III. ENVIRONMENTAL IMPACT OF DREDGING AND IWT DEVELOPMENT*

. Dredging

Dredging is the process of removing material from the bed or banks of a waterway and disposing it in another part of the waterway, where it presumably will not be readily resuspended and return to the main channel, or disposing on land. Dredging operations are primarily for the purpose of deepening or widening navigation channel or to obtain fill material for land development.

The main advantage of dredging lies in that it can improve navigation conditions in many reaches of rivers immediately. But the dredged channel is usually unstable, and has to be maintained. Hence, a combination of dredging and training works is considered as more appropriate. It is possible to train the river mainly by using dikes and bank revetment, and to maintain the channel by dredging.

Once dredging is used to improve navigation conditions, one should determine the following factors:

location and alignment of the dredged channel;
dimensions of the dredged channel;
the type of dredge to carry out dredging operations; and
the site for deposing the dredged material.

The problems mentioned above will be discussed in this part.

1.1 Location and Alignment of a Dredged Channel

From the view of sediment movement and river bed configuration, an alluvial river is usually in an equilibrium state. Dredging will destroy the balance and the dredged channel may be silted again. Thus, the location and alignment of the dredged channel or the dredge cut should be determined very carefully. As far as the deepening of approach channels to harbors is concerned, the location is more or less dictated by local circumstances. However, the determination of the optimum alignment of a navigation channel through river crossings is more difficult. If this alignment does not comply with the natural characteristics of the river, the channel will either fill up rapidly or else never become as deep or wide as required.

In determining the location and alignment of a dredge cut, the following principles should be applied:

The location of a dredge cut must be selected based on the thorough analysis of the cause of shoal formation, the regularity of shoal evolution, and the effect of special topography on river morphology.

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To keep away from sediment silting area, the dredge cut should be laid out near the dominant bank and have the same alignment as the bank. Close to a shifting side flat, island and the downstream of a sand spit should be avoid. If the grain size of bed material differently distributes over a shoal, the site with coarse bed material, where sediment transport capacity is higher, may be chosen for the dredge cut.

To reduce the possibility of siltation, the velocity of flow in the dredged channel should be greater than the velocity before dredging and also greater than the velocity of the upstream river reach. Furthermore, the mean velocity should increase along the dredged channel so that the incoming sediment can be transported downstream farther.

The orientation of the channel to be dredged should conform primarily to the main current direction at mid-low level in the river or the main current direction of ebb-tide at the estuary. When channels are dredged in open water at an angle of 15° or less to the predominant current direction, the mean velocity of flow tends to increase due to an increase in hydraulic radius. This may lead to a self-cleaning situation. According to both Chinese and overseas engineering experiences, a dredged channel is unstable when the angle exceeds 20°. The angle usually ranges from 12° to 15° in the Yangtze River, 8° - 16° in the Songhuajiang River (located in north-east China), and 9° - 15° in the Xiangjiang River and Dongting Lake (both located in central China).

To make navigation and construction easy, a short dredge cut may be connected to the upper and lower pools in a straight line; while a long dredge cut may be of slightly curved pattern formed by broken lines, connecting smoothly with the upper and lower pools, this will let each stretch of the dredged channel at a small angle to the main current direction.

To enable vessels to freely enter the channel and to attract more flow into the channel, the entrance stretch of a dredge cut may be widened into the flaring shape. For the outlet stretch of a dredge cut in a plain river, where incoming sediment is usually very high, it is advisable to deepen it according to specific conditions.

Channel Dimensions

Dredged channel dimensions include channel depth, channel width and side slope. The depth and width of a dredged channel depend on the types and sizes of vessels and tows as well as their maneuverability. The side slope should be adopted according to the soil characteristics. These will be briefly described below.

Standard Water Depth

According to the "Technical Code of Regulation Works for Navigation Channels" issued by the Ministry of Communication of P. R. China (MOC), the standard water depth can be calculated as follows (Figure 1):

$$H = t + \Delta H \quad (1)$$

where: H - standard water depth of the channel (m);
t - standard draft of ships (m);
ΔH - allowance for water depth (m)(see Table 1)

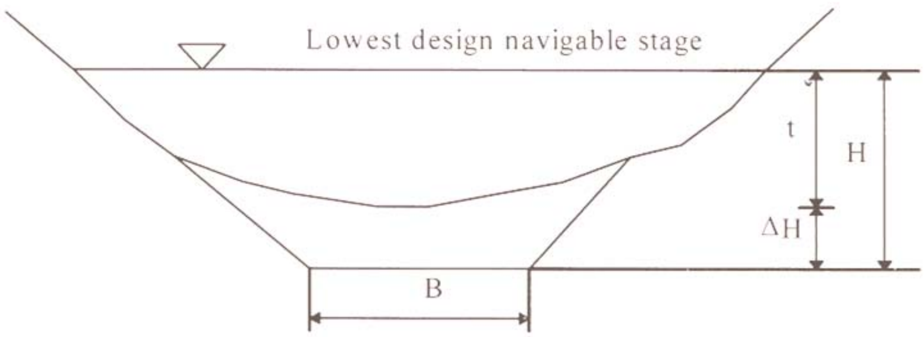


Fig. Definition of channel dimensions

Table 1 Allowance for water depth (m) (required for sand/mud river bed)

Standard water depth (m)	< 1.5	1.5 - 3.0	≥ 3.0
Depth allowance (m)	0.2 - 0.3	0.3 - 0.4	0.4 - 0.5

Note: 0. - 0.2 m should be added to the tabulated figures for rock/pebble river beds.

Standard Width

The standard width of navigation channel classified as double-lane and single-lane channel may be selected according to traffic density and channel conditions.

Straight Line Section. The width of a double-lane channel can be computed by the following formula:

$$B = b_1 + L_1 \sin\theta + b_2 + L_2 \sin\theta + 2D + \Delta B \quad (2)$$

where: B - width of a double-lane channel (m);
b_1, b_2 - widths of up-bound/down-bound fleet (m);
L_1, L_2 - lengths of up-bound/down-bound fleet, or length of the longest barge in case of a tow fleet (m);
θ - drift angle of the on-going barge fleet or ship. It maybe taken as 3° - 5°;
D - distance between shipboard and the sideline of navigation channel (m);
B - transverse distance between boards of two barge fleets (m).

The width of a single-lane channel can be calculated on the down-bound fleet basis:

$$B = b_2 + L_2 \sin\theta + 2D \tag{3}$$

Bend Section. The channel width of a bend section should be determined by such factors as radius of curvature, flow velocity and direction, flow regime, barge fleet length and its maneuverability, etc.

The channel width of a river bend need not be widened when R > 6L, but ought to be properly widened when R < 3L. When 3L < R < 6L, whether the channel needs to be widened may be decided by the specific conditions of water flow, etc.

It is recommended that the width increment of a river bend be determined through test runs of prototype ships, or be selected, according to circumstances, through verification by the following formula:

$$\Delta B = \frac{L^2}{2R + B} \tag{4}$$

where: B - width increment of a bend (m);
R - radius of curvature (m);
B - channel width of straight section (m);
L - maximum length of push barge fleet or the longest barge length of towing fleet (m).

Side Slope

Typical side slopes below water level for various soil types are shown in Table 2. These values are often adopted and have been found to be satisfactory over long periods of time. The characteristics of mud and silts depend to a great extent on the time during which consolidation has been taking place. In the extreme they may be little more than liquids. For example, at the estuary of the Yangtze River the bed material is composed of silts, the side slope of a dredged channel there is usually taken as 1:100.

Table 2 Typical side slopes below water level

Soil type	Side slope (vertical : horizontal)
Rock	Nearly vertical
Stiff clay	1 : 1
Firm clay	1 : 1.5
Sand clay	1 : 2
Coarse sand	1 : 3
Fine sand	1 : 5
Mud and silt	1 : 8 to 1 : 60

1.2 Dredging Equipment

Almost all modern dredging equipment can be classified as mechanical and hydraulic. Mechanical dredges lift the dredged material by means of diggers or buckets of various design; hydraulic (suction) dredges pick up the dredged material by means of suction pipes and pumps. In the following paragraphs a number of dredge types will be described.

Mechanical Dredges

Mechanical dredges remove loose soft or hard materials by a dipper or bucket of some type and usually operate with disposal barges that are filled with the excavated material and then move to the disposal site for unloading. Typical examples of this type are the grab dredge, the dipper dredge, and the bucket dredge. All these dredges are not normally self-propelled and are moved to the work site by a tow.

Grab Dredge. This type of dredge is essentially derrick mounted on a barge and equipped with a wire-mounted bucket of the type deemed most appropriate for the material to be dug. The barge is normally equipped with two spuds forward and one spud aft, the latter spud for advancing the dredge. When dredging, the bucket is dropped through the water in an open position and digs into the bottom material; it is closed, removing material from the bottom, and then raised and emptied. The bucket capacity ranges from 0.8 to 13 m^3, and the operating depth is limited to about 40 m.

The grab has the advantages of being relatively low priced, having modest manning requirements, being able to work in confined areas near docks, and able to pick up large particles

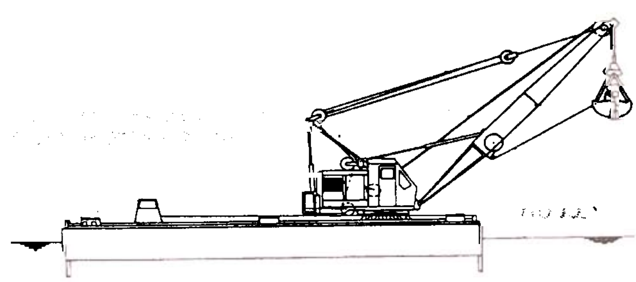


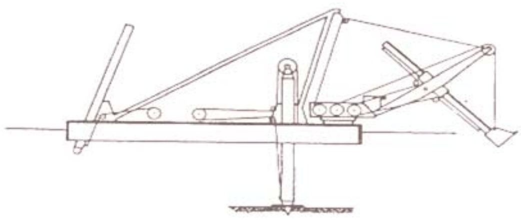
Fig. 2 Grab dredge

such as boulders, cable, and miscellaneous trash that are difficult for hydraulic dredge to handle. Another significant advantage derives from its wire rope connection to the dredge, i. e., its ability to work in sea-state that would incapacitate any dredge that has its bucket or excavator rigidly attached to the dredge. Also, the digging depth of the grab is limited only by the amount of wire it can carry on its drums. Increasing the digging depth of most dredges is a major undertaking, but for a grab it is a simple matter.

The grab does have its limitations. It is of inherently low capacity, and due to the difficulty of accurately "spotting" the bucket, is not a good channel digger. It does not give good results in light free-flowing material, because as the bucket is raised, much material is washed out of the bucket. Even in heavy sand, the bucket may come up empty except for the oversized particle that prevents the jaws of the bucket from closing, allowing the sand to run out like an hourglass.

Briefly stated, the grab is a low-priced dredge with low capacity, limited project application, and good sea-state response.

Dipper Dredge. The dipper dredge is essentially barge-mounted power shovel with considerable digging power. Like the grab, its barge has three spuds with the aft spud for advancing the dredge. The bucket capacity is normally about 4 to 6.5 m^3 (0.15 to 1.0 m^3 for small type dipper dredges) and the operation depth is up to 15 m.



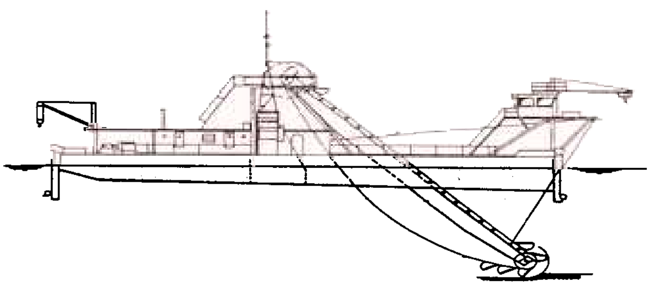
Dipper dredge

The dipper is moderately priced, and has all the advantages of the grab, except for its deep-digging and sea-state capacities. The bucket is structurally connected to the dredge, and in heavy seas, would be subject to severe damage if and when the bucket is driven into the bottom by dredge hull descending from a swell.

The dipper is of low to moderate capacity, but, because of its structural connection, can be "spotted" more accurately than the wire-mounted bucket, and can therefore excavate a more accurate channel. It can lose capacity in light material, but performs well in coarse sand, gravel, rock, and clay, including firm material.

Briefly, the dipper is a moderately priced dredge, of low to moderate capacity, broad project application, and poor sea-state response.

Bucket Dredge. The bucket dredge consists essentially of an endless chain of buckets. The top of the chain is thrust into the underwater deposit to be dredged so that each bucket digs its own load and carries it to surface. The dredge operates on wires by swinging parallel to the work face, and advances on a lead wire, while being held in position by stern wires. The productivity of bucket dredge ranges from 10 m^3/h to 1000 m^3/h. The capacity of each bucket is usually 0.2 - 0.8 m^3, maximum 1.0 m^3.



Bucket dredge

The bucket has the advantages of continuous operation, high cutting force, minimum dilution, definitive positioning for channels, and the capacity of picking up everything it excavates including large particles.

The disadvantages are high first cost, mobilization, and maintenance. It is very sensitive to swells.

The bucket dredge is an expensive mechanical dredge with continuous operation, broad project application, good excavating characteristics and poor sea-state response.

Hydraulic Suction Dredge

Hydraulic suction dredges can be categorized according to the means of disposal of the dredged material into: hopper (trailing suction), pipeline (cutterhead) and sidecasting dredges.

Trailing Suction or Hopper Dredges. Trailing suction hopper dredges are self-propelled seagoing ships equipped with propulsion machinery, sediment containers (hopper), dredge pumps, and other special equipment required to remove material from a channel bottom or ocean bed. Hopper dredges have propulsion power adequate to dredge against strong currents and the maneuverability for safe and efficient work in rough, open water. Dredged material is raised by dredge pumps through dragarms connected to the drag on the channel bottom and discharged to the hopper built in the vessel. Once loaded, hopper dredges move to the disposal site to unload before resuming dredging. Unloading is accomplished by opening the doors at the bottom of the hopper and allowing the dredged material to sink in an open-water disposal area, or the material can be pumped to upland disposal sites. The hopper dredge is shown in Figure 5.

Hopper dredges are classified according to hopper capacity with the largest hopper having capacities of 6500 m3 and greater and the small hoppers having capacities ranging from 500 to 2000 m3. Hopper dredges can travel at speeds of 2 to 3 mph (3.2 to 4.8 km/h) during dredging operations and can dredge in depths from 3 to 25 m.

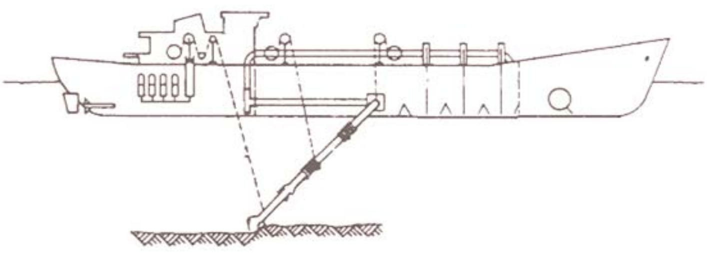


Fig. 5 Trailing suction hopper dredge

The hopper dredge has the following advantages and disadvantages:

It is the only type of dredge that can work effectively, safely and economically in rough, open water;

It can move more quickly and economically to the dredging project area under its own power;

Its operation does not interfere with or obstruct traffic in the waterway;

Its method of operation produces usable channel improvement almost as soon as work begins since the dredge normally traverses the entire length of the problematic shoal, excavating a shallow cut each pass;

The hopper dredge may be the most economical to use where disposal areas are not available within economical pumping distances of hydraulic pipeline dredge.

Its deep draft precludes its use in shallow waters, including barge channels;

It cannot dredge continuously since normal operation involves loading, transporting material to the dump site, unloading and returning;

The hopper dredge excavates with less precision than other types of dredges;

It has difficulty dredging side banks of hardpacked sand;

The hopper dredge cannot dredge effectively around piers and other structures;

Consolidated clay material cannot be economically dredged with the hopper dredge.

Cutterhead Dredge. The hydraulic pipeline cutterhead suction dredge draws a slurry of bottom material and water through a suction line and pumps the soil-water mixture through a floating discharge line to the disposal site. The cutterhead dredge is generally the most efficient and versatile, and is widely used all over the world. Because it is equipped with a rotating cutter apparatus surrounding the intake end of the suction pipe, it can efficiently dig and pump all types of alluvial materials and compacted deposits, such as clay and hardpan. A schematic drawing of the dredge is shown in Figure 6.

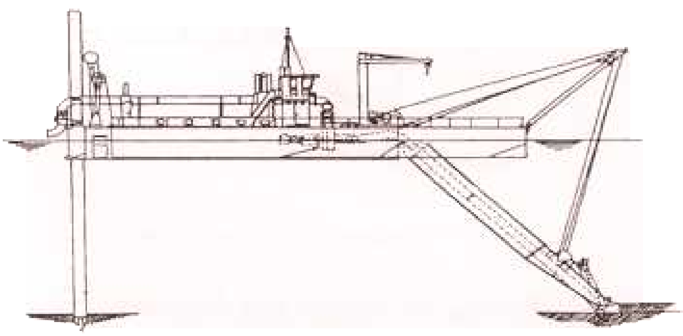


Fig. 6 Cutterhead dredge

The dredge production rate is defined as the volume of in-situ sediment dredged in a given time, usually expressed in terms of cubic metres per hour. Slurry of 10 to 20 percent solids (by dry weight) is typical. The production rate varies with the characteristics of the material being pumped, dredging depth, pump horsepower, distance to the disposal area and other operation factors. For dredging, pipeline transport distances usually range up to 5 km. For longer distances it is necessary to add booster pumps. In areas where material must be transported a very long distance, the excavated material may be placed in hopper barges for disposal in open water or in confined areas.

The cutterhead dredge has the following advantages and disadvantages:

> Cutterhead dredges are used on new work and maintenance projects because they are capable of excavating most types of material and pumping it through pipelines for long distances to upland disposal sites;
>
> The cutterhead operates on an almost continuous dredging cycle, resulting in maximum economy and efficiency;
>
> The large and powerful machines are able to dredge rocklike formation such as coral and softer types of basalt and limestone without blasting.
>
> Cutterhead dredges have limited capability for working in open-water areas without endangering personnel and equipment;
>
> Conventional cutterhead dredges have problems removing medium and coarse sand in maintaining open channels in rivers with rapid currents. This is due to slippage of the working spud due to scouring effects. When the dredge works downstream, the material that is loosened by the cutterhead can not be pulled into the suction intake and deposits ahead of the dredge;
>
> The pipeline from the cutterhead dredge can cause navigation problems in small, busy waterways and harbors.

Sidecasting Dredges. The sidecasting dredge is a self-propelled, shallow draft, and seagoing vessel especially designed to remove material from bar channels at small coastal harbors that are too shallow for hopper dredges and too rough for pipeline dredges to operate. Sidecasting dredges are similar to hopper dredges but usually do not have hopper bins. Instead of collecting the material in hoppers onboard the vessel, the sidecasting dredge pumps the dredged material directly overboard through an elevated discharge boom (Figure 7). Since dredged material is not collected, the vessel draft remains the same throughout the dredging operation. Dredging operations are controlled by steering the vessel in predetermined ranges through the project alignment.

Fig. 7 Sidecasting dredge

In a normal operation, once the dredge has moved to the work site, the dragarms are lowered to the desired depth, and pumps are started to take material from the channel bottom and pump it through the discharge boom as the dredge moves along a designated line in the channel prism. The dredge operates back and forth across the bar, successively deepening the channel on each pass.

The advantages and disadvantages of the sidecasting dredge include:

> Since the sidecasting dredge is self-propelled, it can move rapidly from site to site. The dredge can therefore be used to maintain numerous projects located far apart.
>
> The shallow draft sidecasting dredge cannot remove large volumes of material compared to the hopper dredge, and some material removed can return to the channel prism due to the effects of tidal and littoral currents;
>
> The sidecasting dredge has only open-water disposal capacity and therefore cannot be used to dredge contaminated sediments.

1.3 Disposal of Dredged Material

Although the selection of proper dredging equipment and techniques is essential for economical dredging, the selection of a disposal alternative is of equal importance especially where dredging is expected to be necessary over the long-term. Available disposal alternatives include:

> Open water
> Confined
> Beneficial uses

Open-water disposal is the placement of dredged material in rivers, lakes, estuaries, or oceans via pipeline or surface release from hopper dredges or barges. Confined disposal is the placement of dredged material within diked or otherwise confined intertidal or upland area via pipeline or other means. Open-water and confined disposal are the two most commonly used disposal alternatives. Beneficial uses include disposal methods that use the material for some productive purpose such as habitat development. Beneficial use as an alternative is widely practised where the material is suitable, and should be encouraged as a first choice whenever possible.

Open-Water Disposal

Dredged material can be placed at open-water sites by direct pipeline discharge, hopper dredge discharge or dumping from barges. Open-water disposal sites can be either accumulative or dispersive. At accumulative sites most of the material remains on the bottom, forming mounds. At dispersive sites, most of the material is dispersed over time and transported away from the disposal site by currents.

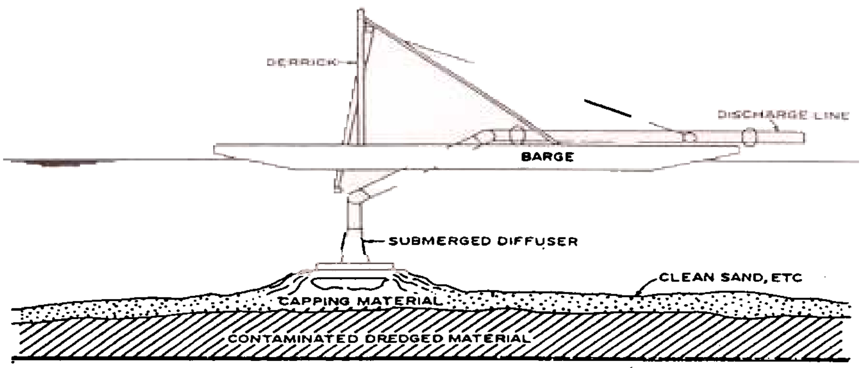
If initial evaluation of the material indicates that water column and benthic effects are acceptable, no special placement techniques (capping, submerged discharge, etc.) are used and material is discharged at a selected point within a designated disposal site.

The criteria for site selection include storage capacity requirements and chemical/biological considerations. The capacity is determined by the volume of accumulated material that can be placed without exceeding the designated site boundaries or exceeding water depth constraints. The capacity may also be determined by the assimilative ability of the water within the designated site boundaries, i.e., the ability to reduce concentrations of suspended material and associated contaminants to an acceptable level.

Because the open-water environment is dynamic, materials placed in open water will be dispersed, mixed and diluted. Estimates of these effects on the maximum concentration of the liquid and suspended particulate phases after initial disposal must be made. When the disposal site is close to the dredged channel, the return of disposed material to the channel should be avoided.

In cases where testing has indicated that water column or benthic effects will be unacceptable, additional precaution must be taken. The techniques used include submerged discharge, contained aquatic disposal, capping or their combination.

Submerged discharge reduces the area of exposure in water column and the amount of material suspended in the water column and susceptible to dispersion. Submerged diffusers can be used to reduce the exit velocities which in-turn reduces resuspension and spread of the discharged material. Water depth, bottom topograph, currents, dredge type and site capacity must be considered when evaluating the feasibility of submerged discharge. (Fig 8)



Capping operation by a submerged diffuser

Source: DEMAS, 1992

The use of subaqueous depressions or borrow pits or the construction of subaqueous dikes can be used to contain material reaching the bottom. These techniques reduce the area extent of a disposal operation, thereby reducing both physical benthic effects and the potential release of contaminants. Dredge type, water depth, bottom topography, bottom sediment type and site capacity must be considered. Precise placement of material and use of submerged discharge points increase success of operation.

Capping is the placement of a clean material over the material considered contaminated. Considerations include water depth, bottom topography, currents, dredged material and capping material characteristics, and site capacity.

Confined Disposal

Confined disposal areas are used to retain dredged material solids while allowing the carrier water to be released from the containment area. The two objectives inherent in the design and operation of a containment area are:

> to provide adequate storage capacity to meet dredging requirements, and
> to attain the highest possible efficiency in retaining solids during the dredging operation in order to meet effluent suspended solids requirements.

These considerations are basically interrelated and depend on effective design, operation, and management of the containment area.

The Constructed dikes form a confined surface area, and the dredged channel sediments are normally pumped into this area hydraulically. Both the influent dredged material slurry and effluent water can be characterized by suspended solid concentration, suspended particle size gradation, type of carrier water (fresh or saline), and rate of flow.

In some dredging operations, especially in the case of new dredging, sand, clay balls, and/or gravel may be present. This coarse material rapidly falls out of suspension near the dredge inlet pipe, forming a mound. The fine-grained material continues to flow through the containment area with most of the solids settling out of suspension., thereby occupying a given storage volume. The fine-grained dredged material is usually rather homogeneous and is easily characterized.

The clarified water is usually discharged from the containment area over a weir. The effluent flow rate is approximately equal to the influent flow rate for continuously operating disposal areas. The flow over the weir is controlled by the static head and the weir length provided. To promote effective sedimentation, ponded water is maintained in the area with the depth of water controlled by the elevation of the weir crest. The thickness of the dredged layer increases with time until the dredging operation is completed. Minimum freeboard requirements and mounding of coarse-grained material result in a ponded surface area smaller than the total surface area enclosed by the dikes. Dead spots in corners and other hydraulically inactive zones reduce the surface area effectively involved with the flow to considerably less than the total ponded surface area. Effluent standards may be imposed as a requirement for water quality certification. Standards in terms of suspended solids or turbidity may be used. Containment areas must be designed to meet such effluent standards.

In most cases, confined disposal areas must be used over a period of many years, storing material dredged periodically over the dredging life. The long-term storage capacity of these areas is therefore a major factor in design and management. Consolidation of layers continues for long periods following disposal, causing a decrease in the volume occupied by the layers and a corresponding increase in storage capacity for future disposal. Once water is decanted from the area following active disposal, natural drying forces begin to dewater the dredged material, adding additional storage capacity. The gains in storage capacity are therefore influenced by consolidation and drying processes and the techniques used to manage the site both during and following active disposal operation.

Beneficial Uses

There is increasing interest in the beneficial use of dredged material as a resource because the amount of material dredged each year continues to increase and increasing urbanization and industrial development near waterways and ports has made it difficult to locate new sites for dredged material disposal in many areas. Also, environmental regulations have restricted both land and water disposal options. As a result, the cost of dredged material disposal has increased rapidly with greater distances from the dredging site to the disposal site and with environmental controls.

By recognizing dredged material as a resource, it can be disposed with minimal environmental damage and can yield benefits. One major beneficial use of dredged material is creating new land, and there are many productive land uses of containment areas after they have been filled. For example:

- Recreational
- Industrial/commercial
- Agricultural
- Institutional
- Waterway-related
- Multi-purpose
- Habitat development

Recreational Use. The use of disposal sites for recreation requires relatively modest funding for planning and development. Recreation sites with much open space and light structure are especially suited to weak foundation conditions frequently associated with fine-grained dredged material. Recreational land is generally for public use, and the high demand for public water-oriented recreation opportunities favours this use. Legislation relating to wetland, coastal zone management and flood control is biased in favour of this type of use. However, such use is dependent on financial backing at the local level.

Industrial/Commercial Uses. Industrial/commercial uses of filled disposal sites provide an incentive for the growth of industrial and commercial activity at harbors and along waterways where raw material can be received and products shipped economically. The use of dredged material disposal sites for port-related facilities is generally supported at the local level because of benefits to the local economy. Economic or social benefits offset environmental impacts.

Agricultural Uses. There are many agricultural uses for dredged material. There has been growing interest in increasing crop yield by amending marginal agricultural land with organic-rich wastes and dredged material has been used as a soil amendment. Some inactive disposal sites are being used as agricultural land. Under the right conditions dredged material can be used to improve marginal agricultural land and can support forage crops.

Institutional Use. Institutional use includes public service and municipal uses of disposal sites such as for electric utilities, transportation systems, and water and wastewater facilities. Facilities developed or planned for development at some disposal sites include university, Army Reserve training centre, sewage treatment plant, small boat and ferry landings, airport runways and runway extensions, taxiway, and parking areas.

Waterway-Related Uses and Multiple Use. Such waterway-related uses as shore protection, beach nourishment, and river control structure construction normally involve creation of land and thus provide opportunities for multiple-use site development. Secondary recreation use in conjunction with waterway-related uses is common.

Habitat Development. Habitat development refers to the establishment of relatively permanent and biologically productive plant and animal habitats. The use of dredged material as a substrate for habitat development offers a disposal technique that is often a feasible alternative to more conventional open-water, wetland, or upland disposal options. The four general habitats that are suitable for establishment on dredged material include marsh, upland, island, and aquatic. Determination of the feasibility of habitat development centres on the nature of the surrounding biological communities, the nature of the dredged material, and the site selection, engineering design, cost of alternatives, environmental impacts, and public approval.

1.4 Design

Cost and potential environmental impacts are fundamental considerations in evaluating alternative dredging and disposal methods and disposal sites, and many factors must be considered in developing a dredging operation, including:

> Determining the quantity of material to be dredged initially and the frequency and quantity of future maintenance dredging
>
> Sampling to determine the physical and chemical properties of material to be dredged to ensure that the appropriate type of dredge is used, to assess dredge production rates so that time and cost estimates are realistic, and to identify any pollutants in material to be dredged
>
> Selecting the appropriate dredge type and size, disposal methods, and disposal area to ensure environmental protection
>
> Identifying adequate disposal areas for both initial and future maintenance dredging, considering the physical and chemical properties of the dredged material
>
> Long-term management of disposal sites to maximize the storage volume and beneficial use after the sites are filled

Dredging is a very costly operation and involves many uncertainties that affect project cost, including the realistic estimate of the total quantity of material to be dredged and characteristics of the material as they are related to the dredge production rate (the rate at which solids are dislodged at the dredging site and transported to the discharge point). Various other factors also affect dredging cost. A pipeline dredge operating in a navigation channel may obstruct navigation unless special arrangements are made. Dredges normally operate 24 hours a day, and if the work site is in or near an urban area, noise may preclude night operation. Weather conditions may also limit operations under some circumstances.

Adequate data on material to be dredged can be obtained only by field surveys, field sampling, and laboratory analyses. Determination of dredging limits and quantities is normally based on hydrographic surveys of the area prior to dredging. Sufficient samples of the material to be dredged should be taken to accurately define all materials slightly beyond the limits of the project channel cross section since dredging by most types of plant is not a precise operation. Data from laboratory soil tests of the bottom material samples are the basis for selecting the proper dredge plant, designing channel side slopes and retention dikes, estimating long-term storage capacity of disposal areas, and evaluation and designing disposal procedures. Laboratory tests should be performed on representative samples. For fine-grained sediments, laboratory tests normally include natural water content, plasticity index, and specific gravity. For coarse-grained sediments, laboratory tests generally are limited to grain size analysis and in-situ density determinations.

A post-dredging hydrographic survey immediately following project completion indicates the project dimensions achieved by dredging, and comparison of the pre- and post-dredging surveys normally is the basis for quantity estimates on which payment to the contractor is based. It is important, therefore, that these surveys be accurate and repeatable and be based on precisely established horizontal and vertical controls.

2. Environmental Impact of Inland Water Transport Development

Inland Water Transport (IWT) represents a significant resource for China as well as other countries of the world. The total length of navigable river reaches in China is about 110,000 km, or one-forth of the world's total. Despite the fact that IWT is the oldest transport mode, recently there has been renewed interest. There is considerable potential for development. The Ministry of Communication (MOC) of China has decided that more efforts will be made to improve and develop IWT systems in China during the "Ninth Five-Year Plan" period from 1996 to 2000.

IWT development projects will change the environment in project areas or regions, both directly and indirectly. Some effects can be positive, such as promoting the regional economic development, and some can be negative, such as deteriorating water quality. Thus, MOC has stipulated in the "Technical Code of Regulation Works for Navigation Channels" that:

> *Based on the "Law of Environment Protection in P. R. China" and related concrete rules of environment protection issued by the State, the environmental impact assessment (EIA) of navigation channel regulation works on the construction area should be specially carried out.*

In this part the contents of EIA will be briefly introduced, and then the impact identification related to an IWT development project and a dredging project will be discussed. The emphases will be focused on adverse effects and possible mitigation measures.

2.1 Environmental Impact Assessment

Environmental impact assessments (EIA) are becoming more and more common. Based on the "Law of Environment Protection in People's Republic of China", environmental impact assessment of every planned engineering project, including regulation works for navigation channels, should be carried out. The local environmental protection bureau, where the project is located, will examine the potential impacts on environment. A project will be approved, only when its environmental impacts are acceptable. A thorough environmental impact assessment must incorporate an assessment of the economic impact of a project, the physical and chemical condition of the area, the flora and fauna and human reflections.

Inland Water Transport development projects, like any others, have impacts on the environment. The magnitude of the impacts, of course, depends on the scale of the works. For this reason one should also realize that the extent of the investigation is not always the same. The points to be considered for EIA are given. One should assess for every project, in the feasibility study, the scope and the size of EIA.

A complete environmental impact assessment study should describe the following items:

A description of the "as is" situation before the project starts in the area influenced by the project.

A description of the proposed project and its influence on the environment after completion.

A description of the works and actions to be carried out to implement the project.

A description of the probable impact of all works and actions described relating to:

- The biological equilibrium, including:
  - the global ecosystem;
  - the continental ecosystem;
  - the national ecosystem;
  - the regional ecosystem;
  - the fluvial ecosystem; and
  - the human ecosystem.
- The non-biological equilibrium, including:
  - morphology;
  - sedimentology;
  - water quality;
  - hydrology and hydro-geology;
  - air quality;
  - socio-economic factors;

- landscape;
- land use;
- visual intrusion;
- noise;
- employment;
- infrastructure;
- energy resources;
- hazardous situations;
- recreational activities; and
- political opinion.

The possible beneficial environmental effects of the project;

The possible adverse environmental effects of the project;

An evaluation of the effects of various execution methods during the implementation period of the project;

An evaluation of the effects during the period the project is used;

An evaluation of the effects of demolishing a structure during the period of construction;

An evaluation of the (ir)reversibility of impacts;

The range of primary, secondary and tertiary impacts (direct or indirect) of the project;

An evaluation of alternatives to the project; and

A proposal for remedial actions to reduce the impact of the project.

Not all the items indicated above need to be completely investigated for every navigation improvement project. A small sensitivity analysis of the parameters influencing these items may indicate which is the most important. Another choice could be to state that a project of a certain magnitude, such as project value, requires an EIA.

2.2 Potential Environmental Impacts of Inland Water Transport Development Projects

The first step of an environmental impact assessment is to identify the potential effects of a project on environment. In this section, attempts will be made on outlining possible effects of an inland water transport development project (referring to the report "Environmental Impact Assessment for Inland Water Transport Development Projects in the Upper Mekong Subregion" published by ESCAP, 1995) on environment, together with mitigation measures.

Hydraulics and River Morphology

An inland water transport development project usually requires:

the deepening of the channel during the low-water stage;
the widening of the navigation channel; and
an increase of sharp bend radii.

To achieve these goals, both permanent and temporary improvement works on the river are necessary:

Permanent works include rock-blasting, construction of groins and dikes, modification of the pattern of certain meanders.

Temporary works include dredging and other means of material extraction from the river bed. Such works are regarded as temporary since bottom haulage of sediments tends to fill out the excavations and periodical maintenance works are required.

Any such kind of permanent or temporary river-works may affect hydrological characteristics of the river and result in morphological alteration of the river bed, banks and solid discharge in the project area, upstream and downstream of the project area.

Current Velocity. In the sections where the river widens out with formation of sand banks, the project requires groynes (or dikes) to be built perpendicularly to the river banks. By reducing the cross-section of the river such works will locally increase current velocity in the channel, resulting in scouring and deepening of the channel. However, this increase in current velocity will usually not affect the other parts of the river bed.

The removal of such obstacles as rocks and material deposits from the river bed has the immediate effect of locally improving the flow of water and regulating current velocities. As a result the following effects can be expected:

Reduced current velocity on the very site of the rapids; and

Increased velocity upstream and downstream during both the high- and low-water stages.

Local bank protection works may be required at some locations where the current velocity has increased after regulating the channel.

Water Level. The impact on the water level may be caused by the removal of materials from the river bed. The deepening of the channel at the shoals or the increasing of the cross-section areas at the rapids may lead to the lowering of the water level both locally and upstream, causing shoaling problems in the upstream river reach.

Sediment Transport. The river bed is subject to erosion and will be affected by stream variations. The river carries such sediments as sand and gravel during the flood period, by haulage on the river bottom. The sediments will accumulate forming banks of deposits in places where the current velocity has dropped below the critical erosion velocity.

In such a river bed, the removal of reefs or rocky bars may result in transport of sediments which were initially retained behind them. Out-of-control erosions can then be anticipated along with deposits of the same amount of material further downstream.

It should be noted that in places with a mobile river bottom, where dredging is required to increase the water depth or to remove sand banks, the river will ever tend to restore the initial shape of its bed by deposit of new sediments. The maintenance of the dredged channel may be required.

Water Quality

Owing to the development of water transport it is expected that the risk of water quality deterioration in a river will be increased. Actions affecting water quality, together with proper mitigation measures are:

Waste from Ports and Ships. Liquid/solid waste and sanitary waste water from ports and ships may deteriorate water quality in the river. Thus, they are recommended to be collected and treated before discharge and disposal. Adequate storage facilities in ships and ports allow for proper garbage disposal at designated sites.

Storage facilities in ships for bilge water and sanitary waste water, intake facilities together with sewer systems and waste water plants (including oil separators for treatment of bilge water) at the ports will decrease pollution loads of waste water generated by port facilities and ships.

Development of inland water transport is likely to result in industrial and residential development close to the port locations. Increased generation of solid and liquid waste has to be anticipated.

Oil Spills. Ship traffic accidents and inadequate handling may cause escape of oils.

Providing intake and storage facilities, oil separators, ship traffic management and navigation aids, together with oil contingency planning will decrease the risk of contamination by oil spills.

Hazardous Materials. Toxic substances such as pesticides may end up in the river through ship traffic accidents and/or inadequate handling. Transport of inflammables and explosives will enhance risks of accidents.

Rules, regulations and enforcement for water transport of hazardous material can avoid or decrease environmental risks.

Dredging. Dredging and the disposal of dredged material may affect water quality. Possible impacts of dredging on water quality include:

> Increase of suspended solids and turbidity reducing light penetration in the water, settlement of the suspended matter may affect downstream spawning/feeding areas;
>
> The release of nutrients and/or contaminants attached to the sediment can cause algae blooms and/or deterioration of the water quality;

Disposal of dredged material at ecological sensitive areas may affect the aquatic life; and

A positive impact can be the possible use of dredged material for port area development.

The selection of environmentally sound dredging equipment such as dredges which reduce the quantity of process water, the use of closed grab dredges and the application of silt screens around the dredging area will limit the increase of turbidity and possible contamination. The dredged material is recommended to be disposed in diked containments, isolated from the river. If this is not economically feasible the dredged material can be disposed in the river if a skirt is constructed around the disposal area to localize the increase of turbidity. The dredged material, if not contaminated, can also be used for the construction of aquatic life habitat and/or wetlands.

River Pollution

Industrial development, port construction as well as industrial-scale river transport development may cause such nuisances as oil spill, bilge water discharge, solid and liquid wastes, pollution or contamination by industrial waste effluents, dangerous cargoes and toxic substances.

Such nuisances could damage the ecology of the river, of inundated zones and wetlands by disturbance of the natural habitat of the aquatic flora and fauna. They could possibly affect as well agriculture, rice culture, fish migration, capture fisheries and aquaculture. Pollution may also cause degradation and/or contamination of raw water used for water supply to riverine-towns. It could also affect the development of tourism in the project area and in return, have socio-economic impact on the population.

Fisheries, Aquaculture and Aquatic Biology

The causes of main impact on aquatic life and the proper mitigation measures are likely to be:

Rock Blasting. Rock blasting by under water explosive detonation can have lethal impact on aquatic life especially on fish. Of importance for the scale of impact is the type and weight of the explosive charge, the velocity of detonation, the depth of the charge below the water surface, the fish species, the weight of the fish and the depth of the fish in the water column. For buried charges information is needed about the hole depth, collar depth and charge dimension.

Habitat Modification and Loss of Habitat. Through the removal of rocks, dredging and channelization in the river a loss and/or change of aquatic life habitat will occur. Removal of rocks may result in transport of sediment, which may possibly result in considerable destruction of habitats.

Mitigating measures may include a compensation program, including the design and construction of aquatic life habitats and/or wetlands at designated sites where navigation will not be hampered. Site selection for port construction and selection of disposal area of dredging spoil should avoid interference with migration, spawning and feeding of fish. Not contaminated dredging spoils can be used for the construction of aquatic life habitat and/or wetlands.

Deterioration of Water Quality. Waste water discharge, inadequate handling of hazardous materials and ship traffic accidents cause deterioration of water quality possibly affecting aquatic life. Particularly sensitive areas are flood plains which function as the spawning and/or nursery ground. Mitigating measures will focus on the management of waste from ports and ships, and the management of hazardous material transport.

Water Supply

Small private water supply facilities using the main stream as a water source may be affected by water contamination, and large-scale water supply projects located on the river may also be affected if serious pollution occurs. Mitigating measures consist of prevention of water quality deterioration.

Forest/Agriculture/Wildlife

Environmental impacts on forest, wildlife and agriculture can be caused by noise, dust and gaseous emissions due to rock blasting, construction activities and port operation. Dust will be produced during the handling of coal and construction material, such as cement and sand. Noise results mainly from ship engines and the operation of port equipment.

Adequate noise control and proper air pollution control form recommended feasible protection measures.

2.3 Environmental Effects of Dredging

Dredging work is a very important and effective measures often used to improve and maintain navigation channels. Like other regulations, dredging, and transporting and disposing of dredged material, will change the environment in the borrow area, along the transport route and at the disposal site. These effects will be described in this section.

Effects of Dredging Operation

Interference With Traffic. Dredging as an activity interferes with regular activities in the dredging area. The dredges may work in a shipping lane and depending on the type of dredge, hamper the traffic. A pipeline running from the dredging area to the disposal area occupies land and causes a loss of productivity in farmland due to the traffic along the line and the occupation of land itself. Dredges and transport barges sailing from the dredging area to the dump site or to the reclamation area intensify the traffic and may cause extra delays for ships waiting for locks. Commercial ships then may choose another route which is longer and therefore requires more fuel and time.

Stationary dredges in general interfere more with other shipping than trailing suction hopper dredges. Anchor wires, a floating pipeline to the shore or barges moored alongside the dredge reduce the channel width and thus form an obstacle to traffic. Such obstacles may be the reasons for conflicting situations and collisions and therefore increase the chance of spillage of cargo or injury to people.

A proper navigation aids system with advance signals for the dredging work and clear signals on the dredges will help reduce the chance of conflicts. Mariners should be warned about the dredging work in notices to mariners, by lock operators, by signs along the shore and finally by the signals on the dredge itself. All these messages need to fit into an internationally accepted system to prevent misunderstandings.

The dredge crew for its part, whether on a stationary dredge or on a trailing suction hopper dredge, always has to be on the alert for other ships. Since they have the latest soundings of the area and know where they have already dredged, they have the opportunity to reduce the risks to passing ships.

Objectionable Noise. Dredges have powerful engines and many heavy machines on board which are noisy. This noise may be music for a dredging man, but is regarded as noise pollution by people passing by or living in the neighbourhood of a dredging site. Silencers on engines and better greasing of rolling parts may reduce the noise level. Bucket chains of bucket dredges are well known for their characteristic noise. Some companies reduce the noise level considerably by improving the roller bearings and by capping the bucket chain. It is still sometimes necessary to stop the work at night because of the noise level, especially near residential areas.

Turbidity. Turbidity of the water surrounding a dredging project is often the major cause of environmental impact of dredging on a natural environment. The impact of turbidity works through a number of aspects:

> The fines dispersed in the water travel outside the dredging area and settle. This will cover the flora around the dredging area and may kill part of the flora.
>
> The turbidity reduces the penetration of light into the water and thus changes the circumstances for flora and fauna near and on the bottom.
>
> After dredging, a layer of fine material (settlement) will cover the bottom and thus the conditions of life change there, both for flora and fauna.
>
> Nutrients embedded in the dredged material will become available for ecosystem, causing algae to blossom.
>
> The marine life in the dredging area may flee because of the changes in availability of food and cover.

Some of the changes only occur during the period of dredging while other changes influence the ecosystem for a long period afterwards.

The Turbidity generated by dredging must be seen in relation to the turbidity that results from natural causes, the so-called background turbidity. Stationary flow conditions and the flow climate (tidal areas and density flows) cause this background turbidity. Storms and variations in the discharge of rivers will even increase the level of turbidity in the natural situation and thus increase the background turbidity.

On top of this natural turbidity, one should add the turbidity caused by other human activities. Effluent discharges and navigation generate turbidity which might be of the same magnitude as the turbidity caused by dredging.

In areas where such high background turbidity levels exist, marine life is already adapted to the situation by natural selection and the dredging activity will hardly change the situation.

In some situations even the opposite may happen. An intensively used shipping channel where ship propellers continuously disturb the bottom usually has a high turbidity. The ship propellers do not influence the bottom anymore and the water becomes clear after the dredging of the channel. The short-term effect of dredging then is that the turbidity increases during the dredging work. However, the long-term effect is that after dredging the turbidity decreases below the original background level.

It is essential to evaluate the acceptability of the turbidity, especially with regard to water quality and quality of the bottom sediments. The functions of the dredging area and its direct surroundings are very important to a proper assessment. A harbor basin in an industrial area asks for different standards compared to a watercourse in a recreational area or in a natural sanctuary.

The multi-functional use of the water bottom after dredging, which should be the basic philosophy of most projects, is not always necessary or feasible in an industrial area. With regard to turbidity, the following groups of factors are important: those related to the nature of the subsoil, to the dredging technique used and to the hydrodynamics and water quality.

Flora and Fauna. In watercourses where flora and fauna freely develop, after some time, an ecosystem will exist. Dredging in such a watercourse will suddenly change the equilibrium and thus disrupt the ecosystem.

The first, short-term effect is directly visible: the turbidity increases, flora will be covered by sediment, fish move out of the area and some plants will suffocate and die. The release of nutrients or toxicants or the reduction of available nutrients may change the living conditions in the ecosystem.

The long-term effect will be that the living conditions for flora and fauna change in such a way that a new equilibrium will be reached. The environmental value of such a new equilibrium depends on the new site conditions.

The change in water depth will change the penetration of light to the bottom and thus change the near-bottom conditions. Parts of the bottom which had been covered with vegetation before the dredging started will remain dark after the dredging and the vegetation will not return. Vegetation will only develop in the water depth of less than 2 m. The presence of fish and other fauna is mostly restricted to the upper 8 m of a watercourse. This will influence the biochemical oxygen demand and also the potential of fish to return to the area. Fish and other species need a cover of vegetation as hiding-places to survive from their hunters. The loss of such hideaways will reduce the variety in marine life. Variety in the number and sort of species which live in an ecosystem is regarded as an important yardstick to measure the value of such a system. A greater variety moreover increases the chance that a system will be able to survive any change in the future.

Reducing the area with depths varying between zero and 8 m reduces the potential of the future ecosystem.

Furthermore, dredging reduces the variety in ecosystem if it creates a flat bottom within the preferential maximum depth for marine life. Differences in depth at such an average depth increase the potential variety in the ecosystem.

Salinity Intrusion. The increase in the size of ships entering ports requires the dredging of approach and entrance channels. Since most ports lie along rivers, the mouths of these rivers will be deepened.

Depending on the tidal differences at sea and the average and peak discharges of the river, saline sea water will enter the river over a certain distance. Deepening the entrance of the river mouth will increase the influence of the sea in the river mouth and thus the intrusion of saline water. The heavy saline water enters a river near the bottom while the fresh water runs over it to the sea. Water inlets for drinking water or agricultural use that have been safe from salt intrusion in the past may end up in the saline area after dredging operation. The impact of the salt water reaches the ditches of the agricultural land next to the river and influences directly the vegetation along the borders of the rivers. The water depth in natural rivers gradually changes from the channels towards the shoreline. These areas in and along the rivers show a great variety in vegetation and accommodate numerous kinds of birds and marine life. Dredging may disrupt such areas or cause such areas to be affected by saline water. The ecosystem will change completely if the water becomes brackish or saline instead of fresh. The vegetation has to adapt to new circumstances and this will affect the fauna. Loss of freshwater in tidal areas is considered to have a great environmental impact because such areas are rare.

Erosion. Dredging channels in rivers and estuaries changes the direction of currents and the velocity distribution of the currents.

Deepening channels in general concentrates the discharge of a river in those channels and thus concentrates the flow attack on the embankments of the channels. The currents may undermine the slopes of the embankments and so cause slope failures from time to time. In nature, the failure of slopes and the meandering of rivers is not regarded as a process with an adverse environmental effect. However, often a river erodes an embankment on one side and disposes material on the other side of the river. This creates a variety of landscapes and this again gives a variety of options for flora and fauna.

Dredged channels mostly need to be maintained at the design depth by maintenance dredging. Accretion of material at one side of the channel is dredged and the other side of the channel is protected by artificial means. Owing to all these countermeasures executed to maintain the design profile, the variety in landscape and the potential variety in vegetation along the embankments are reduced. Since the variety in ecosystems is considered to have a great value, this must be seen as an adverse effect on the environment.

Effects of Transport of Dredged Material

Pipeline Transport. Pipelines are commonly used to transport dredged material from the dredging area to the disposal site.

The pipeline occupies a narrow strip of land for itself and a strip of land for the laying and inspection of the pipe over the full length. Road and water crossings may lead to some restrictions in the size of other traffic, but normally such crossings are designed to allow for the passage of all regular traffic.

The energy consumption of pipeline transport is rather high due to the fact that not only the dredged material itself but also the carrying fluid, water, needs to be transported. The actual energy consumption to pump the mixture over a certain distance depends on the diameter of the pipe, the effective grain size diameter, and the density and velocity of the mixture. Figure 9 shows the energy consumption for a density of 1,300 kg/m^3 and a mixture velocity of 20 per cent above the critical velocity. It gives the energy consumption for a range of pipes from 0.10 m to 1.90 m and average grain sizes ranging from 0.100 mm to 3.200 mm.

It is important to transport the mixture at a velocity above the critical velocity to safeguard the pipeline against blockage.

The energy consumption for this transport could be expressed in a number of units. A proper indication would be to present it as the energy required to transport 1 m^3 of sand at a density of say 2,000 kg/m^3 over a distance of 1 km. The energy consumption is expressed in kJ/(m^3¡¤km) for sand with a density of 2,000 kg/m^3.

The energy consumption given in Figure 9 is valid for straight dent-free pipes which are properly connected. If the pipeline contains many road- or water-crossings the resistance of the required bends and other irregularities has to be added.

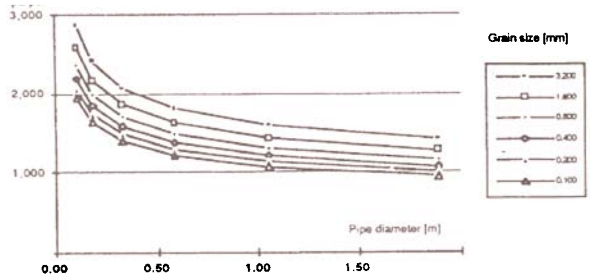


Fig. 9 Energy consumption for pipeline transport

Source: DEMAS, 1992

Wear and tear in a pipeline depends on the grain size distribution of the sand pumped through. For coarse materials, the wear may go up to 1 mm per one million cubic metres of material pumped through. For such materials the pipeline is usually turned regularly to spread the wear over the whole circumference of the pipe. Replacement of pipes is an important issue when talking about the environmental impact of different alternatives of working methods.

Air pollution by the engines driving the pumps adds to the environmental impact. Much attention nowadays is given to the improvement of combustion so as to reduce pollution.

Water Transport. Transporting dredged material by ships and barges is possible when rivers or channels are available from the dredging area to the disposal area. In some cases it is necessary to combine water transport with pipeline or road transport in case ships cannot enter the dredging or disposal area.

Water transport consumes less energy than other means of transport, such as pipeline transport and road transport. Transport of material by conveyor belts has not been considered in this comparison. Figure 10 shows the energy consumption for water transport related to the size of the ship in m^3.

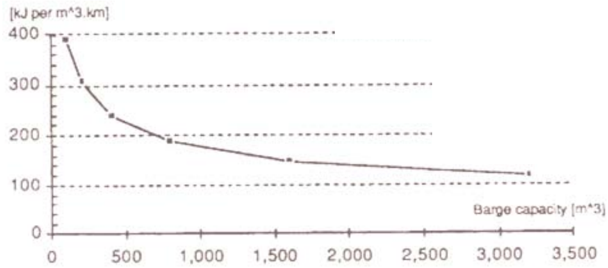


Fig. 10 Energy consumption for water transport

Source: DEMAS, 1992

The grain size of the soil has no influence on energy consumption for the transport of the dredged material. In fact, coarser material settles better in the hopper, thus reducing overflow losses. Consequently loading coarse material takes less time than loading fine material and will also consume less energy.

The grain size of dredged material hardly influences the wear and tear on the ship and the hopper. Only if big boulders or lumps of rock have to be transported may this cause dents in the hopper. Transport of dredged material by barges is the best if the material is dredged by a bucket dredge or grab dredge and/or the distance is long and the watercourse is suitable for the passage of the barges. The unloading of the ship is the easiest done by dumping the material through bottom doors. The energy consumption for dumping is negligible. Unloading the ship by a grab crane or a reclamation dredge adds to the energy consumption of barge transport. This is the reason why for short distances pipeline transport may still be beneficial compared to water transport.

Owing to low energy consumption and high efficiency of modern engines, water transport causes little air pollution compared to pipeline and road transport.

Road Transport. As compared with transport by water, the transport of the dredged material by road is not affected by grain size in the consumption of energy. The benefit of road transport is that it requires little preparation and one can distribute small quantities to different sites. The dredged material needs to be comparatively dry, with a maximum water content of 15 to 20 per cent by volume for sand, before it can be loaded on a truck. Depending on the percentage of organic material and the grain size distribution of especially fine sands, silts and clays, the minimum water-solid ratio may be 40 to 60 per cent by weight. After dredging, the material has to be deposited on a rehandling site to remove the water. This can also be done by processing the sand through dewatering sieves. Then the material needs to be picked up again to load the truck which also consumes energy.

The transport of dredged material by road has a high energy consumption and the wear and tear on the road system is quite heavy. Trucks themselves show little wear and tear due to the dredged material, unless the material contains boulders or stones.

Air pollution is due to the high fuel consumption and the number of times a truck shifts gear.

Another adverse aspect of heavy trucks travelling on normal roads is noise pollution and safety problem. Road transport has the highest human casualty rate of all the modes of transport.

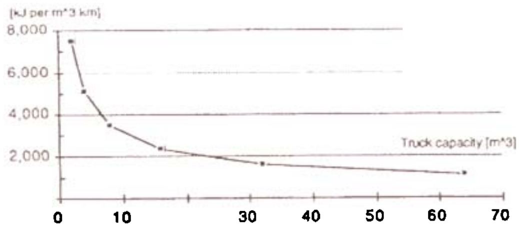


Fig. 11 Energy consumption for road transport

Source: DEMAS, 1992

Figure 12 shows a comparison of the energy consumption for the three modes of transport of dredged material, road, pipe and water. It is clear that water transport is the most economical. Rail transport, which is also sometimes used for transport of sand or other materials, has a slightly higher energy consumption than water transport. The energy consumption for transport of sand and water mixture still depends on the grain size of the material to be transported. The energy consumption for the pipeline is valid for sand with a grain size of 225 microns and mixture density of 1,300 kg/m^3.

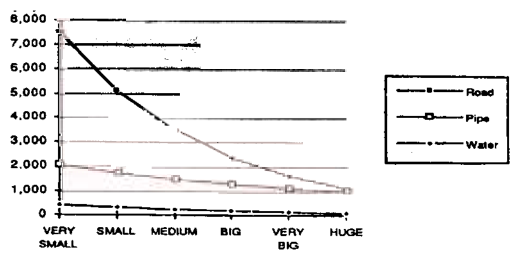


Fig. 12 Energy consumption comparison for road, pipeline and water transport

Source: DEMAS, 1992

Effects of Disposal of Material in Water

Disposal in Rivers and Estuaries. If a dredging project is executed to increase or maintain the cross-section of a river or a channel, the dredged material has to be disposed off. For economic reasons a short transport distance and the subsequent utilization of the dredged material are beneficial for the environment. However, due to costs and constraints with respect to the allocation of disposal sites onshore, the material is often dumped in deep spots in the rivers or branches in the estuaries.

The dumping of the dredged material will result in shoaling of the dumping area and thus change the currents. The effect will be that vegetation, if present, will be covered by the dredged material and marine life will die or flee the area. During the period of execution of the project, the dumping area will therefore lose value as a habitat. The quantity of material dumped and the size of the dumping area used determine, together with the variety in the ecosystem, how long it takes before the system recovers. The new equilibrium depends on the newly created limiting conditions.

The method of execution of dumping can influence the impact of dumping outside the actual dumping area. Owing to turbidity, density flows and river currents, part of the material dumped will end up outside the dumping area. On some occasions the dredged material is spread over as vast an area as practicable. In other situations, for instance whilst dumping contaminated material, settling outside the dumping area needs to be limited.

The side-casting method is often applied to spread the material over a wide area. An example is dredging bars in river crossings. The dredge just lifts the material from the bottom and jets it directly back into the water. The current in the river transports the material to deeper spots where it will settle. From the point of view of energy consumption, this is a very good method. In consideration of the turbidity, however, it is not a very good method. The overall impact on the environment depends on the existing variety in the ecosystem and the background turbidity in the area. Rivers like the Yamuna in Bangladesh, the Yangtze in China and the Ganges in India have already such a high background turbidity and transport of so much bedload that the effect of any dredging is hardly noticeable.

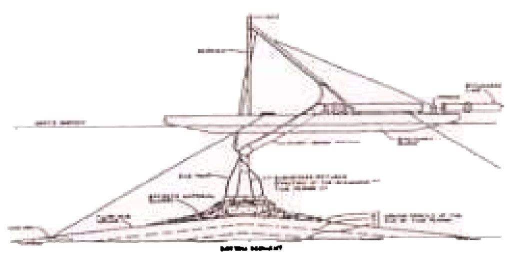


Fig. 13 Diffuser to dump the material close to the bottom

Source: DEMAS, 1992

In situations where turbidity must be limited, a system to discharge the material close to the bottom of the river or the pit may be applied. Trailing suction hopper dredges may be able to discharge their load through their suction pipes or they might be connected, through their shore connection, to a floating pipeline ending in a diffuser system. The diffuser will be located near the bottom at the end of a pipe which hangs from an anchored pontoon. The dumping of the dredged material through the bottom doors often limits its spread. Especially when the dump-pit is deep, compared to its surroundings, this is still a good and speedy solution.

Close attention should be paid to the presence of intakes of drinking water or irrigation water. Intakes for cooling water for power plants and refineries also pose restrictions on turbidity.

Fishing grounds for oysters and other shellfish as well as other fish may limit the maximum turbidity in a river or estuary. In China fishermen are compensated for loss of productivity of their oyster-beds caused by increased turbidity. A rehandling pit in Deep Bay, Hong Kong, had to be separated from its surroundings through a floating skirt.

Disposal at Sea or in the Ocean. The problems with dumping dredged materials at sea or in the ocean are similar to dumping in an estuary. Extra complications are the depth of the dumping site and the possibility that dredged material containing fresh or brackish water is dumped in a saline environment.

Dumping the material in deep water increases the chance of the spread of the material over a vast area due to currents. The fines especially settle very slowly and may be spread over huge areas. The effect of the settling material will diminish as a function of the distance to the dumping site. The effect of dumping dredged material containing fresh or brackish water in a saline environment depends greatly on the circumstances near the bottom and the distance to the river outlet. If the area is already influenced by material coming from a river, for instance during high discharges of the river, the ecosystem adapts to such changes. In deeper spots, farther from the shore, the natural bottom is often very loosely packed and dumping may have a considerable impact. The loosely packed saline bottom material then will be mixed with dumped material containing fresh water. This will change the living circumstances in and near the bottom for all living species. The overall impact on the environment depends on the area of the dumping ground compared to the whole area. Furthermore, it depends on the variety in the ecosystem at the dumping point. It is better to dump at locations where the variety is already limited at the start of the project.

Of course, the overall impact depends on the scale of the operation. The quantity of fresh water entering, per dredging cycle, into the area may be small compared to the volume of water in the area. The impact may even not be measurable.

Effects of Disposal of Material on Land

Disposal on Land. The disposal of dredged material on land is one of the most commonly used methods. Dredged material is disposed on land for two objectives. The first is that the land owner wants to raise his land by using dredged material. The second is that the land owner has to accept the dredged material, because the dredged materials originating from the maintenance of a watercourse need to be stored.

In the first situation reclamation is often carried out because of a change in the use of the land. If agricultural land is changed into a residential or industrial area, the land needs to be leveled and, in low-lying areas, to be raised above the water-level. The environmental impact of the dredging then has to be taken into account in the general EIA study for the development of the area. The benefits of reclamation by using dredged material have to be compared to other means. Differences may be found in the factors that depend on the working method. To make a choice, one should consider several factors for each reclamation system, i.e., energy consumption, air-pollution, noise pollution, effects of the discharge of process water, the possible impact on the area around the reclamation area and the effect on the borrow area.

The second objective is the necessity to deepen or widen a watercourse, or maintain its original dimensions. The environmental effect then is part of the consideration whether the maintenance of the function of the water course has a beneficial or adverse effect on the environment. If the deepening or widening is considered to be necessary, then the method of carrying it out has to guarantee a minimum effect on the environment.

The disposal of the dredged material has to be considered from the point of view of possible future use of the occupied land. Disposal areas normally have a flat profile, thus reducing the topographic features. In a naturally developed landscape this will mean a reduction in the variety of ecosystem. As such, it will have a negative impact on the environment. In the case where the area is already designated as residential or industrial, the disposal itself hardly contributes to the adverse environmental effect.

Eventual changes in the water-table in the area and the effect of such changes on the ecosystem need to be carefully evaluated. The extra load on the surface of the area will cause settlement of the underlying layers and may squeeze out thin impermeable layers. The connection of two water-bearing layers may lead to leakage of salt water into fresh water. Also anaerobic water in one layer could be exchanged with aerobic water in another layer. The effects of such changes on the ecosystem, in the long run, have to be evaluated.

Disposal near Shore in Diked Containment Areas. The disposal of dredged material on land may have a positive or a negative effect on environment. Dredged material is often used to reclaim wetland. Since wetlands have a high ecological value, because of the variety in such systems, such reclamation is considered to have a negative environmental impact. However, if such an area is already earmarked to be an industrial area, which is to be reclaimed, dredging is a good way to effect the reclamation.

Effects of Disposal of Process Water

The process water of a dredging project is taken in at the suction mouth of the dredge or in the bucket of a bucket dredge or a grab dredge. This water has the same properties as the water around the dredge. The water mixes with the dredged material and is transported to the disposal area. In the disposal area the dredged material settles and the water has to be disposed. Depending on the time elapsed between the mixture entering the disposal area and the process water leaving the disposal area, some of the finer particles will remain suspended. If this process water is disposed in the dredging area this will slightly increase the turbidity in the area. In situations where such an increase in turbidity is not acceptable, the settling time in the disposal area needs to be increased. This can be done by increasing the dimensions of the disposal area, by making compartments, or by adding a siltation basin. An alternative solution is to add flocculants to the water.

In many situations the water is disposed next to the disposal area. This is acceptable if the water quality in the watercourse is not affected by the water flowing out of the disposal area. It is also acceptable if the fines are sufficiently trapped in the disposal area and the watercourse is part of the same system as the water in the dredging area.

In a watercourse where the natural silt content is already high, the environmental impact of the discharge of the process water is negligible. However, in a river with clear water, the discharge of process water will, through the decrease of penetration of light, change the limits of potential variety. In natural environments this may have a great impact while in industrial areas, where the ecosystem is poor already for other reasons, the impact is negligible. For every situation the potential impact needs to be evaluated. Choosing the correct period of the year, e.g., when marine life is inactive, may reduce the impact considerably.

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