CHAPTER 5

Design Factors and Studies

5-1. Tides and Currents.

a. Currents. In most navigation project design studies, tidal or river currents are usually the most important environmental conditions and dominate environmental ship forces. Measurements and predictions of currents are needed to determine the effects on ship motions and controllability for analysis of project navigation. The current patterns are also used to estimate the rates of sediment erosion and deposition, to determine the extent and characteristics of salinity intrusion, and to define the possible environmental impacts, such as changes in flushing characteristics. Currents may be caused by tidal forces, tributary stream inflow, or upland river discharge. Wind stress effects on open-water bodies will also generate currents, such as in coastal regions and large lakes or bays. Project current patterns (speed and direction) should be available for a variety of discharges and/or tide ranges for typical navigation situations, including the existing and proposed project design conditions. Tidal currents in some coastal harbor channels are predicted and available from the National Oceanographic and Atmospheric Agency (NOAA). River discharge data are measured and published by the U.S. Geological Survey (USGS). These data sources can be used as starting points for initial studies but should be supplemented by field data and physical or mathematical model studies during continued design studies.

b. Current Forces. Current effects on ship navigation are dependent on the direction and pattern of currents with respect to the direction of the navigation channel. Currents aligned with a straight channel centerline coincident with the ship sailing direction will cause a simple addition or subtraction to the ship speed, depending on whether the current is adverse or fair. Sailing with a fair tide can make control of a ship difficult due to the reduced propeller speed and rudder forces, while the ship moves with increased ground speed. A ship sailing in a channel will require a constant yaw angle if a crosscurrent is present in the channel causing a transverse ship force. Strong current forces can adversely affect navigation while the ship is maneuvering through the harbor channels and turning basins, especially when ships are being decelerated before turning around or berthing. The project planner/designer must consider current forces and their navigational impact on the channel and turning basin dimensions. Crosscurrents and spatially nonuniform flow are particularly hazardous to ships where the bow and stern are affected by different magnitudes and/or direction of currents, thus inducing a turning moment about the ship. Locally increased channel width may be required where currents are strong to compensate for the increased difficulty. Current effects on ship navigation are also important in channel turns, even when currents are aligned with the channel, due to the change in ship attitude with respect to the current direction.

c. Current Modeling. In most cases, navigation project design studies will require the development of a mathematical current model for use in predicting tidal or river currents with various project flow conditions. Early in the project formulation phase during the initial study, such an investigation should be planned by the navigation project study manager. For ship simulator studies, current patterns along and across the navigation channel are required. A two-dimensional (2-D) finite element model that gives depth-averaged current calculations has been most advantageous. The same hydrodynamic model can often be used to drive salinity, water quality, and sedimentation studies if the project study requires these considerations. Examples of applications of this model and additional guidance are available in EM 1110-2-1607 and Thomas and McAnally (1985).

d. *Water Levels.* Both maximum and minimum water surface level frequencies and durations as well as amplitudes of water level fluctuations are needed for design. Water levels can be affected by ocean tides, storm surges, harbor seiches, lake fluctuations, and river discharges. High-water levels are used to determine wave penetration and height of jetties, training structures, and overhead obstructions. Low-water levels are used to determine available and needed depths for various size ships and other vessels.

e. *Tide Predictions.* NOAA calculates and publishes tide height predictions and tide ranges for all major coastal ports and harbors in the United States. Published tide predictions are suitable for initial studies; other sources of published data should be inventoried and used in design where suitable and available. Tide level and current modeling for existing and proposed navigation project conditions is usually required at later design stages.

f. *Tidal Datums.* Channel depths for navigation projects are usually authorized and referred to some long-term average low-water datum plane based on measured field water level data. These measurements are usually conducted by NOAA and are used in their chart and tidal prediction tables and in establishing appropriate tidal datums. All project design features should be developed in a consistent manner, using the appropriate low-water datum plane. It is especially important to reconcile different datums presented in a variety of maps, charts, hydrographic data, etc., which can lead to confusion and possible mistakes. The relationship of the low-water datum to the National Geodetic Vertical Datum (NGVD) will also be needed for vertical control of design and construction. The low-water datum for the Atlantic and Gulf Coasts is being converted to mean lower low water (mllw) to be consistent with the Pacific Coast. The appropriate low-water datums for various localities are listed:

(1) Tidal ocean coastlines: mllw.

(2) Great Lakes: International Great Lakes Datum (IGLD).

(3) Nontidal rivers: Mean 15-day lowest navigation season water level referred to as the Low-Water Datum Plane.

5-2. <u>Wind and Waves.</u>

a. *Effects on Ships.* Wind effects on a project include the direct forces on ships sailing through the navigation channels and the indirect development of wind waves in the harbor or coastal ocean region. Waves generated in the harbor or bay area are usually small in height and normally have minor effects on typical design ships. However, wind waves generated by local storms near the port entrance channel (seas) may have an impact on ships. Estimates of wind are needed for project design, mainly because of the effect on ship motions and controllability. Historical wind data are usually available from the National Weather Service. Local topography may modify the wind data, usually available only at the local airport, and change the wind patterns at the navigation channel. Wind studies should include prevailing wind directions and speed, both averages and variability. Seasonal variations of the mean and extreme wind conditions with appropriate statistics (return period, frequency of occurrence, duration, etc.) are to be included in the wind study.

b. *Wind Forces.* Direct forces on ships from the wind are of primary importance for certain types of ships, especially when ship speeds are restricted or are reduced during normal operations. The forces are in direct proportion to the ship area exposed above water (projecting areas, also called the wind or sail area), which varies due to superstructure design and ship loading condition. The following situations are especially important and require careful consideration:

(1) Tankers in ballast (light ship) condition.

(2) Bulk carriers in ballast (light ship) condition.

(3) Automobile or car carriers.

(4) Containerships with containers on deck.

(5) Ferry boats.

(6) LNG and liquified petroleum gas (LPG) ships.

5-3. Sedimentation. The following aspects of sedimentation must be considered for deep-draft navigation projects: characteristics of the native soils or materials to be removed within the project channel; characteristics of sediments introduced into the upper reaches of the navigation project by riverine or other upland discharges; characteristics of sediments introduced into the lower reaches of the project by littoral processes, including wave action, resulting in beach erosion, and salinity intrusion; hydrodynamic and water chemistry conditions in the project region; and limitations or restrictions on dredging ,dredged material disposal techniques and beach erosion control using sand bypassing methods. More detailed discussion on beach erosion and sand bypassing is available in EM's 1110-2-1502, 1110-2-1616, and 1110-2-2904.

a. *Native soils*. Native soils must be considered first from the standpoint of channel construction. Problem soils encountered in channel construction may consist of consolidated clays, cemented sands, or outcroppings of bedrock. These materials may require special dredging equipment, techniques, and disposal and will thus have an impact on construction costs. Channel location and alignment may be determined by the existence of hard-to-remove materials along alternate channel routes. Native soils must also be considered from the standpoint of maintenance dredging following project construction. The existence of fine sands, silts, or easily erodible clays along the route of the project may indicate large dredging requirements to maintain the project channel in future years. For example, wind or ship waves in shallow areas adjacent to the navigation channel may resuspend significant quantities of unconsolidated fine sediments that might eventually be transported toward and deposited in the navigation channel. Surficial sediment sampling should be conducted throughout the project area, and core borings and/or subsurface acoustic measurements should be made along the most attractive channel routes to fully assess the composition and characteristics of native soils or the presence of rock. Methods will be discussed later to predict the fate of sediment particles located near the navigation channel.

b. *Riverine sediments*. Sediments transported to the project by riverine flows in estuaries or embayments usually consist of coarse to medium sands carried primarily as bed load, medium to fine sands carried as bed and/or suspended load, and silts and clays carried as suspended load. When the project channel includes the zone where rivers enter embayments, the coarse and medium sands and even some of the fine sands and silts may deposit as flow velocities are reduced below that necessary to maintain motion of the sediment particles. These deposits of sand and silt are often in the form of delta-shaped shoals that recur annually and require maintenance dredging for control. The finer sands and silts will usually be deposited in the lower reaches of the navigation project, but the deposition will usually be distributed over a fairly long reach of the channel. High stage-discharge events may alter the pattern of deposition from time to time and distribute the coarser particles over a longer reach of the channel than usual. Deposition of clay particles is dependent on the hydrodynamics and water characteristics of the lower reaches of the navigation project. If the project is in an estuarine setting where salty water from the ocean can mix with the sediment-carrying riverine waters, such as Savannah Harbor for example, a phenomenon known as flocculation occurs, whereby the clay particles aggregate into larger and heavier flocs that are likely to deposit. In some instances, very heavy concentrations of the flocs remain in suspension in a layer near the bottom, referred to as fluff or fluid mud. Prior to permanent deposition of clay sediments, which is a time-dependent process, the tidal hydrodynamics of an estuarine system tend to concentrate the location of the flocs. If the estuarine system is of the stratified type, i.e., there is a well-defined saltwater layer underlying the freshwater layer, the bulk of the clay-particle shoals will be concentrated in a zone mapping the upstream intrusion of the saltwater layer. If the saltwater-freshwater interface is less well defined, the clay-particle shoals will be distributed more widely through the middle and lower reaches of the project. In nonsaltwater settings, such as the Great Lakes, the clay particles may remain in suspension and be introduced into the lake region as suspended load. Maintenance dredging is almost always required to maintain channel depths and widths through the areas of clay particle deposition. Methods for predicting the locations and magnitudes of the sand- and clay-particle deposits in the navigation project will be discussed later.

c. *River reaches*. In cases where the deep-draft project extends well upriver (above the zone of flow reversal), such as the Columbia River or the lower Mississippi River, deposition of medium to coarse sands occurs in the river crossings, with most of the fine sand and silt moved downstream to estuarine or coastal zones. Not all river crossings along a navigation project require maintenance dredging. In many cases, the minimum crossing depth that occurs naturally over a water year is greater than the project depth. For example, of the several river crossings that exist on the lower Mississippi River from Baton Rouge, LA, downstream to the Head of Passes, a distance of about 225 river miles, only about 7 of the 225 miles require annual maintenance dredging. Of course, if the project were deepened, the number of crossings requiring maintenance dredging would most likely increase.

d. *Littoral sediments*. Sediments are introduced into the navigation project from the littoral systems that exist in all lakes and oceans. Nearshore currents driven by waves, wind, tides, or water-mass movement cause sediment particles, usually medium to fine sands but occasionally clays and silts, to be moved along the shore. As the sand-size sediments reach the deeper waters of the navigation project, deposition occurs in and near the entrance channel. Clays entering from the lower end may be transported upstream by estuarine circulation. Structures such as jetties are used to trap the sands and keep shoals from forming in the navigation project. A sand-bypassing arrangement may be necessary to maintain the trapping capability of the jetty structures and to minimize damage to adjacent beaches that interruption of the littoral process usually causes. The planner/designer is required to study and develop predictions of erosion and accretion for a distance of 10 miles on either side of an entrance channel improvement project.

e. *Predictive techniques*. Four basic approaches are available to study sedimentation processes in deep-draft navigation channel projects: field studies, physical hydraulic model studies, numerical model studies, and combinations of these study techniques. Field studies include collection of prototype data in such a manner that future behavior can be extrapolated or developed into general design principles, and also trial-and-error remedial measures in which proposed remedial schemes are constructed without the benefit of corroborating studies. The collection of prototype data is always recommended for deep-draft navigation projects; trial-and-error remedial schemes must be highly justified prior to installation because of the high risk of failure involved. Physical models have been used for many years to study sedimentation problems associated with deep-draft navigation projects, but it is not possible to accurately predict deposition volumes. Numerical modeling of sedimentation phenomena is becoming a relatively well-developed technique that employs special computational methods such as finite difference or finite element approximations to solve mathematical expressions that do not have closed-form solutions. In some situations, numerical models can provide a reasonable prediction of deposition volumes. Physical and numerical models are discussed in more detail in EM 1110-2-1607. It should be stressed that both physical and numerical models rely heavily on prototype observations; therefore, if model studies are anticipated, the lead time and resources must be provided to collect the quality and quantity of data necessary to support these studies. In some cases, combinations of the various techniques may be used that involve the application of physical and numerical models as well as prototype data and analytical procedures to take advantage of the strong points of each technique.

f. *Channel shoaling*. Sediment budget and shoaling studies are needed for before- and after-construction conditions. These studies provide the basis for estimating maintenance dredging requirements, disposal area locations, training structures, and entrance sand-bypass assessment. Shoaling rates are needed for river expansions caused by port facilities and turning basins. Information on sediment budget is contained in the *Shore Protection Manual* (1984).

g. *Beach erosion*. Many navigation channels connect the ocean to an estuary or bay through sandy beaches. When jetties are built to prevent littoral drift from entering the channel, the volume of sand reaching the downdrift beach is reduced. This reduced littoral drift usually results in erosion of the downdrift beach. If the erosion is unacceptable from an economic or environmental standpoint, mitigation measures will be required. Traditional methods of erosion control are shoreline protection with revetments, breakwaters, groins, and nourishment by bypassing sand from one side of the inlet to the other. Some bypassing methods involve the use of weirs with sand traps, detached breakwaters, and various methods of dredging and sand pumping, including jet pumps.

h. *Bank protection.* To reduce bank erosion, bank protection is sometimes provided. Guidance on the design of riprap protection on navigable waterways is provided by Maynord (1984). A computer program, NAVEFF, is available to assist in determining the drawdown and return flow velocities generated by a ship moving through a restricted waterway (Maynord 1996, 1999). Information on the design of flexible revetments is also available, (Permanent International Association of Navigation Compresses (PIANC) 1987). This reference also provides guidance on the computation of ship wake waves. Use of reinforced vegetative bank protection using geotextiles may also be useful (PIANC 1996).

5-4. <u>Water Quality Impacts.</u>

a. Physical Changes. The development of a navigation channel that is larger than previously existed in an estuary or bay could cause physical, biological, and water quality changes affecting the ecosystem. The following physical changes require evaluation:

(1) Salinity.

(2) Tide heights (water levels).

(3) Current velocities and duration.

(4) Water circulation pattern.

(5) Shoaling and erosion in the vicinity of the channel.

(6) Possible effects on adjacent shoreline resulting from changes in wave patterns.

(7) Tidal flushing rate.

(8) Pollution dispersion rate.

These changes could be negligible when the channel improvement is small compared with the natural ecosystem cross-sectional area. When the physical changes are estimated, a biological assessment of project effects on estuary aquatic life is needed to determine if design changes and mitigation measures are justified. Numerical models are presently the most reliable method of predicting post project conditions and determining the most effective remedial measures that might be required.

b. Ecological Considerations. An interdependence exists between the physical, chemical, and biological components of a system. Modification or manipulation of any component will have some effect on the others. Tides, currents, and salinity characteristics determine tidal circulation patterns and thus have a profound influence on the movement and distribution of aquatic plants and animals. The means and extremes of salinity and temperature influence the types and distribution of aquatic life. The effects of navigation projects, including the dredging operations and disposal facilities, upon the environment or ecological relationships are the results of both the direct physical alterations associated with construction activities and the physical or chemical changes that develop after construction. These activities influence water movement, water quality, sediment movement and quality, substrate physical and chemical properties, etc. and will always cause some environmental change in the project area. The effect need not be adverse, and engineering modifications in a tidal ecosystem may be used to enhance ecological conditions by remedying adverse conditions in an estuary caused by previous impacts from urbanization and industrialization. Engineering modifications can also be used to stabilize large variations in natural conditions thereby increasing biological diversity or improving conditions for an individual or group of species. Some of these modifications may provide desirable habitat where that habitat is not presently available.

5-5. Local Coordination.

a. *Pilot Interviews.* Navigation project planners/designers should develop strong coordination with the local pilot groups throughout the project development. Pilot interviews can be used to determine the user's opinion on existing channel navigation safety and wind and wave conditions to be used for design analysis, and the feasibility and safety of proposed channel design alternatives.

b. *U.S. Coast Guard.* The local U.S. Coast Guard (USCG) office should also be contacted early in the project development to solicit views and coordination on channel dimensions and alignment relative to safe navigation. The USCG can also provide guidance on aid to navigation placement and waterway analysis study results.

5-6. Accident Records. Accident Records. Marine accident records are available from the U.S. Coast Guard annual compilation of casualty statistics in an automated system called Coast Guard Automated Main Casualty Data Base (CASMAIN). Accident data on existing navigation channel projects proposed for enlargement or improvement should be studied to determine the number, cause, and location for analysis. In some accidents, the Coast Guard will conduct an inquiry, which may also be valuable in determining navigation problems. The National Transportation Safety Board also reviews specific accidents and develops reports and recommendations on site-specific safety issues. Information from the local pilots and, at some ports, data from vessel traffic services (VTS), if available, can provide valuable information in designing proposed channel improvements. The local Coast Guard District Office and Captain of the Port should be consulted for any available data and investigation summaries.