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GEOMORPHIC SITE SELECTION TOOL FEASIBILITY REPORT

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EXECUTIVE SUMMARY

The Office of Naval Research (ONR) tasked the Naval Facilities Engineering Service Center (NFESC) to assess the feasibility of developing a site planning tool for estimating offshore sediment properties and thickness by correlating these properties to observable land forms and ocean patterns detected using satellite imagery. This type of information is needed to adequately select sites and develop plans for the installation of expeditionary coastal structures, such as the Elevated Causeway, modular, (ELCAS (m)), or Rapidly Deployed Pier (RDP), that use deep foundations for structural support, and for other systems that rely on subsurface soil strength and depth for bearing or holding capacity. Currently, no suitable method exists for defining subsurface soil type and thickness at sites of tactical interest, and little or no historic data of this type is available for most potential operations areas. Part of the reason for this gap in information is that most other aspects of amphibious operations require only a general description of soil type for the top few inches, or top few feet at most, of seafloor sediments. The standard data collection and analysis procedures used in commercial offshore construction practice are not feasible for expeditionary or covert operations. An alternate method for determining subsurface soil type and thickness is required.

A concept for estimating offshore sediment properties and layer thickness, by correlating this information to observable coastal landforms and ocean hydrodynamic patterns, was formulated. Successful development of this concept would enable planners to select installation sites that offer faster and safer construction, allow the identification and accommodation of requirements for additional system components or equipment prior to system deployment, and predict more realistic installation times for expeditionary coastal structures that rely on subsurface soils for foundation support. The primary input to the correlation model would consist of satellite imagery data and any available historic data regarding sediment properties, regional geologic processes, and offshore hydrodynamics. The output of the model would be a general description of the sediment type inferred from the data, an estimate of the sediment layer thickness, identification of any significant anomalies that may be present, and an estimated level of confidence for the results.

The feasibility assessment was broken down into three separate tasks. The first was the assessment of the actual, scientific, feasibility of correlating coastal geomorphology to offshore sediment properties and layer thickness. The second was an evaluation of existing sediment-related data for regions of tactical interest, in part to determine the relative value between historical data and the correlation theory for estimating offshore sediment properties. If the correlation theory cannot improve upon estimates derived from the analysis of available data, then further development of the correlation model would not be warranted. Available sediment, geologic and hydrodynamic information also was investigated to determine the quantity and quality of information available for use within the correlation model itself, to enhance the reliability

of the output with whatever data exists for a specific region of interest. This portion of the feasibility study also included assessing the availability and quality of satellite-imagery data and other satellite-acquired data, needed to support the model. The third aspect of the feasibility study addressed the hardware and software requirements of the proposed site selection system.

The results of this investigation indicate that the use of morphodynamic correlation's and process models to estimate offshore sediment type and thickness is feasible and is expected to produce useful results for selecting sites and planning for the installation of expeditionary coastal structures. While a certainty of only 20 to 50% is predicted for results obtained using the correlation model alone (assuming no historical data were available), the inclusion of any local or regional historical data available will help to improve the reliability of the output. Because the output from this system may be the only or best data available regarding the subsurface sediment profile for a site of tactical interest, the correlation and modeling process will provide useful data to planners even if historical data is not available to augment the correlation. In addition, most of the uncertainty involves the accurate prediction of sediment layer thickness. However, for planning expeditionary facility installations, knowledge of the *actual* thickness is not required - a determination of whether the sediment thickness at the site is *adequate* or not, is all that is needed. Reducing the requirement for the model to estimate sediment thickness to estimating whether or not some threshold layer thickness is present is expected to improve the reliability of the output.

An unclassified literature and data search of the Northern Adriatic Sea region was conducted to assess the availability of historic data relevant to offshore sediments. This region was selected for two reasons. First, it represented an area of recent tactical interest where the quantity of available historical data was unknown. Second, the organization tasked to conduct the search had recently completed a similar search for the same area. Selecting this region allowed them to take advantage of data sources and contacts already made during the previous search, freeing more time for actual identification and assessment of data.

The results of this search indicate that insufficient offshore sediment data is available to adequately estimate sediment properties and layer thickness for many regions of strategic interest. It is recommended that classified data sources be identified and assessed in a follow-on effort to confirm this finding. It also is recommended that follow-on development efforts include a more rigorous comparison of correlation model output to sediment properties estimates derived from available historical data, once the model has been advanced to a stage suitable for this type of evaluation. The data search results also showed that extensive information on general hydrodynamics and regional geology is available in the open literature that would be useful in the development of region-specific models to correlate observable landforms and ocean patterns to offshore sediment properties and thickness. Extensive high quality archival satellite imagery is available to support the model, and site-specific data can be acquired easily in near real-time. Because the DMA is the lead agency for mapping and imagery products for military applications, all imagery will be acquired through DMA.

The results of the support system feasibility assessment show that no development is required to assemble a suitable computer system for the Geomorphic Site Selection

Tool. All hardware and software is commercially available, off-the-shelf. The acquisition cost for a system is estimated to cost $18,500 if operated and maintained by the NFESC or another organization with resident site licenses for suitable image interpretation and analysis software and GIS/database software, or $38,500 if a complete stand-alone system is required.

The proposed concept for the geomorphic site selection system is the integration of multiple numerical models in a computer-based geomorphic correlation algorithm, with a database of satellite imagery data and available geological, oceanographic, and climatic data. The system will predict the characteristics of the upper 150 feet of the stratigraphic sequence of the nearshore sediment column at sites of interest anywhere in the world. The core of the site selection system will be a robust commercial GIS, used to compile a spatial database of sites of interest and to manipulate and describe site information in a form useful to the analytical correlation models that estimate offshore sediment type and thickness.

The results of this feasibility assessment indicate that the development of a Geomorphic Site Selection Tool could provide a valuable asset for estimating offshore sediment properties and layer thickness, required for safe and expedient installation of deep-founded structures and systems used to support sustainment operations. Initial study results indicate that only limited and sporadic historical sediment data may exist for areas of tactical interest, and that this data is likely to be insufficient to adequately support planning and installation operations for expeditionary coastal structures critical to sustainment operations. While the predicted level of confidence associated with correlation model estimates alone is lower than originally anticipated, being only in the range of 20 to 50%, this may still be the only information available for operational planners to use in identifying suitable sites and for determining equipment, personnel and installation time requirements. Extensive data is available to support the development and use of the correlation model, and requirements for the supporting computer system are commercially available off-the-shelf at a relatively low cost. Ongoing efforts to advance knowledge of geologic processes will support development of the correlation model. Similarly, rapid advances in satellite-based sensor technology are providing more and more detailed information available across the globe and in near-real time, and satellites planned for launch within the next one to two years will increase these capabilities even further. It is recommended that development of the Geomorphic Site Selection Tool be advanced to the next level of effort, with reassessments of feasibility included at appropriate intervals.

Based on the results of this feasibility study, it is recommended that follow-on efforts in development of the correlation model, historical database, and satellite-acquired data analysis be pursued. As currently envisioned, and based on the results of this study, the recommended system should be:

- Configured for operation as both a stand-alone site selection tool, and as part of an overall command and control facilities engineering and site planning system.

- Configured for use by a supporting organization, such as the NFESC, with resident technical capability to operate and maintain the system. This will provide for more cost-effective and accurate use of the system, since technical expertise will be utilized to operate the tool, without requiring ongoing specialized training of military personnel in system operation and geotechnical or geologic interpretation. Site-licensed software also would be used in this scenario, reducing system cost by approximately $20,000. While this is the recommended configuration, the development should proceed such that stand-alone use of the system is not precluded and can be easily accommodate with minor, if any, system modifications.

- Configured to allow expansion or augmentation to include other site information of value to operational planners, such as surf zone location, current and wave data, shallow water bathymetry, and location of shoaling areas such as sand bars.

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1.0 BACKGROUND

1.1 Tasking. In FY96, The Office of Naval Research (ONR) tasked the Naval Facilities Engineering Service Center (NFESC) to complete a feasibility study on the development of a site planning tool that can estimate offshore seafloor sediment type and thickness by correlating these properties to observable land forms and ocean patterns detected using satellite imagery. This report documents the results of that feasibility study.

1.2 Technology Need. A great deal of data regarding surface seafloor sediments throughout the coastal regions of the world is readily available, and is used to support amphibious landing operations, mine warfare and mine countermeasures operations, and most aspects of joint logistics over the shore (JLOTS) operations. However, some JLOTS assets, such as the Elevated Causeway (ELCAS) systems, and systems currently in development like the Rapidly Deployed Pier (RDP), include pile-founded structures that depend on the strength properties of soils well below the surface sediments. Other systems like the developmental Landing Ship Quay/Causeway (LSQ/C), and operations that rely on the use of drag embedment or propellant embedded anchors, also must rely on subsurface soil properties (at varying depth) to provide adequate bearing or holding capacity. Data on offshore sediment type and sediment layer thickness is not widely or readily available in most coastal regions of tactical interest to the United States. Sediment properties and thickness significantly impact system installation time, which in turn can critically impact the ability to sustain troops ashore. For example, if the ELCAS system were to be installed in an area with very soft soils (requiring pile splices and additional driving to reach a suitable bearing capacity), the projected installation time of 7 days could easily double. If this information were not known in advance, operations plans would be delayed without advance warning to planners, or worse, sufficient piles and pile splices may not have been deployed with the system, resulting in the inability to install the system at all.

With the new modular ELCAS, ELCAS (m), which is built using a cantilevered construction method, as is the approachway of the RDP system, each successive roadway section must bear the weight of the construction crane lifting the next span or modules, immediately after driving piles for the supporting span. If adequate bearing capacity can not be achieved due to soft, or sensitive or thixotropic soils, (which lose strength when disturbed and gradually regain strength with time), construction operations could effectively be shut down after each section is driven to allow the soil adequate time to regain strength, or worse, the construction loads could exceed actual capacity of the soil resulting in a catastrophic failure of the system, resulting in loss of life and equipment. Another impact of not knowing the subsurface soil profile could be inadequate sediment thickness. While the pile may be driven to a depth where it can bear on bedrock, providing adequate axial capacity, the pile may not have been driven deep enough through the sediment layer to provide adequate lateral stability for the system, which also could result in a catastrophic failure of the system. All of these situations, whether potentially dangerous or imposing serious delays on sustainment operations, could either be avoided or planned for if adequate subsurface sediment information were available during the planing stages of an operation.

Currently, no suitable method exists for defining subsurface soil type and thickness at sites of tactical interest, and little or no historical data is available. The current site survey techniques include bathymetric surveys and a general determination of the surface soil at an installation site, but no means are available for determining deeper soil properties. The primary reason for the lack of historical data and expeditionary methods for determining deep soil properties, is that no other driving need exists for this type of data. Mine warfare and mine countermeasures, as well as landing operations, only require a knowledge of the uppermost few feet or even inches of the seafloor soil type. Commercial offshore construction, which does require this type of information, does not need to rely on covert and/or expedient means of obtaining this data. Detailed geotechnical investigations are typically conducted prior to any offshore construction enterprise. The standard data collection and analysis procedures used in commercial practice are not feasible for expeditionary or covert operations. Another method for determining subsurface soil properties is required. A concept for estimating offshore sediment properties and thickness by correlating this information to coastal landforms (geomorphology) and ocean patterns was formulated. The concept is described in the following section. Successful development of this concept would enable planners to select installation sites that offer faster and safer construction, allow the identification and accommodation of requirements for additional system components or equipment, and enable planners to predict more realistic installation times for expeditionary coastal structures that rely on subsurface soils for foundation support.

1.3 Description of Concept. The hypothesis behind the Geomorphic Site Selection Tool concept is that offshore sediment properties and layer thickness can be estimated by correlating these properties to observable landforms in the adjacent coastal regions and the observable hydrodynamic patterns offshore. A simplified example of this concept is to infer that the seafloor sediment found offshore from an estuary fed by a large river would consist of recently deposited cohesionless soils, with grain size decreasing with distance offshore. Similarly, a coastal area characterized by steep coastal cliffs of river bed conglomerate, with a steep beach front in the nearshore area, may be inferred to have a gravel or cobble seafloor offshore.

It was further hypothesized that the coastal landforms and relevant ocean hydrodynamic patterns (current patterns, predominant wave directions, and relative intensity of wave energy) could be estimated from satellite imagery data, either already available in image archives, or obtained specifically for use with the site selection tool. With a working correlation model and satellite imagery, offshore sediment properties could be estimated without the need for dangerous, unfeasible or expensive in situ data collection, and far enough in advance to provide operational planners with the information needed for adequate site selection, cargo loadout planning, and development of realistic estimates for system installation times.

In addition to using satellite imagery data, the reliability of estimates produced by the site selection tool could be enhanced by incorporating any historical data available for a region or site. Geographic Information System (GIS) technology can be used to correlate and analyze the data and to provide database storage and access. The correlation algorithm would incorporate this data in developing its output of estimated sediment properties and the level of confidence in the estimate. Integration of specialized algorithms, such as the geomorphic correlation model, with GIS systems and their resident databases is standard practice using current technology.

In overview, the primary inputs to the model would consist of satellite-acquired imagery data, and any historical data regarding sediment properties, regional geologic processes, and offshore hydrodynamics, as available. The output of the model would be a general description of the inferred sediment type, an estimate of the sediment layer thickness, identification of any significant anomalies that may be present, and an estimated level of confidence for the results. A hypothetical example of output might be: "Fine grained cohesionless sediment, underlain by bedrock of the Pleistocene epoch, with sediment layer thickness estimated to vary between 80 and 200 feet over the region, with the possibility of lenses of soft organic material interspersed throughout the site. The level of confidence in the estimate of sediment type is 65%, 75% for estimates of sediment layer thickness, and 30% regarding the presence of lenses of organic materials."

Although the site selection tool concept was initially envisioned only as a means for estimating subsurface soil properties, satellite imagery and other satellite sensor data could provide a broad range of useful data to amphibious operations planners, including near-real-time information on coastal currents, winds, and shallow water bathymetry including the location of sandbars, other shoaling areas, and the surf zone.

The site selection tool could be useful not only as a stand-alone tool for amphibious operations planners, but also could be used as an offshore site selection module in an overall command and control facilities engineering and site planning tool.

1.4 Scope of Feasibility Study. To assess the feasibility of developing a site planning tool base on correlating coastal geomorphology to offshore sediment properties and thickness, three different aspects of system development were addressed. Each of these is described further below. Findings for each of these tasks are reported in sections 2.0, 3.0, and 4.0 of this document.

1.4.1 Correlation Feasibility. The primary aspect to be addressed in this study was the scientific feasibility of correlating coastal geomorphology and observable ocean patterns to offshore sediment properties and layer thickness. This included identifying and studying the results of related geologic modeling work, selecting an appropriate correlation theory to form the outline for the correlation model, and estimating a level of confidence in the correlation and resulting estimate for offshore sediment properties and types.

1.4.2 Data Availability. This task included assessing the quantity and quality of historical data available regarding offshore sediments, and the availability, quality and cost of satellite imagery data. The reasons for investigating historical sediment data as part of this feasibility study was twofold. First, it was reasoned that if sufficient historical data was available that could be used to infer offshore sediment properties with a greater degree of confidence than the correlation model could produce, then the correlation model would not be worth pursuing at this time, and efforts to develop a method for expeditiously determining offshore sediment properties should be redirected accordingly. Second, if the correlation model was determined to be worth pursuing, any available historical data would be used to enhance the output of the model, to increase the reliability of the prediction. Having a feel for the type, quantity and quality of this data is needed to help identify the ultimate requirements of the overall system architecture for the site selection tool. The availability, quality and cost of suitable satellite data to support the system and model also was addressed in this task, to determine if sufficient and accessible data was available to support the correlation model.

1.4.3 Support System Requirements. The third aspect of the feasibility assessment was identification of the hardware and software requirements for running the correlation model, including database software, statistics software, automated satellite imagery analysis programming, and integration of the correlation algorithm with the other components of the system

2.0 CORRELATION FEASIBILITY ASSESSMENT

To determine the scientific feasibility of developing a correlation model suitable for estimating subsurface soil properties, NFESC investigated previous and ongoing efforts in geologic modeling. Experts in geologic modeling for coastal areas were consulted regarding the suitability of using models for the purposes of estimating sediment properties and thickness regarding the proposed concept. The results of these investigations are described below, and a proposed system concept based on the findings is presented later in Section 5.0 of this document.

2.1 Background. Geomorphologists currently view the ocean shoreline as part of a much larger system with intimate connections between the beach, estuary, nearshore, shoreface and shelf (Reference 1). The long-term evolution of coastal and nearshore systems is dominated by four external controls: (1) The geological and physiographic setting, (2) relative sea-level changes, (3) the sediment supply to the area, which changes over time, and (4) the energy characteristics of the site (climate and waves), which also change over time (Reference 2). If this process can be modeled for a region, then the resulting nearshore stratigraphy, defined in simplest terms by sediment type and thickness, could be estimated by the model. This is the basic hypothesis behind the development of the Geomorphic Site Selection Tool. Different modeling approaches and their applicability to development of the Geomorphic Site Selection Tool are discussed next.

2.2 Phenomenological-Based Models. Regional sedimentary geological models have been developed by geologists in the petroleum and mineral exploration industries for many coastal areas and validated with corings and geophysical data (References 3 and 4). These models are based on the "correlation of facies" concept (also known as "Walther's Law"), which states that the succession of laterally adjacent sedimentary facies are also present vertically. Models also have been developed that describe the resulting stratigraphy for transgressive and regressive shorelines (i.e., shorelines moving inland or seaward, respectively) of different coastal morphological classes (e.g., deltaic region, lagoon-barrier coast, etc.), (References 5, 6, 7, 8, and 9).

While these types of models could be used to qualitatively predict nearshore sediment trends using landform data collected from satellite imagery, they are insufficient for estimating the thickness of the stratigraphic layers present. However, these models could be used as a first-order screening tool in the overall site selection process to characterize the shoreline and the processes that formed it. They also could potentially be used in conjunction with another correlation scheme (Reference 10) designed to expressly estimate offshore sediment thickness by correlating it to satellite-observable indicators and large scale geological features that are expected to be identifiable in the open literature.

2.3 Short and Medium Term Deterministic-Based Models. Deterministic models model the actual processes that form or modify the nearshore area. Deterministic coastal process models have been developed for short (hours to weeks) and medium (weeks to months) time periods to predict along-shore changes in sediment volume (References 11 and 12) and changes in the beach profile due to storms (References 13 and 14). These models all assume sediment conservation within the system modeled. Sediment at depth, on the inner continental shelf, also is assumed to remain essentially static. These models are useful for coastal engineering applications, but do not help in predicting the sediment characteristics at depths significant to the goals of the geomorphic site selection tool effort. Although they are not directly applicable to the main problem of estimating sediment type and thickness, they may be very useful if integrated into the Geomorphic Site Selection Tool to help predict the effects of storms and seasonal patterns on sediments at particular sites where Navy facilities have been or will be installed. For example, if a great deal of sediment is "lost" from the upper area of the beach front to sandbars further offshore during the stormy season at an area, this could impact the lateral holding capacity of foundation piles. If this were known previous to system installation, for systems to be operated across changing seasons, piles could be installed to a depth adequate to provide sufficient capability even after the temporary sediment loss expected with the storm season.

2.4 Long Term Morphodynamic Models. These models, also called large-scale coastal behavior models, are hybrid phenomenological and deterministic models that address changes in coastal topography, nearshore bathymetry and processes over time on the order of 10 to 100 years (Reference K15). A schematic of a typical long-term coastal system morphodynamic model is shown in Figure 1, where the resulting stratigraphy of an area is ultimately represented as a function of the local topography, the coastal hydrodynamics and weather patterns, sediment gains from terrigenous sources, and sediment losses from offshore and coastal hydrodynamic processes.

In these models, coastal evolution is primarily represented in terms of its two-dimensional behavior in the vertical plane perpendicular to the coastline. The models themselves are computer-based numerical simulations which express the dynamic complexity of the process using a combination of the "Bruun Rule", a diffusion-based equilibrium model, and correlations or "geometric rules" empirically identified for different sediment types. The "Bruun Rule" is a nearshore profile equilibrium hypothesis first proposed by Per Bruun in 1954, which relates the energy environment at a site (waves, currents, etc.) to the beach profile. This rule implies that sites with similar energy environments will have similar beach profiles. Diffusion-based equilibrium models (References 16 and 17), in simple terms, take the Bruun rule a step further, applying it to shorelines over time and taking into account sea level changes. As the sea level changes over time, presenting a "new" face to the nearshore area, the energy at the site acts on the recently exposed or submerged features, eventually modifying them to match the resulting beach profile associated with that energy environment. The third component in the structure of these models, the "geometric rules", are specific to sediment type and are previously derived from process studies and current surface-morphology data (Reference 18). These are essentially correlations based on observable features, and in that regard differ from the process-related equilibrium models that make up the rest of the simulation program. Figure 2 is a pictorial representation of diffusion-based equilibrium profiles calculated by the model for incremental changes in sea level heights, resulting in a simulation of coastal shoreface evolution and sequential stratigraphic formation. This modeling approach was developed by Peter Cowell and his colleagues at the University of Sydney, Coastal Studies Unit during the late 1980's and has subsequently been adapted by others in related modeling efforts (References 4, 19 and 20). This model or similar geologic time-scale morphodynamic model is recommended as the basis for the major process modeling component of the Geomorphic Site Selection Tool. However, to adequately "reconstruct" the evolution of the offshore area, the Geomorphic Site Selection Tool model will need to look at a time-scale of roughly 13,000 years. This corresponds to the end of the last glaciation at the end of the Pleistocene and beginning of the Holocene epochs, and is marked by a global rise in sea level. The impact of this time-scale is discussed more fully in section 2.5 below.

2.5 Sources of Uncertainty. Although the same physical processes that control short-term morphodynamic changes (which can be reliably modeled for short-term applications) may also be considered responsible for long-term changes, other influences come into play and modeling becomes more difficult and less certain when time-scales of decades or longer are involved (Reference 17). These other influences include: (1) Relative sea level changes realized during interglacial periods, or caused by local tectonism or isostatic rebound of continental blocks as the load of the ice sheets diminishes, (2) the influence that evolutionary changes in the topography and bathymetry of an area have on the active processes that in turn influence the topography/bathymetry, and vice versa, (3) changes in sediment supply over time, and (4) the need to average process parameters over long time scales.

The greatest uncertainty in modeling long-term morphodynamic processes are the approximations that must be made regarding the quantity of regional sediment transport over time (References 21, 22 and 23). There is not sufficient observable present-day evidence to accurately estimate how much terrigenous sediment has been delivered to a region over the 13,000 year time period. While current day estimates can be made for sediment loads, this reflects only one point in geologic time, and assuming that that value is representative of the past 13,000 years introduces a major uncertainty in the estimation of the resulting sediment thickness in the region modeled. Regional weather changes, for example, that have left no obvious mark on the landscape, could have resulted in significant changes in the amount of sediment delivered to a nearshore region.

Another source of uncertainty results from the current state-of-the-art in modeling near-shore hydrodynamics, which is not well understood at this time. This uncertainty, applied to a 13,000 year time period, results in significant uncertainties (Reference 17) primarily related to estimating sediment thickness, since hydrodynamics play a major part in deposition and erosion of sediment. Other poorly understood processes that could impact the outcome of the model are the dynamic relationship between estuaries and the coastal shelf, and the role that relic landforms and sediment distribution patterns may have had on earlier phases of nearshore evolution.

Other uncertainties arise from the possibility of local biological activity in the region (Reference 15) that may not leave any observable clues on the land-based topography, but could result in a layer of soft organic material in the nearshore stratigraphy. Similarly, no traces of infrequent catastrophic events such as floods or underwater landslides may be observable in current-day surface features, but could have had profound impacts to the offshore sediment profile. Also, the complexity of the geomorphology at a site introduces additional uncertainty to the modeling process (Reference 15).

2.6 Predicted Certainty in Model Output. Despite the limitations described above, long-term morphodynamic models have produced results that show at least qualitative and in many cases good quantitative agreement with observed continental shelf stratigraphy (Reference 17). An assessment of the feasibility of using this type of model to predict offshore sediment type and thickness for planning the installation of expeditionary coastal structures was made by discussing the goals of the project with numerous experts in the geomorphology and marine geology fields (References 24, 25, 26, 27, 28 and 29). The experts concurred with the choice of the Cowell et al morphodynamic model as the most promising technique available for the effort. None of the experts were aware of any other parallel attempt to predict offshore sediment thickness by using satellite imagery data and long-term morphodynamic modeling techniques. Their overall, general assessment of the practicality of the proposed site selection tool was encouraging, and a certainty index in the range of 20% to 50% was estimated for attaining "essentially correct" results from the tool.

While certainty in the range of 20% to 50% is far from ideal, this may be the only offshore sediment information available to planners. In addition, and quite importantly, a great deal of the uncertainty involves the estimation of the thickness of the sediment offshore. In most instances, the actual thickness of the sediment offshore is not important; just knowing whether or not there is adequate competent sediment is the true goal. For example, if the sediment type offshore is estimated to be a sand, in which pile driving depths of 30 to 50 feet may be required, it is only important to know if the sand layer is expected to be 50 feet thick or not. Whether the actual thickness of the layer is 70 or 300 feet is not important to the operations planning. Alternately, if the site selection tool output indicates that a layer of softer sediments may be underlying stronger surface sediments, this will provide useful data to planners even if the model cannot accurately estimate the actual thickness of the different layers at the site. It is recommended that future work on the development of this tool include a review of the threshold requirements for sediment thickness data for all systems that this tool may be useful to, and that the model be designed to produce the most reliable results possible for the actual data needed for adequately planning installation and operations. This may help to simplify the requirements of the model, resulting in potentially higher reliability of the output.

2.7 Ongoing Work and Advances Relevant to Morphodynamic Modeling. In the course of this feasibility assessment, several related efforts were identified that will provide results and data useful to the development of this tool in the next few years. These efforts are listed below:

- Coastal Ocean Processes study, co-sponsored by the Office of Naval Research and the National Science Foundation, studying coastal hydrodynamics in particular.

- Geological Society of America Working Group on GIS and Integrated Digital Databases

- Coastal Morphodynamics Project (Programme G-8), of the European Community, Marine Science and Technology Programme. The research goal of this study is to improve the ability to understand and correctly model large-scale coastal behavior. Major participants include research institutes and universities in the Netherlands, U.K., Denmark, France, Germany, Spain and Portugal.

- International Association of Geomorphologists Working Group on Frequency and Magnitude in Geomorphology Processes.

- International Association of Geomorphologists Working Group on Geomorphology and Global Tectonics.

- International Association of Geomorphologists Sub Group on Geometric Global Relief Classification.

- International Geological Correlation Program, Project 396, studying the records of the Quaternary period on the continental shelves and their interpretation, correlation and application.

- International Geological Correlation Program, Project 397, addressing late Quaternary coastal records of rapid change and their application to present and future conditions.

- International Geographical Union's Commission on Coastal Studies, with several active and co-sponsored sessions related to coastal studies.

- International Union of Geological Science Sub-commission on Tectonic and Surface Process Interactions, informally coordinating research efforts on tectonic-landform relationships at regional to local scales.

2.8 Conclusions. The use of morphodynamic correlations and process models to estimate offshore sediment type and thickness is feasible and is expected to produce useful results for selecting sites and planning for the installation of expeditionary coastal structures. While a certainty of only 20 to 50% is predicted for results obtained using the correlation model alone (assuming no historical data were available), the inclusion of any local or regional historical data available will help to improve the reliability of the output. Because the output from this model may be the only or best data available regarding the subsurface sediment profile for a site of tactical interest, the correlation and modeling process will provide useful data to planners even if historical data is not available to augment the correlation. In addition, most of the uncertainty involves the accurate prediction of sediment layer thickness. However, *actual* thickness data is not required for facilities installation planning - only a determination of *adequate* depth is needed. Reducing the requirement for the model to estimate sediment thickness to estimating whether or not some threshold layer thickness is present is expected to improve the reliability of the output.

3.0 DATA AVAILABILITY

To assess the value of the correlation model, by comparing it to inferred offshore soil properties deduced from historical data, a literature and data search was conducted to assess the amount and value of data available for a hypothetical site of tactical interest. The reasoning behind this portion of the feasibility assessment was twofold. First, if sufficient historical data was available that could be used to infer offshore sediment properties with a greater degree of confidence than the correlation could estimate, then the correlation model would not be worth pursuing at this time, and efforts to develop a method for expeditiously determining offshore sediment properties should be redirected. Second, historical data would be valuable in enhancing the reliability of the output of the model, and information regarding the type and quality of this data would be needed to eventually develop the overall system architecture for the site selection tool. In addition to assessing historical sediment-related data, this task also included assessing the availability and quality of satellite imagery and other satellite-acquired data useful to the site selection tool.

3.1 Historical Data Search. It was determined that the most expedient and cost-effective way to assess the quantity and quality of data available for areas of potential tactical interest would be to conduct an unclassified literature and data search for a limited but representative coastal region of the world of tactical interest to the United States. MAR, Inc., of Diamond Head, Mississippi was tasked to conduct the search. Because of current activities related to United Nations operations in the Northern Adriatic sea, MAR, Inc. had previously been tasked to conduct a similar literature search for the Northern Adriatic Sea region. It was decided to conduct the sediment-related data and literature search for the same region to take advantage of data sources and contacts already made during the previous search, thereby allowing more time to be spent on actual identification and assessment of data sources. The results of MAR, Inc.'s study are documented in Reference 30.

3.1.1 Scope of Investigation. The coastal regions investigated in the study were bound by latitudes 43 to 46 degrees north, and by longitudes from 13.5 to 17 degrees east, covering approximately 315 miles of the coast. The area is shown in Figure 3, and includes the vast majority of the Croatian coastline, the entire coastline of Slovenia, and the coastal area near Trieste, Italy, included because of its proximity to Slovenia. Information on seafloor sediments, ocean currents and hydrodynamics and other data relative to the development or use of the correlation model (such as regional or local geomorphologic classification or sedimentation processes) was identified. For each source, a brief description of the contents and a preliminary assessment of its value to the effort was documented, along with the title, author and date of the resource.

3.1.2 Findings. Specific findings from this study are described in the following paragraphs.

3.1.2.1 Seafloor Sediment Data. In the study, 60 references were initially identified as containing information in some way related to seafloor sediments in the region. Of these, sixteen were identified as being potentially useful in determining offshore sediment characteristics. All of the references identified as being potentially useful were papers from technical journals, none containing comprehensive information on sediment properties for the region. Of the sixteen, eleven represented data from studies conducted for very localized areas. These areas are indicated in Figure 3. Of the five remaining resources that included more widespread data, two were pollution-related studies, one was related to offshore oil exploration, one to Pleistocene deposits, and the last to underlying carbonate formations. While each of these references may contain some clues useful in estimating offshore sediment properties, the focus of each study was not directed toward the goal of defining offshore sediment properties or layer thickness. It is unlikely that the pollution-related studies addressed deep sediments, and the reference regarding oil exploration activities appeared to be general and is expected to be focused on deeper hydrocarbon-bearing stratigraphic layers. The two papers on Pleistocene and carbonate deposits may contain data on overlying sediment thickness, and potentially sediment type, that could be useful for the purposes of operational planning. In summary, eleven localized, and two general information references were identified for the 500 mile stretch of coastline considered.

Although a search and assessment of classified data was not completed in the course of this preliminary feasibility assessment, it is not anticipated that much information on deep sediment characteristics and layer thickness is available, since this data is not of importance to most facets of a naval amphibious operation. However, in regions of historical strategic interest, geotechnical or geophysical information may have been obtained for other reasons, and could provide valuable information relative to the determination of subsurface soil properties. It is recommended that follow-on efforts include an investigation of classified data sources.

In addition to the MAR, Inc., study, the U.S. National Geophysical Data Center was contacted to determine if their sediment thickness database included any data in the eastern portion of the Adriatic Sea. This database contained no records for this area. Another potential source of data for this region is the oil industry, since the western Adriatic has some limited oil production and the entire basin is identified as having the potential for hydrocarbon recovery (References 31 and 32). However, this type of data is considered proprietary to the companies involved in exploration activities, and is not published in the open literature.

The results of this portion of the search indicate that very limited and sporadic data is available that might be used to conclusively identify sediment type and layer thickness in this 500 kilometer long region. Because the surface sediments in this region of the Adriatic are not homogeneous (Reference 33), historical data from one location may not be representative of conditions in adjacent areas. Additional information regarding sediments and/or sedimentary processes closer to the actual operations area would be required to characterize sediment properties and layer thickness. It is assumed that similar results would be obtained for other areas of strategic interest where the U.S. or U.S. allies have had little or no scientific or commercial reason for offshore exploration. However, it is recommended that these initial findings be confirmed in follow-on efforts by obtaining the specific documents containing potentially valuable information, and conducting a "blind" comparison of estimated sediment properties derived from (1) a thorough analysis and assessment of the available historical data and (2) from the geomorphic correlation model, once developed. This comparison will provide a more definitive and quantitative measure of feasibility which is not possible until the model is further developed.

3.1.2.2 Oceanographic and Geomorphologic Data. The MAR, Inc. study identified over 200 references containing information on currents, hydrodynamics, geomorphology, and geology of the Adriatic Sea basin. While not directly indicative of subsurface soil properties, this information could be useful in the development of a correlation model for this region, and indicates that good sources of supporting data are generally available for model development and use.

3.2 Satellite-Acquired Data. The availability and quality of data obtained through satellite-based sensors was investigated to determine the resources available for supporting the correlation model. Both satellite imagery data and other supporting data were looked at in the course of this assessment. Specific findings are described below.

3.2.1 Satellite Imagery Data. Satellite imagery data will be needed in the correlation model to provide the basic information on the coastal landforms and continental drainage features from which offshore sediment properties and thickness would be deduced. Existing low resolution imagery data is already available from the Defense Mapping Agency, and data covering a wide range of resolution also is available from the National Oceanographic and Atmospheric Administration's (NOAA) satellites, and from various commercial satellites, both domestic and foreign.

As part of Small Business Innovative Research (SBIR) contract tasking related to this effort, Dynamics Technology, Inc. (DTI), completed an assessment of suitable satellite sensors from which to obtain archival or new imagery data to support the Geomorphic Site Selection Tool. The results of this study are documented in Reference 34. In order to adequately characterize the coastal features from which offshore soils properties will be inferred, a spatial resolution no greater than 30 to 100 feet will be required. A larger resolution would prevent smaller but important coastal features from being detected. For example, a 100 foot wide beach may not be detected by a sensor with 200 foot resolution. Sixteen different satellite-based optical or radar sensors were identified that could provide suitable archival or newly obtained data for the site selection system. Resolution of these sensors varies from three to 100 feet, and area size covered by the image (scene size) varied from 3.8 miles square up to 116 miles square. The cost of commercial archival images varies by sensor from $600 to $6,250 per view, depending on resolution and scene size. To maximize the value of data acquired and used for this site selection system, it is recommended that the lower resolution data be used for initial and general assessments, and that high or very high resolution data be used for assessing specific locations points as the site selection process narrows down, and/or be included at statistically valuable spatial intervals to enhance the accuracy of the overall accuracy of the analysis. Commercially-acquired data may not be required, however, depending on the resources available to the Defense Mapping Agency (see section 3.2.3).

The acquisition time to obtain archival images varies from a matter of two to three hours for U.S. satellites that can transmit data across the Internet, up to roughly eight weeks to obtain data from Russian-owned satellites. It is expected that the acquisition time for both archival and near-real-time satellite data will drop to a matter of hours by the end of 1997 for most sensors, as imagery data providers take further advantage of "on-line" ordering and delivery methods.

In addition to commercial sources, high resolution imagery for regions of tactical interest may be available from U.S. allies. For example, Italy and Croatia have unclassified imagery data for the Northern Adriatic Sea areas, and Japan and South Korea may have imagery data available on the coastal regions bordering the Yellow Sea and Sea of Japan.

3.2.2 Other Satellite-Acquired Data. In addition to imagery data, several satellite-based sensors are capable of providing near real-time data on ocean current location, direction and speed, the direction, height and period of surface waves, limited seafloor topography, water temperature, wind direction and speed, and suspended sediment load. Data regarding suspended sediment load would be useful in estimating the sediment input parameter for the process model. Information on current patterns, prevailing weather and sea conditions and seafloor topography will be useful to the correlation algorithm if it can be surmised that they are representative of long term patterns that would have influenced offshore sediment deposition or erosion. This information also would be valuable to planners responsible for site selection and operational planning for the installation of expeditionary coastal structures to support sustainment operations, and for overall amphibious operations planning.

3.2.3 Acquisition of Satellite Data. At the initiation of the feasibility assessment, three options for obtaining satellite imagery data were considered. These were purchasing archival data or obtaining existing data from U.S. Government agencies, directly purchasing newly acquired imagery data from commercial sources, or including the capability for satellite-direct acquisition of data in the system. However, the Defense Mapping Agency (DMA) was identified as the coordinating lead organization for all mapping and imagery products for military applications. Therefore, the two options of direct purchase of commercial images and direct satellite acquisition of images were eliminated from further investigation. DMA products are provided at no cost to supported activities, and during wartime, DMA is expected to provide satellite data in near real-time.

3.3 Conclusions. Based on an unclassified literature and data search of the Northern Adriatic Sea region, it appears that insufficient offshore sediment data is available to adequately estimate sediment properties and layer thickness for many regions of strategic interest. It is recommended that classified data sources be identified and assessed in a follow-on effort to confirm this finding. It also is recommended that follow-on development efforts include a more rigorous comparison of correlation model output to sediment properties estimates derived from available historical data, once the model has been advanced to a stage suitable for this type of evaluation.

The data search results also showed that extensive information on general hydrodynamics and regional geology is available in the open literature that would be useful in the development of region-specific models to correlate observable landforms and ocean patterns to offshore sediment properties and thickness. Extensive high quality archival satellite imagery is available to support the model, and site-specific data can be acquired easily in near real-time. Because the DMA is the lead agency for mapping and imagery products for military applications, all imagery will be acquired through DMA.

4.0 SUPPORT SYSTEM DEVELOPMENT FEASIBILITY

The third task in assessing the feasibility of developing the Geomorphic Site Selection Tool was to identify the system requirements, both hardware and software, needed to support the model and database. The results of this portion of the study indicate that support system requirements are well within the current state of the art, and all hardware and software systems needed are commercially available today. More detailed descriptions and specific recommendations are described below.

4.1 Hardware. It was determined that the hardware requirements for supporting the Geomorphic Site Selection Tool can be met by a stand-alone desk-top (or even lap-top) computer system configured with abundant Random Access Memory (RAM), storage, and high processing speed. The high levels of memory, storage and speed are required for loading and interpreting the satellite imagery data, and for accessing and using the data stored in the GIS database.

The recommended hardware configuration to support the site selection tool is a machine with a processing speed of 200 MHz, minimum of 32 megabytes of RAM, minimum of 4 gigabytes of hard drive storage, an NT operating system, and a Compact Disk Read Only Memory (CD ROM) disk drive. Systems capable of being configured with up to 256 megabytes of RAM are commercially available, and are recommended for this application to handle the size of the images and database used in the model. Similarly, hard drive storage can be enhanced by linking additional external hard drives. All equipment is commercially available as off-the-shelf hardware. The recommended hardware system is estimated to cost $16,000.

4.2 Software. Imagery interpretation and analysis software, GIS/database software, and a statistics package for supporting the correlation algorithm are required components of the Geomorphic Site Selection Tool. All software requirements identified are commercially available off-the-shelf. Satellite imagery interpretation and analysis software is estimated to cost $10,000. An appropriate GIS/database software, such as ARC/INFO (by Environmental Systems Research Institute), is estimated to cost an additional $10,000. Instead of developing a separate statistical analysis program within the correlation model, it is recommended that a commercially available statistics package be utilized instead. Programs designed to interface directly with the database portions of GIS systems are commercially available and cost roughly $2500. Therefore, the total software cost for a complete stand-alone Geomorphic Site Selection Tool system would be about $22,500. However, it is foreseen that this type of system would best be operated and maintained by an organization with the resident technical capability, such as NFESC, which already has site licenses for suitable image interpretation and analysis and GIS system software. Therefore, the total software acquisition cost needed would be reduced to $2,500. The correlation algorithm would be developed separately and interfaced with the system software.

4.3 Conclusions. No development is required to assemble a suitable computer support system for the Geomorphic Site Selection Tool. All hardware and software is commercially available, off-the-shelf. The acquisition cost for a system is estimated to cost $18,500 if operated and maintained by the NFESC or another organization with resident site licenses for suitable image interpretation and analysis software and GIS/database software, or $38,500 if a complete stand-alone system is required. The correlation algorithm would be developed separately and interfaced with the commercial software.

5.0 PROPOSED GEOMORPHIC SITE SELECTION SYSTEM

5.1 Overview. The proposed concept for the geomorphic site selection system is the integration of multiple numerical models in a computer-based geomorphic correlation algorithm, with a database of satellite imagery data and available geological, oceanographic, and climatic data. The system will predict the characteristics of the upper 150 feet of the stratigraphic sequence of the nearshore sediment column at sites of interest anywhere in the world. The core of the site selection system will be a robust commercial GIS, used to compile a spatial database of sites of interest and to manipulate and describe site information in a form useful to the analytical correlation models that estimate offshore sediment type and thickness.

5.2 Correlation Models. A first-order model would be applied to the data first, performing a preliminary screening function to eliminate obviously unsuitable sites, and classifying the morphology at the site. The output from this coarser model would be used to select the most suitable higher resolution model from a suite of second-order models, used to estimate offshore sediment type and thickness. Both of these types of models are described in more detail below.

5.2.1 First-Order Regional Model. The first model applied to the data from a site will be a nearshore regional geomorphic model used to initially identify regions suitable for amphibious system installation and operations. This first-order model will be used as a screening tool to eliminate the more obvious unsuitable areas allowing the more detailed analyses that will follow to focus on smaller, potentially suitable areas. The regional first-order model will look at coastal regions on the order of 40 to 100 miles in length and would have a target resolution on the order of 25 square miles (i.e., 5 miles long by 5 miles wide). This model would be based on direct correlations of observable features to predicted sediment type and thickness and would not incorporate the process-related models that simulate evolution of the nearshore area. This model also would be used classify the region as a particular type, which is used by the system to select the appropriate second-order model, described below. In some instances, the information provided by the coarser second-order model may be adequate for planning purposes. It is recommended that the follow-on development effort include an assessment of the value of the first-order model alone, once developed and tested, compared to the additional gains expected from the continuing development of the second-order higher resolution model.

5.2.2 Second-Order Models. The suite of second-order, higher resolution models, would be state-of-the-art long-term geomorphic diffusion-based equilibrium models used to essentially reconstruct the evolution of the stratigraphy at the site over the past 13,000 years, providing estimates for sediment type and layer thickness in the nearshore area. A second-order model would be optimized for each classification represented in the output of the first-order model described above. It is envisioned that approximately twenty second-order models would be needed to adequately represent the different coastal type-areas that may be considered as potential installation sites. The second-order models would address coastal areas approximately 5 miles in length, with a target resolution of 0.25 square miles (e.g., an area 0.5 miles long and 0.5 miles wide) in the horizontal plane, and about 30 feet for vertical stratigraphic resolution. These models would require the use of satellite imagery data with spatial resolution no greater than 30 feet.

5.3 Conceptual Correlation Process. The conceptual process for nearshore site predictive modeling for the geomorphic site selection tool begins with a compilation of appropriate remote sensing data, any available historical geological data and physical properties data for the selected site, drawn from the GIS database of composite maps. The site data is analyzed and parameterized by the GIS system, resulting in a group of variables to be used as input to the two levels of morphodynamic modeling. The parameterization tasks include the following:

- Definition of the site's present inner continental shelf profile shape.
- Definition of the adjacent coastal landform topography and upland sediment source areas.
- Determination of whether the shoreline is destructional, due to active erosion processes, or constructional, due to active deposition.
- Definition of the morphological class of the region being evaluated.
- Estimation of projected nearshore bathymetry inferred from coastal topography and/or historical bathymetric data.
- Determination of sediment sources, fluvial bed-load mechanics, and an estimation of the sediment dynamics and flux at the site.
- Determination of local system energy regime characteristics, such as seasonal climatic and oceanographic characteristics

- Compilation of a list of correlatable parameters to be used in the first-order regional model

After the parameterization operations are completed, the results are analyzed by the first-order correlation algorithm to screen out obviously unsuitable areas and to further define the area in question for selecting the most appropriate high resolution model for the site classification. The second-order model is then activated to predict the vertical stratigraphy and sediment characteristics for the site being evaluated. Output will include an estimation of the sediment type, an estimation of sediment layer thickness, an indication of any irregular stratigraphic features that might be expected at the site (e.g., pockets of gravel, lenses of soft organic materials), and an index of the certainty associated with the set of predictions resulting from that particular application of the system.

5.4 User Requirements. While many of the parameterization tasks accomplished in the process described above can be automated in the system, it is expected that some level of geologic interpretation expertise would be required in most cases for optimum application of the second-order modeling process. In general, the higher the level of complexity, the greater the need for involvement and interpretation of the data and results by a user trained in geology or a related science. For this reason, it is recommended that the system be operated by an organization with the resident technical expertise to provide that level of support. Other recommended capabilities for the supporting organization are the ability to directly obtain the required imagery data from DMA, familiarity with satellite interpretation, and experience and expertise with GIS systems. NFESC can provide all of the capabilities needed to support application of the system.

6.0 SUMMARY AND RECOMMENDATIONS

6.1 Feasibility Study Summary. The results of this assessment indicate that the development of a Geomorphic Site Selection Tool is feasible and could provide a valuable asset for estimating offshore sediment properties and layer thickness, required for safe and expedient installation of deep-founded structures and systems used to support sustainment operations. Initial study results indicate that only limited and sporadic historical sediment data may exist for areas of tactical interest, and that this data is likely to be insufficient to adequately support planning and installation operations for expeditionary coastal structures critical to sustainment operations. While the predicted level of confidence associated with correlation model estimates when no historical data is available is lower than originally anticipated, being only in the range of 20% to 50%, this estimated data may still be the only information available for operational planners to use in identifying suitable sites and for determining equipment, personnel and installation time requirements. Extensive data is available to support the development and use of the correlation model, and requirements for the supporting computer system are commercially available off-the-shelf at a relatively low cost. Ongoing efforts to advance knowledge of geologic processes will support development of the correlation model.

Similarly, rapid advances in satellite-based sensor technology are providing more and more detailed information available across the globe and in near-real time, and satellites planned for launch within the next one to two years will increase these capabilities even further. It is recommended that development of the Geomorphic Site Selection Tool be advanced to the next level of effort, with reassessments of feasibility included at appropriate intervals.

6.2 Recommendations for Follow-on Development. Based on the results of this feasibility study, it is recommended that follow-on efforts in development of the correlation model, historical database, and satellite-acquired data analysis be pursued. As currently envisioned, and based on the results of this study, the recommended system should be:

- Configured for operation as both a stand-alone site selection tool, and as part of an overall command and control facilities engineering and site planning system.

- Configured for use by a supporting organization, such as the NFESC, with resident technical capability to operate and maintain the system. This will provide for more cost-effective and accurate use of the system, since technical expertise will be utilized to operate the tool, without requiring ongoing specialized training of military personnel in system operation and geotechnical or geologic interpretation. Site-licensed software also would be used in this scenario, reducing system cost by approximately $20,000. While this is the recommended configuration, the development should proceed such that stand-alone use of the system is not precluded and can be easily accommodated with minor, if any, system modifications.

- Configured to allow expansion or augmentation to include other site information of value to operational planners, such as surf zone location, current and wave data, shallow water bathymetry, and location of shoaling areas such as sand bars.

Specific recommendations for follow-on development work are described in the following sections of this report.

6.2.1 Support System Set-Up. To support development and testing of the correlation model, the recommended hardware and software configuration listed in sections 4.1 and 4.2 will be acquired and set up for the Geomorphic Site Selection Tool. Because this will be developed and used at NFESC, existing site licenses for imagery interpretation and analysis software and GIS/database software will be used, precluding the need to purchase new software. Once configured for use, supporting data for the regions selected for initial model development will be loaded into the database.

6.2.2 Database Development. Historical data for three regions selected for initial correlation model development will be collected and loaded into the database to support further model development and testing. Two well-known sites with ample supporting data will used, plus an additional foreign site for which little historical data is available. Data to be obtained and stored in the database includes archival imagery data that will be used to set up the baseline geographic information for each area, regional information needed to support the model, such as coastal hydrodynamics and recent geological processes that would impact deposition or erosion of offshore sediments, and any available historical data on sediment properties and layer thickness for the location. In addition to loading the appropriate data, the system must be configured to translate this data into a format usable to the correlation models. A search of classified data sources also should be conducted early in the follow-on development work to reconfirm that adequate historical data does not exist that might preclude the need for the Geomorphic Site Selection Tool.

6.2.3 Satellite Data Interpretation and Analysis. Using expertise resident at the nearby University of California at Santa Barbara's (UCSB) Remote Sensing Research Center (RSRC), and results from related SBIR studies, specific sensors, data types, and analysis techniques will be identified that best meet the needs of the correlation model. Included first in this task is identification of the specific data required to characterize nearshore areas sufficiently for use in the model. The next step will be defining and configuring automated techniques to derive this data in a format usable by the model. This will require integrating the capabilities of the commercially available imagery analysis and interpretation software with any specialized interpretation routines that needed to satisfy the input requirements of the correlation model.

6.2.4 Correlation Algorithm Development. This includes development of both the first-order and second-order models.

6.2.4.1 First-Order Correlation Model. Existing regional-scale geological facies models will be obtained and used for this portion of the program. Correlatable parameters that are common to all of the regional models will be identified and analyzed, and each variable will be weighted for each of the regional facies models. Based on these weighted classification variables, a nearshore regional geomorphic classification algorithm will be developed to serve as a first-order screening tool. A determination of suitable type-areas for different expeditionary systems will be developed for use in this part of the system. Once developed, this portion of the algorithm will be tested against data from the two well-known sites and for the poorly-characterized foreign site, and feasibility reassessed.

6.2.4.2 Second-Order Correlation Model. If the results of the first-order model development effort are promising, existing state-of-the-art long-term geomorphic diffusion-based equilibrium models will be optimized for use in the Geomorphic Site Selection Tool development. This work will be accomplished via contract with experts at either the University of Sydney's Coastal Studies Unit, or the Geography Department at the University of California at Santa Barbara. The model will be tested using input parameters determined from the imagery-derived database for the two well-known study sites, and comparing the output to historical core data from the site.

If evaluation of the second-order model output shows favorable results, testing at more complex sites should be considered as well as determining the feasibility of adding third-order short and medium-term deterministic models to the system to predict impacts of seasonal changes or storm events on the coastal profile. These advanced development considerations are not included in the development cost estimate discussed later in Section 6.2.6 of this report.

6.3 Testing and Demonstration. Three separate tests or demonstrations of the concept are recommended in the course of system development. Each test is included to not only provide useful information to the development effort, but also to ensure that continued development investments are based on the sound feasibility and value of the concept. Each test or demonstration recommended is described separately below.

6.3.1 Evaluation of First-Order Model. The first-order model will be evaluated at all three study sites to assess its performance in classifying coastal regions and in screening obviously unsuitable sites from further consideration. This test will serve to both assess the feasibility of continuing overall system development, as well as identifying the value of the first-order screening tool as a stand-alone tool for applications where lower resolution may be all that is required.

6.3.2 Comparison of Second-Order Model Output to Estimates Based on Historical Data Alone. Once the model development work has advanced to a level where sediment properties and layer thickness can be estimated, model results will be compared to the results of an evaluation of the historical sediment data available for the poorly-characterized foreign site. This will not require that the correlation algorithms be computerized, or that imagery analysis and interpretation be fully automated. It is recommended that this comparison be conducted well before that stage is reached, if possible, to confirm the value of continued concept development. The two prediction efforts will be completed separately to prevent bias of results, and compatible methods for estimating the level of confidence for the results of each prediction will be used so that a viable comparison can be made. The completion of this test will also serve as a decision point for continuing system development.

6.3.3 Test of Overall Model for Two Well-Documented Sites. This will compare output from the correlation model for the two geotechnically well-known nearshore sites located in the continental U.S. to actual historical geotechnical data available for the areas. The model will be run without the benefit of the historical data, and the output compared to the known conditions at the site. The results of this test will provide a more definitive indication of the accuracy of the model. As with the other tests recommended above, the completion of this comparison will mark a decision point for continued system development.

6.3.4 Demonstration of Site Selection Tool During Regional Exercise. As a final proof-of-concept test for system development, the Geomorphic Site Selection Tool will be demonstrated during a regional exercise such as RIMPAC, which is scheduled to take place every two years. This demonstration will not only serve to demonstrate the concept in a more realistic environment and provide an assessment of the value of the system's output to actual end-users, but also will be used to identify any configuration or operational modifications that should be made to the system during final engineering development.

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30. MAR, Inc., (June, 1996), "Investigations into Data Availability and Related Efforts for Geomorphic Site Selection Tool", under contract to the Naval Facilities Engineering Service Center.

31. *The Times Atlas and Encyclopaedia of the Sea*, Edited by Alastair Couper. Harper and Row, 1989, New York, New York.

32. *The Rand-McNally Atlas of the Oceans.* Rand McNally, 1977, Chicago, Illinois.

33. *Oceanographic Atlas of the North Atlantic Ocean, Volume 5: Marine Geology.* Publication No. 700, U.S. Naval Oceanographic Office, 1965, Washington, D.C.

34. Dynamics Technology, Inc., (August 1996), "Feasibility Study for the Geomorphic Site Selection Software Tool, Results of Task 1: Assessment of Suitability of Satellite-Based Sensors". Prepared for the Naval Facilities Engineering Service Center under Contract N47408-96-C-7225.

Figure 1: Typical Coastal System Morphodynamic Model

(after Cowell & Thom, 1994, [Reference 18])

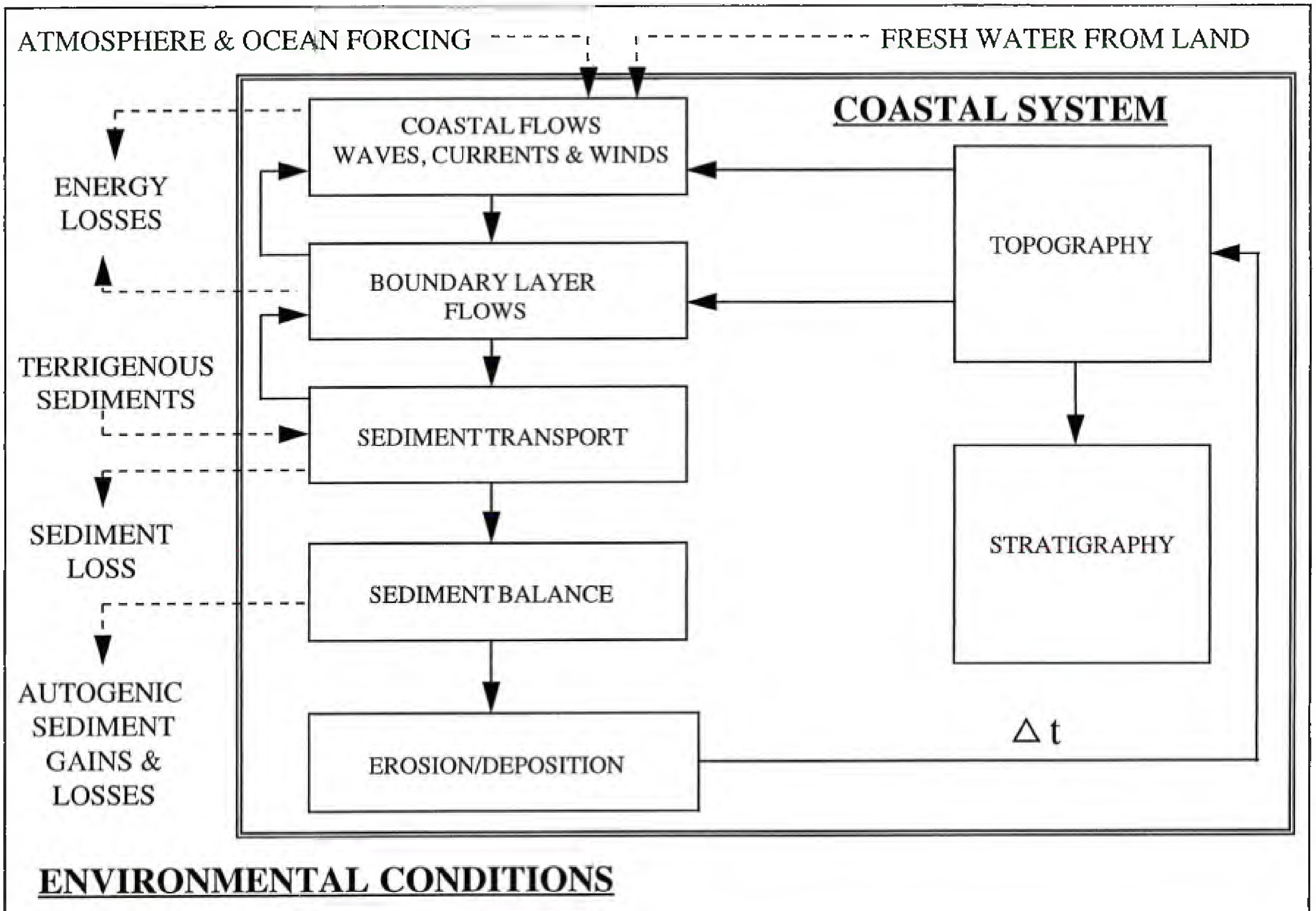

Figure 2: Large Scale Coastal Behavior Computer Simulation

(After Cowell et al, 1995 [Reference 15])

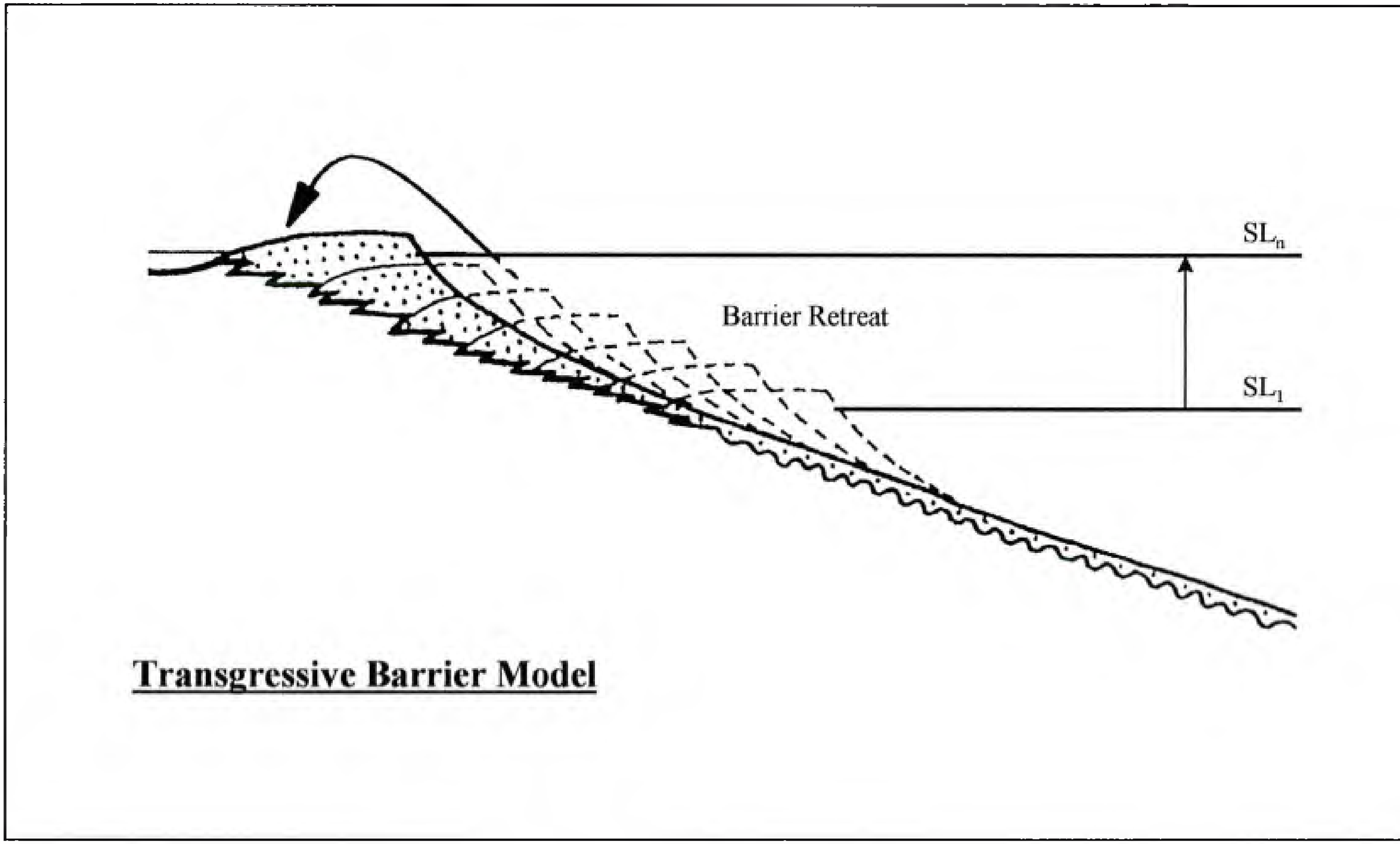

Figure 3: Area of the Northern Adriatic Sea Selected for Historical Data Search

(After Reference 30)