Navigation

Navigable waters are bodies of water that can be used in the service of interstate or foreign commerce and the transportation of goods and/or people. Such water bodies (like river, canal or lake) is **navigable** if it is deep, wide and calm enough for a water vessel to pass safely.

Advantages

Inland water transport is a competitive alternative to road and rail transport. Apart from least cost and land saving, it offers an environment friendly alternative in terms of both energy consumption, noise and green house gas emission. In addition, inland waterway transport ensures a high degree of safety. Finally, it contributes to the decongestion of the overloaded road network in densely populated regions.

According to recent studies, the total external cost of inland navigation (in terms of accidents, congestion, noise emissions, air pollution and other environmental impacts) are seven times lower than that of road transport.

River Navigation

Thus, River Navigation or Inland Waterway Transport (IWT) is an important mode of transportation and has the advantage of the least cost, least energy consumption, environment friendy and *land saving*, as compared to other modes of transportation.

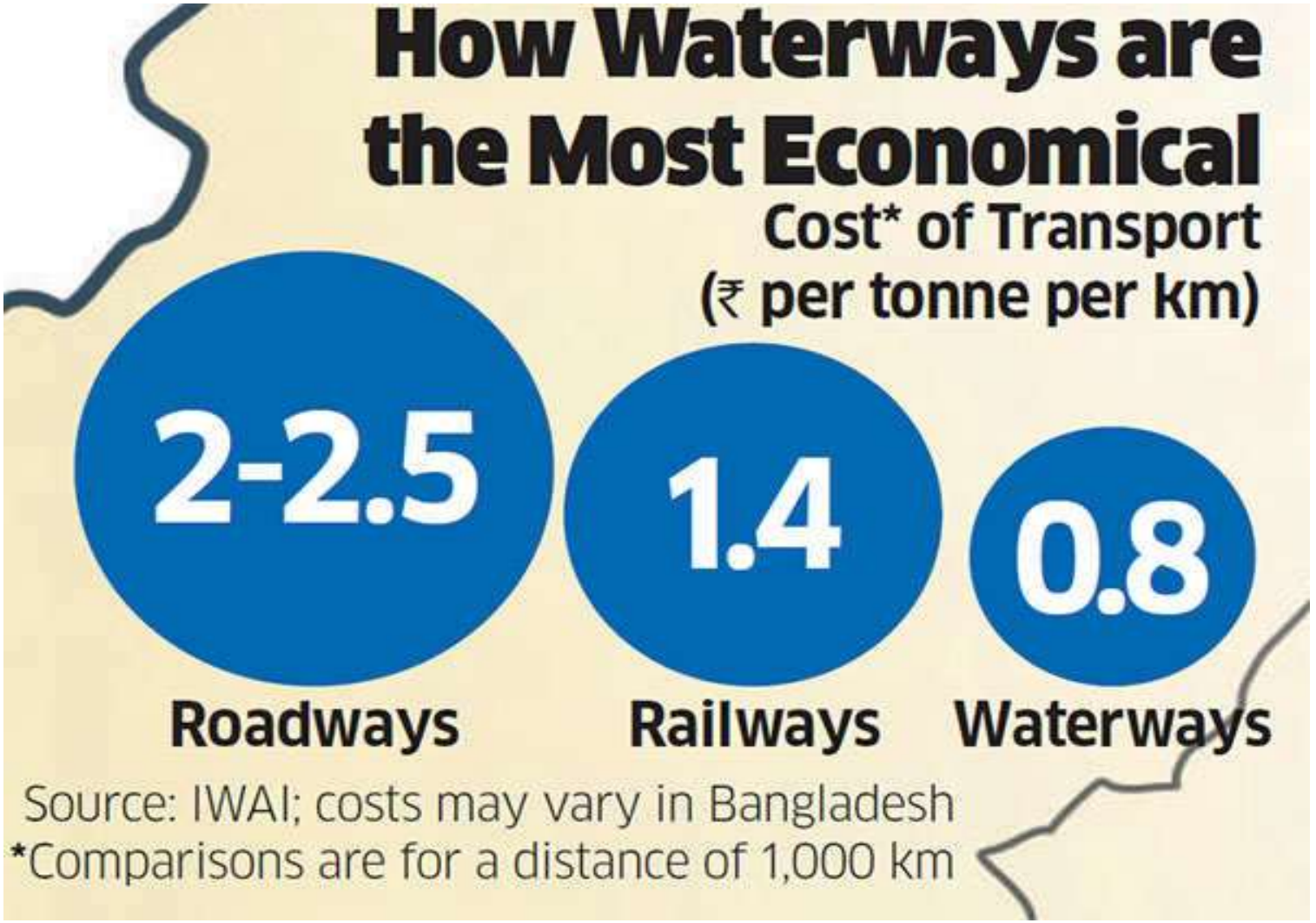
The order of the ratios between water, railway and road transportation is within the ranges of 1:2:5 in **cost** and 1:1.5:4 in **energy consumption** respectively.

Water transport is cheaper because of carrying massive load, less infrastructure and manpower, and high fuel efficiency (the coefficient of friction being small), one horse power can pull 4 tons ; while on road and rail, it can move approximately 0.15 ton and 0.5 ton, respectively.

Although IWT is not as fast as railway or highway, it continues to be competitive for transportation of bulk products (grains, oil, coal etc.). Moreover, inland trans-shipment is also an issue (causes delay).

Factors affecting navigation

There are two types of factors affecting navigation:

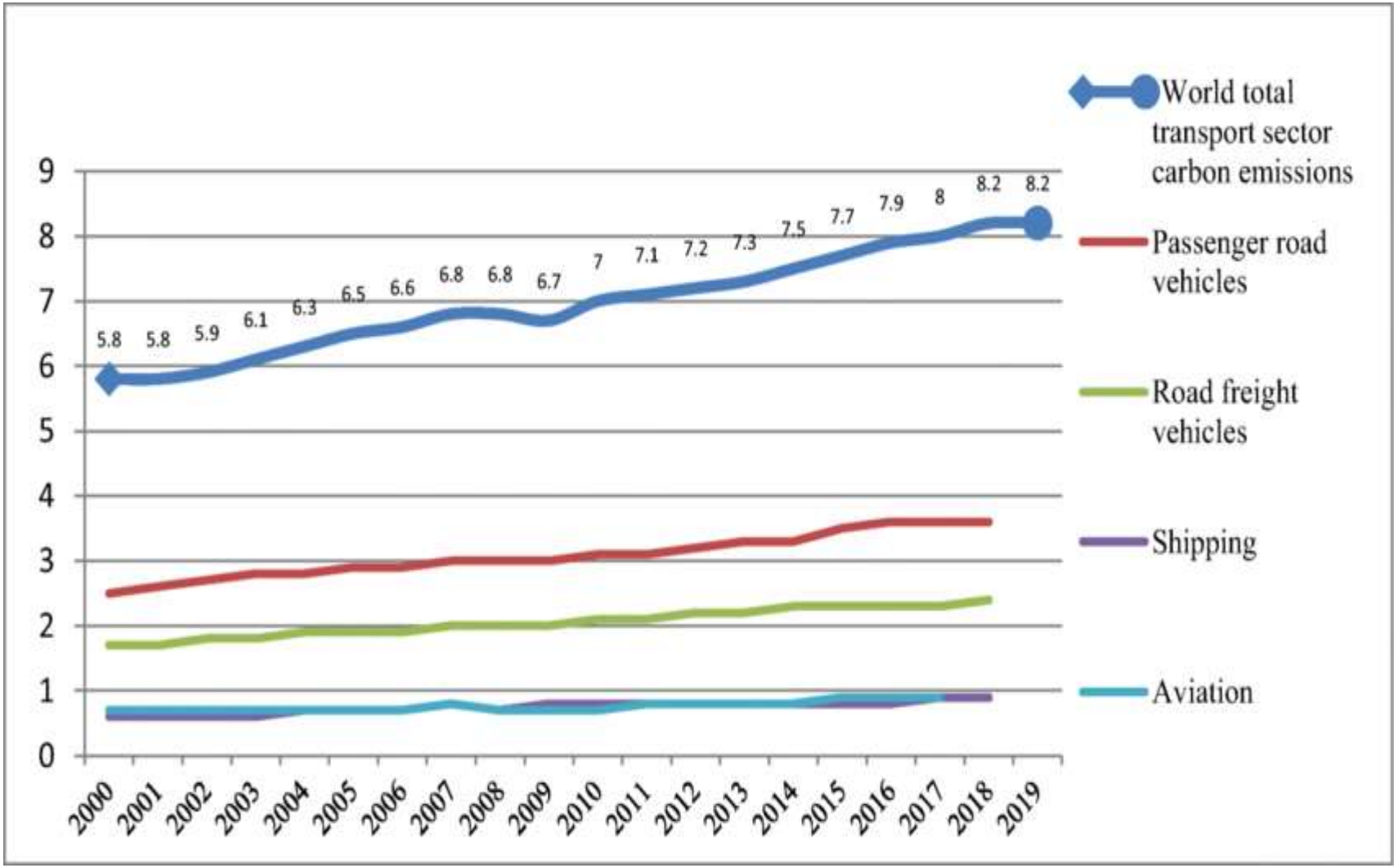


In Bangladesh the costs are Tk. 6.5 for road, Tk. 5.6 for railway and Tk. 1.7 for waterway.

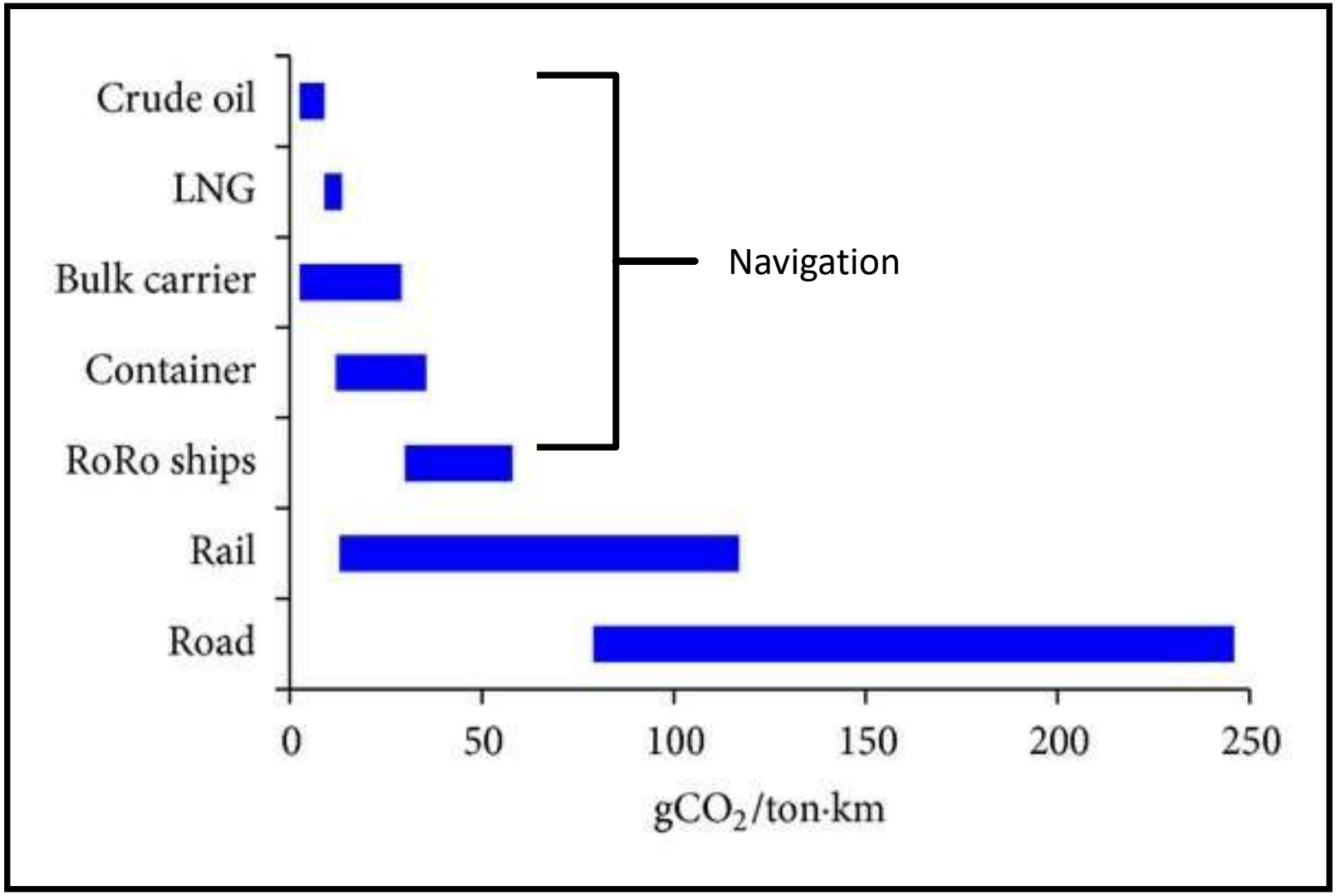
Transport costs for different types of shipping methods in China.

Transportation Mode	Traffic Route Type	Transport Cost (yuan/ton-km)
Highway	Highways	0.80
Railroad	Common rails	0.27
Waterway	Waterways above level three (YHWTP)	0.05
	Waterways of level four and five	0.10

Water – Rail – Road: 1 : 3 : 8



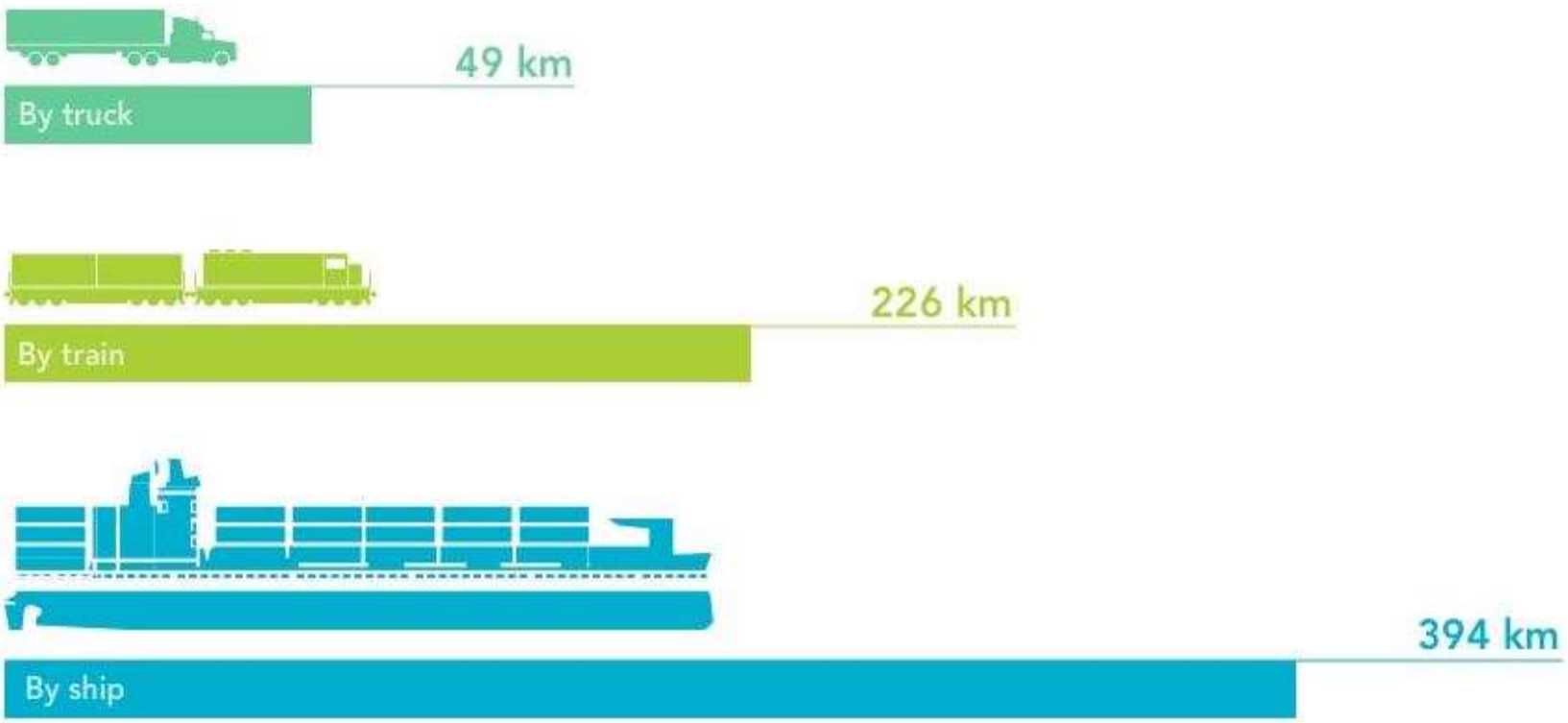
Global transport sector carbon emissions (2000–2019). Sources: Teter et al. (2020) and IEA (2019b)



Ship CO_2 emissions comparison to rail and road.

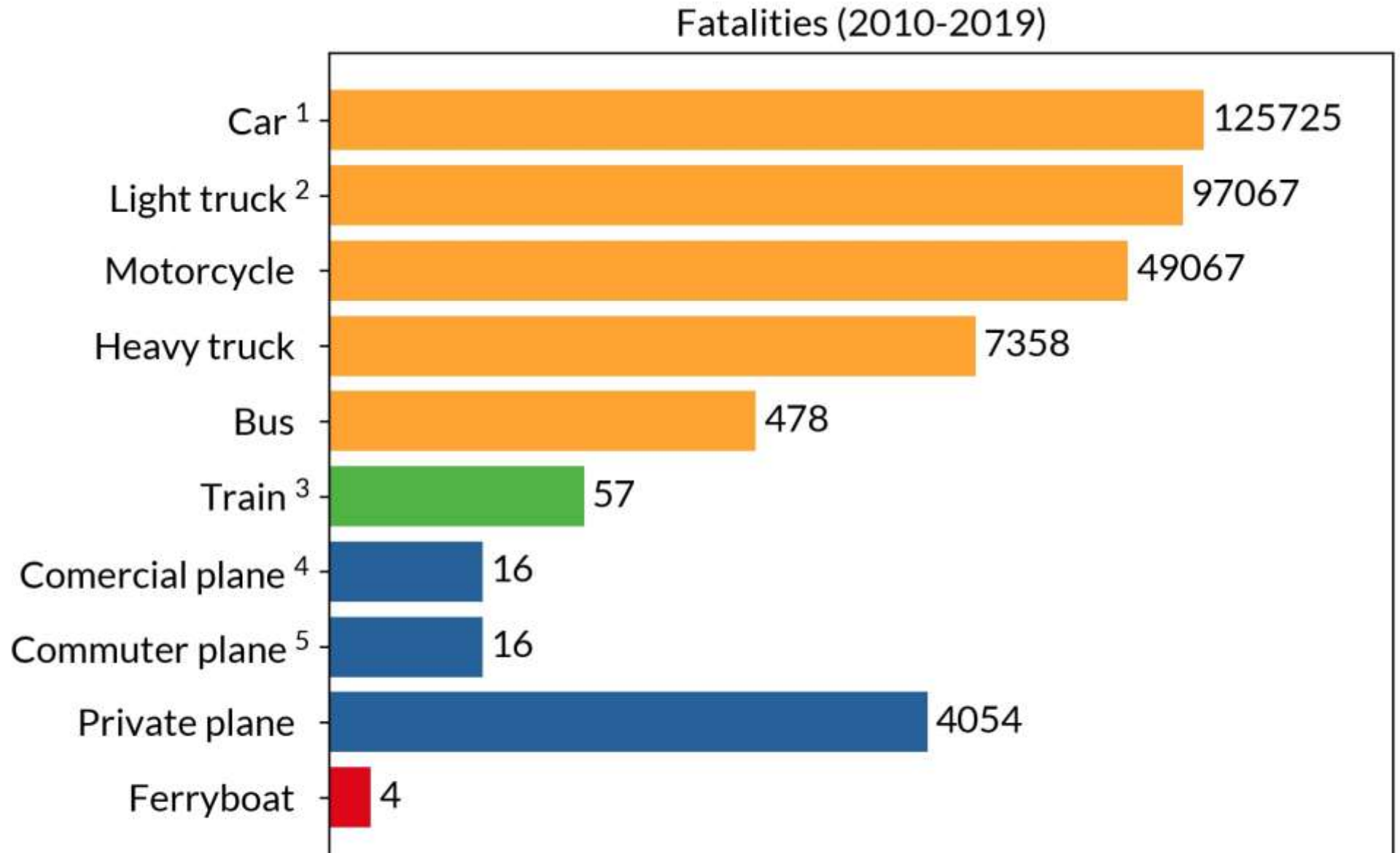
Energy Efficiency of Transportation Modes

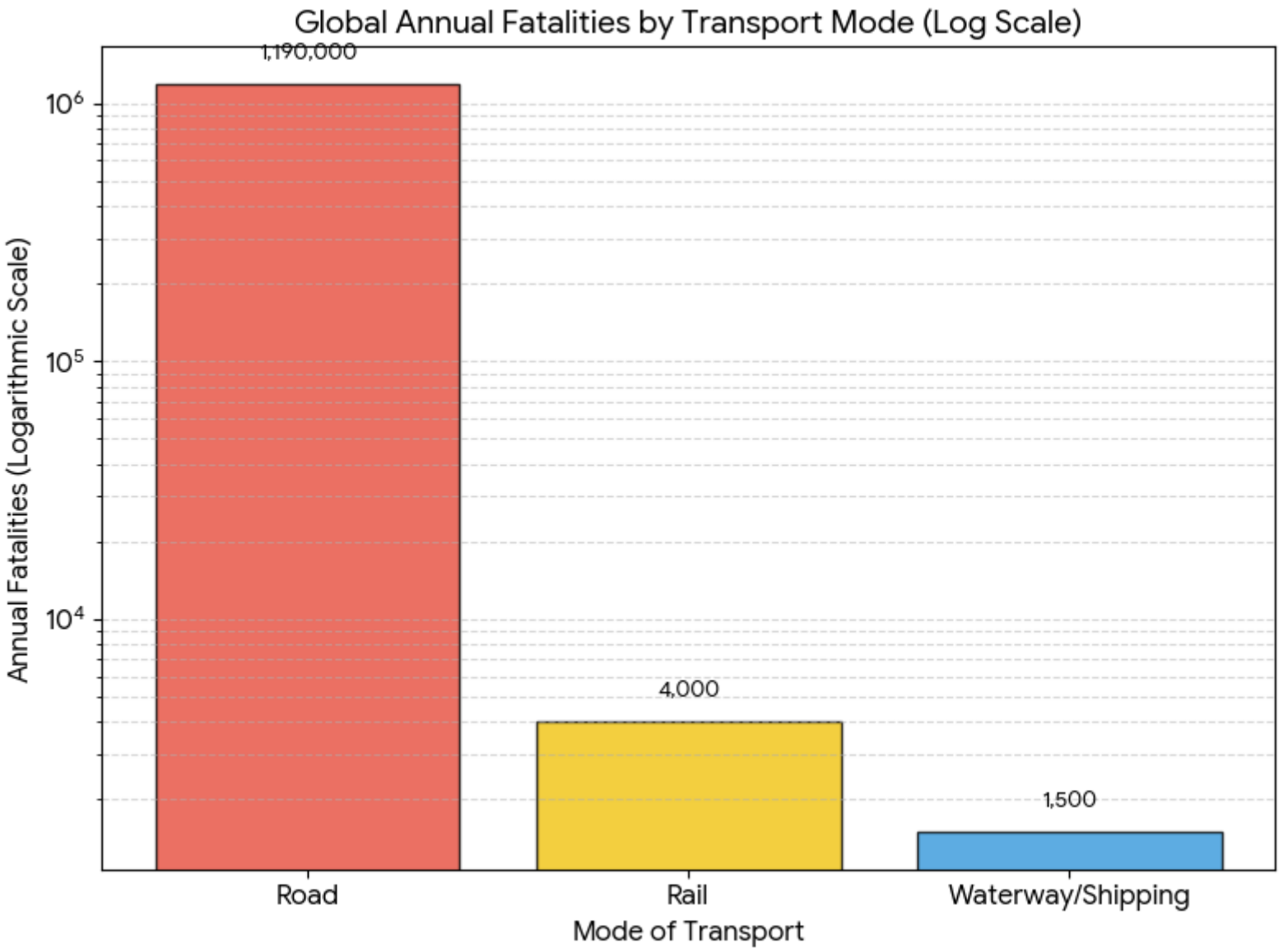
Distance 1 tonne of cargo can travel on 1 litre of fuel in Canada's Great Lakes and St. Lawrence Seaway.

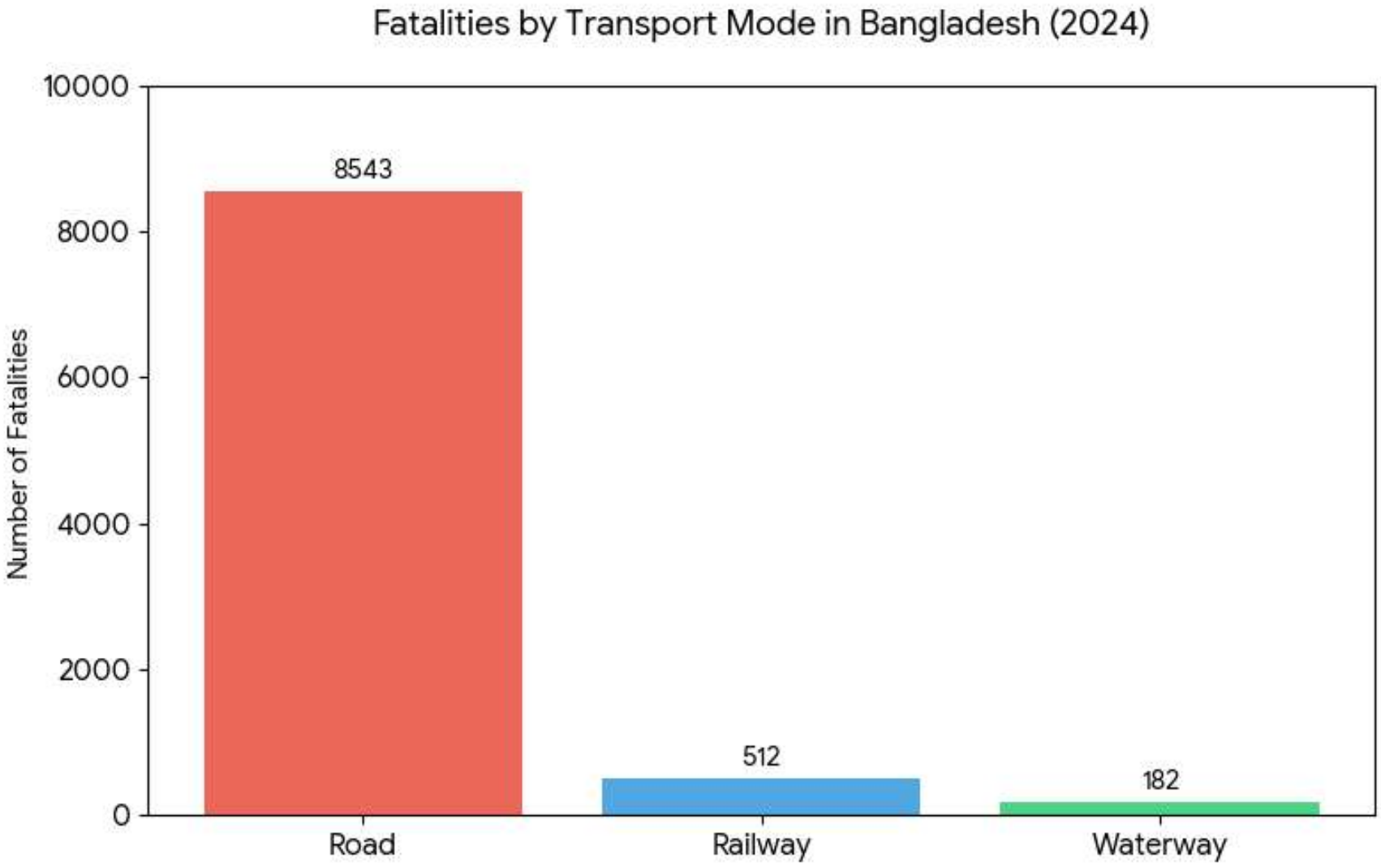


Energy Efficiency: 1 : 4.5 : 8 (Road: Rail: ship)

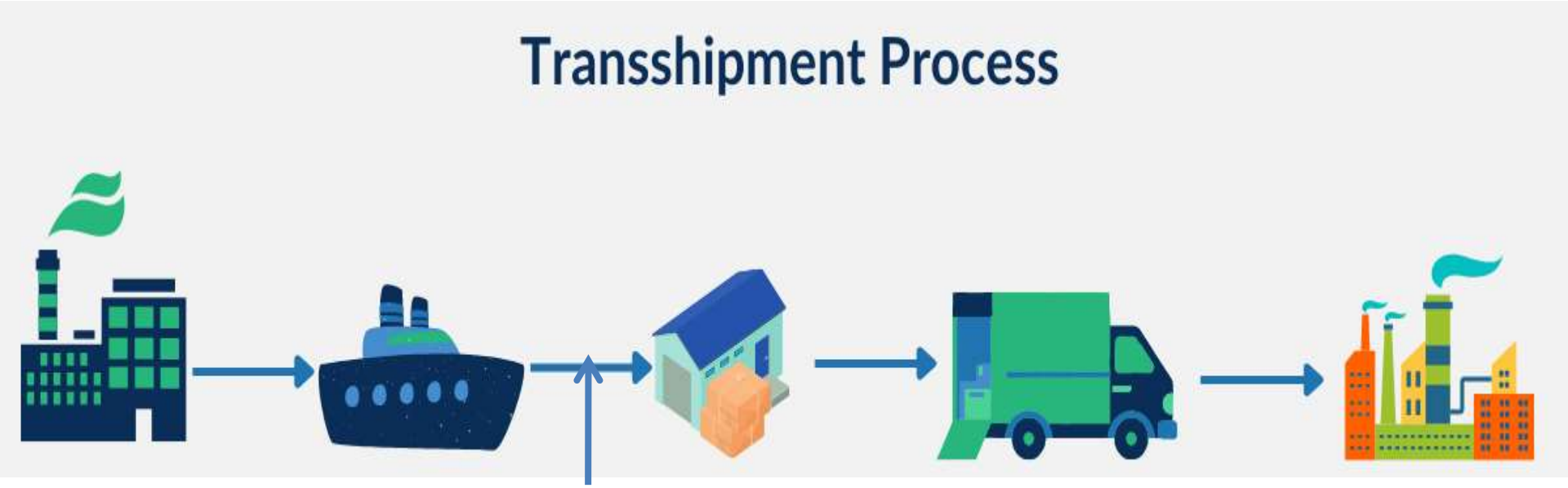
Safety of Transport Modes




Global Annual Fatalities by Transport Mode (Log Scale)
Annual Fatalities (Logarithmic Scale)
10^6
10^5
10^4
1,190,000
4,000
1,500
Road
Rail
Waterway/Shipping
Mode of Transport


Fatalities by Transport Mode in Bangladesh (2024)
Number of Fatalities
10000
8000
6000
4000
2000
0
8543
512
182
Road
Railway
Waterway

The cost of shipment may vary depending upon the cost of transshipment and loss due to delay in shipment.



Transfer to lighter vessel

One is the channel dimensions including the available depth, the width, the radius of curvature at bends, the cross-sectional area and so on – the morphological factors. The other is the flow conditions including current velocities and flow patterns, which are also very important for the vessels to navigate safely and easily – the flow factors.

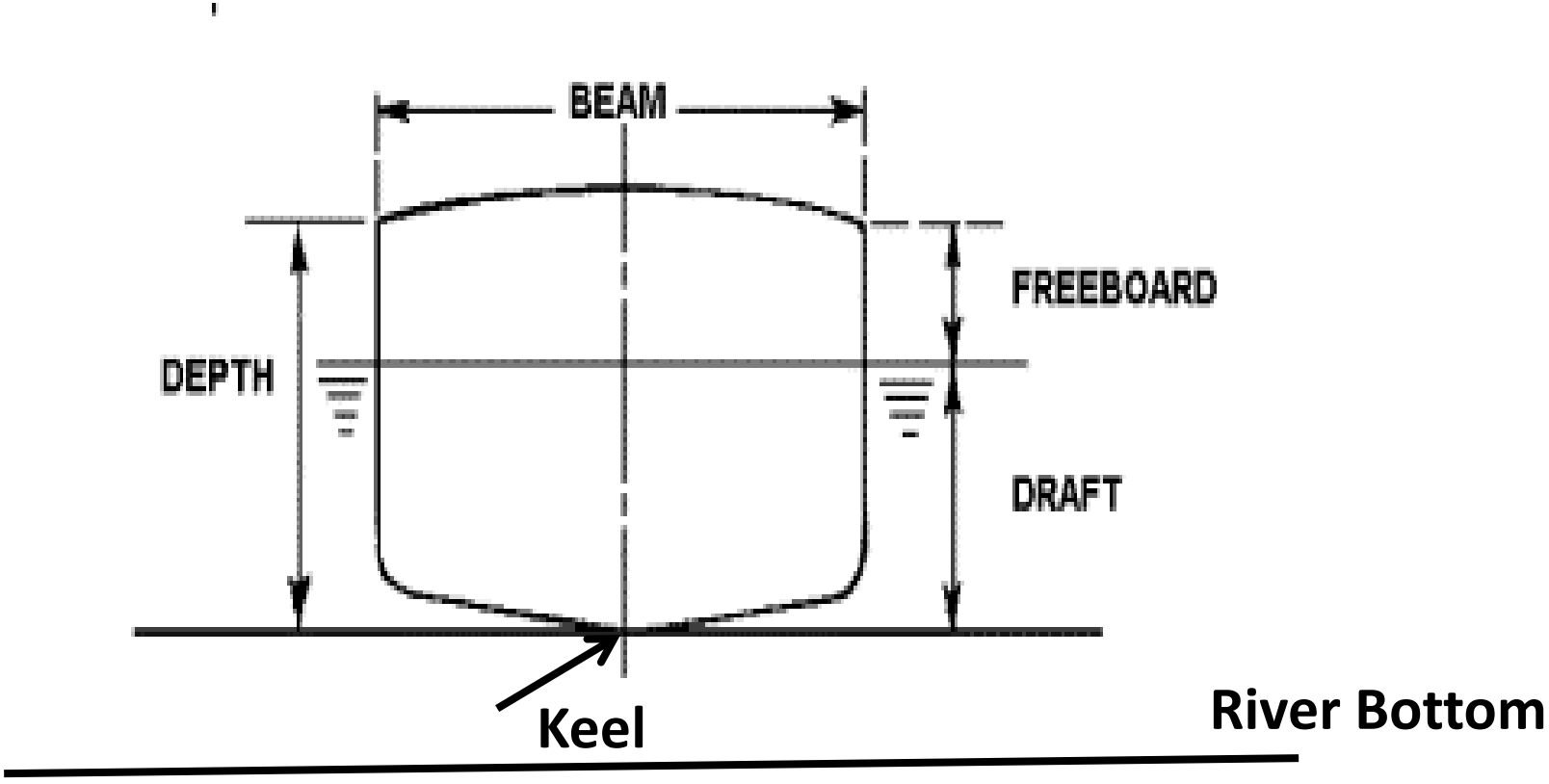
Morphological Factors

Channel Depth

Obviously the actual depth required by vessels must be larger than the draft of the vessel. The reason is that keeping some under keel clearance can make for easy steering and avoid risk of grounding caused by extra sinking due to wind, wave, etc.

The consumption of fuel decreases as the depth of water between the bottom of the ship and the bottom of the river increases. This is because, when the clear depth between the barge and the river reduces, an increased drag force is developed which increases the consumption of fuel (the fuel consumption can be reduced by about 25%, if this clear space is increased from 0.6 m to 1.5 m).

The **draft** of a **ship's** hull is the vertical distance between the waterline and the bottom of the hull (keel). **Draft** determines the minimum depth of water a **ship** or **boat** can safely navigate.



Channel Width

The width of a channel in straight reaches should be sufficient for two-way traffic with safe clearance between passing vessels.

The channel width must be larger at bend than that of straight reaches since tows assume greater drift angles when traversing bends.

Clearances must also be greater in bends due to the presence of cross currents towards outer (concave) bank.

Channel Radius of Curvature at Bends

Bends with a large radius are easier to navigate than sharp curves, therefore, a large radius is preferred.

The minimum radius of curvature of a navigation channel is 3 times the length of the tow-barge fleet.

A tighter radius can be negotiated, but will result in the loss of speed. In any case, it should never be smaller than 2 times the length of the tow-barge fleet.

Channel Cross Sectional Area

This is primarily a navigational efficiency consideration.

The ratio of the cross-sectional area of the channel (Ac) to the submerged cross-sectional area of the vessel (Av) is known as the 'Blockage Factor' (Ac/Av).

Low values of Ac/Av will cause high resistance to the forward motion of the vessel, limit the speed, increase vessel squat and increase channel erosion. The suitable value of Blockage Factor is not less than 6 for 'two-way cross-section'.

Flow Factors

Flow Velocities

High velocity currents make it difficult for up bound vessels to move and for down bound vessels to steer.

It is recommended that the maximum longitudinal surface velocity should not be larger than 3 m/s in natural rivers.

Transverse Currents/Helical Current

Transverse currents are dangerous since they will produce a side thrust pushing vessels away from the navigable channel and may lead to an accident and such velocity should not be larger than 0.3 m/s.

Hazardous Flow Patterns

There are mainly 3 kinds of obstacles/hazards restricting navigation: shoals (submerged bars) where depths are not enough, rapids where currents are too strong, and hazards where the flow patterns are dangerous for vessels to navigate (vortices, confluence etc.). All of those obstacles are called shoals/rapids.

Method of Achieving Navigavbility

There are three methods of achieving/improving navigability of a river. The methods are:

1. Channel regulation
2. Navigation lock and dam
3. Canalization

Canal Regulation

Canal/Channel regulation (river training, or rectification and stabilization) work provide and maintain adequate channel dimensions for navigation. It involves the use of channel improvement and stabilization structures to control the river behavior.

The main purpose of channel regulation is to increase channel depths, improve alignment and stabilize the channel through the construction of regulating structures such as spurs/groynes, revetments etc.
Dredging - While channel regulation works aid in the maintenance of the channel dimensions for navigation, rapid fluctuations in flow may still result in shoaling/bars and sedimentation/aggradation.
Consequently, periodic maintenance dredging is required to maintain a navigable depth throughout the year.

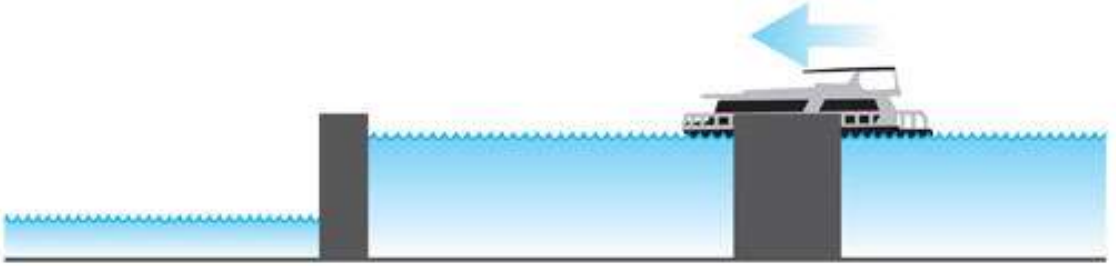
Navigation lock and dam

In this method a river is transformed from a free-flowing stream to a series of slack water pools by construction of a number of locks and dams.
A lock is a structure designed to pass vessels from one water level to another water level – from upstream to downstream or vice versa. It is an open chamber with gates at both ends--at the upper pool and at the lower pool.
There are as many as 29 locks and dams on the Upper **Mississippi River** operated by the U.S. Army Corps of Engineers.

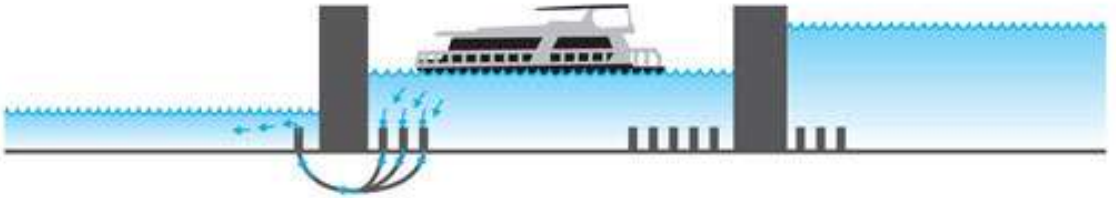
Regulation by spurs



DOWNSTREAM - LOCK OPERATION



Upstream gates open as a vessel enters the lock chamber

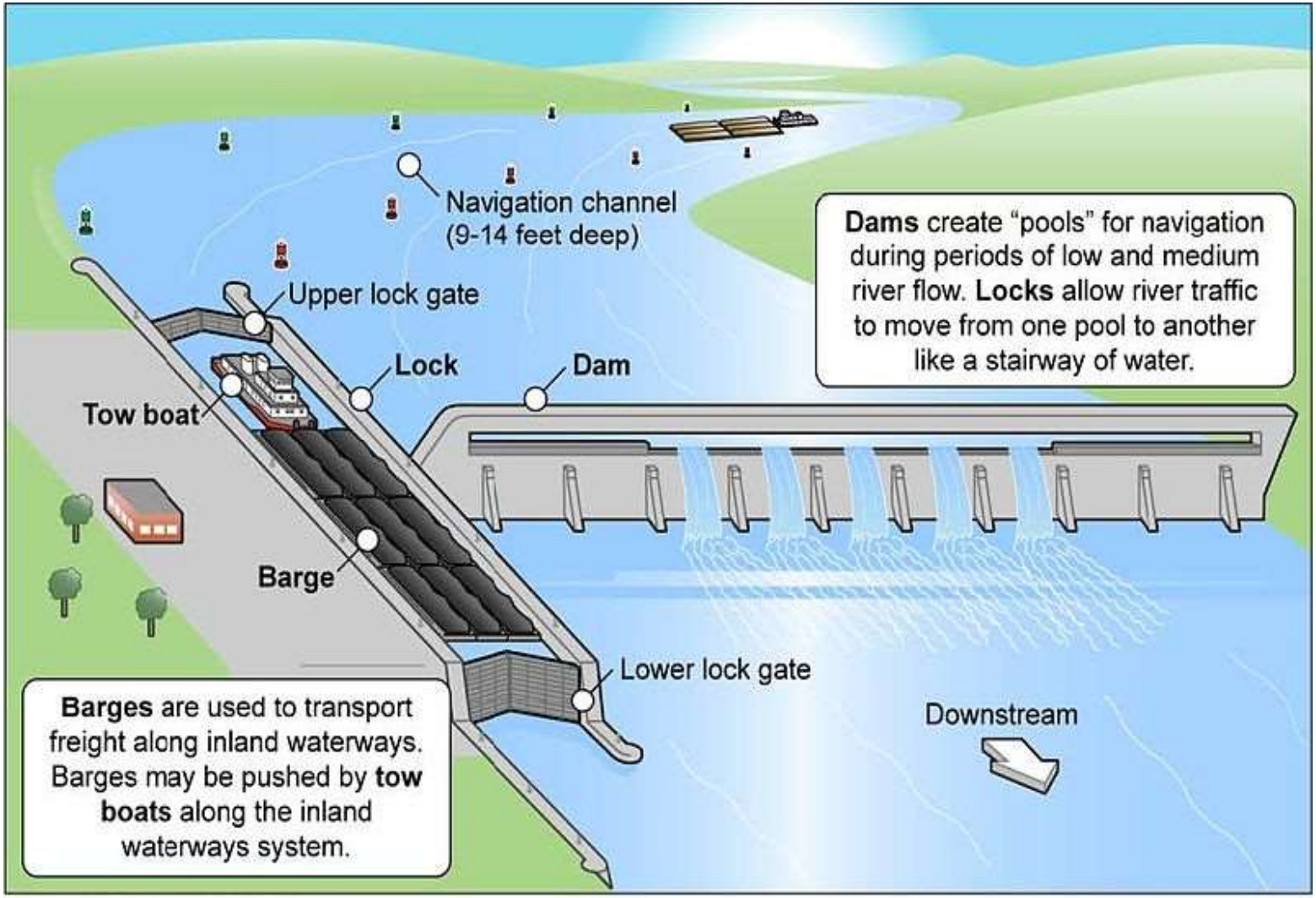


Upstream gates closed
Water is released downstream through butterfly valves
Water in lock chamber lowers



When water levels are equal downstream gates open

Navigation lock and dam



Source: GAO. | GAO-16-682

There are water passages to allow water to come into the lock chamber from the upper pool to fill the lock and to discharge it to the lower pool to empty the lock.
In this method the flow requirement is much less than that required for Regulation Method. Hence, when the available flow is less, these arrangements may have to be adopted.
Because of the pools behind each lock and dam, the waterway width is wide and channel velocities are low, thus conditions are very favorable for navigation.
Lock and dam is an expensive program, and there are also time delays for traffic passing through the locks that increase operation costs.
Moreover, the method is **suitable only on rivers bringing only a little sediment load**. Because, highly silt laden river-waters shall fill up the pools rapidly.

Canalization

Canalization means cutting a canal through land to bypass an impassable obstruction (rock outcrops, rapids, etc.) of an otherwise navigable river or for connecting two navigable rivers.

Such a cut is generally economical only when a short length of new channel opens a large length of existing waterways.

Canalization is generally expensive to construct because of heavy costs for land acquisition, the quantity of excavation required, and problems associated with disposal areas for the excavated material and are adopted only when very short lengths are required.



Cut-offs for Navigation

A cut-off or meander cutoff, can be both natural and artificial, is a meander that has been abandoned by its stream after the formation of a neck **cutoff**. A lake that occupies a cutoff is known as an oxbow lake.

The cut-off is artificially induced with a pilot channel to divert the river from a curved flow and may be required for several reasons:

1. to improve the situation for navigation – e.g. reduce the length and increase ease of maneuvering of a navigating vessel
2. to improve flood discharge capacity – It may also be used to direct the river from the curved flow which may be endangering valuable land and property
3. to stop severe bank erosion - to straighten out the approach of the river. Bend cutting is executed by dredging a new channel along a much shorter but stable alignment.

As the cut-off shortens the length of the river, it is likely to cause disturbance of regime upstream and downstream till readjustment is made. Model tests come in handy in finalizing this form of river training works wherever needed.

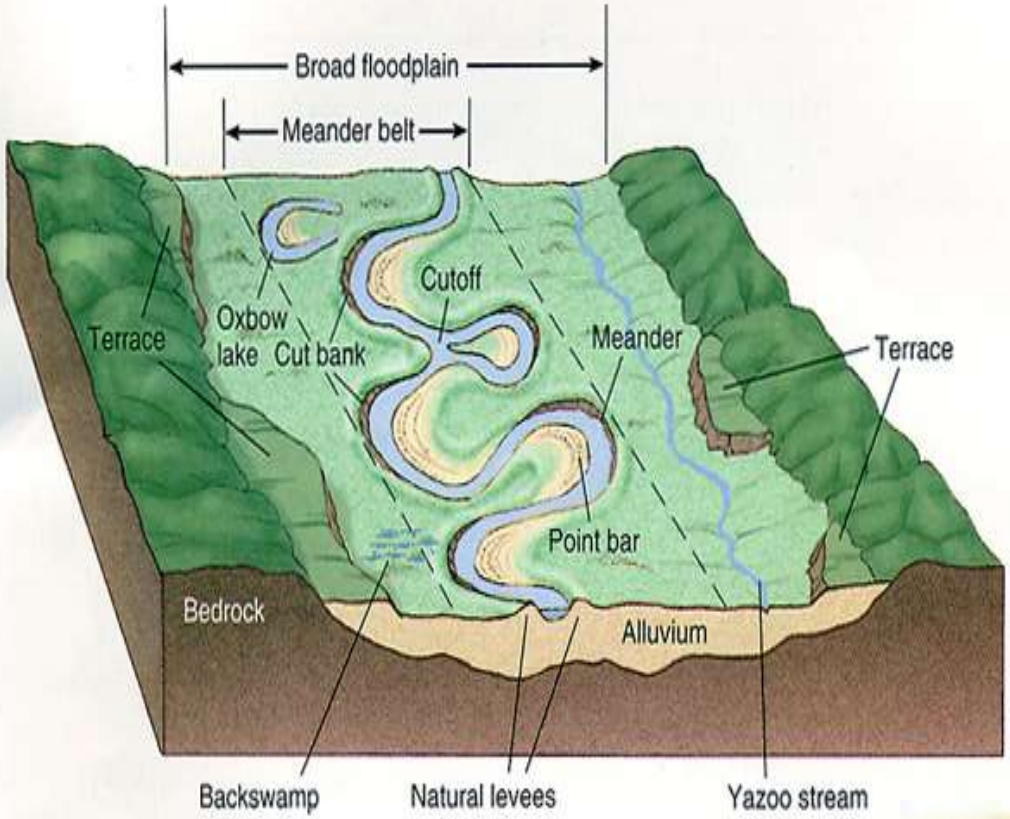
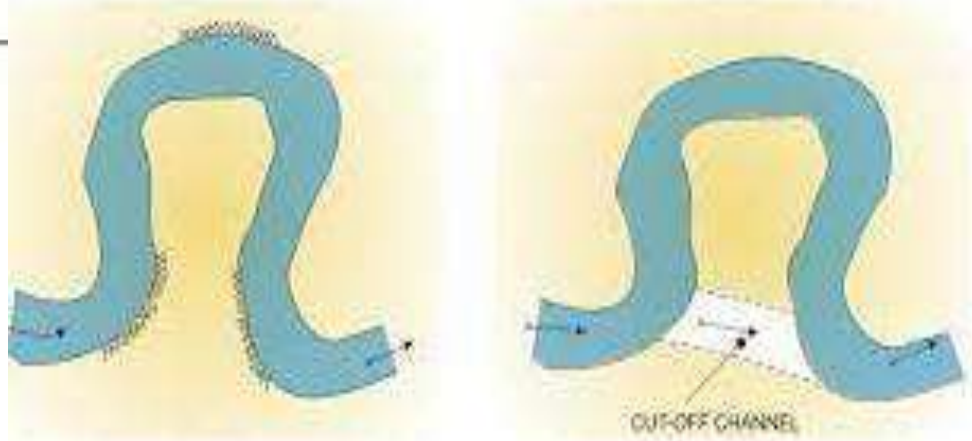


FIGURE 8.6
Features of a stream with a gentle gradient.



(a) (b)

Figure 7 a Meandering river with possible threat to bank erosion (marked X-X)
b An engineered cut-off channel

Morphological consequences of cut-offs are:

If the elevations at points A and B remain unaltered, the longitudinal slope between the two points along the cut-off is considerably increased (Figure). As a result, there are two transitions. From the mild slope upstream of A to the steeper slope of the cut-off and from the steeper slope of the cut-off to the mild slope downstream of B. Generally, erosion starts first not far from point A and deposition will take place in the vicinity of point B. With time, the erosion moves upstream from point A, and sedimentation advances downstream from point B. The back erosion and progressing deposition are carried on until eventually a new longitudinal slope is established, more or less similar to the original slope.

Dredging for Navigation

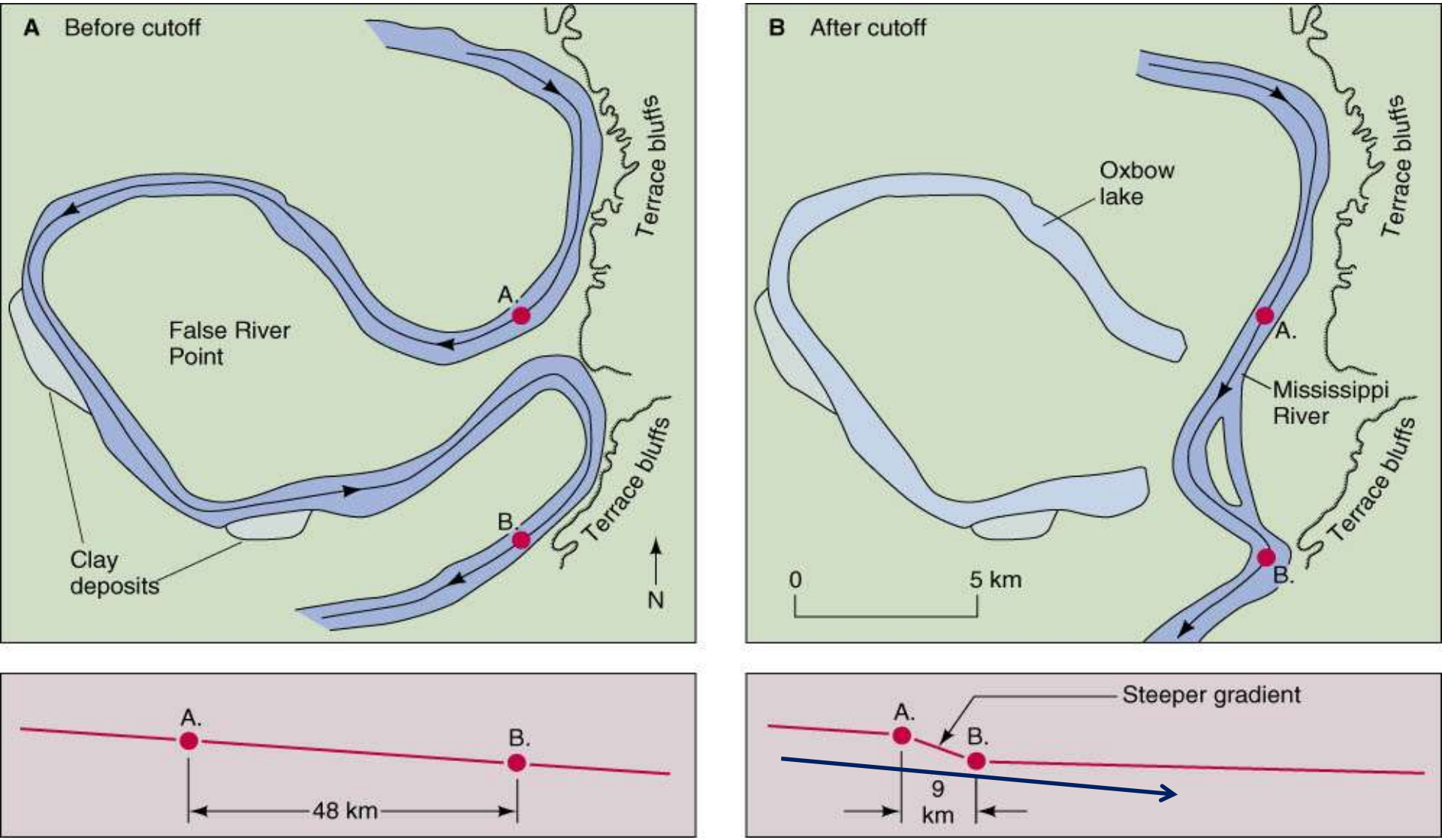
Dredging is the operation of digging, transporting and dumping material from underwater by a floating plant/machine known as a dredger. The dredging process includes loosening and digging of the underwater material, lifting it to the water surface, transporting it to the site where it is to be relocated/dumped and the relocation/dumping operation.
The quantity of soil moved per unit of time is called Production.

Requirements for dredging

The basic requirements to assess dredging works are:

- an accurate estimate of the volumes to be excavated or dredged; and
- an accurate evaluation of the nature of the material to be excavated.

Growing meanders can intersect each other and cut off a meander loop, forming an oxbow lake.



Cutoff in Mississippi River, USA

Types of Dredgers

Dredgers can dig hydraulically or mechanically.

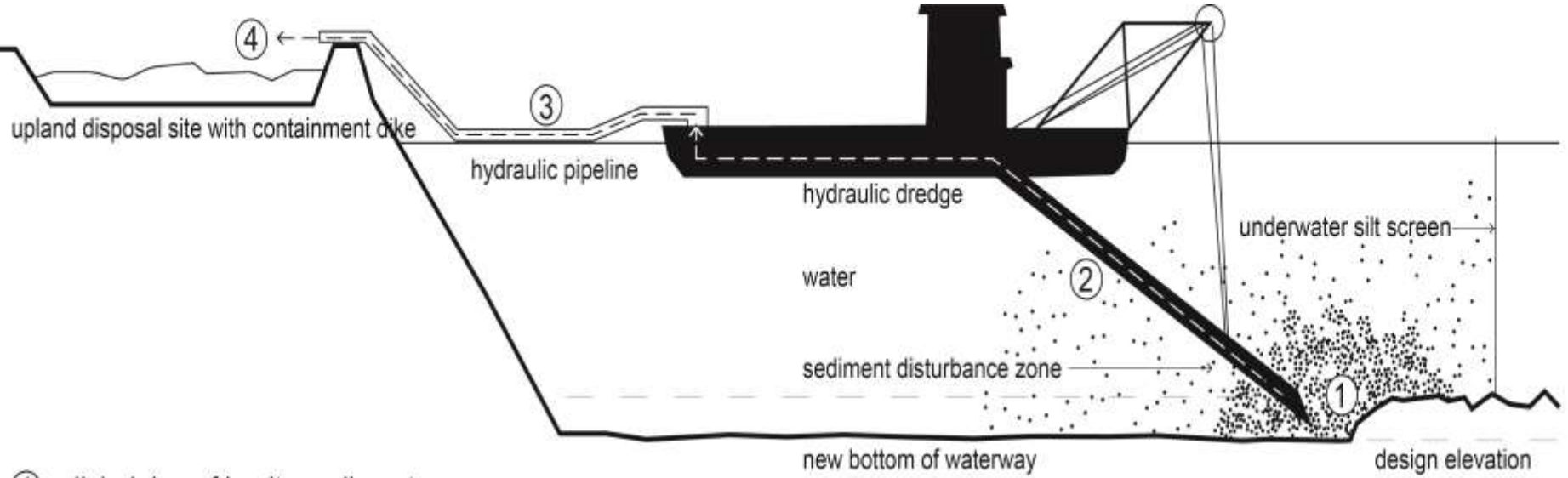
Hydraulic Dredger - hydraulic digging make use of the erosive working of a water flow. A water flow generated by a dredge pump which will erode the sediment bed and forms a soil-water mixture before it enters the suction pipe. Hydraulic digging is mostly done in cohesionless soils such as silt, sand and gravel.

Hydraulic dredgers are self-contained units, they can dig the material as well as dispose of either by pumping the material through a floating pipeline or by storing in hoppers. They are more efficient, versatile and economical to operate.

Hydraulically operating dredgers are of four types: (a) pipeline (plain suction, cutterhead) (b) hopper (e) bucket wheel and (d) sidecasting.

Mechanical Dredger - mechanical digging is done by knives, teeth or cutting edges of dredging equipment and is applied to cohesive soils. All mechanical dredgers are characterized by their inability to transport the dredged material over long distances and relatively low production.

Hydraulic Dredger



① - dislodging of in-situ sediment

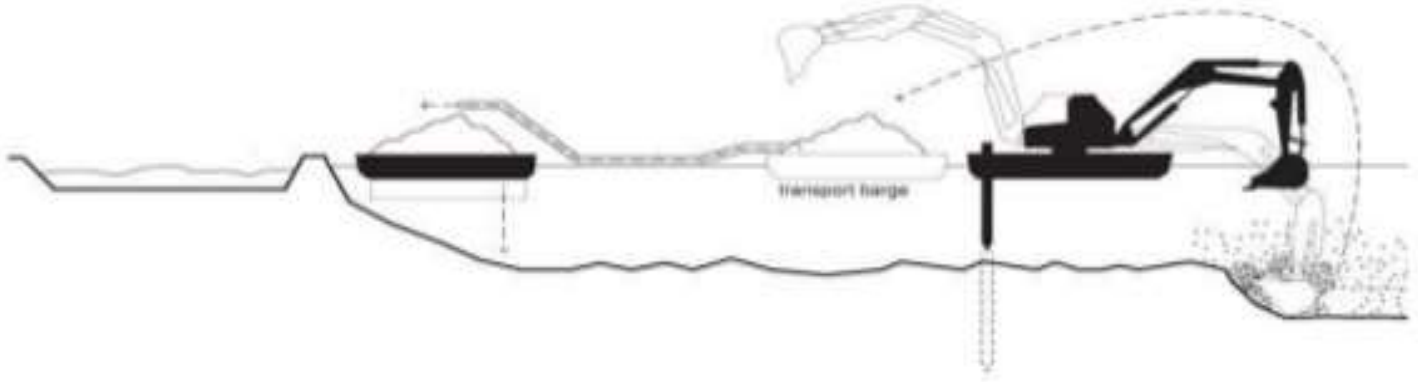
② - raising of dredged material to the surface

③ - horizontal transport

④ - placement or further treatment

Mechanical Dredger

DREDGING OPERATION LAYOUT



SEDIMENT DISPOSAL	SEDIMENT TRANSPORT	DREDGER	DREDGE SITE
• Open Sea Disposal	Barge transport	Type	Open
• Confined Disposal	Pipeline	Size	Confined
• Beneficial Reuse	Combi – B-P	Dredging depth	Sediment
	Rainbowing	Productivity	
	Fall pipe vessels		

Dredging is broadly divided in to two types: Capital Dredging and Maintenance Dredging.

Capital Dredging/Development Dredging: is the initial deepening of an area for the creation of a new canal or the digging/deepening of an existing dead/sedimented river or channel.

Maintenance Dredging: is the removal of material from an area which has previously been deepened, but the depth has reduced because of the deposition/sedimentation. It has to be undertaken periodically. Maintenance dredging typically happens each year.

Dredging process can be divided into four phases:

(1) Pretreatment
(2) Extraction
(3) Transportation
(4) Disposal and placement of dredged material

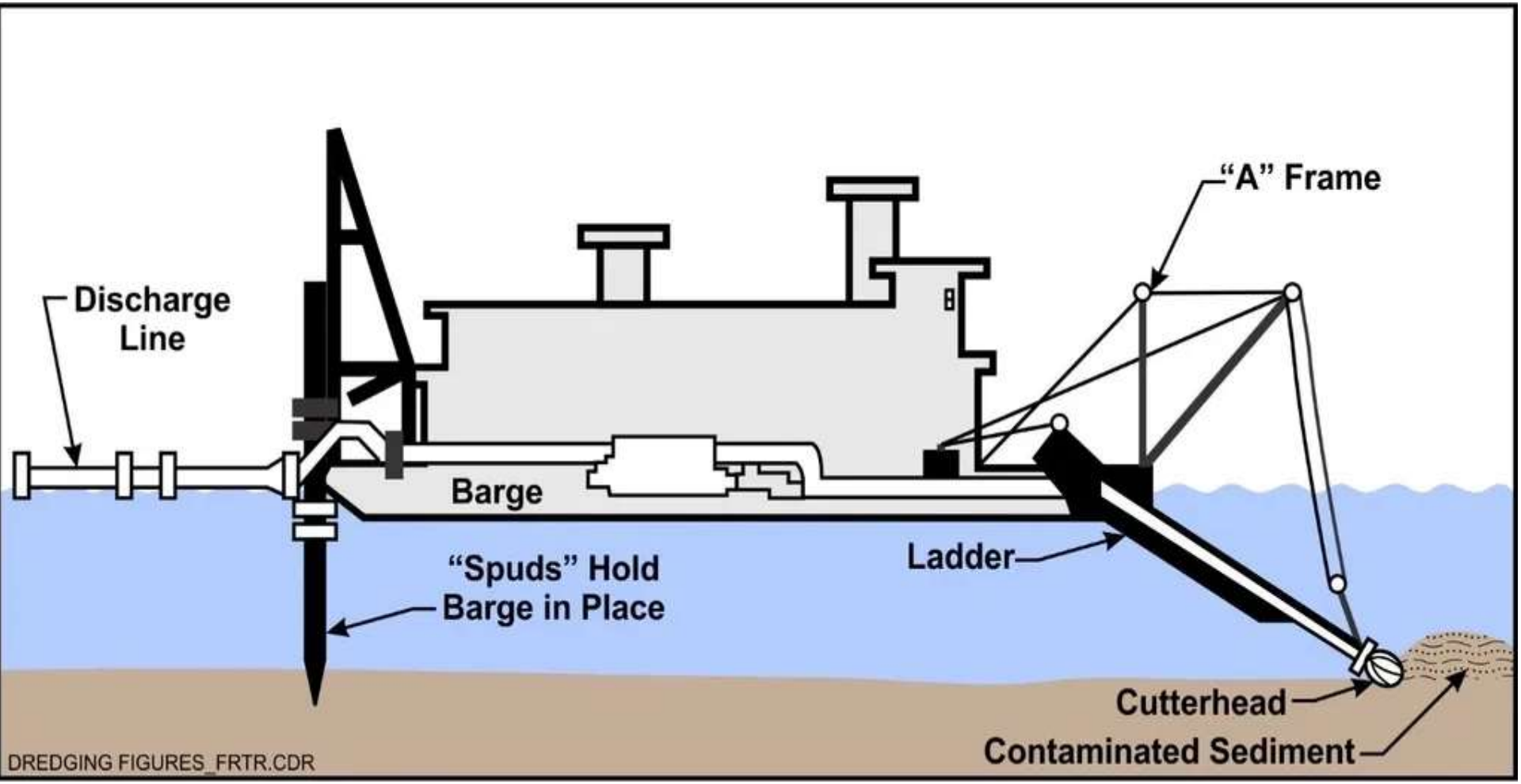
Pretreatment means treatment of the ground before dredging operation. Two methods of pretreatment are chemical and mechanical and both are applied to rock or cemented soil.

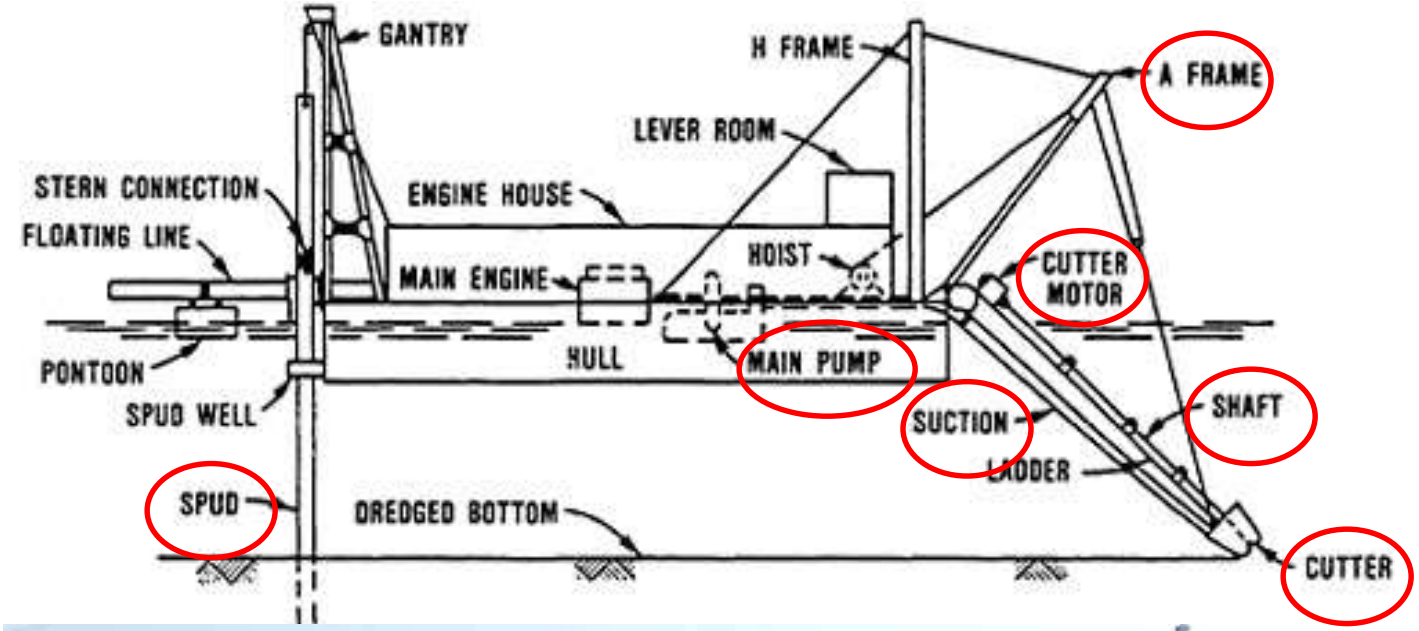
Extraction process involve, the movement of the spoil from its natural or pre-treated position into vertical transportation and is delivered to the transport system.
Transportation is the movement of the dredge spoils from the dredge site to dumping ground. It may be achieved by the use of the main dredging machine or by other means (barge or dump barge).
Disposal and placement of dredged material - three major categories of dredged material disposal may be considered: (a) Open-water, (b) confined (dike) disposal and (c) beneficial use (land filling).

Cutter Suction/Head Dredger (combination of both hydraulic and mechanical)

The cutter suction dredger is a stationary dredger equipped with a cutter device (cutter head) which excavate the soil before it is sucked up by the flow of the dredge pump(s). During operation the dredger moves around a spud pole.
This type of hydraulic dredger is capable to dredge all kind of material and is accurate due to their movement around the spud. The spoil is mostly hydraulically transported via pipeline and the transport distance is limited to maximum 10 km.

Cutter Suction/Head Dredger




GANTRY
H FRAME
A FRAME
LEVER ROOM
STERN CONNECTION
ENGINE HOUSE
FLOATING LINE
HOIST
CUTTER MOTOR
MAIN ENGINE
HULL
MAIN PUMP
PONTOON
SPUD WELL
SUCTION
SHAFT
LADDER
SPUD
DREDGED BOTTOM
CUTTER











Navigation Status of Bangladesh

Bangladesh has about 24,000 km of rivers, streams and canals that together cover about 7% of the country's surface.
Out of 24,000 km of rivers, streams and canals only about 5,968 km (about 25%) is navigable by mechanized vessels during monsoon period which shrinks to about 3,865km (16%) during dry period. Lack of maintenance, reduction in upstream flow (both resulting in sedimentation) as well as human interventions are being blamed for such a decline in navigable waterways.
About 12,000 big inland ships and as many as one million mechanized country boats provide transport services.
The combined transport output of this fleet has been estimated at 15 billion passenger-km (modal share 12% of passenger traffic) and 5.50 billion ton-km (modal share 21% of cargo traffic).

Status of inland waterways

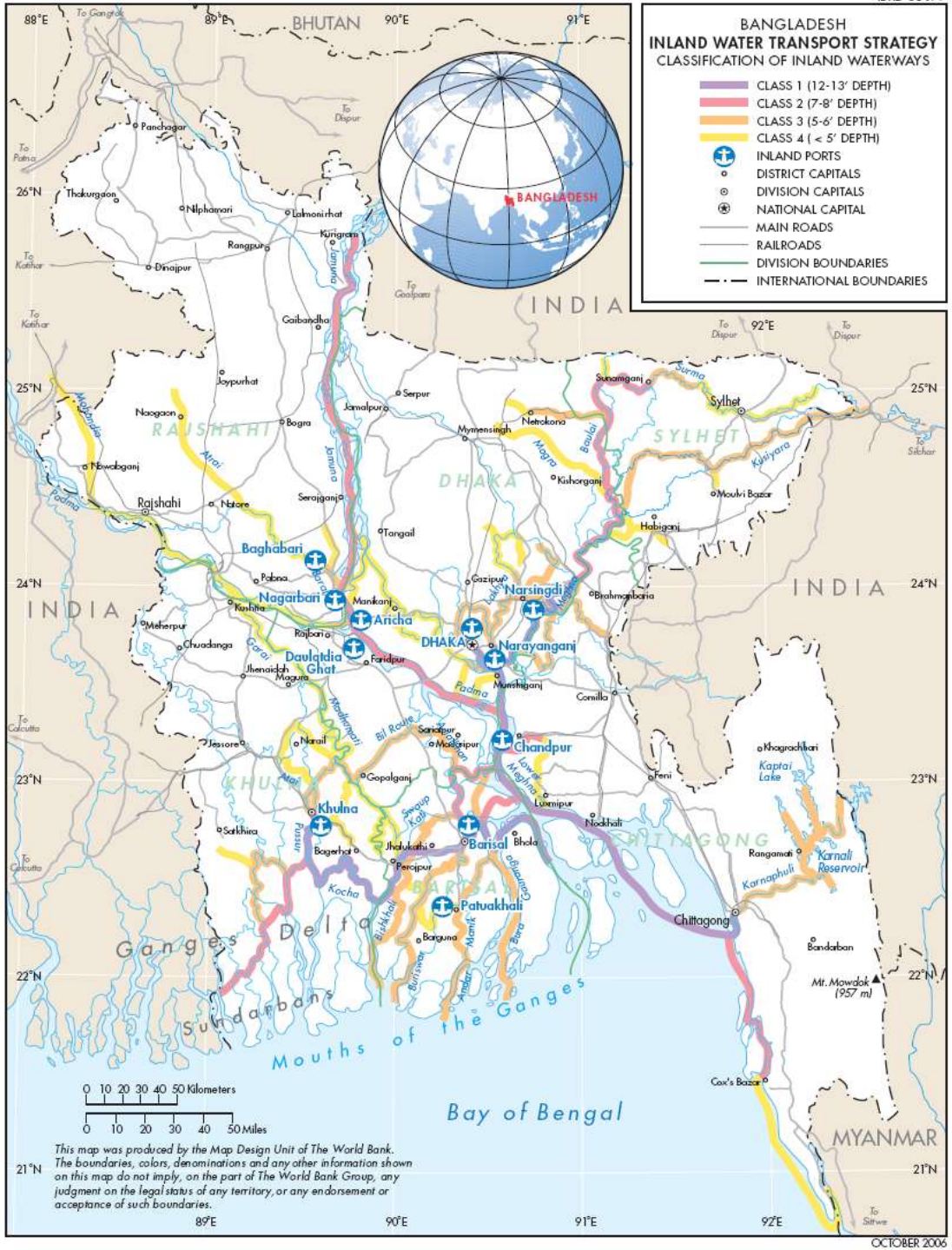
The waterways of Bangladesh have been classified into four categories by Bangladesh Water Transport Authority (BIWTA) depending on least available depth (LAD) ranging from 3.90 m to 1.50m.

Table 1: Classification of IWT River Routes in Bangladesh

Class	Max Vessel Draft (& Min Advertised River Depths)	Minimum Channel Width	Minimum Vertical Clearance	River Length	% of total IWT km
I	3.65 m (3.96m)	76.22 m	18.30 m	683 km	11%
II	2.13 m (2.43m)	76.22 m	12.20 m	1,000 km	17%
III	1.52 m (1.82m)	30.46 m	7.62m	1,886 km	32%
IV	<1.52 m	20.00m	5.00m	2,400 km	40%

BIWTA's four Class-I routes (depth 3.66 m - 3.96m, length about 683 km)- are:

1. Chittagong-Chowkighata-Chandpur-Shambhupura-Narayanganj/ Dhaka
2. Shambhupura-Demra
3. Shambhupura-Bhairab Bazar/Ashuganj; and
4. Chowkighata-Barisal-Mongla-Khulna-Maheswarpasha



Vertical Clearance

According to the 2010 gazette, minimum vertical clearance:

Class-I route is 18.30 m

Class-II 12.20 m

Class-III 7.62 m

Class-IV 5.00 m

from the standard high water level (SHWL).

For waterways that have not been classified by the BIWTA, the local requirement for passage of fishing vessels, boats, trawlers and barges has to be considered.

Dredging in Bangladesh

Dredging of river bed is a common phenomenon and widely undertaken in Bangladesh.

It is occasionally conducted for improving channel navigability and mostly for collection of sand/ gravel/soil which are used as construction and filling materials.

In Bangladesh every year millions of tons of sand/soil materials are collected through dredging river bed.

Hydraulic and suction type of dredging is found cheaper and easier to transport, hence widely used.

In spite of having some positive effect of dredging like increasing navigability, it has negative consequences too.

The negative impact may be both short and long term, local and remote, in upstream and downstream, in river bed and bank or adjacent areas.

Dredging not only causes vertical instability in the channel bed, but also causes lateral instability in the form of accelerated stream bank erosion and channel widening.

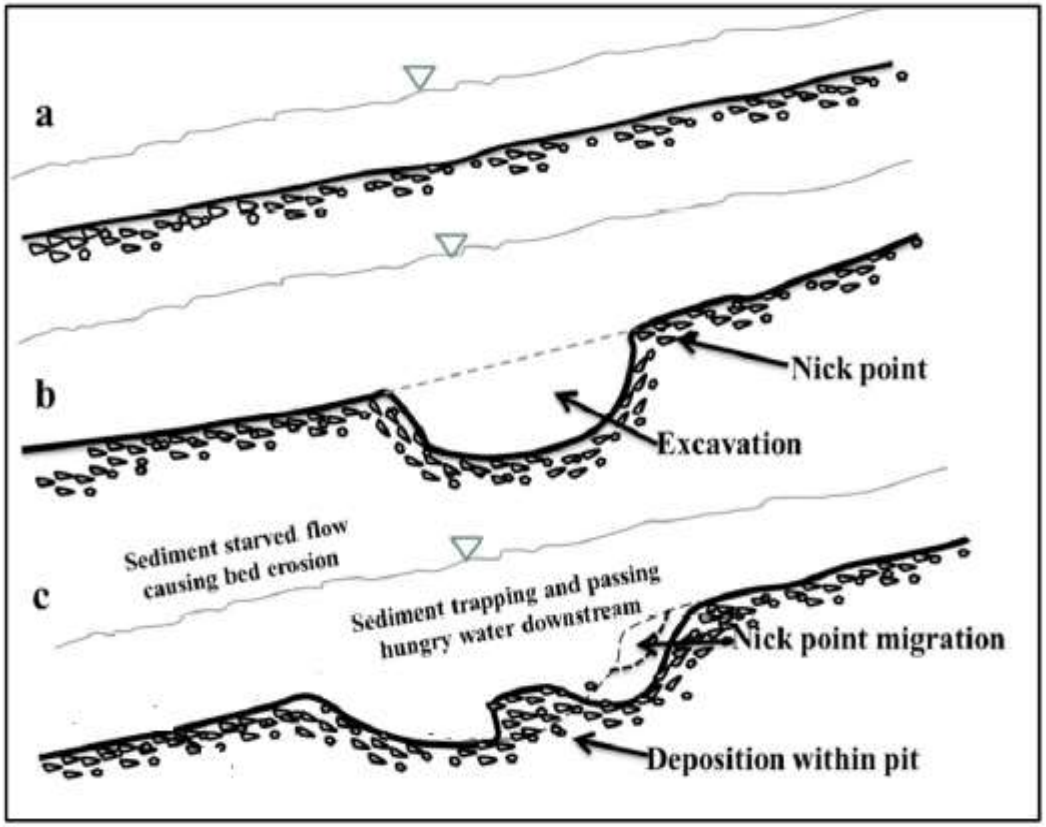
Table 1. The overall situation of dredging in Bangladesh, March 2017.

Dredging Activities	2013-14		2014-15		2015-16	
	IWTA	BWDB	IWTA	BWDB	IWTA	BWDB
Number of dredgers	18	28	18	30	21	35
Total Volume (MCFT)	350.48	83.23	603.52	162.51	999.31	154.22
(a) Public	113.30	80.58	268.85	158.17	300.42	151.71
(b) Private	237.18	2.65	334.67	4.34	698.89	2.51
Total Cost (Million Tk.)	1271.95	471.08	326.45	592.33	3991.71	450.04
Per CFT Cost (Tk.)	3.63	5.66	3.83	3.64	3.99	2.92

The average cost was Tk. 184 per cubic meter in 2018 (about Tk. 300 now)

The morphology of any river channel is the result of three main variables: the material properties of the bed and banks, the flow hydraulics and the sediment transport within the river.
All of these variables interact to produce the channel form, and therefore any alteration of any the variables will cause an effect upon the others.
River bed dredging or in-stream mining directly alters the channel geometry and bed elevation and lateral channel instability, by interrupting sediment transport and making the flow sediment-starved.
Unusual depression of river bed caused due to dredging, alters the equilibrium profile of the streambed, creating a locally steeper gradient at upstream as shown in the figure.

The increase in upstream slope (with its increased stream power) commonly erodes upstream in a process known as head cutting which may propagate upstream of the main river.
Again, at and downstream of the dredging the decrease in slope (with its decreased stream power) create pits to trap much of the incoming sediment.
Thus, when a new equilibrium is achieved, much of dredged section is again aggraded.



In Bangladesh dredging is carried out by both BWDB and IWTA.

The dredging by BWDB is mostly capital/development dredging for flood control and drainage (reviving old/dead/sedimented river and canal and for land reclamation.

The dredging by IWTA is mostly maintenance dredging for navigation.

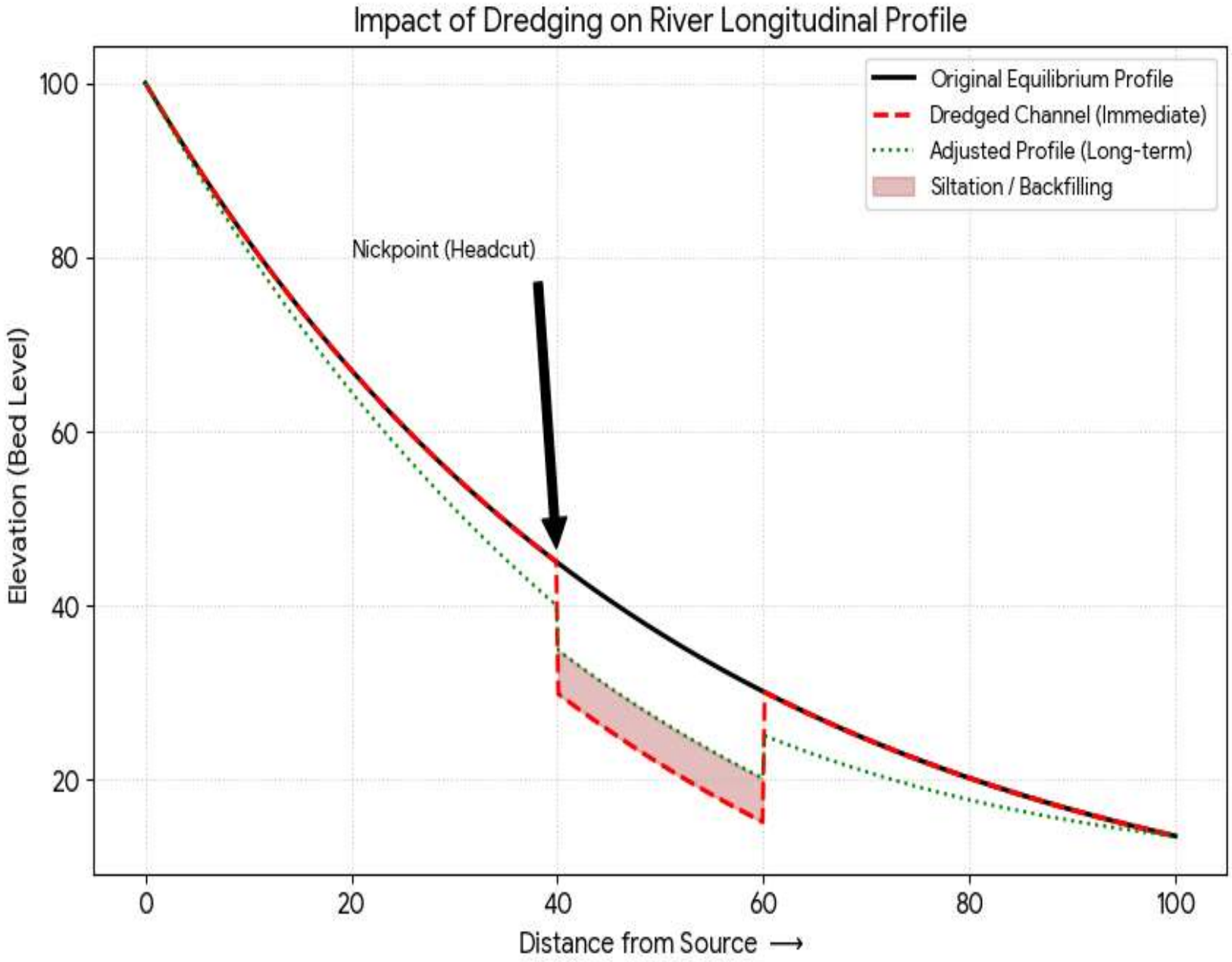
https://www.prothomalo.com/bangladesh/district/ny3e2k6dp3

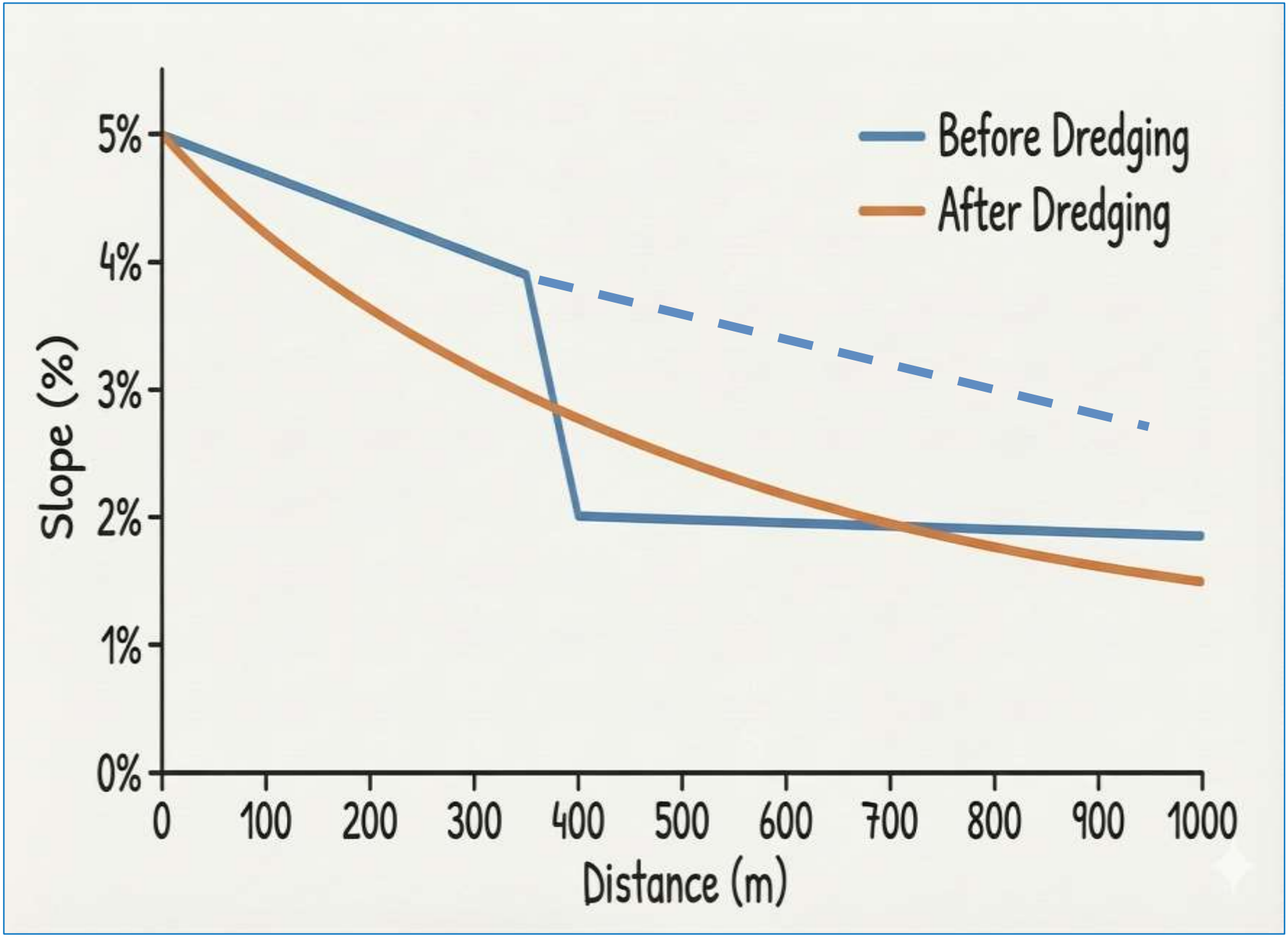
Effect of Dredging on the Longitudinal Profile of a River

In a natural state, a river's long profile typically follows a smooth, concave-downward curve. Dredging introduces a sudden, artificial depression that changes the local bed slope in two primary ways:

Upstream (The "Headcut"): The upstream edge of the dredged pit becomes a steeper gradient, known as a nickpoint. Because the water must drop into the deeper trench, its energy and "stream power" increase, causing it to erode the bed material at this edge. This erosion progresses upstream (headcutting), often for kilometers, effectively lowering the entire upstream bed profile.

Downstream (Sediment Starvation): The dredged pit acts as a sediment trap. Water exiting the pit is "sediment-starved" (hungry water) and lacks the natural load needed to maintain the downstream bed. To compensate, the river erodes its own bed downstream of the site to regain sediment, leading to a flatter gradient and generalized downstream incision.


Impact of Dredging on River Longitudinal Profile
Original Equilibrium Profile
Dredged Channel (Immediate)
Adjusted Profile (Long-term)
Siltation / Backfilling
Nickpoint (Headcut)
Elevation (Bed Level)
Distance from Source ⟶
100
80
60
40
20
0
20
40
60
80
100


Before Dredging
After Dredging
Slope (%)
5%
4%
3%
2%
1%
0%
0
100
200
300
400
500
600
700
800
900
1000
Distance (m)

Selection of Dredge Section of Gorai River (Gorai River Restoration Project, Phase I, 1996)

Proposed dredged section is a trapezoidal one (GRRP, 2000). In this study a dredging section of 200 m base width having side slopes of 1:20 and 13 m deep from the side banks has been used to understand the dredging response on the river hydrodynamics.

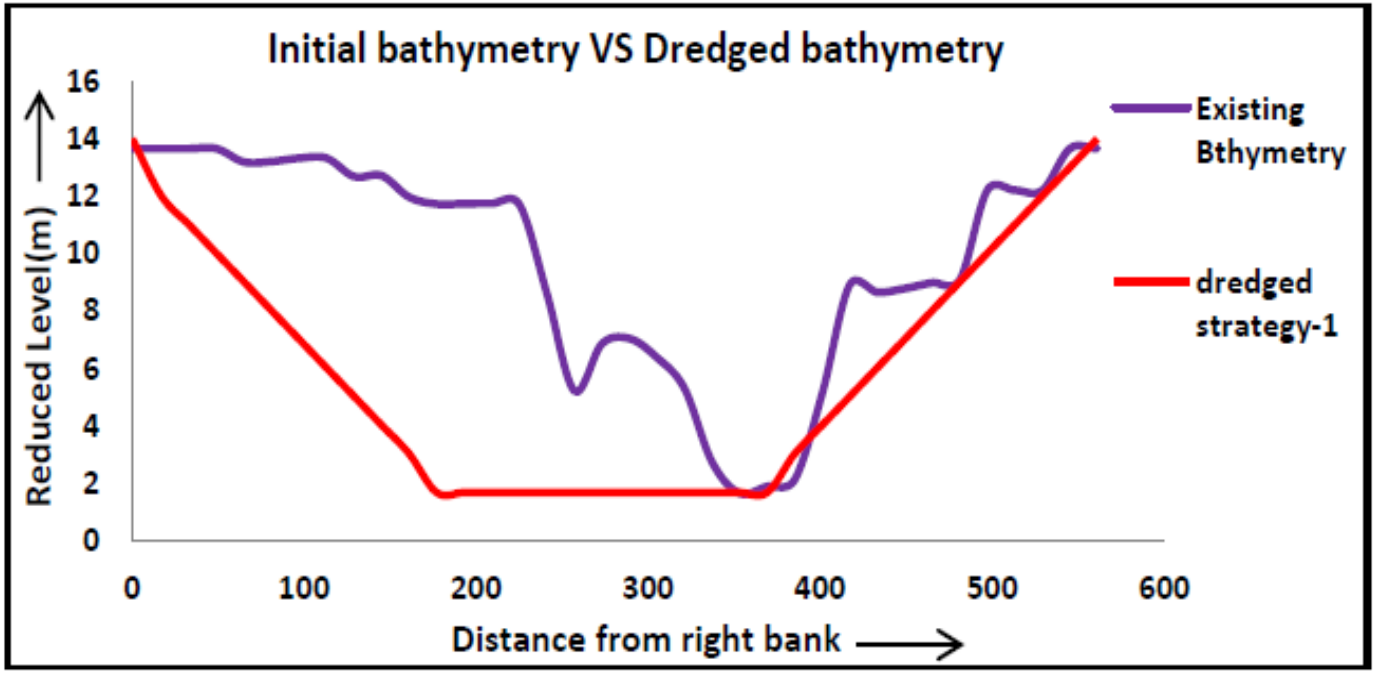


Fig. 2: Initial bathymetry Vs dredged Bathymetry

v) The effective discharge for low flow bed formation of Gorai is found as 50% of dominant discharge. It is found that the bottom bed level of pilot dredge will go back to its pre-dredge regime state and therefore, only the dredging will not be a self-sustaining solution for low flow augmentation.

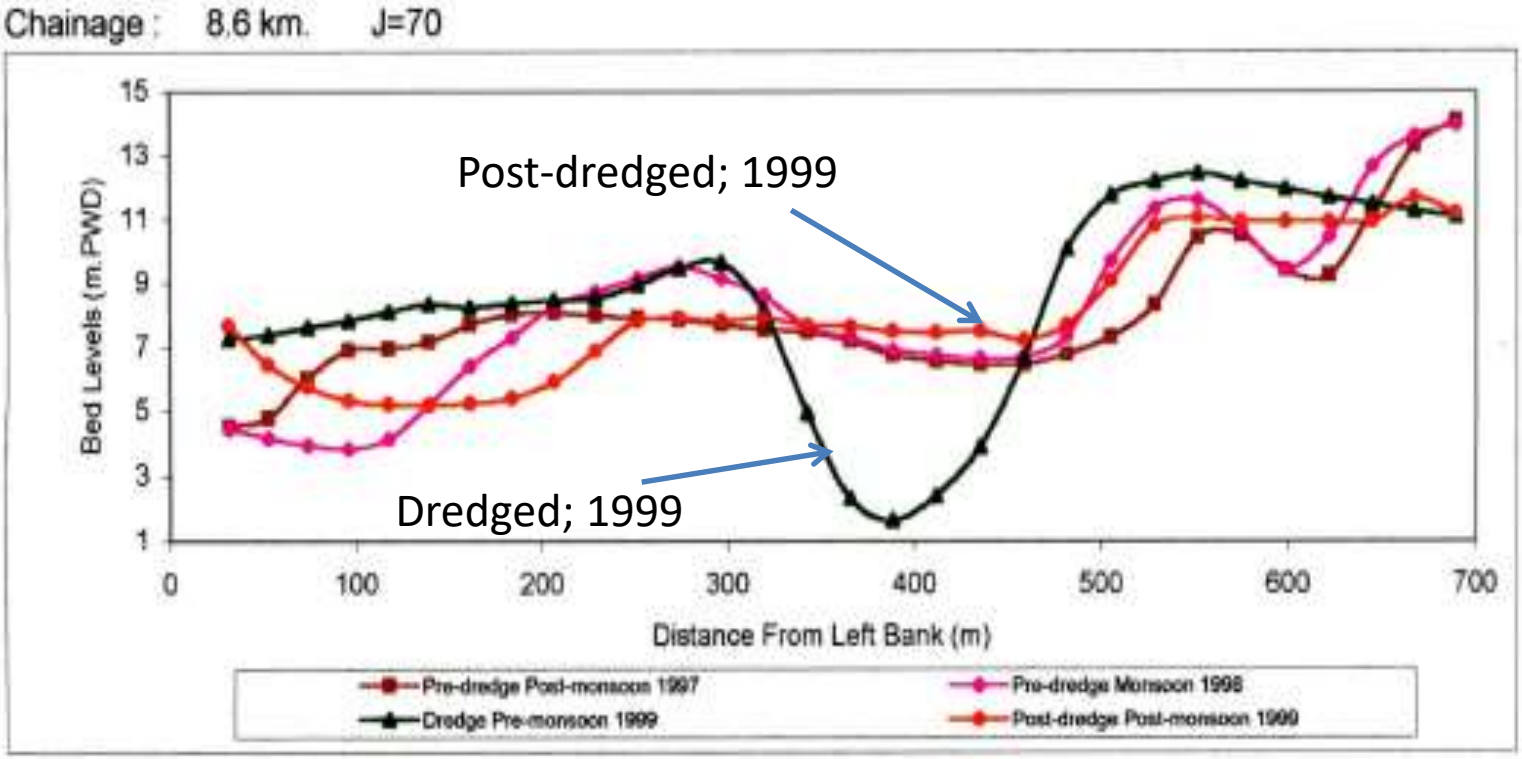


Figure 4.6 : Comparison of dredge, pre-dredge and post-drege sections

The bottom bed level of the dredged Gorai has been raised all along the length of dredge, after the passage of' 1999 flood event which indicates that the dredged bed level could not be maintained for low flow augmentation. Moreover, the pattern of raising profile of the bottom bed level shows that it tends to go back to the low flow pre-dredge state.

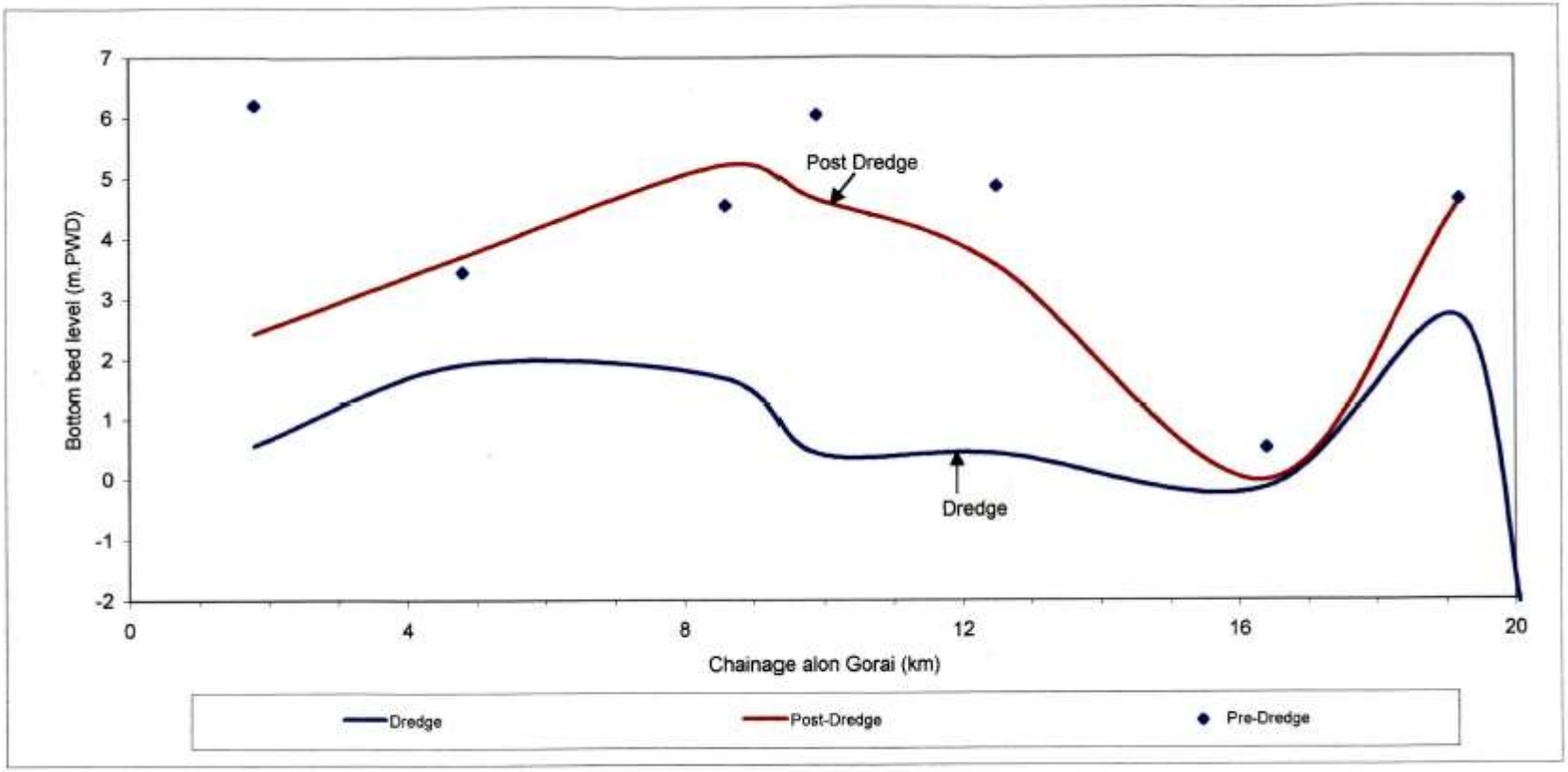


Figure 5.5 : Chainges in bottom bed level (thawlweg) along the Gorai (Dredge and Post Dredge)