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	Engineering and Design HYDRAULIC DESIGN FOR COASTAL SHORE PROTECTION PROJECTS	
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CECW-EH

DEPARTMENT OF THE ARMY
U.S. Army Corps of Engineers
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ER 1110-2-1407

Regulation
No. 1110-2-1407

30 November 1997

Engineering and Design
HYDRAULIC DESIGN FOR COASTAL SHORE PROTECTION PROJECTS

1. Purpose

This regulation defines the hydraulic design engineer's responsibilities for initial design of coastal shore protection projects, for engineering inspection and evaluation during the construction and subsequent operation of such projects, and for the nourishment of coastal storm damage reduction beach fill projects.

2. Applicability

This regulation applies to all USACE Commands having Civil Works responsibility.

3. References

References are listed in Appendix A.

4. Distribution Statement

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5. Background

a. Shore protection projects are projects which reduce the damaging effects of coastal flooding, wave impacts, or erosion due to tides, surges, waves, or shore material deficits resulting from natural or human causes. Typical project features are listed in Appendix B. These projects are constructed in support of U.S. Army Corps of Engineers (USACE) coastal navigation and coastal storm damage reduction mission areas.

b. An Institute for Water Resources study (U.S. Army Corps of Engineers Institute for Water Resources 1994) found that since 1930, there have been 137 shore protection projects specifically authorized and constructed with some degree of Federal participation. Prior to 1950, only five projects were authorized. During the 44 years since 1950, a high of 18 project authorizations occurred in 1954. Ten or more projects were also authorized in 1958(13), 1962(14), 1965(10), and 1986(17). The study noted that fewer projects are built (82) than authorized, and the number of projects that are constructed lag authorizations. The number of beach restoration projects completed increased during the 1960's and peaked in the 1970's. Due to a lack of water resource authorizations in the 1970's, construction declined in the 1980's. In response to the Water Resources Development Act of 1986, there were as many projects completed in the 1990-93 period as there were during the entire decade of the 80's.

c. During this relatively brief period of experience in developing shore protection projects, the art has moved from "try it and see if it works," to "rules of thumb," to the use of modern technology (satellite positioning, computer-aided design and modeling, laser surveying and mapping, etc.).

6. Policy

a. Responsibility. At each District, the Chief of the Engineering Division is responsible for ensuring that shore protection projects are adequately designed and that appropriate quality assurance and engineering support are provided for design, construction, operation, inspection, periodic nourishment, rehabilitation, and maintenance of each new and existing shore protection project.

b. Qualifications. The engineering division's project design engineer shall have an academic background or subsequent continuing education that includes wave

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This ER supersedes ER 1110-2-1407, dated 30 November 1990.

mechanics, storm surge analysis, sediment budget estimates, coastal structure designs, profile change modeling, shoreline change modeling, inlet stabilization, and coastal geomorphology. The engineer shall also have at least 5 years experience in the design, inspection, and evaluation of shore protection projects. The project design engineer will be the person directly responsible for the design or evaluation, or responsible for technical review if design or evaluation is performed by a consulting engineer.

c. Required actions.

(1) Design phase. The engineer shall ensure that the shore protection project is designed per USACE guidance, that it is safe, and that it will be able to reliably perform its intended function. The project must be properly analyzed and detailed, and specifications must be technically adequate and consistent with the design intent. Required design phase actions are more fully described in paragraph 7.

(2) Construction phase. It is important that the engineer communicate with those responsible for construction to discuss technical requirements for material sources, plan layout and staging or progression of construction, and to review specified contractor submittals. Required construction phase actions are more fully described in paragraph 8.

(3) Operation phase. For USACE operated shore protection projects, inspections will be every 5 years or more frequently when needed. The engineer will coordinate with operation personnel to provide needed inspections, evaluations, and technical support for maintenance and repairs. Required operation actions are more fully described in paragraph 9. Where project operation is the responsibility of the local sponsor, the Operations and Maintenance Manual will identify the sponsor's responsibilities and coordination mechanisms.

(4) Periodic nourishment. When periodic nourishment is part of the shore protection project, the project design engineer is responsible for the adequacy of the periodic condition and poststorm beach surveys and their evaluation as to the project need for nourishment (adding sand to the project) or maintenance (moving sand within the project and other maintenance activities).

(5) Purpose attainment. Following significant storm events, the engineer may, as part of the above analysis, estimate the damaging conditions that would have existed without the project. These conditions will reflect the shoreline erosion that would have occurred without the project during the time elapsed since project construction. The extent of flooding and damaging wave penetration that would have occurred without the project should be compared to the existing with-project conditions. This information should be provided to the non-Federal project sponsor so that the damages prevented by the project can be estimated.

7. Design Phase

a. Design rationale. The hydraulic design of a coastal shore protection project must result in a safe, efficient, reliable, and cost-effective project with appropriate considerations for environmental and social aspects. A satisfactory design must cover portions and/or extensions of the following elements to the degree appropriate as the design progresses through the various stages of project development.

(1) Safety - potential hazards to humans and property, creation of a false sense of security, storm warnings, evacuations, and consequences of storm intensities exceeding the design parameters.

(2) Efficiency - structure cross section (including beach fill), materials, and plan configuration (including tie-backs, terminal structures, foundation preparation, and beach fill transitions) selected to optimize the probability of achieving the degree of protection based on estimated life-cycle costs and benefits.

(3) Reliability - probability or certainty in the ability to achieve project purposes throughout the project evaluation period and proper functioning of features such as beach fills, breakwaters, seawalls, and groins. Periodic nourishment cost should be expressed as the likely minimum, maximum, and expected annual cost at an acceptable level of confidence.

(4) Cost effectiveness - value engineering review; expected initial cost plus life-cycle operational, maintenance, repair, and replacement cost optimized on an annual cost basis; the range between minimum and maximum values and the percent of confidence in the costs provided.

(5) Environmental aspects - environmental enhancement opportunities, minimize adverse ecological impacts, evaluate and, if appropriate, provide for hazardous and toxic waste presence, provide initial beautification efforts, and mitigate significant adverse impacts.

(6) Social aspects - reduce risk to life and property, enhance recreational opportunities, maintain community cohesion, preserve historic sites, and improve aesthetics.

b. Design process.

(1) The initial step in the hydraulic design process is to develop a study plan in support of the project design effort. This plan will indicate the time, manpower, cost, and scheduled completion of the various design studies to be performed as the design progresses through the stages of project development. Careful consideration of the type and complexity of the hydraulic design studies, data acquisition (Appendix C), and phasing of this effort with other ongoing project development efforts is necessary. Coordination with other disciplines to ensure the timely availability, compatible format, and coverage adequacy of the hydraulic design technical information inputs and outputs from the studies is essential. Physical and mathematical model studies (ER 1110-2-1403) should be provided for early in the study plan, when they are needed. The hydraulic design study plan should be flexible and able to adjust to changes in the project development as long as all required studies are accomplished. A thorough analysis using the best technology reasonably available is required for preconstruction design, particularly with respect to projects involving public safety.

(2) Shore protection plan comparisons should be made on the basis of elements listed in paragraph 7.*a*. Alternative designs are to be studied and presented in sufficient detail to provide a valid basis for plan comparison and plan selection. The life-cycle period of evaluation must be the same for each alternative plan. Appropriate consideration must be given to amortization of replacements, major structural rehabs, nourishments, etc. Transitions at the ends of the protective beach plan or terminal structures will be designed to minimize average annual periodic nourishment costs (including the annualized costs of the structures when used). Borrow material sources adequate to supply material for the initial construction, advanced nourishment, and periodic nourishment for the period of evaluation (usually 50 years) should be identified and used in developing project costs. Over-fill ratios and dredging loss factors should be applied to the entire quantity of project fill. When urban flood damage reduction benefits are claimed, the flood with two-tenths of a 1-percent chance of annual exceedance, with and without the plan, must be described.

(3) The hydraulic design presentation will discuss and illustrate historic and existing wind, wave, water level, and sediment transport conditions affecting the study site. This information will be analyzed to identify problem causes. Studies such as, but not limited to, wave climate and storm surge elevations (EM 1110-2-1412, EM 1110-2-1414), shoreline and depth contour changes (EM 1110-2-1502), inlet effects, and sediment budgets (EM 1110-2-1618) are typical.

(4) The hydraulic design analysis will provide the estimate of most likely future conditions which can be anticipated in the absence of a Federal Project. The amount of shoreline retreat, the depth and extent of flooding, the extent of damaging wave action, and the frequency of damaging events requiring emergency action or disrupting commerce will be documented over the project evaluation period. Significant environmental degradation or enhancement predicted as a consequence of future conditions should also be evaluated. From this, the economic and environmental value of mitigating such events, either partially or totally by the alternative plans can be determined by an economic and environmental analysis. Environmental impacts, both beneficial and adverse, must be identified and mitigation measures for significant adverse impacts developed (EM 1110-2-1204).

(5) The hydraulic design analysis and presentation will include all alternatives considered and demonstrate that the most appropriate protective measures have been selected. The basis for selecting the project design conditions must be provided. Appendix B lists some of the more common alternative measures. All elements of the shore protection project must perform satisfactorily (no damage exceeding ordinary maintenance) up through the design conditions or it must be shown that an appropriate allowance has been made for deterioration or periodic replacement. A large storm event may cause either little or substantial damage to the protective structure depending on its design; therefore, alternative designs must take into account differences in costs of repairs, periodic replacements, and rehabilitations. Protective measures provide different degrees of damage reduction for the same storm events; therefore, these variations must be reflected in the benefits to obtain a true evaluation of alternative designs. At the feasibility stage a full range of alternatives will be considered, including those which make explicit trade-offs between initial investment cost and maintenance, repair, replacement, and major rehabilitation costs.

(6) The hydraulic design presentation portion of all reports forwarded for approval or information will contain sufficient detail to allow an independent review and assessment as to the soundness of the report conclusions and recommendations. The accuracy of hydraulic design

studies (computations, physical and mathematical modeling, etc.) is dependent on the accuracy of input data and the degree to which the analytical procedure is representative of the hydraulic phenomena. The effects of uncertainty in significant design elements should be demonstrated through an appropriate risk analysis (ER 1105-2-100).

(7) The hydraulic design presentation will cover the results of physical hydraulic model studies used to predict project or structure impacts or behavior, etc. It will also include appropriate information on mathematical models similarly used to predict hydraulic phenomena at the site and resulting shoreline and profile changes, etc. Coverage of the verification data for model studies is essential. A copy of the model study report and, when used, mathematical model program listing, input data and output data will be retained in the District project files as part of the design documentation.

c. Plans and specifications. Plans and specifications (P&S) shall be prepared in accordance with ER 1110-2-1200. The P&S are the final products of all the preceding design and review efforts. They define the legal requirements for the contractor and are the basis for construction bids. The engineer shall ensure that the P&S include all necessary requirements governing construction of the shore protection project. Guide specifications may be used as a tool for preparing project specifications; however, the engineer must ensure that guide specifications are properly adapted to reflect specific project requirements.

d. Technical review. Independent technical review is a key element in design quality control plans. The engineer responsible for the shore protection project should ensure that an adequate review is performed, and that issues raised in the review are fully resolved.

e. Certification. The Chief of Engineering is required to certify the adequacy of certain design processes and products. For each shore protection project, the engineer must provide appropriate input for such certifications.

f. Repairs, modifications, and nourishments. Designs of repairs, modifications, and periodic nourishments for existing shore protection projects shall meet the requirements for new designs, as discussed above.

g. Operation and maintenance manual. As a continuation of the design process, the Engineering Division prepares a project Operation and Maintenance (O&M) Manual, though this may be done during the construction phase (ER 1110-2-401).

8. Construction Phase

a. General. The engineer should provide engineering support for the shore protection project during construction. Areas of involvement may include bid protest, shop drawings and other construction submittal reviews, contract modifications, value engineering (VE) proposals, construction site visits, and consultation with office and field construction personnel on interpreting the P&S.

b. Engineering considerations and instructions for field personnel. As required by ER 1110-2-1150, the Engineering Division should transmit a report to the Construction Division, and to the area/resident engineer, to aid them in supervision and inspection of the construction contract. Participation by the designers in preconstruction conferences and partnering meeting between construction and contractor personnel is beneficial for identifying and discussing contract requirements and establishing a partnering relationship. As a minimum, the coverage in the report and meeting should include any special materials, construction procedures, and quality control testing and quality assurance plus any special construction sequences that must be followed; critical tolerances that must be met; or contractor-performed extensions of design that must be reviewed by design engineers. Submittals to be reviewed by the engineer should be so indicated on the Submittal Register. Also, as required by ER 1110-2-112, the schedule of field visits by design personnel should be included.

c. Design during construction. Typically, during the construction phase, the only design analyses performed by the engineer are those required to resolve field problems. All design actions during construction are subject to the same technical review requirements as for new designs. The engineer should be involved in evaluating contract modifications that impact the design to ensure that both design criteria and construction concerns are satisfied.

d. Review and submittals. The engineer must coordinate with the Construction Division to be designated as the reviewer of the appropriate submittals on the Submittal Register. Any extension-of-design actions by the contractor should be reviewed by the appropriate engineer.

e. Contractor value engineering submissions. VE proposals that involve changes to the design portion of the contract P&S shall be reviewed by the appropriate engineer. Review shall ensure that proposed changes result in an equally comparable project by complying with the original design criteria established for the project.

f. Final inspection of completed construction. The engineer shall be a member of the engineering team that participates with construction personnel performing a final inspection before final acceptance of the project from the contractor.

g. Permanent records. Records that document the materials and quality of construction are important for future evaluation. Engineering and Construction Divisions shall assemble an original set of items including design documents, as-built drawings and specifications, any required certificates, and details of contractor designed items, and shall retain them as permanent records. A copy of the records will be forwarded to the appropriate Project Field Office.

9. Operation Phase

a. General. It is important that engineering and operations personnel maintain a close working relationship concerning any significant problems which occur during the life of the shore protection project. The engineer must coordinate with the local sponsor in developing the scope and schedule for local monitoring activities and joint inspections (EM 1110-2-3301 and EM 1110-2-1004). For beach fill and periodic nourishment projects, as part of the periodic nourishment effort, the engineer should coordinate the timing of annual (or, if needed, more frequent) condition surveys and the conditions that will trigger beach profile surveys in conjunction with storm damage determinations and project condition assessment. These items should be spelled out in the O&M Manual (ER 1110-2-2902 and EM 1110-2-3301).

b. Coverage in engineering appendix. The hydraulic design section of the Engineering Appendix will include an operation and maintenance presentation that covers the hydraulic design aspects related to the O&M of project features. This presentation will form the basis for the detailed information to be included in the report O&M section and the O&M Manual to be furnished to local interests. Costs of carrying on the hydraulic design O&M activities (annual costs basis) will be in the overall project O&M costs. Coverage, if not covered elsewhere, will include, but not be limited to, the following:

(1) The provisions of ER 1110-2-2902, Prescribed Procedures for the Maintenance and Operation of Shore Protection Works.

(2) The provisions of Federal Code 208.10, Title 33 as approved by the Secretary of the Army (ER 1150-2-301, paragraphs 10 and 11) when flood control is a project purpose.

(3) The project condition survey plan when periodic nourishment is construed as "construction" (PL 727 (60 STAT, 1056) 79 Congress) and permanent features in support thereof, such as bench marks, survey markers, gauges, and other instruments, are considered part of the continuing construction of the project. These items are cost-shared as construction costs.

(4) Local surveillance or monitoring requirements (types, frequency, and costs) and features in support thereof, such as fixed camera stands, markers for beach stations at which to place the beach berm width or make other observations, are part of the beach maintenance and therefore a non-Federal responsibility .

(5) When the project includes a protective beach fill and/or periodic nourishment as a project construction feature, a set of minimum profile conditions must be specified below which the protective integrity and/or the restored beach alignment is in jeopardy. Comparative analysis of these minimum permissible conditions with the condition survey data will indicate where and when beach nourishment is needed. These costs are considered part of the project construction costs.

(6) Real estate needs in support of the project should be identified, such as work areas, access, borrow areas, disposal areas, pond areas, etc.

c. Modifications, major repairs or rehabilitations, and beach nourishments. All nourishments and significant modifications, repairs or rehabilitations shall be designed or reviewed by the engineer and shall conform to the requirements of paragraph 7. Execution of these efforts shall be subject to the applicable requirements of paragraph 8, whether the effort is performed by contractor or project personnel. Adequacy of the efforts will be verified by the engineer and included in the permanent project files.

d. Types of inspections.

(1) Operations inspections. Local project personnel frequently inspect all project features. The engineer should coordinate with them whenever these inspections reveal any significant distress. Information from these inspections is useful in developing plans for the engineering inspection.

(2) Routine inspections. ER 1110-2-100 requires periodic inspection, by Engineering Division personnel, of completed Civil Works structures. A periodic inspection is a regularly scheduled inspection consisting of sufficient observations and measurements to determine the physical and functional condition of the project, to note any changes from previously recorded conditions, to identify any developing problems, and to ensure that the project and structures continue to satisfy present service requirements.

(3) Damage inspections. A special inspection may be required to assess damage resulting from natural causes, accidents, or normal wear. It may follow a specific damaging event, or be a more detailed inspection following identification of distress during previous operational inspections. The scope of inspection must be sufficient to determine whether a local maintenance and repair effort is needed, or whether to initiate design efforts for a project nourishment effort. The amount of effort expended on this type of inspection will vary significantly depending on the extent of the damage and urgency of restoring the shore protection. A refined analysis may be necessary to establish or adjust the nourishment cycle, quantity, or procedures.

10. Summary

The design of shore protection projects requires an understanding of the problem, assembly and evaluation of all pertinent facts and development of a rational plan. The design engineer is responsible for developing the design rationale and sufficient alternative plans so the economic optimum plan is evident, the environmental consequences are understood, and the recommended plan is substantiated. Applicable Corps of Engineers guidance and pertinent textbooks, research reports, or expertise from other sources may be used as source information. The usual necessary steps leading to a sound plan are listed below:

a. Review appropriate ER's, EM's, ETL's, etc.

b. Assemble and analyze pertinent factors and environmental data.

c. Conduct baseline studies.

d. Develop most likely future conditions without the project.

e. Select rational set of design conditions.

f. Develop trial layouts with life-cycle annual costs.

g. Conduct performance analysis covering the range of expected future conditions.

h. Assess environmental and other impacts.

i. Develop O&M and periodic nourishment plans.

j. Select the economic optimum plan.

k. Develop recommended plan.

FOR THE COMMANDER:

Otis Williams

OTIS WILLIAMS
Colonel, Corps of Engineers
Chief of Staff

3 Appendixes
APP A - References
APP B - Typical Shore Protection Project Features
APP C - Principal Factors Affecting Hydraulic Design

APPENDIX A
References

Public Law 727 (60 stat, 1056) 79th Congress 13 August 1946, as amended.

33 CFR 208.10
Local flood protection works; maintenance and operation of structures and facilities

ER 1105-2-100
Guidance for Conducting Civil Works Planning Studies

ER 1110-2-100
Periodic Inspection and Continuing Evaluation of Completed Civil Works Structures

ER 1110-2-112
Required Visits to the Construction Sites by Design Personnel

ER 1110-2-401
Operation, Maintenance, Repair, Replacement, and Rehabilitation Manual for Projects and Separable Elements Managed by Project Sponsors

ER 1110-2-1150
Engineering and Design for Civil Works Projects

ER 1110-2-1200
Plans and Specifications for Civil Works Projects

ER 1110-2-1403
Studies by Corps Hydraulic and Hydrologic Facilities and Others

ER 1110-2-2902
Prescribed Procedures for the Maintenance and Operation of Shore Protection Works

ER 1150-2-301
Policies and Procedures

EM 1110-2-1004
Coastal Project Monitoring

EM 1110-2-1204
Environmental Engineering for Coastal Shore Protection

EM 1110-2-1412
Storm Surge Analysis and Design Water Level Determinations

EM 1110-2-1414
Water Levels and Wave Heights for Coastal Engineering Design

EM 1110-2-1502
Coastal Littoral Transport

EM 1110-2-1614
Design of Coastal Revetments, Seawalls, and Bulkheads

EM 1110-2-1616
Sand Bypassing System Selection

EM 1110-2-1617
Coastal Groins and Nearshore Breakwaters

EM 1110-2-1618
Coastal Inlet Hydraulics and Sedimentation

EM 1110-2-1913
Design and Construction of Levees

EM 1110-2-2904
Design of Breakwaters and Jetties

EM 1110-2-3301
Design of Beach Fills

EM 1110-2-5025
Dredging and Dredged Material Disposal

U.S. Army Corps of Engineers Institute for Water Resources 1994
U.S. Army Corps of Engineers Institute for Water Resources. 1994. “Shoreline Protection and Beach Erosion Control Study; Phase I: Cost Comparison of Shoreline Protection Projects of the U.S. Army Corps of Engineers,” Fort Belvoir, VA.

APPENDIX B
Typical Shoreline Protection Project Features

1. Beach fills are the artificial building up and widening of the beach by direct placement of the fill material on the shore and nearshore (EM 1110-2-3301). Various beach fill elements are designed to serve different purposes.

a. A seaward beach alignment is restored and nourished by constructing a relatively stable beach alignment (advancing the above-water and below-water active beach profile), taking into consideration seasonal and long-term erosion losses. The seaward alignment is held by periodic nourishment, sand bypassing (EM 1110-2-1616), feeder beaches, nearshore feeder berms, shoreline stabilization structures, or combinations of these. Suitable beach fill material is obtained from the most economic and environmentally acceptable source. Frequently sand is dredged from off-shore borrow sources (EM 1110-2-5025); less frequently it is obtained from land sources, or it can be imported from distant or foreign sources.

b. Protection from storm-induced erosion and wave impacts is provided by constructing a seaward, nearly horizontal, extension of the natural storm berm and preserving it, as with 1*a*. above. Often a quantity of advanced nourishment is provided to help preserve the storm berm during common frequent storms and long-term erosion, so that it will be intact to mitigate the effects of less frequent storms with greater landward damage potential.

c. Protection from wave overtopping and storm overwash is provided by reinforcing and making existing dunes continuous or by constructing a storm protection dune which forms the landward boundary of the storm berm described above.

2. Groins are structures built from shore into the water to trap littoral material, retard erosion losses, or accommodate a change in shore alignment (EM 1110-2-1617 and EM 1110-2-2904).

3. Revetments are veneers of stone, concrete armor units, or other material built on the shore to prevent loss of land and damage to landward structures caused by wave action or currents (EM 1110-2-1614 and EM 1110-2-2904).

4. Seawalls are massive structures designed primarily to resist wave action elevated by storm surge in areas where a high level of landward protection is warranted (EM 1110-2-1614). They are usually constructed of poured-in-place concrete, placed stones, or both.

5. Bulkheads are retaining walls, usually built of wood, steel, or concrete sheet piles, which are used to retain or prevent sliding of the land while providing protection against light to moderate wave action (EM 1110-2-1614). They are often used in harbor and sheltered water areas to protect the upland from wave and current action.

6. Breakwaters block or reduce the wave energy in the lee of the structure available to attack the shore (EM 1110-2-1617 and EM 1110-2-2904). Segmented, closely spaced, nearshore (shallow-water) breakwaters are designed to allow enough wave energy through the gaps and over the top to provide limited sediment transport and circulation, while retaining most of the beach fill. In some cases, breakwaters are designed to create widely spaced or a single hard point(s) along the shore resulting in the creation of a more stable spiral-shaped beach alignment.

7. Levees constructed for coastal storm flood protection generally serve the same purpose as those constructed for river flood protection (EM 1110-2-1913). They are usually located some distance inland, on or near a bay or estuary protecting urban or industrial development from storm surges. Similar associated closure structures and interior drainage facilities are required along with provision for wave attack and shore erosion to ensure proper functioning. Some projects may contain gated navigation or drainage canal openings.

8. Surge barriers are built across the entrances of bays, lagoons, sounds, and estuaries to block the progression of storm setup or surge into these areas. These barriers generally consist of dikes with circulation and/or navigation openings which are left open during fair weather and closed when coastal storms threaten to flood the area.

APPENDIX C
Principal Factors Affecting Hydraulic Design

1. Physical.

a. Topography.

b. Bathymetry.

c. Geology.

d. Development.

e. Sediment characteristics and area distribution.

f. Sediment sources and sinks (natural and artificial).

g. Erosion/accretion rates.

h. Sediment budgets.

i. Subsidence/rebound.

j. Existing structures.

2. Climatic.

a. Temperature.

b. Pressure field (typical and/or historic).

c. Winds (speed, direction, duration, frequency, seasonality).

d. Precipitation (monthly, seasonal, storm related).

3. Hydraulic/hydrologic.

a. Waves (height, period, direction, duration, frequency, seasonality).

b. Wave transformation (shoaling, refraction, diffraction).

c. Tides (type, height (NAVD), range, frequency, duration, constituents).

d. Currents (littoral and/or tidal, speed, maximum, minimum, median, direction, duration) .

e. Discharges (riverine and/or tidal, quantity and/or rate, maximum, minimum, median, duration, frequency).

f. Historic storms and their physical consequences.

g. Sediment transport (quantity and/or rate, sources, sinks, travel paths, budgets).