A TECHNIQUE FOR RESOURCE CLASSIFICATION AND CAPABILITY ANALYSIS IN COASTAL ZONE MANAGEMENT

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B.A., University of Washington, 1969

A THESIS SUBMITTED IN PARTIAL FULFILMENT OF
THE REQUIREMENTS FOR THE DEGREE OF
MASTER OF SCIENCE

in the School of
Community and Regional
Planning

We accept this thesis as conforming to the
required standard

THE UNIVERSITY OF BRITISH COLUMBIA

May, 1972

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ABSTRACT

The coastal zone consists of a narrow resource complex occurring at the interface between the sea and land. It not only serves as a transition zone between the marine and terrestrial environments but is also a unique environment possessing qualities which emerge from the dynamic relationship between land and sea. Man has, throughout history, found the resources of this area to be highly desirable for a multiplicity of uses. Now, however, segments of society are expressing considerable dissatisfaction with the way coastal resources have been allocated and abused over the past decades. The unrestrained exploitation of coastal resources has resulted in serious degradation and single purpose co-optation of resources resulting in the denial of benefits from many coastal resources to different groups in society. Such conditions indicate the need to establish coastal zone management institutions which can respond to these problems by producing a mixture of goods relevant to the needs and desires of today's society while preventing future generations from being despoiled of the use of coastal resources. In order to design effective management institutions and policies which can fulfill this need, a careful and systematic analysis of coastal resources' inherent capabilities and limitations must be accomplished.

This study postulates that, through the use of a methodology which integrates the evaluation of coastal resources and resource use capability with an evaluation of user resource requirements in an ecological framework, opportunities can be identified for allocated resources to various users in a way that will reduce the degradation of resources and use conflicts.

To conduct this study it was necessary to develop a system for classifying and evaluating coastal resources for different uses. The literature regarding coastal resource systems was examined to provide a basis for designing a classification scheme. Additionally, three current resource evaluation techniques were studied for procedures relevant to evaluating coastal resources for a variety of uses. The evaluation procedure used in the study represents a synthesis of parts of these techniques. The technique was applied in a case study to provide a foundation for evaluating its applicability to planning the use of coastal resources. The coast of Whatcom County, Washington, was selected as the case study area. The results of the study were evaluated in a scenario comparing the existing resource-use situation and the county comprehensive plan in the study area to the alternative patterns of resource use revealed by the capability analysis.

The classification and evaluation of the coast of Whatcom County demonstrated that the inherent capabilities and distribution of coastal resources provides an opportunity to design alternative patterns of use allocations. Analysis of user environmental impacts indicated that these patterns could be selected for their utility in reducing user conflicts and the degradation of coastal resources. In addition, the classification and evaluation of the Whatcom County coast illustrated that the technique could be useful for identifying and defining the nature of prospective resource use problems that will affect the design of coastal management institutions.

ACKNOWLEDGEMENTS

The author would like to express his deepest appreciation to Professors W. E. Rees and Brahm Weisman for their many comments and suggestions made during this study.

Sincere thanks are due to Mr. Harry P. Fulton of the Whatcom County Planning Department for making available information necessary to complete this study. It is with a great deal of respect that my comments regarding the County's planning program are made.

Without the support and patience of my wife, Terri, and the understanding of my daughter, Lorraine, it would not have been possible to complete this thesis. My greatest appreciation is extended to both of them.

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A NEED FOR PLANNING

Man has had a long association with the sea, frequently colorful and always intimate. He has built great cities where the land comes down to the sea--cities dependent upon commerce borne by the sea. Estuaries and embayments, protected from ocean forces, have provided convenient locations for building harbors with access to inland resources. The sea has been one of the world's major sources of protein and is now being considered for an even greater role in supplying food for future world populations (Ehrlick, 1970). The variety of scenery and expanse of beaches found in coastal areas has always been a source of inspiration to man, and hence are highly valued as a recreational resource. Now, however, the impact of man's use of the sea, most intense at the water's edge, has strained the coastal environment to the limit of endurance. The ability of the natural system in coastal areas to continue to supply the resources desired by man is in doubt.

The coastal zone receives the impact of nearly all land-use changes that occur in coastal watersheds. Destruction and fouling of shellfisheries has resulted from increases in pollution and sedimentation from land runoff, dredging, and land projects. The viability of harbors for navigation has been threatened by alterations in the pattern of siltation caused by modifications in river inflow and the construction of dikes, jetties, bulkheads, and causeways. The perdition of beaches has resulted from the combined effects of marine erosion and the loss of supplies of sediment which replenish the material eroded. Supplies of sediment have been reduced because of river diversions, the trapping of sediment in reservoirs and behind structures such as jetties and groins which obstruct the longshore transport of beach material.

These are only a few examples of some of the undesirable consequences of human action on coastal resources. Many other environmental consequences of man's actions are noted elsewhere (Sorenson, 1970; Cronin, 1967) and constitute an extensive list of alterations in the coastal environment. All these examples point to the need to rationally plan man's activities in the coastal zone. Rational planning, based on sound knowledge of environmental systems in coastal areas is needed to maintain the utility of these resources to present users and future generations.

While the area referred to as the coastal zone cannot be precisely defined, it is desirable to have some idea of what is meant by the term as it is used broadly in this paper. In general the coastal zone includes the area of sea and land adjacent to the triple interface of land, sea, and atmosphere. The zone encompasses the land where terrestrial "activities" are oriented to the marine environment and life processes influenced by the sea and the water areas where marine activities and life forms are significantly influenced by the resources of and activities on land (Schaefer, 1969).

It has been noted that planning the coastal zone has emerged primarily in those areas experiencing intense pressure from uses competing for limited coastal resources (Sorenson, 1970). The growth of population in North America, most pronounced in urban areas along the coast, has accentuated this pressure and the need for planning the use of coastal resources. In 1970, it was estimated that 70% of the United States population lived within one hour's drive of the coast (including the Great Lakes) and that 33% lived in coastal counties which comprise only 15% of that nation's total land area. Within these same counties nearly all types of U.S. industry are represented with only a few exceptions (U.S.A. Department of the Interior, 1970). Moreover, new uses of the coastal zone such as offshore airports, oil terminals, and nuclear power generating plants are forseeable in the near future. Such new uses will present problems with which we have only limited or no experience at all, yet must be prepared to encounter.

Canada's population has similarly displayed a propensity to locate in or near coastal areas. The author has estimated that in 1966 more than 62% of Canada's population lived within thirty miles of the coast including the Great Lakes and the St. Lawrence Seaway (Isodemographic Map of Canada, 1971). In most areas this is a distance of less than one hour's travel time by auto. Moreover, the growth in Canada's major industrial cities, located within this narrow thirty mile ban of coastal zone, has created tremendous pressure to develop available open space for industrial, residential and recreational facilities. Out of the 13 incorporated cities in Canada over 100,000 population in 1966, eight are located in the coastal zone and have a metropolitan area population of 6.9 million or 1/3 of the total 1966 population of Canada (Dominion Bureau of Statistics, 1966).

A discussion of conflicting uses and resource degradation illustrates the need to utilize biogeophysical information in coastal zone planning. Nearly all the users of the coastal zone are dependent upon the unique characteristics of coastal resources. Ironically, however, many use conflicts result from the adverse effects of certain resource uses on other resources equally responsible for attracting man to the coast. Many undesirable consequences are unforseen prior to human activities. Most disturbing, however, are the long run consequences forseen as undesirable but given inadequate attention to be eliminated. Failure to give adequate attention to the consequences of such activities as landfill projects in waterfront areas, and modifications in river basin hydrology, pose a greater threat to the natural resources of the coastal zone than the dramatic effects of some isolated events such as oil spills. Mismanagement of inland watersheds, urban expansion onto flood plains, and construction of dams, dikes, jetties, bulkheads, and groins for protection against floods and wave action can have dangerously cumulative effects on the biophysical processes in the coastal zone. Dumping dredge spoils as land fill increases water turbidity, smothers bottom organisms and alters depths. Dam construction creates barriers to upstream spawning migrations of marine fish and alters water salinity gradients. Jetty and groin construction alters the local movement of sand, changing beach ecology and upsetting sessile organisms (Salo, 1970).

Recreation appears to be one coastal activity that will generate intense demands on coastal resources in the near future. The Outdoor Recreation Resources Review Commission (1962) estimated that during the post war years the average annual increase in attendance at outdoor recreation areas was greatest at resource-based water oriented facilities. Moreover, the projections for the year 2000 are the largest for this same category. The Commission (1962) estimated that by the year 2000 there will be a fortyfold increase in the demand for "resource-based recreation shoreland--essentially national seashore areas." Increases in pleasure boating will also place additional pressure on shore areas for expanded or constructed new moorage facilities. British Columbia has witnessed a nearly 100% increase in the number of foreign pleasure boats entering the Gulf Islands area alone between 1960 and 1970 (Department of National Revenue, 1970). In addition, boat ownership in British Columbia increased from approximately 20 boats per thousand population to more than 40 between 1953 and 1966 and is projected to be about 55 per thousand population by 1985 (Lea, 1966).

It is important to note that these recreation demands are for very specific types of land areas with special resource characteristics. Accordingly, Brooks (1961) pointed out that the satisfaction of recreational demands invariably involves the availability of special land and water areas. However, the U.S. President's Commission on Marine Resources and Engineering Development (1968) stated that while "the sea and shoreline can provide unique and valuable opportunities for recreation, . . . Contamination or destruction of beach, marsh waterway, and shoreline aggravates the pressures (for recreation) by denying use of the sea and shore to a growing population." (My parentheses)

Special land or water areas are also requirements of most other coastal uses. Port facilities are a prime example. Rapid technological changes in shipping methods and the large size of new vessels has increased the need for new deep water port locations and to make major adjustments in docks, channels and on-land storage areas in existing ports. Nuclear power plants are also being located in coastal areas because of the availability of large supplies of water for cooling purposes. Use of coastal waters for cooling, however, is one of the activities most threatening to the maintenance of the natural biotic resource system in the coastal zone (Odum, 1971). This threat is particularly evident when one considers the role of temperature as a limiting and controlling factor in ecosystems and the potential heat that may be discharged from nuclear power plants. "It is anticipated that, in the thermally less efficient nuclear power plants. . .the discharge temperature will be in excess of 11°C above ambient, with an expected discharge by a single plant of fresh or salt water of up to 1,250,000 gallons per minute" (Sylva, 1969).

Biologists note that temperature is one of the most important factors affecting life (Hedgpeth & Gonor, 1969). The introduction of large quantities of waste heat into coastal waters can be expected to affect, among other things, the physical properties of water, the rate of chemical reactions that take place in sea water, the metabolic rate of animals and thereby their tolerance to other environmental changes (U.S.A. Department of Interior, 1970). Strickland (1969) considered the effects of heat on ecological periodicity and the availability of food in marine ecosystems. He postulates that in addition to the direct effects of heat on fish species, heat discharges into estuarine waters may also alter the reproductive cycle of planktonic species. Delayed or premature production of plankton may result in lower survival rates of larval stages of fish because of inadequate supplies of the right type of food at critical stages of the life cycle.

The fisheries industry is highly dependent upon the resources of the coastal zone. About 63% of the commercial catch on the Atlantic Coast is made up of species thought to be dependent on estuaries at some stage of their life cycles (McHugh, 1966). Seven out of ten of the most valuable species in American fisheries spend all or an important part of their lives in estuaries (President's Commission, 1969). Yet it is estuarine areas that are most likely to be filled for residential expansion and industrial and recreational uses. Estuarine areas are attractive for land fill because they are often protected from the forces of the sea by natural barriers and they are typically shallow. The amount of shallow estuarine area that can be easily filled is extensive. Cain (1967) estimated that out of the total area of the United States estuarine waters nearly one third are less than six feet deep.

Finally, the practice of disposing of waste products in coastal waters is widespread (Table 1). The effects of waste disposal in the sea are not fully understood. However, a few cases indicate the potential damage to the environment that can ensue from this practice. Off the coast of California, some areas previously known to be lush with vegetation, providing food and shelter for many species of fish, have been reported to be barren in places where garbage and other sewage have been dumped (Hedgepeth, 1970). A copper compound dumped into the North Sea in 1965 in an amount that would supposedly increase the presence of the substance in marine water by only one millionth of a gram per liter resulted in large kills of fish off the coast of Norway (Marx, 1967). The currents that were to dilute the copper substance, instead, concentrated it inshore in proportions deadly to the fish. Dumping of untreated wastes in the oceans not only alters the quality of the water for the growth of natural fauna and flora but obviously for man's utility. Shellfish in an estimated 1.2 million acres, or 8% of the U.S. shellfish

TABLE 1: ESTIMATED AMOUNTS OF WASTES BARGED TO SEA BY THE U.S. IN 1968[1]

WASTES	Pacific Coast disposal Tons	Atlantic Coast disposal Tons	Gulf Coast disposal Tons
Dredging spoils	7,320,000	15,808,000[2]	15,300,000
Industrial wastes (chemicals, acids, caustics, cleaners, sludges, waste liquors, oily wastes, etc.):			
Bulk.	981,000	3,011,000	690,000
Containerized	300	2,200	6,000
Garbage and trash[3]	26,000		
Miscellaneous (airplane parts, spoiled food, confiscated material, etc.)	200		
Sewage sludge		4,477,000[4]	
Construction and demolition debris		574,000	
TOTALS	8,327,500	23,872,000	15,996,000

1 Does not include outdated munitions.
2 Includes 200,000 tons of fly ash.
3 At San Diego dumping of 4,700 tons of vessel garbage was discontinued in Nov. 1968.
4 Tonnage on wet basis. Assuming average 4.5% dry solids, this amounts to approximately 200,000 tons dry solids per year being barged to sea.

SOURCE: U.S.A., President, 1970.

grounds have been declared unsafe for human consumption (U.S.A. President's Commission, 1970). Nektonic fishes are also affected by the use of marine waters for waste disposal. For example, some of the damaging effects of sulfite pulp-mill wastes have been discussed recently. Juvenile salmon migrating through harbors may be injured, phytoplankton activity may be suppressed thereby decreasing available supplies of food, and the eggs of English Sole may be directly damaged by toxic material from sulfite pulp mills (Salo, 1970). In a study of Alberni Inlet, British Columbia, Harger and others (1971) concluded that dark pulp mill effluent operating as a "light trap" may be creating conditions of reduced food supplies for young salmon which use the estuary to feed and adapt to the salt water environment. The study group also noted the restricted development of sessile communities adjacent to the mill effluent outfall. Two possible causative relationships were theorized to account for this restricted development. In both theories, conditions of low food supply were predicted to prevail in an estuary where "evolutionary forces can be expected to have programed a demand for nutrition." (Harger et al., 1971).

DEFINING THE COASTAL ZONE

Attempts to provide an operational definition of the coastal zone have emerged primarily from the need to resolve conflicts among alternative or competitive uses. While most definitions implicitly recognize that the land-water-air interface of the coastal zone constitutes a network of ecological relationships, they tend to vary depending upon the nature of the problems being considered in a particular area at different times. The U.S. Congress has considered the coastal zone to be ". . .land, waters and waterbottoms near the coastline extending to the. . .territorial limits, including, but not limited to beaches, salt marshes, coastal and intertidal areas, sounds, embayments, harbors, lagoons, inshore waters, rivers, and channels" (U.S. Congress, 1971). Another congressional definition reflecting an awareness of marine influences inland, defines the zone as, ". . .lands, bays, estuaries, and waters within the territorial sea. . . and extending inland to the landward extent of maritime influences" (U.S. Congress, 1969).

Providing ecological criteria for defining the coastal zone is difficult. The basic ecosystems concept implies that management boundaries can not be drawn to encompass all the parameters effecting an ecosystem. Instead, it emphasizes that ecosystems do not exist independently from one another. There are transition areas between contiguous communities interacting through physical and biological processes over time and space.

In order to provide a resource base for management decisions, geographical units of land or water with sufficiently common characteristics are usually established. But these areas are "natural" only in the sense that they display a recognizable association of resource attributes over space. These areas cannot be assumed to exist independent of processes occuring in adjacent geographical areas. Any geographical area established for management purposes will be subject to forces generated outside its borders. The implication of this for resource analysis has been pointed out by Stanley Cain (1966):

> It is suggested that it be kept in mind that single-factor operation does not occur in biological nature, that the environment apparently cannot be completely analyzed, and that diverse analytic data cannot at present be synthesized back again into anything like the natural whole of the ecosystem.

The coastal area itself is a transition between two major environments, the land and the sea. In broad terms it includes 1) that area of land directly affected by its proximity to the sea and land which directly influences the ecology of the adjacent marine waters; and, 2) that portion of the sea affected by its proximity to the land. It is narrow and rather abrupt compared to the transition zones between other major world ecosystems.

Many persons dealing with the problems of defining the zone for planning are in agreement on its seaward boundary as the limit of the continental shelf. The continental shelf has been defined by the Coast and Geodetic Survey for legal and other purposes as the submarine area adjacent to the mainland to a depth of 200 meters (Shalowitz, 1964). It is a convenient physical structure that can be identified and used for establishing a seaward boundary to the coastal zone even though ocean forces effecting marine life in the coastal zone derive from far beyond the area of the shelf. The 200 meter depth is acceptable since it marks the average point where the bottom drops more rapidly to form the deep basins of the ocean (Odum, 1971). Furthermore, its width affects the forces of ocean waves striking the shore and consequently the processes of beach erosion and accretion (National Estuarine Pollution Study, 1970).

Defining the inland extent of the zone presents a more difficult problem. It has been defined as the limit of tidal influence (U.S.A. Department of the Interior, 1970), less objectively as the limit of immediate access* from land (Sorenson, 1970), and curiously as the limit of view from offshore waters whenever it extends beyond two miles inland and adjusted to include other areas significant to coastal ecology (U.S. Bureau of Sports

* Access to what is not defined.

Fisheries and Wildlife, 1970). Whether this last definition is adjusted for visual conditions is not evident. However the landward boundary is established, it will reflect a different "point of view." The use of different boundary criteria yields different geographical areas and thereby different combinations of biogeophysical factors to be considered as within the zone. As a result, wherever coastal zone boundaries are established they will reflect some social and economic bias. Thus, no boundary should be interpreted to suggest that effective management can be accomplished without recognizing influences that derive from outside the zone.

Given this understanding of the problems involved in delimiting and using ecological regions, the author has defined the coastal zone, for purpose of resource classification, in two phases:

1. COASTAL WATERS: From the seaward limit of the continental shelf, defined as the point of submerged land at a depth of 200 meters, to the line marked by the point of mean low water.

2. COASTAL LAND: Landward from the point of mean low water to the furthest extent of marine influences such as water salinity, climate, and marine salt air effecting vegetation growth and land and water use activities dependent upon coastal resources.

STUDY PREMISE AND HYPOTHESIS

Identifying existing use conflicts and the impacts of man on the resource of the coastal zone is only a preliminary step in planning for its use. Rational planning must also attempt to anticipate future demands and be prepared to allocate uses without damaging the environment and foreclosing options for future uses (Wilkes, 1969). As stated by the

Commission on Marine Resources and Engineering Development (1970):

> The challenge before us is to find opportunities for multiple compatible uses of the shoreline and inshore waters, and to maintain options for future uses not foreclosed by degradation of the resource. This will require identifying multiple compatible uses and also encouraging the development of effective mechanisms for making rational choice among incompatible uses.

Implied in this statement is the need to understand the host relationship of the resource base to man's activities. The variety of natural conditions found in the land and water resources of the coastal zone provide opportunities for use. These resources have intrinsic capabilities and limitations which contribute to user's satisfaction. Angus Hills (1961), Ian McHarg (1969), and others have described how the physiographic features and ecological processes form the basis for determining the land's use-capability. Capability, however, includes more than the ability of the land to supply resources. Capability also includes the ability of the resource to absorb the effects of use. Holling (1971) has defined this as the system's resilience. To define capability, then, one must understand the interaction between man and the resource system in terms of system resilience. Human impact on resources feeds back through the ecosystem to alter the subsequent ability of the resources to satisfy human requirements. Consequently, the continuous supply of opportunities for present uses and options for future uses can be threatened by resource management which fails to consider this feedback process.

Hypothesis

Within this context of man's relationship to the environment, the hypothesis for this study is recognized as:

> Through a process which integrates the evaluation of biogeophysical characteristics of the resource base and an assessment of resource use-capability with an analysis of the resource requirements of specified users, opportunities may be identified for allocating land to various users in a way that will reduce environmental degradation and resource use conflicts.

METHODOLOGY

This study comprises three phases: Phase one is the development of a coastal zone resource classification and capability rating system. Phase two is the application of this system to a selected case study area. Phase three is the evaluation of the usefulness of the methodology in terms of the stated hypothesis.

Phase One

To develop the classification and rating system the following process has been established.

A. Review of Coastal Ecological Systems. An examination of coastal ecological systems, in general, will aid in selecting those features of current resource analysis techniques salient to classifying coastal resources. An understanding of the functional role of various features of the coast will provide the ecological framework for evaluating the resources and user impacts.

B. Review of Resource Evaluation Techniques. Current resource analysis techniques used in land-use planning will be examined. The way in which the methods inventory and describe land and water resources and evaluate them for use will be scrutinized. Quantitative methods for establishing the resources use values will also be considered.

C. Synthesis of Evaluation Techniques. Within the ecological framework of the coastal system, those features selected above will be synthesized into a methodology for classifying, evaluating and rating coastal resources for various uses.

Phase Two

In a case study, the technique will be applied to establish capability ratings and a resource allocation system for the coastal land and water areas of Whatcom County, Washington. The following objectives have been established for conducting the case study:

A. To demonstrate the integrated evaluation of resources, user requirements and use impacts in establishing resource capability ratings.

B. To use capability ratings for allocating resources to potential uses.

C. To provide a framework for testing the applicability of an integrated resource evaluation technique in reducing adverse environmental impacts and use conflicts in the coastal zone.

Phase Three

An evaluation of the methodology will be conducted to ascertain its effectiveness in reducing adverse environmental impacts and use conflicts. This will be accomplished in a scenario comparing the allocation of potential uses assuming two different management policies. The first policy will assume land to be allocated on the basis of the resource capability analysis described herein. The second one will assume the policy of land assignment implied in the 1971 comprehensive plan developed for Whatcom County, Washington.

CHAPTER TWO: COASTAL ECOSYSTEMS AND RESOURCE ANALYSIS

Recent literature on resource analysis and classification techniques is replete with statements emphasizing the importance of utilizing ecosystem concepts (Mabbutt, 1968; Hill, 1970; McHarg, 1969). The ecosystem concept is seen as the framework for conducting systematic evaluations of resources as they relate to life processes and productivity. Unfortunately, the difficulties in operationalizing the ecosystem concept in resource analysis have not been entirely overcome. Presently, information regarding the structure of ecological systems and an understanding of their functional processes is not complete. Secondly, resource management institutions are fragmented into single purpose agencies making it difficult to implement a holistic approach to natural resources management.

To develop a resource analysis and classification technique for the coastal zone, it is imperative to recognize principles of ecology as they relate to man's alteration of natural resource systems and the quality he desires in his environment. A review of ecological principles and their implications for resource management is given below to establish the basis for a study of two major coastal ecosystems: estuaries and the intertidal zone of the marine ecosystem.

ECOLOGICAL CONCEPTS

Odum (1971) defines ecology as "the study of the structure and function of nature," and describes an ecosystem as:

> any unit that includes all of the organisms in a given area interacting with the physical environment so that a flow of energy leads to clearly defined tropic structure, biotic diversity, and material cycles within the system. . .

Within any ecosystem there are two major components; abiotic and biotic components can be recognized. Abiotic substances make up the physical and chemical environment within which interactions between the biotic components take place. Biotic components of the ecosystem are the producer, consumer, and decomposer organisms. The producers are largely green plants which utilize light energy, carbon dioxide and mineral substances to manufacture their own food. Collectively they are referred to as autotrophs. The consumers are organisms that utilize energy rich organic material manufactured by autotrophs. Since consumers derive their energy from food manufactured by producers they are referred to as heterotrophs. The decomposers, also heterotorphic organisms, are considered as one of the main constituents of the biotic world because of the role they play in the cycling of nutrients. Decomposers do not ingest food as do the herbivore and carnivore consumers. Decomposers secrete enzymes onto dead organic matter which degrades the matter so that some of it may be absorbed into the decomposer's body. Because this process of degration and digestion takes place external to the decomposer, certain nutrients and other compounds found in dead plant and animal material, remaining after bacterial and fungal decomposition, are made available for reuse by producer and consumer organisms.

Nutrient Cycling

In the cycling of nutrients, two circuits are recognized. The grazing circuit involves the consumption of living plants or plant parts by heterotrophic organisms, mostly herbivores. The detritus circuit refers to the cycle which involves dead plant and animal material (detritus) and its decomposition by decomposer organisms. Together these two nutrient circuits form the major channels by which nutrient material is cycled through an ecosystem.

The cycling of nutrients involves both the biotic and physical-chemical constituents of the ecosystem in what are called biogeochemical cycles. Biogeochemical cycles can be divided into two major groups, one in which the atmosphere acts as the major reservoir of elements as they exist in a gaseous phase and the other in which the lithosphere acts as the reservoir of elements (Kormondy, 1969). Minerals are released from the lithosphere by the processes of weathering and bacterial action to form the sedimentary cycle. Both types of cycles, atmospheric and sedimentary, are important in marine ecosystems and must be considered in evaluating the potential effects of air, land, and water pollution on coastal resources. Moreover, it is important to recognize the role that the physical aspects of these cycles play in marine ecosystems since marine systems tend to be dominated by physical processes.

Community Energetics

Community energetics is the study of the flow of energy from one trophic level to another. Energy in biological systems comes ultimately from the sun. This radiant energy is transformed into a chemical form in photosynthesis by green plants. Each trophic level of organisms beyond the producer plant level depends on the fixation of radiant energy in organic matter by green plants. At each transfer of energy from one trophic level to the next or between constituents of the same trophic level there is a progressive decrease in available energy because at each transfer of energy a large part of the energy is degraded into heat.

Watt (1968) points out for resource management purposes, that the most efficient long term energy utility occurs under natural conditions. Hence, modifications of an ecosystem which result in conditions other than prevail naturally cause a reduction in the utilization of energy. Therefore additional inputs of energy would be needed to maintain the level of production in an ecosystem modified to conditions which do not prevail naturally. The corollary of this for biotic resource management is that the greatest productivity will occur under those conditions which most nearly resemble natural conditions. This concept is central to understanding one of the major resource management problems today; that is, man's inability to divert optimum productivity occurring in nature to his own use without upsetting the natural order in an ecosystem and thereby reducing its productivity.

The implications of this for determining resource capability are noted by Hills (1961). He states that:

> The biological productivity of an area is dependent not only upon the potential of the land to supply matter and energy to the biotic community which it supports but also upon the ability of the organisms to utilize this energy.

The importance of this principle for coastal zone planning is in establishing the limits within which man may modify coastal resource systems without reducing the productivity of those resources for other users and future generations.

The Concept of Habitat and Niche

Habitat and niche are concepts useful in understanding relationships which exist between organisms and their environment. In the habitat approach (Odum, 1971), attention can be focused on specific geographical areas such as the coastal zone that one may wish to investigate for ecological purposes. Moreover, it is a concept that can be readily adapted in resource management because it adds a spatial dimension to the application of ecological principles.

An organism's habitat is the aggregate of the biotic and abiotic characteristics of an organism's environment. It is a concept of place in the sense that it describes the environmental characteristics where an organism lives. An organism's niche, however, is within the habitat and defines the functional role of the organism in the community. (The community being defined as all of the organisms collectively within the habitat.) Odum (1971) distinguishes between habitat and niche in the following analogy:

> It may be said that the habitat is the organism's "address" and the niche is its "profession", biologically speaking.

Information about an organism's niche tells us about the organism's activities, including its nutrition and energy sources, metabolism and growth, effect on other organisms it contacts, and the extent to which it modifies or is capable of modifying operations in the ecosystem (Odum, 1971). Use of the niche concept in resource analysis is helpful in understanding the extent and significance of environmental modifications made by organisms. For example, organisms appearing to be economically insignificant in an ecosystem may make environmental modifications necessary for the survival of those specied deemed "valuable" in the market place.

COASTAL ECOSYSTEMS

The following discussion of coastal ecosystems is primarily concerned with the estuarine habitat, and the intertidal zone of the marine habitat. The major emphasis of this discussion is on the physical processes affecting these habitats. Physical processes are emphasized because of the important role they play in controlling the biological world and because of the nature of man's actions in the coastal zone. Physical aspects of estuarine and marine habitats determine to a great extent patterns of community zonation and productivity. The nature of man's action in the coastal zone is primarily in changing the physical environment. Thus, patterns of community zonations provide a structure relevant to the analysis and classification of coastal resources for human use.

The Marine Habitat

The sea can be classified into subzones or sub-habitats horizontally and vertically. The continental shelf is the principal physiographic feature used to delimit horizontal subzones. The nearshore area of the continental shelf, often shown extending from the point of mean high tide to approximately where the continental slope begins, is called the neritic zone. The intertidal zone, then, is the shore area that lies in the neritic zone between the highest line that the tide can reach in any one year and the yearly lowest line to which the tide receeds (Bauer, 1971). The area inland, beyond the intertidal zone, to the furthest extent where the forces of tide and extreme wave and wind energy cause erosion and accretion of the coast, is termed the supra-tidal zone or backshore (Bird, 1968). The oceanic zone lies seaward beyond the continental shelf.

Vertical zonation of the sea is also recognized. The major vertical zones are based on the penetration of light into sea water. The upper zone, where the penetration of light into the water makes photosynthesis possible, is the euphotic zone. The euphotic zone is separated from a thicker aphotic zone below where no photosynthesis occurs by a compensation zone. The compensation zone is the area between the euphotic and aphotic zone where respiration of phytoplankton balances their photosynthetic activity resulting in no net productivity.

Further subzonation of these vertical and horizontal zones is accomplished by both physical and biological processes (Odum, 1971). Vertical subzonation in the aphotic zone is recognized by the existence of two broad types of communities, the benthic and the pelagic. The benthic community includes all those organisms that live on or in the bottom material respectively referred to as epifauna and infauna. The pelagic community includes all those free swimming or floating organisms in the open water. A transect of a sandy and a rocky beach, shown on the following pages as Figures 1 and 2, illustrates the horizontal subzonation of the neritic zone and backshore area that can be distinguished by the dominance of certain species of plants and animals.

Perhaps the most dominant factor influencing life in intertidal zones

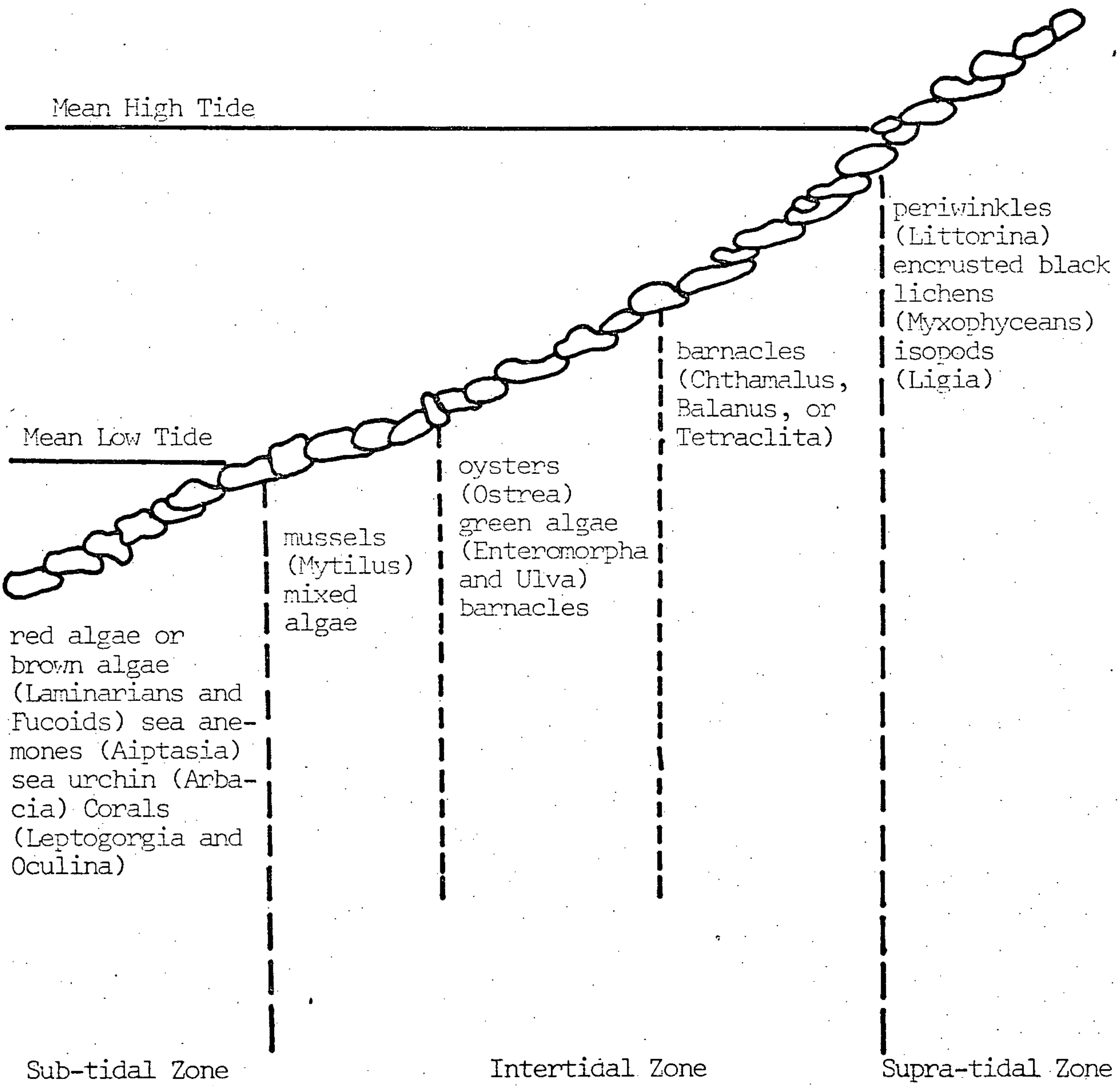
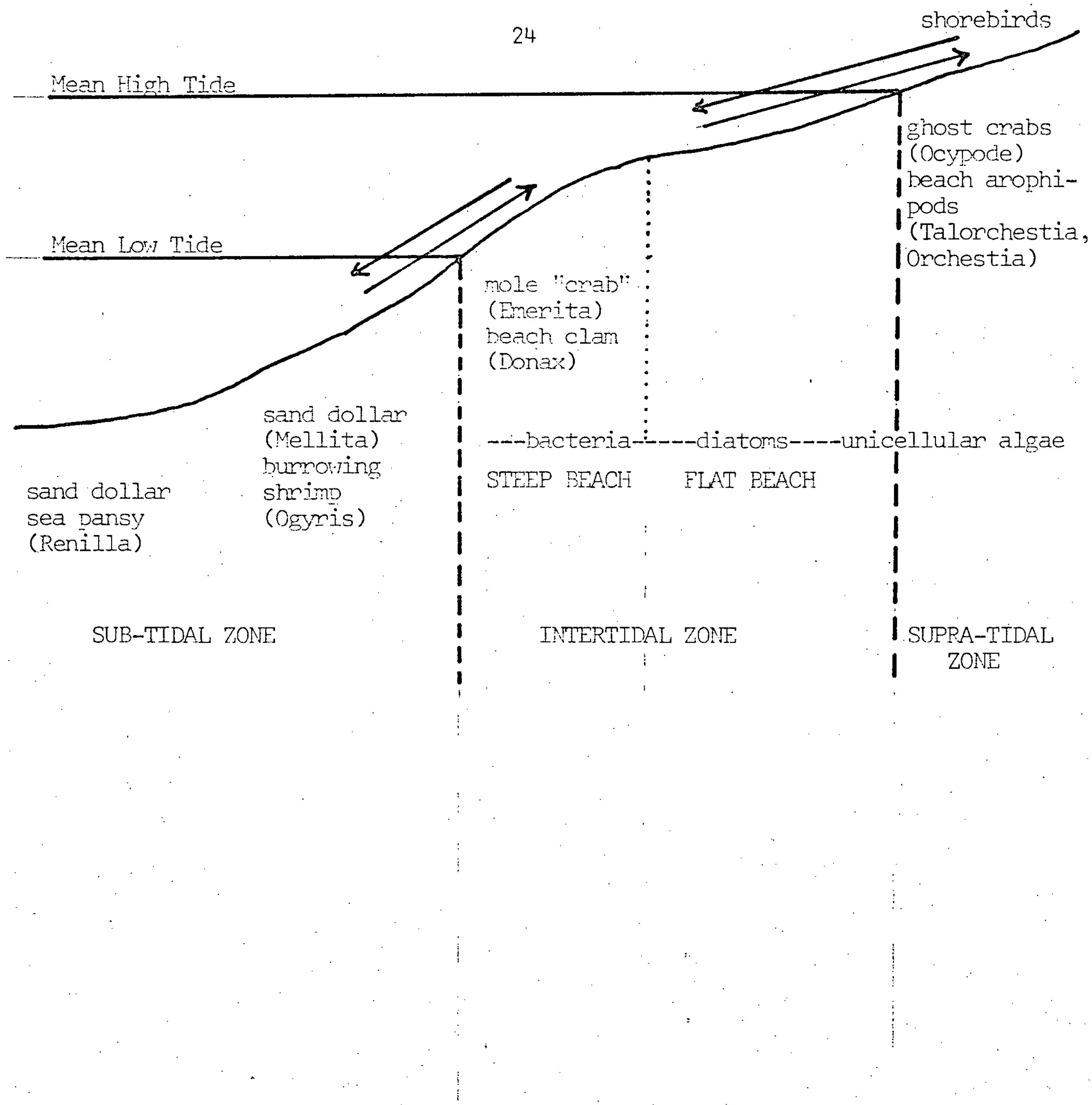


FIGURE 1: TRANSECT OF A ROCKY BEACH

LEGEND:

Characteristic Biota of Beach Zones - - - - - - - - - - -

Source: Stephanson and Stephanson 1952



TRANSECT OF A SANDY BEACH

Legend:
Biota Characteristic of Beach Zones - - - - - - - -

Source: Odum, 1971

Figure 2

is the periodic covering and uncovering of plants and animals by tidal action. For this reason Reid (1967) has defined the intertidal zone as the zone of extremes. Life in this zone must be capable of tolerating extreme changes in salinity, temperature, moisture and in many instances periodic disruptions in the structure and composition of the zonal material.

Reid (1967) has classified intertidal communities into three groups according to the type of beach material extant in an area. These groups are sandy shore, rocky shore and muddy shore community types. In each group, the physical factors of wave action, tidal action, currents and geological material interact to produce distinctively different environmental conditions for colonization by different plants and animals.

Sandy Shores: Beach profiles provide one way to distinguish between different sandy shore communities. The profile of a beach is indicative of the physical processes operating in a coastal area. Profiles subsequently indicate the type and distribution of plants and animals that may be found along a sandy shore. Kinne (1970) has noted that, in general, the slope of a beach can be associated with the particle size of the beach material. Odum (1971) notes that, in general, benthic communities will be found to replace one another from the shore to the edge of the continental shelf depending largely upon the type of bottom material. Thus, at a very general level, the factors important in shaping beach profiles are also useful in understanding the nature of the environment which affects the distribution of organisms in the intertidal zone.

Waves and geological material are the major factors in the development of beaches. The effect of wave action on the movement and deposition of beach material varies depending upon the size of material. This results in different patterns of transport and deposition along the backshore and intertidal areas of the coast. The beach profile resulting from this process of transport and deposition will subsequently modify the force of wave action, thus resulting in new patterns of transport and deposition. Beach formation, therefore, is a dynamic process of the effect of wave action on transport and sedimentation being continuously modified by the profile of the beach.

In the process of beach formation, sand particles are transported up the beach by breaking waves that wash on to the beach in a diagonal direction and retreat in a direction vertical to the beach. At the same time, longshore currents are created in the submerged intertidal zone by the force of the diagonally approaching waves on intertidal currents. Beach material suspended by the force of breaking waves is transported in one direction or another by the longshore current (Bird, 1968). Longshore drifting of material often results in the net transportation of beach material in one direction causing the loss of material in some areas and gains in others. Natural or artificial structures in the intertidal zone may act to trap the material transported by longshore currents. In cases where the longshore currents are diverted far from shore, the material is often lost to sediments in deep ocean canyons.

Spits and barriers form along shorelines where the shoreline direction changes and the strength of longshore currents diminishes allowing sediments to be deposited. Spits typically curve landward and their outlines are shaped by wave action (Bird, 1968). Salt marshes often form on the landward side of spits where sedimentation and stable surface conditions permit plant occupancy. River mouths and entrances to coastal bays are altered by the development of spits and barriers. Barriers develop initially as spits, emerged bars or barrier islands offshore. With continuous sedimentation the barriers develop to eventually seal off the mouth of inlets or bays. Both spits and bays alter the patterns of water circulation and deposition in embayed areas and river mouths.

It is stated that, the profile of a beach at any one point in time will be determined by the wave conditions during the preceding period (Bird, 1968). Severe storms will erode or scour much material away from beaches due to force of the retreating waves. During calm weather, however, the waves will constructively move material back on to the beach. This destructive and constructive action is called cut and fill and is evidenced by the presence of beach ridges or berms. New ridges are built up in front of those that survive storm conditions as sand is supplied to the beach in succeeding phases of calmer weather (Bird, 1968). In time, the more stable landward ridges are colonized by successional stages of vegetation. The vegetation stabilizes the ridges, protects them from erosion, and promotes the development of soil.

The environmental variability found in the intertidal zone resulting from the action of tide and waves challenges plant and animal colonization. However, even in intertidal areas appearing to be barren of life an abundance of life in benthic communities beneath the surface is often present. In addition, a variety of pelagic organisms periodically migrate into this area to feed and find shelter.

Surface plants are conspicuously absent on the intertidal portion of sandy beaches. Unstable surface conditions of the beach prohibit successful colonization by plants. On the other hand, organisms buried in the sand are abundant even though their variety is not as great as in the less physically variable submerged neritic areas. Some epifauna also inhabit the intertidal zone. Moving in and off shore with the tide epifauna feed on other animals and organic debris.

There are some marine animals, not restricted to living in intertidal zones, that utilize the intertidal zone for feeding and breeding. These animals, including fish, birds, and mammals, add to the diversity of consumers which utilize the intertidal zone. As the tide rises and falls these consumers alternate in ranging into the intertidal zone to feed. One can thus appreciate the high productivity of this area in considering that this feeding pattern results in a continuous harvest of the intertidal zone.

Rocky Shores: On rocky shores a zonal pattern in the distribution of plants and animals is more evident than on muddy or sandy shores. The Stephansons (1952) delimited three major zones on rocky shores (Figure 1): 1) a dry supra-tidal zone characterized by periwinkles and dark blotches on rocks caused by lichens and algae; 2) an "intertidal zone" (more narrowly defined than our definition) characterized by the abundance of barnacles; and, 3) a subtidal zone partially uncovered only during very low tides and characterized by seaweed (see also Odum, 1971). The upper beach zone is frequently very dry limiting inhabitants to species that can avoid being desiccated. The "intertidal zone" is a narrow area between mean low tide and mean high tide that experiences uninterrupted covering and uncovering by tidal action. One of the major characteristics of this zone is the occurrence of tidal pools which harbor separate communities that can be considered subzones within the intertidal zone. Reid (1967) notes that to survive in the intertidal zone organisms must: 1) "be equipped with strong hold fast structures or protective shells (or both)"; or, 2) "be able to seek shelter among other residents." The subtidal zone or seaweed zone delimited by the Stephansons is characterized by less stressful tidal influences but is subject to the forces of waves and currents which affect the distribution and kinds of organisms in this zone.

Muddy Shores: Muddy shores occur where the forces of coastal currents and wave action are reduced allowing fine particles of silt to settle to the bottom. The result is an accumulation of mud on the shores of protected bays and mouths of coastal streams and rivers. Since bays and mouths of rivers are estuarine they will be considered in more detail in the section on estuarine habitats. However, some muddy shore areas do occur in coastal inlets and embayments where salinity is about the same as the adjacent sea. In these areas, currents, wave action and salinity determine the kinds of plants and animals that inhabit the muddy intertidal shore.

Few plants have adapted to living on muddy shores. Their growth is restricted by turbidity which reduces light penetration into the water and thereby inhibits photosynthesis. In addition, the lack of solid structures to which algae may attach itself and siltation which smothers the plants effectively prevents much plant colonization of muddy shores.

In areas where there is a mixture of mud and sand, certain algae and eelgrass will grow successfully. Since the distribution of sand and mud mixtures is usually uneven, the distribution of these plants will be patchy (Reid, 1967).

Muddy shores display zonal patterns similar to the vertical and horizontal zonation of sandy shores. Among the many kinds of epifauna on muddy shores one may find species of crab, hydroids, and gastropod mollusks and shell-less gastropods (Green, 1968). The infauna of muddy intertidal zones are predominately pelecypods and other mollusks, worms, and crustaceans (Green, 1968). The distribution of infauna is determined by the effects of various mixtures of silt and sand in bottom sediment and by the effects of the ebb and flow of the tide. While the lack of oxygen in the mud makes life on muddy shores difficult, the abundance of food as organic detritus provides nutrition for a large number of detritus feeders (Reid, 1967).

The Estuarine Habitat

Estuaries are a major environment in the system of coastal resources. Estuaries are a permanent habitat for many fish and shellfish and also provide breeding, nursery, and feeding grounds for many other elements of the fauna. As noted in Chapter one, more than 60% of the commercial fish catch on the Atlantic Coast consists of fish entirely or partially dependent upon estuaries. Odum (1971) notes the importance of estuaries to the productivity of coastal marine waters. In a process he calls "outwelling", estuarine nutrients flow into adjacent marine areas and contribute to their high productivity.

The most commonly used definition of an estuary is the one provided by Pritchard (1967):

> An estuary is a semi-enclosed coastal body of water having a free connection with the open sea and within which the sea water is measurably diluted by fresh water derived from land drainage.

The salinity of an estuary is usually considered to range from between 0.5 parts per thousand (ppt) and 5ppt at the fresh water entrance to near 35ppt at its mouth. The salinity of ocean water usually ranges between 35ppt to 40ppt.

The types of estuaries that may be included under this broad definition are tremendous. The drowned river valley estuaries resulting from changes in the level of continental land masses or levels of the sea are probably the most typical. In the Pacific Northwest we are familiar with the glacier-gouged fjord type of estuary. Other types of estuaries include those formed by earthquakes such as the San Francisco Bay or more slowly by the gradual development of barrier beaches creating embayment or lagoon types of estuaries. Within each of these types of estuaries, forces of tidal action, waves, and currents act to make each estuary unique.

Biogeophysical processes common to estuaries operate to produce a dynamic, variable, and highly stressful environment for life. These processes exert stresses very selective on the kinds of organisms that may inhabit an estuary and determine to a great extent the abundance and distribution of organisms within the estuary. River current and the ebb and flow of the tide are the major forces creating complicated patterns of erosion, sedimentation, and water mixing in estuaries (Reid, 1961). The mixing of salt and fresh water produces a chemical environment unlike either freshwater or marine environments. The diurnal rise and fall of the tide produces highly variable salinity and moisture conditions throughout the estuarine habitat.

Marine and Fresh Water Mixing: At any one point in an estuary the levels of salinity vary so greatly that relatively crude measures of salinity are adequate for most biological studies (Green, 1968). In most estuaries, gradients of salt content can be detected and shown as isohaline lines running across the estuary. These lines do not run straight across the estuary. Due to the coriolis force, the isohaline lines are further inland on one side of an estuary than on the other. In the northern hemisphere they are higher on the right hand side of the estuary when one faces upstream (Cronin, 1970). In addition, the ebb and flow of the tide carries the isohaline lines up and down the estuary.

Four classes of estuaries, based on patterns of water circulation and salinity, have been outlined by Bowden (1967). Tidal current relative to river flow is the basic force determining the type of water circulation in estuaries. In general, river water tends to flow seaward as a layer of fresh water on top of heavier salt water. The two layers are separated by a rather distinct interface. Tidal currents, which produce turbulent mixing action, break down the interface and cause various mixing patterns of salt and fresh water. In a vertical column of estuarian water this turbulence may produce mixing in one part or throughout the length of the column of water. Shape and size of the estuary and the force of the earth's rotation also influence the mixing process of salt and fresh water in estuaries.

In the first type, a salt wedge estuary, salt water extends as a wedge into the river basin or embayment with little or no interruption in the salt and fresh water interface. If there were no friction between the salt and fresh water, salt water would extend up the river to the point where the river bottom is at sea level. However, a certain amount of friction does occur, forcing the upstream edge of the salt wedge to slope downward.

The second type of estuary is also characterized by a two-layered flow of salt and fresh water but with entrainment of salt water occurring in the upper layer of fresh water. Salt water is moved upward and entrained in the upper layer by internal waves on the interface created by a strong river or surface layer flow. Water circulation of this type usually occurs in deep fiord type estuaries.

In shallow estuaries, greater mixing of salt and fresh water takes place to produce an unstratified estuary. While there will be marked differences in the flow of water from top to bottom a marked salinity interface will not occur. The salinity content usually grades continuously from the surface to the bottom. When the tidal current is very strong, mixing of salt and fresh water is intense, producing the fourth class of estuary having no vertical salinity gradients. There still exists a salinity gradient inland and across the estuary due to the ebb and flow of the tide and the rotation of the earth. In shallow estuaries where the ratio of width to depth is relatively small the earth's rotation will not affect the circulation of water.

Extensive modification of these three basic patterns results from variations in the shape and size of individual estuaries. Such modifications are too numerous to list and are outside the scope of this study. Hence, it is important to keep in mind that, in every estuary, conditions exist to produce unique variations in the mixing of salt and fresh water.

Salinity patterns have a tremendous influence on the organisms using estuaries. The most noticeable influence of salinity gradients is on the distribution of sessile (fixed) and slow moving organisms. But, according to McHugh (1967) salinity gradients and changes will also directly and indirectly affect estuarine nekton.

The distribution of oysters in estuaries illustrates the effect of salinity on one organism. Although the oyster is extremely tolerant to salinity changes, its distribution in an estuary is indirectly controlled by salinity. Upbay distribution is limited by the maximum flow of fresh river water and downbay the oyster's distribution is limited by predators which exist only in high salinities.

Patterns of salinity and water mixing have important implications for resource management within estuaries and their fresh water tributaries. Alterations in the flow of river, for example, can affect the intrusion of salt water, and with it, predators of estuarine fauna. Cyclical variations in fresh water flow often regulate primary production in estuaries. Thus, alterations in annual flow cycles can affect the productivity of the entire estuarian system. Migratory populations such as juvenile salmon, dependent upon an abundant supply of food available when they arrive in the estuary, can be seriously impaired if productivity is delayed or reduced (Harger, 1971). Since patterns of salinity affect the rate of siltation in different parts of an estuary, changes in fresh water inflow can alter the bottom sediment patterns and upset conditions for benthic organisms.

Shape and Size of Estuaries: The shape and size of estuaries determines, to a great extent, modifications in patterns of water movement, fresh and salt water mixing, erosion, sedimentation, and the kinds and distribution of estuarine biota. The initial forms of estuaries are modified by the processes of erosion, transport, and sedimentation. There is a constant input of sediment into an estuary from land runoff. Currents and wave action within the estuary erode material away from shores. Ocean currents erode peninsulas or headlands bordering estuaries and deposit much of the eroded material at the seaward end of the estuary (Pritchard, 1967). River sediment tends to fill the estuary and build deltas into the sea. Green (1968) notes, however, that where the tidal range is great and ocean currents strong, the formation of deltas may be prevented.

Deposition of sediment material in an estuary will occur at different rates in different places depending upon the patterns of salinity and growth of vegetation. The salts in sea water cause fine particles of suspended material to group, or flocculate, and settle more quickly. Along estuarine shores, deposition of material will be encouraged by salt tolerant plants that occupy and stabilize shore areas. Over long periods of successful plant occupancy and the deposition of material in shore areas, marsh lands will form and gradually build into the estuary (Reid, 1961). High tides and continous wave action will erode the marsh and carry organic nutrients into the estuary. In highly turbid estuaries marshes become a major source of organic material. Turbidity reduces light penetration in estuarine water and restricts photosynthesis by submerged or floating plant organisms.

Under natural conditions the processes of erosion and deposition will reach a state of equilibrium. But, when embankments and sea walls are built, less wave and current energy is avilable to transport materials in suspension. The result is increased deposition of materials in the estuary, often creating conditions inimical to estuarine plant life and benthic organisms.

Gradations in the mixture of sand, silt, and clay material deposited in an estuary influences the distribution of benthic organisms. Odum (1971) notes that the infauna often respond sharply to grain size of the bottom. Filter feeding fauna predominate in and on sandy substrate, while deposit feeders are more common on silty or muddy substances. Alterations in the pattern of deposition will impose stressful demands on populations of these organisms to seek out areas with environmental conditions suitable for their existence.

Thermal Properties: Reid (1961) has stated that from a broad ecological point of view the thermal properties of water and the conditions associated with temperature are unequivocally the most important factors in maintaining water as a life support system. In estuaries, the temperature regime is largely a function of depth together with the effects of stream inflow and tidal exchange. Stream water is typically cooler in winter and warmer in summer than the sea water and therefore creates temperature gradients that reverse seasonally along the length of an estuary. Deep estuaries will maintain relatively constant bottom temperature with an intermediate range of temperature and salinity in a halocline layer of water between the surface low saline layer of water and the bottom salt water layer. Shallow estuaries are susceptible to the warming and cooling effects of climatic conditions and to the thermal effects of pollution due to the thorough mixing processes of water (Moore, 1958). Thus, they display almost daily temperature variations.

Kinne (1970) has listed three principal ways in which temperature affects living systems. First, temperature "determines the rate and mode of chemical reactions and hence of biological processes; second, it affects the physical state of water as the basic life-support medium in estuaries, and third, it modifies the basic properties of living matter." Consequently, the abundance, productivity and distribution of biota is influenced by gradations and variations in estuarine temperature. Kinne further notes that while variations in temperature are characteristic of estuaries the variability is constant. This provides a relatively permanent variability in estuaries to which the biota are rather narrowly adapted. The major response mechanisms to pertubations in the constant variations of temperature are escape and acclimation (Kinne, 1970). The range of escape, however, is limited by organisms' mobility and tolerance to physical factors which vary throughout the estuary. Acclimation is a physiological process that takes place over time and is of only limited aid to organisms exposed to abrupt changes in temperature. As McHugh (1967) has noted, sudden cold waves or influxes of heat in estuarine waters can immobilize or kill estuarine nekton at temperatures not normally lethal when sufficient time is allowed for the nekton to acclimate. Thus, in terms of resource analysis, two important parameters of temperature to consider are the constancy of variation and the range of organisms' tolerance to different degrees of change in the pattern of temperature variations.

Physiological responses of organisms and the dynamics of estuarine populations are not controlled by a single environmental factor such as temperature. Many factors operate in combination to support or modify the organisms' responses to changes in any one or all the physical factors in estuaries (Kinne, 1967). In resource analysis, therefore, an attempt should be made to account for the effects of all environmental factors on estuarine life.

Oxygen in Estuaries: Temperature and salinity variations play an important part in controlling the content of dissolved oxygen in estuarine water. The solubility of oxygen in water decreases as both temperature and salinity increase. Concomitantly, it takes less heat to raise the temperature of a given volume of salt water than it does to raise the temperature of the same amount of fresh water. Thus, one can visualize the gradations and fluctuations in dissolved oxygen content that occur in estuaries receiving fresh cool water from river discharges at one end and warm marine water from the ocean at the other end.

Daily rates of photosynthesis and the rise and fall of the tide produce diurnal patterns of dissolved oxygen content in estuaries. Areated ocean water, containing near the maximum of dissolved oxygen, is carried into estuaries and mixed with fresh water by tidal action. The influence of the mixing of fresh and marine water on the total content of dissolved oxygen in an estuary at any point in time is most meaningful when considered in relationship to the flushing time of individual estuaries. The flushing time is the time it takes for an accumulated volume of fresh water, at a given instant, to be removed from the estuary by river flow and tidal action (Pritchard, 1967). In a large drowned valley estuary the flushing time may be as long as a hundred tidal cycles, but only a couple of cycles in a small estuary (Green, 1968).

In highly turbid estuaries, diurnal changes in oxygen produced by photosynthesis are not detectable. Suspended sediment from erosion or pollution can act as a "light trap" to restrict photosynthesis and the production of oxygen in the water (Harger, 1971). When this occurs in estuaries, the content of dissolved oxygen will depend largely on contributions from the inflow of fresh and marine water. Mixing of aereated marine water with fresh water will depend upon many physical factors including river flow, tidal action, and the shape and size of the estuary. In areas receiving insufficient circulation of oxygen rich water substantial oxygen deficiencies may occur rendering the area uninhabitable to most fauna (McHugh, 1967).

Structures in estuaries such as bulkheads, jetties and breakwaters that reduce the energy in current and wave action can be expected to restrict the circulation of aereated ocean water to various parts of the estuary. On the other hand, these structures may promote increased rates of sedimentation thereby reducing turbidity and provide a greater area of clear surface water in which photosynthesis may take place. If, however, the rate of photosynthesis is not limited by turbidity and is encouraged by an abundant supply of nutrients and favorable temperature conditions, large phytoplankton blooms may frequently occur. When these blooms die, oxygen used in decomposition depletes the supply of dissolved oxygen in the estuary to levels lethal to fish and other marine fauna.

The Chemical Environment of Estuaries: The chemical composition, quantitatively, of estuarine water results from the continuous mixing of seawater with land-sourced water. Odum (1971) states that the high productivity of estuaries is due to this continuous input of chemicals in nutrient rich waters. Accordingly, he describes the input process as an energy subsidizing one. Once in an estuary, inorganic substances may enter into any one of many complex estuarine phases of biogeochemical cycles. For example, chemicals may become physically associated with silts and microorganisms, react chemically with other elements and compounds or enter the biochemical process of estuarine biota (Cronin, 1970).

Biogeochemical cycles, in estuaries, are dominated by physical processes (tide, river flow, temperature, basin shape). Man's effect on the environment results largely from his actions as an agent of physical change. Because of this, man's influence on estuarine processes, particularly the distribution and productivity of estuarine biota, is the consequence of his indirect impact on biogeochemical cycles. Additionally, since the estuary is the ultimate recipient of all changes along the contributory waterways, the effect of these changes on estuaries can be cumulative and multiplicative over time and space. As an example, increasing the organic waste load of a river can increase the biological oxygen demand(BOD) in estuarine waters. But, the effects of BOD are moderated by a process of flushing as the tide rises and falls. Decreasing the inflow of river water, however, results in reduced flushing, increased residency time of organic matter and thereby accumulation of waste and increased BOD. Single actions such as increasing organic waste loads or decreasing flushing action may be insignificant in themselves, but taken together, they can compound the ultimate consequences with a loss in overall estuarine utility. Thus, in considering the effects of human activities on estuaries, resource managers must become fully aware and appreciative of biophysical process, especially the dynamic nature of these processes.

Estuarine Biota: The effect of all these physical factors is to make estuaries nutrient rich, but highly stressful environments. Organisms that do inhabit or utilize the estuary must have special abilities to adapt to the variations that occur in the physical environment of estuaries. Kinne (1967) says that to exist under estuarine conditions organisms must be "euryplastic". They "must be able to endure extreme ranges and intensity fluctuations of environmental factors." Yet as Odum (1971) notes, even though this harsh environment results in low biota diversity, the estuarine environment is one of the most highly productive environments in the world.

The only primary food producing organisms in estuaries, as on the rest of the earth, are plants. Through photosynthesis plants use nutrients and carbon dioxide and water to manufacture organic material. The major producers in most estuarine waters, in contrast to terrestrial environments, are small single celled plants, called phytoplankton. They are present in the estuaries in quantities of millions of organisms per liter of water and their productivity continues through the entire year.

Rooted plants and plants attached to the bottom by means of holdfast structures also play an important role as producers in many estuaries. Generally these plants are located in shallow water areas along the margins of estuaries. The submerged plants trap suspended sediments and nutrients, provide protection to small nekton from predators, and release organic matter that becomes part of the detritus food chain.

Rooted plants along the shores of estuaries and in estuarine marshes provide large quantities of organic material to the detritus food chain. The rooted plants in marsh areas trap sediments flowing through estuaries and thereby become nutrient reservoirs for the estuary. The marsh areas provide a rich habitat for many fish, shellfish, reptiles, birds and mammals (Cronin, 1970).

Zooplankton, in estuaries,include copepods, the larvae of almost all of the animals which live in estuaries plus those that utilize estuaries as nursery grounds, jellyfish, and other drifting species (Cronin, 1970). These organisms are secondary consumers that feed on phytoplankton or browse on large plants. Their abundance is greater in estuaries than in adjacent marine waters, but displays highly variable seasonal cycles (Riley, 1967). The distributions of zooplankton have been noted to vary primarily with temperature and salinity gradients. Riley (1967) notes studies of the Delaware River Estuary where persistent changes in species composition along the length of the estuary were easily related to salinity gradations. In these studies the most abundant populations were found in the middle reach of the estuary between the 5 and 18 ppt. salinity levels.

Salinity appears to be one of the major factors influencing the distribution and composition of benthic organisms in estuaries (Carriker, 1967). Minimum diversity is noted in the zones of steepest gradation between fresh and marine water. Laterally, the benthos are distributed the entire width of the estuary with individual species found on different mixtures of sand, silt, and clay sediments. For example, the oyster is found near the center of the estuary on firm sediment (Cronin, 1970). The distribution of detritus feeders and filter feeders relative to bottom composition mentioned earlier is another example.

Low salinity parts of many estuaries are regions of high value to fish. These regions receive fish eggs, larvae, and young from freshwater spawners; semi-anadromous and anadromous fish, estuarine spawners and some ocean spawners (Cronin, 1970). The Croaker, for instance, spawns at the entrance of the estuary where young are transported upbay by the movement of deeper marine water to reach plankton rich, low saline water.

Productivity of Estuaries: The balance that is achieved between the biotic and abiotic components in estuaries results in a highly productive ecosystem. In summary, Odum (1971) gives three basic reasons for this high productivity. First, estuaries act as nutrient traps in which nutrients are constantly maintained in a rapid cycling process. Benthic organisms prevent nutrients from being lost to marine sediments and assist the entry of nutrients into estuarine nutrient cycles. Deep rooted plants, burrowing animals, and microbial action help to recover nutrients from deep estuarine sediments. Secondly, the producers in estuaries are varied to such an extent that photosynthesis takes place continuously throughout the year. And, thirdly, the ebb and flow of the tide removes wastes and transports nutrients so that organisms may utilize less energy in searching for food. The mixing action in estuaries brings food to them. In essence, many important estuarine organisms live a relatively sessile or immobile existence.

IMPLICATIONS FOR RESOURCE ANALYSIS

Ecological principles pertaining to population dynamics, community energetics and community organization can be incorporated into three basic procedural considerations in the analysis of coastal resources. These three procedural considerations have been summarized by Foster (1971) in the following way:

1. The relationship between components of the ecosystem must be determined in order to utilize the resources in such a manner as will not disrupt those relationships.

2. No change in a natural system is an isolated change, but rather has repercussions on all other constituents in the system. Therefore, it is imperative to recognize the factors which influence any specific system, and to maintain those factors above some minimum level beyond which the system stability is adversely affected.

3. The natural state of any renewable resource complex at any point in time represents the optimal combination of biotic and abiotic constituents, providing the optimal allocation of energy within the system and minimizing the system instability.

These three considerations are important to resource analysis since the natural characteristics of coastal resources are what make the living resources valuable to man. In other words, the primary utility man finds in the living resources of the coastal zone is the product of the functioning of the coastal ecosystems as they exist in a "natural" state. Since man modifies coastal ecosystems in attempts to crop or exploit both the natural biological and physical geological attributes of the coastal zone, the basic goal of resource management should be to retain the characteristics of the coastal resource system as near their natural state as possible. The authors of the National Estuarine Pollution Study (U.S.A.

Department of Interior, 1970) recognized this in the statement:

> The primary objective of technical management is to achieve the best possible combination of uses to serve the needs of society while protecting, preserving and enhancing the biophysical environment for the continuing benefit of present and future generations.

The goal to retain the natural characteristics of coastal ecosystems as near their natural state as possible suggests that certain constraints will have to be imposed on the way in which man may use coastal resources. Moreover, given present technological capabilities, this goal may imply that the short run or present utility of coastal resources may be reduced for potential users or limited to a select few users. Nevertheless, in order to maintain the continuous biological and economic productivity of coastal resources the limitations of the coastal ecosystem must be identified and incorporated into making decisions regarding the allocation of uses to coastal areas.

Habitat Zonation

The marine, estuarine and terrestrial habitats of the coastal zone and zonations within them, provide the spatial orientation necessary for conducting the above procedural considerations. The habitat approach facilitates the application of ecological concepts in resource planning which must deal with finite units of space. Moreover, the use of habitats and habitat zonations in the classification and analysis of coastal resources allows one to generalize the findings of the procedural considerations to other similar habitat areas. This is of practical significance to reconnaisance level resource studies and conceptual planning because it allows one to plan the development of large geographical units that ultimately affect the range of planning alternatives for specific sites.

The processes within the coastal habitats from which limitations or constraints to man's activities in coastal areas may be derived are as follows:

1. The transport of nutrients and wastes by water driven by the forces of tide and gravity.

2. The transport of geological material by water driven by the forces of tide and gravity.

3. The processes of erosion, and deposition of geological material along beaches and in estuarine waters.

4. The mixing of nutrients, fresh and saline water and water of different temperatures in marine and estuarine areas.

5. The trapping of nutrients in estuarine marsh areas.

6. The productivity of organic matter in marsh areas and its introduction into estuarine waters.

7. The processes of nutrient "outwelling" from productive estuarine areas to coastal marine waters.

8. The processes of upwelling of nutrients from the deep parts of the ocean to coastal and inland areas by water currents, fish, and birds.

CHAPTER THREE: ANALYSIS OF RESOURCES IN THE COASTAL ZONE

RESOURCE ANALYSIS

Analysis of resources to assess and display their capability to support land and water uses usually involves three operations: 1) resource inventory and classification; 2) resource evaluation; and, 3) land classification. Resource inventory and classification is the process of identifying resources and aereally subdividing the land into units possessing similar biogeophysical attributes that can be systematically evaluated for potential uses. Resource evaluation is the process of evaluating the resource classes to ascertain the capability of the resources to support selected uses. Land classification is the process of aggregating and mapping classes of resources with similar use capabilities into land classes which can be used in managing resources under various institutional arrangements.

The distinction is made between resource inventory and classification and resource evaluation to facilitate an understanding of the processes involved in resource analysis, to provide flexibility in incorporating improved forms of information into the analysis, and to maintain the resource classification as an information framework relatively immune to changes in the evaluation process. Christian (1957) notes that present knowledge of land use problems and what constitutes the best form of land use changes as more information is gained and as the economy changes. For this reason, he states that it is desirable that the resource classification of a region be based on fundamental qualities of land and be independent of present knowledge of land uses. Resource inventory and classification, therefore, should be regarded as a separate operation within a framework of resource analysis. Hills (1961) makes the same observation in noting that since man's use of the land and its resources changes continuously with changes in the condition of the economy, renewable resources must be classified according to the fundamental factors which affect biological productivity. Finally, it is important to make the conceptual distinction between the three phases in resource analysis to provide a framework for operationalizing institutional and interdisciplinary arrangements that are necessary for carrying out a comprehensive program of resource analysis.

Several techniques of resource analysis demonstrating significant variations in the three operational phases outlined above have influenced the author's approach to an analysis of coastal resources. Most applicable to this study are those techniques developed by McHarg (1969), Hills (1961 and 1970) and the Canada Land Inventory (Canada Department of Regional Economic Expansion, 1969). McHarg (1969) recognizes that "ecological determinism" is the basis for evaluating natural resources. In his approach, McHarg utilizes a personal understanding of nature as a process, in order to determine the best use for different resources. Similarly, Hills' (1961) approach to resource analysis has the underlying premise that land-use planning which optimizes the use of resources is based on an analysis of the biological productivity of the resources. Hills points out that in the context of man's changing economic and social condition, the biological productivity of resources is the most fundamental base for the management of renewable resources. His work greatly influenced the format for the Canada Land Inventory (CLI) which is a national program of resource analysis with the objective to inventory and evaluate Canada's supply of land resources. The technique of resource analysis used in the CLI is based primarily on the identification of resource characteristics which limit the usefulness of resources for different economic activities. Thus, it indicates broad levels of resource capability with subclasses indicating the type of limitation.

<u>Resource Inventory and Classification</u>

Hills (1970) defines resource classification as a process of "fixing-to-begin" in which the objective is to systematically subdivide land and water resources of a given region into units suitable for describing and evaluating their potential productivity and for planning the development and management of the resources. Productivity is defined by Hills as 1) <u>physiographic production</u> in which earth products such as sand, gravel and water are mined; 2) <u>biological production</u> in which biological products are cropped; 3) <u>artifact production</u> in which man-made things are produced through art, manufacturing and construction; and, 4) <u>societal production</u> which results from changes in the social, intellectual, political and religious life of a community.

Since the relationships between each type of production and the biogeophysical attributes of the earth are complex and vary with changes in the mode of production, the approach and criteria for subdividing or classifying resources must be explicit, otherwise a resource classification can be of little value to the evaluation.

Three approaches to defining and classifying resource characteristics on the basis of prescribed sets of principles are discussed below.

The Genetic Approach: In the genetic approach, land is subdivided into natural regions on the basis of causal environmental factors, particularly climate and geomorphology (Mabbutt, 1968). The approach is based on the concept that each part of the land surface is the end product of an evolution governed by parent geological material, geomorphological processes, past and present climates, and time (Christian, 1957). Thus, users of the approach attempt to group resources according to the dominant environmental factors determining the association and distribution of resources.

Most attempts to establish coastal resource classes on the basis of genetic factors have not met with great success (Bird, 1964). Advancements in theory regarding the genesis of coastal landforms brought about by continuous research into the subject have tended to nullify the usefulness of most genetic classifications developed to date. Mabbutt (1968) notes that, in general, genetically determined resource classes or regions are very large, have vaguely defined boundaries and limit resource analysis to making only broad and general statements about the environmental context within which resource attributes are found. In short, the breakdown of genetically determined regions can only be accomplished to a level of the genetic bond which does not provide sufficiently small and discrete resource classes for most evaluation purposes.

On the other hand, the genetic approach cannot be discounted entirely. It is important to understand the way in which biogeophysical factors interact to produce resource characteristics important to man. In this context then, an understanding of the genesis of particular resource attributes is valuable in evaluating resources for a variety of purposes. Thus, the premise that each part of the land surface is the end product of an evolution governed by parent geological material, geomorphological processes, past and present climates and time is of practical significance to an approach to classification which relies heavily on interpreting the characteristics of resources from recognizable landscape components.

The Landscape Approach: In the landscape approach, a geographical area is subdivided into a hierarchy of land units on the basis of the occurrence of landscape components or component patterns recognized from empirical investigations. Use of the approach is based on the premise that the landscape reflects the underlying biological and physiological controls governing the association and distribution of resource attributes within a region (Christian, 1957). Through interpretation techniques, the landscape components and patterns can be analyzed to identify resource attributes which can be generalized to other similar landscape components.

The landscape approach is different from the genetic approach in that the concern is not with subdividing areas on the basis of genetic process which produce particular resource characteristics but with recognizing and differentiating between areas having different sets of associated resource attributes (Mabbutt, 1968). It is, however, useful to understand the genesis of different landscape patterns in order to interpret landscape patterns to make predictions about their resource attributes.

The Parametric Approach: As user requirements for resources are recognized as being more specific and critical in evaluating resources for different uses, the landscape approach often becomes too general and inaccurate to be useful (Mabbutt, 1968). Then it is necessary to supplement the landscape approach with an approach based strictly on the direct measurement of resource attributes relevant to the specific purpose of the evaluation. Mabbutt (1968) defines the parametric approach as the "division and classification of land on the basis of selected attribute values." Since these selected resource attributes are, in general, more closely defined for a specific purpose, the parametric approach represents a major shift away from the criteria outlined by Christian that the resource inventory and classification should be independent from the present knowledge of land uses.

The major problems in utilizing the parametric approach are in choosing resource attributes to be measured and in establishing the degree of internal differentiation to be made of attribute values. The attributes chosen for measurement in this approach, are relevant to the purpose of the evaluation. This could limit the usefulness of the inventory for other purposes and in the future. Since resource requirements for a particular type of use vary with time and between different geographical situations it is risky to assume the relevancy, in one location, of attributes chosen by inference from other locations or to assume their relevancy at a future point in time. Moreover, since resource characteristics change because of the effects of biogeophysical processes and the influence of man, it is unlikely that any attribute value will remain constant over the length of a 20-30 year planning period.

The parametric approach to resource classification may be inappropriate for planning at levels more generalized than site planning. As Mabbutt (1968) notes, under the parametric approach the integrated concept of land gives place to the expression of attributes in specific and limited terms selected for their significance for a proposed land use. This suggests a detail of investigation and specificity not normally practicable in conceptual or reconnaisance levels of resource analysis.

Since the parametric approach does give more reliable and precise data about resources it can be expected to replace the genetic and landscape approaches in many "fine grained" planning situations. However, the parametric approach is not suitable for general survey level resource classification. Until ecological models become more readily available for planning, use of the parametric approach in planning will have to be supplemented with a classification system that will provide the ecological context for making resource evaluations.

Resource Evaluation

Resource evaluations generally aim to identify the best land areas for different land or resource uses. The methods of evaluation are described by Steinitz (1970) as having increasing levels of complexity, specificity and usefulness in resource planning. His five methodological categories, in order of increasing complexity, are listed below:

(A) Descriptive
(B) Static, Single-factor analysis

(C) Static, Multi-factor analysis
(D) Dynamic, Single-sector models
(E) Dynamic, Multiple-sector models

The descriptive methods are basically inventories of resources described nominally with the intent that there will eventually be an evaluation of the resources for different uses. In the static single-factor analysis, land areas are evaluated for prospective uses on the basis of a single resource or resource characteristic. Static multi-factor analysis methods are more useful in that they consider a larger number of resources as variables in the analysis. The drawback of the static methods is that they do not consider changes in resources that occur naturally over time or because of the influence of man. However, the static methods do provide a quick overview of resource capabilities and help to pinpoint areas requiring more detailed and intensive analysis.

Dynamic types of evaluation have basically the same objective as the static methods, namely to identify the best areas for different land or resource uses. But, in these methods a question suited to computer simulation is asked, such as, "What happens if a certain use of a resource is permitted to occur?" Within the context of this question, the dynamic methods attempt to predict the consequences of a use on the resource. Then, the alternative uses or courses of action can be measured and compared in a general planning model (Lowry, Ira, 1965).

Steinitz (1970) stresses that in evaluating resources it is important that the distinction between "should" and "could" be made in interpreting the results for normative purposes. Hills' (1970) three types of evaluations, capability, suitability and feasibility, are useful for accomplishing this.

Capability measures are used to indicate "the potential of an area to produce goods and services of various kinds under specified types and intensities of economic and technological controls" (Hills, 1970). Two criteria used to establish capability measures are the level of production of a specific crop and secondly, the kinds and degrees of limitations which prevent a specific area from reaching the maximum productivity established for the larger region.

Use suitability ratings indicate "the relative ability of a specific area in its present condition to produce specific goods and services" (Hills, 1970). Thus, it is a measure of the technological effort required to bring a specified site to a desired level of production.

The third type of evaluation, use feasibility, is conducted to measure or indicate "the relative advantage of using a specific area of land for a specific type and intensity of use" (Hills, 1970).

Land Classification

Using ratings similar to Hills' resource capability, suitability, and feasibility measures, land should be classified according to the use or combination of uses that are best suited for the area under study. Hills (1970) accomplishes this in two phases of his evaluation process--the recommended-use phase and the use-programming phase. Recommended uses are designated for land areas on the basis of resource capability, suitability and feasibility ratings. Use-programming involves the timing or phasing of resources into different uses according to changes in social and economic factors which determine the demand for a resource use.

In the resource evaluation method developed by McHarg (1969), land classification for recommended uses is achieved through the synthesis of two evaluation processes. First the intrinsic values of resources for different uses are established on a scale of most suitable to least suitable. These values are mapped on transparent material for each prospective use and then superimposed in order to show the area of occurrence of different resource values. Since the resources are valued for human use, this composite of maps shows areas of greatest and least social values. From an analysis of the compatibility of uses, compatible and coexistent land uses for each area in the total study area are mapped in compatible associations. Through a synthesis of the two maps, (the composite map and the map of compatible association land uses), a suitability map showing the maximum conjunction of coexisting compatible land uses that can be sustained by every area in the total study area is produced (Belknap and Furtado, 1967).

The programming of land uses is achieved in McHarg's method in the matching of the land-use suitability maps (a measure of resource supply) with an economic evaluation of the nature, locational and spatial requirements of demand (Belknap and Furtado, 1967).

A CLASSIFICATION AND EVALUATION SCHEME FOR COASTAL RESOURCES

Resource Inventory and Classification

The resource classification used in this study combines the genetic, landscape and parametric approaches. On the basis of landscape patterns and selected user specific resource characteristics, a coastal area is divided into a hierarchy of resource areas. An understanding of the genesis of the landscape features and specific resource characteristics enables interpretation of landscape patterns in order to make predictions about their attributes and interrelations.

A resource inventory and classification scheme can be of little value to an evaluation of resources for different uses if the criteria for classification are vague and do not specify the bases for selecting and classifying resources. Thus, an attempt has been made in the inventory and classification scheme to meet two criteria:

1. The classification must express those biogeophysical attributes relevant to the uses for which the evaluation is to be made.

2. The classification divisions must represent or express biological and geophysical interrelationships that exist between geographically distinct areas because of:
   (a) the migratory nature of the biota of the sea,
   (b) the capacity of water to transport biotic and abiotic components,
   (c) the interpenetration of land by water providing access between the sea and land to man and other organisms, and
   (d) biogeochemical cycles.

Coastal Belts

One of the main purposes of this study is to provide a way to consider the biotic productivity of resources in planning. Because of this, coastal belts, based on the designation of coastal habitats, are established as the first step in classifying coastal areas. Incorporating the concept of habitats into the classification allows considerations to be made of the relationships between geophysical factors and the living biotic constituents of coastal areas. Since a habitat is defined in terms of the bio-geophysical factors which affect organisms, the concept aids in evaluating areas for their suitability for different types of biological productivity and in making limited predictions about the potential effects coastal changes will have on biotic communities.

The designation of three coastal belts is based on the delimitation of terrestrial, estuarine and marine habitats. The coastal marine belt includes only the subtidal portion of the neritic zone as defined in Chapter two. The estuary-shore belt includes the estuarine habitat and the intertidal and backshore portion of the neritic zone. The estuary-shore belt is composed of terrestrial, estuarine and marine habitats because of the close biological and physiological relationship between the habitats in this area and also to provide a geographically unified area along the coast for the purposes of evaluation. The third belt is the terrestrial belt. Unfortunately, the inland boundary of the terrestrial belt is the most arbitrary boundary to establish within the coastal belts. There are no bio-geophysical parameters that are easily recognized and useful as criteria for precisely defining the terrestrial belt for all situations.

To establish overriding criteria for defining the terrestrial belt, the definition given by Schaefer (1969) is most useful. Namely, the coastal terrestrial area should include those terrestrial activities that are oriented to the marine environment and life processes influenced by the sea. Schaefer stated that an area extending about 2 or 3 miles inland from the sea would satisfy this definition in most areas.

Since this definition is based on terrestrial and marine activities, it is helpful to consider coastal activities of man in the way that they affect the marine environment or are affected by marine processes. Schaefer provides the following classification:

I. Direct uses of living resources
   a. Extractive use for food and other marine products (i.e. commercial fisheries and aquaculture).
   b. Extractive use for recreation (sport fishing and hunting).
   c. Non-extractive uses; observation for recreation, observation for science and education.

II. Other uses of the coastal zone that importantly depend on the biota.
   a. Waste disposal-biodegradable wastes.
   b. Biological extraction of inorganic materials.

III. Human activities that incidentally affect, or are affected by, the biota.
   a. Uses of marginal lands
      1. Solid waste disposal and sanitary fill
      2. Building sites
      3. Airports
      4. Harbor construction
      5. Modification of shoreline for recreation
      6. Beach erosion and maintenance.
   b. Waste disposal-nonbiodegradable wastes.
   c. Ocean shipping
   d. Other forms of transportation (pipelines, etc.)
   e. Power generation
   f. Ocean mining
      1. Hard minerals and construction materials
      2. Petroleum and natural gas
   g. Shoreside recreation (picnicking, swimming, surfing, etc.)
   h. Communications
   i. Military defense

The Coastal Categories

In addition to the coastal belts designated on the basis of major coastal habitats, it is useful to divide the coast into a hierarchy of biogeophysical units on the basis of an examination of climate, geology, landform, hydrology, soils, vegetation and wildlife. A classification based on a consideration of these factors aids in explaining the differences that exist between and within coastal areas. In addition, the biogeophysical classification defines geographical units of associated resources which can be the focal point for management policies.

To define biogeophysical classes of the coastal zone, a combination of genetic, landscape and parametric approaches are used. Each coastal class is defined primarily on the basis of climate, landscape patterns, discrete landscape features, and biogeophysical characteristics significant to the purpose of the evaluation. Broader resource aspects, such as landscape patterns are used to define the larger classes, while resource characteristics specific to the uses being evaluated are used to define the finest level of coastal class. The definition of each coastal class is given below with suggested criteria for establishing and characterizing the class in a geographical area.

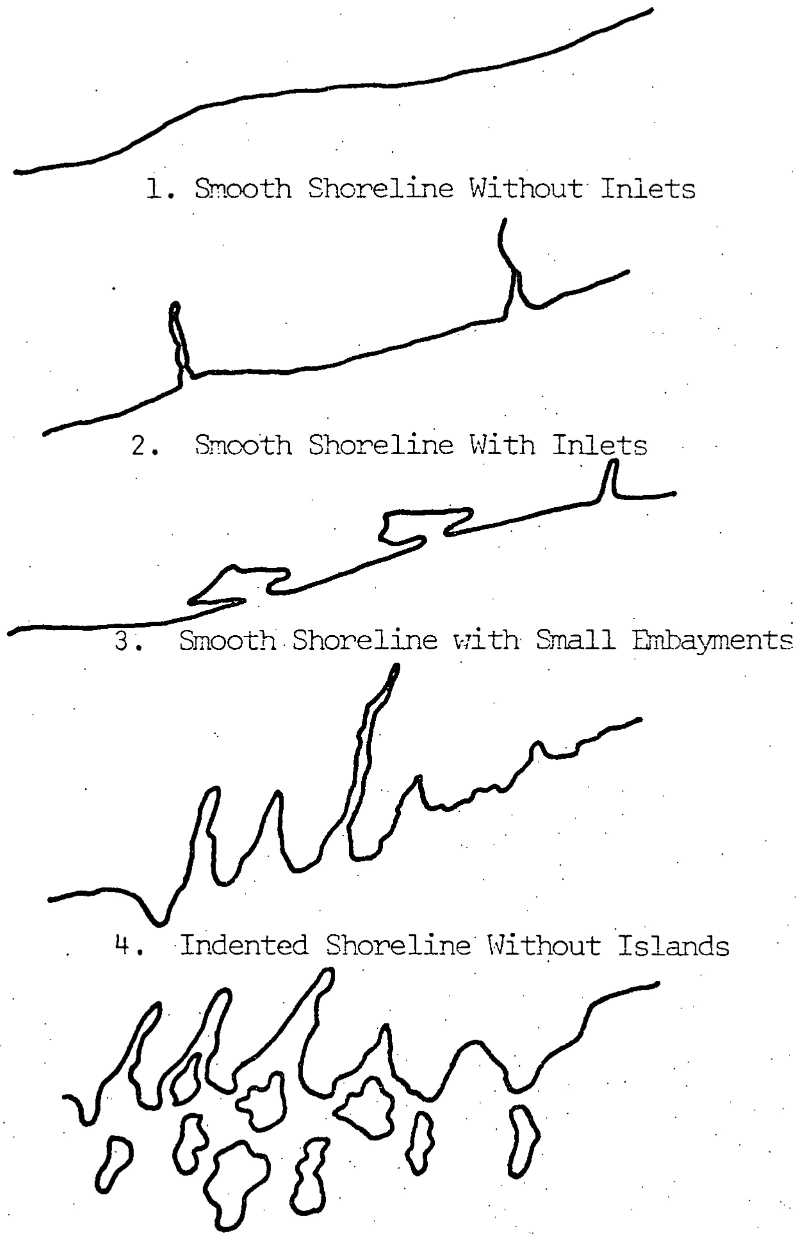
The Coastal Region: Coastal regions are defined as the occurrence of major coastal landforms in association with bioclimatic communities along the coast. McGill's (1958) map of coastal landforms of the world, based in part on both genetic and descriptive factors, is an excellent guide to identifying different landforms in an area. McGill's map is used primarily at the coastal region level because he has modified it to include nearly all landform features that can be observed empirically, such as delta coasts, fiord coasts, plain coasts and mountainous coasts. Krajina's (1965) delimitation of bioclimatic zones is used to identify climatic climax communities associated with regional landforms in the Pacific Northwest. The fiord-skerry coast of British Columbia and the southern panhandle of Alaska are for example associated primarily with

Krajina's coastal western hemlock bioclimatic zone. Other factors such as distinct differences in the width of the continental shelf, major world ocean currents, world climatic patterns, and tidal action can also be used to describe and differentiate coastal regions.

The Coastal Subregion: The coastal subregion is at a level of generality comparable to Lacate's (1969) land district which he defines as an area of land characterized by a distinctive pattern of relief, geology, geomorphology and associated vegetation. The coastal subregion is a subdivision of the coastal region based on the separation of major physiographic and geologic patterns which characterize the region as a whole. For example, groups of common land-water forms are the basis for identifying the coastal subregions within a coastal region. However, because some distinct features extend over great distances by themselves, such as a smooth shoreline, not all coastal subregions need actually be groups of landform features. Given below is an outline of landforms that occur in groups or singly which can be used to characterize coastal subregions within the coastal region. Definitions and examples of these coastal features follow below.

1. Smooth Cliff shoreline
2. Smooth shoreline without cliffs
3. Indented shoreline (inlets and embayments)
    a. Fiords
    b. Rias
    c. Embayments
    d. Lagoon coast
    e. Fiord skerry coast

The smooth and indented shorelines are shown in Figure 3. The genesis of cliffed coasts varies throughout the world (McGill, 1959). In the



MORPHOLOGICAL CLASSIFICATION OF COASTLINES

Source: U.S.A. Department of Interior 1970

Figure 3

Pacific Northwest we are familiar with the predominantly cliffed shores of Puget Sound and the cliffs of the British Columbia Fiord Skerry coast resulting from the drowning of glacier gouged valleys by the sea.

A distinction between cliffs can be made on the basis of whether or not an intertidal platform exists at the base of the cliff. Cliffed coasts consisting of nonresistant geological material may be eroded largely by marine forces, although land run-off also contributes to the erosion process. As the land mass is abraded, a wedge of material is removed leaving a gently sloping intertidal platform of various shapes at the bottom of the steep cliff. The eroded material may accumulate on the platform as a beach or be washed along shore or out to sea. Cliffs composed of more resistant geological material resist erosion and therefore do not form intertidal platforms. These cliffs are characterized as plunging cliffs (Bird, 1968).

Rias are branched inlets of partially submerged river valleys occurring in coastal lowlands. On the other hand, fiords are inlets at the mouths of glaciated valleys on steep coasts. The valleys scoured out by ice action have been subsequently submerged by the sea as the ice melted. At the mouth of fiords there is usually a bottom formation called a sill which is a rocky feature or glacial moraine that extends across the mouth of the fiord as a shallow threshold. A fiord skerry coast is a fiord coast characterized by a series of offshore islands which affect ocean currents, and climatic conditions within the fiord. British Columbia's coast is an excellent example of this type of coast. Most fiords are fed by rivers which sometimes have large enough discharges to create estuarine conditions throughout the fiord.

Kinne (1970) defines an embayment as all bodies of water separated from the open ocean by some physiographic feature but not possessing estuarine conditions. Two criteria which help to define embayments are 1) it receives a limited local land drainage; and, 2) the hydrographic characteristics and biota are dominated by oceanic regimes. The basis for distinguishing fiords from embayments is that a fiord is the product of glacial action and posseses a "sill" at its entrance to the sea.

Lagoons are embayed areas or inlets of the coast partially or completely enclosed by depositional barriers. The basic characteristic of a lagoon is the existence of a fresh water zone at the point of river discharge or land drainage, a marine tidal zone near the entrance to the sea and a transition zone of moderately saline water between the fresh and salt water zones (Bird, 1968). The entrance to lagoons is maintained by river flow or tidal action. The size of the entrance is usually in a constant state of flux as tidal action and river flow increase and subside either encouraging deposition of material at the entrance or eroding material away from the entrance.

The Coastal Component: The coastal component is composed of the discrete land features and water properties within the coastal subregion. For example, an indented fiord type of coast could be subdivided geographically on the basis of each fiord or perhaps on the existence of distinctively different regions of water mixing and water properties. Thus, coastal components can be characterized on the basis of the occurrence of major morphologic features in association with distinct marine water properties and climate conditions identified empirically. The morphological features which characterize a coastal component and differentiate areas within coastal subregions are given below:

1. Smooth cliff shoreline
   a. Cliffs with an inter-tidal platform
   b. Cliffs with shore platform at about high tide
   c. Cliffs with a shore platform at low tide
   d. Plunging cliffs with no shore platform

2. Smooth shoreline
   a. Characterized by adjacent land features
      1) Dune ridges and old stabilized backdunes
      2) Coastal marsh
      3) Beach composition

3. Indented shoreline
   a. Fiords with intermittant coastal drainage
   b. Fiords with continuous river in-flow
   c. Embayments without coastal drainage
   d. Embayments with intermittant local coastal drainage
   e. Rias
   f. Lagoons with intermittant coastal drainage
   g. Lagoons with continuous river in-flow

Coastal Sub-components: Each coastal component is composed of physiographic sub-components that are recognizable and measurable features of the coastal component. The sub-components which characterize the coastal component explain differences between and within coastal units that affect the biological and artifact productivity of the coastal unit. Some of the more common characterizing features of sub-components are listed below. Measurable or descriptive attributes are also indicated which can be used to define the finest coastal categories--coastal phases.

1. Cliffs
   a. Mineral composition
   b. Degree of consolidation
   c. Slope
   d. Height

2. Beaches
   a. Profile of backshore area and foreshore area
   b. Material particle size within backshore and foreshore areas
      1) Cobbles
      2) Pebbles
      3) Granules
      4) Very coarse sand
      5) Coarse sand
      6) Medium sand
      7) Fine sand
      8) Very fine sand
      9) Silt
      10) Clay (Bird, 1968 - Wentworth Scale)

3. Spits: "Depositional features built along the shore, usually ending in one or more landward hooks or recurves" (Bird, 1968).
   a. Shape
      1) Recurved
      2) Tombolos: spits linking an island to the mainland
      3) Cuspate spits: occur at points of convergence of longshore drift thus building sediment from two directions and creating a triangular shaped spit pointed seaward
   b. Retrograding
   c. Prograding

4. Barriers: Strips of narrow offshore land composed entirely of beach sediment and having no dunes or associated marshes
   a. Beach material composition
   b. Retrograding
   c. Prograding

5. Salt marshes
   a. Channelized
      1) Having one main channel
      2) Having distributory channels
   b. Retrograding
   c. Prograding
   d. In equilibrium

6. Marine and estuarian water bodies
   a. Depth at high and low tides
   b. Bottom sediment composition
      1) Gravel
      2) Sand
      3) Mud
   c. Mixing of salt and fresh water
      1) Stratified
      2) Entrainment
      3) Partially mixed
      4) Homogeneous

d. Salinity- Venice System (Reid, 1961)
   1) Hyper-saline--salinity greater than 40ppt
   2) Euhaline--40ppt & 30ppt
   3) Mixohaline--30ppt to 20ppt
   4) Mixopolyhaline--30ppt to 18ppt
   5) Mixo-oligohaline--5ppt to .5ppt
   6) Limietic--.5ppt

3. Other marine and estuarine water properties that display spatially differentiated values.

The Coastal Phase: The definition of the coastal phase follows Hills' (1961) definition of the physiographic site phase. The coastal phase is determined on the basis of one or more physiographic factors relevant to the purpose of the evaluation. Thus, the coastal phase is established from a parametric approach to classification rather than from a landscape or genetic approach. The coastal phase represents a data category given a geographic reference. Because of its specificity, it is given an ecological frame of reference by its position in the classification scheme.

Resource Evaluation

Since the objective of this study is to evaluate the coastal zone of Whatcom County, Washington, as a resource complex for four specific uses--Residential uses (recreation cottages and permanent homes), Waterfront Industrial Uses, Oyster Raft Culture and Public Outdoor Recreation Uses--the analysis includes both the descriptive and static multi-factor methods of evaluation. The evaluation establishes capability ratings for the different uses on the basis of biogeophysical factors which attract or limit the use of a resource. Attractive factors are those characteristics of climate, geology, landform, hydrology, soils, vegetation and wildlife which are identified as important or beneficial for each of the uses. Limiting characteristics in each of the resource categories are those characteristics which are detrimental to the proposed uses or which cannot absorb the impact of the users' activities. An assessment is made of the potential impact the proposed uses may have on the resource system and thereby on other resource users. An environmental impact matrix (Table 2) is used to display the potential for adverse impacts to occur.

The matrix was also constructed to aid in the analysis of conflicts associated with alternative patterns of resource use. The matrix does not provide direct evidence of environmental impact within the study area or actually predict the occurrence of environmental impacts. It only indicates the relative potential of adverse environmental impacts to occur and result in use conflicts by reference to situations of a similar character and through an understanding of the coastal ecosystem as outlined in Chapter two. For additional information concerning these other situations see Sorenson (1971), United States Department of Interior (1970), Harrison (1971), and Olson (1971).

Table 3 indicates the relative value, ranging from excellent to poor, of the resource characteristics identified as important in evaluation of land and water for the selected uses. Using this table, it is possible to assign a relative weight to each user resource requirement indicating the degree biogeophysical limitations affect specified uses. The result is an array of user specific resource values in each coastal component. To establish use-capability ratings for the coastal components the array of resource values for each use is consolidated into a value from one to six. The value of 1 indicates high resource use-capability and the value of 6

USES	OYSTER CULTURE										RESIDEN- TIAL						WATERFRONT INDUSTRIES						OUTDOOR RECREATION					
RESOURCE REQUIREMENTS / USES AND ASSOCIATED ACTIVITIES	Salinity	Water Quality	Water Temperature	Water Mixing	Protection from Waves	Consistency of Bottom	Absence of predators	Amount of Intertidal Area	Depth for Rafts	Access	Beach Composition	Vegetation	Freshwater Quality	Outward View	Seawater Quality	Beach Access	Protection from Waves	Water Circulation	Water Depth	Water Access	Space	Freshwater Quality	Freshwater Quality	Vegetation	Saltwater Quality	Beach Composition	Beach Access	Outward View
OYSTER CULTURE																												
Structures														X						X	X						X	X
Diking											X		X			X		X		X	X						X	X
Bottom Preparation											X													X		X		
Waste Disposal											X	X												X		X		
RESIDENTIAL																												
Structures								X		X										X	X		X			X	X	X
Transportation Facilities										X										X	X				X	X	X	X
Clearing						X													X			X	X		X	X		
Irrigation	X						X															X	X	X	X			
Groundwater Withdrawal	X						X															X						
Drainage Improvements	X	X					X															X	X	X	X			
Land Leveling	X	X				X																	X					
Bulkheading				X		X		X		X													X	X	X		X	
Diking				X		X		X	X																		X	X
Sewage Disposal		X				X																X	X		X			
WATERFRONT INDUSTRIES																												
Structures						X		X		X		X		X		X								X			X	X
Transportation Facilities						X		X		X	X	X		X		X								X			X	X
Clearing		X				X					X	X		X	X				X				X	X	X	X		X
Water impoundments		X					X	X				X	X										X	X				
Groundwater withdrawal	X	X										X	X										X	X				
Drainage		X										X	X		X								X	X	X			
Leveling		X				X					X	X			X								X	X		X		
Bulkheading				X		X		X	X	X						X								X		X	X	
Diking			X	X		X		X	X	X	X					X								X		X	X	
Dredging		X	X	X		X	X	X	X		X	X			X				X					X	X	X	X	
Waste Disposal	X	X	X			X					X	X	X		X								X	X	X	X		
OUTDOOR RECREATION																												
Structures								X		X		X			X	X				X	X							
Camp Ground Facilities										X		X				X				X	X							
Clearing		X					X				X			X	X				X			X						
Waste Disposal	X	X		X			X				X			X								X						
Transportation Facilities	X	X			X				X	X	X	X			X					X	X							
Water Withdrawals	X							X				X		X								X						

Table 2: Environmental Impact Matrix

Key: "X" indicates that a possibility exists for uses and associated activities to have an adverse impact on the resource requirements of other uses.

COASTAL RESOURCE USER REQUIREMENTS / IMPORTANT RESOURCE CHARACTERISTICS	SOILS **				BEACH MATERIAL				SLOPE				WATER DEPTH *				SURFACE WATER CIRCULATION				WATER QUALITY							WIND WAVES		EXPOSURE			
	Soft	Gravelly	Slow Permeability	Poorly Drained	Cobbles	Shingle	Sand	Mud	0-6°	7-12°	13-15°	15°+	30'+	16'-29'	6'-15'	0'-5'	No Mixing	Vigorous Mixing	Toward Shore	Away from Shore	Salinity(30ppt-40ppt)	Salinity(5ppt-30ppt)	Salinity(0ppt-5ppt)	Low Dissolved Oxygen	High Coliform Count	Temp. (32°F-40°F)	Temp. (40°F-60°F)	Sheltered	No Shelter	South	West	North	East
OYSTER CULTURE:																																	
Oyster Growth					D	B	B	C	A	C	D	D					D	A	B	B	B	A	D	D	D	B	A						
Rafts													A	B	D	D												A	C				
Bottom Consistency					D	B	B	C																									
Predators																					C	A	A										
Beach Area													D	D	C	A																	
Access									A	B	C	D	A	A	A	D																	
RESIDENTIAL:																																	
Wind Shelter																												A	D	C	C	B	B
Sun Shelter																												A	D	A	A	B	B
Vegetation Cover	B	D	B	D	D	D	B	B	A	B	D	D																					
Viewing																																	
Foundation and Drain.	D	B	D	D					A	B	D	D																					
Freshwater									A	B	C	D									D	D	A	D	D	A	C						
Beaches					C	A	A	D	A	B	D	D	D	B	A	A	D	A	A	B						C	B						
Flood Protection																												A	D				
Auto Access																																	
Waste Disposal		A	D	D							D	D	A	B	D	D	D	A	D	B													
WATERFRONT INDUSTRIES:																																	
Navigation Facilities					A	A	A	C					A	B	D	D																	
Building structures	D		D	D					A	C	D	D																					
Waste Disposal			D	D									A	C	D	D	D	A	D	A	A	A		D	D	A	B						
Auto access									A	C	D	D																					
OUTDOOR RECREATION:																																	
Campsites	C	C	B	D					A	B	B	D																A	C				
Recreation area	C	B	B	D					A	A	A	C	D	D	B	A												B	B				
Auto access	D	B	C	D					A	B	C	D																					
Freshwater																					D	D	B	C	D	A	B						
Protection from wind																												A	C				
Viewing																														A	A	C	C
Beaches					D	B	A	D									A	A	A	B													

Table 3: RESOURCE CHARACTERISTICS LIMITING USES

DEGREES OF LIMITATION

A-Slight limitation
B-Moderate limitation
C-Strong limitation
D-Severe limitation

Blank-No interdependence

* At mean lower low tide
** See references 1, 2, 52

indicates very poor resource capability with intermediate values indicating the relative degree of capability between these two values.

CHAPTER FOUR: THE BIOGEOPHYSICAL CHARACTERISTICS OF THE WHATCOM COUNTY COAST

RESOURCE INVENTORY AND CLASSIFICATION

Analysis of the biogeophysical characteristics in the study area follows the sequence outlined in Table 4. The outline is designed to aid in considering the deterministic nature of geophysical and biological processes.

Location of the Study Area

As shown on Map 1, the Whatcom County coast occupies the northern portion of Washington's shoreline on the east side of Southeast Georgia Strait, between latitude 48° 40' and 49° 0' and longitude 122° 40' and 123° 5'.

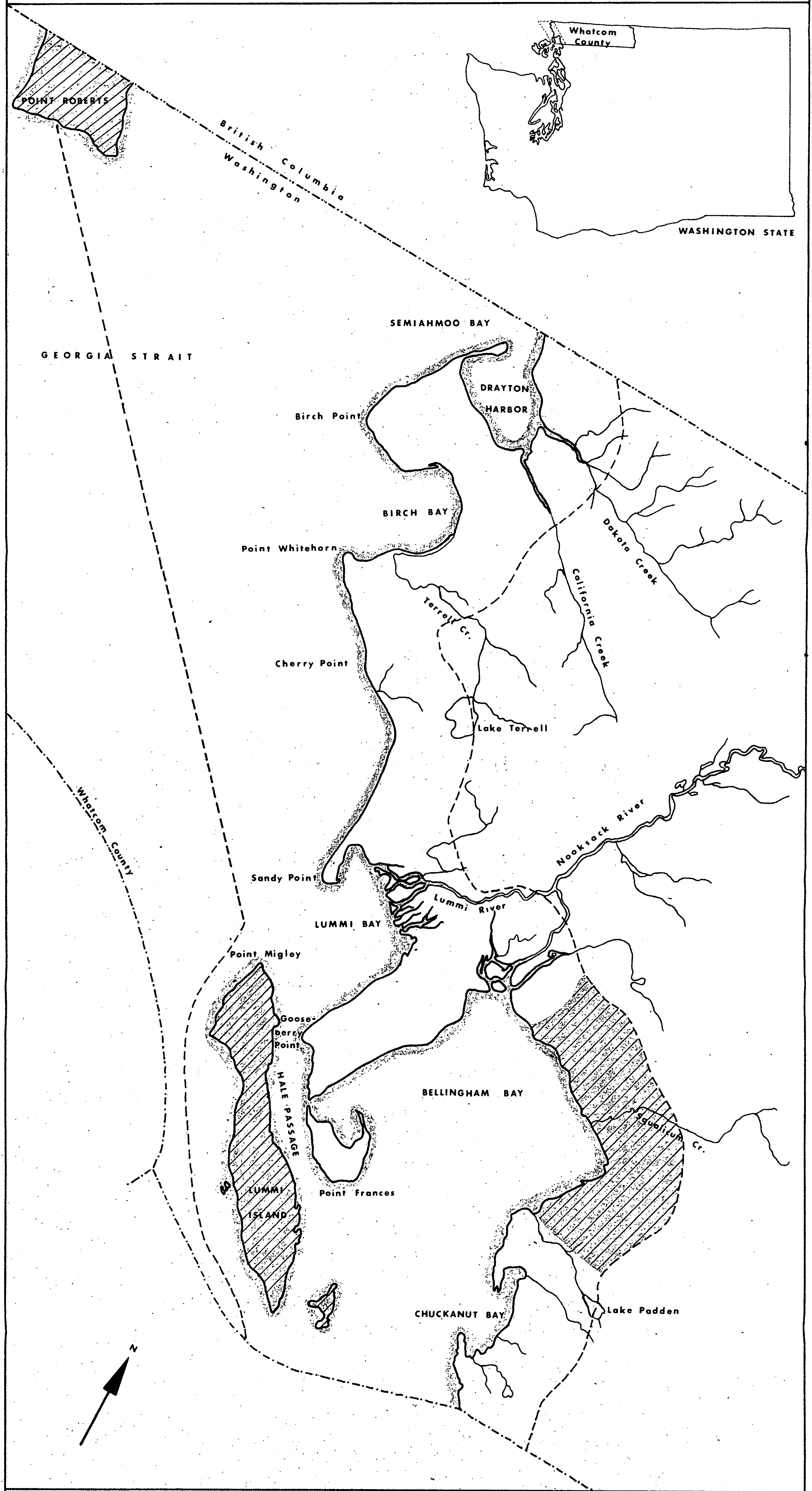
The study area falls within a physiographic region described as the Puget-Willamette Trough (Pacific Northwest River Basins Commission (PNRB), 1970), a relatively flat lowland area lying between the Cascade and Olympic Mountain Ranges. The length of the trough extends from the Fraser River on the north in British Columbia to the Klamath Mountains in southwestern Oregon. The trough is separated into a northern and southern portion by the divide between the Cowlitz and Chehalis River basins just south of the southern end of Puget Sound. The northern section will be referred to as the Puget Sound Lowland.

Temperature and Rainfall

As demonstrated in Table 5, the study area falls within the Pacific

Table 4: Inventory Elements For Coastal Resource Analysis

Major Inventory Element	Significant Aspects	Major Inventory Element	Significant Aspects
I. Climate	1. Bioclimatic Zones	IX. Marine Vegetation	
	2. Temperature		1. Eel Grasses
	3. Precipitation		2. Shore Vege-
	4. Exposure to sun		tation
	5. Wind directions	X. Wildlife Distri-	1. Salmon
II. Freshwater	1. Flows	bution, Numbers,	2. Herring
Hydrology	2. Temperature	and Productivity	3. Clams
	3. Dissolved Oxygen		4. Oysters
	4. Suspended Sediment		5. Oyster
	5. Acquifers		Drills
	6. Acquifer Recharge		6. Waterfowl
	Areas	XI. Land Use	1. Agriculture
	7. Coliform Count		2. Rural non-
	8. Other Quality		farm
	Meas.		3. Residential--
III. Marine	1. Current patterns		Recreation
Hydrology	2. Depth		Cottages
	3. Sedimentation		Permanent
	patterns		Homes
	4. Temperature		4. Recreation--
	5. Salinity		Intensive
	6. Turbidity		Extensive
IV. Geology	1. Morphology		5. Commercial
	2. Topography		Aquaculture
	3. Slope		6. Industrial
	4. Mineral Composition		7. Navigation
V. Soils	1. Parent Material		and other
	2. Silts--Distribution		Transportation
	3. Loams--Distribution		8. Shoreline
	4. Sands--Distribution		Structures--
	5. Gravels--Distribution		bulkheads,
VI. Beach	1. Silt and Mud		dikes, jetties
Material	2. Sand		causeways,
	3. Shingle		docks, etc.
	4. Cobbles	XII. Ownership	1. Public
	5. Boulders		2. Private
VII. Marine	1. Mud		3. Large Private
Bottom	2. Sand		
	3. Cobbles and Boulders		
VIII. Vegetation	1. Climax Community		
	2. Typical Ground Cover		
	3. Agricultural Crops		



THE COAST OF WHATCOM COUNTY

LEGEND:

Study area boundary
Political boundary
Excluded from study
Edge of water area

Scale 1/2 inch = 1 mile

SOURCE:

Whatcom Engineering Department
1967

MAP 1

Zone Climax[1]	Region Climate Type	Temperature °F Mean Annual	Mean monthly Jan.	July	Annual Total Precipitation	Annual Total Snowfall (inches)	Number of frost free days	Altitude	Climatic Climax Association
Coastal Western Hemlock	Pacific Coast Meso-thermal	41-49	24-41	55-64	70-262	5-295	150-250	0-3000	Douglas fir--Western Hemlock
Study Area[2]	Pacific Coast Meso-thermal	50.2	37	62.8	35-75	9.7-18.2	170 average annual	0-3000	Douglas fir--Western Hemlock

TABLE 5: COMPARISON OF CHARACTERISTICS OF COASTAL WESTERN HEMLOCK ZONE TO CHARACTERISTICS OF WHATCOM COUNTY

1 Source: Karjina, 1965.

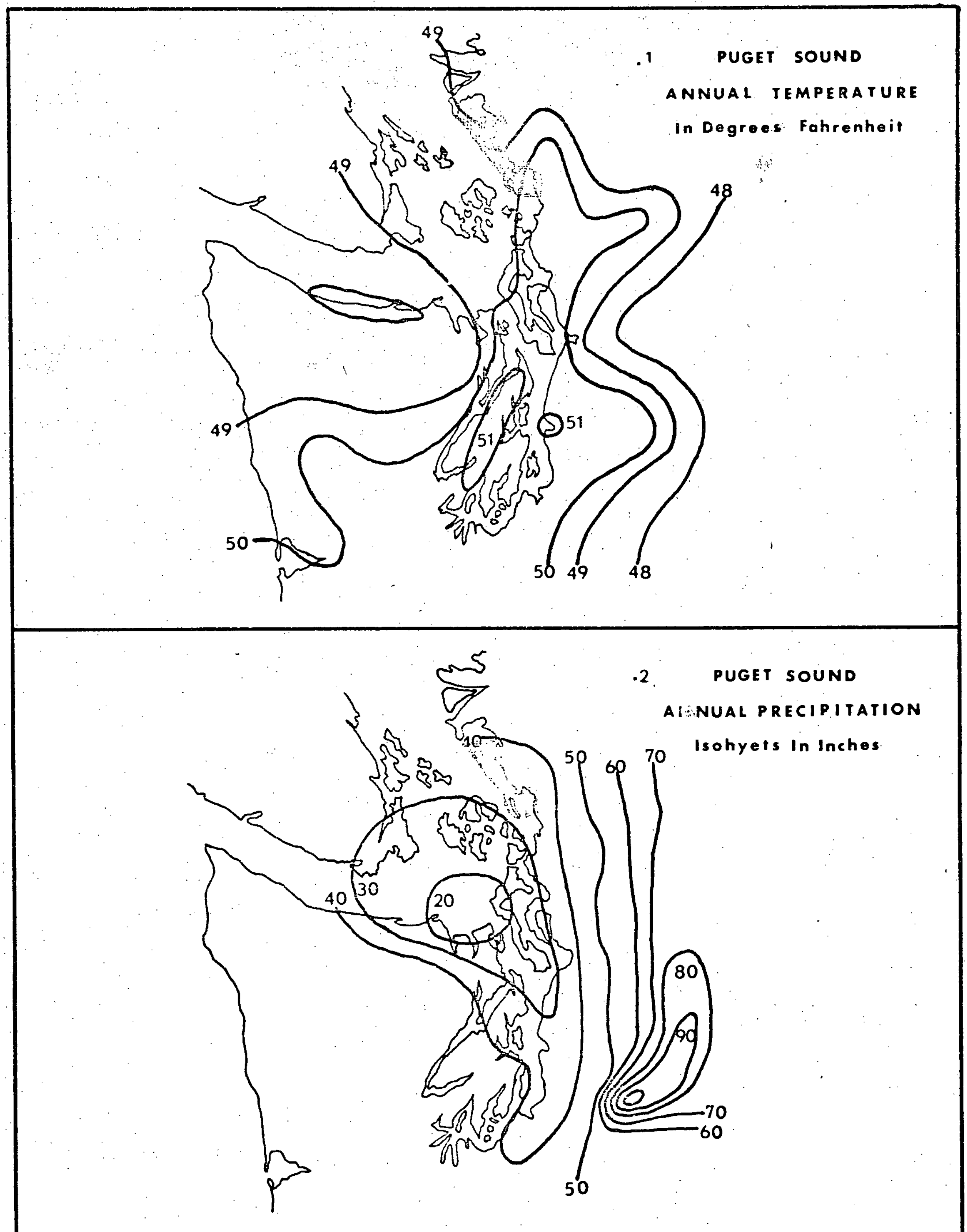
2 Source: Phillips, 1966.

coastal mesothermal forest region as defined by Krajina (1965). The climate of the study area is greatly influenced by its proximity to the Pacific Ocean. Most of the air masses which reach the area have their source regions over the Pacific Ocean. Air from these regions effectively moderates both the summer and winter climatic conditions in the study area (Phillips, 1966).

A prevailing westerly and northwesterly flow of air into the region causes a dry season to begin in May and continue through the summer. Beginning in October, a prevailing southwesterly and westerly flow of air produces a wet season that reaches a peak in mid-winter and decreases in spring (Phillips, 1966). Most precipitation in the Puget Lowland falls as rain. Annual precipitation in the study area ranges approximately from 35 to 50 inches over the lower elevations to 75 inches or more in the Cascade foothills and to between 150 and 200 inches on the slopes of the Cascade Mountains. During the summer, afternoon temperatures in the Puget Lowland remain in the lower 70°'s F while in the winter the average afternoon temperature in the lowland ranges between 35° F and 45° F (Phillips, 1966). On the following page, gradients of precipitation and temperature over the Puget Sound area are shown for different seasons (Figure 4).

Surface Winds

Wind patterns influence greatly micro-climatic conditions and the strength and direction of waves that cause shoreline erosion and subsequent transport of the eroded material. The seasonal patterns of surface winds that occur in the study area, (Figure 5.1 and 5.2), can be attributed to the circulation of air around a semi-permanent high pressure cell which dominates the eastern



TEMPERATURE AND RAINFALL

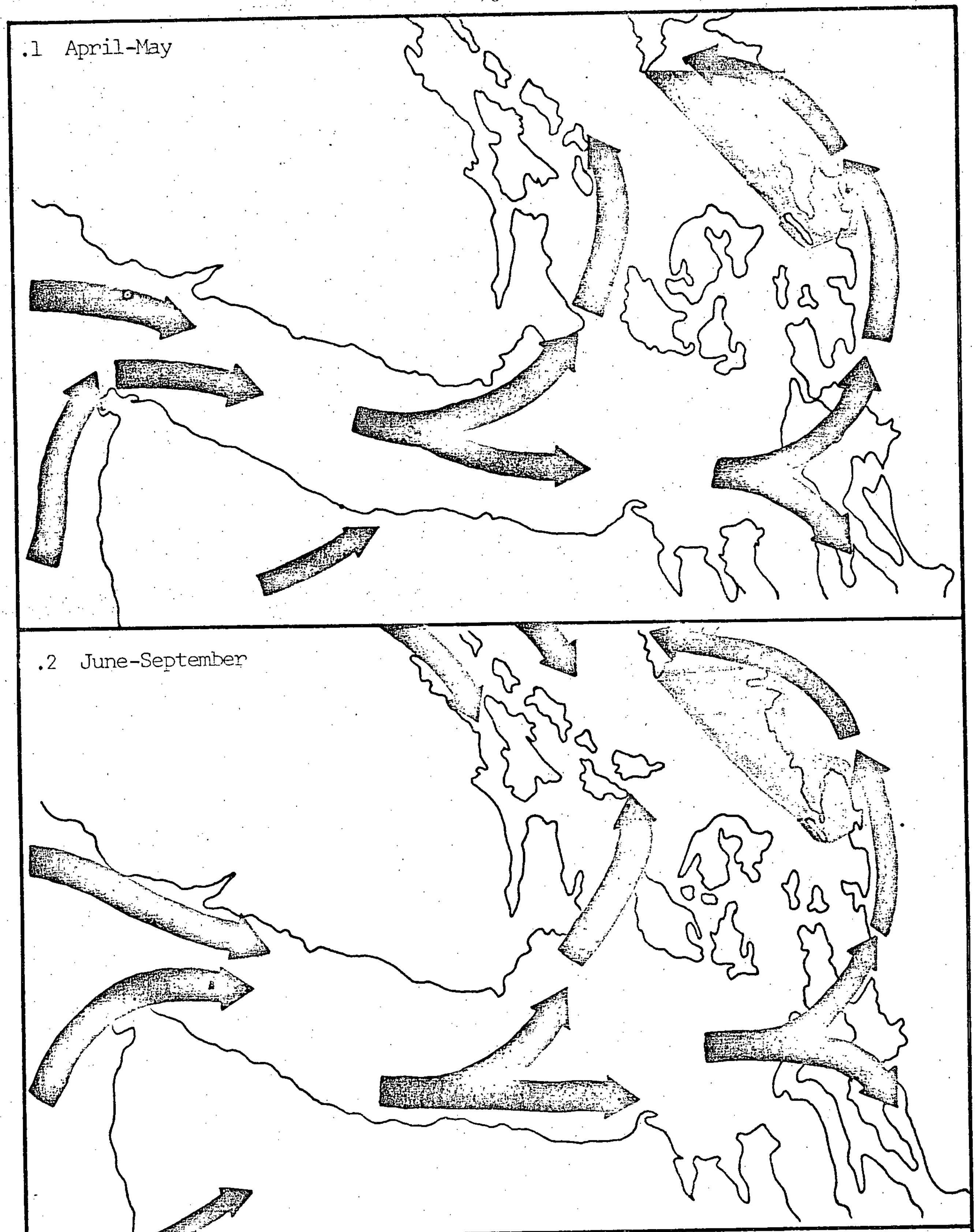
The Puget Sound Region

Legend:

Study area

Source: University of Washington 1953

Figure 4



SURFACE WIND PATTERNS: S.E. GEORGIA STRAIT; STRAIT OF JUAN DE FUCA

LEGEND:

1. Arrows indicate surface wind direction
2. Width of arrow indicates average speed: 0-9 10-20 > 20 mph
3. Length of arrow indicates frequency in % of total hourly observations: 0 5 15 20

Study Area

Russell 1954

Figure 5

Pacific Ocean (Russell, 1954). During the summer months this high pressure cell causes a prevailing northwesterly flow of air in the Puget Sound area and west of Vancouver Island. However, Russell (1954) notes that the surface winds show a sharp contrast to the general flow of air indicating the strong effects of topography. Thus, a contrast is noted between the flow of air over Puget Sound as far north as Bellingham Bay and the flow over Georgia Strait farther north. In the southern portion of the region the flow is predominantly from the south while over S.E. Georgia Strait, approximately at the level of Boundary Bay, the winds are from the east. There is no doubt that this results from the deflection of wind to the east by the Fraser River valley. There is, however, a net northerly movement of air in this area because of the considerable percentage of high velocity winds in a northerly direction.

Hydrology

The potential supplies of freshwater for domestic and industrial consumption in the study area are large on an annual basis. Unfortunately, the seasonal distribution is not favorable. During the dry summer period the runoff is very low providing low quantities of water for industrial uses and irrigation (USDA, 1953). Consequently, reservoir sites have been identified and some small reservoirs constructed.

The major river in the study area is the Nooksack. Numerous other tributaries and streams flow through the area, including Dakota Creek, California Creek, Terrell Creek, the Lummi River and Chuchanut Creek. The natural flow of the Nooksack has two peaks, one occurring in late fall with the advent of winter rains and the other higher peak in the spring because of snow melt (PNRB, 1970). The average yield of wells in the study area ranges between 11 and 500 gallons per minute, with the higher yields occurring in the Nooksack basin and the Dakota and California Creek watersheds. Few of the wells are over 50 feet deep and some are capable of producing 1,000 gallons per minute. Areas of inadequate ground water supplies are Lummi Penninsula, Point Roberts, the Lake Terrell area and Birch Point. Most acquifers within about two miles of the shoreline produce water of low quality because of salt and dissolved iron contents (PNRBC, 1970).

There are few reservoirs in the study area and no major reservoir on the Nooksack. Hence, its flow is nearly unregulated. The largest diversion of the Nooksack is by the Puget Sound Power and Light Company for their power plant on the north fork. This withdrawal is returned to the river. The city of Bellingham is the next major water user withdrawing a maximum of 102 cubic feet per second (cfs) from the middle fork of the river for municipal supply. None of this is returned to the middle fork. Approximately 25 cfs are diverted from the mainstream for the Mobile Oil refinery and Italco Aluminum Corporation. Information concerning water use by the Atlantic Richfield Corporation refinery was not obtained.

The tides in the study area are of the mixed type. Mixed tides are characterized by variations in the successive heights of low and high water. The tidal reference point for the study is at Point Migley. Tides at this station are calculated by the Coast and Geodetic Survey by adjusting for time and tidal amplitudes from the reference station at Port Townsend, Washington. At Point Migley, the mean range of tide is 5.2 feet and the diurnal range is 8.6 feet (Kincaid, et. al., 1954). Mean tidal range is the difference in height between mean high and mean low water. The diurnal tidal range is the difference in height between mean higher high and mean lower low water, as shown on Figure 6. Variations in the successive heights of tides are affected by meteorological conditions. Onshore winds can build up tide levels while offshore winds lower them. Atmospheric pressure also alters the tidal height, a fall in pressure will be accompanied by an increase in height and a rise in pressure with a depression of the tidal height. The tide affecting the S.E. Georgia Strait floods from the Strait of Juan de Fuca. Hence, the tidal current in the northern portion of the study area (Neptune Beach to Semiahmoo Bay) moves in a counter clockwise direction (Kincaid, 1954). It was noted in the study by Kincaid (1954) that the tidal current will tend generally to move polluted water and debris in a northerly direction along the northern shoreline. Due to the effects of surface winds and bottom topography, the direction of water movement in any specific area will vary from this norm.

With concern increasing over the problems of municipal and industrial waste disposals in S.E. Georgia Strait and the possibility of oil spills in the area, several studies of nearshore current pattern have been conducted in the study area (Kincaid, 1954; Schwartz, 1971). (See Figures 7, 8, 9, 10) Two water mixing areas appear to exist in this area as a northern and southern regime. The boundary between the two regimes fluctuates with the tide but falls approximately as a curve drawn from the refinery pier at Neptune Beach to between Matia and Sucia Islands

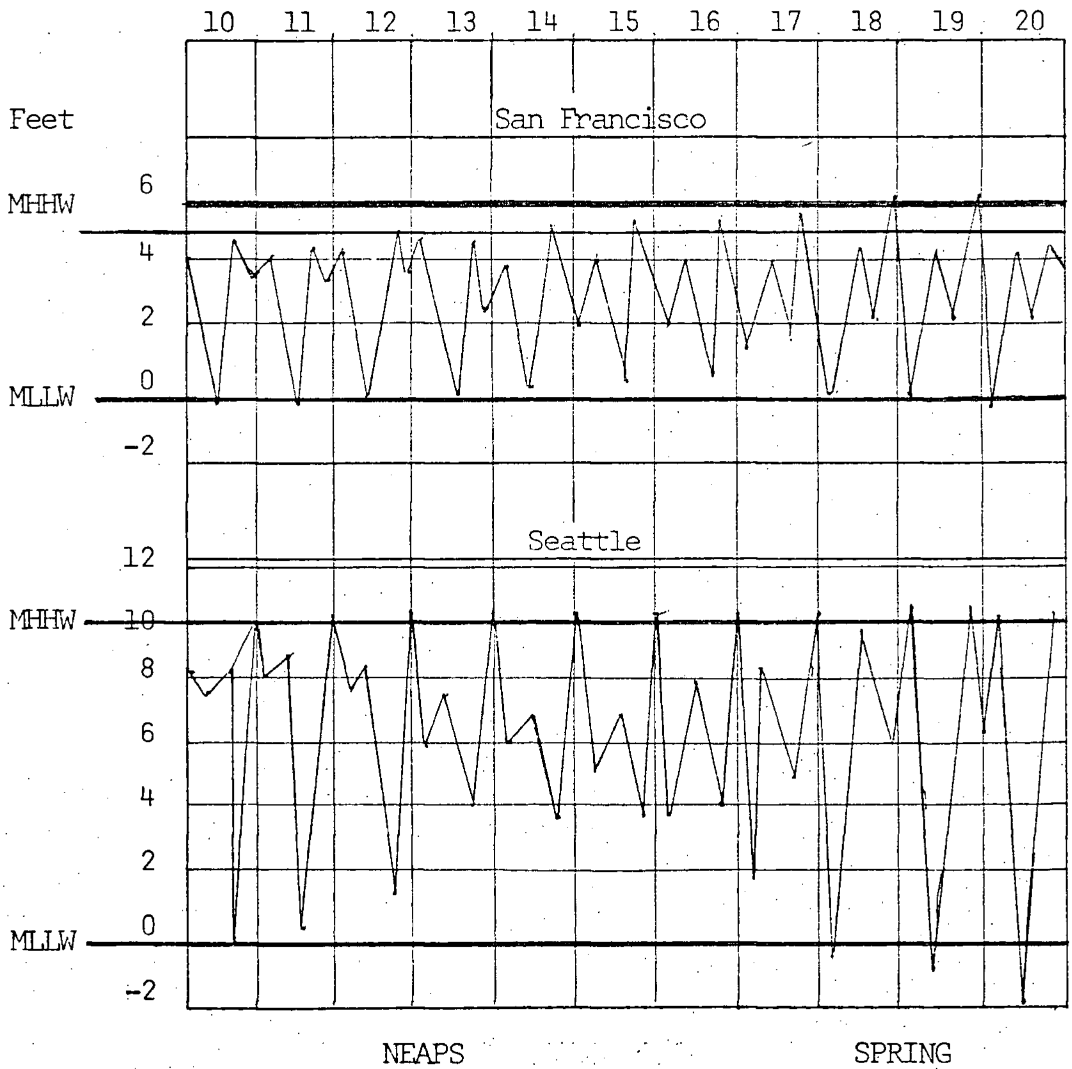


Figure 6: Tide Curves (The change in water level with Time)

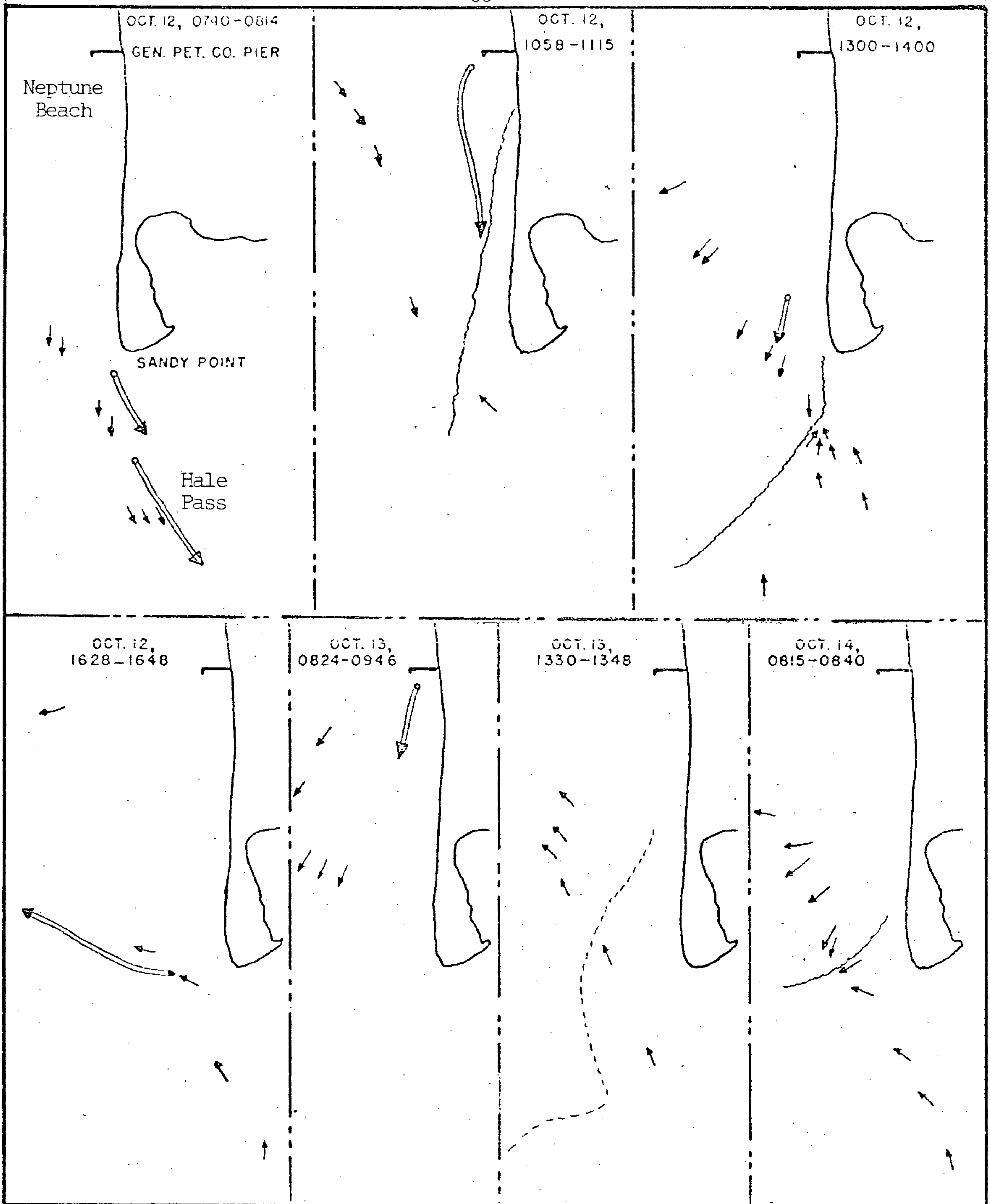
Key:

MLLW - Mean of lower low water = the average of the lowest of the two daily low tides

MHHW - Mean of higher high water = the average height of the highest of the two daily high tides

Neaps - Tide of minimum range (distance between two consecutive tides) for a semi-diurnal tide.

Spring - Tide of maximum range for semi-diurnal tide.



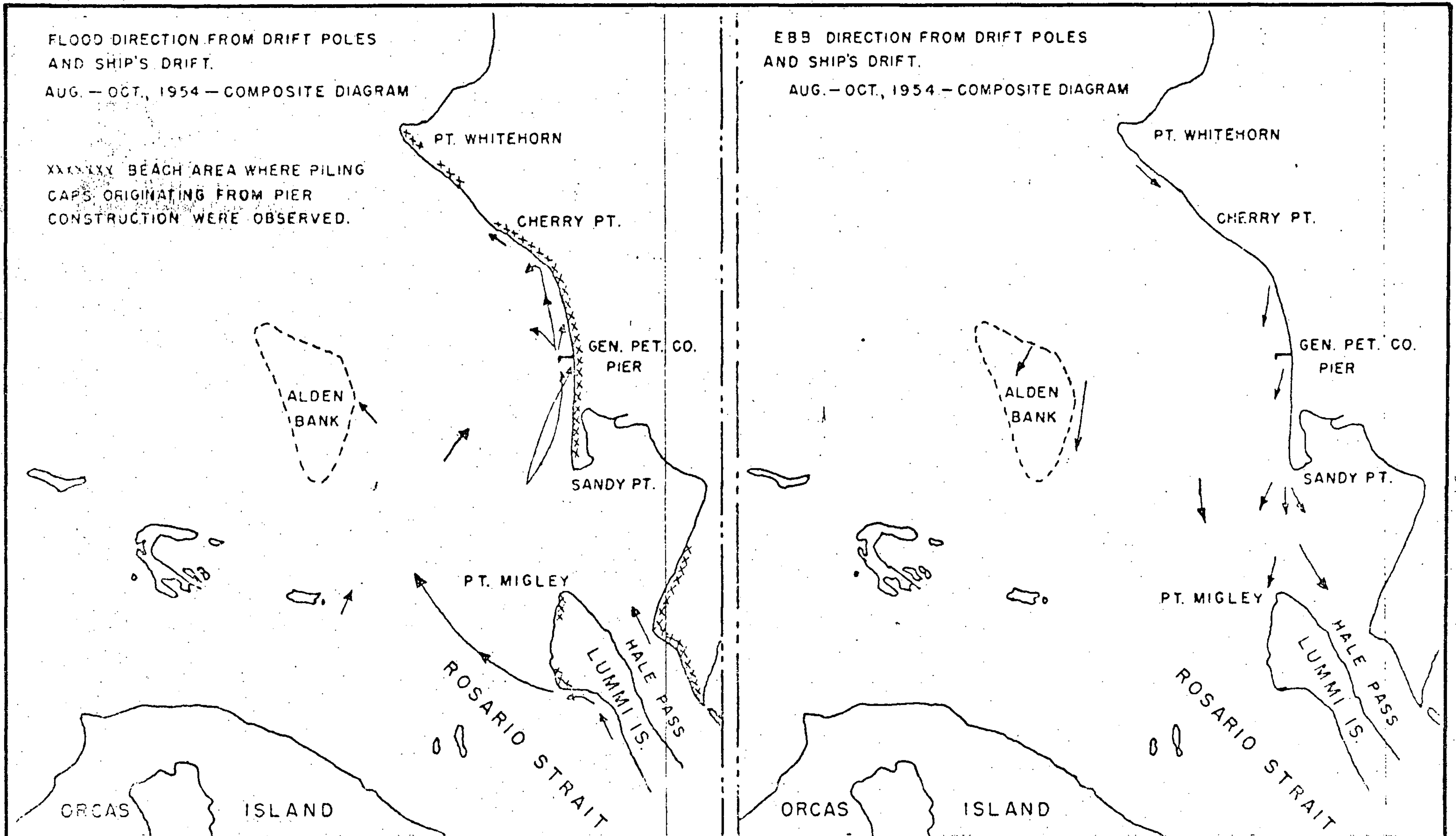
SURFACE CURRENT PATTERNS

Neptune Beach to Hale Pass

LEGEND:
Drift pole
Float
Surface Current Convergence

Source: Kincaid, et. al 1954

Figure 7

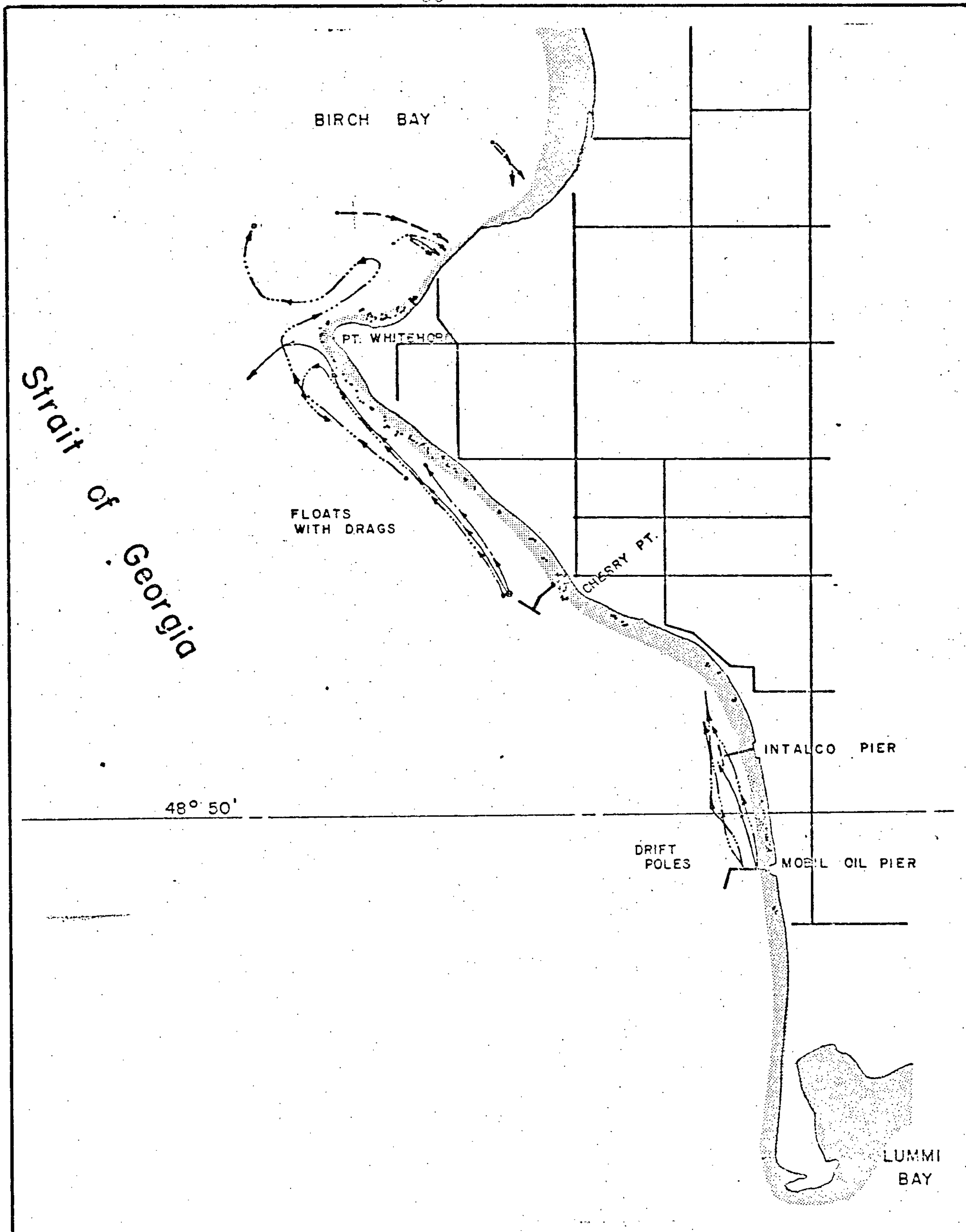


FLOOD AND EBB CURRENTS

Cherry Point to Hale Pass

Source: Kincaid, et. al 1954

Figure 8



NEARSHORE CURRENT PATTERNS

Movement on Flood Tide

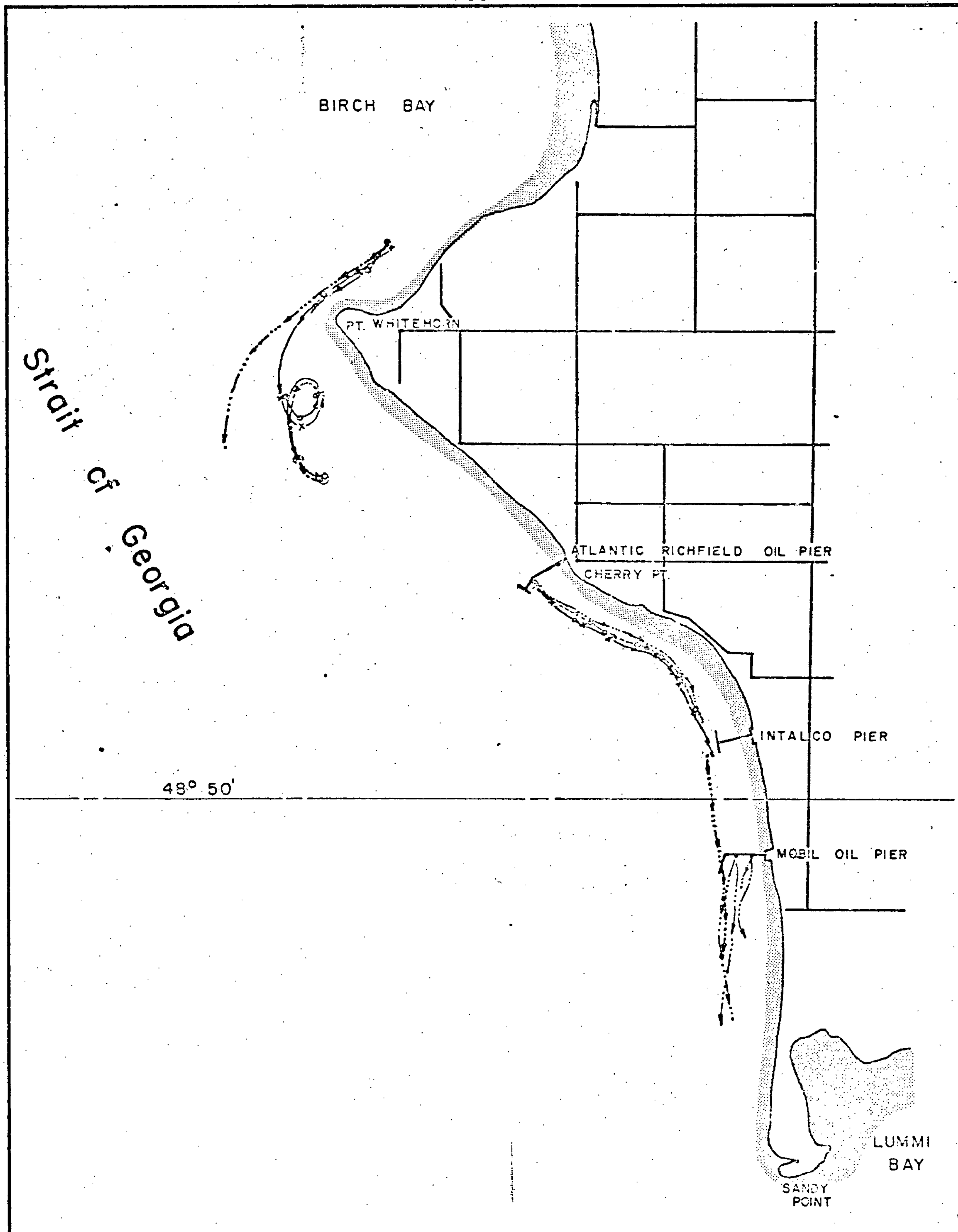
LEGEND:

At surface —— · · · —— · · · ⟶ 25' depth —— — ——⟶

16' depth ——————⟶

Source: Schwartz 1971

Figure 9



NEARSHORE CURRENT PATTERNS

Movement on Ebb Tide

LEGEND:
- At surface — · · · — · · · →
- 16' depth ———————→
- 25' depth — — — — — →

Source: Schwartz 1971

Figure 10

(Kincaid, et. al., 1954). Kincaid (1954) notes that the dominate feature of the northern regime is the large amount of freshwater from the Fraser River creating conditions for intense mixing. In the southern regime the mixing processes result mainly from the convergence of channel flows. Thus, in the southern regime, surface temperature gradients are small and the salinity variations from top to bottom are reduced.

In the northern regime the water properties are dominated by the effects of the Fraser River outflow. The influences of the Fraser varies seasonally but is particularly strong during the spring freshet. It is at this time that the greatest fresh and salt water stratification occurs while surface salinity concentration decreasesand dissolved oxygen increases. During peak flow periods the freshwater moves southward to the vicinity of Birch Bay and Cherry Point (Kincaid, et. al., 1954).

In general, most properties of the water mass reflect the existence of these two regimes with a distinct interface between them. The properties of the marine water in the study area during the period August 23 to October 15 during which Kincaid (1954) conducted his initial study are representative of the differences that exist in the two regimes. Salinity in the Point Roberts and Birch Bay area was about 28 parts per thousand (ppt) or less. In the Cherry Point and Neptune Beach vicinity the surface salinity ranged slightly higher, between 27 ppt and 30 ppt. In the Sandy Point, Hale Passage, and Village Point area the surface salinity ranged between 28 ppt and 30 ppt. Water temperature for the same period in the northern regime varied between 52° F to 55° F on the surface. In the southern regime the surface temperature ranged from 48° F to 52° F.

Dissolved oxygen values in the two regimes reflect the pattern of salinity and temperature. In the southern regime Kincaid (1954) recorded lower oxygen values than in the northern regime.

Geology

The Puget Sound trough attained its present form toward the end of the tertiary glacial period. The northern portion was occupied several times by ice sheet glaciers during the Pleistocene epoch. As a result most of the topographic features which characterize this area are a direct result of glacial erosion and deposition (Easterbrook and Rahm, 1970).

During the Quaternary period, four continental glacial masses are believed to have advanced and retreated into the Puget trough. These glaciers, being several thousand feet thick and having the power to scour, pulverize and transport large volumes of geologic material eroded the mountains on both sides of the trough and deposited the sediment in the trough (Pacific Northwest River Basin Commission, PNRBC, 1970).

The glacial till is thickest at the shoreline of the sound and thins to a rather thin layer over consolidated rocks in upland areas. In the PNRBC Study (1970) it is noted that the compact nature of the deposits in upland areas, restricts infiltration and favors runoff. Hence, in upland areas, ground water supplies are insufficient to support large yielding wells. Most acquifers can be found in areas of unconsolidated sediments of the Quaternary period. Large amounts of water are stored in the sand and gravel recessional outwash areas which occur in the lower areas adjacent to the till covered uplands.

Existing as an anomaly to the north-south grain of the Puget trough is an east-west arm of the Cascade Mountains called Chuckanut formation which extends into the sound to the San Juan group of Islands. It affects the micro-climatic conditions in the southern portion of the study area by altering surface wind patterns and the general movement of air. Precipitation and water runoff are notably higher in this area (USA Department of Agriculture, 1953).

During the post glacial epoch the topography of the Puget Lowland has been modified by fluvial and marine erosion and deposition. Rivers and streams depositing large quantities of sediment in the relatively quiet waters of Puget Sound have built deltas of land seaward (Easterbrook and Rahm, 1966). Waves and currents impinging on the shoreline have eroded material away from the base of the bluffs and transported the material laterally along the shore or out to deeper areas of the sound. Concurrently the bluffs have been moved landward and an extensive system of narrow beaches has been created.

Within the study area, the Nooksack River has built two deltas into the Sound. Prior to the establishment of the present river course into Bellingham Bay, the Nooksack River discharged water and sediment into Lummi Bay creating an extensive tide flat area and linking Lummi Penninsula to the mainland. For a period, the river alternated its course between Lummi Bay and Bellingham Bay. Now, it empties primarily into Bellingham Bay where it has developed a large delta which is exposed as a tidal flat at extreme low tide for approximately two miles into the Bay (Easterbrook and Rahm, 1966).

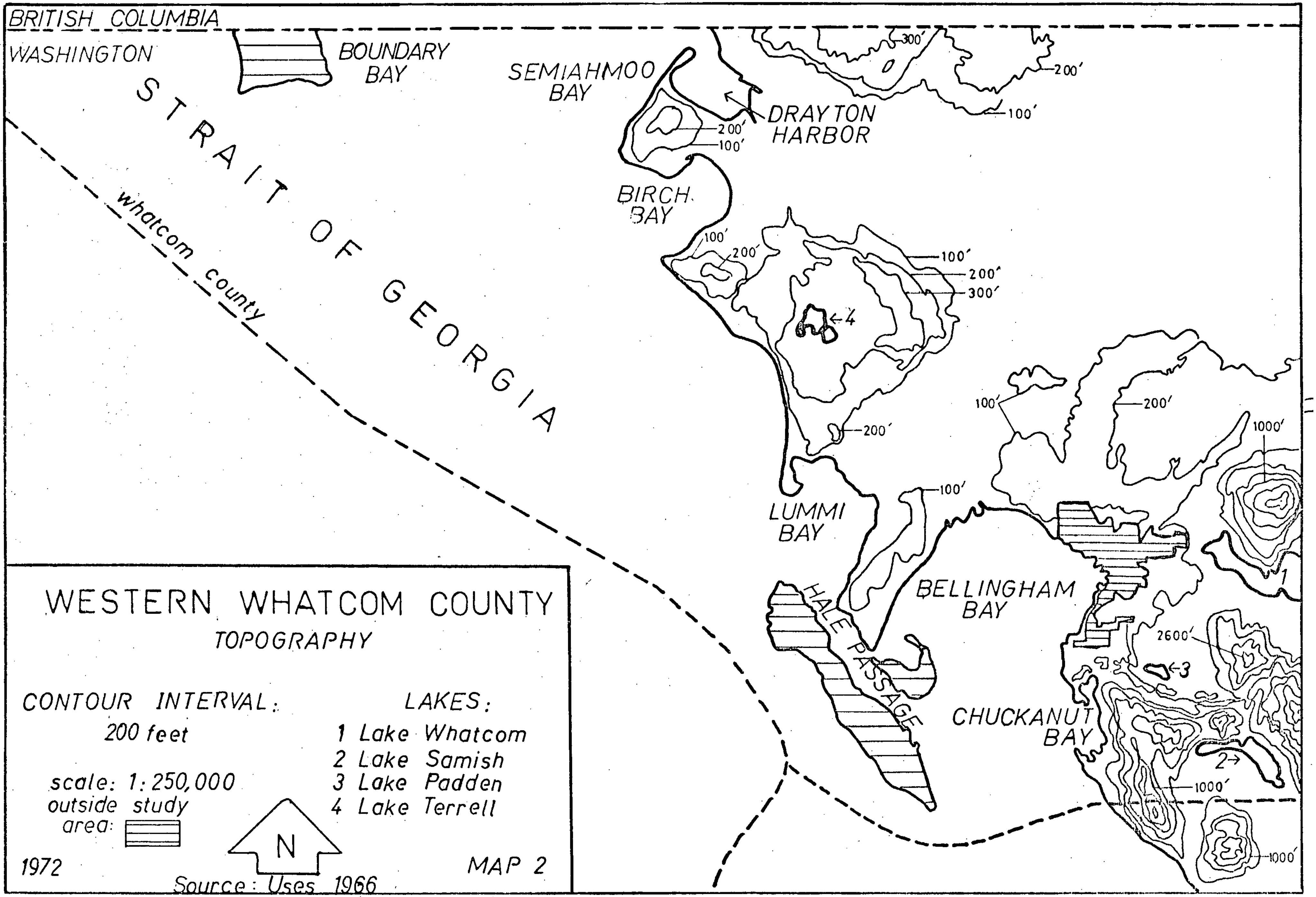
Numerous spits and beaches composed of various grades of material exist in the study area. Material eroded from the bluff at Neptune Beach has, for example, been transported south by lateral currents and constructed a spit into Lummi Bay. The north shore of Birch Bay is partly composed of a spit formed by material also transported and deposited in that area by longshore drift. In Birch Bay the longshore drift moves in a northerly direction. Since the energy in the current dissipates from south to north the southern beaches of Birch Bay are composed of coarse material while the northern beaches are made of finer material (Schwartz, 1971).

Topography

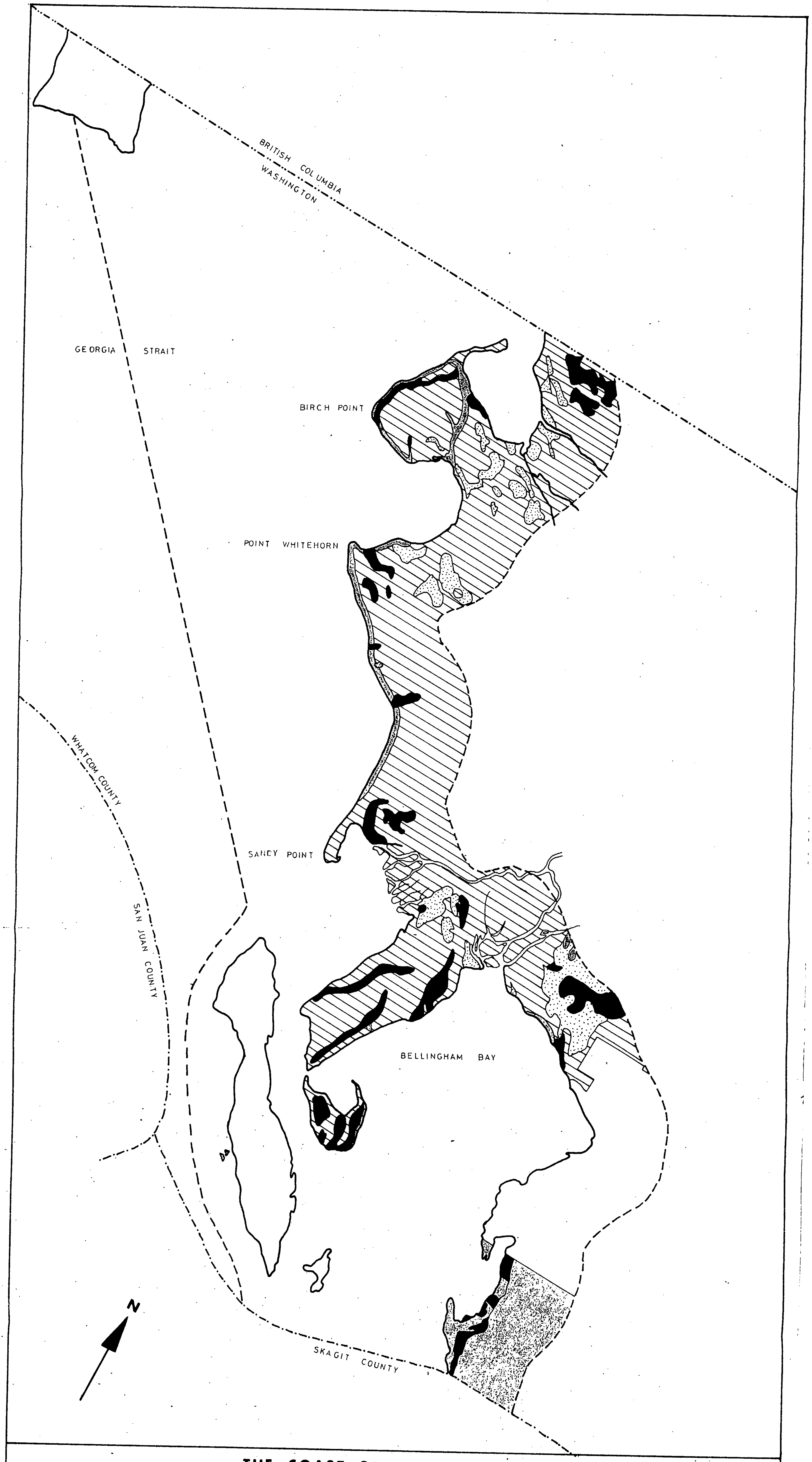
The study area is quite flat (Map 2) though bluffs ranging in height from 20 to 500 feet rim nearly the entire extent of Southeast Georgia Strait (PNRBC, 1970). As shown on Map 3, the slope on the study area rarely exceeds 20% with the exception of the Chuckanut formation.

The shoreline bluffs are nearly vertical formations. There are few areas where these bluffs do not exist. The beaches at the base of these bluffs are relatively narrow or non-existent. Most of the beaches are composed of material eroded by marine action from the cliffs. Few beaches have a slope exceeding 5% (Schwartz, 1971).

The topography of the bottom underlying marine water in the study area exerts a dominant influence on the nature of water circulation and mixing. Examination of the bathymetry reveals two distinct physiographic regions. Extending west from the eastern shore of the Georgia Strait, the bottom grades gradually and continuously to about 50 fathoms. This



BRITISH COLUMBIA
WASHINGTON
BOUNDARY BAY
SEMIAHMOO BAY
DRAYTON HARBOR
STRAIT OF GEORGIA
whatcom county
BIRCH BAY
LUMMI BAY
HALE PASSAGE
BELLINGHAM BAY
CHUCKANUT BAY
300′
200′
100′
1000′
2600′
1
2
3
4
WESTERN WHATCOM COUNTY
TOPOGRAPHY
CONTOUR INTERVAL:
200 feet
scale: 1:250,000
outside study area:
LAKES:
1 Lake Whatcom
2 Lake Samish
3 Lake Padden
4 Lake Terrell
N
1972
MAP 2
Source: Uses 1966



THE COAST OF WHATCOM COUNTY

SLOPE ANALYSIS

MAP 3

LEGEND:
- 0 % – 6 %
- 6 % – 12 %
- 10 % – 15 %
- 15 % – 30 %

STUDY AREA BOUNDARY

OUTSIDE STUDY AREA

SOURCE: U.S.A. DEPARTMENT OF AGRICULTURE

SCALE: 1/2" = 1 MILE

is shown as a line drawn approximately from Point Migley on Lummi Island to Point Roberts (See study area, Map 1). West of the line the bottom becomes rugged with steep slopes occurring around the San Juan Islands (Kincaid, et. al., 1954).

Soils and Beach Material

The soil resources in the study area are a product of the forces of climate, topography, biological action and time acting on the geological material deposited in the area by glacial and water action (Allard, 1971). The parent material consists of a variety of bedrock and unconsolidated sediments, compacted glacial materials, loose glacial outwash material, debris eroded from upland areas, and organic material found in lake bottoms, shallow slackwater stream channels, and bays (PNRBC, 1970).

The soil landscape of the northern portion of the Puget trough to which the study area belongs consists of extensive ground moraine till areas represented by the Alderwood, Whatcom, Squallum, and Bow soils (University of Washington, 1968). These are generally loamy, silty or sandy clay till compacted and weakly cemented. The Chuckanut formation consists of shallow weathered soils over sandstone. Land adjacent to the confluence to streams and marine water areas is composed of silt and clay soil stratified with organic material.

The composition of the beach material in the study area has resulted from large amounts of glacial gravels and erratic boulders being washed down to the intertidal area by marine erosion. Longshore drift and wave action have subsequently sorted and transported the material throughout the area. Few comprehensive studies have been completed which outline the composition of the beaches along Puget Sound and S.E. Georgia Strait. Consequently the information used in this study comes from the author's own cursory examination and Kincaid's (1954) study of the intertidal area of the study area.

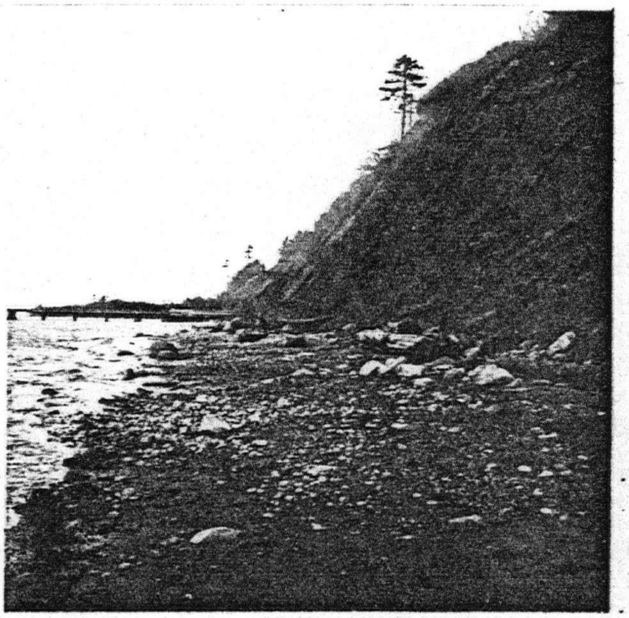
There is a wide variety of beach compositions in the study area. In general, the beaches are composed of a coarse sand and gravel mixture ranging from sandy beaches to beaches composed entirely of large cobbles with medium to large glacial erratics interspersed throughout. To provide an idea of the type of beaches comprising the study area, a series of pictures keyed to place names are provided in Plates 1 and 2.

Bottom sediment is an important oceanographic variable which influences the geology of the marine environment including the distribution and productivity of benthic flora and fauna and some pelagic forms. Sediment information can also be used to determine the means of deposition, the source of the sediment, the water characteristics involved in the transport of the sediment (Waldichuck, 1953).

The sediment information for this study, as shown on Map 4, was obtained from Kincaid (1954) and from the Coast and Geodetic Survey Maps. The composition of the bottom is described as being mud, sand, gravel, boulders, or rocks.

1. Mud; very fine material (5.005 to 0.5 mm in diameter)
2. Sand; coarser material (.05 to 2 mm in diameter)
3. Gravel; coarse material (2 to 256 mm in diameter)
4. Boulders; material larger than cobbles, (greater than 256 mm in diameter)
5. Rocks; solid mass of rocks

Intertidal Beach Between
Mobile Oil Refinery and
Italco Aluminum Company Pier

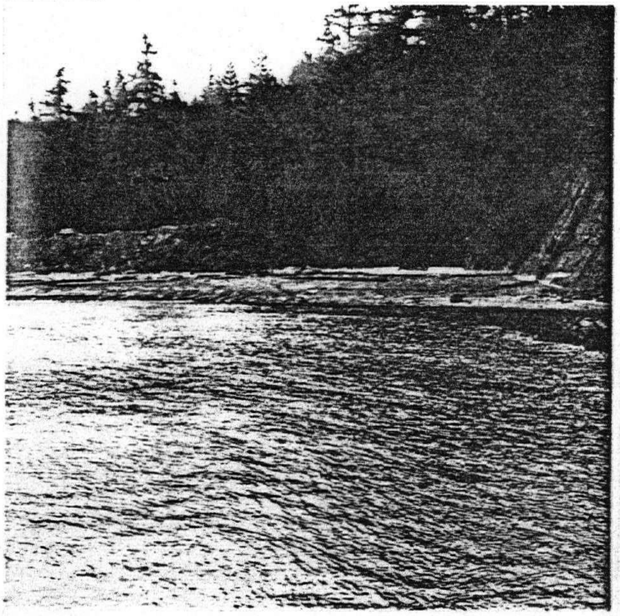


Intertidal Beach Between
Cheery Point and Neptune
Beach

Beach at Birch Bay

Bulkhead and Groin Structures
in Birch Bay

PLATE TWO: NEPTUNE BEACH TO BIRCH BAY BEACH



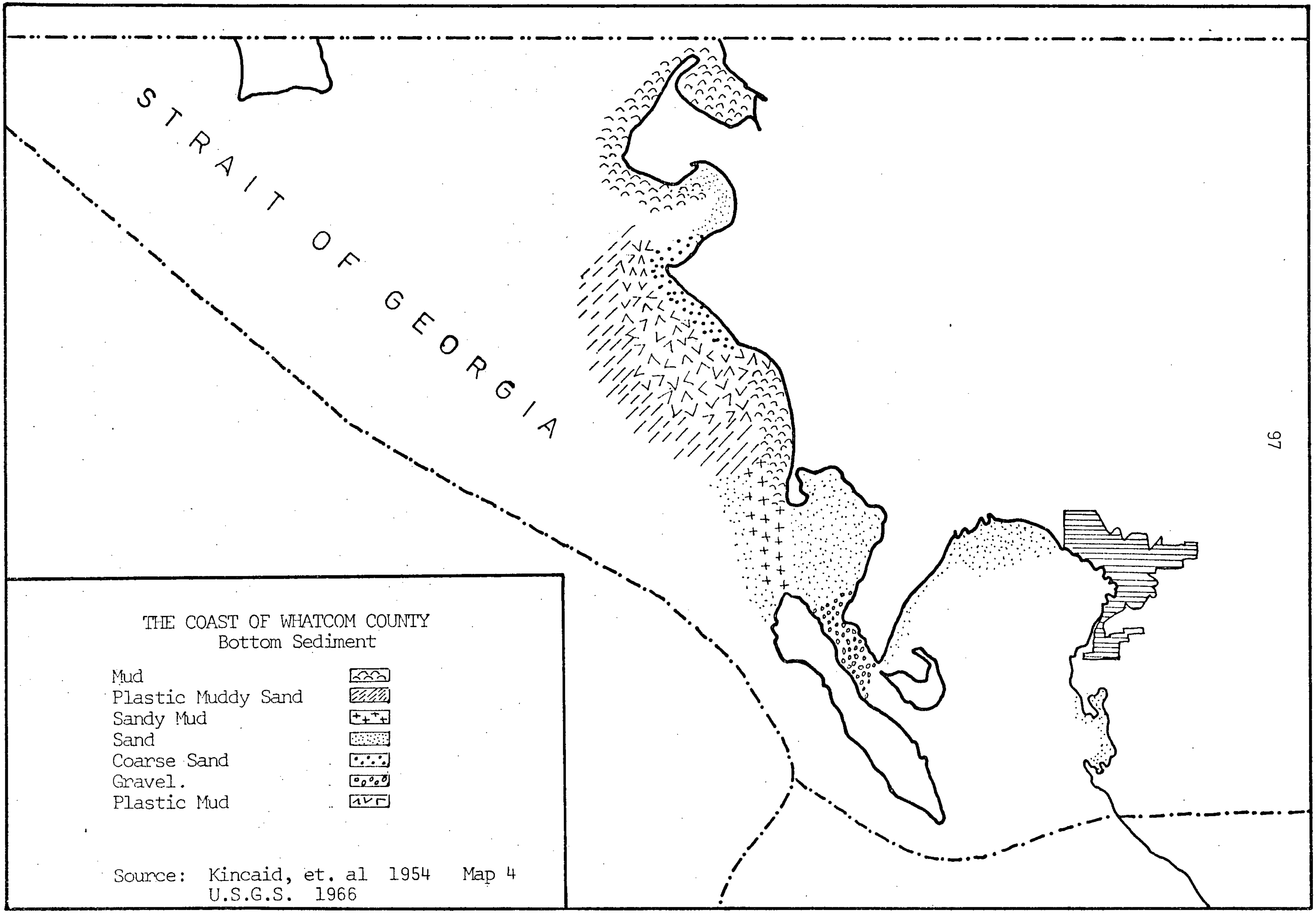
Pleasant Cove in Chuckanut Bay

The Beach at Hale Passage:

Lummi Bay and Golf Course Development on Estuary Shore Zone

Beach at Sandy Point: Note Refinery Pier in Background

PLATE ONE: CHUCKANUT BAY TO SANDY POINT

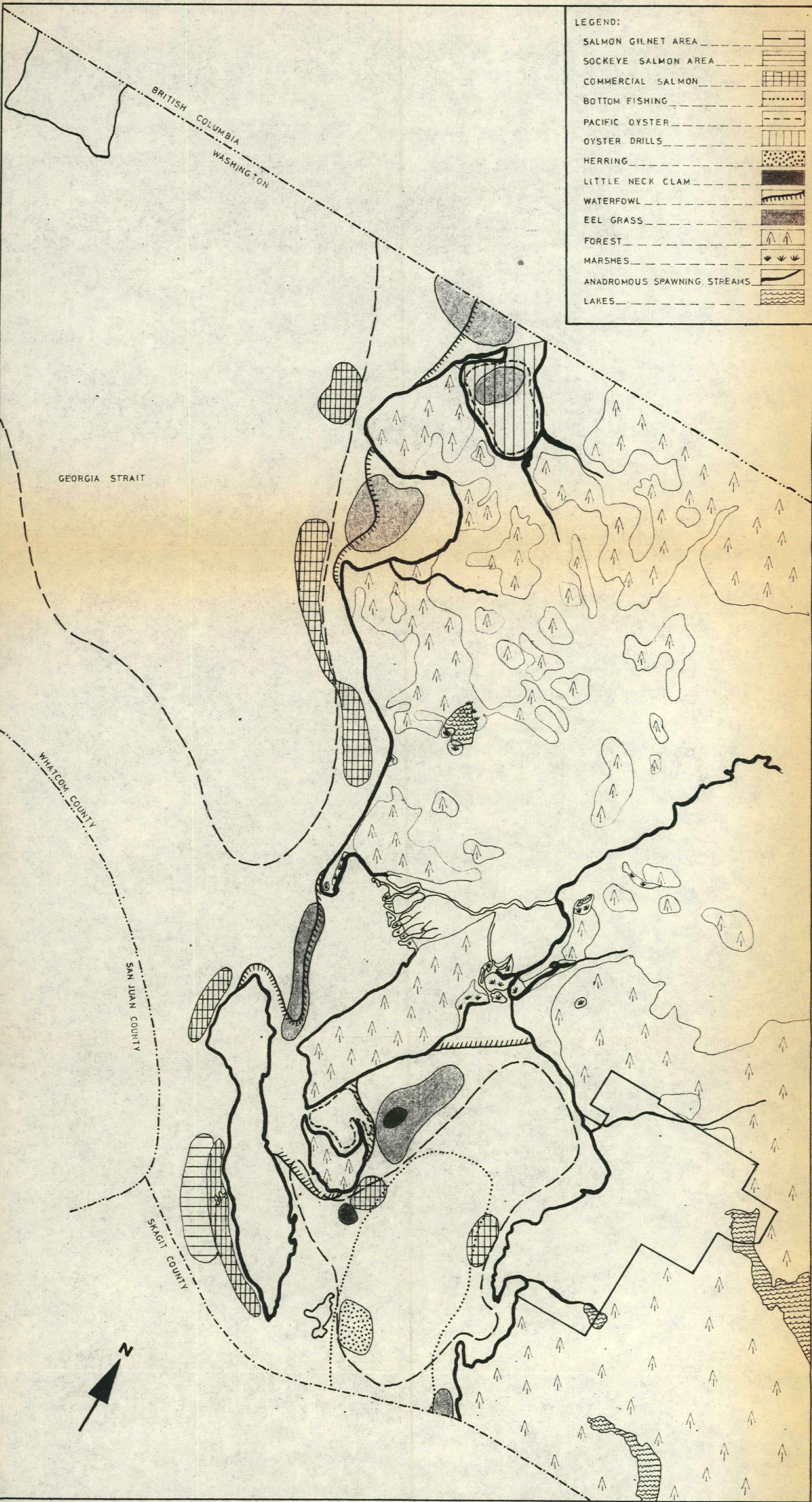

STRAIT OF GEORGIA
THE COAST OF WHATCOM COUNTY
Bottom Sediment
Mud
Plastic Muddy Sand
Sandy Mud
Sand
Coarse Sand
Gravel.
Plastic Mud
Source: Kincaid, et. al 1954 Map 4
U.S.G.S. 1966

Vegetation

The most common forest vegetation community found in the Puget Lowland is the western hemlock community (University of Washington, 1968). In Krajina's (1965) bioclimatic classification, this area belongs to the coastal western hemlock zone which occurs along the coast of British Columbia and the Washington coast along S.E. Georgia Strait. Coniferous species associated with the western hemlock zone comprise a rather large list, including Douglas Fir (*Pseudotsuga menziesii*), Lodgepole Pine (*Pinus contorta*), Western White Pine (*Pinus monticola*), and Western Yew (*Taxus brevifolia*). Douglas Fir is often the dominate species in the dryer areas of this community (Washington, University of, 1968). The forest areas grow right to the edge of the bluffs overlooking the Strait of Georgia making shoreline areas quite uniform in appearance except where man has cleared the forests.

Grasscovered prairie-like areas are found in the lowland where soil and climatic conditions do not favor forest growth. The vegetation cover in these areas consists mainly of grasses, interspersed with stands of Douglas Fir, Oregon White Oak (*Quercus garryana*), Scotch Broom (*Cytisus scoparius*) and other shrubs (PNRBC, 1970).

Tidal marsh areas (Map 5) are colonized predominantly by a salt-grass (*Spartina* spp.) cover (PNRBC, 1970). Eel grass beds (Map 5) provide important habitats within the estuarine environment. They often support pupulations of algae and small fauna that provide food for grazing fish and other swimming organisms. The Marine Land Management Division of the Washington State Department of Natural Resources has located eel grass beds in the



THE COAST OF WHATCOM COUNTY

VEGETATION AND WILDLIFE

MAP 5

Source:
Department of Natural Resources, 1971

Scale: 1/2 inch = 1 mile

study area as an important marine resource affecting decisions regarding the use of State owned marine land.

Wildlife

As shown on Map 5, various types of shellfish occur throughout the study area. Several species of clams are sufficiently abundant to be attractive for recreational shellfish digging most of the year. Areas on the north of Lummi Island and the Lummi Penninsula are used for commercial shellfish production (PNRBC, 1970). Commercial oyster growing areas are in Bellingham Bay, Lummi Bay and Drayton Harbor. In Lummi Bay, the Lummi Indians have developed an aquaculture operation aimed at producing commercial quantities of oysters and salt water trout. Non-commercial areas of abundant oysters have been located by the State Department of Natural Resources.

The main factors which limit shellfish production in the study area are poor water quality, adverse physical conditions, and predation. Kincaid (1954) and the PNRBC Study (1970) reported that poor water quality is one of the major problems for oyster growing in the study area. The Blaine area (Semiahmoo Bay and Drayton Harbor) possesses excellent seed oyster beds, but, because of pollution the oyster cannot be fattened for market from this area.

Along the mainland, from Gooseberry Point to Birch Bay, Kincaid (1954) notes that the grinding action of upper beach material is not conducive to benthic organisms. Lummi Bay, open to southerly storms does not provide physical conditions particularly favorable to fragile shellfish production.

However, an extensive diking system constructed by the Lummi Indians has remedied this problem and made the area useful for oyster and fish culture. Shoreline development in Birch Bay, Lummi Bay and Bellingham Bay has expropriated shellfish producing tidelands though bulkhead construction and land fill operations. Oyster drill colonies have also become established in several areas, making oyster production difficult. Oyster drill populations are located primarily in Drayton Harbor.

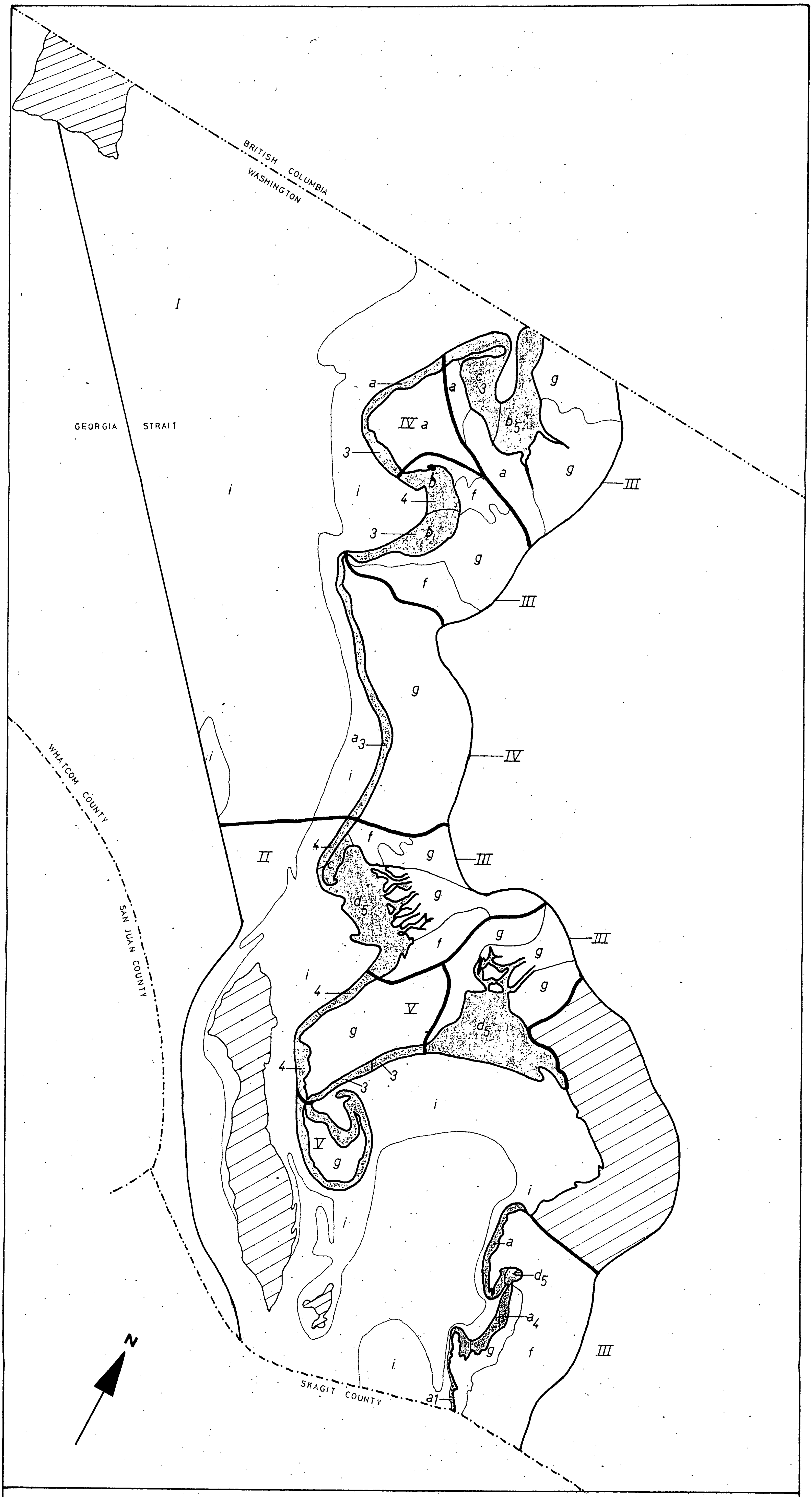
Commercial and sport fishing for salmon and bottom fish occurs throughout the year. The principal salmon fisheries resource in this area is the Sockeye salmon run on the Fraser River (Kincaid, et. al., 1954). The Sockeye that migrate through United States' waters enroute to the Fraser River pass the west coast of Lummi Island, travel past Birch Bay toward Point Roberts and then head for the Fraser River (Kincaid, et. al., 1954). Natural salmon spawning streams in the study area include the Nooksack River, Squalicum Creek, Chuckanut Creek, Terrell Creek, California Creek and Dakota Creek (USDA, 1953). Chinook and pink salmon spawn only in the Nooksack while nearly all the streams receive Chum and Coho Salmon. Searun trout are also found in these creeks and the Nooksack during different times of the year. They constitute a popular sport fishery.

CLASSIFICATION OF THE WHATCOM COUNTY COAST

There are no coastal regions or subregions within the study area. The Whatcom County coast is contained within the Puget trough which is a subregion of the Pacific Northwest Coastal region of the United States (U.S. Department of Interior, 1970). Numerous embayments or indentations and the estuarine character of the water are two distinctive features of the coastal subregion. The subregion has been characterized as both one large estuary and as a series of small estuaries (U.S. Department of Interior, 1970).

As shown in Map 6, the study area is divided into coastal components, coastal subcomponents, and coastal phases according to the classification outline in Chapter Three. The coastal phase class is indicated within subcomponents of the estuary-shore belt on the basis of beach composition.

The coastal belts (marine, estuary-shore, and terrestrial) discussed in Chapter Three, have been delimited from analysis of the bathymetry, tides, topography, water quality and land use. Unfortunately, all the criteria established for delimiting the terrestrial belt could not be utilized. In particular, an area of vegetation displaying the effects of the marine environment could not be established. Hence, following Schaeffer (1969), the inland boundary of the terrestrial belt was set at two miles from the shoreline to include most land uses affected by the marine environment or having a direct impact on coastal resources. Interestingly, it was noted in the PNRBC study (1970) that many wells within two miles of the shoreline may encounter salinity problems when driven deeper than one hundred feet. The estuary-shore belt includes the area between the line of mean lower low tide and the line of mean high tide. Differentiation of the estuary-shore belt is accomplished by coastal subcomponent designations. The seaward boundary of the marine zone follows the line between the two distinct (east and west) bottom areas in S.E. Georgia Strait. As noted in the foregoing section on topography, the bottom west of the line is quite



THE COAST OF WHATCOM COUNTY

LEGEND:
- Coastal belt boundary
- Estuary shore zone
- Coastal components boundary
- Coastal subcomponents boundary
- Coastal phase

COASTAL CLASSIFICATION
1972
MAP 6
Scale 1/2 inch = 1 mile

COASTAL CATEGORIES:
- Component eg. I–V
- Subcomponent eg. a–i
- Phase eg. 1–5
- Outside Sudy area

rugged while east of the line the bottom grades smoothly from the shore to about 50 fathoms.

Difference in water properties and surface winds divide the marine belt into two coastal units. In the northern unit, water properties and surface winds are dominated by the effects of the Fraser River and Fraser Valley, respectively. In the southern unit, the water mixing and physical properties reflect the influence of the many channels which converge in the area. With seasonal variations, surface winds in the southern unit flow from the south while surface winds in the northern unit flow from the south and east (Russell, 1954).

The estuary-shore and terrestrial belts are broken into nine components and thirty-six subcomponents largely on the basis of physiographic features. This provides a first level or coarse screen classification of the coast of Whatcom County. The ideal classification would incorporate all those biophysical attributes of resources which affect the productivity and distribution of organisms as discussed in Chapter Two. An analysis more detailed and comprehensive than could be carried out during this study would be needed to accomplish a truly ecosystematic classification of the coast of Whatcom County.

The coastal components are characterized as being either embayed, exposed directly to the Strait or affected by the influence of barrier islands or barrier bars. Coastal subcomponents are designated within the coastal components of the estuary-shore and terrestrial belts. The following physiographic factors were considered in delimiting coastal subcomponents: 1) shoreline cliffs; 2) spits; 3) tidal flats; 4) marshes; and,

5) upland topography. The subcomponents of the estuary-shore belt are characterized further by a beach phase indicating beach composition. Table 6 outlines the classification categories for the coast of Whatcom County.

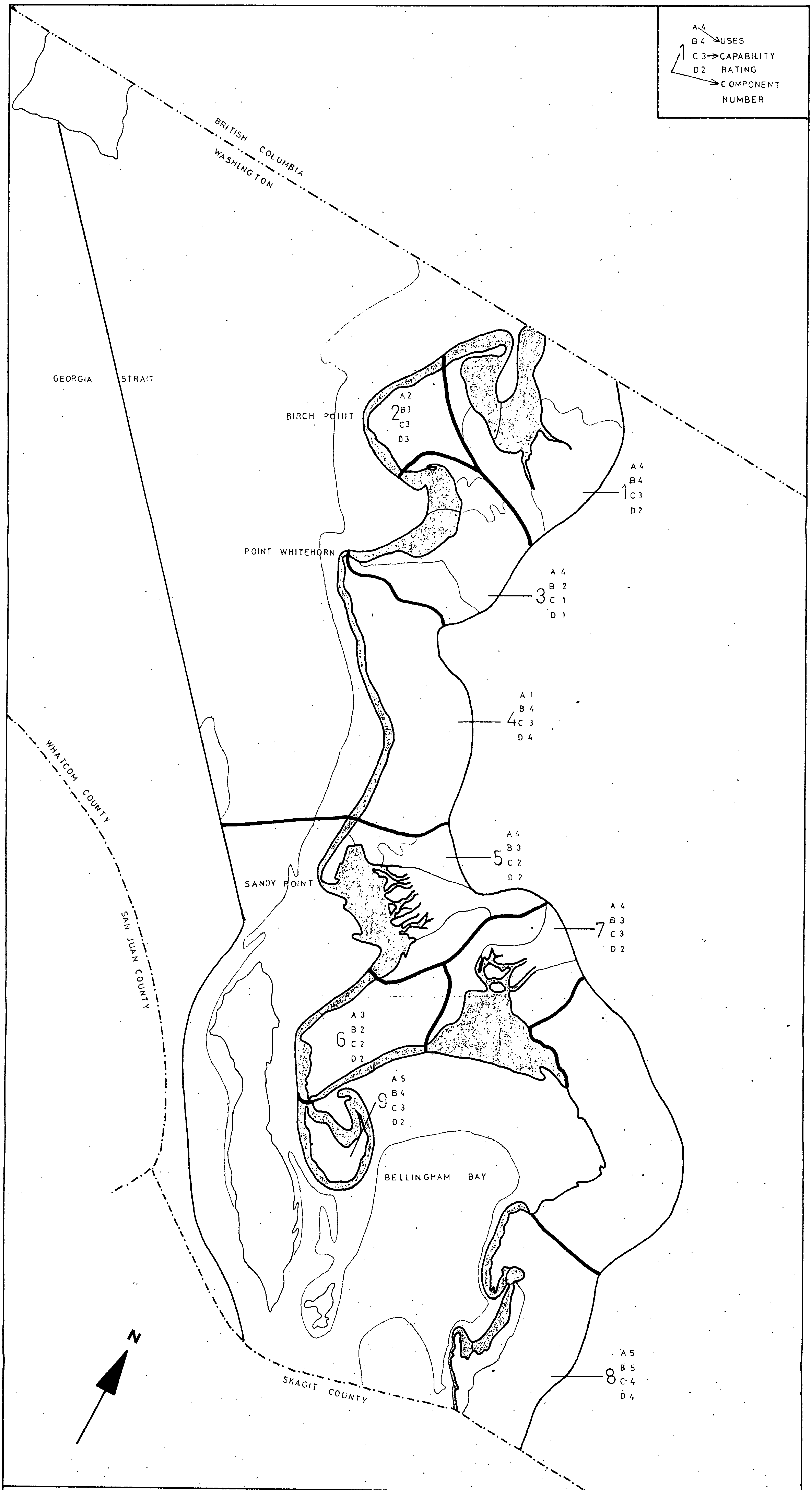
RESOURCE CAPABILITY EVALUATIONS

In this section, each coastal component is rated for its ability to support four different representative types of resource uses. The ratings are based on an evaluation of the subcomponents' potential to supply the resources required by the prospective users and on the absence of conditions that would limit the users' ability to exploit resource or result in damage to the environment and the user. Oyster raft culture, residential (recreation cottages, and permanent homes), waterfront industry, and public outdoor recreation (organized camping and day use) types of uses have been selected to carry out the evaluation of the components. These uses have been chosen to represent the diversity of possible coastal zone uses and are not considered as inclusive of all prospective coastal zone resource uses. The coastal component numbers and use capability ratings for each component are shown in Map 7.

The capability ratings are shown only for the coastal components and represent the synthesis of the evaluation of marine, estuarine, and terrestrial resources which are divided into coastal subcomponents. In order to establish the capability value for the coastal components, each of the subcomponents was examined separately in relation to the various relevant resource requirements. For example, the marine subcomponents were rated for waterfront industry docking facilities while the upland

Table 6: CLASSIFICATION OF THE COAST OF WHATCOM COUNTY

Coastal Class Symbol	Coastal Belt	Distinguishing Feature
Components		
I	Marine	Water Properties: surface currents, temperature, salinity. Surface Winds
II	Marine	
III	Estuary-Shore & Terrestrial	Embayed Shoreline
IV	Estuary-Shore & Terrestrial	Exposed Shoreline
V	Estuary-Shore & Terrestrial	Barrier Protected Shoreline
Subcomponents		
a	Estuary-Shore	Cliffed Shoreline
b	Estuary-Shore	Plain or Terraced Shoreline
c	Estuary-Shore	Spits
d	Estuary-Shore	Tidal Flats
e	Estuary-Shore	Marsh
f	Terrestrial	Upland slope predominately greater than 10%
g	Terrestrial	Upland slope predominately less than 10%
h	Marine	Depth less than 35 feet
i	Marine	Depth greater than 35 feet
Phases		
1.	Estuary-Shore	No beach
2.	Estuary-Shore	Cobble beach
3.	Estuary-Shore	Gravel beach
4.	Estuary-Shore	Sandy beach
5.	Estuary-Shore	Muddy beach



THE COAST OF WHATCOM COUNTY

LEGEND:
- COASTAL BELT BOUNDARY
- COASTAL COMPONENT BOUNDARY
- COASTAL SUBCOMPONENT BOUNDARY
- COASTAL PHASE BOUNDARY
- ESTUARY SHORE ZONE

CAPABILITY FOR SELECTED USES
1972
MAP 7

SCALE 1/2" = 1mile

COMPONENT NUMBERS eg. 1 - 9
CAPABILITY CLASSES (1 to 6)
A. WATERFRONT INDUSTRIES
B. RESIDENTIAL
C. OUTDOOR RECREATION
D. OYSTER CULTURE

terrestrial subcomponents were rated for waterfront industry building sites. In the capability rating tables, each of the values represents the rating of subcomponents relevant to the given resource requirements. Where more than one subcomponent in a coastal component was relevant to one resource requirement, an average value was estimated by judging how strongly the characteristics of each subcomponent complemented or detracted from the overall quality of the coastal component.

It is important to consider the capability rating for the whole in addition to the subcomponent parts. The coastal components are a practical size for carrying out assessments of the user impacts on the interrelated resources and resource uses. Hence, during the early stages of allocating uses to coastal areas, a broad perspective can be maintained to identify potential use conflicts. It is recognized, also, that many conflicts occur well beyond the boundaries of coastal components. The components, for purposes of identifying these conflicts, provide groups of resources that can be related, as a whole, to other components in terms of being either the source area of adverse environmental impacts causing resource use conflicts or the recipient of adverse impacts.

Oyster Raft Culture

Oyster culture in Puget Sound and S.E. Georgia Strait has been practiced since the last part of the 19th century. The earliest recorded oyster production in B.C. was in 1884 (Quayle, 1969).

In Washington State the total oyster production is between 6 and 8 million pounds of meat annually with Puget Sound producing about 30 to

40 percent of the total. Yet, the full potential of the Puget Sound and S.E. Georgia Strait has not been realized (Westley, 1971). Westley (1971) calculated that if the demand for food in the world became great enough, approximately 187,408 total surface acres or about 28% of the surface area of Puget Sound could be brought into production.

Oyster culture for commercial purposes is very demanding of the resource base. Although no single requirement, except depth for raft cultures, is very restrictive, taken as a group, the resource requirements severely limit the capability of areas to support commercial oyster production. Additionally, not all resource requirements are understood well enough to provide a great deal of certainty in identifying those areas that will satisfy the resource requirements for oyster raft culture. Quayle (1961) stated in several places that trial and error is the only effective way to fully determine the capability of an area to support oyster production. Ten biogeophysical factors have been identified as important for evaluating the initial capability of areas for oyster culture. They are:

1. Salinity
2. Water temperature
3. Air temperature
4. Water exchange increasing the fertility
5. Protection from waves
6. Water depth for raft culture
7. Bottom conditions for holding primary seed for raft cultures and for maturing oysters
8. Protection from or absence of predators; oyster drill, starfish and crabs
9. Amount of intertidal area for seed beds
10. Backbeach slope for accessibility

The range of salinity in Puget Sound poses no great problem for oyster culture. The principal species grown commercially in the Pacific Northwest, the Pacific Oyster (*Crassostrea gigas*), is very tolerant to salinity variations. It can live in salinities up to 33 ppt and can remain in freshwater for up to eight hours without being damaged (Quayle, 1971). Only those areas experiencing continuous freshwater conditions such as near the head of an estuary are likely to be unfit for oyster production.

The Pacific Oyster may also tolerate a fairly wide range of temperatures. The oyster is found in water between 40° F and 75° F and can withstand freezing air temperature of 25° F when uncovered by the tide. Productivity is higher, the higher the water temperature within the range of tolerance.

Ground suitable for oyster culture must coincide with areas of suitable water conditions, have a firm bottom, be at the desired tidal level, and be protected from waves. A firm bottom of fine gravel, sand and mud or any combination of these provides the best ground culture areas (Quayle, 1969). The area should also be free of silting. Grounds at a tidal level of 1 to 6 feet above mean lower low water provide the best production and harvesting conditions. Since extreme waves will move oysters along the bottom and onto beach areas, additional labor will be required to return the oysters to the beds in grounds not sufficiently protected from severe wave action.

In raft culture operations, the usual practice is to hang strings up to 40 feet long holding clusters of shells with oyster spat from rafts anchored in water deep enough to prevent the strings from dragging bottom (Figure 11).

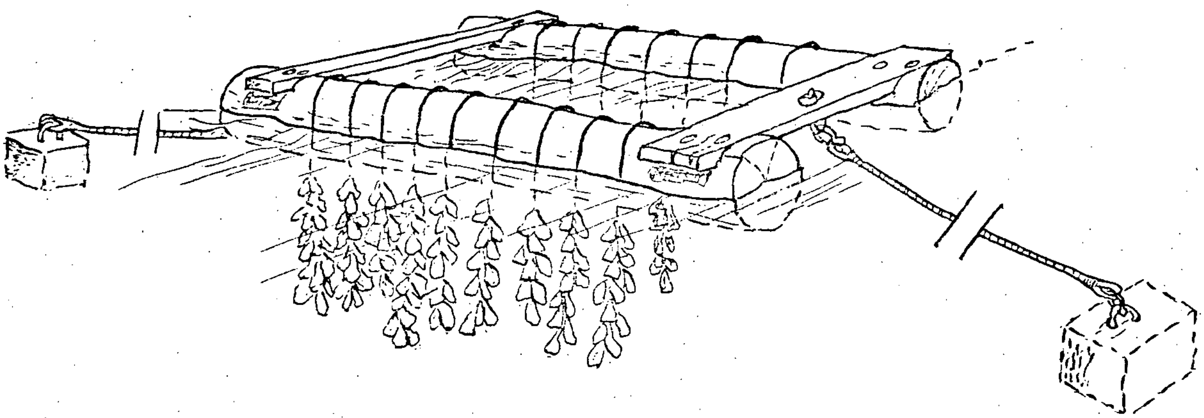


Figure 11: Diagram of oyster culture raft (Quayle, 1971)

The raft should be anchored in an area protected from waves exceeding 2 feet or raft damage may ensue destroying the oysters (Quayle, 1971).

Since an oyster is a sessile, filter feeding organism, it depends upon water circulation to transport its food and wastes. In oyster culture, a fairly large exchange of water is required for high productivity. However, too great an exchange can increase upwelling of cool water that slows an oyster's growth.

In raft culture operations, depths of 15 to 20 feet have been recommended by Quayle (1971) as the minimum at low tide. Westley (1971) considers 20 fathoms (120 feet) the maximum depth practicable for anchoring rafts.

Each of the coastal components has been evaluated for oyster culture. A value of 1 to 4 indicating excellent to poor quality for each resource characteristic has been assigned to the coastal components as shown in

Table 7. In addition a relative weight has been assigned to each user resource requirement to incorporate the relative importance of each resource to the user into the evaluation. Each of the values indicating the quality of the resources in the component is multiplied by this weighting factor. The relative weights also range in value from 1 to 4 indicating insignificant to significant importance and are based on the analysis of resource limitations shown in Table 3 of Chapter Three. The considerations made to establish the relative weight of any one user resource required include: 1) the range of variation of any one limiting resource characteristic which the user can tolerate; and, 2) the capacity of resources to absorb the impact of different uses.

Given the weighting for the ten important characteristics for evaluating oyster culture, the range of values for the sum of the products in each component is from 25 to 102. These values are distributed among six resource capability classes shown below:

Range of Limitations	Capability Rating for Oyster Culture
25-39	1. Very High
40-50	2. Moderately High
51-60	3. Moderate
61-70	4. Moderately Low
71-85	5. Low
86-102	6. Very Low

Residential (Recreation Cottages and Permanent Homes)

Development of land for homes along the Whatcom County coast is now a familiar sight. The magnificant view provided to Georgia Strait, the west and southwesterly facing shorelines and the expanse of beaches (although often inaccessible) are attractive to developers and home

		COASTAL COMPONENTS								
		1	2	3	4	5	6	7	8	9
RESOURCE REQUIREMENTS	RW*									
Salinity	3	2/6	2/6	2/6	2/6	2/6	2/6	3/9	2/6	2/6
Water Temperature	2	1/2	1/2	1/2	3/6	2/4	3/6	2/4	3/6	2/4
Air Temperature	2	2/4	2/4	2/4	2/4	2/4	2/4	2/4	2/4	1/2
Water Exchange	3	2/6	1/3	2/6	1/3	1/3	1/3	2/6	1/3	1/3
Protection From Waves	3	1/3	4/12	2/6	4/12	1/3	1/3	1/3	4/12	1/3
Bottom consistency	2	1/2	3/6	1/2	4/8	2/4	1/2	3/6	4/8	1/2
Predators	2	3/6	2/4	1/2	2/4	1/2	1/2	1/2	1/2	1/2
Amount of Intertidal Area	3	1/3	3/9	1/3	4/12	1/3	2/6	2/6	4/12	2/6
Depth for Rafts	4	4/16	1/4	1/4	1/4	3/12	2/8	3/12	1/4	3/12
Access	1	1/1	3/3	1/1	4/4	2/2	1/1	1/1	4/4	1/1
SUM OF PRODUCTS		49	53	36	62	43	41	53	61	41
CAPABILITY CLASS		2	3	1	4	2	2	3	4	2

Table 7: RESOURCE USE-CAPABILITY RATINGS OF COASTAL COMPONENTS FOR OYSTER RAFT CULTURE

Key: *RW - Relative Weight of Resource Characteristics

Quality rating of resource in component

Product of Relative weight times Quality of Resource

Range of Limitations	Capability Rating
25-39	Very high
40-50	Moderately high
51-60	Moderate
61-70	Moderately low
71-85	Low
86-102	Very low

purchasers. Unfortunately, in many situations such as this, the beauty of the area can obscure concern for the physical limitations to home developers.

With respect to characteristics that are important in evaluating land for home developments in the study area, the Canada Department of Forestry and Rural Development (1967) identified nine biogeophysical characteristics for the recreation lodging sector of the Canada Land Inventory which are applicable. They are: 1) shelter from wind; 2) exposure to sun; 3) capability for vegetation cover; 4) outward aspect for viewing; 5) soil material for foundation and drainage from septic tanks; 6) availability of freshwater; 7) upland slope; 8) backbeach slope; and, 9) protection from flooding. Beach composition has also been added by the author because of its importance in determining the capability of an area to support recreation activities.

Slope characteristics determine to a great extent the capability of a site to support different uses. In addition, slope is indicative of several soil characteristics that may be limiting to prospective uses. Foster (1971) points out that as slope increases above 10% soil conditions for drainage, vegetation growth and foundation stability become less favorable. In terms of shoreline development there are two areas where slope is a critical concern; first, the slope of the immediate beach backland affects beach access and second, the slope of the upland site chosen for development affects a site's capability to support building foundations, to provide accessibility by automobile, and provide drainage and vegetation. A slope of 25% or greater in the immediate beach backland can be considered to severely restrict beach access. Upland slopes of 15%

or less can be considered for most home site development (Canada, Department of Forestry, 1967). Good automobile access, however, is not provided on slopes exceeding 7% (Lynch, 1962).

The direction from which an area receives its sunlight is important to consider in site planning. Obviously, in the Northern Hemisphere those slopes which face the west and southwest will receive the desirable afternoon sun while east, northeast and north facing slopes are less favorable in this respect (Lynch, 1962). The benefits of receiving sunlight must be considered in relationship to benefits derived from alternative scenery views and of course, weighted by the degree of slope (Lynch, 1962).

The procedure for rating the coastal classes for recreation home developments follows the same procedure used in rating areas for oyster culture. Table 8 displays the values assigned to the areas for each important resource characteristic. Since there are ten biogeophysical factors considered and given the weighting assigned to each resource factor, the possible range of the sum of products is from 29 to 117. These values are grouped into six capability classes as follows:

Range of Limitations	Capability Rating for Recreation Home Sites
29-40	1. Very high
41-52	2. Moderately high
53-65	3. Moderate
66-80	4. Moderately low
81-95	5. Low
96-117	6. Very low

Waterfront Industries

Navigation facilities and waterfront industries in the study area are located largely in Bellingham Bay. Other navigation facilities are located

RESOURCE REQUIREMENTS	RW*	COASTAL COMPONENTS 1	2	3	4	5	6	7	8	9
Beach Composition	2	4/8	2/4	1/2	4/8	3/6	1/2	4/8	4/8	2/4
Shelter from Wind	2	1/2	2/4	2/4	3/6	2/4	2/4	1/2	3/6	3/6
Exposure to Sun	2	2/4	1/2	1/2	1/2	1/2	1/2	1/2	1/2	2/4
Vegetation Cover	2	1/2	1/2	1/2	1/2	1/2	2/4	1/2	1/2	2/4
Soil Conditions	4	4/16	1/4	4/16	2/8	4/16	2/8	4/16	4/16	2/8
Freshwater Availability	3	1/3	3/9	1/3	2/6	1/3	3/9	1/3	4/12	4/12
Outward View	3	3/9	2/6	1/3	2/6	2/6	1/3	1/3	1/3	1/3
Upland Slope	4	2/8	2/8	1/4	1/4	1/4	1/4	1/4	4/16	3/12
Beach Access	3	2/6	3/9	1/3	4/12	1/3	1/3	1/3	4/12	3/9
Protection from Floods	4	3/12	1/4	3/12	1/4	4/16	1/4	4/16	1/4	1/4
SUM OF PRODUCTS		70	52	51	58	62	43	59	81	66
CAPABILITY CLASS		4	3	2	4	3	2	3	5	4

Table 8: RESOURCE USE-CAPABILITY RATINGS OF COASTAL COMPONENTS FOR RESIDENTIAL USE (RECREATION COTTAGES AND PERMANENT HOMES)

Key: *RW – Relative Weight of Resource Characteristics

—Quality Rating of Resource in Component

—Product of Relative Weight Times Quality of Resource

Range of Limitations	Capability Rating
29–40	1. Very high
41–52	2. Moderately high
53–65	3. Moderate
66–80	4. Moderately low
81–95	5. Low
96–117	6. Very low

in Drayton Harbor, Birch Bay, Lummi Bay and Hale Passage, and at three locations between Point Whitehorn and Sandy Point. These last three facilities are private bulk terminals serving two oil refineries and an alumina ore processing plant. Except for the three privately owned navigation facilities and those in Bellingham Bay, all other facilities are designed primarily to handle small boats. Ferry terminal facilities at Gooseberry Point serve Lummi Island (PS & AW, 1970).

No single set of navigation facility requirements are suitable for assessing potential sites for all types of waterfront industries. One of the distinguishing characteristics of modern water borne commerce is the variety of cargo and vessels in use. Additionally technological innovations have been rapidly altering the physical requirements of navigation facilities. For example, in 1949, the largest tankers in use had a capacity of approximately 30,000 deadweight tons and a draft, fully loaded, of about 32 feet. In 1967 the "supertanker," Idemitsu Maru, was launched which had a dead weight capacity of 210,000 tons and a draft of 58 feet (Graves, 1968). Larger vessels have been launched since that time. Although the facilities required to handle these tankers are relatively simple (Graves, 1968), the increase in draft has created problems in providing navigation channels deep enough to handle "supertankers."

With the shift to large bulk carriers, waterfront facilities have had to be modified to accommodate larger ships with greater drafts and to provide facilities and space for the processing and storage of bulk products. Because the cost of dredging navigation channels to depths greater than 45 feet is very high, naturally deep water areas near shore and near markets have come under consideration as alternatives to modifying existing port facilities (Graves, 1968).

In addition to deepwater (35 to 75 feet at mean lower low tide) other physical requirements for waterfront industries include:

1. Relatively calm water,
2. Sufficient area to accommodate all the processing facilities,
3. Soil characteristics that will support foundations for heavy structures, provide good drainage, and be excavable for installation of underground utilities,
4. Flat land within a 2% to 5% slope range,
5. Water circulation for diffusing waste products.

Barber (1967) notes that soft soils should be avoided wherever possible. But, for industries requiring access to water transportation, avoiding soft soil conditions may be impossible. In many cases, bulk storage facilities and processing plants do not need to be located directly at the shoreline. Material conveyance mechanisms can often be extended, within certain technical and economic limits, inland to suitable sites. But, this provides only a limited amount of flexibility to avoid undesirable soil conditions.

For the purposes of this study the six physiographic characteristics discussed in the preceding paragraphs have been used to rate the capability of the coastal units for heavy waterfront industry facilities. The rating scheme is consistent with the scheme for rating oyster raft culture and residential home sites. Given the relative weights for the six resource factors being analyzed, the range of possible sum of products is from 22 to 80. This range has been divided into six capability ratings in the following manner:

Range of Limitations	Capability Rating for Waterfront Industry
22-31	1. Very high
32-42	2. Moderately high
43-52	3. Moderate
53-62	4. Moderately low
63-72	5. Low
73-80	6. Very low

Table 9 shows the results of the resource evaluation and capability analysis for heavy waterfront industries.

Public Outdoor Recreation (Day-use and Overnight Camping Facilities):

Day-use and overnight camping facilities in the study area are provided by the Washington State Parks and Recreation Department at Larabee State Park near Chuckanut Bay and at Birch Bay State Park. Both of these parks provide excellent day-use and camping facilities and are used intensively throughout the summer months, June to September. Moreover, both parks are located in areas possessing extremely different physiographic features, thereby offering two distinctively different types of recreational experiences. Because there is a great variety of shoreline characteristics in the study area, other areas offering the possibility of equally different types of recreational experiences are available.

Despite the various types of shoreline offering different recreational opportunities, there are certain user requirements that must be satisfied before an area can be considered to have high recreational capability. Nine essential biophysical requirements for organized camping facilities were identified in the recreation sector of the Canada Land Inventory which are useful for evaluation of the Whatcom County coast (Canada Department of Regional Economic Expansion, 1969). These requirements are by no

		COASTAL COMPONENTS								
		1	2	3	4	5	6	7	8	9
RESOURCE REQUIREMENTS	RW*									
Protection from High Waves	1	1/1	2/2	2/2	2/2	1/1	1/1	1/1	2/2	1/1
Water Circulation	4	3/12	1/4	4/16	1/4	3/12	1/4	3/12	1/4	2/8
Depth	3	4/12	3/9	4/12	1/3	4/12	4/12	4/12	1/3	4/12
Soil Bearing Capacity	4	4/16	2/8	4/16	2/8	4/16	3/12	4/16	4/16	3/12
Slope	4	1/4	2/8	1/4	2/8	2/8	2/8	1/4	4/16	4/16
Land Space	4	2/8	1/4	1/4	1/4	3/12	2/8	3/12	4/16	4/16
SUM OF PRODUCTS		53	35	54	29	61	45	57	67	65
CAPABILITY CLASS		4	2	4	1	4	3	4	5	5

Table 9: RESOURCE USE-CAPABILITY RATINGS OF COASTAL COMPONENTS FOR WATERFRONT INDUSTRIES

Key: *RW - Relative Weight of Resource Characteristics

—Quality of Resources in Component

—Product of Relative Weight times Quality of Resources

Range of Limitations	Capability Rating
22-31	1. Very high
32-42	2. Moderately high
43-52	3. Moderate
53-62	4. Moderately low
63-72	5. Low
73-80	6. Very low

means inclusive of all outdoor recreation biophysical requirements, nor are they absolute. They provide a general framework for accomplishing a general evaluation of an area's capability to provide public outdoor recreation benefits. Thus, they serve the purposes of this case study. The preferred biophysical requirements are:

1. Stable unconsolidated surface material for camp site construction.
2. Extensive area of low gradients or very frequent level terraces for recreational activities and camp sites (2 to 5 percent).
3. Slope conditions suitable for vehicle access (Less than 10%).
4. Proximity to potable water.
5. Tree cover to provide wind and sun shelter.
6. Scenic outlook.
7. Proximity to waterfront features having good bathing or other popular water-oriented recreational activities.
8. Accessibility for boats.
9. Beach composition.

Since there are nine requirements to be considered in evaluation of areas for recreation day-use and camping facilities the range of total values is from 26 to 104. Table 10 shows the values assigned to the coastal components for each resource characteristic. Given below is the distribution of these values to the six capability ratings.

Range of Limitations	Capability Rating for Public Day-Use and Camping Facilities
26-38	1. Very high
39-50	2. Moderately high
51-63	3. Moderate
64-76	4. Moderately low
77-90	5. Low
91-104	6. Very low

DISCUSSION OF CAPABILITY RATINGS

The capability ratings established for each coastal component are based

RESOURCE REQUIREMENTS	RW*	COASTAL COMPONENTS 1	2	3	4	5	6	7	8	9
Surface Material	3	2/6	2/6	2/6	2/6	4/12	1/3	4/12	1/3	2/6
Extensive Low Gradients	3	3/9	2/6	1/3	1/3	2/6	2/6	1/3	3/9	2/6
Slope for Auto Access	2	1/2	2/4	1/2	1/2	1/2	1/2	2/4	4/8	2/4
Potable Water Supply	4	1/4	2/8	1/4	2/8	3/12	3/12	2/8	3/12	4/16
Shelter	4	1/4	2/8	2/8	2/8	2/8	2/8	2/8	1/4	1/4
Beach Access	3	3/9	3/9	1/3	4/12	1/3	1/3	3/9	4/12	1/3
Access for Boats	2	3/6	3/6	1/2	3/6	2/4	1/2	2/4	2/4	2/4
Scenic Outlook	2	4/8	2/4	1/2	3/6	1/2	1/2	2/4	1/2	1/2
Beach Composition	3	4/12	2/6	1/3	3/9	2/6	1/3	3/9	4/12	2/6
SUM OF PRODUCTS		60	57	33	60	43	40	61	66	51
CAPABILITY CLASS		3	3	1	3	2	2	3	4	3

Table 10: RESOURCE USE-CAPABILITY RATINGS OF COASTAL COMPONENTS FOR OUTDOOR RECREATION (DAY USE AND OVERNIGHT CAMPING FACILITIES)

Key: *RW - Relative Weight of Resource Characteristics

—Quality of Resources in Component

—Product of Relative Weight times Quality of Resources on the biogeophysical characteristics of the Whatcom county coast. Because of this, uses are not recommended within each component. The capability ratings, by themselves, provide an insufficient basis on which to recommend land uses. The ratings do not distinguish between those land uses that "could" take place in a coastal component and those that "should" (Steinitz, 1970). The capability ratings indicate only the inherent potential of an area to produce utilities to man. As such, the ratings provide answer to primarily two questions: 1) "What level of use and productivity can a coastal component be expected to achieve given certain stated constraints?"; and, 2) "What are the biophysical conditions limiting the use of a coastal component?"

There are many other factors that enter into determining the use of a coastal area. The degree to which a user's resource requirements may be satisfied depends first on the inherent capability of the resource component to supply the resources as indicated by the capability rating and second on the degree to which the component may respond to the user's inputs designed to crop or exploit the natural productivity of the resources. Consideration of the second factor is carried out in the suitability and feasibility types of analysis designed by Hills (1961). Suitability is defined by Hills as a measure of the effort required to bring a given area of land to the level of production which it is capable under prevailing economic conditions. For example, the Sandy Point subcomponent is extensively developed for private recreation homes. To bring it into use for public recreation would require tremendous effort to remove homes or to purchase public access. Conversely, it would require less effort to expand the state park facilities at Birch Bay for public recreation because of the existing facilities.

Through a consideration of the capability and suitability ratings of a coastal component, the feasibility of a component for different uses can be determined. Hills (1961) defines feasibility as the relative advantage of utilizing an area for a given use in terms of the inputs relative to the outputs under existing or projected economic conditions. Given the demands projected for waterfront industrial sites and recreation home sites, most areas displaying comparative capability ratings for these uses may be expected to be feasible for development. The components can also be expected to come under competition for the different uses. Oyster culture, requiring very specific combinations of resource attributes and being in relatively lower economic demand, may not be, at the present time, a feasible development alternative. On the other hand, given the shortage of food in the world (Ehrlick, 1971), development of coastal components of high oyster capability for alternative uses which change irreversibly the capability for oyster culture would be a myopic action.

The final chapter to this study explores the problem of reducing resource use conflicts given the inherent capability of the resources to support different uses. Potential resource use conflicts are identified through the use of an environmental impact matrix (Table 2) and through an examination of the occurrence of comparatively high capability ratings for different uses within each coastal component. The usefulness of the capability analysis in identifying areas of conflict and alternative patterns of allocation is discussed in a concluding scenario comparing the policies implied in the county comprehensive plan with the alternatives generated through the capability analysis.

CHAPTER FIVE: THE OPPORTUNITIES FOR MULTIPLE USE OF COASTAL ZONE RESOURCES

MANAGEMENT PROBLEMS

It was a recognition of the nature of the biophysical characteristics of the coastal resources and the diversity of groups demanding use of coastal resources which led to the hypothesis for this study:

> Through a process which integrates the evaluation of biogeophysical characteristics of the resource base and an assessment of resource use-capability with an analysis of the resource requirements of specified users, opportunities may be identified for allocating land to various users in a way that will reduce environmental degradation and resource use conflicts.

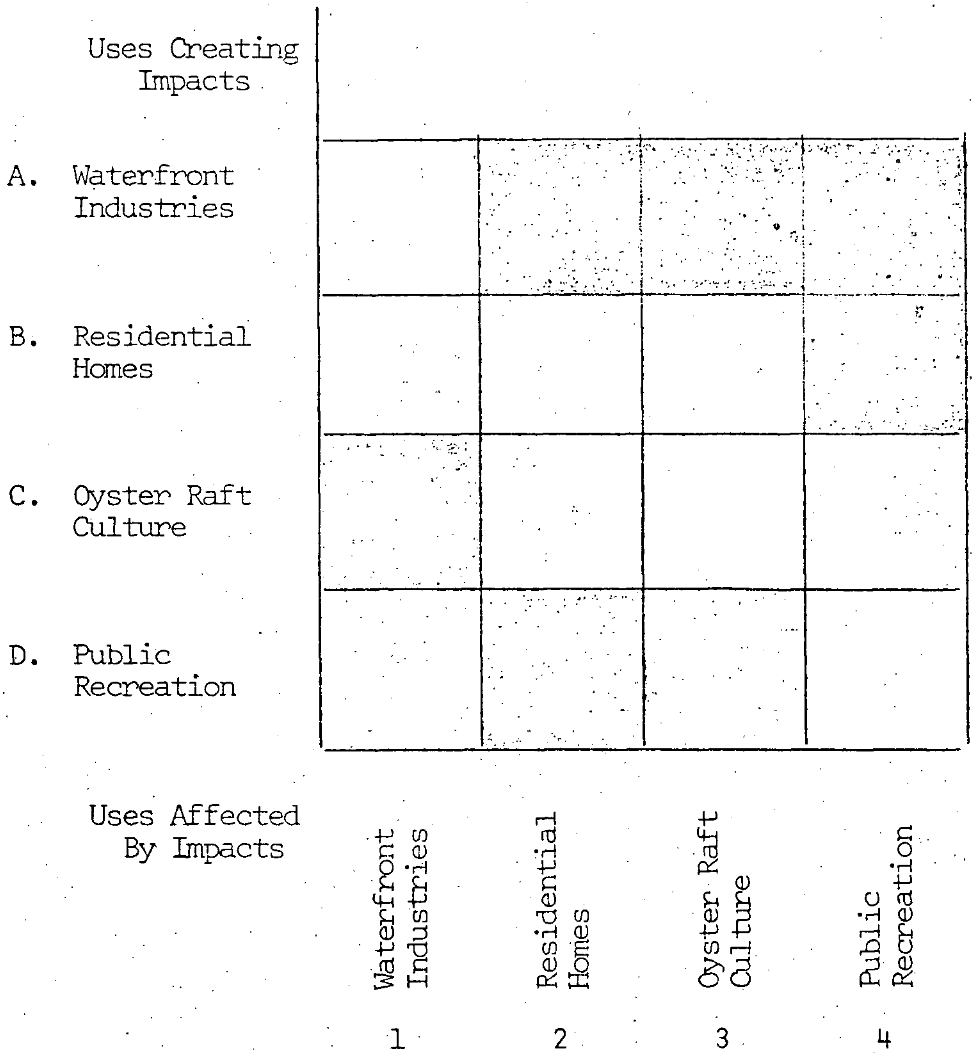
The underlying premise of this hypothesis, as noted in Chapter One, is that the ability of management institutions to respond to the goals of society to prevent environmental damage and use conflicts depends not only on the management body's legal authority, but also upon an appreciation of the social, economic and biophysical characteristics of the coastal zone. Subsequently, the synthesis of a resource classification and evaluation technique was accomplished to aid in developing an understanding of the technical nature of the resource use problems in the coastal zone.

The usefulness of a coastal resource classification and evaluation technique for coastal zone management is in identifying opportunities to resolve resource use problems encountered in coastal zone management. In general, problems to be confronted in managing coastal resources are of two types: 1) conflicts resulting from the interference by one resource user in the exploitation of another resource by a second user; and, 2) competition for the same resources. This division of resource management problems may seem to be rather artificial since each problem relates to the other. But, it is useful since different aspects of the social, economic, and biophysical characteristics of the coastal zone can be more easily related to these problems than to a general problem stated broadly in terms of either social equity, economic efficiency or environmental integrity. Further, these problems are stated in terms that relate to the dissatisfaction which the public experiences in attempts to utilize coastal resources. Such dissatisfaction is manifest in the complaints regarding the lack of access to beaches, inadequate public facilities for coastal recreation, too few areas preserved for future uses, and the damage done to resources because of unrestrained exploitation of their attributes.

To respond to these types of problems in coastal zone management, one must understand their genesis and be aware of the various component parts of the problems. Each type of problem appears to stem from the limited supply of resources available to satisfy a large number of societal groups representing a diverse range of values and from the biophysical attributes of coastal resources attractive for a variety of uses. The range of values held by groups interested in using coastal resources is represented at one end of the spectrum by those groups exploiting specific resource opportunities and at the other end by those groups who derive vicarious enjoyment from knowing beautiful coastal areas exist, while never actually using or even visiting them. Because the supply of resources in the coastal zone is finite and quite limited relative to the potential demand for various uses (U.S.A. Department of Interior, 1970), the resources are likely to become the object of severe competition. In terms of achieving an equitable distribution of resources this competition is not always desirable.

Coastal resources are highly interrelated through biophysical process. Thus, use damages to the environment can be widespread and pervasive. This results in a great propensity for the activities of one coastal resource use to conflict with the resource requirements of other users. As shown by Table 11, certain use combinations are particularly incompatible. In interpreting the impacts for potential use conflicts the assumption has been made that conflicts result from user activities which either eliminate the natural resource due to resource extraction, destroy the utility of the resource for other uses by reducing its natural quality or by preventing other users from obtaining access to the resources. The potential inter-use conflict of possible use combinations is characterized as either prohibitive, restrictive, or a nuisance conflict (U.S.A. Department of Interior, 1970). Prohibitive type land-uses are those which exclude other users from enjoyment of the resources because of major modifications to the coastal resources, or the building of structures which impede access to the resources. In most cases the prohibitive use impacts cause permanent changes in the resources. Restrictive use impacts result from the adverse impact of activities on coastal resources but do not, in all cases, exclude others from using the resources. Water pollution is an example of a restrictive impact. The water can be used by others once it is treated or allowed to

Table 11: INTER-USE CONFLICTS: SUMMARY OF ENVIRONMENTAL IMPACT MATRIX



Key: Nuisance Conflict
Restrictive Conflict
Prohibitive Conflict

cleanse itself. A nuisance type of use conflict is the least severe of the three. It indicates inter-use conflicts resulting from use impacts which are unpleasant or uncomfortable for other resource users, but they are not intolerable. They can, however, require tremendous effort to overcome in order to create more pleasant conditions. The adverse effect of oyster raft cultures on the aesthetic quality of an embayment is considered to be this type of conflict.

THE ROLE OF THE RESOURCE CLASSIFICATION AND EVALUATION TECHNIQUE IN COASTAL ZONE MANAGEMENT

While coastal resources offer multiple opportunities for use and thereby the potential for use conflicts, the resource attributes also provide the opportunity to design many alternative patterns of use allocation based on the inherent ability of resources to support different uses.

The allocation of uses to resources in space is only one possible management approach to producing a "desirable" distribution of benefits and costs resulting from the use of coastal resources. It is, however, a fundamental approach to the problem of resource management. As noted by Craine (1971) each attribute of a complex of resources surrounding a body of water makes possible specific uses and benefits which represent the potential of the resources. Hence, the first step to be taken in managing the use of resources is "a careful analysis of the resource attributes and the problems associated with their use" (Craine, 1970). It should also be noted that the allocation of uses is often the only management technique that can be applied to resolve resource use conflicts and achieve a distribution of resources acceptable to the diverse groups interested in the consumption of coastal resources. This results most often from citizens' unwillingness to accept the risks and uncertainties associated with the effectiveness of other management tools, such as pollution control regulations. One prime example where citizens are often unwilling to accept a regulatory solution to conflicts is in locating nuclear power producing plants near population centers or popular recreation areas.

A resource classification and evaluation process provides the basis for establishing alternative use allocation patterns within a management area. Map number 7 displays the possible alternative resource allocation patterns generated from the resource classification and evaluation conducted in Chapter Four. For each coastal component of the study area the capability for each of the selected uses has been indicated. Table 12 demonstrates several alternative resource allocation patterns using only the first, second and third best uses which could be evaluated for their suitability and feasibility.

Each pattern of allocation reveals a particular combination of the component's possible multiple uses. Through an analysis of both the allocation patterns and user impacts on the resources, the relative potential or risk of conflicts within the coastal components can be established. Since each capability class (e.g. 1-6) is intended to represent only the inherent ability of resources to support different uses, and therefore the relative use limitations of a resource, the next step is to estimate the distributional consequences of each use allocation pattern in terms of 1) the nature and incidence of conflicts and, 2) the costs in resource

Table 12: THE CAPABILITY OF COMPONENTS WITHIN THE COAST OF WHATCOM COUNTY FOR SELECTED USES

	COMPONENT USE CAPABILITIES							
Component* Number	A	B	C	D	1st Class 2nd Class	1st Class 3rd Class	2nd Class 3rd Class	1st Class 2nd Class 3rd Class
1	4	4	3	2	D	C	C D	C D
2	2	3	3	3	A	B C D	A B C D	A B C D
3	4	2	1	1	B C D	C D	B	B C D
4	1	4	3	4	A	A C	C	A C
5	4	3	2	2	C D	B	B C D	B C D
6	3	2	2	2	B C D	A	A B C D	A B C D
7	4	3	3	3		B C D	B C D	B C D
8	5	5	4	4				
9	5	4	3	2	D	C	C D	C D

Key:
- A - Industrial
- B - Residential
- C - Public Recreation
- D - Oyster Culture

Capability Ratings:
- 1 - High
- 2 - Moderately high
- 3 - Moderate
- 4 - Moderately low
- 5 - Low
- 6 - Very low

* See Map 7

limitations that a user would have to incur under different allocation patterns aimed at reducing use conflicts. Sorenson (1971) points out that given a capability analysis of resources to support different uses, use allocation patterns should be evaluated to determine the relative opportunity costs incurred by individual users from not locating in other components of the study area.

These types of cost estimates in terms of resource limitations should not be confused with the suitability and feasibility types of analysis. It is not possible to conduct either of these analyses without an assessment of the existing resource use situation, the demand for resources, and the goals and objectives of the society concerned with the use of coastal resources. Special attention should be paid to the distributional consequences of alternative allocation patterns in a feasibility analysis to determine the relative advantage of each alternative in averting use conflicts.

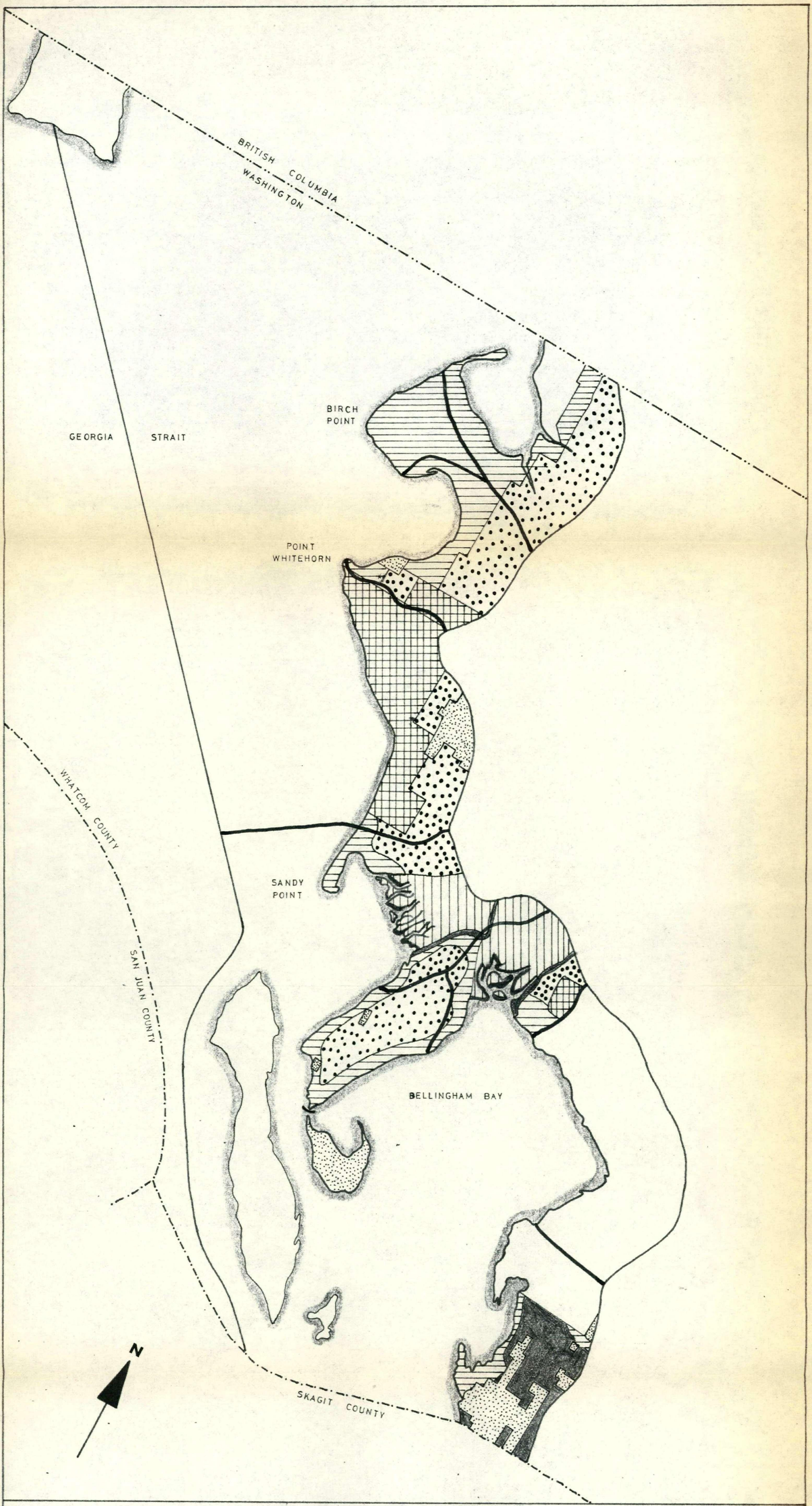
ALTERNATIVE USE ALLOCATIONS AND THE WHATCOM COUNTY COMPREHENSIVE PLAN

The official policies of Whatcom County regarding the allocation of land-uses in the coastal area are manifest in the comprehensive plan. Ostensibly, these policies are based on an analysis of the social, economic, political and biophysical resource characteristics of the County and the goals and objectives of the citizens. It is apparent, however, that a careful analysis of the inherent use potential of the resources did not form the basis of the County's comprehensive plan. Secondly, the County plan does not deal with all types of land uses in the County or all prospective uses. Nor is the plan highly specific or rigid regarding the allocation of land-uses. It was designed to be a tool for guiding the physical development of the county to attain the goals and objectives of the County residents. Thus, it would be possible to modify the plan and incorporate into it additional ways of accomplishing the stated goals and objectives.

Two of the major objectives stated in the plan are particularly pertinent to this study: 1) Conservation of resources; and, 2) Harmony of land utilization. With respect to the conservation of resources, the policies imply that the resources are to be used in a way that will minimize resource damages resulting in short term benefits from their use. The second objective to achieve "harmony of land utilization" is complemented with policies that have specific relevancy to this study. They are: 1) maximum compatibility in the arrangement of uses; and 2) "recognition of the natural limitations and relative suitability of land for various uses."

These and other related objectives form the basis of the comprehensive plan for Whatcom County. Map number 8 shows the portion of this plan within the study area. The coastal components are also shown to facilitate reference between this map and the capability maps.

Since the comprehensive plan does not deal with oyster culture as a prospective coastal use nor does it identify potential recreational areas outside those areas already dedicated to recreational uses, the author has found it necessary to consider alternative allocations of these uses based on the capability analysis. These alternatives are compared to the allocation



THE COAST OF WHATCOM COUNTY

COUNTY COMPREHENSIVE PLAN

MAP 8

SCALE: 1/2" = 1 MILE

LEGEND:

SUBURBAN
INDUSTRIAL
RECREATIONAL
RURAL
AGRICULTURE
MULTIPLE USE FORESTRY
OUTSIDE STUDY AREA
COASTAL COMPONENT BOUNDARY
EDGE OF WATER AREA

SOURCE: WHATCOM COUNTY 1971

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of other uses in the comprehensive plan. Recreation activities were not dealt with in the comprehensive plan because of revisions being made to the County's recreation plan.

The most obvious characteristic of the comprehensive plan is the highly segregated nature of the use allocations. Second, the shoreline areas are assigned largely to two uses--residential and industrial. While this may be a realistic approach to solving problems of land-use conflicts when the nature of the conflict is prohibitive, it is not apparent from the resource capability and environmental impact analysis that this is necessary or desirable in Whatcom County. Thus, it is questionable whether this approach to allocating resource uses is compatible with the plan's objectives to seek a moderation between the extremes of concentration of uses and dispersion of uses and to seek "optimum long-range benefits" from resource use. Further, desires of diverse interests groups to obtain benefits from the use of coastal resources are likely to result in strong pressures for a multiple use of resources in the full range of coastal components despite the present plan of use allocation. Hence, the capability and impact analysis are tools that can aid in making the choice of uses producing the least conflict and environmental degradation. Since the resolution of use impacts is based largely on the choice of alternative patterns of allocation, it stands to reason that the capability and impact analysis would provide considerable insight to the ramifications of carrying out the policies of the comprehensive plan.

Given that the comprehensive plan has been developed on the basis of social and economic information, including an analysis of citizen goals and objectives concerning the physical development of the County, it therefore represents the County's first choice pattern of use allocation. The capability and impact analysis will provide the basis for identifying the range and relative rank of possible alternative patterns, while indicating the kinds of limitations and conflicts associated with potential multiple uses of resources in each component given the allocation provided in the comprehensive plan. The capability of the components to support selected alternative uses and the potential for multiple uses in each component is demonstrated in Table 9. By refering to the capability analysis conducted in Chapter Four, the major biophysical limitations in each coastal component for each use can be ascertained. The environmental impact analysis provides the basis for estimating the potential conflict associated with the prospective multiple use allocations.

Residential Uses (Recreation Cottages and Permanent Homes):

In the comprehensive plan, residential uses are the most predominate uses allocated to the coastal zone. By superimposing the coastal components over the comprehensive plan (Map 8) one can see that residential uses have been allocated by the County to components 1, 2, 3, 5, 6, 7, and 8. (See also Table 13) In each of these components the residential uses impinge on the estuary-shore zone. In component 5, the two major subcomponents demonstrating a high capability for recreation uses are allocated residential uses by the comprehensive plan. (The Sandy Point subcomponent is already developed for residential uses while the northwest shore subcomponent of components is in the process of being "sub-divided.")

Table 13: COMPARISON OF THE WHATCOM COUNTY COMPREHENSIVE PLAN TO RESOURCE CAPABILITY ANALYSIS

Component Number	Comprehensive Plan	CAPABILITY ANALYSIS A	B	C	D
1	B, E*	4	4	3	2
2	B, E	2	3	3	3
3	B, E	4	2	1	1
4	A, C, E	1	4	3	4
5	B, E, F*	4	3	2	2
6	B, E	3	2	2	2
7	B, E, F	4	3	3	3
8	B, C, G*	5	5	4	4
9	C	5	4	3	2

Key:
- A - Industrial
- B - Residential
- C - Public Recreation
- D - Oyster Culture
- E - Rural
- F - Agriculture
- G - Forestry

Capability Ratings:
- 1 - High
- 2 - Moderately high
- 3 - Moderate
- 4 - Moderately low
- 5 - Low
- 6 - Very low

*These uses were not selected for evaluation in this study but are part of the comprehensive plan.

Out of the seven coastal components allocated residential uses in the comprehensive plan, five of the components demonstrate either a first, second, or third class capability for residential uses and components 3, 6, and 9 possess either first or second class capabilities for recreational uses. The five residential areas are capable of providing desirable aesthetic qualities for homes and present few biophysical limitations to overcome in the development of home sites. All other areas, exeept component nine, present severe limitations for residential uses and therefore could require tremendous effort to service with utilities to protect both the home owner and the natural resources from deleterious impacts. The problem in allocating residential uses to all the high capability components is revealed in considering the alternative uses for which each of the five components have equal or higher capability ratings. Since the distribution of residential uses constrains other uses of an area, particularly for outdoor recreation, the county comprehensive plan provides few future opportunities for the public to utilize the recreational potential of the Whatcom County coast. Thus, the County administration will be confronted with the problem of making a choice between the presently planned residential uses of several areas and possible recreational uses when the recreation element is included in the comprehensive plan. The cost of alternative uses, in terms of resource capability limitations and the range of alternatives for allocating recreational and residential uses, should be the major considerations in making this choice.

It appears that the planned allocation of residential uses to component eight can not be supported from a biophysical resource capability viewpoint. Component eight received low capability ratings for all four types of uses. Since our analysis included only four uses out of a wide range of possible uses, it is evident that component eight should undergo analysis for a broader range of uses including extensive recreation, preservation and conservancy types of uses.

Public Recreation Uses

While the entire coast has high capability to support various kinds of recreational uses, components 1, 2, 3, 4, 5, 6 and 9 are especially attractive for organized outdoor recreation--an intensive kind of activity (Table 12). Each of these areas provides a number of desirable recreation amenities and few biophysical limitations. However, each of these components is also attractive for either oyster culture, waterfront industries or residential uses. Therefore, the use conflict potential for recreation is great. The answer to the problem of conflicts is indicated by examining the existing distribution of land-uses and alternative locations for recreation, industrial and residential uses. Possible multiple use areas include components 3 and 5 for oyster culture and residential uses, and component 6 for recreation and oyster culture. The multiple uses in these areas are possible as co-major land uses. Expansion of organized public recreation facilities in component three will be a difficult planning problem because of the present land-use situation. But, because of the high recreation capability of this component an attempt should be made to minimize conflicting activities through facility design and regulatory measures. Recreational values in the other coastal components should also be given consideration for limited types of uses, e.g. view points--boat launching. As noted previously, component eight represents a special problem. Although it did not receive a high rating for intensive recreation, this does not imply that the component is incapable of supporting other types of recreation activities. Hence, component eight should be scrutinized for its capability to support extensive types of recreation activities.

Oyster Raft Culture

As pointed out in the capability analysis for oyster culture in Chapter Four, Puget Sound and Georgia Strait provide very desirable conditions for commercial oyster culture. Thus, there are many alternative locations for this use should it come into great demand. However, by allowing shorelines to be developed for other uses, opportunities for oyster culture could be substantially reduced, especially if the shoreline development activities are not regulated to protect intertidal areas from damage and if the shoreline uses are prohibitive or highly restrictive in relationship to oyster culture. Degradation of views and conflict with navigation are two of the major problems associated with oyster raft culture operations.

All areas except components four and eight are rated within the highest three capability classes for oyster raft culture operations. The rating of components three, five, six, and nine in the top two classes provides a wide range of opportunities to avoid conflicts with other uses in the study area. Unfortunately, because of the ubiquitous distribution of residential uses in the comprehensive plan, this will be difficult to achieve if that plan comes to fruition.

Component nine appears to provide the best opportunity to provide for future oyster raft culture operations. Moreover, its designation as a recreation area in the comprehensive plan is less likely to foreclose the option of oyster raft culture in the future.

Waterfront Industries

Nearly perfect agreement exists between the capability analysis and the County plan allocation of industrial uses to component four. This component has a high capability to support industrial activities and does not present great opportunities for the other uses analyzed in this study which could create conflict situations. Further, the alternative to component four, component six, is less desirable for industry since it also offers development opportunities for recreation and oyster culture.

Opportunities for other uses in component four are limited by several factors. Although the view of Georgia Strait from this component is magnificent, the topographic characteristics do not provide many occasions to view the Strait unless one is nearly at the edge of the bluffs overlooking the shore. Second, the beach area is extremely inaccessible throughout the component because of the steep shoreline cliffs. Further, the easily erodible character of these cliffs represents a safety limitation to most uses unable to avert the risk by constructing protective structures. Finally, at high tide, many of the beach areas are completely covered to the cliff edge making them undesirable for intensive types of recreation activities.

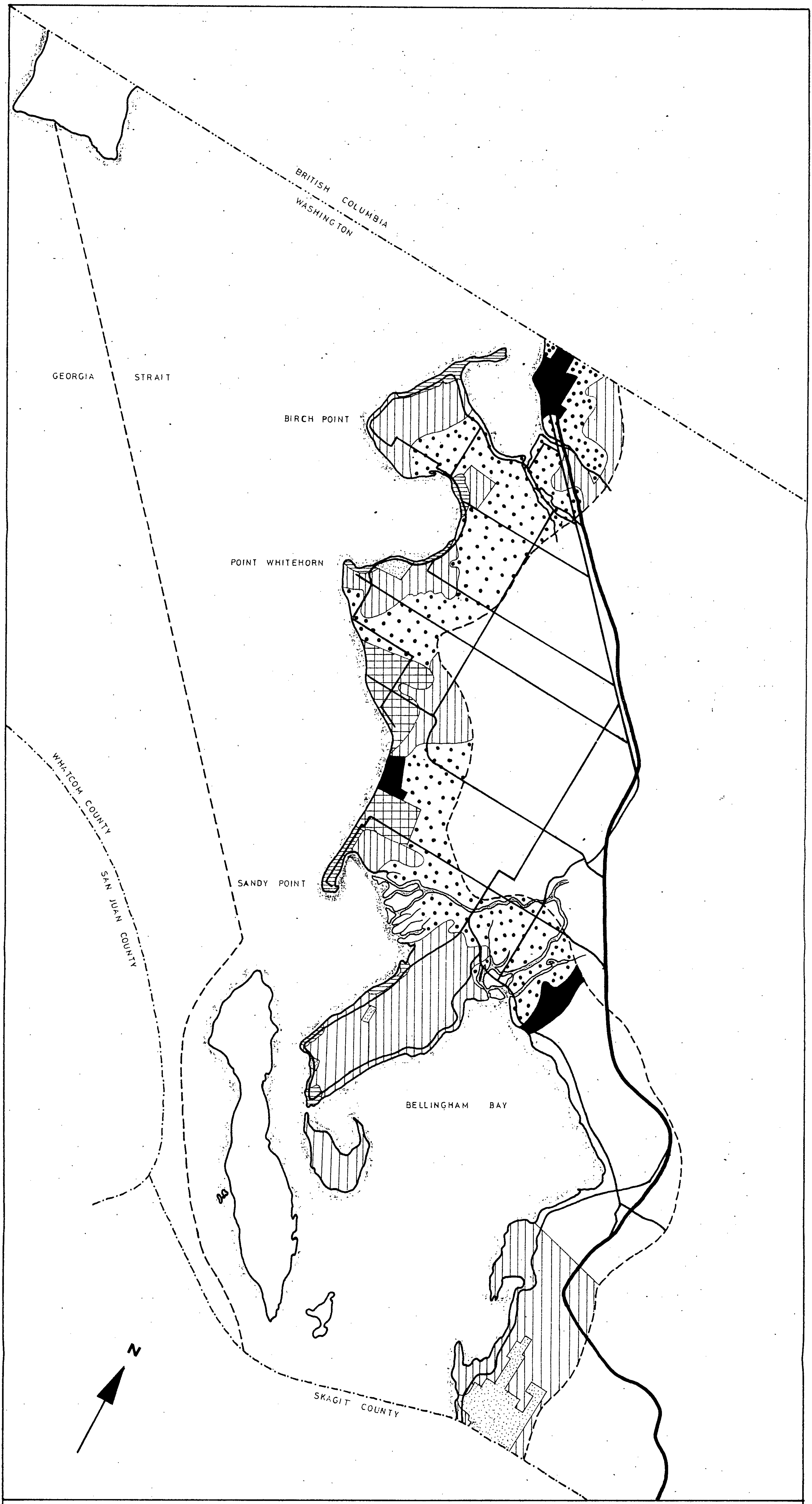
The major considerations in locating waterfront industry in this component or the County are: 1) the possibility of deleterious industrial impacts spilling over to other components and affecting the viability of those components for other uses; and, 2) the desirability of committing this area to an irreversible use when the question of allocating any part of Puget Sound to new waterfront industrial uses is largely unsettled at this time. If the Puget Sound area becomes the trans-shipment center for North Slope oil the impact of industrial and shipping facilities development will certainly require a tremendous coordination effort to prevent a hodge-podge development of industrial development in the locations most convenient to the industries.

Present Land Use

The present land use of Whatcom County's coast has resulted largely from the workings of the private market distorted by the influence of unrelated government policies (See Map 9). The value of considering the existing resource use situation in a resource classification and capability analysis is to observe how the private market allocation of resources realizes the capability of resources to support alternative uses.

There are few areas of coastal land outside the Lummi Indian reservation that are not experiencing residential and industrial development pressures. This is creating a situation of limiting opportunities for alternative uses of the coast in the future, particularly for oyster culture and public recreation.

The greatest contradiction to allocating coastal resources on the basis of their inherent capability is in component five--containing



THE COAST OF WHATCOM COUNTY

LEGEND:
BUILT UP AREAS
INDUSTRIAL
RURAL
PRODUCTIVE WOODLOT
RECREATION PARKS
RECREATION HOMES
OUTSIDE STUDY AREA
STUDY AREA BOUNDARY
INTERSTATE 5
COUNTY ROADS

LAND USE

MAP 9

SCALE: 1/2" = 1 MILE

SOURCE: PACIFIC NORTHWEST RIVER BASIN COMMISSION, 1966

Sandy Point, Lummi Bay and the Lummi River delta. Presently, the Sandy Point and Northwest shore subcomponents in component five are devoted to residential uses (recreational cottages and permanent homes). The Lummi River delta is in agricultural uses and Lummi Bay is being developed for oyster raft culture operations. The East shore subcomponent is in rural-nonfarm and some undeveloped recreational uses. The use conflict in this component exists largely between the residential uses and the emerging oyster culture operations. Additionally, the possibility of developing public recreation facilities in this component has been, for the most part, eliminated by residential developments.

On the basis of the capability analyses it would have been possible prior to the present development situation to accommodate oyster culture, public recreation and residential uses in component five. The component is rated high for both recreation and oyster culture and moderate for residential uses. Within the component, the Sandy Point and eastshore subcomponents have high capability to support recreation uses. The Northwest shore subcomponent has moderate capability to support residential uses and the Lummi River delta and adjacent estuary-shore subcomponents have high capability to support oyster culture operations. Use of each of these subcomponents on the basis of their highest capability would have minimized use conflicts, in particular, allowing public recreational activities to take place in the component. Use of the Northwest shore subcomponent for residential activities would not have prohibited the use of Sandy Point for recreation--its highest rated use. Oyster culture operations would continue to create nuisance conditions to some aspects (e.g. viewing and boating) of recreation and residential activities. On the other hand, it presents an educational opportunity to observe a unique and interesting commercial operation.

In comparing the present resource use situation with the comprehensive plan it appears that the County planning authorities have generously accommodated the existing development interests in the coastal area. Examination of the County plans for intensive and extensive recreation and aquaculture operations would be needed to confirm this. While it is troublesome to note that many opportunities to provide a diversity of uses in the coastal area have been eliminated by a lack of planning and foresight in the past, it is disturbing to note that present plans are unlikely to prevent current uses from co-opting nearly all areas within the coastal zone to the exclusion of other socially beneficial uses.

CONCLUSIONS AND RECOMMENDATIONS

The study has provided indirect evidence that the use of a resource classification and capability analysis can be an aid to reducing damages to the environment and conflicts associated with the use of coastal resources. The identification of alternative patterns of resource use and the cost of those alternatives in terms of biophysical limitations provides the bases for accomplishing these two objectives. Further, it has been demonstrated that the resource base of Whatcom County creates a greater opportunity to achieve multiple uses of coastal resources than was evident in the comprehensive plan. This is a significant accomplishment of the capability analysis, given that coastal resource management must attempt to produce a mixture of goods for public consumption. It indicates that a broader range of interests could be included in the distribution of benefits from the use of coastal resources.

Broader applications of the classification and resource capability analysis have been indicated to the author from this study. In particular, by characterizing the nature of problems associated with alternative patterns of use, management institutions will be better able to evaluate strategies for intervening in the process of converting coastal resources for human use. While alternative strategies of controlling the location of uses is represented by the alternative allocation patterns, other management strategies will also be needed to ensure that the limitations of coastal resources are included in private decisions to engage in using coastal resources. If we accept Craine's (1971) proposition that the use of coastal resources should be viewed as a production function, then, by identifying limiting factors which prevent resources from being brought into desirable uses it will be possible to design ways of regulating individual behavior with respect to these limiting factors. In other words, the capability analysis is a prerequisite to answering the question of the most desirable way to utilize resources to produce public goods that will satisfy society's current preferences and values. In summary, the greatest contribution of this type of analysis to managing coastal resources is in defining the nature of prospective use problems that will affect the use of different types of management strategies and the design of institutions capable of carrying out those strategies.

The physiographic factors used in this study to establish the coastal categories provided a useful but limited foundation for carrying out ecological considerations of resource capability and user impacts. Future development of the classification scheme should concentrate on incorporating, more fully, the ecological concepts and detail discussed in Chapter Two. This would require more accurate and complete information than was available for this study, especially regarding physical oceanographic processes, marine and shore vegetation, beach forming processes, and wildlife distribution and productivity. In an attempt to acquaint one's self with the technical problems involved in coastal resource management, the need to interpret the implications of highly technical and scientific studies for planning became obvious. Hence, an interdisciplinary approach to carrying out the classification and analysis of coastal resources is recommended. The success of such an approach will of course depend on the ability of the generalist planner to coordinate research and special studies of coastal resources with emphasis placed on providing the overall framework for incorporating this information into the coastal zone management decision process--whether it be controlled locally, regionally, or nationally. In addition to information required on the natural resources, it is concluded that successful application of the capability analysis will require greater knowledge regarding the resource requirements of prospective users and the values and preferences of the groups interested in the use or preservation of the coastal zone.

Within the limited resource context which this study was conducted, the practical application and usefulness of the resource classification and analysis was demonstrated. It is, however, important to note that while this kind of analysis can lead to the desired allocation of resources at the local level, it could result in local decision-makers being misled into committing resources to uses for which there is no demand or vice versa. Consequently, it is recommended that an approach integrating the analysis of resource characteristics with user resource requirements be carried out in a broader context inclusive of the total supply and demand of coastal resources. Consideration of the whole to which any specific resource belongs will enable society to optimize the use of resources beyond that which could be accomplished from a local perspective. Finally, it is only within the broader context of resource use that all linkages between management institutions can be established in order to effectively unify the management of coastal resource uses for society's benefit.

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