pumpout system that should be installed, including no facility, a portable pumpout unit, or a fixed station (Blanton, 1979). The decision regarding which system to install should be based on applicable regulations, the installation cost, and the expected demand. If a nearby pumpout facility exists that is underutilized, marina customers can be saved a substantial sum of money in slip rental fees with little inconvenience by opting for no installation. In low demand areas a portable system may be acceptable if the marina can get the local septic service to pump it out on short notice. For heavier demand, a fixed system with an in-the-ground holding tank is recommended (Blanton, 1979).

Sewage pumpout facilities should include equipment to pump or receive and transfer the contents of holding tanks into a sewage retention and disposal system (State of California, 1980). The components required for such a system include a freshwater pressure line and hose, a suction hose, a sludge pump, a discharge pipe, and a shoreside holding tank. The freshwater pressure line and hose are provided for flushing the boat holding tank after pumpout. The State of California (1980) recommends that no domestic water outlets be located near the pumpout station, and that a sign reading "Not for Human Consumption" be posted conspicuously. The pump unit and all associated electrical fixtures must be explosion proof because of methane gas produced by the sewage (Blanton, 1979). The discharge line should be as short as possible, sloped toward shore 1 in. (25.4 mm) in 100 ft (30 m), and fitted with shut-off valves and drains. The last item is necessary for "blowing out" the lines to clean them and to avoid freezing in
cold climates (Blanton, 1979). Holding tanks are usually made of concrete, but properly protected steel tanks are acceptable. Because sewage can be very corrosive, coatings inside and out are required (Commonwealth of Virginia, 1976). Since these tanks must be installed at or below the level of ground water, they must be waterproof and restrained against floating. Holding tank design with respect to size depends on its intended use. If shoreside wastes are to be combined with boat sewage in the holding tank, it must be much larger. Tank size may be specified in health codes according to boat size. Blanton (1979) cautions that these figures represent the "maximum" that should be considered for a first class installation, and that experience indicates that tanks sized for half the specified load will provide years of trouble-free service.

The method of disposal of boat sewage depends primarily on the location of the marina. Because the marina is necessarily situated on the Waterfront, it is usually not near a public sewer line, and the water table often lies so near the surface that a septic system and drain field is not effective (Ross, 1976). If a public sewer line is accessible, it must be determined if the marina is far enough "upstream" of the treatment plant so that its biological systems are not decimated by a concentrated dose of toxic chemicals from treated boat sewage. Blanton (1979) suggests that the best solution is to pay the local "Port-a-John" man to dispose of the wastes in the proper manner. He will have both the experience of handling treated wastes, and a permit to dump into the public sewer at a point far enough from the processing plant that the toxic materials become diluted. Chamber-
lain (1979) notes that in remote locations, marinas have the option of installing packaged sewage treatment plants, but states that proper sizing is a critical design parameter. If such systems are overdesigned, there may not be sufficient sewage inflow to make the biological processes self-sustaining.

Location of Sewage Pumpout Facilities

The location of the pumpout station should be convenient to the customer while keeping the line to shore as short as possible (Blanton, 1979). Depth of water and maneuvering room are important since it is predominantly the larger craft that use the pumpout facility. The State of California (1980) suggests that it is advantageous to have the fuel pumps and sewage pumpout adjacent to each other. The shoreside end of the fuel dock is a location that satisfies all these requirements as well as allowing the fueling attendant to supervise holding tank discharge.

Location is not an element of design for portable pumpout units since they are intended to be taken to the craft to be serviced. A protected storage place is necessary however.

Currently there is little need for direct connection sanitary systems to service boats in their berths (Dunahm and Finn, 1974). Such service would be convenient for boaters that live aboard their craft, but it requires adding another utility line.

8.3 FRESH WATER SERVICE

In addition to electrical and sewage services, fresh water is often supplied by a public utility. It is commonly piped to the slips of the modern marina for drinking, filling fresh water holding tanks,
and for washing boats (Dunham and Finn, 1974). Because water is used for human consumption, the piping system must be sanitary and the water must be potable. In a small dock system, the freshwater line may also serve as a fire fighting device. Fire fighting facilities are discussed subsequently. The regulatory standards, system design considerations, and the location details that pertain to freshwater systems are described below.

**Regulations**

Regulations concerning water services fall into three groups: plumbing, health and safety. The Basic Plumbing Code (BOCA, 1978) is the National standard on plumbing. Some mention of freshwater systems will be made in State health standards since water is used for human consumption. All contact between the water and sewage systems must be avoided to guard against contamination. A newly installed freshwater system must also be completely disinfected before it is put into service (Blanton, 1979). Safety regulations concern the use of the freshwater system for fire prevention and control.

**Design Considerations for Freshwater Systems**

The typical freshwater system for a dock starts at the shoreside manifold. Water is carried by pipes out along the main walks to hose bibbs or risers installed at each slip. Dunham and Finn (1974) state that water is usually provided free to slip renters, and therefore only one meter is required for the marina. Blanton (1979) suggests that water going to the dock system be metered separately to avoid overcharging by the sewage treatment plant. Sewage treatment fees are often proportioned to the water bill, and water to the docks usually will not go into the sewer.
The pipeline is the main component of the freshwater system. While acceptable materials for the pipe include copper, galvanized iron, and polyvinylchloride (PVC) plastic, each has its disadvantages. Copper pipe with silver-soldered joints is good in all locations, but it has become very expensive (Blanton, 1979). Galvanized iron tends to have a shorter life span and it corrodes at the joints if not properly coated and maintained (Dunham and Finn, 1974). PVC plastic is especially good for saltwater marinas since it is non-corrosive. Because it is easily damaged, and becomes brittle in cold weather, Dunham and Finn (1974) recommend that PVC not be used for exposed risers. Translucent plastics should be avoided as light will encourage algae growth within the pipe (Bertlin, 1976). The low flexural rigidity of PVC favors it in pipe selection for floating docks since it conforms to the float displacements more easily than copper or galvanized iron (Dunham, 1969). The joints, fittings, and pipe support system require special attention in a floating system to avoid fatigue failure. With regard to pipe supports or hangars, copper or galvanized iron pipes must be isolated from dissimilar metals to prevent electrolytic corrosion.

Pipe line diameter depends on the demand from the berths, and whether the system is used for fire fighting. Blanton (1970) suggests that in the absence of legal requirements, a 0.75 in. (19 mm) line will serve 20 berths, a 1 in. (25 mm) for 40 berths, 1.25 in. (32 mm) for 60 berths, 1.5 in (38 mm) for nearly 100 berths, and 2 in. (51 mm) for 200 berths. For proper performance of the water system, the pipe should be designed and sized such that a minimum pressure of 25 psi (172 kN/m²) occurs at the most distant outlet in the system under peak demand (State of California, 1980). A 2 in. (51 mm) pipe size will satisfy national fire
regulations and it could serve to distribute water to the slips as well as fire fighting stations.

Expansion and contraction of the pipe should also be addressed by the designer (Chaney, 1961). Temperature changes of 130°F (54°C) seasonally and 50-60°F (10-15°C) in minutes (as cold water runs through warm pipes) can cause damaging stresses unless expansion units are provided. On long straight runs of pipe, long radius pipe bends or slip joints should be installed not more than 140 ft (46 m) apart (Chaney, 1961).

The shoreside end of the freshwater pipe should be protected by a backflow preventer and shut-off valve at each pier (Blanton, 1979). In cold climates, the shut-off valve is best located where it will not freeze. The pipe is then sloped toward shore and provided with drains and air blow-out taps to avoid ice damage. Note that expansion bends must be laid flat so that drainage is not impeded. Blanton (1979) indicates that a slope of 1 in. (25 mm) in 100 ft (30.5 m) is sufficient for proper drainage. In the case of a floating dock, special attention must be given to the shore-float connection to assure flexibility and fatigue resistance. The shore and float pipes should end in down-turned elbows that are connected with a U-shaped flexible hose (Dunham and Finn, 1974). The slip end of the water pipe consists of a riser-rack or hose bibb. One standard (0.75 in. or 19 mm) hose rack is recommended for every two berths (State of California, 1980). If unprotected risers are used, they should extend no more than 1 ft (0.3 m) above deck level (Dunham, 1969). Thread-on fittings and valves are recommended by Dunham and Finn (1974) since they are easier to maintain and replace.
Location of Freshwater Service

Water lines are often hung from the timber walers that protect most docks from boat impact. While this location is convenient in terms of initial installation, the utilities are subject to mechanical damage from boats. Locating the pipes behind the deck stringers insures that they cannot be hooked or used to tie-off boats, but it creates maintenance problems. Curry (1979) suggests that deck troughs are the best solution and are worth the extra cost. Hose bibbs are often located on the knee that forms the junction between the main walk and each finger pier (Figure 8.2). They are usually combined with the electrical outlets that service each slip, and are often mounted on locker boxes or strapped to piles. Care should be taken to avoid placing hose bibbs where they can drip on pressure treated walers and cause decay problems (Curry, 1979).

8.4 FIRE FIGHTING SERVICES

While marina fires occur infrequently according to Blanton (1979), the situation is potentially catastrophic. Many of the materials used in both boat and dock construction are flammable, not to mention the presence of gasoline and oil. If a fire starts on the upwind side of a harbor, a strong breeze can quickly carry it from slip to slip and along the docks. The spread of fire is even faster in covered sheds where access is more difficult. Some form of fire fighting equipment must be provided by the marina to minimize damage and protect against liability. Outlined in the following discussion are the regulations and design considerations relating to fire fighting equipment for docks, piers, and wharves.
A. Typical Water Service Arrangement for Double Berths (State of California, 1980, p. 19)

B. Water Piping Plan (Dunham, 1969, p. 123)

Figure 8.2 Location of Fresh Water Service
Regulations

The National guideline of record is "Marinas and Boatyards" (National Fire Protection Association, 1975). Other regulations written by the National Fire Protection Association include:

1. Fire Prevention Code, 1975
2. Sprinkler Systems, 1980
3. Centrifugal Fire Pumps, 1974
4. Extinguishers, Installation and Maintenance, 1974
5. Fire Hydrants, 1974
7. Flammable Liquids Code, 1973
8. Outside Protection, 1977

Local regulatory agencies have specific requirements for marinas, but in case of a liability suit, the marina owner may also be held to the stricter national standards (Blanton, 1979).

Fire Fighting Equipment

Preliminary to a discussion of fire fighting equipment, some mention of the type of fire to be fought is necessary. Fires are classified A through D according to the type of fuel (Texas A & M, 1971). Class A fires are ordinary combustibles such as wood and are usually fought with water. Class B fires consume substances such as gasoline, oil, tar and grease. Live electrical fires are considered Class C fires and require a non-conductive extinguishing agent. Class D fires are not a problem in the marina since they are caused by combustible metals such as magnesium and sodium which are unstable in the atmosphere and do not exist in a pure state in nature.

The method of fighting fires varies with the type of fire and the extinguishing agent used. Water, foam, carbon dioxide (CO₂) and dry chemicals are the standard fire fighting agents. Water is the most
common substance used because of its availability and low cost. Usually in the form of fog, water is used on Class A fires where it acts to cool the fire, displace available oxygen, and dilute the combustible vapors. Foams are used on Class A and B fires but, according to Texas A & M (1971), they do not work well on flowing liquids or at low temperatures (less than 10°F or -12°C). Carbon dioxide (CO₂) extinguishes by smothering a fire and reducing the available oxygen to a non-combustible level. CO₂ may be used on all fire types, but its effectiveness is greatly reduced by winds. Finally, dry chemical extinguishers are used on all B and C class fires, but they leave behind a residue that may damage electrical equipment.

Marina fire fighting facilities typically consist of a water system supplemented by small dry chemical extinguishers, and a large CO₂ extinguisher on wheels. Chaney (1961) writes that the greatest cause of fires in the marina is the ignition of gas and oils by faulty electrical equipment. The fuel dock satisfies these conditions and requires the Class B and C fire fighting agents (dry chemical and CO₂). A water system is necessary at the fuel dock and throughout the berthing system to prevent the spread of fire and protect the berthed craft (Blanton, 1979). For small dock systems, the freshwater system may be used for fire protection (Dunham and Finn, 1974). Since fire regulations usually require a supply line of at least 2 in. (51 mm) diameter, it is advantageous to install separate systems. Blanton (1979) states that some marinas provide a hydrant at the foot of every pier, with a 2 in. (51 mm) line running out the pier to 1.5 in. (38 mm) hose connections and hoses on 75 ft (23 m) intervals. The pier line is connected to the hydrant by a 2.5 in. (63.5 mm) hose adapter. This system is in com-
pliance with NFPA-303 "Marinas and Boatyards", but is expensive and may not be required by local laws. It does have the advantage of keeping the pier line dry to prevent damage in freezing weather. Dunham (1969) and Dunham and Finn (1974) recommend 75 ft (23 m) of 1.5 in. (38 mm) hose on racks spaced 100 ft (30 m) apart, while the State of California (1980) suggests 150 ft (46 m) intervals. The 75 ft (23 m) and 100 ft (30 m) spacings provide some overlap that allows the use of two hoses simultaneously on one spot while the 150 ft (46 m) spacing does not. Dunham (1969) suggests that the water pressure at the outboard hydrant be no less than 25 psi (172 kN/m²) with two intermediate hoses operating, while the State of California (1980) recommends water be supplied at a rate of 20 gpm (76 l/min) and a minimum pressure of 20 psi (138 kN/m²). Water used for fire fighting should be clean and fresh if possible to minimize corrosion damage after a fire.

In addition to the water system, fire extinguishers are provided throughout the marina. Bertlin (1976) suggests that two dry powder extinguishers (10 lb or 5 kg) be located on each pier in cabinets with break-glass access. Many marinas hang extinguishers on unprotected brackets every 50 ft (15.2 m) but theft and vandalism is a serious problem (Blanton, 1979). A large (40 to 300 lb or 220 to 662 kg) CO₂ extinguisher on a cart is recommended by Quinn (1972) and Blanton (1979) for use on the fuel dock.

**Municipal Fire Departments**

If within the protection of a local municipal fire department, the marina owner should arrange for their services (State of California, 1980). The fire department can provide major fire fighting capabilities and
experience that marina personnel lack. To obtain the best service from
the fire department, ready access to the site must be provided as well
as hose connections compatible with their equipment. A fire department
near the waterfront may have a fire boat to fight fires that are
inaccessible from the shore side. Some marinas choose to outfit boats
with fire pumps so that they are readily available (Blanton, 1979).

8.5 FUELING SERVICES

Nearly all craft including most sailboats have need of fuel and oil
for their engines. It is recommended by Dunham (1969) that every harbor
have at least one marine service station. In lieu of an internal fuel
dock, one that is external to the harbor but nearby may be satisfactory.
An internal fuel dock that is properly designed and operated will produce
revenues through its fuel sales as well as by attracting slip renters.
The simplest solution to providing fueling facilities for a marina is
to lease the privilege to an oil company to develop and operate. According
to Dunham (1969), this is the case for most large fueling stations. Fueling
facilities for smaller operations may be developed by the owner with some
assistance. A competent mechanical engineer, preferably one specializing
in piping, is recommended by Blanton (1979). The following discussion
presents regulations applicable to fueling facilities, guidelines for design
of the fuel dock, and its location within the marina.

Regulations

Fueling facilities are potentially very dangerous. Risk can be
minimized through proper operating procedures and safe construction prac-
tices as specified by local and national regulations. The "Flammable and
Combustible Liquids Code" (NFPA 30-1981) and the "Underground Leakage, Flammable Liquids Tanks" (NFPA 329-1977), published by the National Fire Protection Association, should be consulted, along with the latest published regulations of the National Board of Fire Underwriters.

**Fuel Dock**

The fuel dock is similar in most respects to a dock designed for berthing. In the absence of code specifications, fuel docks may be fixed or floating. Some codes require that the fuel dock be on solid ground or a fixed pier (Dunham, 1969). A floating dock is preferred by both users and operators since it minimizes differential movement between the boat and dock, making the fueling operation much easier. The fuel dock must be more rugged and stable than the common berth structure (Dunham and Finn, 1974). While fixed docks present no problems with regard to stability, floating docks must be "beefed-up" structurally with added flotation to support the weight of the fuel dispensing equipment and supplies. Flexible connections must be provided at each joint between floats and between the dock and shore (Dunham and Finn, 1974).

Fuel is generally stored on land in buried, tar-covered steel tanks (Chaney, 1961). Fuel tanks placed above ground are unsightly, an increased fire hazard, and an insurance liability. The tanks should be installed far enough behind the bulkhead line so that a bulkhead failure will not cause the tank to move, possibly resulting in an underground fuel leak (Blanton, 1979). Blanton (1979) also notes that in areas of high ground water, fuel tanks must be anchored down to restrain them from "floating" as they are emptied. Tanks should have at least 2 ft (0.6 m)
of soil cover and should be vented to a point 10 to 12 ft (3.0 to 3.7 m) above ground level (Chaney, 1961).

The pipeline transporting fuel from the tank to the pump starts with a foot valve in the tank that should be removable for cleaning (Chaney, 1961). To minimize fuel spill in case of pipe rupture, an anti-siphon check valve should be installed where the pipeline passes below the elevation of the tank top, and shut-off valves should be installed on both sides of flexible couplings (Blanton, 1979). Chaney (1961) suggests that the fuel system be air-pressure tested before it is put into service to check for leaks. Fuel line size can be determined from the pumping rate and the number of boats to be serviced simultaneously. Chamberlain (1979) recommends 2 sets of metered, automotive type pumps with 25 ft (7.6 m) hoses so that several craft can be fueled at once.

The area around the dispenser is classified as hazardous by the National Electrical Code (NFPA, 1980) and requires special wiring, switches, and other fixtures. All electrical equipment must be of the explosion-proof type. Automatic nozzles with latch-open devices should be avoided because they encourage spillage (Blanton, 1979). The nozzles should be grounded to shore, and ground bars with cables and clips should be provided for static discharge of fuel tanks (Chaney, 1961).

Some special attention must be given to the materials used in fuel docks. A resistant float material is to be preferred over unprotected polystyrene since it is subject to degradation by hydrocarbons. Concrete decks are an improvement over timber decking as the latter material will soak up fuel and oil and become an increased fire hazard.
Signs should be posted in conspicuous places to warn against smoking, running the engines, or using electrical equipment during the fueling operation (Blanton, 1979).

**Fuel Dock Location**

The location of a fuel dock within a marina is somewhat of a dilemma. It is advantageous to have the fueling facility near the entrance of the harbor to avoid problems with traffic, wake or fire hazard. On the other hand, a distant fuel dock requires lengthy utility and fuel lines. It is more expensive to install and may be a long walk from the administrative office so that it is hard to run at a profit (Chamberlain, 1979). Blanton (1979) suggests that risk can be minimized by locating the fueling facility away from restaurants, fishing piers, and other such gathering places. The fuel dock should be readily accessible with a minimum of travel through the berths, as well as isolated from the berths so fire and explosions cannot spread and damage other craft (State of California, 1980). Chamberlain (1979) proposes two locations for the fuel dock: the first being a short pier perpendicular to the shoreline near the marina office, and the second location being an enlarged "T" head on a central berthing pier (Figure 8.3). In the first case, turning lanes must be provided on either side of the fuel dock that result in wide fairways. A "T" head pier must be large and strong to support a light vehicle such as a golf cart, and possibly a pier-head store. In either case, a minimum of 200 ft (61 m) of clear pier with space and cleats for temporary tie-ups is recommended (Chamberlain, 1979). The fuel dock is also a good location for sewage-pumpout facilities (State of California, 1980).
A. Short, Shoreside Fuel Dock

B. Enlarged "T" Head Fuel Dock

Figure 8.3 Fuel Dock Locations (After Chamberlain, 1979, p. 23)
8.6 SUMMARY

Utilities include electrical power, freshwater, sewage disposal, and telephone connections. Special services include fire fighting facilities and a refueling station. These utility and special services are an essential part of a modern marina.

As such an important convenience to the marina patron, utilities must not be considered add-on systems but instead should be integrated with dock design to assure smooth operation. The design of all these systems is subject to the regulations and specifications on the federal, state, and local level of government and industry. Unfortunately, many of these specifications and controls are written by committees unfamiliar with design in the waterfront environment. It is therefore recommended that national standards be met as long as they are representative of accepted good practice.

The electrical service consists of an outlet at each slip using a waterproof twist-lock receptacle protected by a ground fault circuit interrupter. The electrical service is also used to power flood lights to illuminate the berthing area at night. Typical sewage facilities consist of a pumpout station that transports treated boat wastes to a holding tank for shoreside disposal. A common location for the pumpout station is on the end of the fuel dock. Freshwater is supplied to berths through hose bibbs located at the finger pier-main walkway connection. Freshwater supplies may also be combined with fire fighting pipelines in addition to dry chemical and carbon dioxide extinguishers. The fuel dock dispenses petroleum products to power boats. For safety reasons it should be located away from the berthing area in case of fire.
CHAPTER 9

DREDGING FOR SMALL CRAFT HARBORS

Dredging may be defined as the removal of submerged material by hydraulic or mechanical means (Schubel, Wise and Schoof, 1979). The materials removed may range from rock and sunken debris to fine-grained sediments. Dredging is performed either to create and maintain a waterway, or to "mine" the bottom material for commercial purposes. This chapter concentrates on the waterway and small craft harbor related aspects of dredging. The four main topics that will be addressed are dredging methods and equipment, when dredging is required, dredge materials and their disposal, and the environmental impacts of dredging. Dredging problems will also be discussed briefly.

9.1 METHODS AND EQUIPMENT

Dredging methods may be separated into two categories: hydraulic and mechanical. For either method, the function of the dredge is to raise material from the bottom of a body of water (usually to some point above the surface), and then dispose of it. Mechanical dredges excavate this material by means of buckets or scoops while hydraulic dredges must reduce the material to a slurry so that it can be pumped. The most common types of hydraulic and mechanical dredges, and their operating characteristics were presented by Mohr in 1974 (Table 9.1).

While the basic types of dredges have not changed much since the 1950's, general dredge modernization has been accompanied by a gradual increase in size. Modern dredges are somewhat difficult to classify (as in Table 9.1) since they are often custom designed for a specific purpose and may combine several components. In a recent review
### Table 9.1 Mechanical Dredges (Mohr, 1974, pp. 70, 71)

<table>
<thead>
<tr>
<th>Dredge type</th>
<th>Dragline on barge</th>
<th>Dipper dredge</th>
<th>Clam shell or orange peel bucket dredge</th>
<th>Endless chain bucket dredge</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Dredging principle</strong></td>
<td>Scrapes off material by pulling single bucket over it toward stationary crane. Lifts bucket and deposits dredged material in a conveyance or on a bank.</td>
<td>Breaks off material by forcing cutting edge of single shovel into it while dredge is stationary. Lifts shovel and deposits dredged material in a conveyance or on a bank.</td>
<td>Removes material by forcing opposing bucket edges into it while dredge is stationary. Lifts bucket and deposits dredged material in a conveyance or on a bank.</td>
<td>Removes material by forcing single cutting edge of successive buckets into material while dredge is slowly moved between anchors. Lifts buckets and deposits dredged material in a barge or own hopper.</td>
</tr>
<tr>
<td><strong>Horizontal working force on dredge</strong></td>
<td>Medium intermittent force toward bucket.</td>
<td>High very intermittent force away from bucket.</td>
<td>No forces.</td>
<td>Medium constant force away from bucket.</td>
</tr>
<tr>
<td><strong>Anchoring while working</strong></td>
<td>Dragline crane can be on shore or on barge. If on barge, latter can be secured with spuds or anchors.</td>
<td>Several heavy spuds.</td>
<td>Several spuds or anchors.</td>
<td>Several anchors.</td>
</tr>
<tr>
<td><strong>Effect of swells and waves</strong></td>
<td>Can work up to moderate swells and waves.</td>
<td>Very sensitive to swells and waves.</td>
<td>Can work up to moderate swells and waves.</td>
<td>Very sensitive to swells and waves.</td>
</tr>
<tr>
<td><strong>Material transport</strong></td>
<td>Transport occurs in barges, trucks, or cars. Crane does not transport material. Material disposal occurs in many ways.</td>
<td>Transport occurs in barges, trucks, or cars; dredge does not transport material. Material disposal occurs in many ways.</td>
<td>Transport occurs in barges, trucks, or cars; dredge does not transport material. Material disposal occurs in many ways.</td>
<td>Transport normally occurs in barges. Dredges equipped with hoppers are limited to material disposal by bottom dumping.</td>
</tr>
<tr>
<td><strong>Comments</strong></td>
<td>The term &quot;dredge&quot; is questionable for this machine, since it is not exclusively built for underwater excavation and is frequently used for material removal above water. It is suitable for all but the hardest material and has a low production for its size.</td>
<td>Special hard material dredge of simple principle. Rudimentary machine can be assembled for temporary service by placing power shovel on spud barge. Low production for size of plant and investment.</td>
<td>This machine is simple in principle. It can be assembled in rudimentary form for temporary service by placing a crane on a barge. It is suitable for all but the hardest materials and has a low production for its size.</td>
<td>Highly developed machine. Not used in United States (other than as part of mining plant), but used extensively in other countries. It is suitable for all but the hardest materials and has a high production for its size.</td>
</tr>
</tbody>
</table>

![Silhouetted outline]
### Table 9.1 (cont) Hydraulic Dredges (Mohr, 1974, pp. 72, 73)

<table>
<thead>
<tr>
<th>Dredge type</th>
<th>Cutterhead dredge</th>
<th>Dustpan dredge</th>
<th>Hopper dredge</th>
<th>Sidecasting dredge</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1) Dredging principle</td>
<td>Material is removed with a rotary cutter (or plain suction inlet in light material) picked up with dilution water by the suction pipe, and transported through the pump and the discharge line. While working, dredge swings around spud toward an anchor.</td>
<td>Material is removed with water jets, picked up by a wide but shallow suction opening and transported through the pump and the discharge line. While working, dredge is slowly pulled toward two anchored spuds or anchors.</td>
<td>Material is removed and picked up together with dilution water by draghead sliding over bottom (or stationary) and flows through suction piping, pump, and discharge piping into hoppers of vessel.</td>
<td>Material is removed and picked up together with dilution water by draghead sliding over bottom and flows through suction piping, pump, and discharge arm over side of vessel back into the water.</td>
</tr>
<tr>
<td>(2) Horizontal working force on dredge</td>
<td>Medium intermittent force opposing swing to side.</td>
<td>Medium constant force opposing forward movement.</td>
<td>Slight constant force opposing forward movement.</td>
<td>Slight constant force opposing forward movement.</td>
</tr>
<tr>
<td>(3) Anchoring while working</td>
<td>Two spuds and two swing anchors (one working spud and one walking spud).</td>
<td>Two spuds or anchors secured upstream while working.</td>
<td>Dredge moves under own power to dig a channel or is anchored to dig a hole.</td>
<td>Dredge moves under own power to dig a channel.</td>
</tr>
<tr>
<td>(4) Effect of swells and waves</td>
<td>Very sensitive to swells and waves.</td>
<td>Very sensitive to swells and waves.</td>
<td>Little affected by swells and waves.</td>
<td>Little affected by swells and waves.</td>
</tr>
<tr>
<td>(5) Material transport</td>
<td>Transport occurs in pipeline. Length of discharge line depends on available power, but can be extended with booster pump units to a total length of several miles.</td>
<td>Transport occurs in pontoon supported pipeline to side of dredge. Spoil discharges into water. Booster pump units are not used with this plant.</td>
<td>After material is in hoppers, transport is over any suitable waterway. Material can be bottom dumped or pumped out (if so equipped). Pumpout is similar to pipeline dredge operation.</td>
<td>Transport occurs in pipeline on discharge boom over side of dredge. Material discharges into adjacent water.</td>
</tr>
<tr>
<td>(6) Dredged material density</td>
<td>Diluted to an average of 1,200 g/l.</td>
<td>Diluted to an average of 1,200 g/l.</td>
<td>Diluted to an average of 1,200 g/l.</td>
<td>Diluted to an average of 1,200 g/l.</td>
</tr>
<tr>
<td>(7) Comments</td>
<td>Highly developed machine with intricate horizontal moving procedure used throughout the world. Suitable for all but very hard materials. High production for size of plant.</td>
<td>Special sand dredge used only in United States in Mississippi River. Floating line is positioned with rudder in discharge stream. High production for size of plant.</td>
<td>Highly developed machine used throughout the world. Suitable for all but very hard materials. Production depends on traveling time to dump and mode of discharge.</td>
<td>Special sand dredge. Sand transport is limited to length of discharge boom. Used in coastal inlets or where material discharge into water is not objectionable. High production for size of plant.</td>
</tr>
<tr>
<td>(8) Silhouetted outline</td>
<td><img src="image1" alt="Silhouetted outline" /></td>
<td><img src="image2" alt="Silhouetted outline" /></td>
<td><img src="image3" alt="Silhouetted outline" /></td>
<td><img src="image4" alt="Silhouetted outline" /></td>
</tr>
</tbody>
</table>
of European dredging, Hoffman (1980) found the following advances in
dredging equipment: 1) electronic navigation by radar and transponder is
now used to position the dredge accurately while loading and unloading,
2) sonar mapping of bottom contours is used to estimate dredge quantities
and verify job performance. 3) automatic swell compensators have been
developed to keep the dredge head on the bottom in heavy weather and
waves, 4) self-propelling capabilities have been added to some cutterhead-
suction dredges, 5) water jets are being used on the dragheads of newer
trailing-suction-hopper dredges to help "fluidize" the sediments, and
6) split-hull hoppers have been developed to permit more rapid dumping.

Most of these improvements are aimed at increasing the production
rate of hydraulic dredges on large scale projects. Since dredges in small-
craft harbors must be able to work within the confines of slips and piers,
large hydraulic dredges are not effective. On these small scale projects,
mechanical dredging by clamshell, dragline, or dipper buckets attached to
a barge-mounted diesel crane has been standard practice. While such systems
have relatively low production rates, they also require low capital invest-
ment, are rapidly mobilized, excavate all but the hardest materials, and
produce high density dredge spoil. Waterways are most commonly maintained
by self-propelled cutterhead-suction dredges (Schubel, Wise and Schoof,
1979). These dredges require less manpower to operate than mechanical
dredges but they require larger capital investments, produce low density
dredge spoil, and are difficult to transport and mobilize for a project.
The selection of a dredge best suited for a particular application depends
on the type of material to be handled, its transport distance, disposal
method, and some environmental factors that are becoming increasingly
important. The cost of a dredging operation is a function of the type
of operation and the disposal method. Hydraulic pipeline operations which can pump dredge spoil up to 3 miles (4.8 km) are generally cheaper than hopper dredging, while "bucket and scow" operations are the cheapest of all (Schubel, Wise, and Schoof, 1979). As a rule-of-thumb, the cost of a hopper or scow disposal is directly proportional to the travel distance.

9.2 PRIMARY AND MAINTENANCE DREDGING

Primary dredging is required in a harbor or waterway before it will be navigable by the deepest draft vessel anticipated. Maintenance dredging on the other hand refers to dredging that may be required in the future to maintain the same depth. It is often not clear when maintenance dredging should be performed. Maintenance dredging should be scheduled so that it does not interfere with peak seasonal traffic and so that the damage caused by dredging and disposal operations is minimized. The months of September through February appear to be the most desirable time of year for maintenance dredging according to Schubel, Wise, and Schoof (1979).

Sediments should not be allowed to accumulate until the deeper draft craft (usually sailboats) become grounded and possibly damaged. Since dredging frequency is directly related to the rate at which sediments collect, it is important to be able to predict when maintenance will be required. The process of sedimentation, commonly referred to as shoaling, depends on many factors such as suspended load, particle size, depth, bottom geometry, water velocity, and flow turbulence. Shoaling rates are usually determined with the aid of a sediment transport budget. Briefly, a sediment transport budget requires balancing volumetric
sediment inflow and outflow over a specific time interval for a given area. Budgeting methods for tidal inlets and estuaries are presented by Bruun (1978) and Ippen (1966).

Increased channel depth is usually the object of new dredging projects. Along with increased depth, channel dredging will change the bottom geometry, decrease the average water velocity, and increase the turbulence on the bottom because of a rougher surface. Since all these variables influence shoaling, a preproject sediment budget will no longer be valid. In the past, a number of procedures for accessing the effect of depth on maintenance requirements have been used. The increase in shoaling rate with deepening has been assumed to be proportional to the percent increase in cross-sectional area, or the percent increase in wetted perimeter. These approaches are based on channel geometry alone and are not reliable. Experience from nearby areas and limited historical dredging data have also been used with somewhat better results (Trawle, 1981). Recently, an analytical method to predict the effect of depth on dredging has been developed by the U.S. Army Engineer Waterways Experiment Station (Trawle, 1981). This method requires more effort than the procedures mentioned earlier, but it is much more reliable and can accommodate the effects of advance maintenance dredging.

9.3 DREDGED MATERIALS AND THEIR DISPOSAL

Dredged materials range from clean sands to fine-grained oozes. Most dredged sand comes from the near-shore zone or from waterways where the water velocity is relatively fast. In most cases, sand should be considered a resource to be exploited instead of wasted. It is used in many phases of coastal construction such as concrete work, beach and dune
nourishment, and as a bearing surface under rubble-mound breakwaters (See Ehrlich and Kulhawy, 1982). Fine-grained sediments consist of silt and clay particles mixed with organic matter to form muds that settle in the quiet waters of harbors and bays. More than 75 percent (by volume) of the materials dredged from harbors and bays bordering Long Island Sound, New York are composed of silt and clay (Schubel, Wise, and Schoof, 1979). Malloy (1980) states that about 87 percent of the material dredged by the U.S. Navy Harbor Maintenance is mud (silty-clay or clayey-silt). The in-place densities of these dredged materials range from 80 pcf (12.5 kN/m³) for very loose muds to about 125 pcf (19.6 kN/m³) for sand deposits.

The methods of disposal of dredged materials depends on the type of material, the type of equipment available, the location of the disposal site, and numerous environmental concerns. Some of the alternatives for disposal are offshore dumping, overboard disposal, construction of artificial islands, beach nourishment, and the filling of upland areas. Dredge spoil has been used for fertilizer in the past (mostly in Europe), but this practice is no longer common because the fine-grained sediments that contain the most nutrients are very often contaminated.

An upland disposal site within about 3 miles (4 km) of the dredging site is most economically favorable according to Schubel, Wise, and Schoof (1979). In such a case, the dredge spoil would probably be pumped to a diked containment area through a hydraulic pipeline. There are several disadvantages to such an operation however. Relatively few upland areas adjacent to waterways or harbors are undeveloped, so land acquisition may be very expensive. The containment facilities permanently change the
landscape and have a finite lifespan. They may not be effective in protecting water quality since some of the finer soil particles (carrying the contaminants) can flow over the outlet wiers with the excess water. Finally, the engineering characteristics of most hydraulic fills are poor because of their high water content and weak soil structure. These properties may be improved by draining the deposit and "reworking" it. Saucler (1978) indicates that surface trenching is a cheap and effective way to dewater and densify hydraulic fills.

Beach nourishment is usually accomplished by hydraulic pipeline, but since sand is the only suitable material, containment dikes are not required. Sand is pumped directly onto the beach and settles quickly, allowing the water to run off the shore. The primary reason for beach nourishment is to create or sustain a beach for recreational purposes. Clean sand from nearby maintenance dredging is often used to repeatedly nourish beaches that are not inherently stable. A special case of this situation occurs when jetties are located at river mouths. Sand accumulates on the updrift side of the jetty while the beach or shore on the down-drift side erodes and recedes. If sand is allowed to bypass the jetty, it eventually forms a shoal in the channel. One of the methods of controlling sand bypassing is to dredge the sand and deposit it on the down-drift beach. Figure 9.1 illustrates some common sand bypassing systems. In the absence of a sand bypassing system, deeper sections called "sand traps" are often dredged in the channel where shoaling is expected. To remain functional, these sand traps must be routinely maintained. Jetties and sand bypassing are discussed by Ehrlich and Kulhawy (1982).
Figure 9.1 Beach Nourishment and Sediment Bypassing
(Sorenson, 1978, p. 205)
Artificial islands are constructed in much the same manner as the diked upland disposal sites. First, a shoal area is outlined by a layer of rubble to form the containment. Then the fill (usually sand) is pumped into the middle by a hydraulic dredge. While fine-grained sediments may also be used to build artificial islands, a layer of sand around the perimeter may be necessary to act as a filter zone. Islands formed by dredged material disposal provide the unique opportunity to create an upland habitat that is environmentally beneficial and has wide public appeal (Saucier, 1978). After placement, the island must be stabilized (dewatered and densified) and planted. Woodhouse, Seneca, and Broome (1974) address the problem of establishing salt marshes on dredge spoil. Schubel, Wise and Schoof (1979) discuss the kinds of dredged material suitable for salt marsh construction, and the mobilization of contaminants associated with these materials by salt marsh plants.

Overboard disposal is the term usually used to describe the discharge of dredged materials in unconfined disposal sites relatively close to the area being dredged (Schubel, Wise, and Schoof, 1979). This method of disposal is usually accomplished by picking up the dredge material with a draghead and pumping it (via a discharge arm) over the side of the vessel and back into the water. This type of dredge is called a "side-caster" (See Table 9.1). Side-casting dredges are limited to sand removal because the discharge of fines produces excessive turbidity.

If the only practical alternative is open-water disposal, the proximity and water depth of the disposal site will govern the choice of dredging/disposal methods (Schubel, Wise, and Schoof, 1979). Hydraulic pipeline dredges have an economical spoil transportation limit of about 3 miles (4 km). If the disposal site is farther away but relatively
shallow, the bucket and scow method would probably be used. Hopper
dredging and disposal is most often used when the disposal site is
distant and the water depth at the disposal site is greater than about
30 ft. (9 m) (Schubel, Wise, and Schoof, 1979). Since the cost of open-
water disposal increases proportionately to the travel distance, the most
economical disposal area is closest to the dredging site. Environmental
concerns usually favor the more distant disposal areas, however. Saucier
(1978) states that extensive deep ocean areas are environmentally more
acceptable than are some highly productive continental shelf areas,
especially for contaminated materials.

9.4 ENVIRONMENTAL IMPACTS OF DREDGING

Dredging operations of the past usually had economics as the primary
performance criterion. With today’s increased ecological awareness, how-
ever, environmental concerns are rapidly gaining importance. While it is
evident that dredging does have some environmental impact, not all of its
effects are negative. This section presents some of the advantageous and
deleterious effects of dredging followed by a discussion of some of the
less obvious items.

In a summary of their work on the environmental effects of dredging,
Herbich and Schiller (1974) suggest the following:

A. Advantageous Effects of Dredging

1. removal of polluted bottom sediments for safe storage
and/or treatment.

2. re-oxygenation of sediments.

3. increase of the overall water column oxygen content
by mixing.
4. resuspension of nutrients to make them available to suspension feeders.

5. removal of dissolved and particulate absorbed pollutants from the water column by tying them up in bottom sediments.

6. modification of flow patterns.

B. Deleterious Effects of Dredging

1. removal of habitats.

2. resuspension of pollutants absorbed to sediments, thus increasing their toxicity.

3. physical damage to organisms.

4. may present a barrier to the movement of fish or other marine life.

5. mortality due to burial of habitats.

6. modification of flow patterns.

7. turbidity.

8. All of the above may affect the smallest of marine organisms directly, thus removing them from the food chain and eventually affecting the food supply of man.

There is no doubt that dredging operations can have a severe impact on marine life. With proper control, however, little damage is caused by dredging. Major effects are physical damage to individual organisms, removal of habitat, and burial because of open-water disposal. Physical damage is minimized by limiting the area that the dredges can operate in. Texas, for example, now allows dredges to operate no closer than 300 ft. (90 m) from established live oyster reefs (Laycock, 1968). Removal of habitat cannot be avoided. This affects fish more than shellfish because the fish use forests of seaweed for protection. It may take more than a year for sea grasses and seaweed to recolonize dredged areas (Godcharles, 1971).
Dredged materials settle in a rapid jet after being discharged into open water. The coarser materials go directly to the bottom as a density flow while a small percentage (less than 5% of the total mass released) is suspended as a turbid plume. The spoil then spreads (See Figure 9.2) to either side to form a "pancake" that is thicker and denser at the center. Lacking the mobility of fish, shellfish are often caught under this layer of spoil. Saucier (1978) states that the survival of buried organisms is maximized when the type of material disposed of at a site has the same grain size distribution as the natural bottom.

Pollutants will always be found in varying degrees in dredged materials. The impact of these pollutants is measured by its toxicity which is related to the type of contaminant and its concentration. Contaminants are grouped by Schubel, Wise, and Schoof (1979) into several classes as follows:

1. Heavy Metals, including cadmium, mercury, lead, nickel, and chromium.

2. Halogenated hydrocarbons, including such industrial chemicals as PCB's and pesticides like DDT, Aldrin, and Dieldrin.

3. Pathogenic bacteria and viruses.


5. Other exotic organic and inorganic chemicals.

6. O$_2$-demanding substances.

These materials are all more easily absorbed by fine-grained sediments than by coarser materials like sands. Treatment of dredged material for contaminants is not generally practical because of the very large volumes, the variable nature of the material involved, and the very low concentra-
Figure 9.2 Behavior of Dredged Material Released from a Scow (Schubel, Wise and Schoof, 1979, p. 51)
tion of the contaminants (Saucier, 1978).

The process of dredging in itself tends to re-oxygenate sediments. Especially during hydraulic pipeline operations, in-line re-oxygenation appears to be economically and operationally feasible (Saucier, 1978). The rate at which spoil areas are repopulated can be markedly increased by an increase in the dissolved oxygen content of the sediments.

Turbidity is the one most obvious environmental impact of dredging. Turbidity is caused by the resuspension of fines during dredging and disposal. Turbid waters are much worse in appearance to the observer than they are in their impact on aquatic life. Open-water pipeline disposal causes the greatest turbidity of any dredging method, yet less than 5 percent of the total amount of solid material discharged is incorporated in the turbid plume (Schubel, Wise and Schoof, 1979). Concerning regulatory actions of prescribing maximum turbidity levels, Gustafson (1972) states that such actions have been taken "in almost complete ignorance of the degree of damage, if any, and in spite of the fact that wind and tide generated turbidity dwarf those of man's actions."

On the effect of turbidity or suspended sediment particles on both water quality and aquatic organisms, Saucier (1978) wrote, "turbidity is primarily a matter of aesthetic impact rather than biological importance." ... "most adult organisms can tolerate turbidity levels and durations far in excess of what dredging and disposal operations produce." One of the beneficial effects of turbidity is that in resuspending bottom sediments, nutrients are provided for fish to feed upon.
9.5 DREDGING PROBLEMS

Dredging operations are subject to problems that adversely affect the operation of coastal facilities. These problems may be categorized in three groups, problems that are directly related to the dredge itself, problems caused by the character of the material to be dredged, and problems dealing with the surrounding structures.

Small craft harbors are not generally large enough to justify purchasing a dredge solely for that project. It is therefore necessary to obtain a dredge from some outside source and have it transported to the marina site. The first problem that arises is the cost and difficulty of moving a dredge that may need to be partially dismantled. Secondly, the dredge type available may not be suited to the material to be dredged, and modifications are necessary to prevent an inefficient operation.

Prior to dredging, the character of the bottom materials is usually determined by drilling a number of test holes or test pits scattered around the area to be dredge. By interpolation, these bore hole logs are used to identify the soil types and their distribution. It is relatively easy however to miss pinnacles of bedrock intrusion or large boulders suspended in a softer matrix. Layton (1979) cites a case where a cutter section hydraulic dredge was contracted to excavate a basin in Northern Puget Sound, Washington. Although tests indicated only silt deposits, the dredge soon encountered boulders that jammed the pump and pipeline, and caused structural damage to the cutter head assembly.

Most coastal structures can be easily damaged by dredging operations. Damage occurs either by physical contact with the structure, or by removing the underlying soil so that the structure becomes unstable. Inner harbor structures such as docks, piers, and wharves are the most
vulnerable since there is little room to maneuver. Bray (1979) states that mechanical dredges are more suitable for keeping close tolerances under such conditions because of their accuracy in dredging to a predetermined depth and their positive digging action. Suction dredges, on the other hand, often overdredge to an excessive amount and can easily cause stability problems at the toe of a sheet pile or gravity wall structure.

Dredging operations also present some other problems that are not so obvious. Dredging alters the shoaling characteristics of a harbor bottom and may result in an increase in the depositional rate. The impact of dredging on the environment because of disruption of habitat at the dredging and disposal sites may also be significant. While these factors are difficult to assess or quantify, environmental impact is an important issue that should not be taken lightly.

9.6 SUMMARY

Dredging is an important aspect of harbor design and maintenance. Dredging is performed to excavate basins or waterways for navigation or to maintain these areas as sedimentation occurs with time. Primary dredging is likely to encounter harder, more consolidated materials, while maintenance dredging must remove soft sediments and debris.

There are two general categories of dredges differentiated by the method of spoil removal, including mechanical and hydraulic processes. Within these categories, dredges are often custom designed using components of various types to meet specific conditions.

Dredged materials are either used as fill to create or maintain adjacent land areas, or they are taken to some external disposal site as a waste product. The use of dredged material for agricultural purposes is
discouraged because of the presence of heavy metal contaminants.

The environmental impacts of dredging include favorable as well as deleterious effects. Dredging both destroys and creates marine life habitat, modifies bottom flow patterns, and influences future sedimentation rates.

Dredging leads to problems related to the dredge equipment, dredge materials removed, adjacent structures, and the environment. Proper planning and control can minimize these problems and ensure a successful operation.
CHAPTER 10

SUMMARY AND CONCLUSIONS

Docks, piers and wharves are coastal structures constructed on the shoreline or waterfront to provide an interface between land and water modes of transportation. These structures are often supplemented with the construction of bulkheads and boat ramps for ease of access from the landside. Breakwaters and jetties provide protection on the seaside and create a calm, sheltered harbor that is easily navigated.

Harbor layout and planning should encompass the inner harbor structures as well as the surrounding protective works. Model studies are a very useful tool during the planning and layout phase to confirm that the coastal processes are as expected and to ensure that the resulting installation will be a functional and financial success.

The “ideal” marina should have a land to water ratio of approximately one to one, with convenient access by land and water. It should be located reasonably close to a center of population and to recreational boating waters to minimize travel time for users. Efficient dock, pier and wharf layout requires proper orientation of these structures for convenient use in the least possible space while providing add-on capabilities for future expansion needs.

The various loads that should be considered during the structural design of docks, piers and wharves may be separated into two broad categories: natural and man-made. Natural loads are those caused by environmental processes and occur in the form of waves, wind, current or ice. Man-made loading conditions include boat impact, and dead and live loads. Although the magnitudes of these loads are dependent on
site specific conditions, wind loads are generally dominant. It is
customary practice to combine the various loads in a rational manner when
determining a structural design load. While it may be technically
feasible to build docks, piers or wharves to resist the severe design
loads that are caused by exposed locations and heavy storm action,
construction and maintenance costs become excessive. Under these condi-
tions, breakwaters and jetties are generally provided to attenuate the
environmental loads and create a sheltered berthing area. Catastrophic
events such as earthquakes, hurricanes and tsunamis can cause loads
that are impractical to consider in routine design. Instead, an emphasis
should be placed on early warning and evacuation systems to minimize bodily
injury and property damage.

The principal materials used in coastal construction are concrete,
steel and wood. Aluminum, wrought iron and various synthetic materials
are used less frequently. Most structures are constructed from several
different materials since each material has properties that make it
suitable for different applications. Material selection for a given
application depends on availability, strength, durability and cost.
Because of the harsh marine environment, durability may become a more
critical design parameter than strength with respect to the sizing of
members. Oversizing of structural members is one method of compensating
for the loss of section that results from deterioration and corrosion.
Additives, preservatives, alloys and coatings are also used to increase
material durability.

There are three broad categories of structures used in the con-
struction of docks, piers and wharves. These include solid fill struc-
tures, fixed or pile supported structures, and floating or pontoon supported structures. Small craft harbor facilities are generally a combination of each of these structural types. The trend in modern marina construction is toward the use of a floating berthing area that is accessed by a fixed pier approach. Solid fill walls are used to stabilize the harbor perimeter and provide an abrupt land/water interface.

Solid fill type docks, piers and wharves are constructed of fill that is held in place by a retaining wall. While the anchored bulkhead is the most common wall type, others include the cantilever sheet pile wall, cantilever "L" wall, gabion wall, crib wall, cellular sheet pile wall, concrete caisson wall, and walls supported by relieving platforms. The selection of the appropriate wall type for a given location depends on the project scope, the required depth of water, the consistency of the underlying soils, the loads imposed, and the allowable movement of the wall after completion. Dredging and backfill operations conducted during construction of a solid fill wall must be carefully controlled to avoid damaging the wall.

Docks, piers and wharves that are pile supported are considered fixed structures. They are generally suitable for the construction of berths where the water surface fluctuations do not exceed about 4 ft (1.2 m), the basin depths are less than about 20 ft (6.0 m), and the average user craft are more than 30 ft (9.0 m) in length. The usual structural geometry of a fixed dock or pier starts with a row or "bent" of piles tied together at the top by a pile cap. The bents support longitudinal stringers upon which the decking is laid. Bracing is provided in the
vertical and horizontal planes to create a rigid framework. The long-
term performance of such a structure demands prompt maintenance since a
loose connection or damaged member may create an artificial hinge that
quickly destroys the overall structural integrity of the system.

Pontoon, instead of piles, provide the means of vertical support
for floating docks, piers and wharves. Lateral restraint must be
provided separately by bracing from the shore, by installing guide piles,
or by anchoring with cables to the bottom. Floating docks are generally
favored for sites with water level variations greater than about 4 ft
(1.2 m), basin depths in excess of 20 ft (6.0 m), and user craft less
than about 30 ft (9.0 m) in length. The foam filled shell or pontoon
is the building block of the floating dock. These pontoons support a
framework of stringers, walers, braces and decking that behaves in a
semi-rigid manner. Floating docks are well suited to modular construc-
tion and prefabrication.

Utilities and other services have become a necessary part of the
successful modern marina. Utilities that are commonly provided at the
berth include electrical power and freshwater. Sewage disposal facilities
may be provided in the form of a portable holding tank or a fixed
pumpout station. In some cases, however, sewage hookups as well as
telephone connections are installed at the berths. Fire fighting
capabilities and a station for refueling are examples of special services.
These systems are subject to many regulations on the federal, state and
local level. For proper performance, it is important that utilities and
special services not be treated as add-on systems.

Dredging or the removal and disposal of submerged materials is
often required for the creation or maintenance of waterways and harbors. There are two broad categories of dredges distinguished by the method of spoil removal. Mechanical dredges excavate underwater deposits by means of buckets or scoops while hydraulic dredges must reduce the material to a slurry that can be pumped. Dredged materials can range from very fine-grained soils to large boulders, trash and debris. Some of this material may have value as beach or structural fill. Most dredged spoils are considered waste products and are transported to a disposal site. The environmental impacts of dredging include the creation and destruction of marine life habitat, modification of bottom flow patterns, and increasing turbidity levels.

This report has presented guidelines for the planning, layout and design of dock, pier and wharf structures. With the aid of knowledgeable professionals, these guidelines can help to ensure a successful marina installation. It should be noted, however, that there can be no substitute for sound engineering judgment in coping with unanticipated or unusual conditions that are often encountered when building on the waterfront. Several cycles of analysis and design may be necessary before an optimal design is achieved.


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APPENDIX A

Small Craft Berthing Facilities,
Layout

State of California, 1980
pp. 3-9, 12
II-Design Criteria

A. WATER AREAS

1. CHANNELS - ENTRANCE
   a. Minimum Width: 75 ft. at design depth.
   b. Minimum Depth: 3 ft. below deepest draft vessel anticipated to be berthed in harbor, or 5 ft., whichever is greater. Design depths shall consider anticipated wave action and rate of siltation.

2. CHANNELS - INTERIOR
   a. Minimum Width: 75 ft. at design depth.
   b. Minimum Depth: 2 ft. below deepest draft vessel anticipated to be berthed in harbor, or 4 ft., whichever is greater.

3. FAIRWAYS
   a. Minimum Width:
      (1) 1.75 times length of longest berth where berths are perpendicular to the fairway.
      \[ L_b = \text{length of fingerfloat} \]
      (2) 1.50 times length of longest boat where boats are berthed parallel to the fairway.
      \[ l_b = \text{length of boat (LOA)} \]
   b. Minimum Depths:

<table>
<thead>
<tr>
<th>Berth Length</th>
<th>Minimum Depth</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Power</td>
</tr>
<tr>
<td>up to 25'</td>
<td>4'</td>
</tr>
<tr>
<td>35'</td>
<td>6'</td>
</tr>
<tr>
<td>45'</td>
<td>6'</td>
</tr>
<tr>
<td>55'</td>
<td>8'</td>
</tr>
<tr>
<td>65'</td>
<td>8'</td>
</tr>
</tbody>
</table>
4. BERTHS - SINGLE

a. Minimum water depth: Same as for fairways

b. Minimum width: \( L_b = \text{length of berth (fingerfloat)} \)
   \[ W_b = \text{width of berth} = \text{beam of boat @ waterline} + 2 \text{ ft.} \]

<table>
<thead>
<tr>
<th></th>
<th>POWERBOATS</th>
<th>SAILBOATS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Recommended</td>
<td>[ W_b = 8 \ln L_b - 14 \text{'} ]</td>
<td>[ W_b = 6.5 \ln L_b - 10.5 \text{'} ]</td>
</tr>
<tr>
<td>for Design</td>
<td>for Preliminary</td>
<td></td>
</tr>
<tr>
<td>Work</td>
<td>Layout and Planning</td>
<td></td>
</tr>
<tr>
<td></td>
<td>[ W_b = \frac{L_b}{4} + 6' - R_p ]</td>
<td>[ W_b = \frac{L_b}{5} + 5.5' - R_p ]</td>
</tr>
<tr>
<td></td>
<td>( R_p = 0.1 \text{ ft. for each foot of berth length over 40 feet.} )</td>
<td>( R_p = 0.075 \text{ ft. for each foot of berth length over 40 feet.} )</td>
</tr>
</tbody>
</table>

Note: See Page 3 for table of recommended berth widths.

5. BERTHS - DOUBLE

a. Minimum water depth: same as fairways and singles.

b. Minimum width:
   \[ W_{db} = \text{width of double berth (ft)} \]
   \[ W_{db} = W_b \times 2 \text{ (see 4b above)} \]

c. Where double berths consist of two berths of different lengths, the double berth width \( (W_{db}) \) will be equal to the sum of the two single berth widths:
   \[ W_{db} = W_{b1} + W_{b2} \]

d. Where it is desired to convert a double berth into two single berths by installing a fingerfloat down the center, additional width must be provided for the fingerfloat. Encroachment upon the berthing space will not be permitted.
# Table 1

**Recommended Single Berth Widths**

<table>
<thead>
<tr>
<th>&quot;L&quot; Berth Length (Feet)</th>
<th>In L</th>
<th>Powerboats</th>
<th>**(W_b = 8 \text{ in } L - 14) **</th>
<th>Recommended Widths ***</th>
<th>Sailboats</th>
<th>**(W_b = 6.5 \text{ in } L - 10.5) **</th>
<th>Recommended Widths ***</th>
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* For double berth widths, multiply by two.

** These equations were developed by Cal Boating on an empirical basis via field observation and measurements, and review of boat manufacturers specifications on length and beam of power and sailboats typically found in California marinas and harbors.

*** Recommended widths are rounded "up" to the nearest half foot.

**Note:** To convert feet to meters, multiply by 0.3048.
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Note: Numbers in circles refer to equations on page 7.
(SUPPORT DATA FOR TABLE II-A)

MINIMUM VALUES FOR "F"

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FOR POWERBOATS, \( W_b = 8 \ln L_b^{14} \)  

FOR SAILBOATS, \( W_b = 6.5 \ln L_b^{10.5} \)

**EQUATIONS**

**FOR POWERBOATS:**

1. \( A_{\text{TOTAL}} = (1.875 L_b + 3)(F + 8 \ln L_b^{14}) \)
2. \( A_{\text{DECK}} = F(L_b + 3) + 3(8 \ln L_b^{14}) \)
3. \( \text{BERTHS/ACRE} = \frac{43560}{1} \)

**FOR SAILBOATS:**

4. \( A_{\text{TOTAL}} = (1.875 L_b + 3)(F + 6.5 \ln L_b^{10.5}) \)
5. \( A_{\text{DECK}} = F(L_b + 3) + 3(6.5 \ln L_b^{10.5}) \)
6. \( \text{BERTHS/ACRE} = \frac{43560}{4} \)

**NOTE:** The equations are based on the assumption that main walkways are 6 feet wide (see pg.12)
TABLE III-A
BERTHING LAYOUT PLANNING DATA FOR DOUBLE BERTHS

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Note: Numbers in circles refer to equations on page 9.
TABLE III-B
(SUPPORT DATA FOR TABLE III-A)

<table>
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<tr>
<td>21' TO 35'</td>
<td>3.0'</td>
</tr>
<tr>
<td>36' TO 60'</td>
<td>4.0'</td>
</tr>
<tr>
<td>61' &amp; UP</td>
<td>5.0'</td>
</tr>
</tbody>
</table>

MINIMUM VALUES FOR "F"
(SEE PAGE 12)

\[ W_b = 8 \ln L_d - 14 \]  
FOR POWERBOATS

\[ W_b = 6.5 \ln L_d - 10.5 \]  
FOR SAILBOATS

EQUATIONS

FOR POWERBOATS:

7. \[ A_{\text{TOTAL}} = (1.875 L_d + 3) \left( \frac{F}{2} + 8 \ln L_d - 14 \right) \]

8. \[ A_{\text{DECK}} = \frac{F}{2} (L_d + 3) + 3(6.5 \ln L_d - 14) \]

9. \[ \text{BERTHS/ACRE} = \frac{43560}{7} \]

FOR SAILBOATS:

10. \[ A_{\text{TOTAL}} = (1.875 L_d + 3) \left( \frac{F}{2} + 6.5 \ln L_d - 10.5 \right) \]

11. \[ A_{\text{DECK}} = \frac{F}{2} (L_d + 3) + 3(6.5 \ln L_d - 10.5) \]

12. \[ \text{BERTHS/ACRE} = \frac{43560}{10} \]

NOTE: The equations are based on the assumption that main walkways are 6 feet wide (see pg. 12)
C. FLOATING STRUCTURES

1. DIMENSIONS

a. Marginal Walkways

(1) When serving main walkways which do not have individual gangways, the minimum unobstructed width shall be 8 ft.

(2) When serving main walkways which have individual gangways, the minimum width shall be 6 ft.

b. Main Walkways

(1) Minimum unobstructed width shall be 6 ft.

(2) Maximum length shall be 750 ft.

c. Fingerfloats

(1) For berths up to 20 ft. long, the minimum width shall be 2.5 ft.

(2) For berths between 21 and 35 ft. long, the minimum width shall be 3 ft.

(3) For berths between 36 and 60 ft. long, the minimum width shall be 4 ft.

(4) For berths longer than 60 ft., the minimum width shall be 5 ft.

(5) Tie-down cleats shall be provided as required. However, not less than two (2) cleats shall be provided on each side of each fingerfloat. One (1) cleat per berth shall be provided on the main walkway.