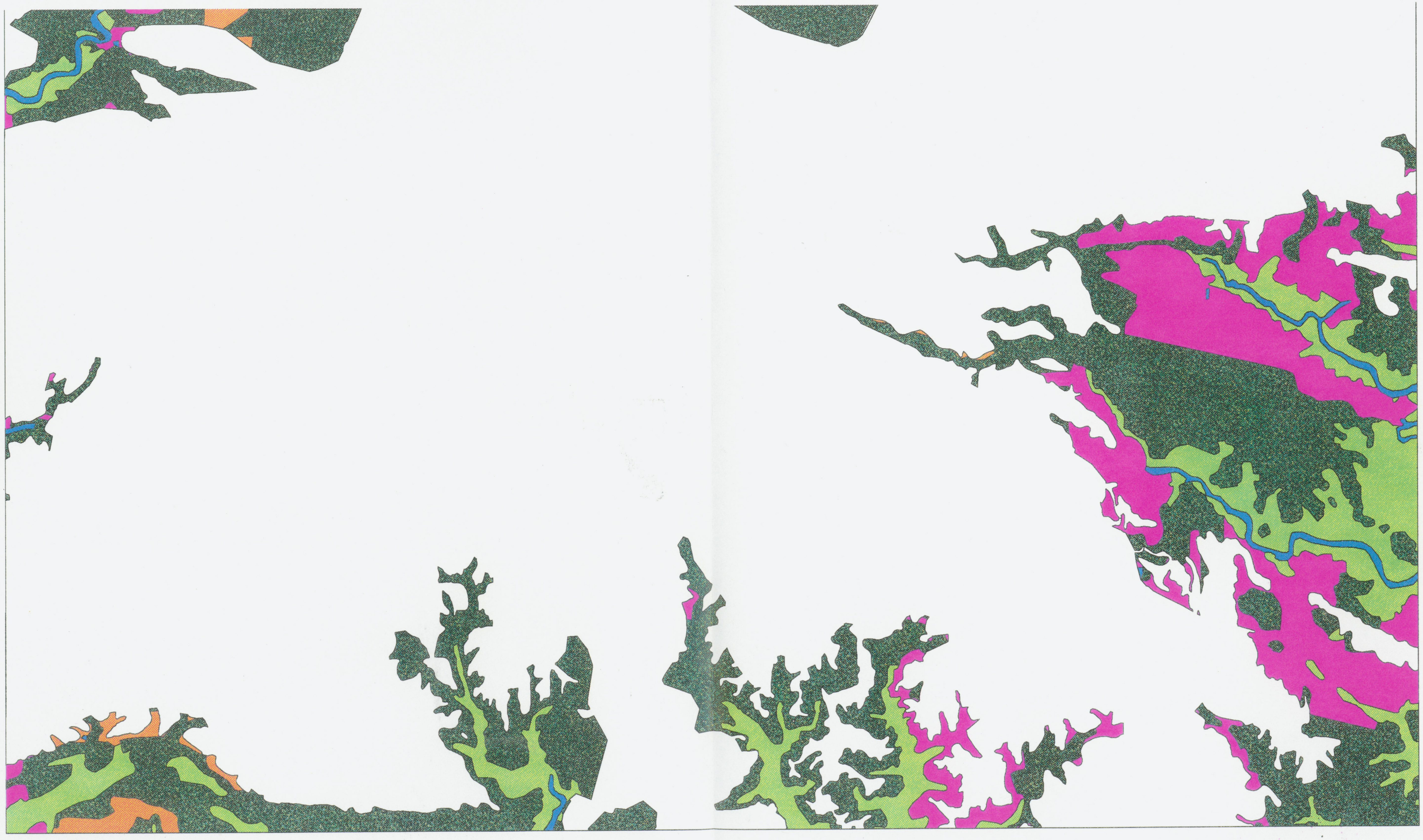
GAUTIER SOUTH QUAD, 1978. 1 in. = .5 mi.



GAUTIER SOUTH QUAD, 1992. 1 in. = .5 mi.

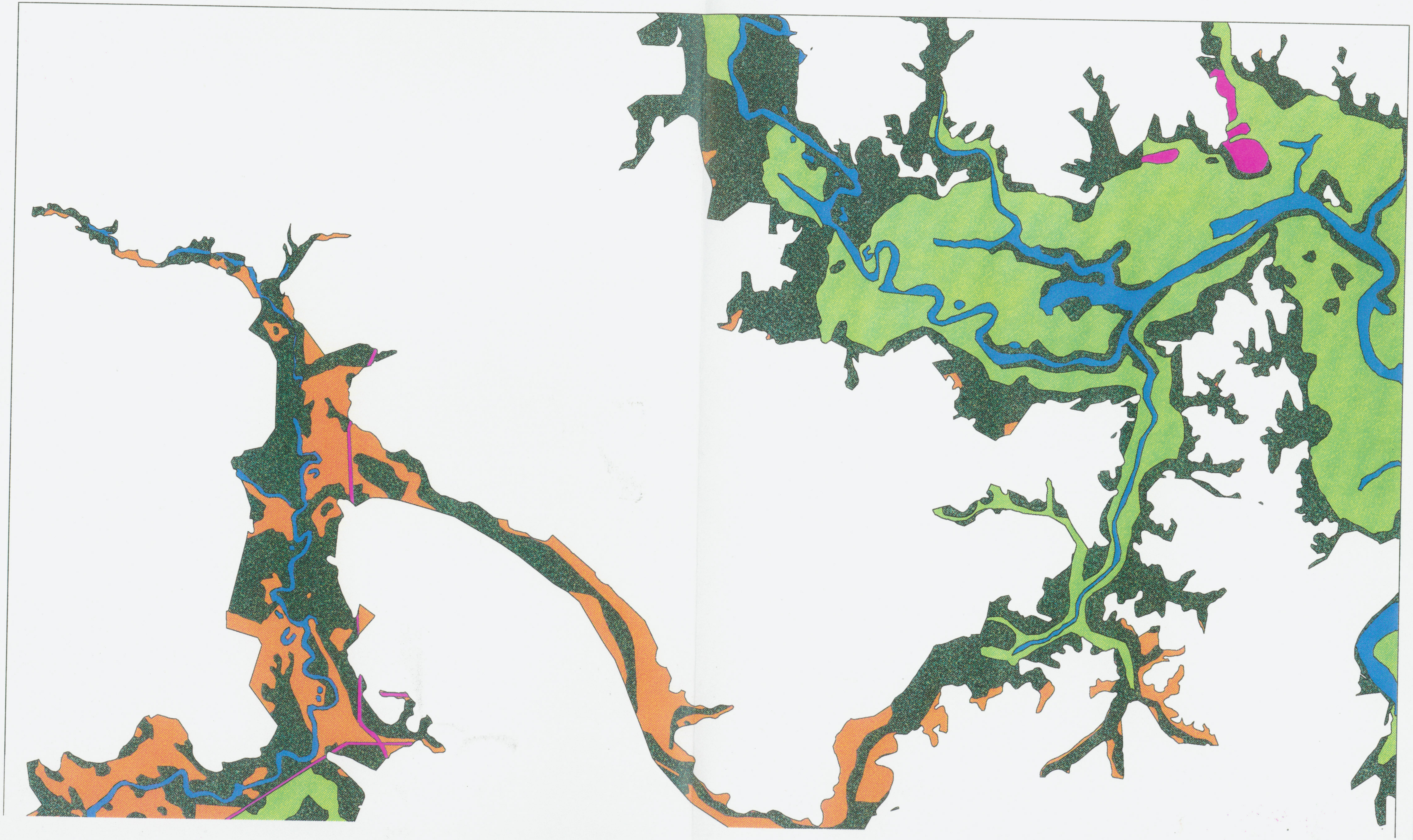
GAUTIER NORTH QUAD (bottom), 1956. 1 in. = .5 mi.

GAUTIER NORTH QUAD (bottom), 1978. 1 in. = .5 mi.

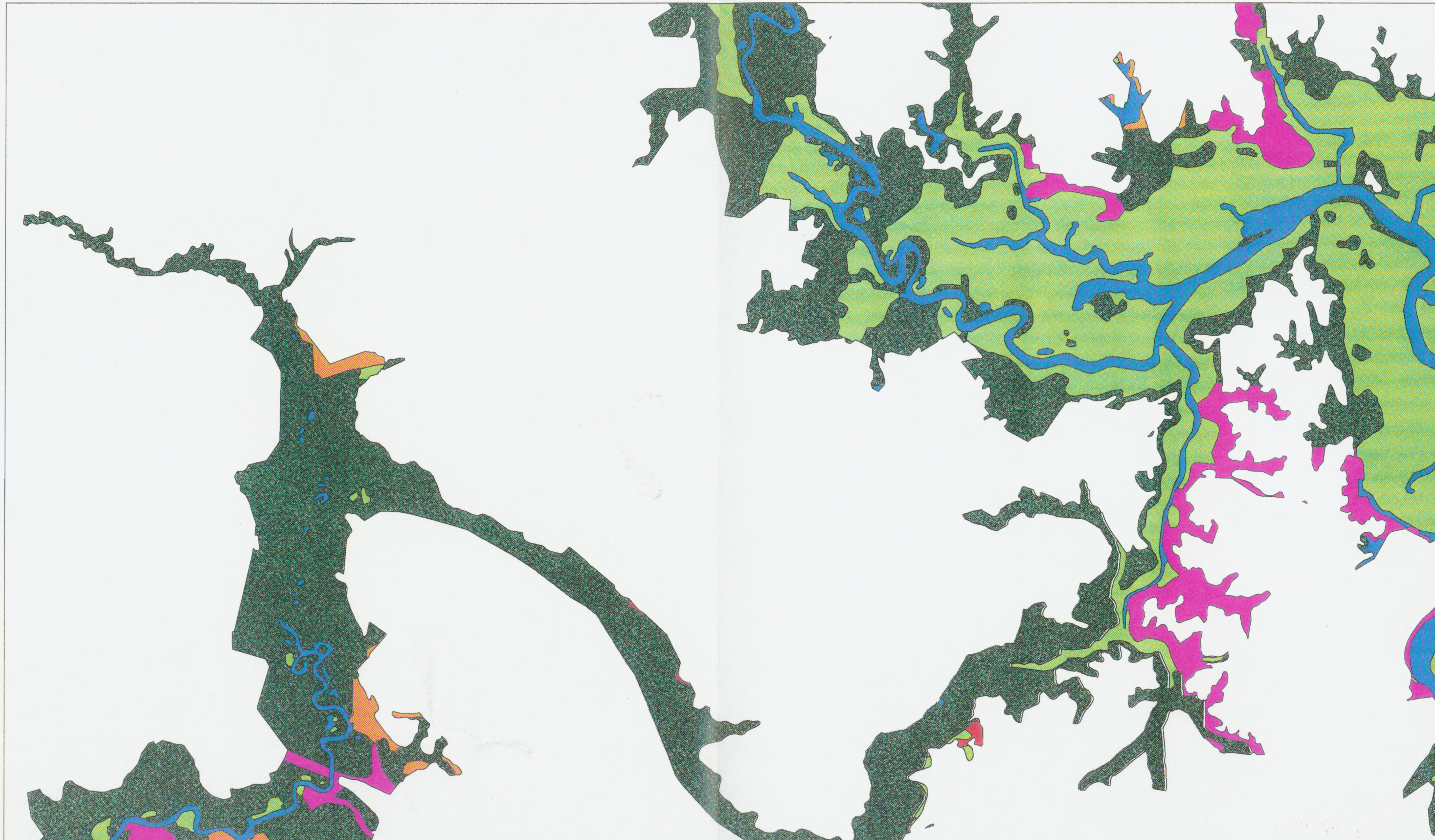


GAUTIER NORTH QUAD (bottom), 1992. 1 in. = .5 mi.

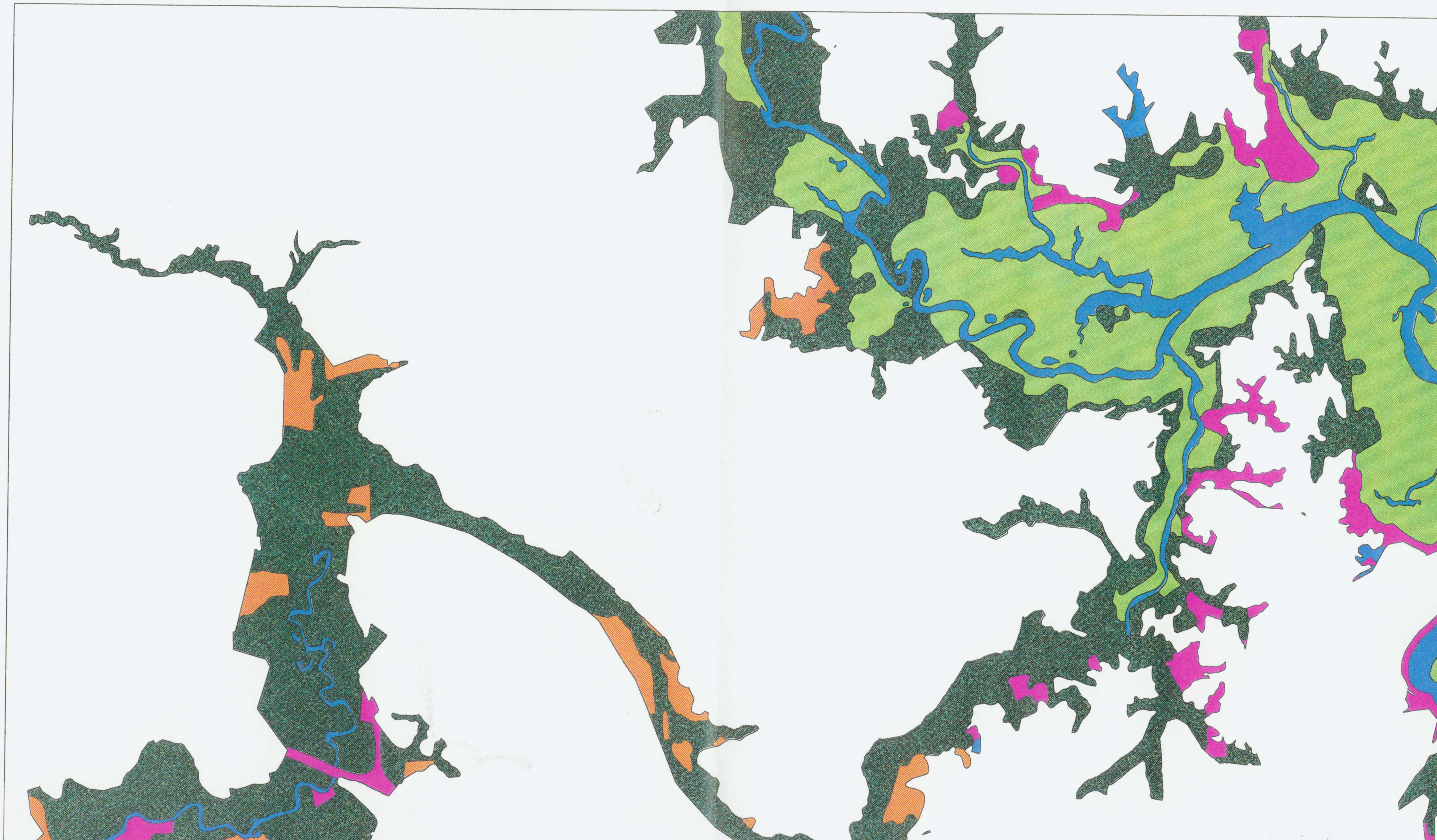
GAUTIER NORTH QUAD (top), 1956. 1 in. = .5 mi.



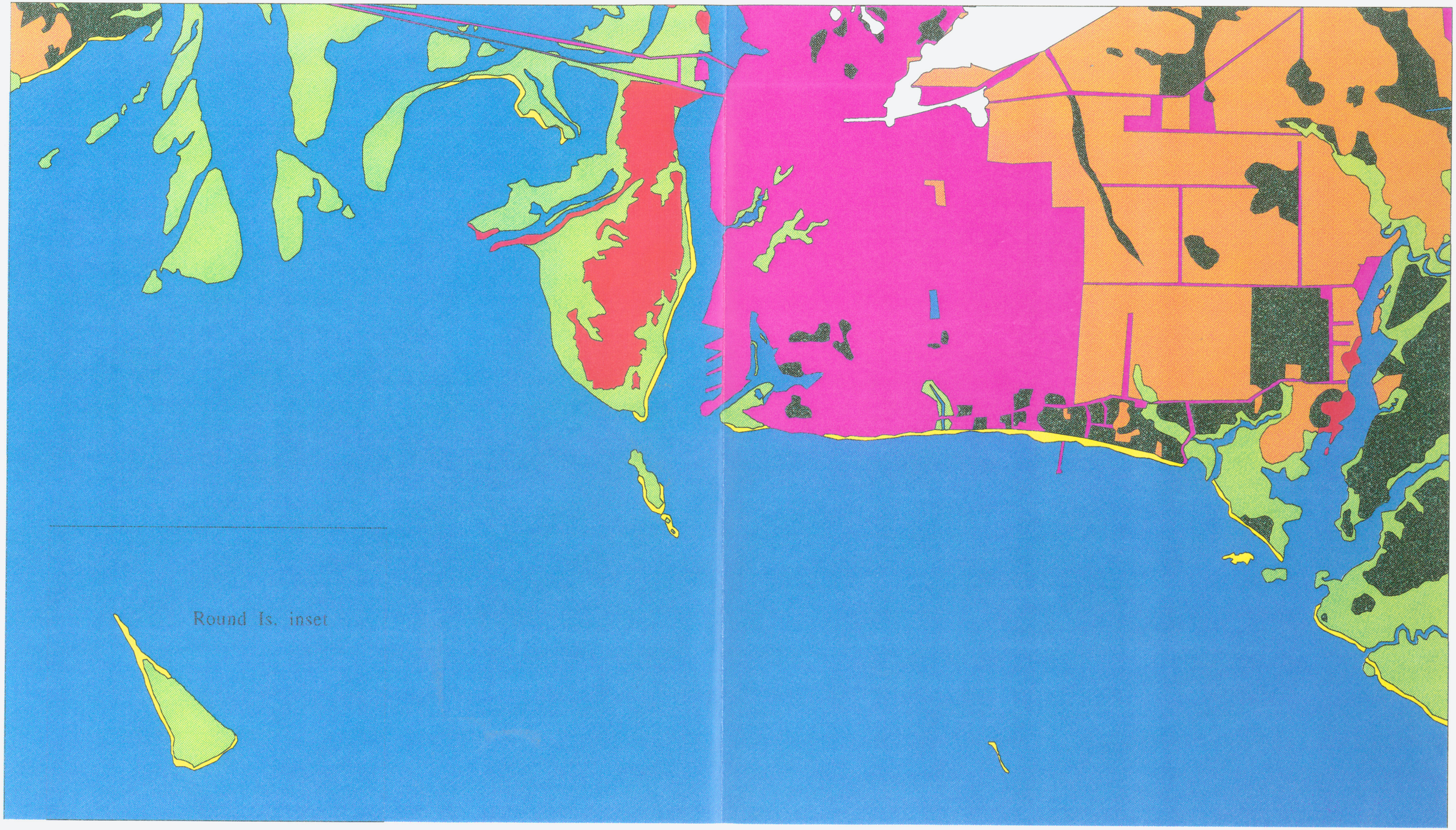
GAUTIER NORTH QUAD (top), 1978. 1 in. = .5 mi.



GAUTIER NORTH QUAD (top), 1992. 1 in. = .5 mi.



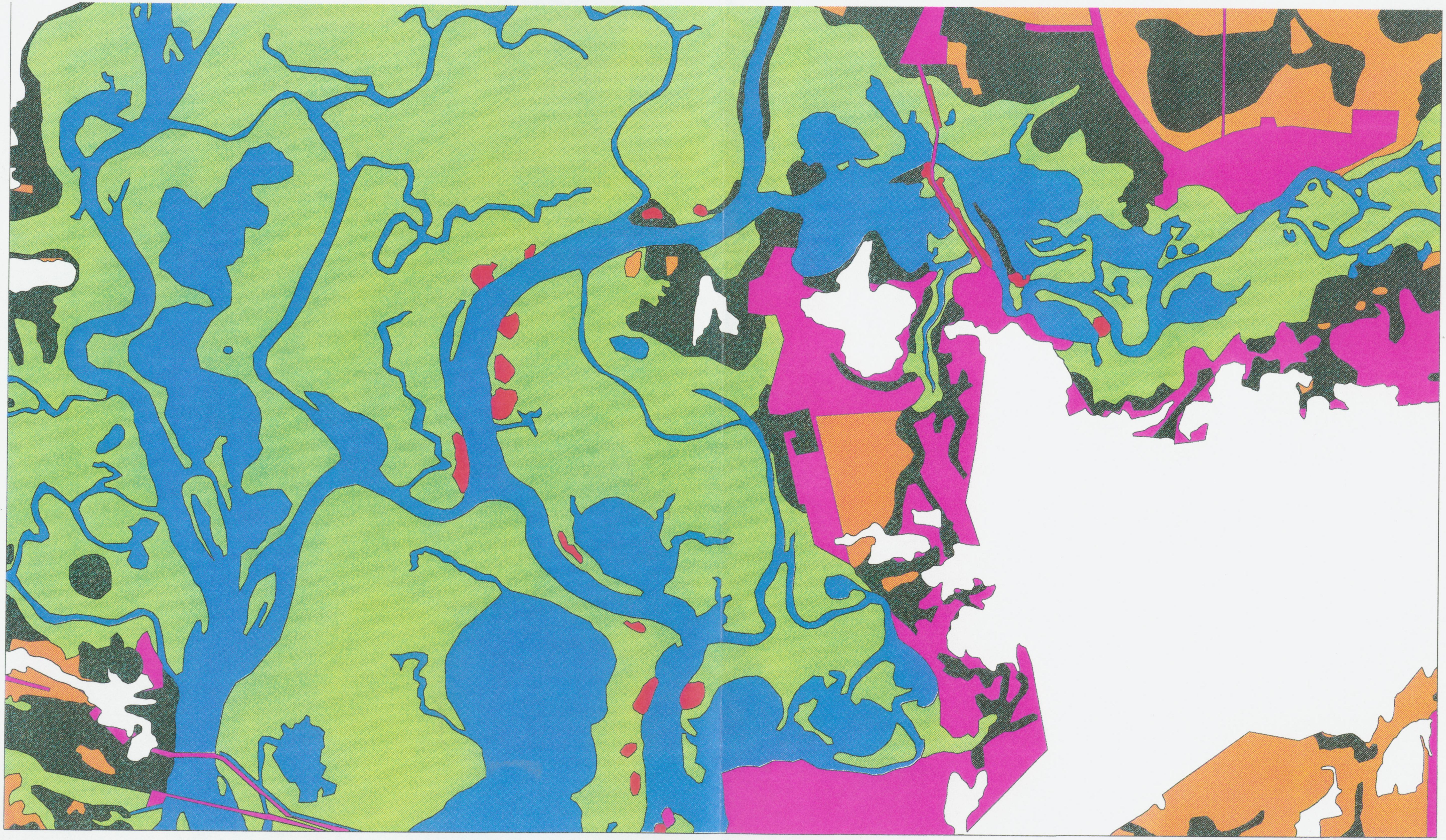
PASCAGOULA SOUTH QUAD, 1956. 1 in. = .5 mi.



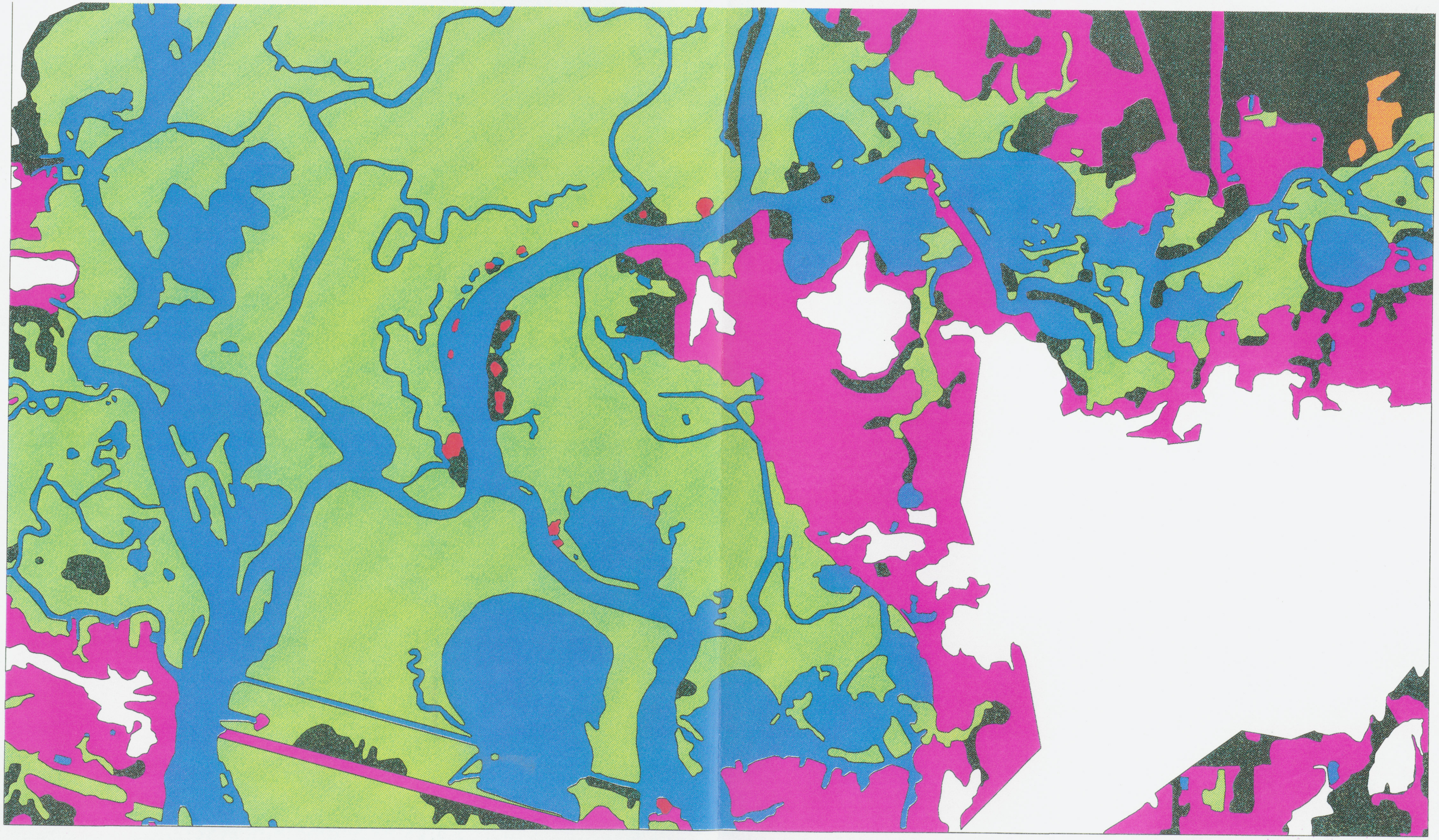
PASCAGOULA SOUTH QUAD, 1978. 1 in. = .5 mi.

PASCAGOULA SOUTH QUAD, 1992. 1 in. = .5 mi.

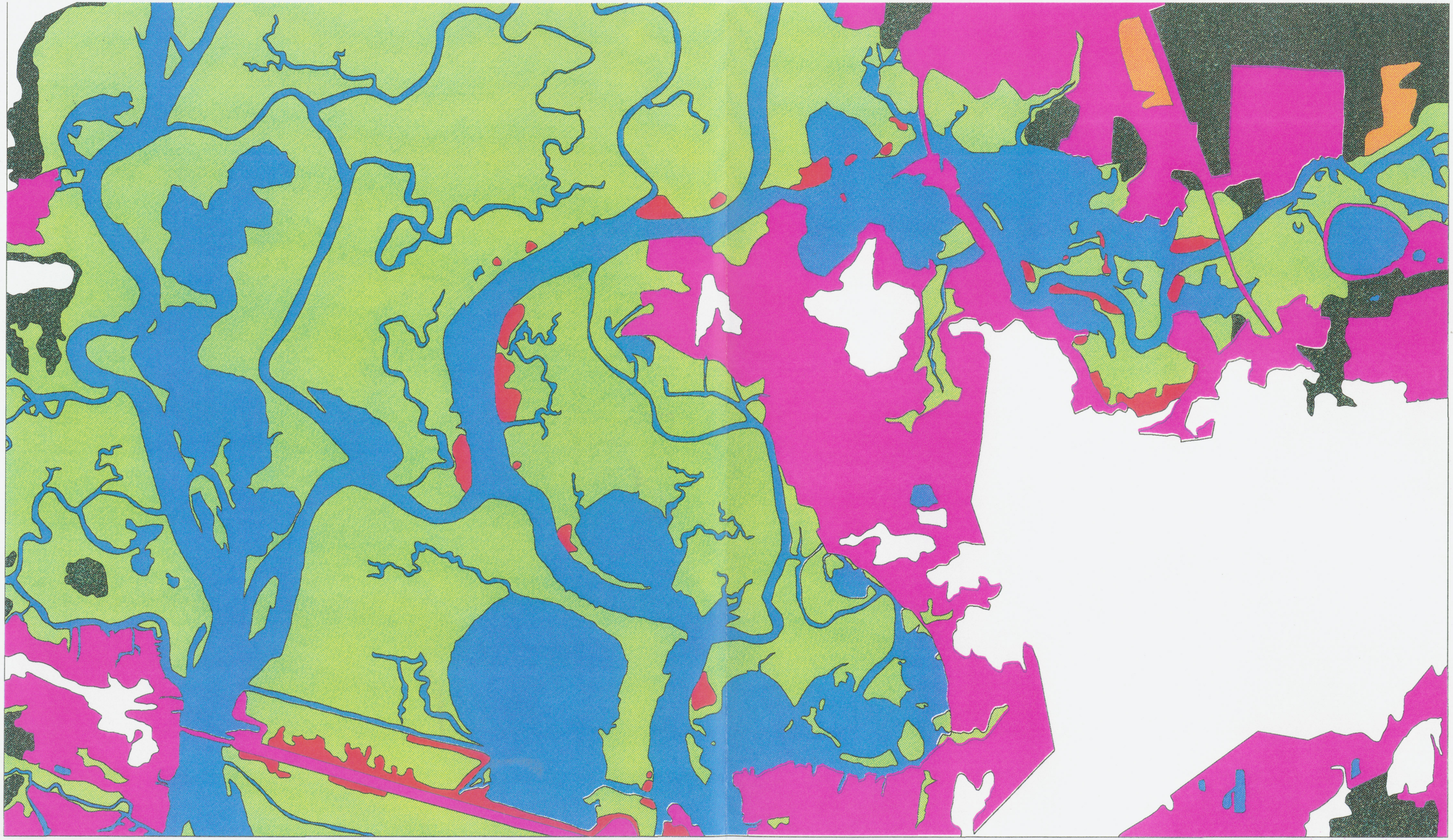
PASCAGOULA NORTH QUAD (bottom), 1956. 1 in. = .5 mi.



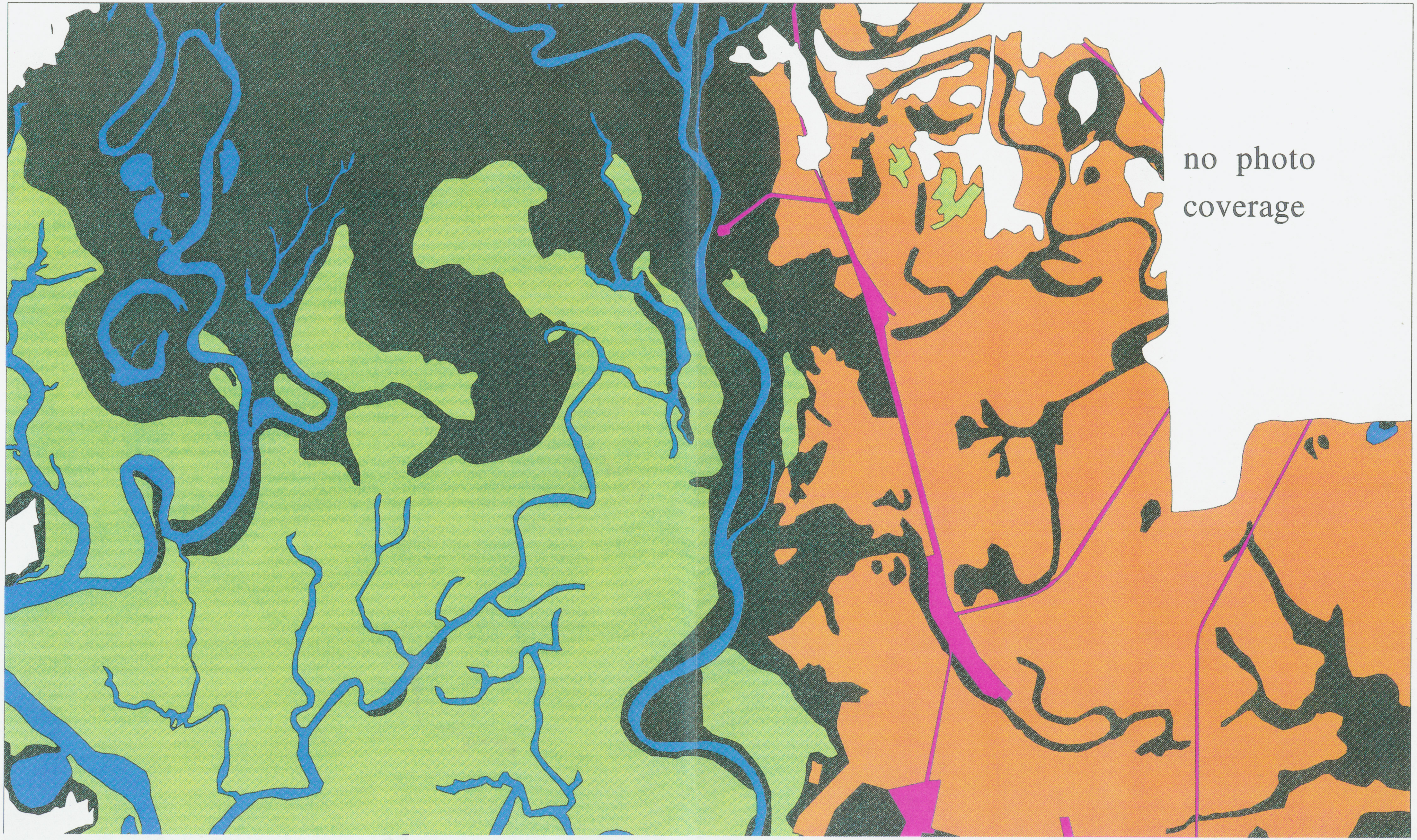
PASCAGOULA NORTH QUAD (bottom), 1978. 1 in. = .5 mi.



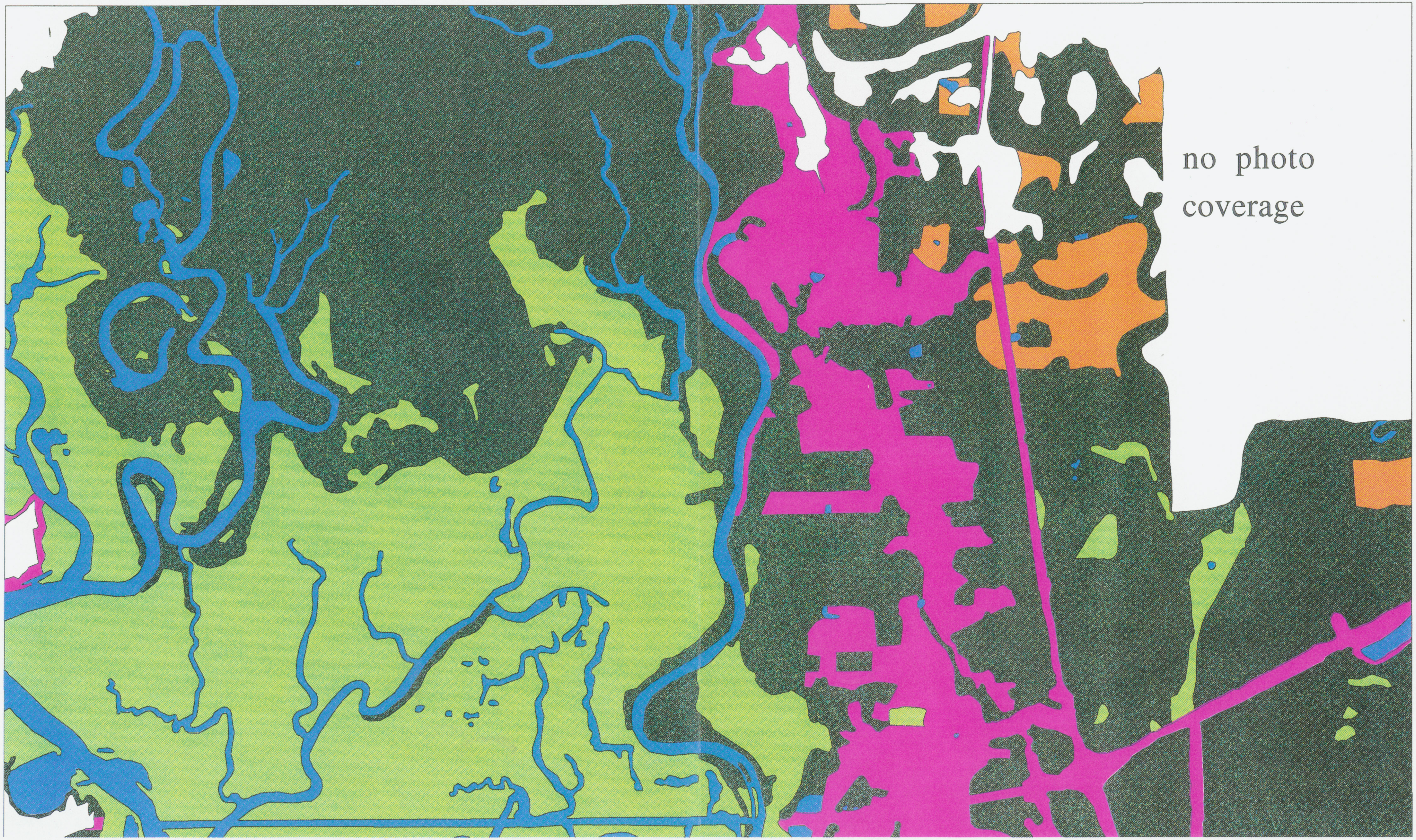
PASCAGOULA NORTH QUAD (bottom), 1992. 1 in. = .5 mi.



PASCAGOULA NORTH QUAD (top), 1956. 1 in. = .5 mi.

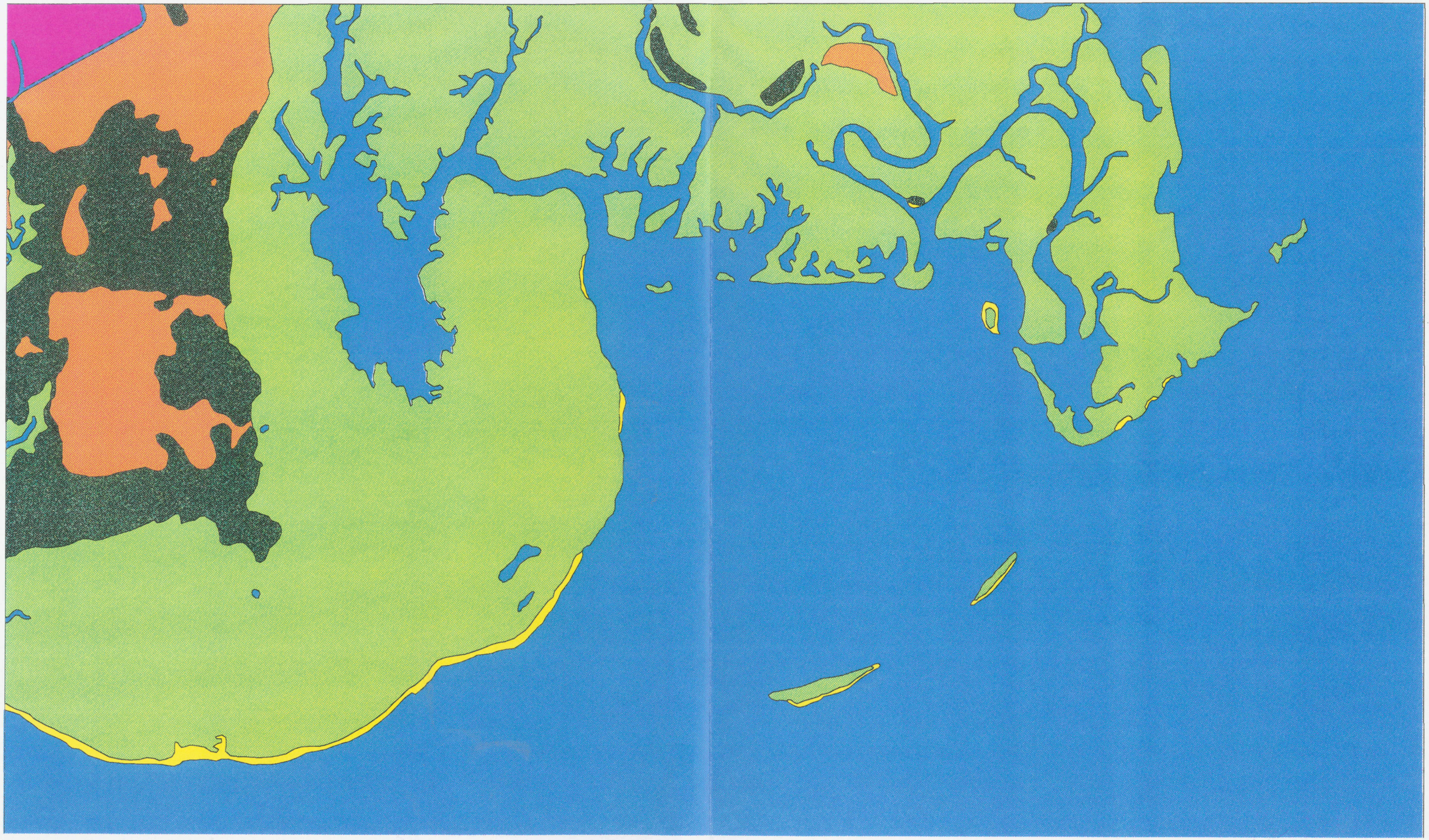


PASCAGOULA NORTH QUAD (top), 1978. 1 in. = .5 mi.

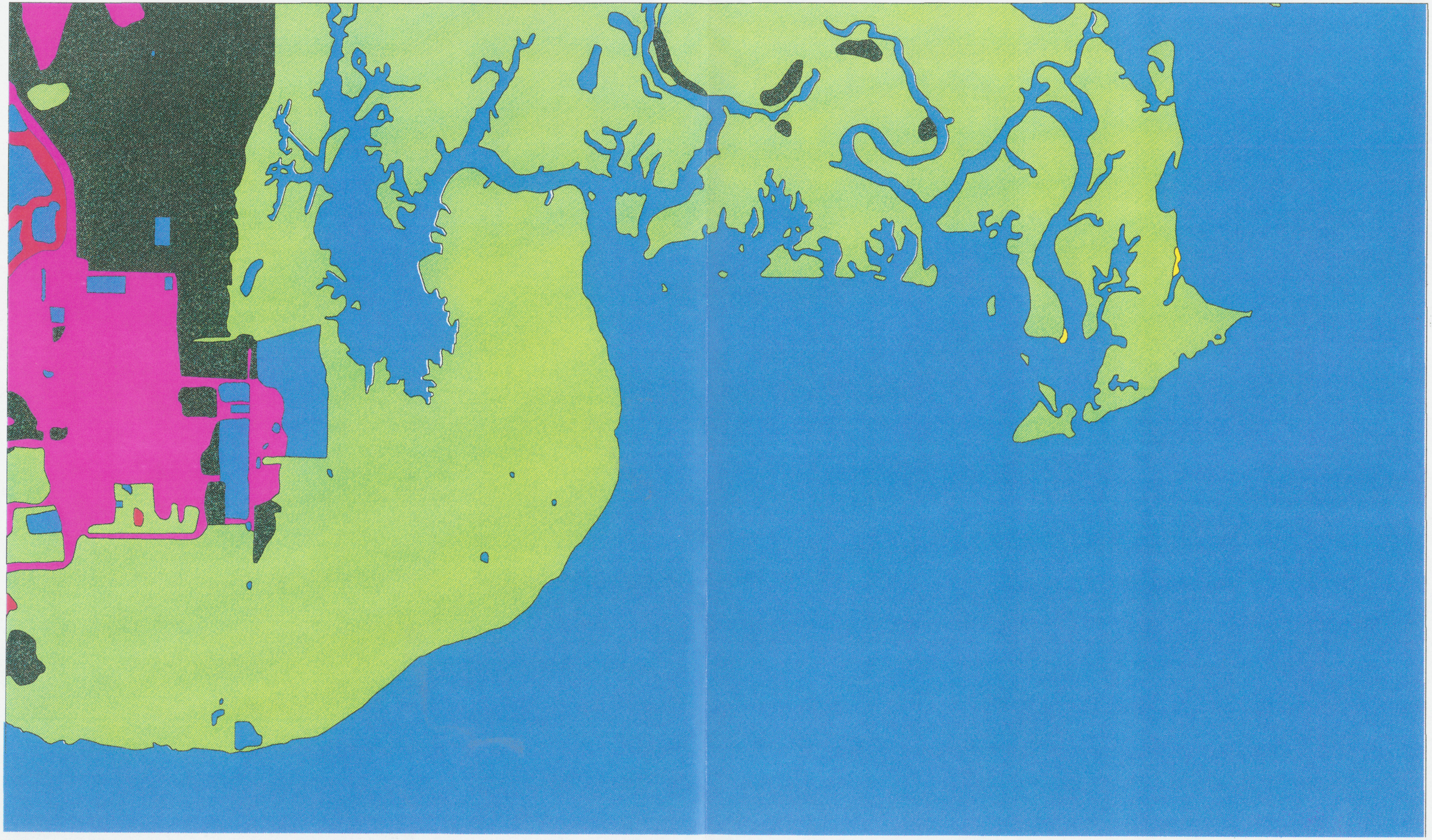


PASCAGOULA NORTH QUAD (top), 1992. 1 in. = .5 mi.

GRAND BAY SW QUAD, 1956. 1 in. = .5 mi.

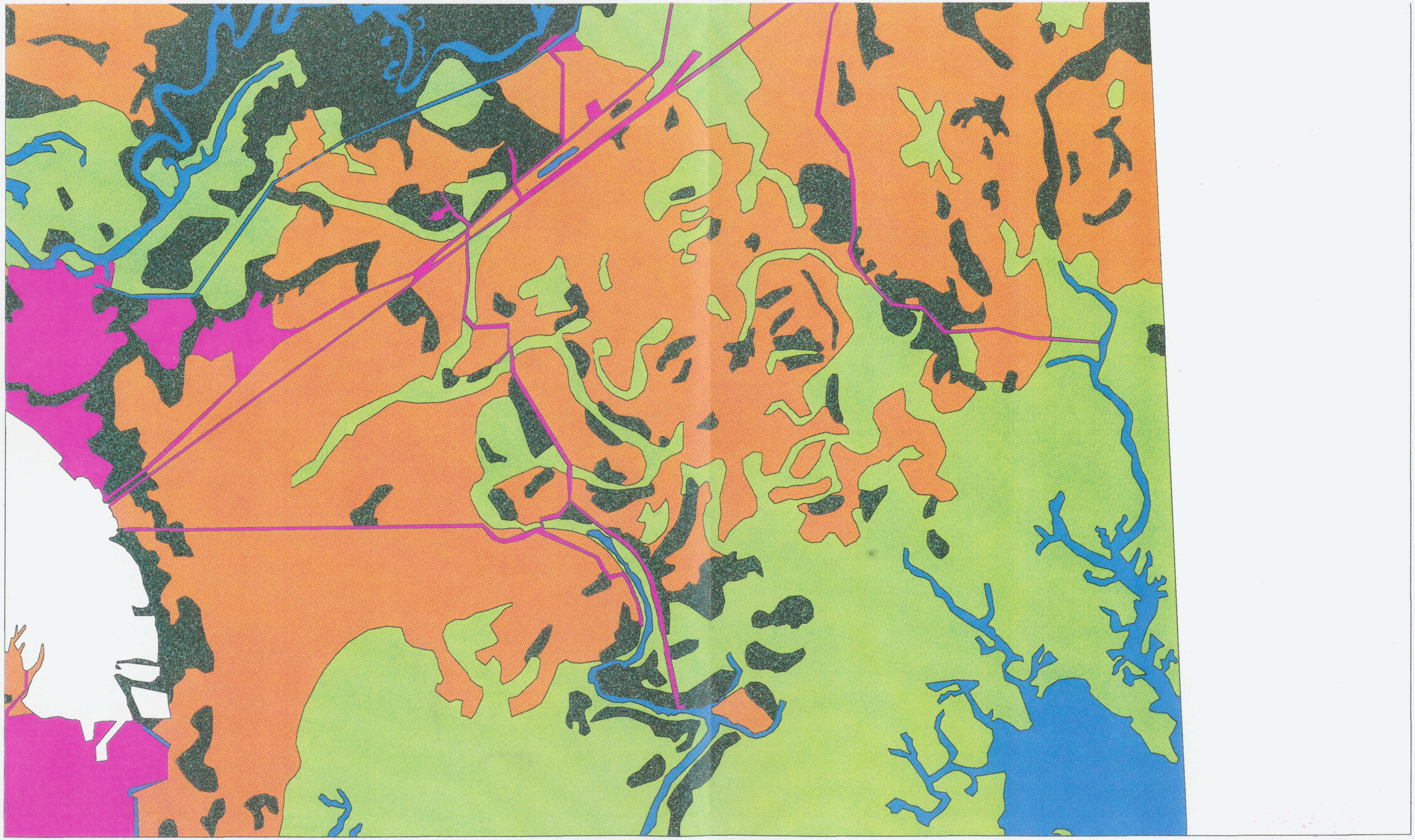


GRAND BAY SW QUAD, 1978. 1 in. = .5 mi.

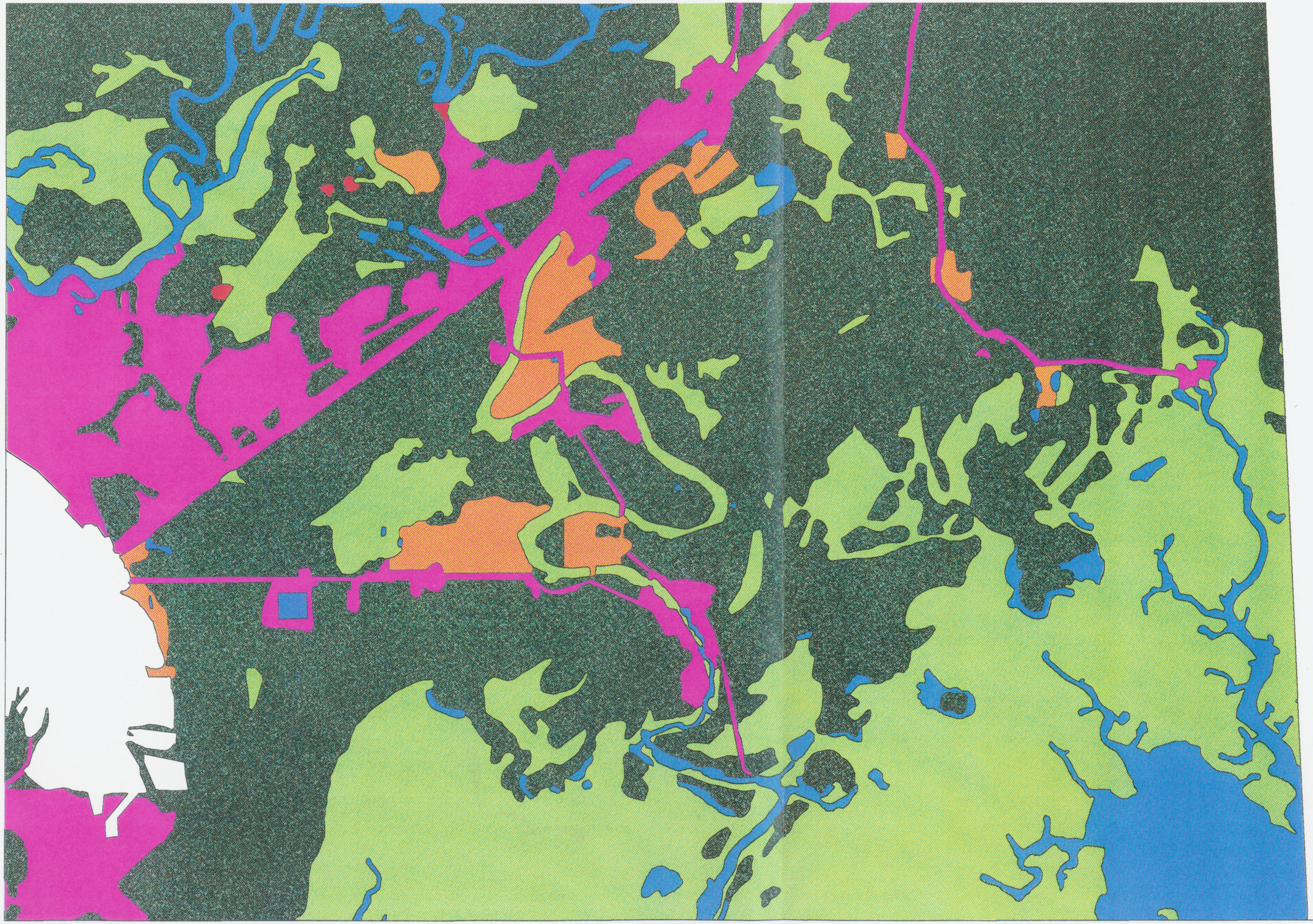


GRAND BAY SW QUAD, 1992. 1 in. = .5 mi.

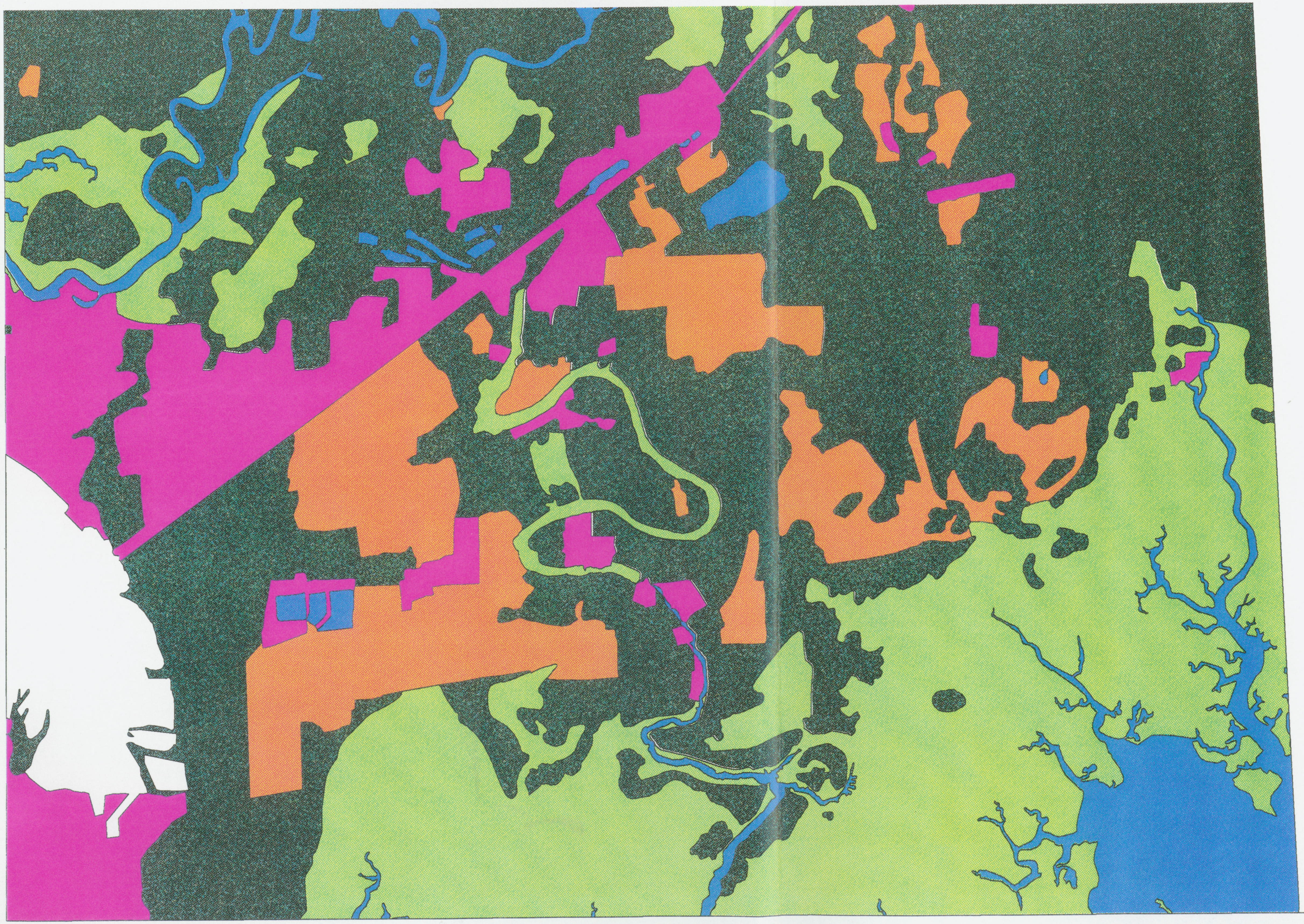
KREOLE QUAD (bottom), 1956. 1 in. = .5 mi.



KREOLE QUAD (bottom), 1978. 1 in. = .5 mi.



KREOLE QUAD (bottom), 1992. 1 in. = .5 mi.

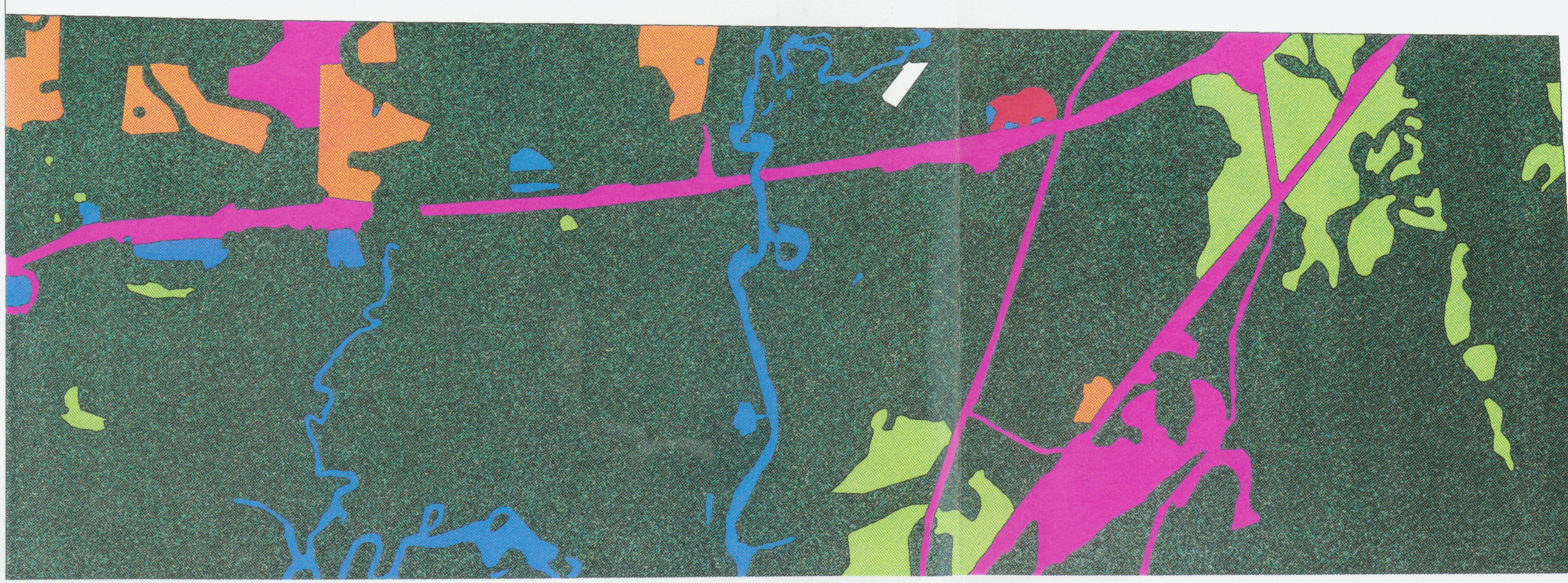


KREOLE QUAD (top), 1956. 1 in. = .5 mi.

no photo coverage

KREOLE QUAD (top), 1978. 1 in. = .5 mi.

no photo coverage



KREOLE QUAD (top), 1992. 1 in. = .5 mi.

no photo coverage