Velsink

COAL BY IWT IN INDIA

INITIAL OPTIMIZATION STUDY OF INLAND WATERWAY COAL TRANSPORTATION FROM COCHIN TO KAYAMKULAM, INDIA

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43
44
76
109
112
117

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by

M.H.M. GIJZEN

Thesis study submitted in the fulfilment of the requirements for the degree of Master of Science in Hydraulic Engineering from Delft University of Technology.

Thesis Professor: Prof.Ir.H. VELSINK

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CONTENTS

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NOMENCLATURE

In literature sometimes different names are used for the same places in the area covered in this study. A list of the old and new names are given below.

old name	new name
Cochin	Kochi
Alwaye	Aluva
Sherthalai	Chertala
Alleppy	Alappuzha
Quilon	Kollam
Elur	Eloor

1 INTRODUCTION

1.1 PROJECT BACKGROUND

The demand for electric power in India has been growing steeply during the past decade in almost all regions of the country and power shortages are frequently experienced, particularly in the rapid industrialising southern regions. The Central Electricity Authority studied this problem and came to the conclusion that establishing a string of coal burning coastal power stations is the preferred long term solution. One of the projected sites for a thermal power plant is at Kayamkulam on the south-west coast of India, supplied by coal from Talcher mines in the north-east (see figure 1.1).

A study undertaken in 1988 by the Central Electricity Authority established that the least coal transport costs from Talcher (Port of Paradip) to the coastal powerstations in the southern region is by means of sea transport.

Different coal unloading locations have been put forward for consideration for the Kayamkulam powerplant:

-an offshore harbour unprotected,
-an offshore harbour protected,
-coastal harbour in lagoon near powerplant,
-coastal harbour at lagoon entrance, 2 km south of powerplant.
-via existing port of Cochin (110 km north of Kayamkulam).

For the last option the following alternative ways for transporting the coal from the coal unloading terminal at Cochin to the powerplant site have been considered:

-rail transport
-inland waterway transport (IWT)
-slurry pipeline
-belt conveyor.

In order to find the most promising coal transport network, on basis of overall economic costs from Talcher mines to two new powerplants at Nandigur and Kayamkulam, a transport optimization study is now being performed by Frederic R. Harris BV, consulting Engineers, The Hague. (FRH)

The FRH project is currently in an Interim Phase between the Inception and Detailed Study phases. The Inception Report (ref.[1]) examined alternatives for the siting and lay-out of coal unloading terminals for the new power stations.

In the assessment of alternatives concerning the coal transport scenarios for the Kayamkulam powerplant it has been required to perform a more in-depth assessment of the option by which coal will be unloaded at the existing port of Cochin and further transported by Inland Waterway Transport (IWT) to the Kayamkulam plant site.

The present project is carried out at FRH from February till August 1993 and is part of the thesis study carried out by the author in the fulfilment of the requirements for the degree of Master of Science in Hydraulic Engineering from Delft University of Technology.

1.2 STUDY OBJECTIVE

The objective of this study is to summarize, interpret and where possible quantify all constraints and opportunities concerning the transportation of the ultimate projected coal throughput of 8.06 million tons per year (mmtpa) from the coal unloading terminal at Cochin to the projected thermal powerstation at Kayamkulam by IWT, using the existing West Coast Canal; and to find the most promising scenario for this transport system on basis of technical feasibility and costs. Total costs of the selected option have to be estimated also.

1.3 LOCATION

The waterway stretch considered in this study is part of the West Coast Canal and runs from Cochin to the Kayamkulam power plant site, situated in south west India. The proposed site for the IWT coal loading facilities is at Cochin Port and the unloading facilities at Kayamkulam are indicated in figure 1.2

1.4 PREVIOUS STUDIES

In order to improve the Inland Waterway Transport facilities in Kerala State, India, the Indian government is exploring the possibilities of improving the navigability of the West Coast Canal (Cochin - Quilon) and adjacent waterways.
Earlier Dutch missions to the West Coast Canal,('Up-dating mission to the Kuttanad region', De Bruin 1985; 'Dutch IWT-mission West Coast Canal', De Bruin 1987) indicated that the alluvial coastal watersystem forms a complex hydraulic-ecological system which is "crying out" for an integral approach to its infrastructural problems.

In 1991 RITES studied the development of inland waterway transport on the West Coast Canal between Kottapuram and Kollam (ref.[4]). This study is a first step in a phasewise development of the entire WCC waterway system, extending over a length of about 560 km along the Kerala coast from Kovalam to Hosdurg. Traffic forecasts of various commodities were made. Hydrological investigations revealed that the waterway under study is influenced by tidal variation and river discharges.

Physical constraints, as identified by RITES, are inadequate waterway dimensions, head clearance at Karumadi Road bridge and dimensional restrictions at Thanneermukkom and Trikkunnapuzha locks.

In 1992 a study has been performed to the improvements of the West Coast Canal for transportation of 8.06 mmtpa coal from Cochin to Kayamkulam (Avarachen 1992 ref.[3]). This study also mentioned that the existing waterway from Cochin to Kayamkulam has many constraints and is not suitable for the transportation of coal required for the power plant. In order to achieve the ultimate requirement of coal for the plant site, it was found necessary to adapt the Thanneermukkom locks to the design vessel and to delete Trikkunnapuzha lock from the transport system.

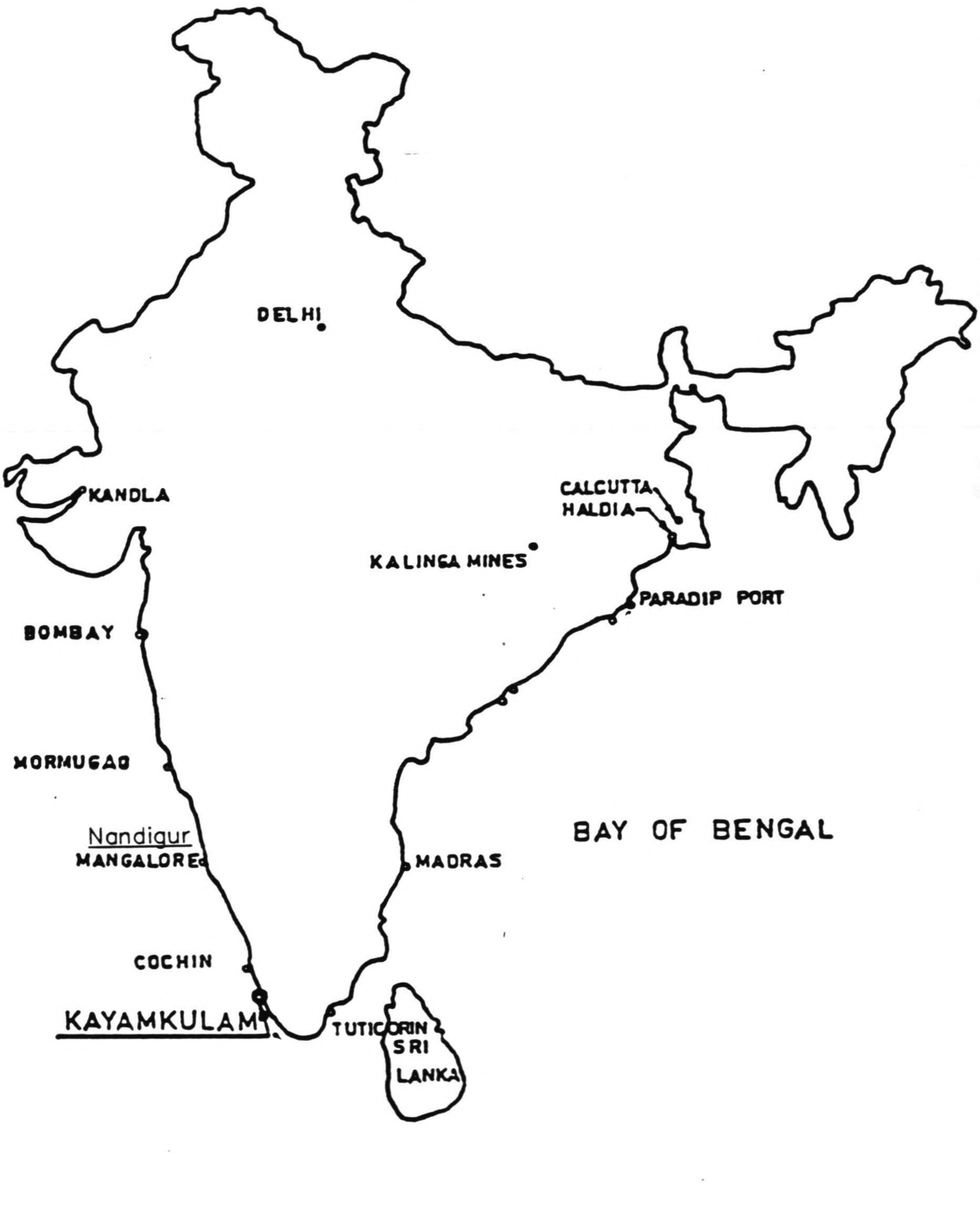


Figure 1.1 Map of India

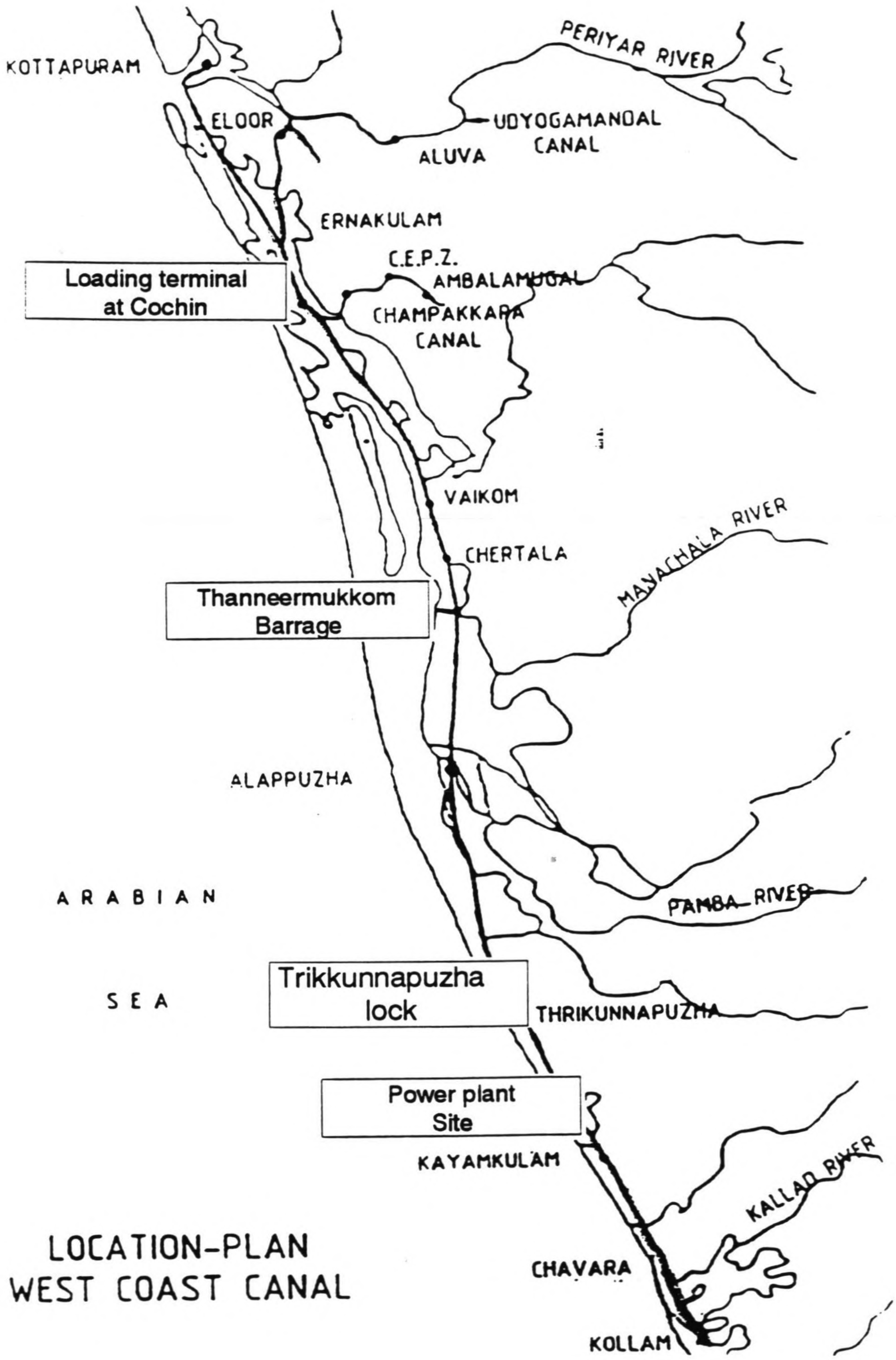


Figure 1.2 Plan of the waterway route

2 METHODOLOGY

Goal of this initial optimization study is to find the most promising transportation scenario and resulting capital- and annual costs for the inland waterway transport system. Reference is made to the study objective. To meet this objective the following methodology will be applied:

1 Make an inventory of the existing IWT situation and identify constraints and bottlenecks

2 Estimate the outline of the projected future situation, especially the future cargo throughput

3 Estimate the transport capacity of the existing waterway

If this capacity doesn't meet with the required throughput, then

4 Generate improvement scenarios

5 Analyze the improvement scenarios with respect to the requirements:
- -terminal berths
- -improvement of the waterway
- -fleet composition

6 Estimate budget costs

7 Select the preferred concept

8 Estimate the improvement requirements for the selected transportsystem

9 Estimate capital- and annual costs as well as the transport costs per ton

METHODOLOGY SCHEME

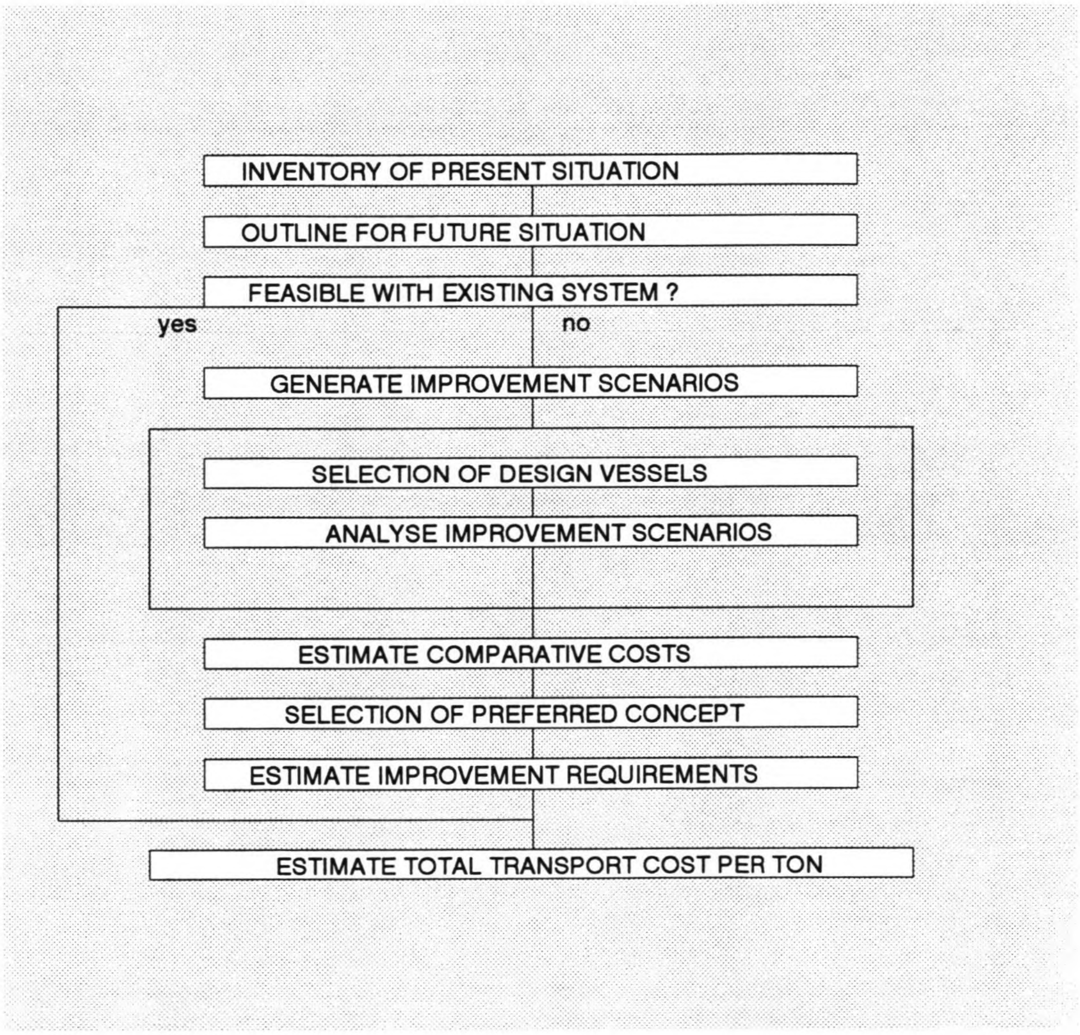


Figure 2.1 Methodology scheme

3 INVENTORY OF THE PRESENT SITUATION

3.1 WATERWAY ROUTE

The waterway route of the West Coast Canal (see figure 3.2) follows the existing coastal lakes and lagoons, rivers and canals between Cochin and Quilon. The length of the route from Cochin to Kayamkulam plant site amounts approximately 95 km. A stretchwise description is given below:

Cochin Port (km. 0).

At Cochin Port two channels are most predominant, Mattancherry- and Ernakulam Channel. The location of the loading terminal is selected at Vallarpadam Island. Hindrance to other traffic will be minimized when the IWT-vessels follow the Ernakulam Channel, having a width of more than 500 meters and depth varying from 3 to 9 m. The tidal waterlevel range is about 1 meter at spring tide and about 0.5 meter at neap tide. The current velocity in the harbour basin may occasionally reach 1.4 to 1.7 m/s. During the monsoon period it can rise to a maximum of 2.2 m/s. Inland navigation is not hampered by rough water, poor visibility or currents. A map of Cochin Port is given in figure 3.1.

Cochin port to Vaikom (km. 0 - 30)

This section has a width of approximately 1 km. and depth is varying from 3 to 9 m. A road as well as a rail bridge crosses the waterway near Aroor (km 10) having a span width of 26m. and a height clearance of 6 m. above MWL.

Vaikom to Thanneermukkom (km. 30 - 41)

In this section the width varies from 2 to 4 km. and depth from 3 to 9 m. There is no need to locate the fairway close to the canal banks, so additional investments for bank protection works (revetments) will not be necessary. There are numerous fishing nets in and along the fairway, in some cases obstructing the safe passage of vessels. At some places ferry boats cross the main channel.
At Thanneermukkom there is a barrage cum lock system. This barrage functions in the dry season as a watershed between the salt and brackish Cochin harbour basin and the fresh water system in Kuttanad. It consists of 93 vents each of 12 m. wide and is controlled by electrically operated shutters. During the monsoon period (from april till july) these vents are opened to discharge the fresh water monsoon flow into northern direction to Cochin. The barrage is a restriction to navigation and it has been provided by two locks at the western side and one at the eastern side; dimensions are given in table 3.2. No guiding structures to these

locks are presently available. The waterlevel experiences little tidal fluctuation of diminishing magnitude from Vaikom to the barrier and doesn't exceed 0.5 meter.

Thanneermukkom to Punnamada (km. 41 - 62)

In this section the waterway passes through the south part of Vembanad Lake having widths varying from 2 to 6 km. In this section depth varies from 1 to 8 meter. The waterlevel isn't influenced by tidal fluctuation, as it is locked between Thanneermukkom and Trikkunnapuzha locks. Six rivers (Kari, Pan, Kalpuzha, Kavan, Meenachil and Chengalam) discharge from the east into this lake and carry, apart from draining water, also an (unknown) amount of silt. The discharge of these rivers during the dry (non-monsoon) period is almost negligible and the waterlevel in the lake can reduce with about 0.5 - 1 cm per day due to evaporation.

Punnamada to Ambalapuzha (km. 62 - 75)

At Punnamada the West Coast Canal route enters a narrow canal, having a width of 50 to 60 m. and a waterdepth of 1 to 2 meters; the canal crosses Vatta Kayal and enters via a narrow canal Pamba River. This area consists of many islands, polders, creeks and short cuts. Banks along the route east of Alappuzha (Alleppy) town are seriously eroded. Earlier Dutch missions (ref.[2]),recommended that major cargo flows should avoid this area, preferably the route should be relocated a few kilometres to the east, following the major branch of Pamba river between Vembanad Lake and Pallathuruth. This recommendation is being reinforced by the fact that fishing is widespread in this area and nets often extend into the channel and many ferryboats and small vessels operate in this stretch. Pamba River has an average width of 100 m. and a depth varying from 4 to 10 m. There are many open connections with creeks but no information about cross currents is available. Near Ambalapuzha the width is around 25 m. and depth is 1 m. At km. 65 a road bridge (Pallathurthy bridge) crosses the waterway, having a span width of 33 m. and a height clearance of 5.5 m.
Also at km. 73 there is a bridge (Karumady bridge) causing serious constraint to navigation, having a span width of only 9 m. and height clearance of 5.6 m.

Ambalapuzha to Trikkunnapuzha (km. 75 - 91)

In this section the waterway is only 25 to 35 m. wide and the (seriously eroded) riverbanks are densely inhabited, are overgrown with palm trees and contain several buildings. The vertical clearance is obstructed by tall palm trees and visibility in curves is often restricted.
Depth varies from 1 to 3 m. Local country crafts ply on this canal stretch frequently.
At Thottapally there is a water outlet into the sea (spillway), which is very old and

not in use. A roadbridge here is crossing the waterway, having a span width of 25 m. and a height clearance of 6 m.
About halfway this stretch there is a temple (Bhagavati Temple) located on the western bank of a sharp curve.
At Trikkunnapuzha there is an old lock system having two lock chambers of which one is permanently out of order. This lock was constructed in order to prevent salt water intrusion from the Kayamkulam lagoon. The whole construction is badly maintained and forms one of the most serious navigational constraint in the waterway route. Lock dimensions are given in table 3.2.

Trikkunnapuzha lock to Kayamkulam plant site (km. 91 - 95)

The stretch from the lock to the lagoon has a width varying from 20 to 60 m. Depth varies from 1.5 to 2.5 m. The lagoon at the powerplant site is very wide (600 m.) but also very shallow (0.8-1.0 m.).

3.2 DIMENSIONS OF WATERWAY AND STRUCTURES

Information about the waterway profile, lock- and bridge dimensions is obtained from RITES' Final Report of the development of IWT on the West Coast Canal (ref. [4].)
In table 3.1 the existing waterway dimensions are summarized stretchwise.

from	from (km)	to (km)	average width (m)	average depth (m)	slope (1 :)
Cochin	0	7	1000	3–9	10
	7	8	1000	2	10
	8	21	1000	3–9	10
Pannavally	21	22	1000	1	10
	22	30	1000	3–9	10
Vaikom	30	49	2000–4000	3–9	10
Mohamma	49	62	2000–6000	1	5
Punnamada	62	65	55	1.5	2.5
	65	73	100	4–10	5
	73	75	25	1	10
Ambalapuzha	75	84	25	2	5
Thottapally	84	91	35	1–2	5
Trikkunnapuzha	91	95	300–600	1	7.5

Table 3.1 waterway profile existing situation

As can be seen, (more or less extensive) dredging will be required for IWT vessels with a draught more than 1 m, sailing from Cochin to Kayamkulam.

Two lock systems, at Thanneermukkom and at Trikkunnapuzha, are present along the waterway route. Dimensions of the lock chambers are presented in table 3.2

Location of lock	km	Basin	length (m)	width (m)	sill depth (m)
Thanneermukkom	41	west I	76.2	9.2	3
Thanneermukkom	41	west II	45.7	6.1	3
Thanneermukkom	41	east	61	12.3	3
Trikkunnapuzha	91		29.3	9.2	3
Trikkunnapuzha *)	91		28.9	6.1	3

*) unservicable

Table 3.2 lock dimensions

Trikkunnapuzha lock forms the main constraint of the present waterway. It determines the maximum dimensions of the vessel sailing between Cochin and Kayamkulam.

Several bridges cross the waterway route. Of these bridges the number of spans along with their corresponding horizontal and vertical clearance is given in table 3.3

Bridge name	km	no. of spans	horizontal clearance	height clearance
Aroor road bridge	12	24	33	6
Aroor rail bridge	12	29	26	6
Pallathurthy road bridge	68	9	33	5.5
Karumadi bridge	77	3	9	5.6
Thottapally bridge	85	2	9	6
Thottapally bridge	85	1	25	6

Table 3.3 Bridge clear profiles

As can be seen in table 3.3, especially the Karumadi bridge forms a severe constraint to navigation with a maximum width clearance of only 9 m.

3.3 WATERMANAGEMENT PROBLEMS IN KERALA STATE

About forty rivers flow from the eastern highlands to the west through the State of Kerala. Large quantities of sediment have been washed down to the coastal area over the years, and became an attractive area for land reclamation.
In order to improve the agricultural production of the surrounding land, a (salt) water barrier was built at Thanneermukkom, at km 41 (see figures 3.2 and 3.3), dividing Vembanad Lake into a salt/brackish northern part and a fresh southern part.
During the dry, non-monsoon period a shortage of water occurs due to evaporation and the use of water in the paddy fields. The waterlevel of Vembanad Lake drops below normal waterlevel, resulting in poor waterqualities.

Many reclamation schemes have been carried out, mainly in the south-east of Vembanad Lake, to meet with the increasing demand for food production and thus for agricultural land. Such reclamations reduced the storage capacity of the water system, resulting in higher waterlevels and hence flooding of the reclaimed areas during the monsoon period. In order to drain away the excess water, open links were excavated to the sea. As a consequence of this, salt water could freely enter the (fresh) water system resulting in a salination problem. The quality of the new reclaimed area's deteriorated rapidly and new efforts to reclaim area were started.

Large quantities of artificial fertiliser are used in an attempt to increase the agricultural production. This resulted (flooding of the fields) in vast quantities of nitrates in the watersystem. As a consequence large quantities of aquatic vegetation growed in the channels, causing hindrance to navigation. In attempts to flush away this vegetation (during the dry period) sometimes the vents of the Thanneermukkom barrier were opened losing at the same time precious "fresh" water.

As can be concluded, the watermanagement problems in the region are highly complicated and effects of human intervention are significant. In fact the development of the waterway route has be tuned to an integral approach.

3.4 AQUATIC VEGETATION

A serious navigational drawback is the occurrence of a dense aquatic vegetation, the Salvinia or African Payal which obstructs navigation and causes further deterioration of water quality. It is stated that the hindrance has considerably increased since the operation of the Thanneermukkom regulator. This is attributed to the change in salinity and the stagnancy of the water during the period when the regulator at Thanneermukkom is closed.

3.5 WATERLEVEL VARIATION

The inland navigation route from Cochin to Kayamkulam was developed by linking natural waterbodies with artificial canals. Several rivers discharge from the east in this waterway. Open sea connections in this route are present at Cochin (km.0) and at Kayamkulam Lagoon (km.110). Because of the waterbarrier at Thanneermukkom and the lock at Trikkunnapuzha, only the stretch north of Thanneermukkom experiences some tidal influence.

Because there is no established permanent gauge system for the entire waterway, little is known about the waterlevel fluctuations along the route. Some observations of the waterlevel at several places were performed by RITES in 1991. These observations are restricted to the lean period from january till may only. The fluctuations stay within a range of one meter. Locations with maximum and minimum waterlevels as recorded in this period are given in table 3.4
Waterlevel observations for a whole year are only available at Cochin Port; these observations are presented in table 3.5 Actually there is little difference in waterlevel variation throughout the year.

3.6 CURRENTS

RITES reported current measurements along the waterway (ref.[4]), which are given in table 3.6. Unfortunately no measurement period or time of the year are given. Obtained water flow velocities along the waterway route are low, and mostly less than 0.5 m/s. The low flow velocity is the result of the gentle gradient of the waterway. These currents are no constraint to navigation.

3.7 GEOTECHNICAL DATA

Limited soil investigations were carried out in 1987 at Cochin (km 0), Arookutty (km 14), Vaikom (km 30) and Thanneermukkom (km 41). See table 3.7 for the stretchwise given bed material characteristics. Boreholes were taken upto a depth of 4 meter. The percentage of sand is high (80 to 99 %). At Allapuzha some silty sand and clay was found.
Median grain size is in the order of 0.3 to 0.5 mm. The soil will not give dredging problems.

3.8 WIND SPEED DATA

Wind speed data were collected and reviewed by Delft Hydraulics in 1992. The all year wind speed distribution on open sea near Kayamkulam/Cochin is given in table 3.8
Looking at the all year wind information, a wind speed (at open sea) of 7 m/s will

not be exceeded for 80 % of the time.

Figure 3.6 illustrates the occurrence of the winds in each speed and direction class in wind-rose form. The length of each bar represents the percentage of the time that the occasion occurs; the wind speed class is given by the type of bar and the direction of the bar represents the direction from which the wind comes. The number in the centre of the rose indicates the percentage of time that the wind is calm.

3.9 PRESENT TRAFFIC

The maximum sizes of vessels sailing on the West Coast Canal between Cochin and Quilon at present are determined by the physical dimensions of the locks at Thanneermukkom and Trikkunnapuzha, the bridge clearances and by the restricted cross profile of the waterway. At present there is actually no mechanised IWT freight service along the waterway between Cochin and Kayamkulam. Traffic at present is sailing with small, mostly wooden country crafts (freeboards of 5 cm are reported !) transporting different kinds of commodities (coconuts, rise, bricks, gravel, earth, fertiliser) over short distances. The maximum carrying capacity of these crafts is about 60 tons.
At present there is no system of rules and regulations; there are no safety measures nor labour inspection and the maximum sailing speed is not restricted by specific legislation. Cargo and vessels are not insured and crew training and education is not organised.
Future traffic estimates by RITES are given in paragraph 4.2

3.10 NUMBER OF OPERATING HOURS PER YEAR

Downtime of the inland waterway transport system may occur due to poor visibility, heavy winds and high waves. Poor visibility (fog/heavy rainfall) occurs up to 3 days per year. Wind will neither cause much downtime: in 98% of the year a wind speed of 11 m/s (at open sea) will not be exceeded and the dense vegetation (palm trees) along the waterway banks will further reduce the wind influence. Waves are directly related to the wind conditions and will also not cause much problems.
Number of workable days per year for the inland waterway transport system is therefore taken at 350.
When considering day and night navigation, two shifts working each 10 hours per day, resulting in 20 working hours per day is taken. For daytime navigation only, one shift working 10 working hours per day is taken.

3.11 LOCK THROUGHPUT CAPACITY AT THANNEERMUKKOM AND TRIKKUNNAPUZHA

Due to the limited waterlevel differences at the lock systems, the average time required for a small vessel to pass the lock system according to RITES, is thirty minutes. For larger vessels, an additional manoeuvring time of ten minutes is assessed.
The total cycle time of the locks is therefore assessed at one hour and twenty minutes (1.4 hours).

In the existing situation the Thanneermukkom locks are not in operation from july to october; they are kept open, discharging monsoon flow. However, in the system calculations the locks are considered to be used for all 350 working days per year because sailing of the coal barges through the lock under strong current conditions will cause serious navigational problems and is therefore not possible.

Resulting theoretical annual lock throughput capacity C
(= nr. of vessels per year per direction) can be calculated as follows:

$$C = \frac{\text{number of operational hours per year}}{\text{lock cycle time}}$$

A lock throughput occupancy rate equal to the theoretical capacity (= maximum intensity) is unacceptable for a longer period. The occupancy rate should not exceed 75% of the capacity to avoid congestion problems and to include some spare time.

This results in an acceptable lock throughput of 3,750 vessels per year for day-and-night navigation, and 1,875 vessels per year for daytime navigation only.

LIST OF TABLES AND FIGURES CHAPTER 3

tables :

figures :

WATERLEVELS IN METERS w.r.t. MEAN SEA LEVEL

STATION	january		february		march		april	
	max	min	max	min	max	min	max	min
Cochin Port	0.59	-0.58	0.50	-0.50	0.42	-0.56	0.47	-0.72
Vaikom	-	-	0.45	-0.37	0.43	-0.39	0.47	-0.39
Thanneermukkom north	0.54	-0.45	0.45	-0.48	0.46	-0.38	0.48	-0.54
Thanneermukkom south	0.28	-0.27	-	-	0.28	-0.28	-	-
Alappuzha	0.05	-0.04	-0.03	-0.10	-	-	-	-
Trikkunnapuzha	-	-	0.22	-0.01	0.24	-0.02	0.30	-0.06
Kayamkulam	-	-	-	-	0.10	-0.03	-	-

Table 3.4 Waterlevel variation along the waterway (Source: RITES)

WATER LEVEL OBSERVATIONS OF COCHIN PORT TRUST
WATER LEVELS W.R.T. MSL

MONTH	MAXIMUM LEVEL	MINIMUM LEVEL
January	0.68	-0.44
February	0.56	0.46
March	0.54	-0.60
April	0.51	-0.67
May	0.37	-0.82
June	0.52	-0.79
July	0.40	-0.73
August	0.43	-0.67
September	0.31	-0.67
October	0.38	-0.68
November	0.55	-0.58
December	0.48	-0.57

Table 3.5 Waterlevel variation at Cochin Port (Source: RITES)

STATION	CHAINAGE	VELOCITY m/s	DIRECTION
Kottapuram	–	0.45	E to W
Manjankad	–	0.18	N to S
Arookutty	14	0.56	E to W
Pallathuruthy	67	0.24	S to N
Chavara	–	0.32	N to S
Chamranihochi	–	<0.20	–
Asthamudi	–	<0.20	–
Kollam	–	<0.20	–

CURRENT VELOCITIES

Table 3.6 Current measurements (Source: RITES)

CHARACTERISTICS OF BED MATERIAL STRETCHWISE

SL. NO.	CHAINAGE (km)	NEAR BY LOCATION	DEPTH OF SAMPLE (m)	% DISTRIBUTION OF GRAVEL	SAND	SILTY CLAY	LIQUID LIMIT	PLASTIC LIMIT
1	0.00	KOTTAPURAM	1.0-1.4	-	54	46	-	Non-plastic
2	2.00	•	1.0-1.4	-	71	29	-	•
3	4.00	•	1.0-1.4	-	87	13	-	•
4	6.00	•	1.0-1.4	3	72	25	-	•
5	8.00	•	1.0-1.4	5	76	19	-	•
6	10.00	CHERAI	1.0-1.4	-	78	22	-	•
7	12.00	•	1.0-1.4	-	68	32	-	•
8	14.00	•	1.0-1.4	-	98	2	-	•
9	16.00	•	1.0-1.4	-	87	13	-	•
10	18.00	•	1.0-1.4	27	47	26	-	•
11	20.00	NAYARAMBALAM	1.0-1.4	-	91	9	-	•
12	22.00	•	1.0-1.4	-	89	11	-	•
13	24.00	•	1.0-1.4	-	92	8	-	•
14	26.00	MULAVUKKAD	1.0-1.4	-	55	45	-	•
15	28.00	•	1.0-1.4	-	99	1	-	•
16	Port area	KOCHI	1.0-1.4	33	65	2	-	•
17	Port area	•	1.0-1.4	-	86	14	-	•
		•	3.0-3.4	-	92	8	-	•
18	Port area	•	1.0-1.4	-	92	8	-	•
		•	3.0-3.4	-	99	1	-	•
19	45.00	AROOKUTTY	1.0-1.4	-	97	3	-	•
		•	3.0-3.4	-	93	7	-	•
20	45.00	•	1.0-1.4	-	99	1	-	•
		•	3.0-3.4	-	98	2	-	•
21	51.50	VAIKUM	1.0-1.4	-	58	42	-	•
		•	3.0-3.4	-	71	23	-	•
22	51.50	•	1.0-1.4	-	96	4	-	•
		•	3.0-3.4	-	89	11	-	•
23	72.00	THANNIRMUKKAM	1.0-1.4	-	98	2	-	•
		•	3.0-3.4	-	96	4	-	•

Table 3.7 Bed material characteristics (Source: RITES)

Wind Speed (m/s)	Wind Direction (deg.N) -15.: 15.	15.: 45.	45.: 75.	75.: 105.	105.: 135.	135.: 165.	165.: 195.	195.: 225.	225.: 255.	255.: 285.	285.: 315.	315.: 345.	Total
< .70	.78	.77	.45	.37	.22	.23	.16	.32	.99	1.97	2.07	1.23	9.57
.70: 2.35	1.51	1.31	1.19	.88	.58	.32	.30	.54	1.17	2.29	2.05	1.61	13.75
2.35: 4.45	2.87	2.35	1.37	1.02	.57	.78	.46	.92	2.72	4.62	5.72	4.13	27.53
4.45: 6.65	1.56	1.39	1.15	.75	.37	.49	.24	.88	2.86	5.28	6.78	4.07	25.83
6.65: 8.95	.35	.57	.60	.33	.15	.09	.15	.58	1.86	4.68	4.37	2.08	15.80
8.95:11.35	.05	.13	.18	.07	.05	.07	.09	.18	.84	2.22	1.47	.49	5.86
11.35:13.85	.	.02	.02	.02	.	.	.02	.	.16	.60	.35	.04	1.22
13.85:16.45	.	.	.	.02	.02	.	.	.	.09	.15	.07	.02	.37
16.45:19.05	.	.	.	.	.	.	.	.	.	.04	.02	.	.05
19.05:21.85	.	.	.	.	.	.	.	.	.	.	.	.	.
21.85:24.85	.	.	.	.	.	.	.	.	.	.	.	.	.
24.85:28.25	.	.	.	.	.	.	.	.	.	.	.	.	.
>28.25	.	.	.	.	.	.	.	.	.	.	.02	.	.02
Total	7.12	6.53	4.96	3.47	1.97	1.99	1.42	3.43	10.70	21.85	22.90	13.67	100.00

Season : All Year
Period : 68 to 80
Area : 72.50 to 76.50 deg. East
7.50 to 10.50 deg. North
No. observations: 5475

Probability that winds occur in the given speed and direction class on open sea near Kayamkulam/Cochin

Table 3.8 All year windspeed distribution (Source: Delft Hydraulics)

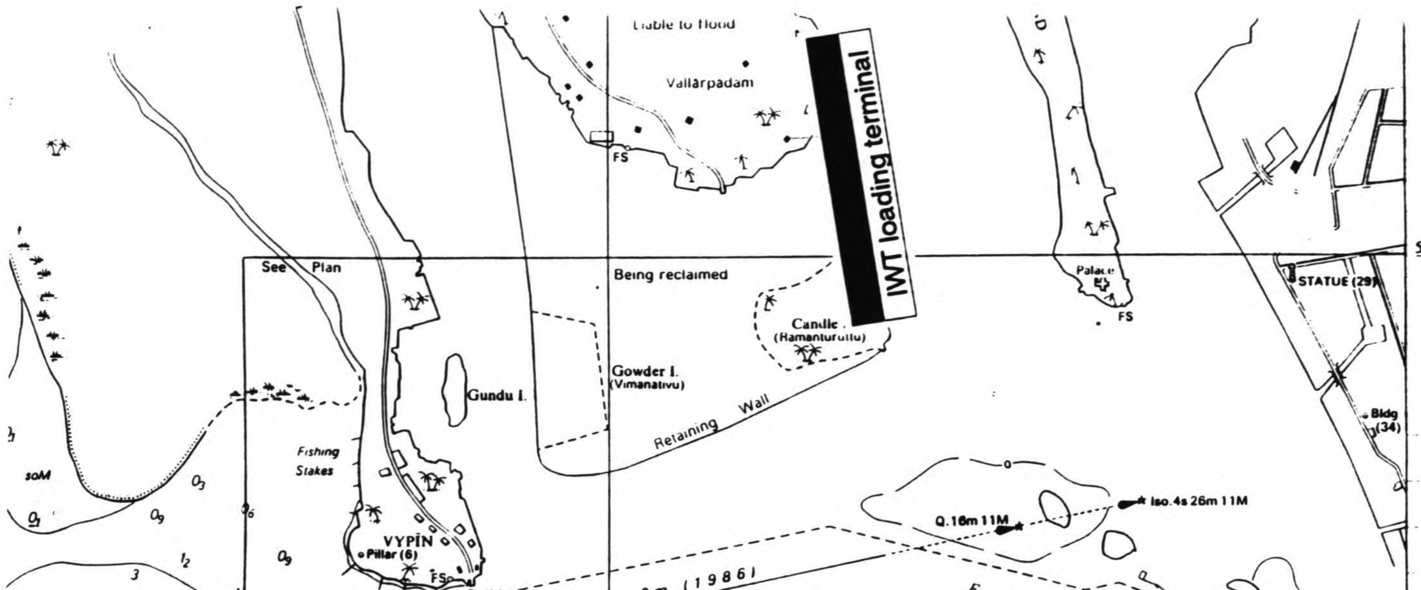


Figure 3.1 Map of Cochin Port

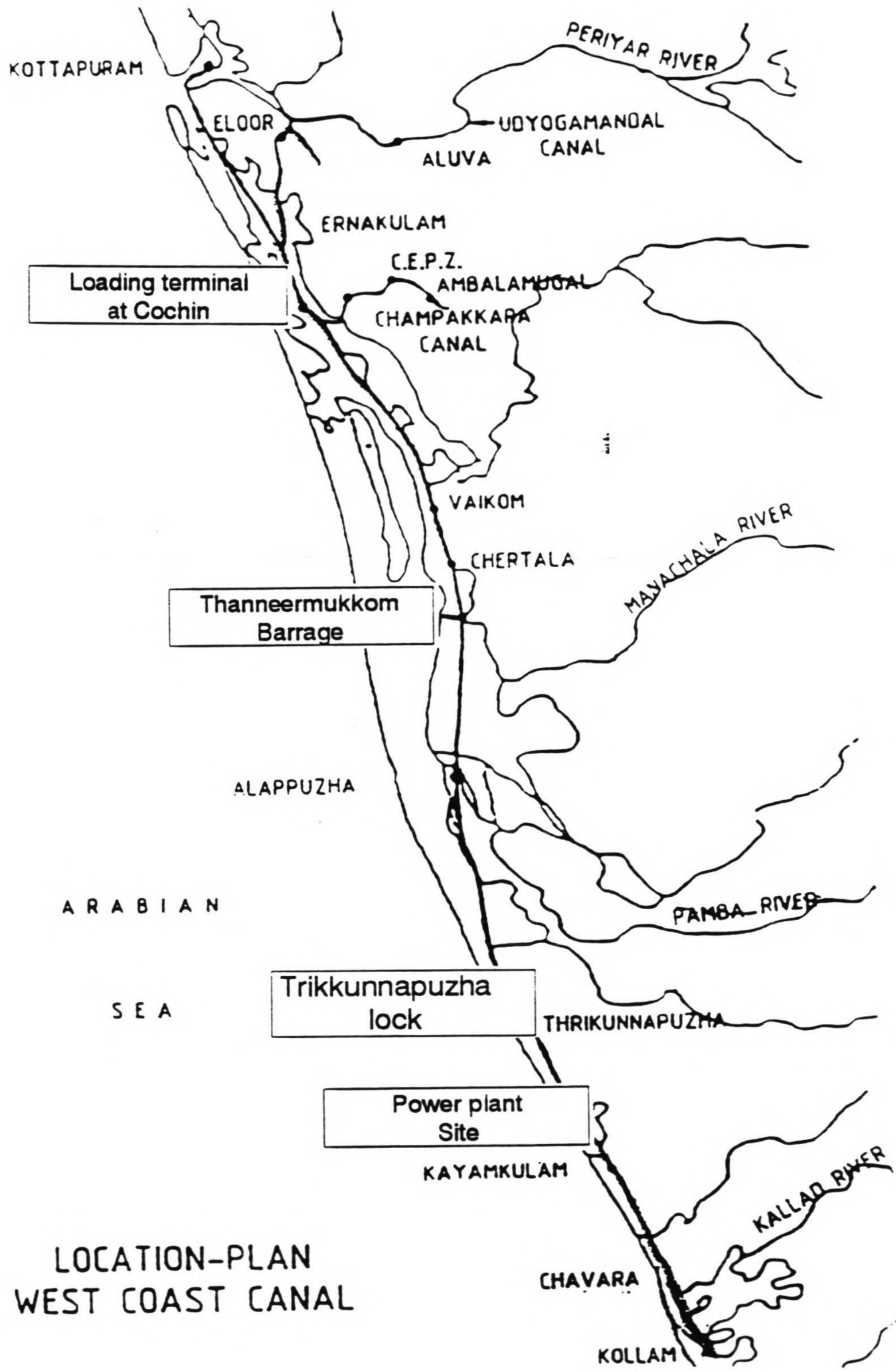


Figure 3.2 Total Plan of the Waterway Route

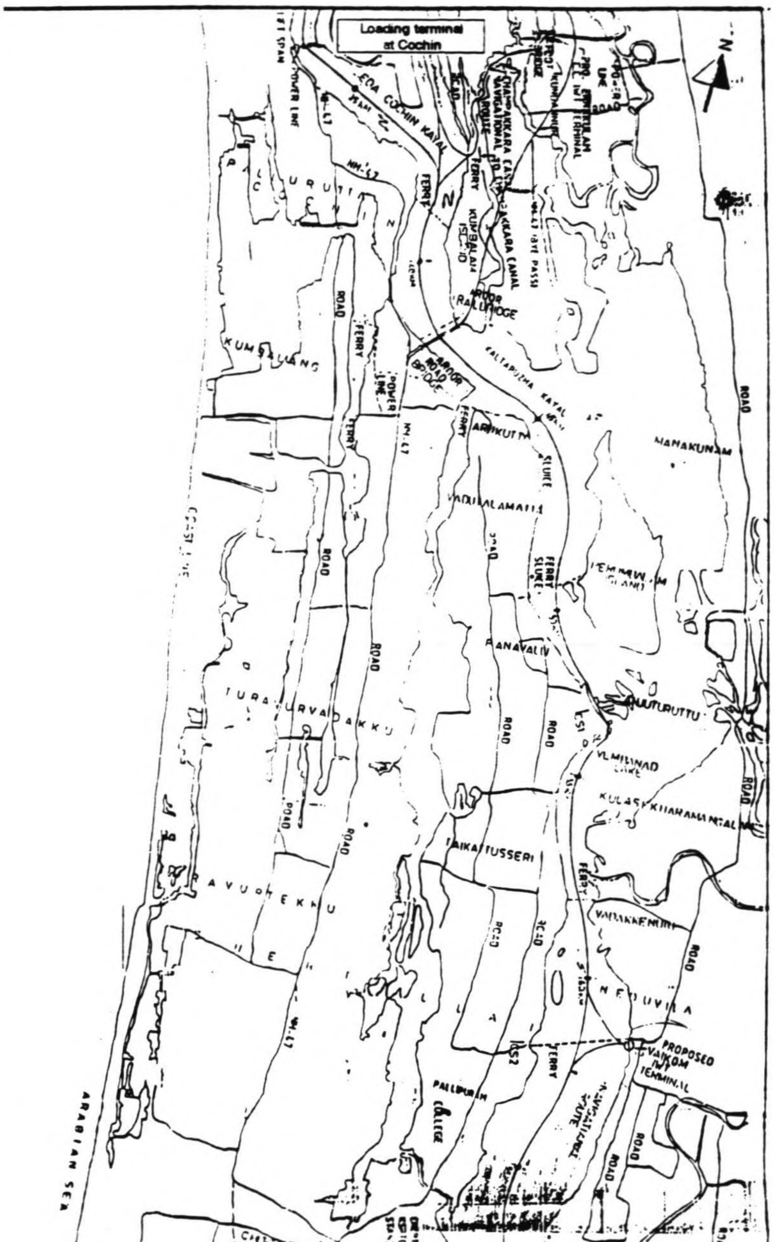


Figure 3.3 Waterway Route from Cochin to Thanneermukkom

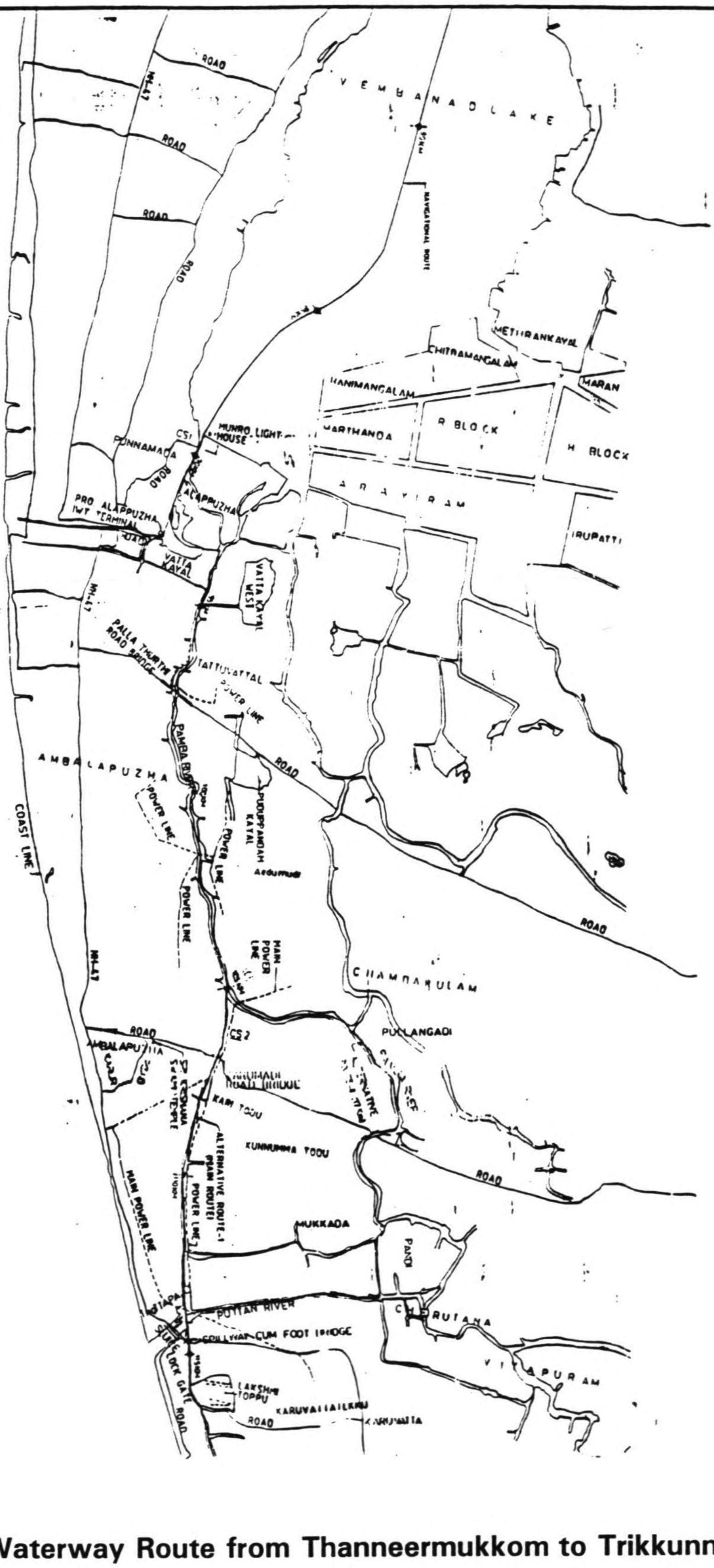


Figure 3.4 Waterway Route from Thanneermukkom to Trikkunnapuzha

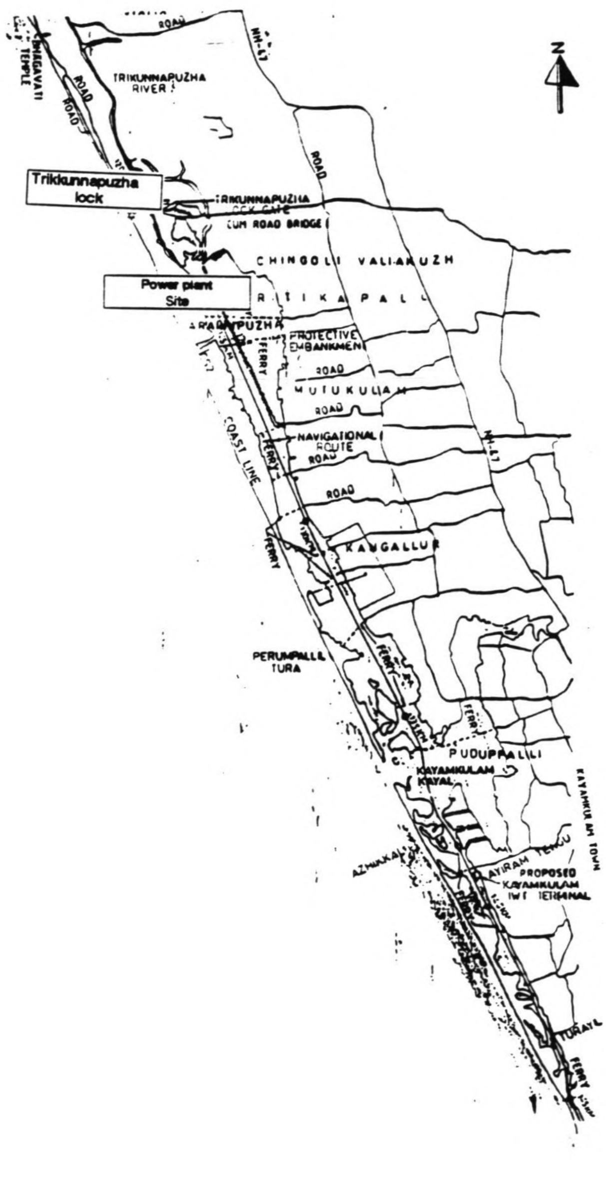


Figure 3.5 Waterway Route from Trikkunnapuzha to Kayamkulam Plant Site

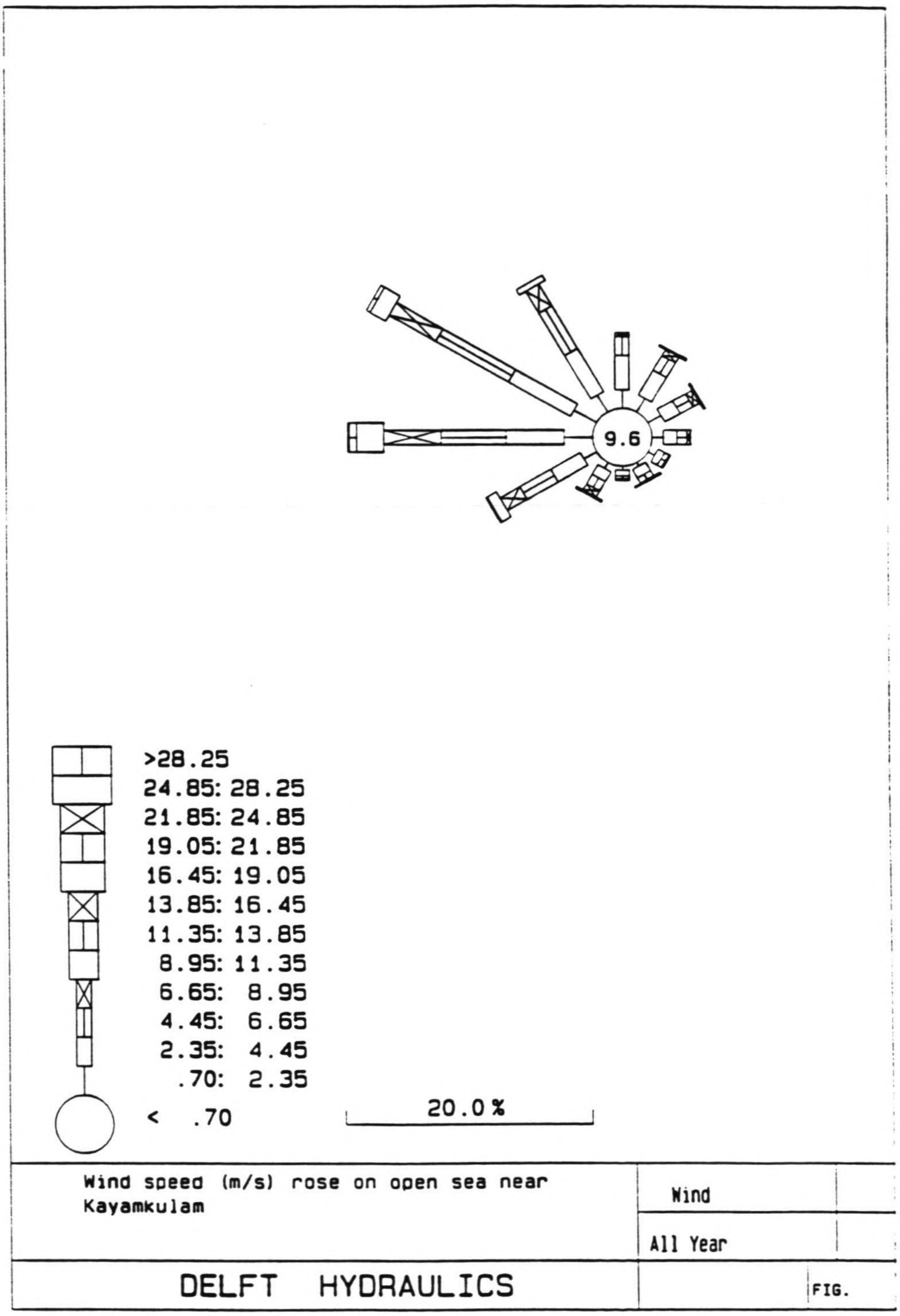


Figure 3.6 All Year windspeed rose (Source: Delft Hydraulics)

Photograph 1 : Typical view of existing canal

Photograph 2 : Typical canal embankment

Photographs 1: Typical view of canal 2: Typical canal embankment

4 FUTURE TRANSPORTATION REQUIREMENTS

4.1 PROJECTED COAL THROUGHPUT

The ultimate projected coal transport requirement for the Kayamkulam power plant is projected to be 8.06 million tons in 2006.

The projected coal throughput will increase phasewise as shown below:

1999	2001	2002	2003	2004	2005	2006>
0.06	1.18	1.70	3.51	5.61	7.71	8.06

Table 4.1 Coal transport requirements in million tons per year

This study considers only the ultimate throughput of 8.06 million tons per year (mmtpa).
In order to include some safety margin in the transportation system, a design throughput of 10 mmtpa is taken.

4.2 OTHER TRAFFIC

Future traffic estimations by RITES, based on a further extension and refinement of a former study (Techno Economic Feasibility Study of IWT in the WCC, RITES 1988) forecast a transportation of approximately 1 million tons per year in each direction in the year 2005. RITES found an optimum vessel carrying capacity of about 400 tons based on this traffic forecast.
In table 4.2 the traffic forecast by RITES is given.

Critical remark:
When this stretch of the West Coast Canal will be developed to accommodate the coal vessels, more traffic may be attracted, using larger vessels.

This other traffic is however not further taken into account. This study only considers the transportation of coal for the powerplant at Kayamkulam and takes therefore only costs directly related to this transport into account. It is nevertheless important to realise that the final waterway is going to be used by the other traffic too and possibly has to be provided with extra lanes.

COMMODITY- ORIGIN - DESTINATION WISE TRAFFIC FORECAST (2004 - 2005)*

S.NO	ORIGIN	DESTINATION	DISTANCE (km)	FOOD-GRAINS	PARCEL & PIECE GOODS	HEAVY GOODS	BULK GOODS	CHEMICAL& FERTILISER	P O L	TOTAL
1	KOCHI	ALAPPUZHA	61	41951						41951
2	KOCHI	KAYAMKULAM	109	12878	32087		44657			89622
3	KOCHI	CHERTALA	40	9843	14684					24527
4	KOCHI	CHAVARA	127	12222						12222
5	KOLLAM	ALAPPUZHA	77	19225	10853		34722			64800
6	ERNAKULAM	KOLLAM	136	13730	19127	10567	2474		150914	196812
7	VAIKOM	KOLLAM	108		33500		12294			45794
8	ALAPPUZHA	KOCHI	61		154762					154762
9	KAYAMKULAM	ERNAKULAM	107		51769		24548			76317
10	THRIKUNNAPUZHA	ALUVA	114		29493		14581			44074
11	KOCHI	KOTTAPURAM	30	3281	328	1182	10035	4591		19417
12	AMBALAMUGAL	KOLLAM	151					14655	88536	103191
13	KAYAMKULAM	KOCHI	109		58118		160494			218612
14	KOLLAM	VAIKOM	108		61247		16170			77417
15	KOLLAM	KOCHI	138		111350					111350
16	KOCHI	KOLLAM	138		60366	3135				63501
17	KOLLAM	ERNAKULAM	136		93847					93847
18	ERNAKULAM	CHERTALA	38		27100		981			28081
19	ERNAKULAM	ALAPPUZHA	59		122937	7467	21324			151728
20	KAYAMKULAM	ALAPPUZHA	40		17792					17792
21	ALAPPUZHA	ERNAKULAM	59		16717					16717
22	ERNAKULAM	KAYAMKULAM	107		24483		21104			45587
23	ALAPPUZHA	KOLLAM	77		9436					9436
24	KOLLAM	CHERTALA	98		1346					1346
25	ALUVA	KAYAMKULAM	132		3293			2350		5643
26	ALUVA	THRIKUNNAPUZHA	114		12349		36769			49118
27	AMBALAMUGAL	ALAPPUZHA	74						89567	89567
28	KOTTAPURAM	KOCHI	30		11479		1772			13251
29	ALAPPUZHA	KOTTAPURAM	91		3281		2624			5905
30	KOTTAPURAM	ALAPPUZHA	91		984		1969			2953
31	AMBALAMUGAL	KAYAMKULAM	122					16224		16224
32	ALUVA	KOLLAM	161					6122		6122
33	ELOOR **	KOLLAM	153					11772		11772
34	KOCHI	ELOOR **	15					272998		272998
35	ELOOR **	ALAPPUZHA	76					59498		59498
36	AMBALAMUGAL	ALAPPUZHA	74				23786	97582		121368
37	ALAPPUZHA	ELOOR **	76				16155			16155
38	KOCHI	AMBALAMUGAL	18					411896		411896
39	CHERTALA	ELOOR **	55				6935			6935
40	CHAVARA	KOCHI	127				111351			111351
41	CHAVARA	ALUVA	150				2155			2155
42	CHAVARA	ELOOR **	142				2156			2156
43	KOLLAM	AMBALAMUGAL	151				5681			5681
44	KOCHI	CHAVARA	127				864			864
45	VAIKOM	ALUVA	53				33682			33682
46	ALUVA	CHERTALA	63				115714			115714
47	ALUVA	ALAPPUZHA	84				109811			109811
48	CHERTALA	ALUVA	63				17251			17251
49	CHERTALA	ERNAKULAM	38				18849			18849
50	ALUVA	VAIKOM	53				8550			8550
51	CHERTALA	CHAVARA	87		41613		12481			54094
52	CHAVARA	CHERTALA	87		18295		35719			54014
53	THRIKUNNAPUZHA	KOLLAM	47		12973					12973
54	KOLLAM	THRIKUNNAPUZHA	47		1769					1769
	TOTAL (TONNES)			113130	1057373	22351	929663	897693	329017	3349227
	TOTAL (TKM)			9354662	100982226	2345755	85360939	30679545	40521198	269264325

* Excludes container traffic at Kochi and CEPZ

** Eloor terminal is an existing terminal

Table 4.2 Other traffic forecast (Source: RITES)

5 COAL TRANSPORT SYSTEM USING THE EXISTING WATERWAY

In this transport system the whole waterway route from the loading terminal at Cochin (km 0) to the projected power plant site at Kayamkulam (km 95) will be considered.
The main bottleneck in this route is the Trikkunnapuzha lock system (km 91).
The vessels are assumed to sail during day and night (20 hours per day).

5.1 VESSELS CHARACTERISTICS

The Trikkunnapuzha lock system, forming the main constraint in the existing waterway, determines the maximum sizes of the coal carrying vessel. These maximum vessel dimensions are :

-Length (L) = 26.0 m
-Beam (B) = 7.0 m
-Draught(T) = 2.5 m

Payload of the design vessel is calculated (according to ANNEX A) as follows:

payload = $L * B * T * c_b * c_l$ = 290 tons.

In which c_b (= block-coefficient) = 0.85
c_l (= load- coefficient) = 0.75

5.2 FEASIBILITY OF THE SYSTEM

As the throughput of Trikkunnapuzha lock is 3,750 vessels per year, the system's coal throughput will be 3,750 * 290 = 1.09 million tons per year.
This throughput is absolutely insufficient for the ultimate required design throughput (10 mmtpa).

It is therefore concluded that this transport system with the present Trikkunnapuzha locks is NOT FEASIBLE for the design coal throughput.

6 COAL TRANSPORT SYSTEM IMPROVEMENT SCENARIO I

6.1 TRANSPORT SYSTEM DESCRIPTION

In this improvement scenario Trikkunnapuzha lock system will be deleted from the system. This can be achieved by :

a) demolishing the lock and building a new salt water barrier and lock south of the power plant site (least costs solution according to Avarachen, ref.[3]).

b) building new locks at Trikkunnapuzha.

c) locating the unloading terminal just north or east of the present lock system.

Solution a) causes serious changes in the hydrological and environmental (saltish) situation of the area. In order to minimize the environmental impacts, an other solution has to be selected.
Solution c) has less obstructions to navigation than solution b): no lock operations at Trikkunnapuzha and less travelling distance, resulting in a shorter sailing time. Solution c) will therefore be considered.

Coal will be transported further by conveyor belt to the plant site over a distance of 4 km.
Vessel travel distance under this scenario is hence reduced to 91 km. The vessels sail day and night (20 hours per day).

The question now is, if the system has a throughput capacity capable to meet the required design throughput.

6.2 VESSEL CHARACTERISTICS

The locks at Thanneermukkom now form the determining factor for the vessel dimensions and thus for the payload capacities.
The eastern- and the largest western lock, having dimensions of 61 * 12 resp. 76 * 9 meters, are considered. The maximum vessel dimensions for these locks are shown in table 6.1.

	EASTERN LOCK	WESTERN LOCK
Length (m) :	55.0	70.0
Beam (m) :	6.6	8.2
Draught (m) :	2.5	2.5
Payload (ton) :	550	850

Maximum vessel dimensions

Table 6.1 Maximum vessel dimensions

6.3 FEASIBILITY

The vessel throughput capacity of each lock is 3,750 (vessels per year), resulting in a maximum annual throughput of
3,750 * (550 + 850) = 5.3 million tons.

This throughput is absolutely insufficient for the ultimate required design throughput. It is therefore concluded that for the required coal throughput, this transport system is NOT FEASIBLE.

7 COAL TRANSPORT SYSTEM IMPROVEMENT SCENARIO II

7.1 TRANSPORT SYSTEM DESCRIPTION

This scenario is a further improvement of scenario I. In this scenario the unloading terminal will, as in scenario I, be located at Trikkunnapuzha locks. The coal will be transported further to the powerplant site at Kayamkulam by a conveyor belt system.
Since the annual throughput capacity of the existing locks at Thanneermukkom (km 41) is far insufficient to meet the required design throughput of 10 mmtpa, these locks have to be reconstructed (deletion will change the environmental conditions dramatically and is therefore considered to be out of the question). In fact a totally new inland waterway transport system is required.
In order to find the most promising new transport system, several options will be assessed and evaluated. Because the characteristics of the transport system (e.g. number of vessels; waterway dimensions) are directly related to the type of vessel applied, a range of vessel options (sizes) will be considered. For each option, in which one type of the vessels will be applied, the required new waterway profile and resulting transportsystem characteristics will be determined. The costs of the main system components will be estimated and the options will be compared. Reference is made to the methodology described in chapter 2.

A distinction has been made between day-and-night navigation and daytime navigation only.

7.2 VESSEL OPTIONS

A large range of vessel options has been considered for which use has been made of the European CEMT-classification, see table 7.2

Considered payload range : 600 - 2,250 tons for the single vessels
3,500 - 11,200 tons for pushbarge formations.

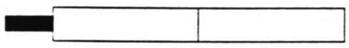
The annual design throughput is 10 million tons, resulting in a number of calls per day (350 per year) of 47.6 for the 600 ton vessel to 2.6 for the 11,200 ton pushtow.

In table 7.1, the selected vessel options are presented.

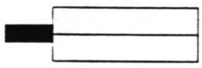
VESSELS		LENGTH (m)	BEAM (m)	DRAUGHT (m)	PAYLOAD (ton)
Campine barge		55	6.6	2.5	600
D.E.K.	1)	75	8.2	2.5	1000
Rhine–Herne canal vessel		85	9.5	2.5	1300
Large Rhine Vessel		110	11.4	2.8	2250
BARGE FORMATIONS					
2*1	2)	185	11.4	2.8 / 4.5	3500 / 5600
1*2	3)	108	22.8	2.8 / 4.5	3500 / 5600
2*2	4)	185	22.8	2.8 / 4.5	7000 / 11200

1) D.E.K. = Dortmund Eems Canal standard vessel

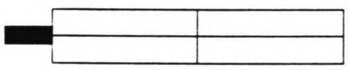
2)



3)



4)



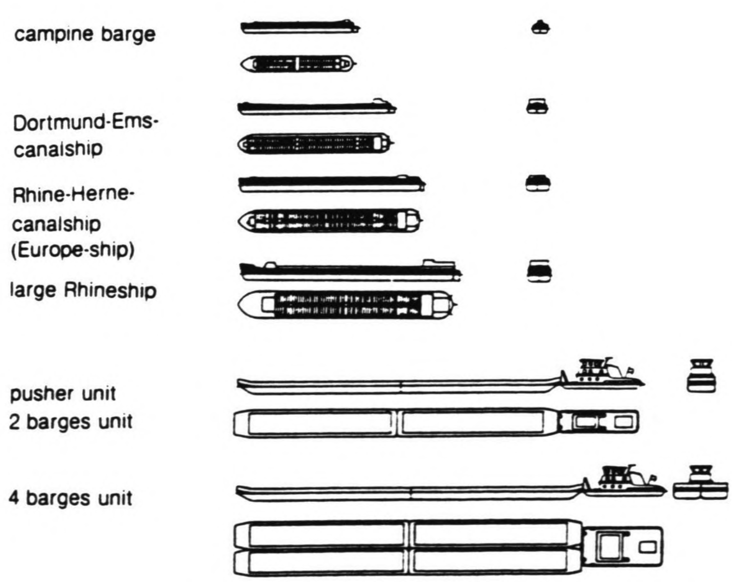


Table 7.1 Selected vessel options

7.3 CHANNEL CROSS PROFILE AND SAILING CHARACTERISTICS

The required waterway dimensions are determined by the governing traffic situation and the size of vessel. For every vessel options the required channel design parameters (channel width and depth) have been determined.
The required channel width is determined by the following factors:

- the vessel's beam
- manoeuvring space
- bank clearance
- space to enable safe encountering manoeuvres
- extra width due to wind influence and
- a safety margin

The required channel depth is determined by:

- the vessel's draught
- squat (waterlevel reduction)
- manoeuvring margin
- safety margin for vertical vessel motions and channel bottom inaccuracies

The resulting total channel width and depth determine the required channel cross profile. In ANNEX B a more detailed description is given of the above mentioned parameters. The output of the determination of the required channel cross profile is presented in tables 7.3 and 7.4 In these tables the channel width parameters considered in ANNEX B are given, expressed in unit of vessel beam (B). Summarised these parameters give the required channel width (also expressed in unit of vessel beam). The same procedure is followed to estimate the required channel depth.

The maximum sailing speed of a vessel is for an important part determined by the channel cross section. When this cross profile has been determineted, the sailing speed of the vessels can be calculated as well as the returnflow, squat and required propulsive power. A detailed description of the calculations of these sailing characteristics is presented in ANNEX A. The output of these calculations is also given in tables 7.3 and 7.4

7.4 TRANSPORTSYSTEM CHARACTERISTICS

The economic sailing speed of each vessel is used in the calculation of the characteristics of the transportsystem, i.e:

- -trip time of the vessel
- -number of trips per year per vessel
- -number of vessels required
- -number of loading- and unloading berths

A berth occupancy factor of about 0.8 is considered for this scheduled transport system from which the number of required berths result.

Input in the calculation is the design coal throughput, the type of vessel (payload), the sailing distance and sailing speed and loading- and unloading rates. Output of the calculation is the total trip time, the number of vessels required to meet with the required throughput and the number of (un)loading berths required.

For a more detailed description of the way of calculation and the outputs of the system calculation reference is made to ANNEX C.

For the system calculations a spreadsheet program was made; the resulting output is given in tables 7.5 and 7.6 for daytime navigation only, and in tables 7.7 and 7.8 for day-and-night navigation.

The daytime-navigation-only options require much more vessels,locks and berths than the day-and-night options due to the reduced operational time. Especially for the smaller vessels the only-day option will be most unfavourable.

7.5 REQUIRED DREDGING

The profile dimensions of the existing waterway between Cochin and Trikkunnapuzha don't always meet with the required profile dimensions for the vessel options. Capital dredging is therefore required.

The profile of the existing waterway and the required new waterway profile are known, so the amount of land acquisition and the amount of dredging can be calculated. The way of calculation and calculation results are presented in ANNEX D. The results are also given in the summary-table 7.9

After completion of the capital dredging works, it is expected that the channel will be subjected to siltation due to several factors:
-The rivers discharging in the waterway carry large volumes of silt and cause sedimentation in the channel, especially when the flow velocities decrease due to the deepening and widening of the waterway.

-In the periods when the rivers are not in spate, tidal (density)currents carry sediment into the lagoon area causing sedimentation.

The estimation of the (annual) amount of maintenance dredging in this stage of the project is very difficult, if not impossible. The waterway system is very complex and there is too little data available (records, waterdischarge, velocities, sediment load, sediment characteristics etc.). In order to quantify the amount of maintenance dredging, a detailed hydro-morphological survey should be conducted. It is however expected that considerable sedimentation will occur. Large quantities of sediment have already been deposited by the rivers in the area over the years forming the present lagoon delta. At places where rivers discharge in the vast expanses of kayals and lakes, sedimentation occured due to the reduction in flow velocity (large reclamation area's in the south of Vembanad Lake). Assuming that there is an (dynamic) equilibrium in sediment transports along the present waterway, enlarging the waterway profile will result in a reduction of waterflow velocities (and hence sediment carrying capacity) and will lead to the resettlement of sediment particles.

The sensitivity of the comparative costs to the rate of maintenance dredging is analyzed in paragraph 7.9 (see table 7.26); it can be concluded that its influence is considerable.
It is assumed that the annual amount of maintenance dredging is 20% of the capital dredging.

REMARK : At the time of submittal of this report new information about the expected rate of siltation was obtained by the author after a visit to BKH Consulting Engineers in Delft. BKH recently carried out a waterbalance study of the backwatersystem of the Kuttanad region. ("Kuttanad Water Balance Study Project"). BKH found that under present conditions the sediment supplied by the rivers is deposited at the transition from dry land to paddy land, where the watersurface slope and the flow velocities decrease. This transition was found at about 10 km east of the waterway under study. Most of the sediment is expected to deposit at these locations of the river. Furthermore, these deposits are at present removed by artisanal sand winning. A lower rate of maintenance dredging than assumed in this study may influence the conclusion of this study. However, this aspect is not further taken into account in this report.

7.6 SUMMARY OF CALCULATIONS AND PRESELECTION

The most important calculation results of all options are summarized in table 7.9 i.e. the required number/amount of:

- vessels
- vessel calls per year at the terminals
- locks
- loading- and unloading berths
- dredging
- land acquisition

In order to achieve a reduction of options, a preselection is carried out based on the results of the calculations. Some options are at first sight unfavourable in comparison to others (reference is made to table 7.9). The 1*2 barge formation is less attractive than the 2*1 barge formation (more dredging and more vessels while the other results are the same). A draught of 4.5 m for barge formations require such an extensive amount of capital dredging that these options are left out from further evaluation.
For further evaluation the following transport systems will be considered:

For daytime navigation only :
- 2*1 barge formation; payload 3,500 t.
- 2*2 barge formation; payload 7,000 t.

Day and night navigation :
- Campine barge; payload 600 t.
- Dortmund-Eems Canal vessel; payload 1,000 t.
- Rhine-Herne Canal vessel; payload 1,300 t.
- Large Rhine vessel; payload 2,250 t.
- 2*1 barge formation; payload 3,500 t.
- 2*2 barge formation; payload 7,000 t.

7.7 COMPARATIVE COST ESTIMATES

In order to compare the options on basis of costs, cost estimates have been made of the following system elements :

- costs of dredging and land acquisition
- costs of new lock(s) at Thanneermukkom
- costs of the loading- and unloading terminal berths including loading- and unloading equipment
- costs of vessels and crew
- costs of fuel and oil
- annual costs of maintenance and repair

For the most promising (least costing) option also the costs of slope protections (revetments), aids to navigation and the conveyor belt from Trikkunnapuzha to Kayamkulam plant site will be considered to obtain the total cost per ton.

Costs are also converted to annual costs by means of the Capital Recovery Factor. This factor gives the annual payment that will repay a $ 1 loan in X years with compound interest on the unpaid balance. Interest + inflation rate is taken total at 10 % The CRF-method to obtain annual costs is not as sophisticated as the Present-Day-Value method; however, it can be used properly for evaluation and comparison purpose in this initial stage of the IWT transport study.
Economic lifetime (X years) used in the calculation is :
30 years for the vessels, barges and handling equipment and
50 years for the civil works.
Maintenance and repair are calculated separately.

Cost estimation of dredging

For the dredging costs calculation the waterway is split into two essentially different parts.

The first, from Cochin to Punnamada (km 0 to km 62), is very wide. Dredged material is supposed to be used for new reclamation works along this stretch.
The second part extends from km. 62 to 91. This stretch is narrow and at many locations the channel banks are overgrown with palm trees. Dredged material from this stretch is proposed to be used for coastal protection works (sand suppletion), since the coastal area suffers from serious erosion.

Information about dredging production capacities, and costs of maintenance, repair, depreciation and interest are obtained from reference [15] to reference [17].

Costs are calculated for 1993 and expressed in US $.
(Exchange: 1US$ = 1.80 Dfl.)

Costs are given by two components:
Depreciation + Interest and Maintenance + Repair.
When more than one shift and working more than 90 hours per week is applied, Maintenance + Repair is multiplied by 2; and Depreciation + Interest is multiplied by 1.2, according to ref.[17].

Charted production

Assumed is a suction cutter dredger with a suction pipe diameter of 400 mm. The material to be dredged is mostly sand (reference is made to paragraph 3.7). For a 400 mm. pipe diameter a production of 250 cu.m. per hour can be achieved for a

pipe line length of 2000 m. Further increase in line length will be achieved by adding booster pumps.
For calculation of the monthly production, 25 days per month and 18 hours per day working is taken.

Equipment

The dredger is not self propelled and an assisting tug will be required.
At the first stretch (km 0 to 62) dredged material has to be transported over about 5 km. to the waterway sides. The pipeline will only be partly floating, enabling small country crafts to pass. Floaters are designed to carry 12 meters of pipeline. A floating booster of 400 kW keeps the system capacity at 250 cu.m. per hour. From km. 62 to 91 the dredged spoil has to be transported to the coast over a distance of about 5 km. In order to achieve a quick replacement of the discharging pipeline, additional pipeline is required. Here are also booster pumps installed. For the removal of trees and other obstacles two bulldozers are required.

Fuel and oil costs

Diesel consumption of the equipment is assessed at 200 grams per kWh.
Diesel price is 200 US$ per ton.
For oil and grease 20% of the fuel costs is selected.

Labour costs

Two shifts of ten men each are assumed, with a shift configuration of:
-3 foreign men costing US$ 14,000 per month,
-7 local (skilled) men costing US$ 1,000 per month.

Other costs

For the spoil disposal areas 10% of the dredging costs are taken.
Overhead costs and profit is 40% of the dredging costs.
Fixed expenses like mobilisation, demobilisation, site clearance and installation are 20% of the dredging costs.

The total costs are calculated as an average per month. Since the production per month is 250 (cu.m/h) * 450 (hrs/month) = 112,500 cubic meters, the dredging costs per cu.m can be calculated. (More dredgers will increase the production, but also increase the costs at the same rate (in this rough estimation); costs per cu.m will stay the same, the work will be completed earlier).

Dredging costs have been calculated for both stretches separately and the resulting calculation output is given in table 7.10

The average dredging costs per cubic meter for the total stretch (km 0 to km 92) are calculated and given in table 7.11 Resulting dredging costs per cubic meter is approximately US$ 4.6

The amount of annual maintenance dredging is very difficult to determine beforehand as described in paragraph 7.5 and has been assumed at 20% of the capital dredging. Costs of maintenance dredging per cubic meter is obtained from Avarachen (ref.[3]) and is 2.6 US$.

Cost estimation of new locks at Thanneermukkom

Lock shape

For the coal vessels the following preliminary design guidelines have been used:

-Length of the lock (chamber) = length of the vessel + an additional length of 10 %
This percentage is based on the fact that the time required for a vessel to sail into the lock will increase considerably with less free space.

-Length of the lock head ≈ width of one lock-door. The lock-head provides the space for the door in opened position.

-Width of the lock = the vessel's beam + an additional width of 25 %
When a vessel sails into the lock the water in the lock has to be displaced and a current out of the lock will be generated. When there is little clearance between the vessel and the lock, the vessel will experience a considerable resistance, resulting in a longer time required to sail into the lock.

-Sill depth = vessel draught + an additional depth of 40 %

Since the cross section of barges has a more rectangular shape, more clearance is required to reduce the resistance when sailing into the lock. For barges an additional width of 30 % and an additional depth of 50 % will be applied.

A height of the lock walls of 1 m above waterlevel for the single vessels is required for the guidance of the (empty) vessel, especially when emptying the lock. According to ref.[13], a height of 1.5 m. is taken for push barge formations.

The lock walls are vertical. If they are battered so that the width of the lockchamber at the top is greater than at the bottom, the vessels could be damaged when the water in the lock is lowered.

The lock only functions as a salt water barrier and waterlevel difference between the upper and lower lockhead doesn't exceed 1 meter, resulting in a maximum uplift of 10 kN/m². The construction thickness of the concrete floor should be at least 10 / 24.5 =0.4 meters to prevent floating up of the structure. (assumed density of concrete: 24.5 kN/m³.)
Calculation of the concrete construction is beyond the scope of this study.
For the whole structure a construction thickness of 1 m is assumed.

Seepage

Both under and beside the lock structure a (subsoil)waterflow will be generated by the difference in waterlevel between the upper and lower side. Excessive flows must be prevented as this can lead to movement of soil particles and thus causing damage due to cavities under and alongside the lock (piping).
Using Lane's method (ref.[13]), which says that:

$1/3\ L_{hor} \geq \gamma \cdot c_L \cdot h$,in which

L_{hor} = the total horizontal seepage length = at least 95 m (Campine Barge)

γ = a safety coefficient = 1.5
c_L = a soil constant ≈ 6 for sand
h = the waterlevel difference over the structure = 1 m

31 ≥ 9 ,so seepage problems are not expected and no additional seepage cut off structures are required.

Costs

The amount of m³ concrete structure is calculated as follows:
-walls: 2*(Basin length + 2 * Headlength)* 1 * Height
-floor: (Basin length + 2* Headlength) * Width * 1
Total structure = walls + floor

Costs per m³ reinforced concrete:

concrete:	100 US$/m³
reinforcement steel:	800 US$/ton, required ≈ 0.1 ton per m³ concrete,
formworks:	3 US$/m², required ≈ 2 m² per m³ concrete,
Total costs per m³ concrete:	186 US$.

Costs of doors, electrical and mechanical installation is according to Dutch practice assessed at 70% of the investment costs. Annual costs of maintenance and repair of the doors and the installations is taken at 10% of the investment costs.

Mobilisation, demobilisation and overhead expenses is taken at 35% of the total investment costs.

The resulting calculation output is presented in table 7.12. The costs of a new lock range from US$ 2.3 million for the Campine Barge to US$ 17.4 million for the 2*2 pushtow.

Cost estimation of terminal berths

In the cost estimation of the loading and unloading berths, quaylength and (un)loading equipment are the main determining factors.

Costs of quay structure

For the length per berth 1.15 * the vessel's length is taken.
Information about costs are obtained from cost estimations made for similar projects. Data used in the calculation are:

Costs of the IWT quay structure	:	700 $/m²
Width of the quay platform	:	15 m
Costs of the IWT quay structure	:	10,500 $/m1

Costs of (un)loading equipment

The IWT vessels are loaded by a continuous conveyor loader. Costs of this loading gear are directly related to the loading capacity and the length of the loading boom and thus the beam of the vessel.
The unloading of the vessels is considered to be done by grabbing cranes. Grabbing cranes belong to the heavier loaded equipment (high fatigue) and in view of the high throughput of 10 million tons per year, they must be of high classification.

Investment costs of the loading- and unloading equipment used in the calculation are given in table 7.13

Maintenance and repair are assessed at yearly 10 % of the investment costs.

Only with a berth occupancy factor of 1, a berth will continuously be in operation and the cranes are fully occupied, requiring one crane per berth. This is however not the case. To obtain the number of cranes required, the number of berths are multiplied by the berth occupancy factor.

Costs of vessels, barges and crew

Prices are obtained from several quotations as collected from Dutch shipyards. Following price indications could be obtained:

-investment costs of	Campine barge	: 850,000 US$
-	Dortmund-Eems vessel	: 970,000 US$
-	Rhine Herne vessel	: 1,100,000 US$
-	Large Rhine vessel	: 1,700,000 US$
-	Push barge (76.5 m)	: 560,000 US$
-	Pushboat	: 850,000 US$

Maintenance and repair costs of vessels and pushtows is yearly 10 % and of barges 5 % of the investment costs.

For only day navigation (10 hours per day) one shift and for day and night navigation (20 hours per day) two shifts per vessel are required. A shift consists of three men costing each 1,500 US$ per year.

<u>Costs of fuel and oil</u>

Diesel consumption of the vessels and pushtows is 200 grams per kWh. Diesel price is 200 US $ per ton. This results in 0.04 US $ per kWh.
For oil and grease 20 % of the fuel costs is taken.
For the vessel options the required propulsive power (ANNEX A) and the total number of operational hours (ANNEX D) are known (see tables 7.6 to 7.8) and annual costs of fuel and oil of the options can be calculated.

Cost estimations have been made for the options and are presented in tables 7.14 to 7.17. Day navigation only is much more expensive than day-and-night navigation due to the larger number of vessels, berths and locks required. Notice that for night navigation special navigational aids will be required which are not yet taken into account; these costs will however not exceed the costs difference.

7.8 LAY-BY DIMENSIONS

Because the dredging costs have a large influence on the total costs, possibilities to include single-lane-traffic stretches are analyzed.

According to Bouwmeester (ref.[5]), alternating one-way-traffic is possible for (short) stretches having a traffic intensity of less than 1.5 vessels per day per direction only. Taking this into consideration, none of the vessel options is qualified. However, the financial consequences are determined for the larger vessel options, the Large Rhine Ship, the 2*1- and the 2*2 pushtow.

Single lane waterway is applied at the narrow stretches :
from km 62 to 65, and
from km 73 to 84.

The required single lane channel profiles (table 7.18) and the amount of dredging and land acquisition have been calculated for each vessel; reference is made to tables 7.19, 7.20, 7.21 and 7.22
Cost estimates of these options show a considerable reduction in dredging and land acquisition costs. See table 7.23 and 7.24. However:

- The transport capacity of the system will be reduced due to additional waiting time of the vessels and additional vessels (and costs) are required to overcome this capacity loss.
- An traffic control system will be required making the option much more costly.
- The 2*2 pushtow option still remains much more expensive than other options.

To get a better insight in the traffic situation with one-way traffic stretches along the waterway and to find a quantification of the loss of capacity, time-distance diagrams have been made for the Large Rhine Vessel and the 2*1 barge formation (reference is made to figures 7.9 to 7.12).

As can be concluded from these figures, the additional waiting times decrease the capacity of the transport system. For the Large Rhine vessel option at least 6 additional vessels are required to overcome the loss of capacity. For the 2*1 barge formations three additional vessels are required.
Comparative costs of these options are given in table 7.23 and 7.24

7.9 EVALUATION AND SELECTION OF VESSEL OPTION

In figure 7.1 the comparative annual costs are given for the above mentioned lay-by options along with the daytime-navigation-only options and the day-and-night options. As can be concluded from this figure, the optimum vessel payload can be found somewhere between the 2,000 and 3,000 tons. Of all considered options the Large Rhine Ship (2,250 tons) sailing day and night is found to be the least costing option.

To get more insight in the contribution of the main cost components to the total annual costs, figure 7.2 does also present these components separately. These components are:

- vessel costs, i.e. annual costs of
  * vessels
  * crew
  * fuel + oil

- dredging costs, i.e. annual costs of
  * land acquisition
  * capital dredging
  * maintenance dredging

- berthing costs, i.e. annual costs of
  * quay structures
  * loading- and unloading equipment

In this stage of the project many assumptions have been made and also the cost estimates are not very detailed. In order to get a better insight in the sensitivity of the total annual cost comparison and hence of the evaluation to disturbances in the cost estimation of the main components, the total annual costs are also calculated at which each main cost component at the time is raised and lowered with 25 % The results are shown in the sensitivity analysis figures 7.3 to 7.8

Using these figures also an indication of the influence of most assumptions can be found, see table 7.25. For instance a lower berth occupancy factor will result in a higher number of berths, figure 7.5 then gives a first indication of the (comparative financial) consequences of this.

As can be seen from these figures these results do not influence the vessel selection (based on least costs).

Maintenance dredging however, as its quantity is related to the amount of capital dredging (which is different for every option), has a significant influence on the annual costs and therefore on the selection of the transportsystem option. An analysis of the influence of the rate of maintenance dredging on the comparative annual costs is given in table 7.26 In this table the least costing option per rate of maintenance dredging has been outlined. As can be concluded does this rate have a great influence on the cost comparison of the options. A rate of 20% has been assumed in paragraph 7.5, resulting in the Large Rhine Vessel as least costing option.

As thus can be concluded, the most favourable vessel option for this transport system is the Large Rhine Vessel having a payload of 2,250 tons.
The transportsystem using this vessel, sailing day and night, is selected as the most favourite option.

LIST OF TABLES AND FIGURES CHAPTER 7

tables :

figures :

CLASSIFICATION DIFFERENCES					
CLASS	ACCESSIBILITY				
	E.C.M.T.	FRANCE	F.R.G.	THE NETHERLANDS	BELGIUM
I	barge	barge	barge	barge	barge
II	Campinois	Campinois	Campinois	II = Campinois IIa = Hague vessel	Campinois
III	DEK	Two-barge unit	DEK	DEK	DEK
IV	RHK	Pushed unit of one GR barge	RHK	RHK	RHK
V	GR	Pushed unit of two barges, reduced draught	Va = GR Vb = two-barge pushed unit	GR	GR
VI	GR	Two-barge pushed unit	VI = four-barge pushed unit VIa = six-barge pushed unit	Four-barge pushed unit	Four-barge pushed unit

Barge = also known as spits
RHK = Rhine-Herne-Canal standard vessel
DEK = Dortmund-Ems-Canal standard vessel
GR = Large Rhine vessel

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PROPOSITION DE STANDARDISATION DES VOIES NAVIGABLES / PROPOSAL OF STANDARDISATION OF WATERWAYS

Classes de voies navigables / Classes of navigable waterways	Automoteurs et chalands / Motor vessels and barges					Convois poussés / Pushed units					Barges de poussage / Push lighters				Hauteur minimale sous les ponts / Minimum height under bridges
	Type de bateau: Caractéristiques générales / Type of vessel: General characteristics					Type de convoi: Caractéristiques générales / Type of pusher - General characteristics					Type de barge: Caractéristiques générales / Type of barge: General characteristics				
	Dénomination / Designation	Longueur / Length	Largeur / Beam	Tir. d'eau / Draft	Tonnage / Tonnage	Dénomination / Designation	Longueur / Length	Largeur / Beam	Tir. d'eau / Draft	Tonnage / Tonnage	Dénomination / Designation	Longueur / Length	Largeur / Beam	Tir. d'eau / Draft	
(1)		m	m	m	T		m	m	m	T		m	m	m	m (4)
I	Péniche / Barge	38.50	5.05	2.20	250 - 400										4.00
II	Kast Campinois / Campine-barge	50 - 55	6.60	2.50	400 - 650										4.50
III	D.E.K.	67 - 80	8.20	2.50	650 - 1000										5.00
IV	R.H.K.	80 - 85	9.50	2.50	1000 - 1500	1 barge E I	85	9.50	2.50	1 240	Europe I	70.00	9.50	2.50	5.25
V a	Grands Rhénans / Large Rhine vessels	95 - 110	11.40 (2)	2.80	1500 - 3000	1 barge E II	95 - 105	11.40	2.80	1 850	Europe II	76.50	11.40 (2)	2.80	7.00
V b						2 barges E II	172 - 185	11.40	2.80	3 700					
VI a						4 barges E II a	185 - 195	22.80	4.50 (3)	6 000 - 12 000	Europe II a	76.50	11.40 (2)	3.90	9.10
VI b						6 barges E II a	270	22.80	4.50 (3)	12 000 - 18 000					
							195	34.20	4.50 (3)	12 000 - 18 000					

1) La classe d'une voie navigable est déterminée par les dimensions horizontales des bateaux ou convois-poussés.
2) Sur le bassin du Danube, cette largeur est généralement de 11 m.
3) Tient compte des développements futurs.
4) Tient compte d'une marge de sécurité entre le tirant d'air du bateau et la hauteur libre des ponts. En cas de transport fluvio-maritime ou de conteneurs, les hauteurs libres devront être adaptées.

1) The class of a waterway is determinated by the horizontal dimensions of the vessels or pushed units.
2) In the Danubian basin, this beam usually is 11 m.
3) Takes into account the future developments.
4) Takes into account a security clearance between the draft of the vessel and the height under the bridges. In case of coastal or container traffic, the height under the bridges should be checked.

Table 7.2 Vessel classification

CALCULATION OF CHANNEL CROSS DIMENSIONS AND SAILING CHARACTERISTICS

crossi1.wk

SELF PROPELLED VESSELS

PARAMETER	SYMBOL	UNIT	Campine Barge	D.E.K.	RHINE-HERNE CAN.VESSEL	LARGE RHINE VESSEL
Length	L	m	55.00	75.00	85.00	110.00
Beam	B	m	6.60	8.20	9.50	11.40
Draught loaded	Tl	m	2.50	2.50	2.50	2.80
Draught unloaded	Tu	m	0.65	0.64	0.63	0.70
Block-coefficient	Cb		0.85	0.85	0.85	0.85
Load-coefficient	Cl		0.75	0.75	0.75	0.75
Payload	P	ton	600.00	1000.00	1300.00	2250.00
TWO LANE CHANNEL WIDTH						
Beam		B	2.00	2.00	2.00	2.00
Manoeuvring						
-drift angle		deg.	2.00	2.00	2.00	2.00
-extra width		B	0.58	0.64	0.62	0.67
Bank clearance		B	0.60	0.60	0.60	0.60
Meeting		B	1.00	1.00	1.00	1.00
Windeffect						
-drift angle		deg.	2.00	2.00	2.00	2.00
-extra width		B	0.29	0.32	0.31	0.34
-slope profit		B	-0.84	-0.68	-0.59	-0.55
Safety margin						
-only daytime navigation		B	0.50	0.50	0.50	0.50
-day + night navigation		B	1.00	1.00	1.00	1.00
TOTAL CHANNEL WIDTH						
daytime navigation only		B	**4.1**	**4.4**	**4.4**	**4.6**
day + night navigation		B	**4.6**	**4.9**	**4.9**	**5.1**
CHANNEL DEPTH						
Draught		T	1.00	1.00	1.00	1.00
Squat		T	0.05	0.05	0.05	0.05
Manoeuvring		T	0.20	0.20	0.20	0.20
Margin		T	0.10	0.10	0.10	0.10
TOTAL DEPTH		T	1.4	1.4	1.4	1.4

CHANNEL PROFILE DAYTIME NAVIGATION ONLY

Slope		arctan	3.00	3.00	3.00	3.00
Depth		m	3.38	3.38	3.38	3.78
Keellevel width		m	27.26	35.89	42.24	51.97
Waterlevel width		m	42.26	50.89	57.24	68.77
Bottom width		m	21.26	29.89	36.24	45.25
Wet channel cross section	Ac	m2	107.20	136.30	157.76	215.49
Average waterdepth	h	m	2.54	2.68	2.76	3.13
Wet vessel cross section	As	m2	14.02	17.42	20.19	27.13
Blockage ratio	As/Ac		0.13	0.13	0.13	0.13
$Vgr / \sqrt{gh}$			0.57	0.57	0.57	0.57
Speed limit	Vgr	m/s	2.84	2.92	2.96	3.16
Vs / Vgr			0.80	0.80	0.80	0.80
Economic vessel speed	**Ve**	**m/s**	**2.27**	**2.34**	**2.37**	**2.53**
$Fr = Vs / \sqrt{gh}$			0.46	0.46	0.46	0.46
z / h			0.04	0.04	0.04	0.04
Waterleveldrop	Z	m	0.13	0.14	0.14	0.16
$U / \sqrt{gh}$			0.09	0.09	0.09	0.09
Returnflow	U	m/s	0.45	0.45	0.46	0.48
Resistance coefficient	Cd		0.44	0.44	0.44	0.44
Required force	Fs	N	22852.81	29714.19	35432.08	53812.61
Efficiency coefficient	n		0.29	0.29	0.29	0.34
Required power	P	kW	214.72	285.60	345.51	474.02
Required power	P	pk	292.23	388.71	470.24	645.14

CHANNEL PROFILE DAY + NIGHT NAVIGATION

Slope		arctan	3.00	3.00	3.00	3.00
Depth		m	3.38	3.38	3.38	3.78
Keellevel width		m	30.56	39.99	46.99	57.67
Waterlevel width		m	45.56	54.99	61.99	74.47
Bottom width		m	24.56	33.99	40.99	50.95
Wet channel cross section	Ac	m2	118.34	150.14	173.79	237.03
Average waterdepth	h	m	2.60	2.73	2.80	3.18
Wet vessel cross section	As	m2	14.02	17.42	20.19	27.13
Blockage ratio	As/Ac		0.12	0.12	0.12	0.11
$Vgr / \sqrt{gh}$			0.59	0.59	0.59	0.60
Speed limit	Vgr	m/s	2.98	3.05	3.09	3.35
Vs / Vgr			0.80	0.80	0.80	0.80
Economic vessel speed	**Ve**	**m/s**	**2.38**	**2.44**	**2.48**	**2.68**
$Fr = Vs / \sqrt{gh}$			0.47	0.47	0.47	0.48
z / h			0.04	0.04	0.04	0.04
Waterleveldrop	Z	m	0.13	0.14	0.14	0.16
$U / \sqrt{gh}$			0.08	0.08	0.08	0.08
Returnflow	U	m/s	0.43	0.43	0.43	0.47
Resistance coefficient	Cd		0.44	0.44	0.44	0.44
Required force	Fs	N	24325.87	31538.26	37524.55	59120.50
Efficiecy coefficient	n		0.29	0.29	0.29	0.34
Required power	P	kW	235.81	312.30	376.56	545.86
Required power	P	pk	320.93	425.04	512.50	742.91

Table 7.3 Calculation of channel cross-profile and sailing characteristics of the self propelled vessels

crossi2.wk

			PUSH BARGE FORMATIONS					
			draught 2.8 m.			draught 4.5 m.		
PARAMETER	SYMBOL	UNIT	2 * 1	1 * 2	2 * 2	2 * 1	1 * 2	2 * 2
Barge unit length	Lu	m	76.50	76.50	76.50	76.50	76.50	76.50
Barge unit beam	Bu	m	11.40	11.40	11.40	11.40	11.40	11.40
Formation length	L	m	185.00	108.00	185.00	185.00	108.00	185.00
Formation beam	B	m	11.40	22.80	22.80	11.40	22.80	22.80
Draught loaded	Tl	m	2.80	2.80	2.80	4.50	4.50	4.50
Draught unloaded	Tu	m	0.56	0.56	0.56	0.89	0.89	0.89
Block-coefficient	Cb		0.90	0.90	0.90	0.90	0.90	0.90
Load-coefficient	Cl		0.80	0.80	0.80	0.80	0.80	0.80
Formation payload	P		3500.00	3500.00	7000.00	5600.00	5600.00	11200.00
TWO LANE CHANNEL WIDTH								
Beam		B	2.00	2.00	2.00	2.00	2.00	2.00
Manoeuvring								
-drift angle		deg.	4.00	2.00	4.00	4.00	2.00	4.00
-extra width		B	2.26	0.33	1.13	2.26	0.33	1.13
Bank clearance		B	1.00	0.60	1.00	1.00	0.60	1.00
Meeting		B	1.50	1.00	1.50	1.50	1.00	1.50
Windeffect								
-drift angle		deg.	4.00	4.00	4.00	4.00	4.00	4.00
-extra width		B	1.13	0.33	0.57	1.13	0.33	0.57
-slope profit		B	-0.59	-0.30	-0.30	-0.95	-0.47	-0.47
Safety margin								
-only day		B	0.50	0.50	0.50	0.50	0.50	0.50
-day + night		B	1.00	1.00	1.00	1.00	1.00	1.00
TOTAL CHANNEL WIDTH								
daytime navigation only		B	**7.8**	**4.5**	**6.4**	**7.4**	**4.3**	**6.2**
day + night navigation		B	**8.3**	**5.0**	**6.9**	**7.9**	**4.8**	**6.7**
CHANNEL DEPTH (*D)								
Draught		T	1.00	1.00	1.00	1.00	1.00	1.00
Squat		T	0.05	0.05	0.05	0.05	0.05	0.05
Manoeuvring		T	0.20	0.20	0.20	0.20	0.20	0.20
Margin		T	0.10	0.10	0.10	0.10	0.10	0.10
TOTAL CHANNEL DEPTH		T	1.4	1.4	1.4	1.4	1.4	1.4

CHANNEL PROFILE DAYTIME NAVIGATION ONLY

PARAMETER	SYMBOL	UNIT	2 * 1	1 * 2	2 * 2	2 * 1	1 * 2	2 * 2
Slope		arctan	3.00	3.00	3.00	3.00	3.00	3.00
Depth		m	3.78	3.78	3.78	6.08	6.08	6.08
Keellevel width		m	88.99	101.82	145.99	84.89	97.73	141.89
Waterlevel width		m	105.79	118.62	162.79	111.89	124.73	168.89
Bottom width		m	83.11	95.94	140.11	75.44	88.28	132.44
Wet channel cross section	Ac	m2	357.01	405.53	572.47	569.01	647.00	915.29
Average waterdepth	h	m	3.37	3.42	3.52	5.09	5.19	5.42
Wet formation cross section	As	m2	28.73	57.46	57.46	46.17	92.34	92.34
Blockage ratio	As/Ac		0.08	0.14	0.10	0.08	0.14	0.10
$Vgr/\sqrt{gh}$			0.67	0.57	0.62	0.69	0.57	0.65
Speed limit	Vgr	m/s	3.86	3.30	3.64	4.87	4.07	4.74
Vs / Vgr			0.80	0.80	0.80	0.80	0.80	0.80
Economic vessel speed (Vs)		m/s	**3.08**	**2.64**	**2.91**	**3.90**	**3.25**	**3.79**
$Fr=Vs/\sqrt{gh}$			0.54	0.46	0.50	0.55	0.46	0.52
z / h			0.04	0.05	0.04	0.04	0.05	0.04
Waterleveldrop	Z	m	0.15	0.18	0.16	0.22	0.28	0.27
$U/\sqrt{gh}$			0.07	0.10	0.08	0.07	0.10	0.08
Returnflow	U	m/s	0.39	0.58	0.45	0.52	0.71	0.61
Resistance coefficient	Cd		0.16	0.16	0.16	0.16	0.16	0.16
Required force	Fs	N	70808.47	150261.91	143498.23	173579.01	373034.97	391463.90
Efficiency coefficient	n		0.45	0.45	0.45	0.45	0.45	0.45
Required power	P	kW	547.05	1073.87	1071.65	1702.61	3289.23	3827.60
Required power	P	pk	744.53	1461.54	1458.52	2317.26	4476.64	5209.36

CHANNEL PROFILE DAY + NIGHT NAVIGATION

PARAMETER	SYMBOL	UNIT	2 * 1	1 * 2	2 * 2	2 * 1	1 * 2	2 * 2
Slope		arctan	3.00	3.00	3.00	3.00	3.00	3.00
Depth		m	3.78	3.78	3.78	6.08	6.08	6.08
Keellevel width		m	94.69	113.22	157.39	90.59	109.13	153.29
Waterlevel width		m	111.49	130.02	174.19	117.59	136.13	180.29
Bottom width		m	87.97	106.50	150.67	79.79	98.33	142.49
Wet channel cross section	Ac	m2	376.96	447.04	613.97	599.54	712.15	980.44
Average waterdepth	h	m	3.38	3.44	3.52	5.10	5.23	5.44
Wet formation cross section	As	m2	28.73	57.46	57.46	46.17	92.34	92.34
Blockage ratio	As/Ac		0.08	0.13	0.09	0.08	0.13	0.09
$Vgr/\sqrt{gh}$			0.69	0.59	0.65	0.69	0.59	0.65
Speed limit (Vgr)		m/s	3.97	3.43	3.82	4.88	4.23	4.75
Vs / Vgr			0.80	0.80	0.80	0.80	0.80	0.80
Economic vessel speed	Ve	m/s	**3.18**	**2.74**	**3.06**	**3.90**	**3.38**	**3.80**
$Fr=Vs/\sqrt{gh}$			0.55	0.47	0.52	0.55	0.47	0.52
z / h			0.04	0.04	0.04	0.04	0.04	0.04
Waterleveldrop	Z	m	0.16	0.18	0.17	0.23	0.27	0.26
$U/\sqrt{gh}$			0.07	0.09	0.08	0.07	0.09	0.08
Returnflow	U	m/s	0.39	0.54	0.45	0.49	0.68	0.56
Resistance coefficient	Cd		0.16	0.16	0.16	0.16	0.16	0.16
Required force	Fs	N	75188.89	152360.87	153905.01	177305.61	369509.95	379823.38
Efficiency coefficient	n		0.45	0.45	0.45	0.45	0.45	0.45
Required power	P	kW	596.59	1111.99	1199.66	1729.77	3332.51	3680.93
Required power	P	pk	811.95	1513.42	1632.74	2354.21	4535.55	5009.75

Table 7.4 Calculation of channel cross-profile and sailing characteristics of the push barges

day1.wk1
23-Feb-93
02-Aug-93
09:30:27 AM

DAYTIME NAVIGATION ONLY

SCENARIO NEW LOCKS THANNEERMUKKOM, AVOIDING TRIKKUNNAPUZHA LOCKS

	UNIT :	CAMPINE-BARGE	D.E.K.	RHINE-HERNE CAN.VESSEL	LARGE RHINE VESSEL
payload	t	**600**	**1000**	**1300**	**2250**
length	m	55.00	75.00	85.00	110.00
beam	m	6.60	8.20	9.50	11.40
draught	m	2.50	2.50	2.50	2.80
DESIGN THROUGHPUT	mmtpa	10.00	10.00	10.00	10.00
TRAVEL DISTANCE	Km	91.00	91.00	91.00	91.00
LOADING TERMINAL					
waiting,manoeuvring,etc.	hrs	1.00	1.00	1.00	1.00
rated loading capacity	t/hr	700.00	1000.00	1500.00	1700.00
efficiency coefficient		0.90	0.90	0.90	0.90
effective loading rate	t/hr	630.00	900.00	1350.00	1530.00
loading time	hrs	0.95	1.11	0.96	1.47
time in loading port	hrs	1.95	2.11	1.96	2.47
TOTAL SAILING TIME PER TRIP					
total sailing distance	km	182.00	182.00	182.00	182.00
sailing speed	m/s	2.30	2.30	2.40	2.50
total sailing time	hrs	21.98	21.98	21.06	20.22
LOCK CYCLE TIME	hrs	1.40	1.40	1.40	1.40
UNLOADING TERMINAL					
waiting, manoeuvring,etc.	hrs	1.50	2.00	2.00	2.00
rated unloading capacity	t/hrs	500.00	500.00	750.00	750.00
efficiency coefficient		0.50	0.50	0.60	0.60
effective unloading rate	t/hr	250.00	250.00	450.00	450.00
unloading time	hrs	2.40	4.00	2.89	5.00
time in unloading port	hrs	3.90	6.00	4.89	7.00
TRIP TIME	hrs	29.23	31.49	29.32	31.09
TRIPS PER VESSEL					
net. working days	d/year	350.00	350.00	350.00	350.00
working hours per day	hrs	10.00	10.00	10.00	10.00
vessel trips	nr/year	119.73	111.14	119.39	112.57
NR. VESSELS REQ.	**nr**	**139.21**	**89.98**	**64.43**	**39.48**
nr of vessels on waterway	nr	104.67	62.80	46.30	25.68
aver. distance between vessels	Km	1.74	2.90	3.93	7.09
inter arrival time at terminal	hrs	0.21	0.35	0.46	0.79
BARGE CALLS PER YEAR	nr	16,666.67	10,000.00	7,692.31	4,444.44

BERTH OCC. LOADING TERM.

vessel in-port time	hrs	1.95	2.11	1.96	2.47
nr. of calls		16,666.67	10,000.00	7,692.31	4,444.44
total in-port time	hrs/year	32,539.68	21,111.11	15,099.72	10,980.39
working days per year	d	350.00	350.00	350.00	350.00
working hours per day	d	10.00	10.00	10.00	10.00
port working hours	hrs/year	3500.00	3500.00	3500.00	3500.00
berth occupancy factor					
	4	2.32	1.51	1.08	**0.78**
number	5	1.86	1.21	0.86	0.63
of	6	1.55	1.01	**0.72**	0.52
berths	7	1.33	0.86	0.62	
	8	1.16	**0.75**		
	9	1.03	0.67		
	10	0.93			
	11	0.85			
	12	**0.77**			
	13	0.72			

BERTH OCC. UNLOADING TERM.

vessel in-port time	hrs	3.90	6.00	4.89	7.00
nr. of calls		16,666.67	10,000.00	7,692.31	4,444.44
total in-port time	hrs/year	65,000.00	60,000.00	37,606.84	31,111.11
working days per year	d	350.00	350.00	350.00	350.00
working hours per day	d	10.00	10.00	10.00	10.00
port working hours	hrs/year	3500.00	3500.00	3500.00	3500.00
berth occupancy factor					
	11	1.69	1.56	0.98	**0.81**
	12	1.55	1.43	0.90	0.74
	13	1.43	1.32	0.83	0.68
	14	1.33	1.22	**0.77**	
number	15	1.24	1.14	0.72	
of	16	1.16	1.07	0.67	
berths	17	1.09	1.01		
	18	1.03	0.95		
	19	0.98	0.90		
	20	0.93	0.86		
	21	0.88	**0.82**		
	22	0.84			
	23	**0.81**			
	24	0.77			

Table 7.5 Calculation of transport system characteristics daytime navigation only I

day2.wk1
23-Feb-93
08-Jul-93
10:04:16 AM

DAYTIME NAVIGATION ONLY

SCENARIO NEW LOCKS THANNEERMUKKOM, AVOIDING TRIKKUNNAPUZHA LOCKS

VESSEL		PUSH BARGE FORMATIONS 2.8 m. DRAUGHT 2 * 1	1 * 2	2 * 2	PUSH BARGE FORMATIONS 4.5 m. DRAUGHT 2 * 1	1 * 2	2 * 2
payload	t	**3500.00**	**3500.00**	**7000.00**	**5600.00**	**5600.00**	**11200.00**
length	m	185.00	108.00	185.00	185.00	108.00	185.00
beam	m	11.40	22.80	22.80	11.40	22.80	22.80
draught	m	2.80	2.80	2.80	4.50	4.50	4.50
DESIGN THROUGHPUT	mmtpa	10.00	10.00	10.00	10.00	10.00	10.00
TRAVEL DISTANCE	Km	91.00	91.00	91.00	91.00	91.00	91.00
LOADING TERMINAL							
waiting,manoeuvring,etc.	hrs	1.50	1.50	2.00	1.50	1.50	2.00
rated loading capacity	t/hr	1700.00	1700.00	2000.00	2000.00	2000.00	3500.00
efficiency coefficient		0.90	0.90	0.90	0.90	0.90	0.90
effective loading rate	t/hr	1530.00	1530.00	1800.00	1800.00	1800.00	3150.00
loading time	hrs	2.29	2.29	3.89	3.11	3.11	3.56
time in loading port	hrs	3.79	3.79	5.89	4.61	4.61	5.56
TOTAL SAILING TIME PER TRIP							
total sailing distance	km	182.00	182.00	182.00	182.00	182.00	182.00
sailing speed	m/s	3.10	2.70	2.90	3.90	3.30	3.80
total sailing time	hrs	16.31	18.72	17.43	15.32	13.30	13.30
LOCK CYCLE TIME	hrs	1.40	1.40	1.40	1.40	1.40	1.40
UNLOADING TERMINAL							
manoeuvring,etc.	hrs	2.00	2.00	3.00	2.50	2.50	3.00
rated unloading capacity	t/hrs	1000.00	1000.00	1500.00	1700.00	1700.00	2500.00
efficiency coefficient		0.60	0.60	0.60	0.60	0.60	0.60
effective unloading rate	t/hr	600.00	600.00	900.00	1020.00	1020.00	1500.00
unloading time	hrs	5.83	5.83	7.78	5.49	5.49	7.47
time in unloading port	hrs	7.83	7.83	10.78	7.99	7.99	10.47
TRIP TIME	hrs	29.33	31.75	35.50	29.32	27.31	30.73
TRIPS PER VESSEL							
net. working days	d/year	350.00	350.00	350.00	350.00	350.00	350.00
working hours per day	hrs	10.00	10.00	10.00	10.00	10.00	10.00
vessel trips	nr/year	119.34	110.25	98.59	119.37	128.18	113.91
NR. VESSELS REQ.	**nr**	**23.94**	**25.91**	**14.49**	**14.96**	**13.93**	**7.84**
nr of barges on waterway	nr	13.31	15.29	7.12	7.82	6.79	3.39
aver. distance between barges	Km	13.67	11.91	25.58	23.28	26.81	53.63
inter arrival time at terminal	hrs	1.22	1.22	2.45	1.66	2.26	3.92
BARGE CALLS PER YEAR	nr	2,857.14	2,857.14	1,428.57	1,785.71	1,785.71	892.86
BERTH OCC. LOADING TERM.							
vessel in-port time	hrs	3.79	3.79	5.89	4.61	4.61	5.56
nr. of calls		2,857.14	2,857.14	1,428.57	1,785.71	1,785.71	892.86
total in-port time	hrs/year	10,821.66	10,821.66	8,412.70	8,234.13	8,234.13	4,960.32
working days per year	d	350.00	350.00	350.00	350.00	350.00	350.00
working hours per day	d	10.00	10.00	10.00	10.00	10.00	10.00
port working hours	hrs/year	3,500.00	3,500.00	3,500.00	3,500.00	3,500.00	3,500.00
berth occupancy factor							
	1	3.09	3.09	2.40	2.35	2.35	1.42
number	2	1.55	1.55	1.20	1.18	1.18	**0.71**
of	3	1.03	1.03	**0.80**	**0.78**	**0.78**	0.47
berths	4	**0.77**	**0.77**	0.60	0.59	0.59	0.35
	5	0.62	0.62	0.48	0.47	0.47	0.28
BERTH OCC. UNLOADING TERM.							
vessel in-port time	hrs	7.83	7.83	10.78	7.99	7.99	10.47
nr. of calls		2,857.14	2,857.14	1,428.57	1,785.71	1,785.71	892.86
total in-port time	hrs/year	22,380.95	22,380.95	15,396.83	14,268.21	14,268.21	9,345.24
working days per year	d	350.00	350.00	350.00	350.00	350.00	350.00
working hours per day	d	10.00	10.00	10.00	10.00	10.00	10.00
port working hours	hrs/year	3,500.00	3,500.00	3,500.00	3,500.00	3,500.00	3,500.00
berth occupancy factor							
	1	6.39	6.39	4.40	4.08	4.08	2.67
number	2	3.20	3.20	2.20	2.04	2.04	1.34
of	3	2.13	2.13	1.47	1.36	1.36	0.89
berths	4	1.60	1.60	1.10	1.02	1.02	**0.67**
	5	1.28	1.28	0.88	**0.82**	**0.82**	0.53
	6	1.07	1.07	**0.73**	0.68	0.68	0.45
	7	0.91	0.91				
	8	**0.80**	**0.80**				
	9	0.71	0.71				

Total kWh's per year: 2.2785E+07 2.3833E+07

Table 7.6 Calculation of transport system characteristics daytime navigation only II

new2.wk1
23–Feb–93
08–Jul–93
10:01:01 AM

DAY AND NIGHT NAVIGATION

SCENARIO NEW LOCKS THANNEERMUKKOM, AVOIDING TRIKKUNNAPUZHA LOCKS

		PUSH BARGE FORMATIONS 2.8 m. DRAUGHT			PUSH BARGE FORMATIONS 4.5 m. DRAUGHT		
VESSEL		2 * 1	1 * 2	2 * 2	2 * 1	1 * 2	2 * 2
payload	t	**3500.00**	**3500.00**	**7000.00**	**5600.00**	**5600.00**	**11200.00**
length	m	185.00	108.00	185.00	185.00	108.00	185.00
beam	m	11.40	22.80	22.80	11.40	22.80	22.80
draught	m	2.80	2.80	2.80	4.50	4.50	4.50
DESIGN THROUGHPUT	mmtpa	10.00	10.00	10.00	10.00	10.00	10.00
TRAVEL DISTANCE	Km	91.00	91.00	91.00	91.00	91.00	91.00
LOADING TERMINAL							
waiting,manoeuvring,etc.	hrs	1.50	1.50	2.00	1.50	1.50	2.00
rated loading capacity	t/hr	1700.00	1700.00	2000.00	2000.00	2000.00	3500.00
efficiency coefficient		0.90	0.90	0.90	0.90	0.90	0.90
effective loading rate	t/hr	1530.00	1530.00	1800.00	1800.00	1800.00	3150.00
loading time	hrs	2.29	2.29	3.89	3.11	3.11	3.56
time in loading port	hrs	3.79	3.79	5.89	4.61	4.61	5.56
TOTAL SAILING TIME PER TRIP							
total sailing distance	km	182.00	182.00	182.00	182.00	182.00	182.00
sailing speed	m/s	3.20	2.70	3.10	3.90	3.40	3.80
total sailing time	hrs	15.80	18.72	16.31	12.96	14.87	13.30
LOCK CYCLE TIME	hrs	1.40	1.40	1.40	1.40	1.40	1.40
UNLOADING TERMINAL							
waiting,manoeuvring,etc.	hrs	2.00	2.00	3.00	2.50	2.50	3.00
rated unloading capacity	t/hrs	1000.00	1000.00	1500.00	1700.00	1700.00	2500.00
efficiency coefficient		0.60	0.60	0.60	0.60	0.60	0.60
effective unloading rate	t/hr	600.00	600.00	900.00	1020.00	1020.00	1500.00
unloading time	hrs	5.83	5.83	7.78	5.49	5.49	7.47
time in unloading port	hrs	7.83	7.83	10.78	7.99	7.99	10.47
TRIP TIME	hrs	28.82	31.75	34.37	26.96	28.87	30.73
TRIPS PER VESSEL							
net. working days	d/year	350.00	350.00	350.00	300.00	300.00	300.00
working hours per day	hrs	20.00	20.00	20.00	20.00	20.00	20.00
vessel trips	nr/year	242.89	220.51	203.64	222.52	207.82	195.27
NR. VESSELS REQ.	**nr**	**11.76**	**12.96**	**7.02**	**8.03**	**8.59**	**4.57**
nr of barges on waterway	nr	6.45	7.64	3.33	3.86	4.43	1.98
aver. distance between barges	Km	28.22	23.81	54.68	47.17	41.13	91.93
inter arrival time at terminal	hrs	2.45	2.45	4.90	3.36	3.36	6.72
BARGE CALLS PER YEAR	nr	2,857.14	2,857.14	1,428.57	1,785.71	1,785.71	892.86
BERTH OCC. LOADING TERM.							
vessel in–port time	hrs	3.79	3.79	5.89	4.61	4.61	5.56
nr. of calls		2,857.14	2,857.14	1,428.57	1,785.71	1,785.71	892.86
total in–port time	hrs/year	10,821.66	10,821.66	8,412.70	8,234.13	8,234.13	4,960.32
working days per year	d	350.00	350.00	350.00	300.00	300.00	300.00
working hours per day	d	20.00	20.00	20.00	20.00	20.00	20.00
port working hours	hrs/year	7,000.00	7,000.00	7,000.00	6,000.00	6,000.00	6,000.00
berth occupancy factor							
	1	1.55	1.55	1.20	1.37	1.37	**0.83**
number	2	**0.77**	**0.77**	**0.60**	**0.69**	**0.69**	0.41
of	3	0.52	0.52	0.40	0.46	0.46	0.28
berths	4	0.39	0.39	0.30	0.34	0.34	0.21
	5	0.31	0.31	0.24	0.27	0.27	0.17
BERTH OCC. UNLOADING TERM.							
vessel in–port time	hrs	7.83	7.83	10.78	7.99	7.99	10.47
nr. of calls		2,857.14	2,857.14	1,428.57	1,785.71	1,785.71	892.86
total in–port time	hrs/year	22,380.95	22,380.95	15,396.83	14,268.21	14,268.21	9,345.24
working days per year	d	350.00	350.00	350.00	300.00	300.00	300.00
working hours per day	d	20.00	20.00	20.00	20.00	20.00	20.00
port working hours	hrs/year	7,000.00	7,000.00	7,000.00	6,000.00	6,000.00	6,000.00
berth occupancy factor							
	1	3.20	3.20	2.20	2.38	2.38	1.56
number	2	1.60	1.60	1.10	1.19	1.19	**0.78**
of	3	1.07	1.07	**0.73**	**0.79**	**0.79**	0.52
berths	4	**0.80**	**0.80**	0.55	0.59	0.59	0.39

Total kWh's per year : 2.5651E+07 2.7043E+07

Table 7.8 Calculation of transport system characteristics day and night navigation II

eva.wk

SUMMARY OF CALCULATION OUTPUT

			SELF-PROPELLED VESSELS				BARGE FORMATIONS draught 2.8 m			BARGE FORMATIONS draught 4.5 m		
			CAMPINE BARGE	DORTMUND-EEMS CANAL VESSEL	RHINE-HERNE KAN.VESSEL	LARGE RHINE VESSEL	2 * 1	1 * 2	2 * 2	2 * 1	1 * 2	2 * 2
		PAYLOAD (tons):	600	1000	1300	2250	2 * 1750	2 * 1750	4 * 1750	2 * 2800	2 * 2800	4 * 2800
DAYTIME NAVIGATION	NUMBER OF VESSELS REQUIRED		140	90	65	40	24	26	15	15	14	8
	NUMBER OF CALLS PER YEAR		16,667	10,000	7,693	4,445	2,858	2,858	1,429	1,786	1,786	893
	NUMBER OF LOCKS REQUIRED		9	6	5	3	2	2	1	1	1	1
	NUMBER OF LOADING BERTHS		12	8	6	4	4	4	3	3	3	2
	NUMBER OF UNLOADING BERTHS		23	21	14	11	8	8	6	5	5	4
	CHANNEL WATERLEVEL WIDTH	m	42	51	57	69	106	119	163	112	125	169
	CHANNEL DEPTH	m	3.4	3.4	3.4	3.8	3.8	3.8	3.8	6.1	6.1	6.1
	REQUIRED DREDGING	million cu.m	2.5	3.5	4.2	6.2	11.1	12.8	21.3	28.3	33.0	49.1
	LAND ACQUISITION	*1000 m2	254	398	512	764	1,589	1,966	3,242	-	-	-
DAY + NIGHT NAVIGATION	NUMBER OF VESSELS REQUIRED		67	43	32	19	12	13	8	9	9	5
	NUMBER OF NUMBER OF CALLS PER YEAR		16,667	10,000	7,693	4,445	2,858	2,858	1,429	1,786	1,786	893
	NUMBER OF LOCKS REQUIRED		5	3	3	2	1	1	1	1	1	1
	NUMBER OF LOADING BERTHS		6	4	3	2	2	2	2	2	2	1
	NUMBER OF UNLOADING BERTHS		11	10	7	6	4	4	3	3	3	2
	CHANNEL WATERLEVEL WIDTH	m	46	55	62	75	112	130	174	118	136	180
	CHANNEL DEPTH	m	3.4	3.4	3.4	3.8	3.8	3.8	3.8	6.1	6.1	6.1
	REQUIRED DREDGING	million cu.m	3.0	4.0	4.8	7.0	11.8	15.1	23.1	30.1	36.7	53.1
	LAND ACQUISITION	*1000 m2	308	470	617	869	1,734	2,285	3,561	-	-	-

Table 7.9 Summary of calculations

km.0 to 62				COSTS PER MONTH IN US $				
quantity		rate	unit	Writing off + Interest	Maintenance + Repair	Others	kW	
1	Cutter plant			14,200	10,350		450	
1	Assisting Tug			7,220	3,890		400	(1/4 of time)
1	Floating booster			19,070	11,190		400	
5000 m.	Pipeline 400mm	6.42	$ / m.	32,100				
160	Floaters	105.56	$ / piece	11,200	5,600			
	Fuel	0.04	$ / kWh			17,100		
	Oil + grease (20% of fuelcosts)					3,420		
6	Labour Dutch:	14000.00	$ / man			84,000		
14	Local:	1000.00	$ / man			14,000		
				______+	______+	______+		
more work coefficient writing off + interest = 1.2			SUM TOTAL =	83,790	31,030	104,520 U.S. $		
more work coefficient maint. + repair = 2			* coeff. =	100,548	62,060			
					TOTAL PER MONTH =	267,128 US $		

TOTAL FIELD COSTS KM 0 – KM 62 : (In US $ per month)	267,128	
RECLAMATION AREA (10%):	26,713	
OVERHEAD + PROFIT (40%):	106,851	
FIXED EXPENSES (20%): – (de)mobilisation, site clearance, etc.	53,426	
	______+	
TOTAL DREDGING COSTS PER MONTH :	454,118	U.S. $
TOTAL DREDGING COSTS PER CUBIC METER:	**4.0**	**U.S.$**

km.62 to 91				COSTS PER MONTH IN US $				
quantity		rate	unit	Writing off + Interest	Maintenance + Repair	Others	kW per unit	
1	Cutter plant			14,200	10,350		450	
1	Assisting Tug			7,220	3,890		400	(1/4 of time)
2	Land booster			17,800	10,160		400	
15000 m.	Pipeline 400mm	6.42	$ / m.	96,300				
10	Floaters	105.56	$ / piece	700	350			
2	Bulldozers	2222.22	$ / piece	2,460	2,060		100	(1/2 of time)
	Fuel	0.04	$ / kWh			18,900		
	Oil + grease (20% of fuelcosts)					3,780		
6	Labour Dutch:	14000.00	$ / man			84,000		
14	Local:	1000.00	$ / man			14,000		
				______+	______+	______+		
more work coefficient writing off + interest = 1.2			SUM TOTAL =	136,220	24,750	108,030 US $		
more work coefficient maint. + repair = 2			* coeff. =	163,464	49,500			
					TOTAL PER MONTH =	320,994 US $		

TOTAL FIELD COSTS KM 62 – KM 91 : (In US $ per month)	320,994	
RECLAMATION AREA (10%):	32,099	
OVERHEAD + PROFIT (40%):	128,398	
FIXED EXPENSES (20%): – (de)mobilisation, site clearance, etc.	64,199	
	+	
TOTAL DREDGING COSTS PER MONTH :	545,690	U.S. $
TOTAL DREDGING COSTS PER CUBIC METER:	**4.9**	**U.S.$**

Table 7.10 Calculation of dredging costs I

dreco2.wk CALCULATION OF AVERAGE DREDGING COSTS PER CU.M. FOR THE ENTIRE CHANNEL

DAYTIME NAVIGATION ONLY

	KM 0 – KM 62		KM 62 – KM 91			
VESSEL	AMOUNT OF DREDGING (million cu.m)	COSTS OF DREDGING (million US$)	AMOUNT OF DREDGING (million cu.m)	COSTS OF DREDGING (million US$)	TOTAL AMOUNT OF DREDGING ENTIRE CHANNEL (million cu.m)	**AVERAGE DREDGING COSTS PER CU.M ENTIRE CHANNEL (million US$)**
2*1 4)	3.6	14.4	7.5	36.75	11.1	**4.6**
2*2 5)	5.9	23.6	15.4	75.46	21.3	**4.7**

DAY AND NIGHT NAVIGATION

	KM 0 – KM 62		KM 62 – KM 91			
VESSEL	AMOUNT OF DREDGING (million cu.m)	COSTS OF DREDGING (million US$)	AMOUNT OF DREDGING (million cu.m)	COSTS OF DREDGING (million US$)	TOTAL AMOUNT OF DREDGING ENTIRE CHANNEL (million cu.m)	**AVERAGE DREDGING COSTS PER CU.M ENTIRE CHANNEL (million US$)**
Campine barge	0.9	3.6	1.6	7.84	2.5	**4.6**
D.E.K 1)	1.3	5.2	2.2	10.78	3.5	**4.6**
R.H. 2)	1.5	6	2.7	13.23	4.2	**4.6**
G.R. 3)	2.2	8.8	4	19.6	6.2	**4.6**
2*1 4)	3.9	15.6	7.9	38.71	11.8	**4.6**
2*2 5)	6.4	25.6	16.7	81.83	23.1	**4.7**

1) Dortmund–Eems Canal Vessel
2) Rhine Herne Canal vessel
3) Large Rhine Vessel
4) 2*1 Barge Formation
5) 2*2 Barge Formation

Table 7.11 Calculation of dredging costs II

lock.wk estimation of investment costs new locks

			VESSEL					
			Campine Barge	D.E.K.	Rhine-H.	Large Rhine	2*1 Pushtow	2*2 Pushtow
vessel	length	m	55	75	80	110	185	185
sizes	beam	m	6.6	8.2	9.5	11.4	11.4	22.8
	draught	m	2.5	2.5	2.5	2.8	2.8	2.8
lock	length	m	61	83	88	121	204	204
dimensions	head length	m	17	21	24	29	30	59
	width	m	8	10	12	14	15	30
	height	m	5	5	5	5	6	6
concrete construction		cu.m	2700	3937	4649	6966	11123	20792
costs/cu.m =	186	US$						
concrete construction costs		US $	502,165	732,201	864,778	1,295,682	2,068,967	3,867,348
costs of doors, electronical and mechanical installations		US $	1,170,045	1,706,027	2,014,933	3,018,938	4,820,693	9,010,921
Total constr.+install.		US $	1,672,210	2,438,228	2,879,711	4,314,620	6,889,659	12,878,269
Mob./Demob./Overhead (35%)		US $	585,273	853,380	1,007,899	1,510,117	2,411,381	4,507,394
TOTAL INVESTMENT COST		million US $	2.3	3.3	3.9	5.8	9.3	17.4

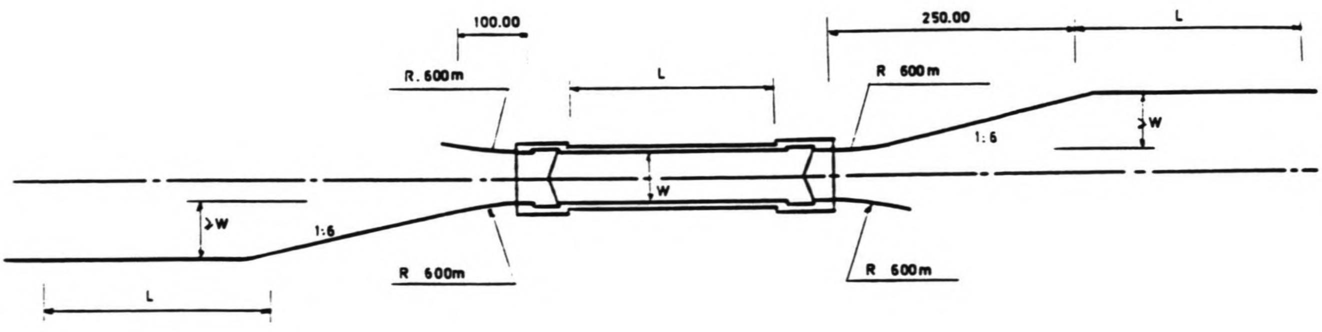


Table 7.12 Calculation of lock construction costs

	unit	SELF PROPELLED VESSELS				BARGE FORMATIONS	
vessel payload	ton	600	1000	1300	2250	3500 (2*1750)	7000 (4*1750)
length	m	55	75	85	110	185	185
beam	m	6.6	8.2	9.5	11.4	11.4	22.8
draught	m	2.5	2.5	2.5	2.8	2.8	2.8
IWT LOADING TERMINAL							
(continuous loader)							
rated loading capacity	t/h	700	1000	1500	1700	1700	2000
effective loading capacity	t/h	630	900	1350	1530	1530	1800
number of berths		6	4	3	2	2	2
investment costs	US$	500,000	500,000	750,000	750,000	750,000	1,000,000
IWT UNLOADING TERMINAL							
(grabbing crane)							
rated unloading capacity	t/h	500	500	750	750	1000	1500
effective unloading capacity	t/h	300	300	450	450	600	900
number of berths		11	10	7	6	4	3
investment costs	US$	3,000,000	3,000,000	3,500,000	3,500,000	4,000,000	4,500,000

WORKING DAYS PER YEAR : 350
WORKING HOURS PER DAY : 20

Table 7.13 Loading- and unloading equipment

cod.wk COMPARATIVE COST ESTIMATE FOR 2*1 AND 2*2 BARGE FORMATION

DAYTIME NAVIGATION ONLY

	COMPARATIVE COST ESTIMATE							YEAR: 1993 CURRENCY: US $						
	2*1 BARGE FORMATION (2 * 1,750 = 3,500 ton)							2*2 BARGE FORMATION (4 * 1750 = 7,000 ton)						
Item	Quantity	Unit	Unit Rate (US$)	Subtotals mil.US$	Cap.Rec. factor	Maint. + Repair (mil.US$)	Yearly subtotal (mil.US$)	Quantity	Unit	Rate (US$)	Subtotals mil.US$	Cap.Rec. factor	Maint. + Repair (mil.US$)	Yearly subtotal (mil.US$)
Vessels		each		0.0					each		0.0			
Pushboats	24	each	850,000	20.4	0.106	2.04	4.2	15	each	850,000	12.8	0.106	1.275	2.6
Barges	48	each	560,000	26.9	0.106	1.344	4.2	60	each	560,000	33.6	0.106	1.68	5.2
Labour	72	men/year	1,500				0.1	45	men/year	1,500				0.1
											0.0			
Locks	2	each	9,300,000	18.6	0.101	0.96	2.8	1	each	17,400,000	17.4	0.101	0.9	2.7
											0.0			
Land acquisition	1,600,000	m2	1.4	2.2	0.101		0.2	3,200,000	m2	1.4	4.5	0.101		0.5
Capital Dredging	11,100,000	m3	4.6	51.1	0.101		5.2	21,300,000	m3	4.7	100.1	0.101		10.1
Maintenance Dredging	2,220,000	m3/year	2.6				5.8	4,260,000	m3/year	2.6				11.1
Loading Berths	4	each						3	each					
Quay structure	851	m	10,500	8.9	0.101		0.9	638.25	m	10,500	6.7	0.101		0.7
Vessel loaders	4	each	750,000	3.0	0.106	0.3	0.6	3	each	1,000,000	3.0	0.106	0.3	0.6
Unloading Berths	8	each						6	each					
Quay structure	1702	m	10,500	17.9	0.101		1.8	1276.5	m	10,500	13.4	0.101		1.4
Vessel unloaders	7	each	4,000,000	28.0	0.106	2.8	5.8	5	each	4,500,000	22.5	0.106	2.25	4.6
Fuel + oil	22,785,000	KWh	0.044				1.0	23,833,000	KWh	0.044				1.0
TOTALS (in million US$)														
INVESTMENT COSTS				**177.0**							**213.9**			
YEARLY COSTS							**32.6**							**40.6**

Table 7.14 Comparative cost estimation daytime navigation only

con1.wk COMPARATIVE COST ESTIMATES FOR CAMPINE-BARGE AND D.E.K.-VESSEL

DAY AND NIGHT NAVIGATION

	COMPARATIVE COST ESTIMATES							YEAR: 1993 CURRENCY: US $						
	CAMPINE BARGE (600 ton)							DORTMUND-EEMS-CANAL standard vessel (1000 ton)						
Item	Quantity	Unit	Rate (US$)	Subtotals mil.US$	Cap.Rec. factor	Maint. + Repair (mil.US$)	Yearly subtotal (mil.US$)	Quantity	Unit	Rate (US$)	Subtotals mil.US$	Cap.Rec. factor	Maint. + Repair (mil.US$)	Yearly subtotal (mil.US$)
Vessels	67	each	850,000	57.0	0.106	5.695	11.73	43	each	970,000	41.7	0.106	4.171	8.59
Pushboats		each		0.0					each		0.0			
Barges		each		0.0					each		0.0			
Labour	402	men/year	1,500				0.60	258	men/year	1,500				0.39
				0.0							0.0			
Locks	5	each	2,300,000	11.5	0.101	0.585	1.75	3	each	3,300,000	9.9	0.101	0.513	1.51
				0.0							0.0			
Land acquisition	308,000	m2	1.4	0.4	0.101		0.04	470,000	m2	1.4	0.7	0.101		0.07
Capital Dredging	3,000,000	m3	4.6	13.8	0.101		1.39	4,000,000	m3	4.6	18.4	0.101		1.86
Maintenance Dredging	600,000	m2/year	2.6				1.56	800,000	m2/year	2.6				2.08
Loading Berths	6	each						4	each					
Quay structure	552	m	10,500	5.8	0.101		0.59	345	m	10,500	3.6	0.101		0.37
Vessel loaders	5	each	500,000	2.5	0.106	0.25	0.52	3	each	500,000	1.5	0.106	0.15	0.31
Unloading Berths	11	each						10	each					
Quay structure	1012	m	10,500	10.6	0.101		1.07	862.5	m	10,500	9.1	0.101		0.91
Vessel unloaders	9	each	3,000,000	27.0	0.106	2.7	5.56	8	each	3,000,000	24.0	0.106	2.4	4.94
Fuel + oil	75,482,000	KWh	0.044				3.32	60,245,000	KWh	0.044				2.65
TOTALS (in million US$)														
INVESTMENT COSTS				**128.6**							**108.8**			
YEARLY COSTS							**28.1**							**23.7**

Table 7.15 Comparative cost estimation day and night navigation I

COMPARATIVE COST ESTIMATES FOR RHINE-HERNE- AND LARGE RHINE VESSEL

DAY AND NIGHT NAVIGATION

	COMPARATIVE COST ESTIMATES							YEAR: 1993 CURRENCY: US $						
	RHINE HERNE KAN. VESSEL (1300 ton)							LARGE RHINE VESSEL (2250 ton)						
Item	Quantity	Unit	Rate (US$)	Subtotals mil.US$	Cap.Rec. factor	Maint. + Repair (mil.US$)	Yearly subtotal (mil.US$)	Quantity	Unit	Rate (US$)	Subtotals mil.US$	Cap.Rec. factor	Maint. + Repair (mil.US$)	Yearly subtotal (mil.US$)
Vessels	32	each	1,200,000	38.4	0.106	3.84	7.91	19	each	1,700,000	32.3	0.106	3.23	6.65
Pushboats		each		0.0					each		0.0			
Barges		each		0.0					each		0.0			
Labour	192	men/year	1,500				0.29	114	men/year	1,500				0.17
Locks	3	each	3,900,000	11.7	0.101	0.603	1.78	2	each	5,800,000	11.6	0.101	0.604	1.78
Land acquisition	617,000	m2	1.4	0.9	0.101		0.09	869,000	m2	1.4	1.2	0.101		0.12
Capital Dredging	4,800,000	m3	4.6	22.1	0.101		2.23	7,000,000	m3	4.6	32.2	0.101		3.25
Maintenance Dredging	960,000	m3/year	2.6				2.50	1,400,000	m3/year	2.6				3.64
Loading Berths	3	each						2	each					
Quay structure	293.25	m	10,500	3.1	0.101		0.31	253	m	10,500	2.7	0.101		0.27
Vessel loaders	3	each	750,000	2.3	0.106	0.225	0.46	2	each	750,000	1.5	0.106	0.15	0.31
Unloading Berths	7	each						6	each					
Quay structure	644	m	10,500	6.8	0.101		0.68	759	m	10,500	8.0	0.101		0.80
Vessel unloaders	6	each	3,500,000	21.0	0.106	2.1	4.33	5	each	3,500,000	17.5	0.106	1.75	3.61
Fuel + oil	53,822,000	KWh	0.044				2.37	39,446,000	KWh	0.044				1.74
TOTALS (in million US$)														
INVESTMENT COSTS				**106.1**							**106.9**			
YEARLY COSTS							**22.9**							**22.3**

Table 7.16 Comparative cost estimation day and night navigation II

con3.wk COMPARATIVE COST ESTIMATES FOR 2*1 AND 2*2 BARGE FORMATIONS

DAY AND NIGHT NAVIGATION

	COMPARATIVE COST ESTIMATES							YEAR: 1993 CURRENCY: US $						
	2*1 BARGE FORMATION (2 * 1750 = 3500 t)							2*2 BARGE FORMATION (4 * 1750 = 7000 t)						
Item	Quantity	Unit	Rate (US$)	Subtotals mil.US$	Cap.Rec. factor	Maint. + Repair (mil.US$)	Yearly subtotal (mil.US$)	Quantity	Unit	Rate (US$)	Subtotals mil.US$	Cap.Rec. factor	Maint. + Repair (mil.US$)	Yearly subtotal (mil.US$)
Vessels		each		0.0					each		0.0			
Pushboats	12	each	850,000	10.2	0.106	1.02	2.1	8	each	850,000	6.8	0.106	0.68	1.4
Barges	24	each	560,000	13.4	0.106	0.672	2.1	32	each	560,000	17.9	0.106	0.896	2.8
Labour	72	men/year	1,500				0.1	48	men/year	1,500				0.1
											0.0			
Locks	1	each	9,300,000	9.3	0.101	0.482	1.4	1	each	17,400,000	17.4	0.101	0.901	2.7
											0.0			
Land acquisition	1,734,000	m2	1.4	2.4	0.101		0.2	3,560,000	m2	1.4	5.0	0.101		0.5
Capital Dredging	11,800,000	m3	4.6	54.3	0.101		5.5	23,100,000	m3	4.7	108.6	0.101		11.0
Maintenance Dredging	2,360,000	m3/year	2.6				6.1	4,620,000	m3/year	2.6				12.0
Loading Berths	2	each						2	each					
Quay structure	425.5	m	10,500	4.5	0.101		0.5	425.5	m	10,500	4.5	0.101		0.5
Vessel loaders	2	each	750,000	1.5	0.106	0.15	0.3	2	each	1,000,000	2.0	0.106	0.2	0.4
Unloading Berths	4	each						3	each					
Quay structure	851	m	10,500	8.9	0.101		0.9	638.25	m	10,500	6.7	0.101		0.7
Vessel unloaders	4	each	4,000,000	16.0	0.106	1.6	3.3	3	each	4,500,000	13.5	0.106	1.35	2.8
Fuel + oil	25,651,000	KWh	0.044				1.1	27,043,000	KWh	0.044				1.2
TOTALS (in million US$)														
INVESTMENT COSTS				120.6							182.3			
YEARLY COSTS							23.7							35.9

Table 7.17 Comparative cost estimation day and night navigation III

cross3.wk

PARAMETER	SYMBOL	UNIT	LARGE RHINE SHIP	PUSH BARGE FORMATIONS draught 2.8 m. 2 * 1	2 * 2
Barge unit length	Lu	m		76.50	76.50
Barge unit beam	Bu	m		11.40	11.40
Formation length	L	m	110.00	185.00	185.00
Formation beam	B	m	11.40	11.40	22.80
Draught loaded	Tl	m	2.80	2.80	2.80
Draught unloaded	Tu	m	0.70	0.56	0.56
Block-coefficient	Cb		0.85	0.90	0.90
Load-coefficient	Cl		0.75	0.80	0.80
Formation payload	P		2250.00	3500.00	7000.00
SINGLE LANE CHANNEL WIDTH					
Beam		B	1.00	1.00	1.00
Manoeuvring					
-drift angle		deg.	2.00	4.00	4.00
-extra width		B	0.34	1.13	0.57
Bank clearance		B	0.60	1.00	1.00
Windeffect					
-drift angle		deg.	2.00	4.00	4.00
-extra width		B	0.34	1.13	0.57
Safety margin					
-day + night		B	1.00	1.00	1.00
TOTAL CHANNEL WIDTH day + night navigation		B	**3.3**	**5.3**	**4.1**
CHANNEL DEPTH					
Draught		T	1.00	1.00	1.00
Squat		T	0.05	0.05	0.05
Manoeuvring		T	0.20	0.20	0.20
Margin		T	0.10	0.10	0.10
TOTAL CHANNEL DEPTH		T	**1.4**	**1.4**	**1.4**
SINGLE LANE CHANNEL PROFILE DAY + NIGHT NAVIGATION					
Slope		arctan	3.00	3.00	3.00
Depth		m	3.78	3.78	3.78
Keellevel width		m	37.32	60.01	94.21
Waterlevel width		m	54.12	76.81	111.01
Bottom width		m	30.60	53.29	87.49

Table 7.18 Calculation of single lane channel cross-profile for the Large Rhine Ship, the 2*1 and 2*2 barge formation

dres1.wk1

REQUIRED DREDGING FOR PARTLY SINGLE LANE CHANNEL–PROFILE LARGE RHINE SHIP
PARTLY SINGLE LANE

DAY AND NIGHT NAVIGATION

CHAINAGE (km.) from	to	AVAILABLE PROFILE WIDTH (m.) (average)	DEPTH (m.) (average)	SLOPE (arctan)	A (m2)	REQUIRED PROFILE WIDTH (m.) at bottom	DEPTH (m.)	SLOPE (arctan)	A (m2) dredge cross section	REQUIRED DREDGING (cu.m.)
0.00	7.00	1000.00	4.00	10.00	4343	51.00	3.80	3.00	275	0
7.00	7.50	1000.00	2.00	10.00	2463	51.00	3.80	3.00	275	50,760
7.50	21.00	1000.00	4.00	10.00	4343	51.00	3.80	3.00	275	0
21.00	22.00	1000.00	1.00	10.00	1493	51.00	3.80	3.00	275	166,320
22.00	30.00	1000.00	4.00	10.00	4343	51.00	3.80	3.00	275	0
30.00	49.00	3000.00	4.00	10.00	13343	51.00	3.80	3.00	275	0
49.00	62.00	3000.00	1.00	5.00	4496	51.00	3.80	3.00	275	2,162,160
62.00	65.00	55.00	1.50	2.50	105	31.00	3.80	3.00	189	261,510
65.00	73.00	100.00	5.00	5.00	426	51.00	3.80	3.00	275	0
73.00	75.00	25.00	1.00	10.00	30	31.00	3.80	3.00	189	317,540
75.00	84.00	25.00	2.00	5.00	44	31.00	3.80	3.00	189	1,305,180
84.00	91.00	35.00	1.50	5.00	60	51.00	3.80	3.00	275	1,503,390
									TOTAL DREDGING :	**5,766,860** cu.m.

Table 7.19 Calculation of amount of dredging partly single lane channel for the Large Rhine Ship

dres2.wk1

REQUIRED DREDGING FOR PARTLY SINGLE LANE CHANNEL–PROFILE 2 * 1 BARGE FORMATION ; DRAUGHT 2.8 M. (payload 3500 t)
PARTLY SINGLE LANE

DAY AND NIGHT NAVIGATION

		AVAILABLE PROFILE				REQUIRED PROFILE				
CHAINAGE (km.) from	to	WIDTH (m.) (average)	DEPTH (m.) (average)	SLOPE (arctan)	A (m2)	WIDTH (m.) at bottom	DEPTH (m.)	SLOPE (arctan)	A (m2) dredge cross section	REQUIRED DREDGING (cu.m.)
0.00	7.00	1000.00	4.00	10.00	4343	88.00	3.80	3.00	434	0
7.00	7.50	1000.00	2.00	10.00	2463	88.00	3.80	3.00	434	84,060
7.50	21.00	1000.00	4.00	10.00	4343	88.00	3.80	3.00	434	0
21.00	22.00	1000.00	1.00	10.00	1493	88.00	3.80	3.00	434	269,920
22.00	30.00	1000.00	4.00	10.00	4343	88.00	3.80	3.00	434	0
30.00	49.00	3000.00	4.00	10.00	13343	88.00	3.80	3.00	434	0
49.00	62.00	3000.00	1.00	5.00	4496	88.00	3.80	3.00	434	3,508,960
62.00	65.00	55.00	1.50	2.50	105	53.00	3.80	3.00	283	535,110
65.00	73.00	100.00	5.00	5.00	426	88.00	3.80	3.00	434	0
73.00	75.00	25.00	1.00	10.00	30	53.00	3.80	3.00	283	506,740
75.00	84.00	25.00	2.00	5.00	44	53.00	3.80	3.00	283	2,156,580
84.00	91.00	35.00	1.50	5.00	60	88.00	3.80	3.00	434	2,617,090
									TOTAL DREDGING :	**9,678,460** cu.m.

Table 7.20 Calculation of amount of dredging partly single lane channel for the 2*1 barge formation

dres3.wk1

REQUIRED DREDGING FOR PARTLY SINGLE LANE CHANNEL–PROFILE 2 * 2 – BARGE FORMATION ; DRAUGHT 2.8 M. (payload 7,000 t)

DAY AND NIGHT NAVIGATION

CHAINAGE (km.) from	to	AVAILABLE PROFILE WIDTH (m.) (average)	DEPTH (m.) (average)	SLOPE (arctan)	A (m2)	REQUIRED PROFILE WIDTH (m.) at bottom	DEPTH (m.)	SLOPE (arctan)	A (m2) dredge cross section	REQUIRED DREDGING (cu.m.)
0.00	7.00	1000.00	4.00	10.00	4343	151.00	3.80	3.00	705	0
7.00	7.50	1000.00	2.00	10.00	2463	151.00	3.80	3.00	705	140,760
7.50	21.00	1000.00	4.00	10.00	4343	151.00	3.80	3.00	705	0
21.00	22.00	1000.00	1.00	10.00	1493	151.00	3.80	3.00	705	446,320
22.00	30.00	1000.00	4.00	10.00	4343	151.00	3.80	3.00	705	0
30.00	49.00	3000.00	4.00	10.00	13343	151.00	3.80	3.00	705	0
49.00	62.00	3000.00	1.00	5.00	4496	151.00	3.80	3.00	705	5,802,160
62.00	65.00	55.00	1.50	2.50	105	87.00	3.80	3.00	430	973,710
65.00	73.00	100.00	5.00	5.00	426	151.00	3.80	3.00	705	3,137,280
73.00	75.00	25.00	1.00	10.00	30	87.00	3.80	3.00	430	799,140
75.00	84.00	25.00	2.00	5.00	44	87.00	3.80	3.00	430	3,472,380
84.00	91.00	35.00	1.50	5.00	60	151.00	3.80	3.00	705	4,513,390

TOTAL DREDGING : 19,285,140 cu.m.

Table 7.21 Calculation of amount of dredging partly single lane channel for the 2*2 barge formation

acs.wk1 CALCULATION OF AMOUNT OF LAND ACQUISITION
PARTLY SINGLE LANE CHANNEL

	WATERWAY STRETCH (km.) from	to	AVAILABLE WIDTH (m.) (average)	REQUIRED WIDTH (m):	LARGE RHINE SHIP STRETCHWISE LAND ACQUISITION (*1,000 m2)
	0	7	1000	74	0
	7	8	1000	74	0
	8	21	1000	74	0
	21	22	1000	74	0
	22	30	1000	74	0
	30	49	3000	74	0
	49	62	3000	74	0
single lane	62	65	55	54	0
	65	73	100	74	0
single lane	73	75	25	54	58
single lane	75	84	25	54	261
	84	91	35	74	+ 273
			TOTAL LAND ACQUISITION (*1000 m2) =		592

	WATERWAY STRETCH (km.) from	to	AVAILABLE WIDTH (m.) (average)	REQUIRED WIDTH (m):	2*1 PUSHTOW STRETCHWISE LAND ACQUISITION (*1,000 m2)
	0	7	1000	111	0
	7	8	1000	111	0
	8	21	1000	111	0
	21	22	1000	111	0
	22	30	1000	111	0
	30	49	3000	111	0
	49	62	3000	111	0
single lane	62	65	55	77	66
	65	73	100	111	88
single lane	73	75	25	77	104
single lane	75	84	25	77	468
	84	91	35	111	+ 532
			TOTAL LAND ACQUISITION (*1000 m2) =		1,258

	WATERWAY STRETCH (km.) from	to	AVAILABLE WIDTH (m.) (average)	REQUIRED WIDTH (m):	2*2 PUSHTOW STRETCHWISE LAND ACQUISITION (*1,000 m2)
	0	7	1000	174	0
	7	8	1000	174	0
	8	21	1000	174	0
	21	22	1000	174	0
	22	30	1000	174	0
	30	49	3000	174	0
	49	62	3000	174	0
single lane	62	65	55	111	168
	65	73	100	174	592
single lane	73	75	25	111	172
single lane	75	84	25	111	774
	84	91	35	174	+ 973
			TOTAL LAND ACQUISITION (*1000 m2) =		2,679

Table 7.22 Calculation of amount of land acquisition for single lane channel for the Large Rhine Ship, the 2*1 and 2*2 barge formation

cons1.wk COMPARATIVE COST ESTIMATE FOR LARGE RHINE VESSEL

DAY AND NIGHT NAVIGATION INCLUDING SINGLE LANE STRETCHES

	YEAR: 1993 CURRENCY: US $						
	LARGE RHINE VESSEL (2250 ton)						
Item	Quantity	Unit	Rate (US$)	Subtotals mil.US$	Cap.Rec. factor	Maint. + Repair (mil.US$)	Yearly subtotal (mil.US$)
Vessels	25	each	1,700,000	42.5	0.106	4.25	8.75
Pushboats		each		0.0			
Barges		each		0.0			
Labour	150	men/year	1,500				0.23
Locks	2	each	5,800,000	11.6	0.101	0.604	1.78
Land acquisition	592,000	m2	1.4	0.8	0.101		0.08
Capital Dredging	5,800,000	m3	4.6	26.7	0.101		2.69
Maintenance Dredging	1,160,000	m3/year	2.6				3.02
Loading Berths	2	each					
Quay structure	253	m	10,500	2.7	0.101		0.27
Vessel loaders	2	each	750,000	1.5	0.106	0.15	0.31
Unloading Berths	6	each					
Quay structure	759	m	10,500	8.0	0.101		0.80
Vessel unloaders	5	each	3,500,000	17.5	0.106	1.75	3.61
Fuel + oil	51,902,632	KWh	0.044				2.28
TOTALS (in million US$)							
INVESTMENT COSTS				**111.2**			
YEARLY COSTS							**23.8**

Table 7.23 Comparative cost estimation day and night navigation partly single lane for the Large Rhine Ship

cons2.wk COMPARATIVE COST ESTIMATES FOR 2*1 AND 2*2 BARGE FORMATIONS

DAY AND NIGHT NAVIGATION **INCLUDING SINGLE LANE STRETCHES**

COMPARATIVE COST ESTIMATES								YEAR: 1993 CURRENCY: US $						
	2*1 BARGE FORMATION (2 * 1750 = 3500 t)							2*2 BARGE FORMATION (4 * 1750 = 7000 t)						
Item	Quantity	Unit	Rate (US$)	Subtotals mil.US$	Cap.Rec. factor	Maint. + Repair (mil.US$)	Yearly subtotal (mil.US$)	Quantity	Unit	Rate (US$)	Subtotals mil.US$	Cap.Rec. factor	Maint. + Repair (mil.US$)	Yearly subtotal (mil.US$)
Vessels		each		0.0					each		0.0			
Pushboats	14	each	850,000	11.9	0.106	1.19	2.5	8	each	850,000	6.8	0.106	0.68	1.4
Barges	28	each	560,000	15.7	0.106	0.784	2.4	32	each	560,000	17.9	0.106	0.896	2.8
Labour	84	men/year	1,500				0.1	48	men/year	1,500				0.1
											0.0			
Locks	1	each	9,300,000	9.3	0.101	0.482	1.4	1	each	26,800,000	26.8	0.101	0.901	3.6
											0.0			
Land acquisition	1,258,000	m2	1.4	1.8	0.101		0.2	2,679,000	m2	1.4	3.8	0.101		0.4
Capital Dredging	9,700,000	m3	4.6	44.6	0.101		4.5	19,300,000	m3	4.7	90.7	0.101		9.2
Maintenance Dredging	1,940,000	m3/year	2.6				5.0	3,860,000	m3/year	2.6				10.0
Loading Berths	2	each						2	each					
Quay structure	425.5	m	10,500	4.5	0.101		0.5	425.5	m	10,500	4.5	0.101		0.5
Vessel loaders	2	each	750,000	1.5	0.106	0.15	0.3	2	each	1,000,000	2.0	0.106	0.2	0.4
Unloading Berths	4	each						3	each					
Quay structure	851	m	10,500	8.9	0.101		0.9	638.25	m	10,500	6.7	0.101		0.7
Vessel unloaders	4	each	4,000,000	16.0	0.106	1.6	3.3	3	each	4,500,000	13.5	0.106	1.35	2.8
Fuel + oil	29,983,333	KWh	0.044				1.3	27,000,000	KWh	0.044				1.2
TOTALS (in million US$)														
INVESTMENT COSTS				**114.2**							**172.6**			
YEARLY COSTS							**22.5**							**33.0**

Table 7.24 Comparative cost estimation day and night navigation partly single lane 2*1- and 2*2 barge formation

more.wk1 Influence of assumptions on other system components
See also the sensitivity analysis of figures 7.2 to 7.8

Assumption:		System components: Number of vessels	Number of berths	Amount of dredging
Number of working days per year is 350	more	less	less	–
	less	more	more	–
Berth occupancy factor is 0.8	more	–	less	–
	less	–	more	–
Rate of annual maintenance dredging is 20%	more	–	–	more
	less	–	–	less
Cross channel profile is X m2	more	less *)	–	more
	less	more	–	less
Waterway route amounts 91 km	more	more	–	more
	less	less	–	less
(Un)loading rate is X ton/hour	more	less	less	–
	less	more	more	–
Lock cycle time is 1.4 hours	more	more	–	–
	less	less	–	–

*) A larger channel profile gives a higher economic sailing speed

Table 7.25 Influence of assumptions on the system components

main.wk1 Sensitivity analysis of the influence of the rate of maintenance dredging on the selection and comparative annual cost of the transport system options.

Comparative annual cost (mill. US$)			Rate of maintenance dredging:		
	Vessel option:	Payload (t):	10 %	20 %	30 %
Daytime Navigation Only	2*1	3,500	29.7	32.6	35.5
	2*2	7,000	36.0	41.5	47.1
Day and Night Navigation	Campine Barge	600	27.4	28.1	28.9
	D.E.K.-Vessel	1,000	22.6	23.7	24.7
	Rhine-Herne	1,300	21.7	22.9	24.2
	Large Rhine ship	2,250	20.5	22.3	24.2
	2*1	3,500	20.6	23.7	26.7
	2*2	7,000	30.9	36.9	42.9
Day and Night Navigation + Single Lanes	Large Rhine ship	2,250	22.3	23.8	25.3
	2*1	3,500	19.9	22.5	25.0
	2*2	7,000	27.9	33.0	38.0

Table 7.26 Sensitivity analysis of rate of maintenance dredging on the comparative annual costs of the options

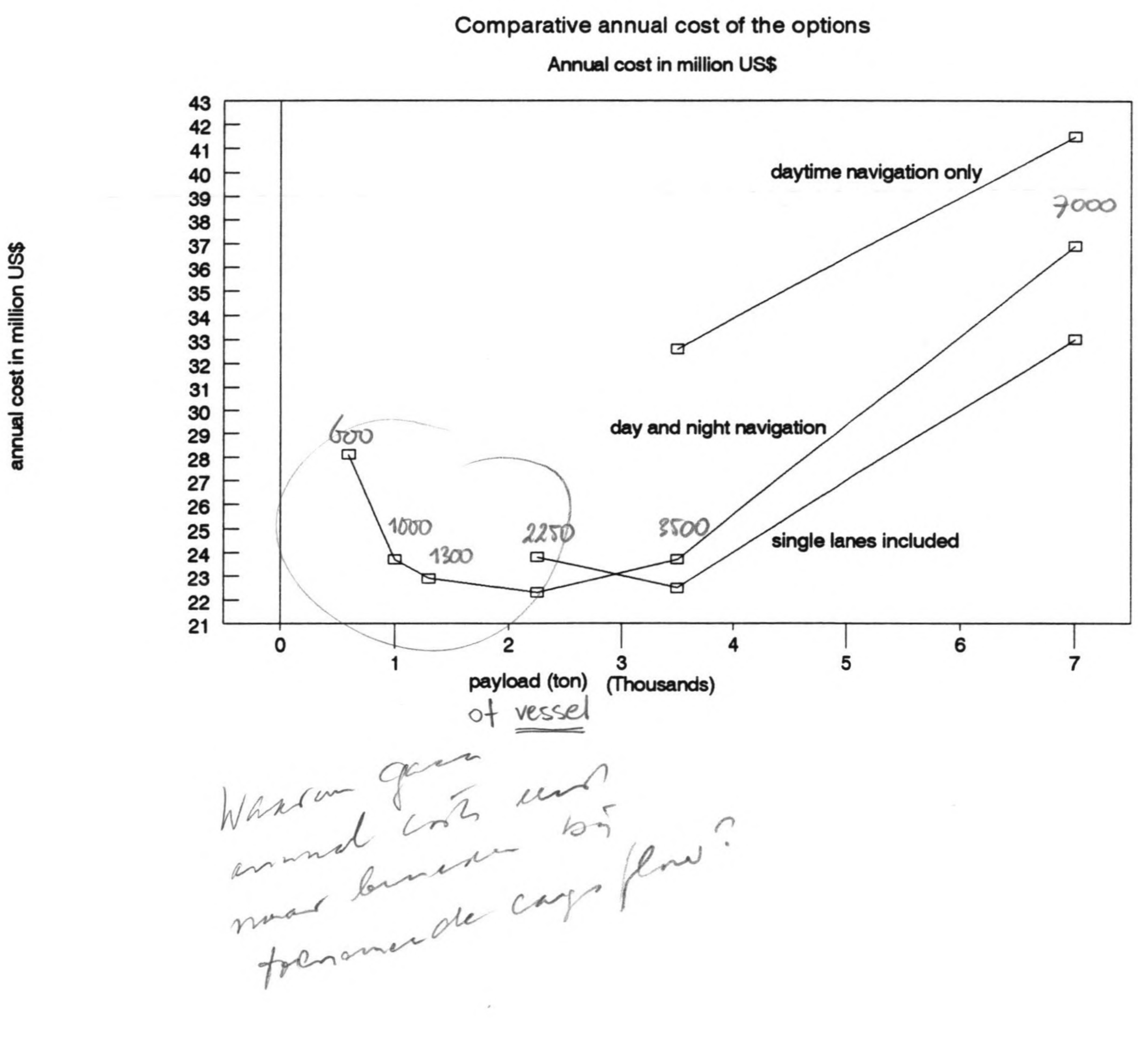


Figure 7.1 Comparative annual costs of day-and-night-, daytime only- and partly single lane navigation

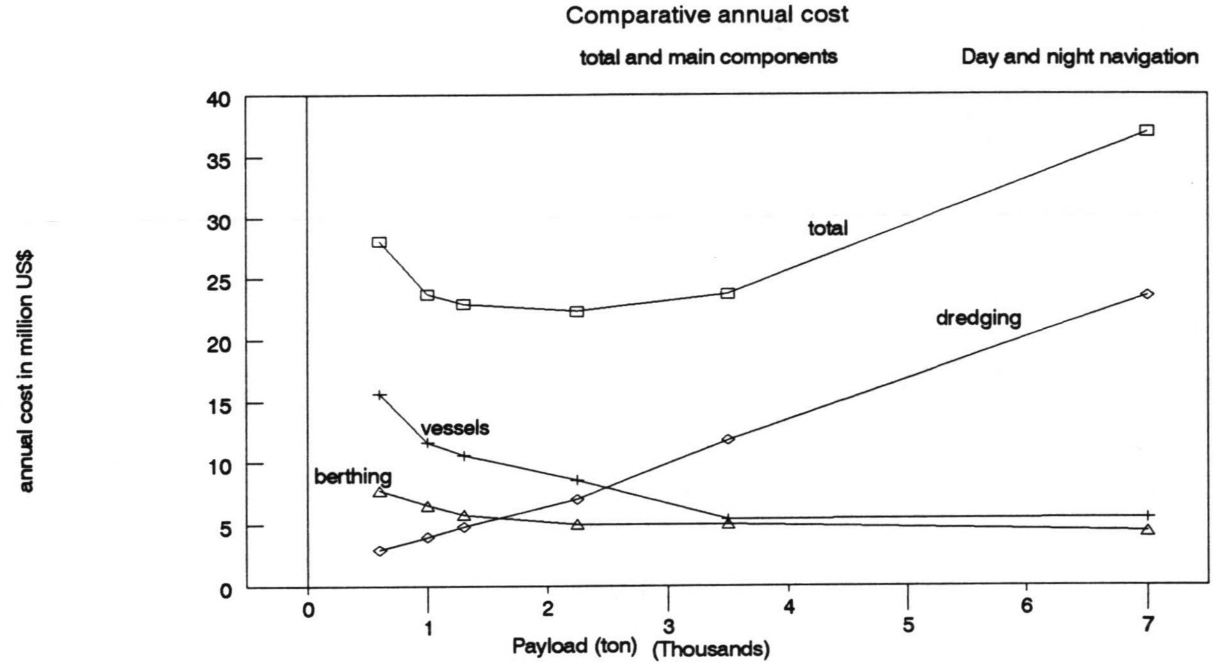


Figure 7.2 Comparative annual costs of total and the main components of day-and-night-navigation

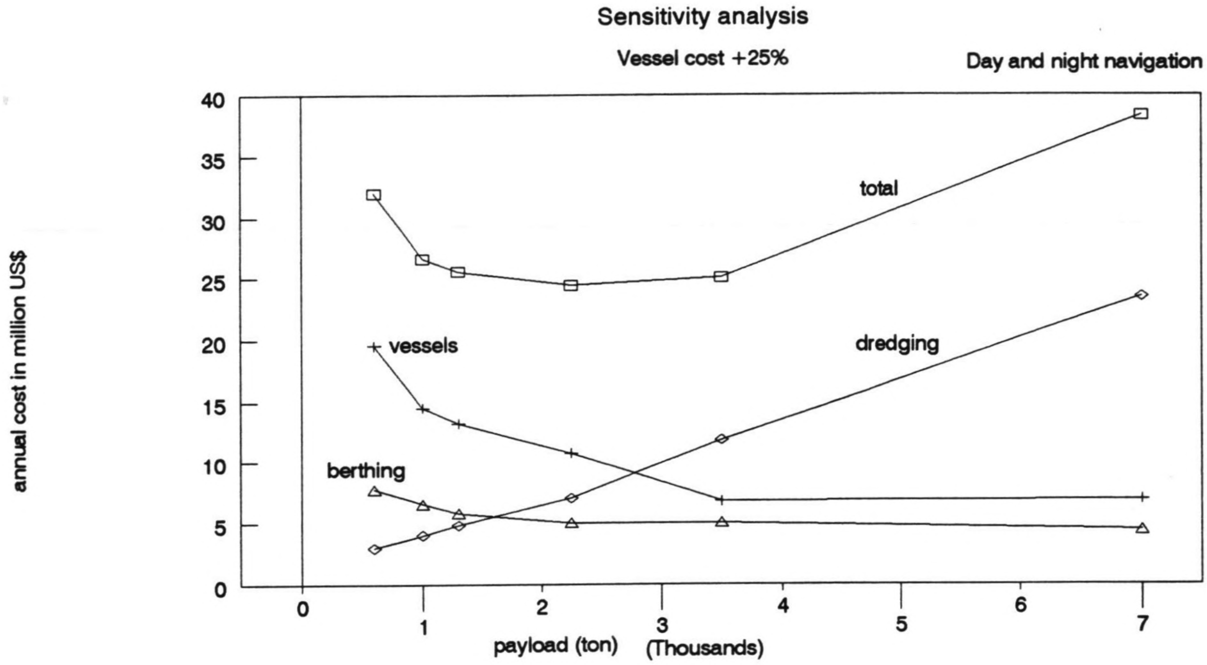


Figure 7.3 Sensitivity analysis vessel costs +25%

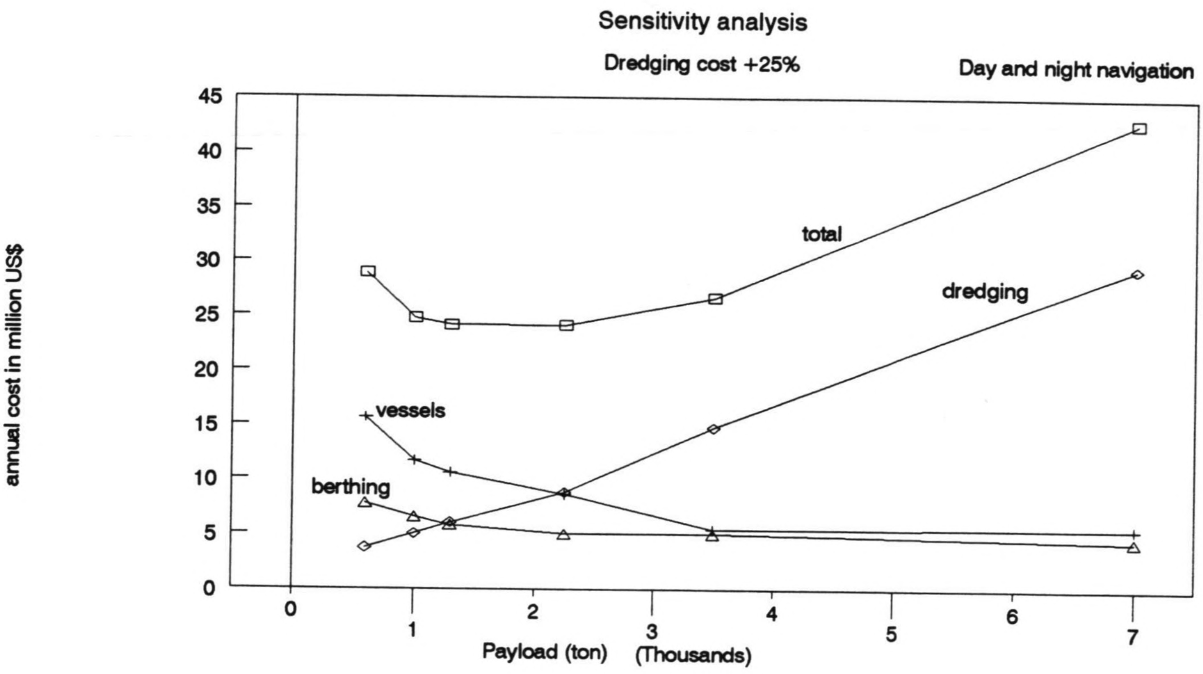


Figure 7.4 Sensitivity analysis dredging costs +25%

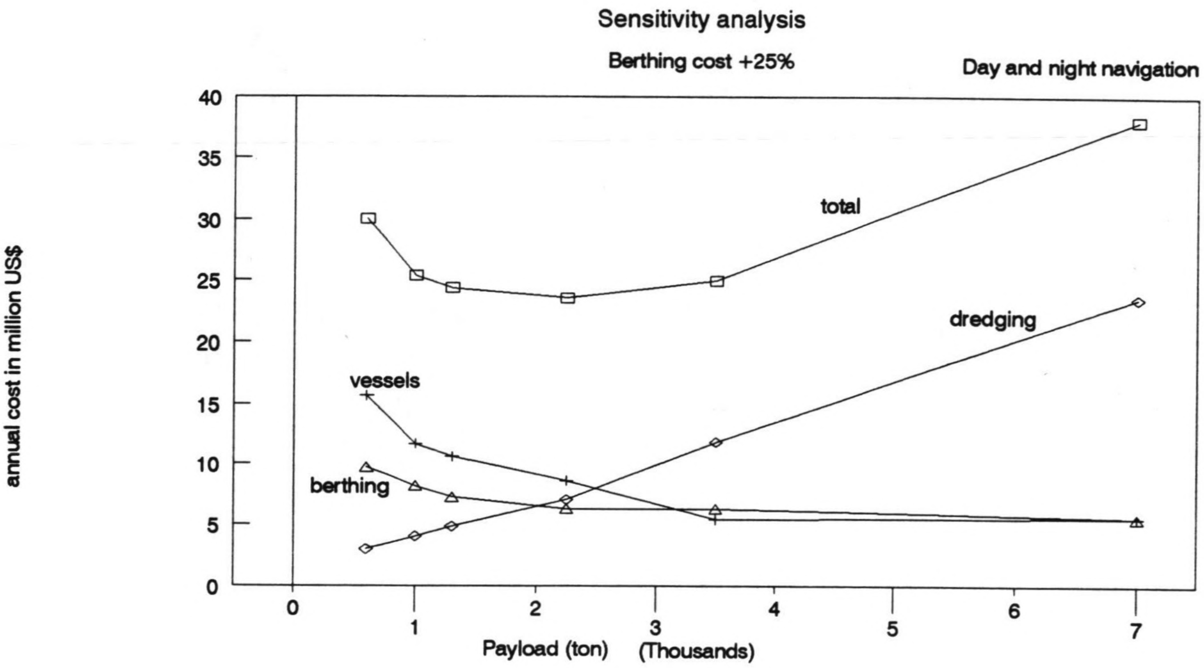


Figure 7.5 Sensitivity analysis berthing costs +25%

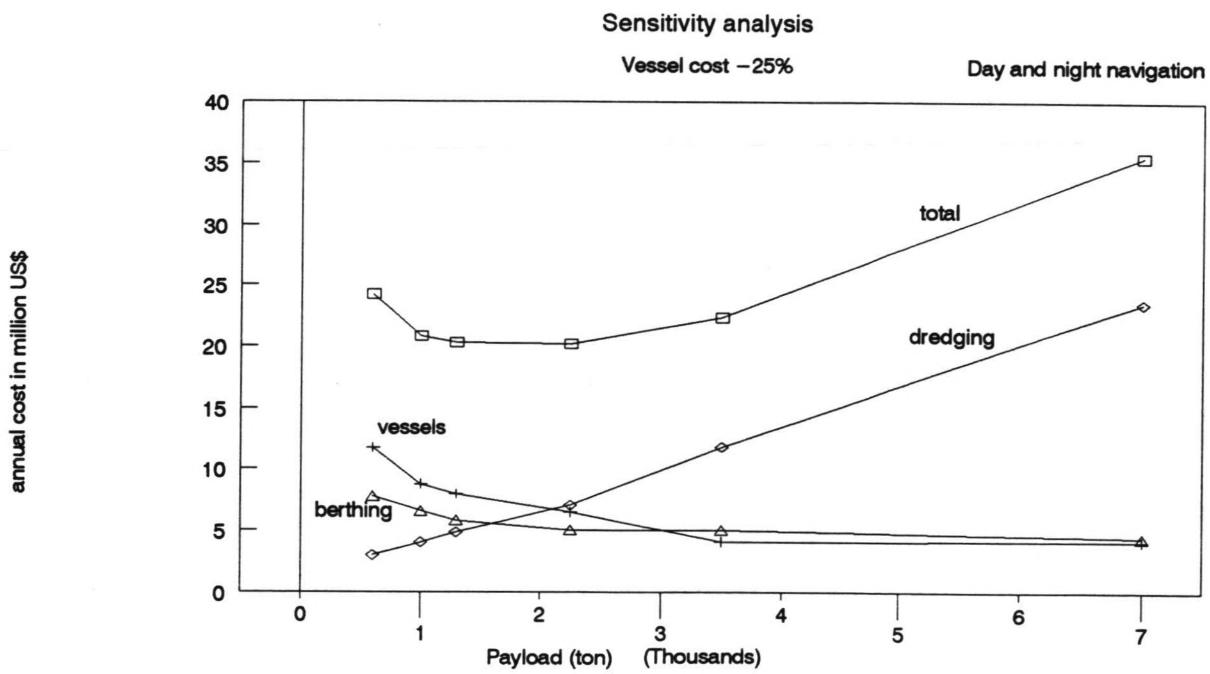


Figure 7.6 Sensitivity analysis vessel costs -25%

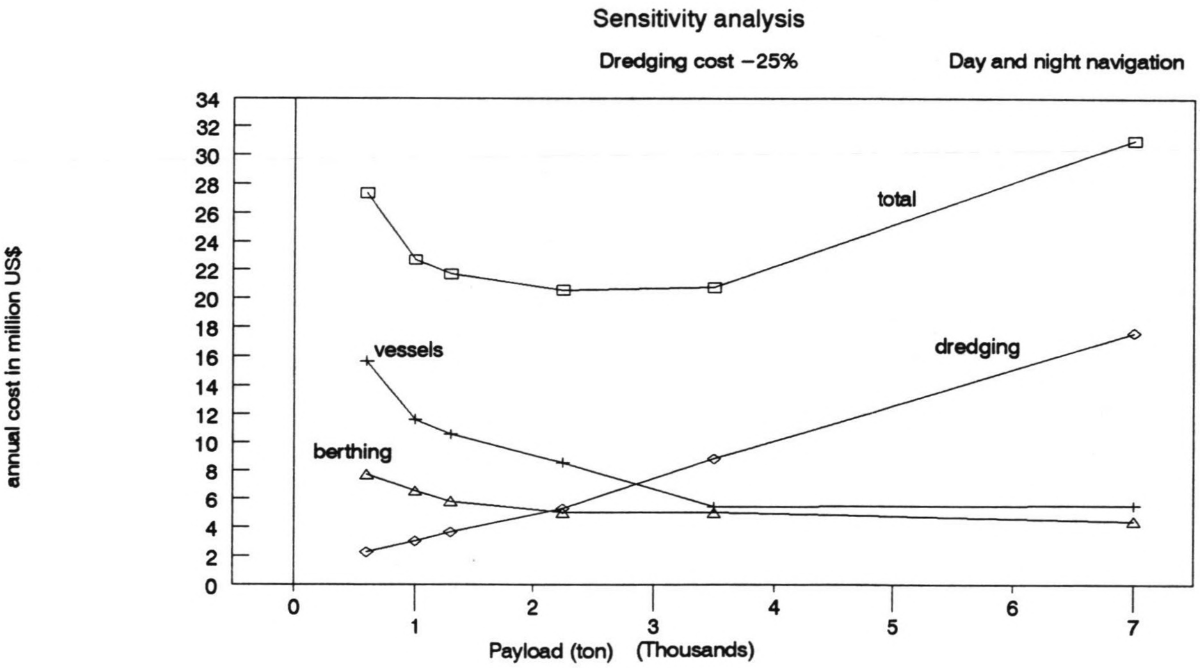


Figure 7.7 Sensitivity analysis dredging costs -25%

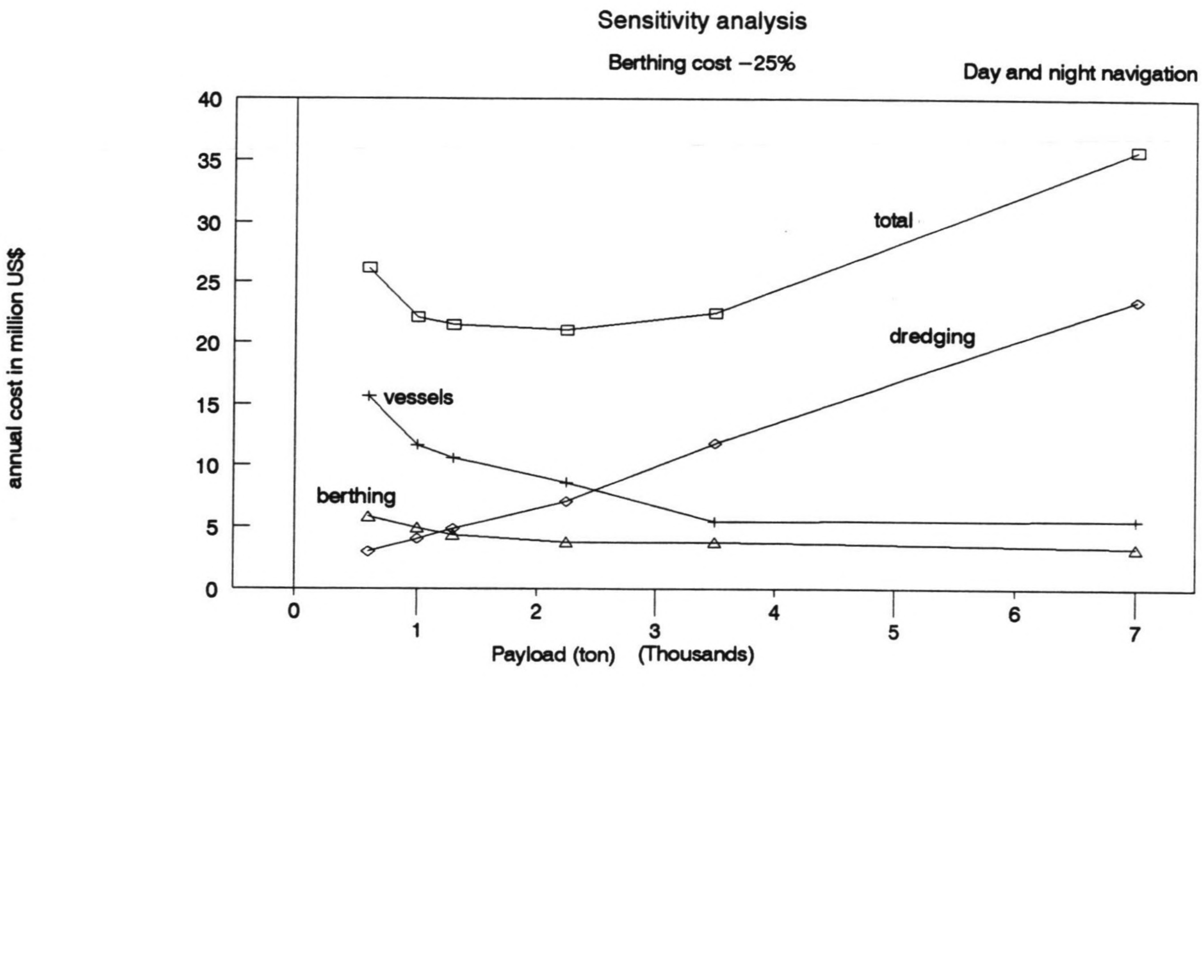
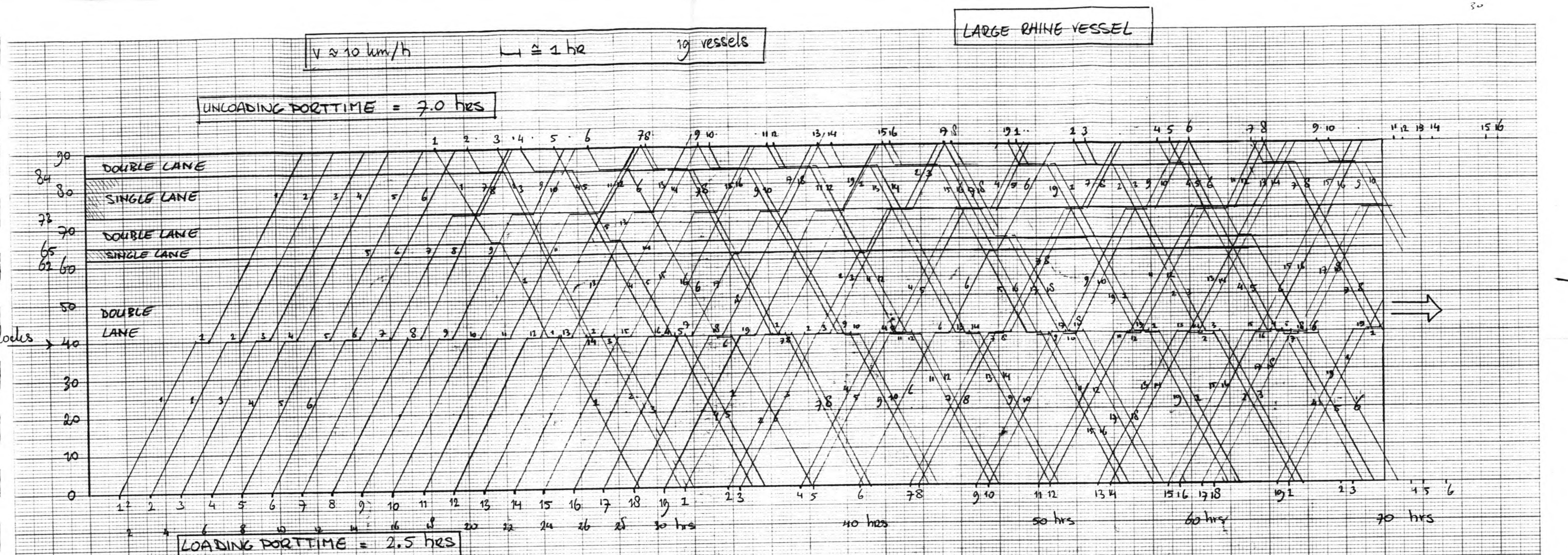
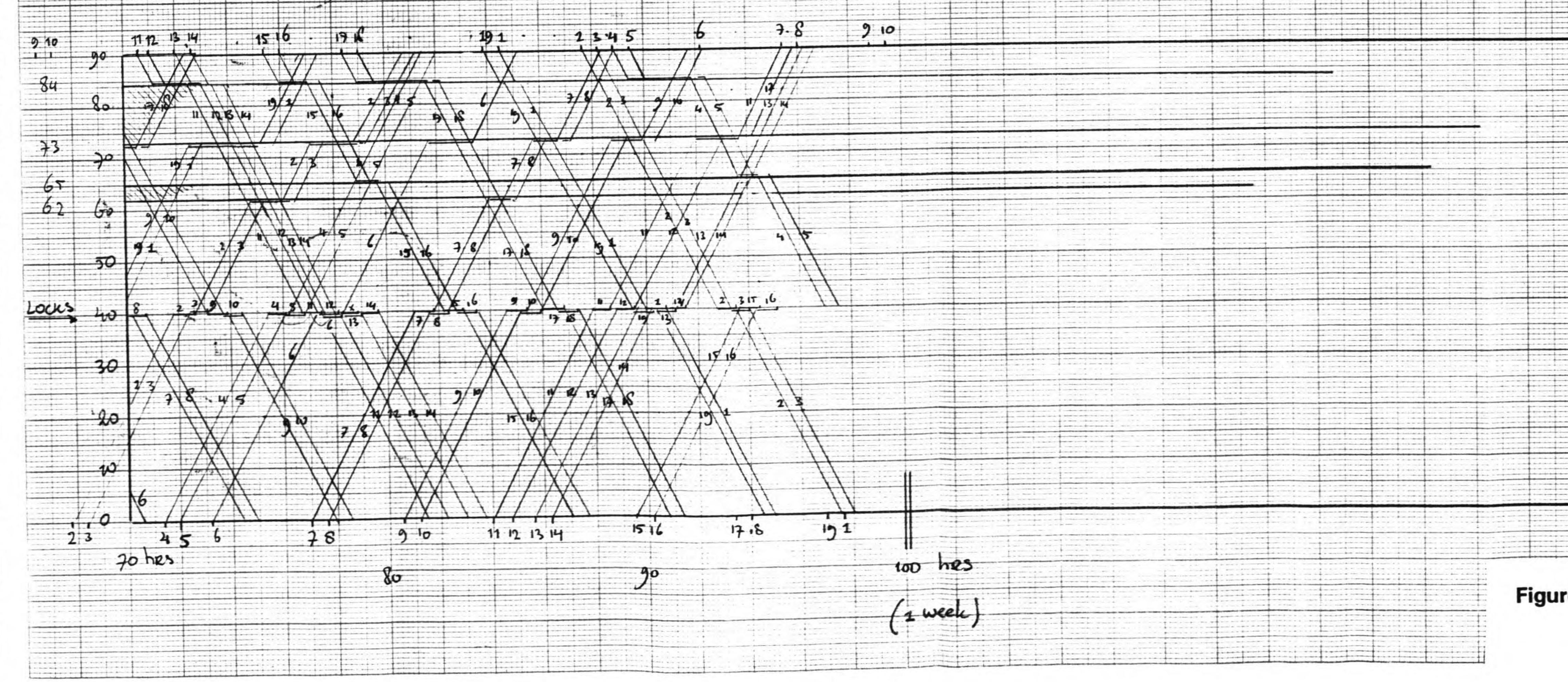


Figure 7.8 Sensitivity analysis berthing costs -25%





number of hours : 100-17 = 83
number of arrivals : 41
vessels per hour : 0.49
vessels per year : 0.49 * 350 * 20 = 3458
capacity per year : 3458 * 2250 = $7.8 \cdot 10^{6}$ t
(payload = 2250 t)
triptime ≈ 38 hrs
trips per vessel per year : $7.8 \cdot 10^{6}$/2250/19 = 182
capacity per vessel : 182 * 2250 = 410.000 tpa
extra vessels req : $(10-7.8) \cdot 10^{6}$ / 410.000 =
(at least) = 6 vessels

Figure 7.9 Time distance diagram; partly single lane for the Large Rhine vessel

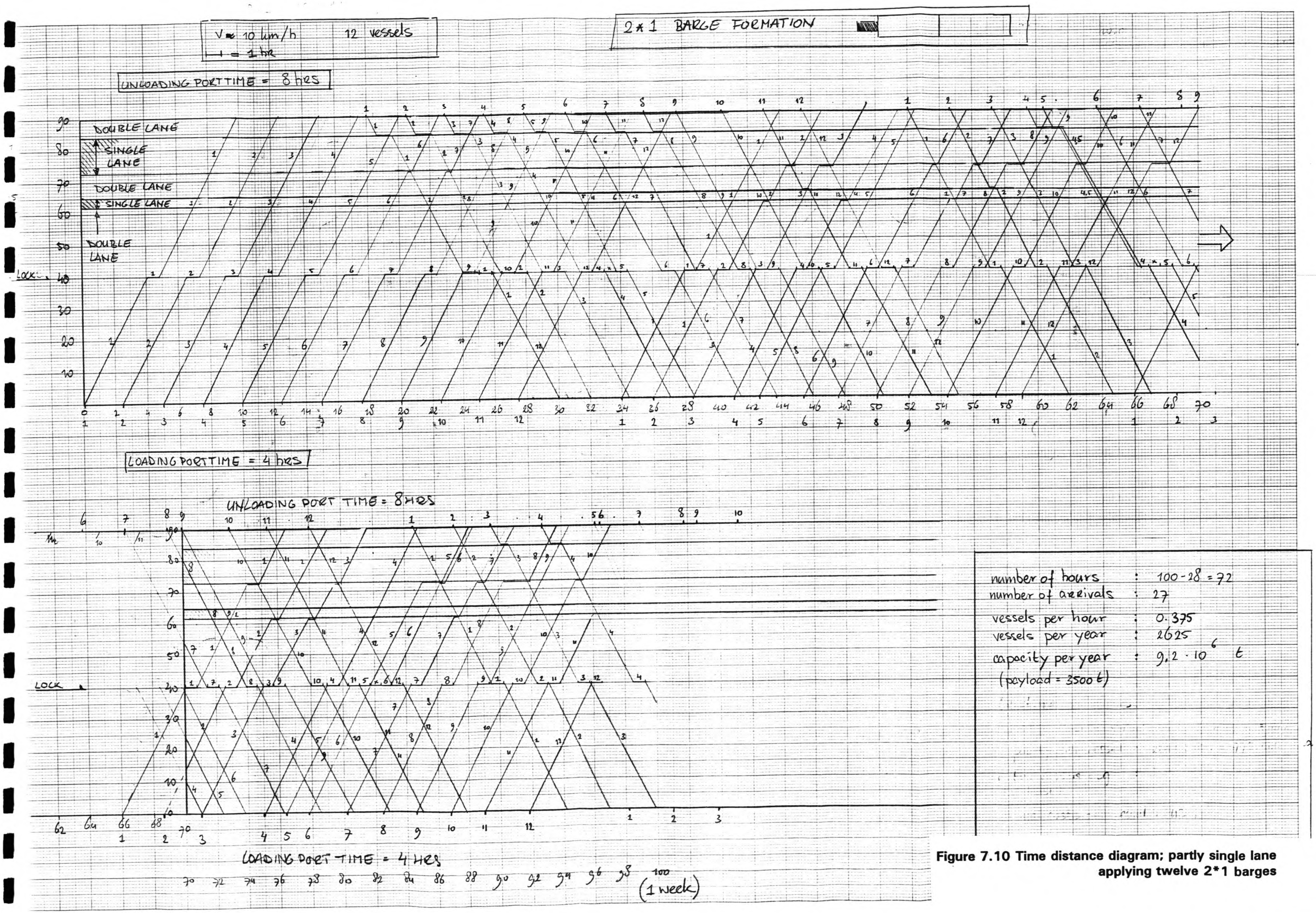
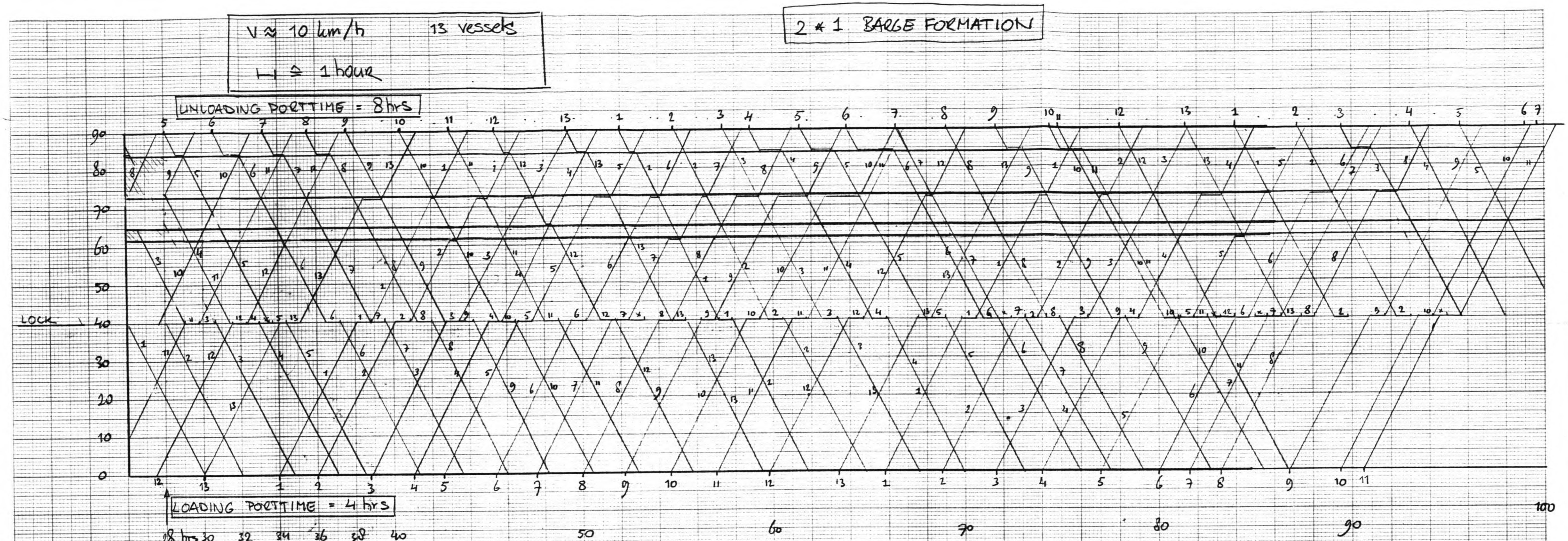


Figure 7.10 Time distance diagram; partly single lane applying twelve 2*1 barges



nr of hours : 100 - 28 = 72

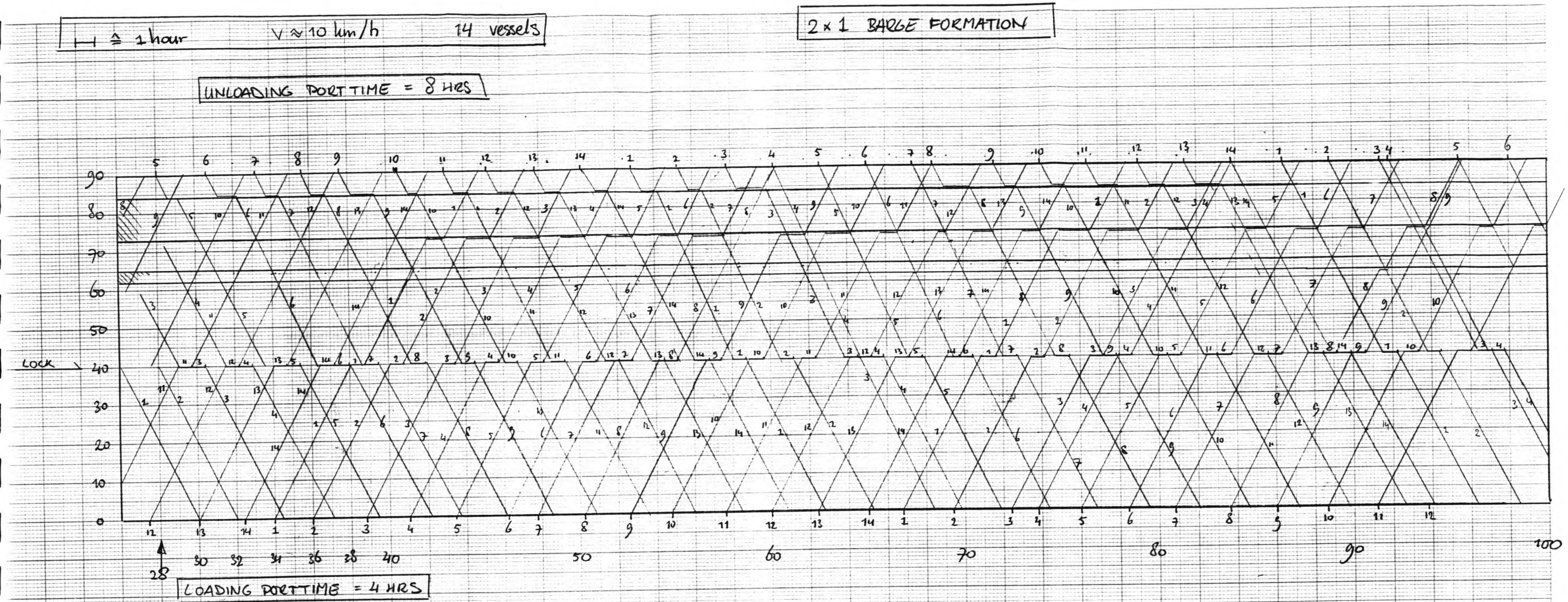
nr of arrivals : 29

arrivals per hour : 0.40

per year : 2819

capacity per year : $9.87 \cdot 10^6$ t

Figure 7.11 Time distance diagram; partly single lane applying thirteen 2*1 barges



nr of hours : 100 - 28 = 72

nr of arrivals : 30

arrivals / hour : 0.42

arrivals / year : 2917

capacity / year : $10.2 \cdot 10^6$ t

Figure 7.12 Time distance diagram; partly single lane applying fourteen 2*1 barge formations

8 DESCRIPTION OF SELECTED TRANSPORT SYSTEM

In the selected transport system the loading terminal is located at Vallarpadam Island - Cochin Port. From here the coal will be transported by 2,250 ton carrying vessels to the unloading terminal at Trikkunnapuzha. From Trikkunnapuzha the coal is transported further to the power plant stockyard over a distance of 4 km using a conveyor belt system. The transport system is operating day and night, 350 days per year.
A brief description of the main system components is given in the next paragraphs.

8.1 LOADING TERMINAL

Location

Actually no exact location has yet been assigned for the coal loading terminal at Cochin Port. Nevertheless the most promising location seems to be at the eastern side of Vallarpadam Island.
See figure 8.4

Transportsystem at the terminal

A troughed conveyor belt system is used to bring the coal from the sea vessel quayside to the storage area and from the storage area to the IWT-vessel quayside.

Storage at the terminal

At the terminal coal is shifted from sea vessels to the inland waterway vessels. Because of the discontinuity between the momentanuous capacity of the two modes of transport, a storage area (figure 8.1) is required. This requires a lot of handling, careful management and coordination of the different activities involved.

Equipment used for storage are stackers for stacking the coal and reclaimers for discharging the stored coal from the stockpile to the IWT-vessel quayside. Also combined machinery called stacker/reclaimers (figure 8.2) can be used.
It may be necessary to use a bulldozer to keep the stockpile within the reach of the reclaimer boom. The equipment is heavy, so that good soil conditions or foundation works are important.

figure 8.1 coal stockyard

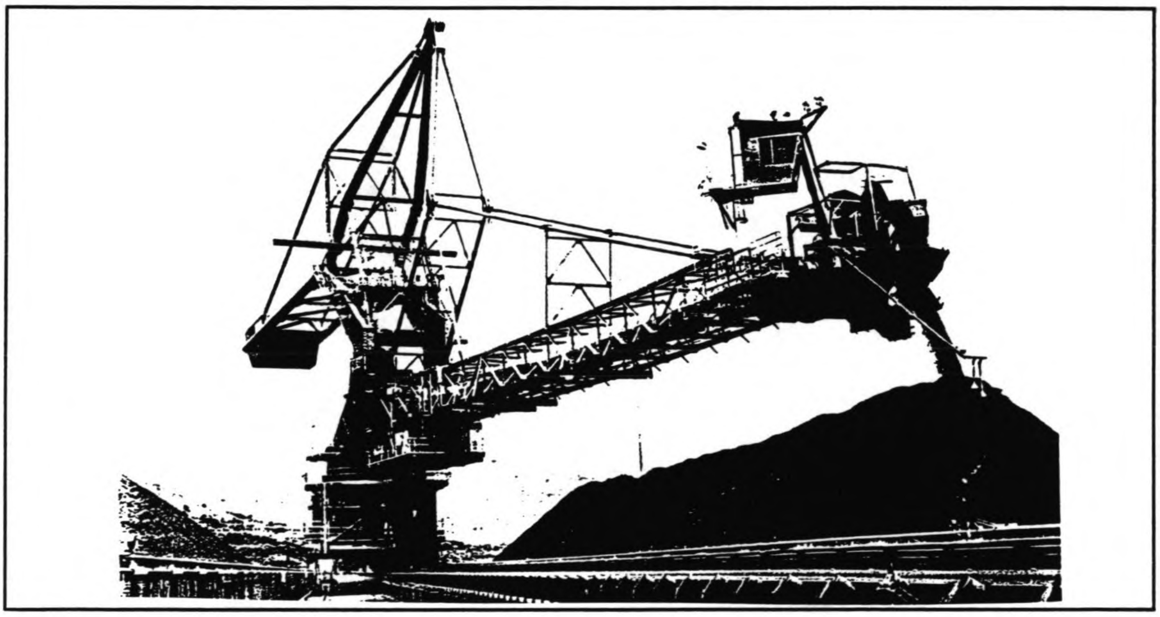


figure 8.2 bucket wheel stacker/reclaimer

Berthing of the IWT vessels

Two loading berths are required for the IWT vessels. The selected vessel has a length of 110 meters, resulting in a total required quaylength of 2 * 1.15 * 110 = 253 meters. (per berth is 1.15 * 110 = 126.5 meters required).
The resulting berth occupancy factor of the loading terminal is 0.78

Loading system

The IWT vessels are loaded by two continuous vessel loaders each having a rated loading capacity of 1,700 t/h.

A principle sketch of the loading terminal is given in figure 8.5

8.2 SELECTED VESSEL

The selected vessel is the Large Rhine Vessel having a payload of 2,250 tons. For the system 19 of these vessels are required to be operational 20 hours per day and 350 days per year.

8.3 WATERWAY ROUTE

The waterway route follows the West Coast Canal from Cochin to Trikkunnapuzha as described in paragraph 3.1

8.4 UNLOADING TERMINAL

Location

The unloading terminal will be located at Trikkunnapuzha, 4 km north of the projected powerplant site.

Berthing of the vessels

Six unloading berths are required resulting in a quaylength of 6 * 1.15 * 110 = 759 meters. Berth occupancy factor of the unloading berth is 0.74

Unloading system

The IWT vessels are unloaded by (in total) five portal grab unloaders (figure 8.3) each having a rated unloading capacity of 750 t/h.

Figure 8.3 portal grabbing crane

Transport system at the landside

The grabbing crane discharges the coal into a hopper, feeding the conveyor belt system transporting the coal further to the powerplant stockyard.

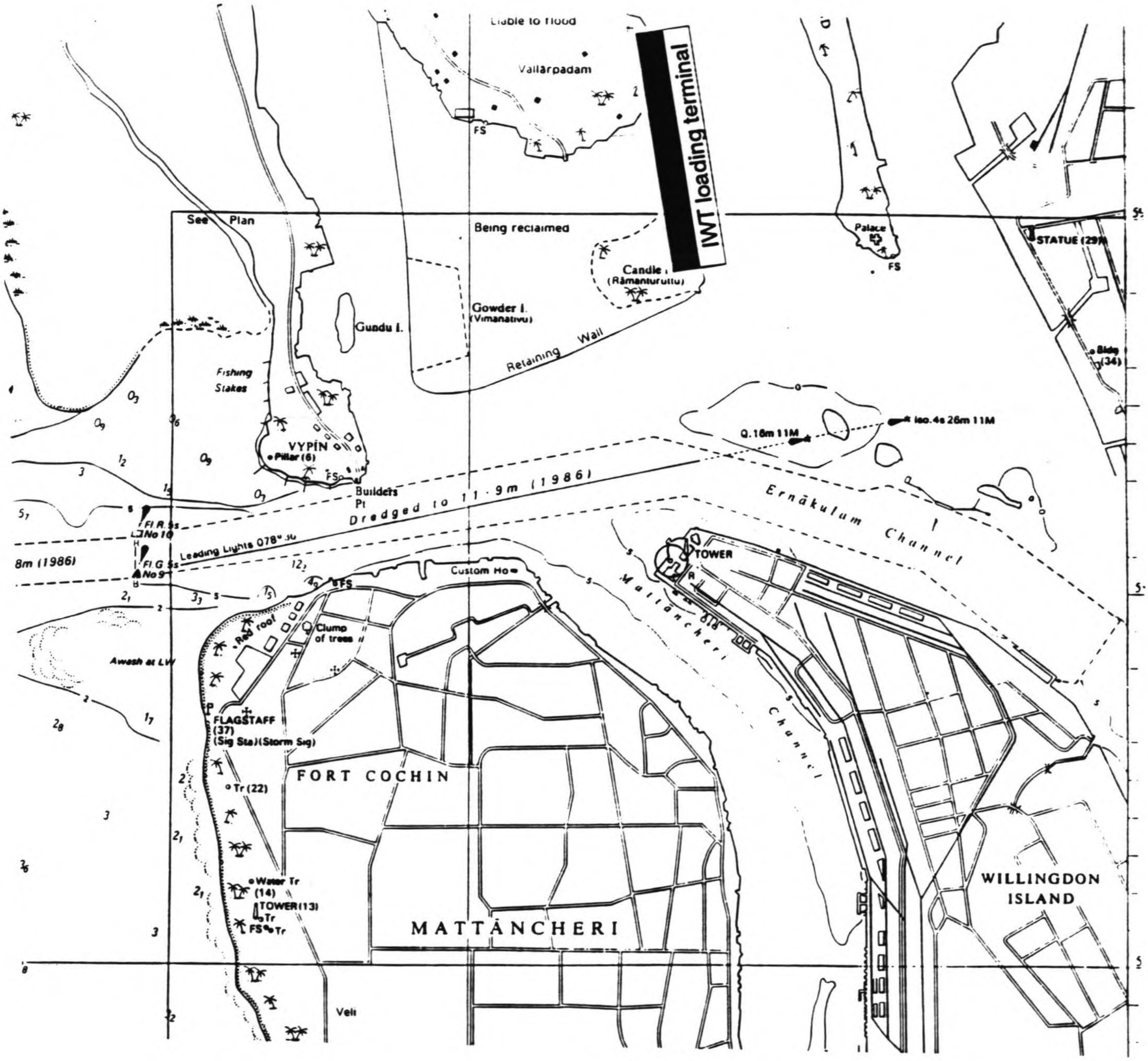


Figure 8.4 Location Loading Terminal

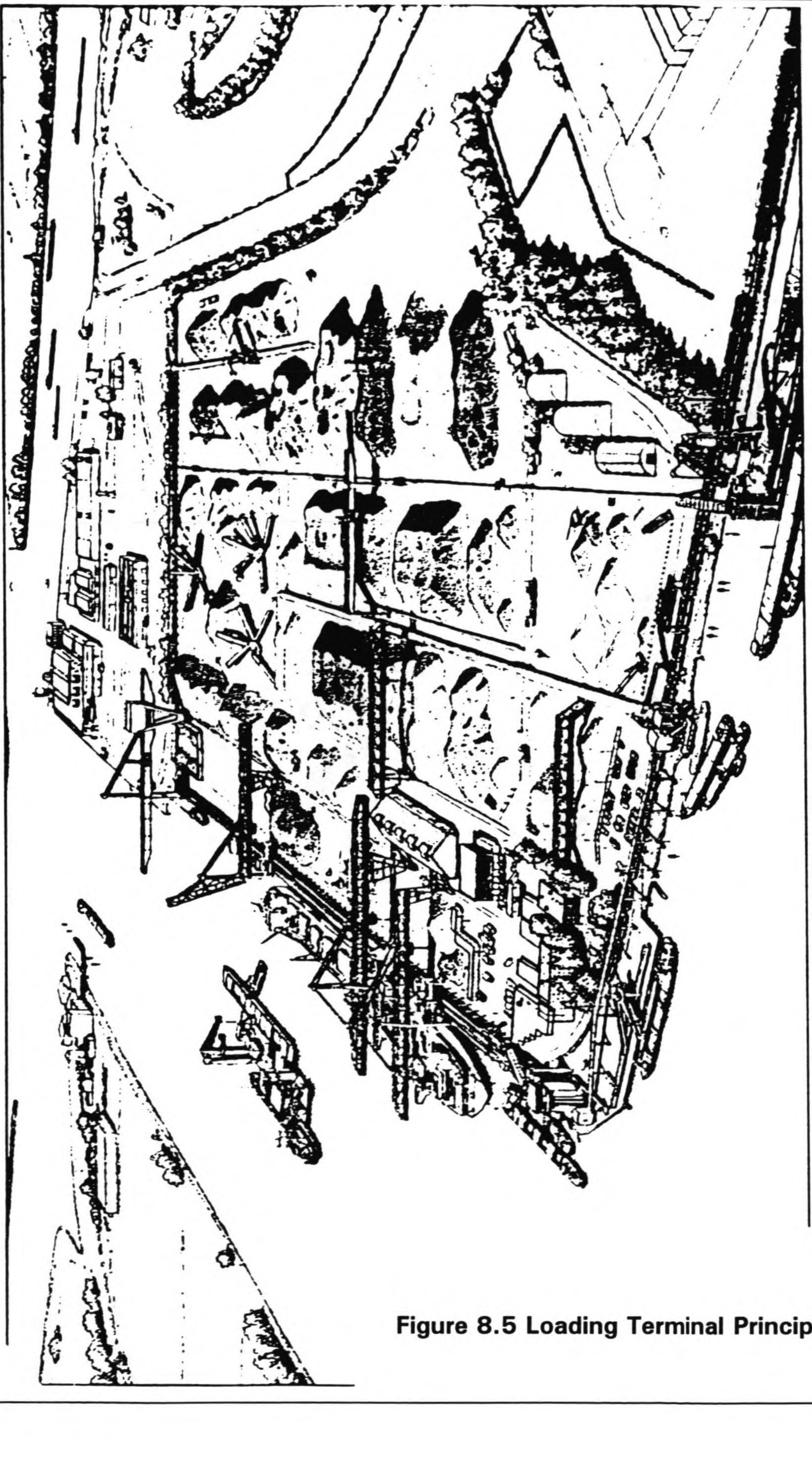


Figure 8.5 Loading Terminal Principle Sketch

9 IMPROVEMENT REQUIREMENTS FOR THE SELECTED TRANSPORT SYSTEM

9.1 WATERWAY IMPROVEMENTS

The existing waterway has to be adapted to the required channel cross profile (waterlevel width = 75 m ; depth = 3.8 m ; bottom width = 51 m). This requires an amount of capital dredging of 6.2 million cubic meters and an amount of land acquisition of about 870,000 m^2.

Two new locks for the coal vessels are required at Thanneermukkom; this also implies the demolition of (a part of) the existing locks and waterbarrier.

The existing bridges should be supplied with guidance and protection works and probably with a traffic control system. Karumadi bridge, having a restricted width of 9 m. needs reconstruction.

9.2 REVETMENTS

The coal vessels generate waves and currents inducing hydraulic loads attacking the waterway bottom and banks. The banks need protectionworks (revetments), especially at the less wide stretch from km 60 to km 91.

9.2.1 REQUIREMENTS OF THE REVETMENT

The primary function of the revetment is to stabilise and prevent erosion of the soil particles of the waterway embankment. In order to fulfil this function the revetment has to meet certain requirements:

Functional requirements

-The revetment must be capable to withstand the imposed hydraulic loads.
-The revetment has to prevent migration of subsoil particles.
-The revetment may not loose its function due to aging during its design lifetime.
-The revetment must be flexible in order to follow subsoil deformations without loosing the above mentioned functions.

Construction requirements

-The materials to be used must be suitable to execute the work under the local conditions.
-It must be considered that during execution sublayers may have to withstand greater loads than under 'normal conditions'.

Inspection, maintenance and repair requirements

-Loss of function and possible start of failure must preferably be recognized clearly in time.
-It must be possible to repair damage quick and easy and preferably using the same material and construction method to prevent discontinuities in the revetment. (Experience shows that much damage takes place at transitions in type of revetment).

Environmental and socio- economic requirements

-Ecological damage due to used materials must be avoided.
-The revetments should preferably fit well in the surroundings.
-It must be considered that human activities also can cause damage to the revetment due to:
+ vandalism and theft (loose blocks)
+ landing of boats, etc.

9.2.2 GEOTECHNICAL CHARACTERISTICS OF SUBSOIL MATERIAL

The primary function of the revetment works is to ensure the stability of the waterway embankments. This stability considers:

-local stability; the stability of the soil particles of the banks,
-overall stability; the stability of the bank as a whole.

Very little information is found about the geotechnical characteristics of the embankment soil material (see paragraph 3.6). The soil probably mainly consists of sand and the median grain size was found to be in the order of 0.3 to 0.5 mm. Further the following assumptions are made concerning the cohesion (c) and angle of repose (φ):
For sand the cohesion is practically zero, $c = 0$,and φ varies between 30° and 45°, taken is $\varphi = 40°$

Failure mechanisms of local stability are local sliding, scour and migration of material through the revetment structure. Local stability has to be ensured by the revetment (a functional requirement).

Loss of the overall stability and failure of the total embankment may occur due to sliding. According to the Mohr-Coulomb criterium the critical slope along which sliding will occur, makes an angle of $45° - ½\varphi = 25°$ to the vertical. The embankment having a slope of 1:3 is therefore considered stable. Nevertheless existing slip planes or lenses of weaker material within the soil may have a significant effect on the bank stability. Site investigations are be required.

9.2.3 IMPOSED HYDRAULIC LOADS

Watermotion induces hydraulic loads in the form of shear stresses and pressure heads acting upon the bed and bank of the waterway. Two phenomena will be considered: natural- and ship induced water motion.

Natural watermotion

Reported flow velocities along the waterway are low and less than 0.5 m/s. According to RITES these currents do not cause any bank erosion. Due to restricted fetch lengths and wind speed (dense vegetation such as palm trees along the waterway) wind waves also do not cause significant loads.

Ship induced watermotion

Sailing vessels generate significant hydraulic loads which are affected by several factors:

-the waterway geometry (see figure 9.1);

The considered waterway profile has the following characteristics:

bw = waterlevel width of the waterway = 75 m
bb = bottomwidth of the waterway = 51 m
h = waterdepth of the waterway = 3.8 m
α = slope angle = 19°
Ac = wet channel cross section = 237 m²

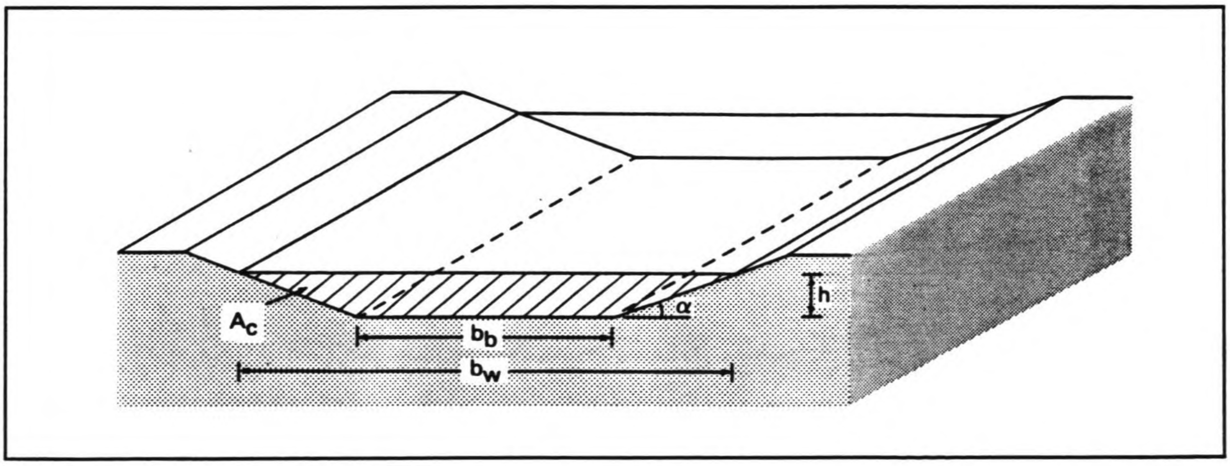


Figure 9.1 The waterway geometry

-the ship dimensions;

The selected vessel (2,250 t) has the following dimensions:

L_s = length = 110 m
B_s = beam = 11.4 m
T_{sl} = draught loaded = 2.8 m
T_{su} = draught unloaded = 0.75 m (average)
A_{sl} = wet loaded midship cross section = 27 m^2

Asu = wet unloaded midship cross section = 8 m^2

-the sailing course;

In general the vessels will sail along the channel centerline. In the considered channel with two lane traffic, the vessels also have to sail closer to the channel banks during encountering manoeuvres for instance. The more a vessel sails from the centre of the channel, the higher the hydraulic load at the channelbanks will become.The distance between the centreline of the waterway and the sailing course is expressed by the eccentricity y, see also figure 9.2.
Since the minimum distance between the centre of the vessel and the embankment at waterlevel = ½ times the vessel beam + bank clearance + draught * cotα = ½ B_s +0.3 B_s +T_s*3 = 5.7 +3.4 +8.4 = 17.5 m , the maximum eccentricity y becomes ½b_w - 17.5 = 20 m

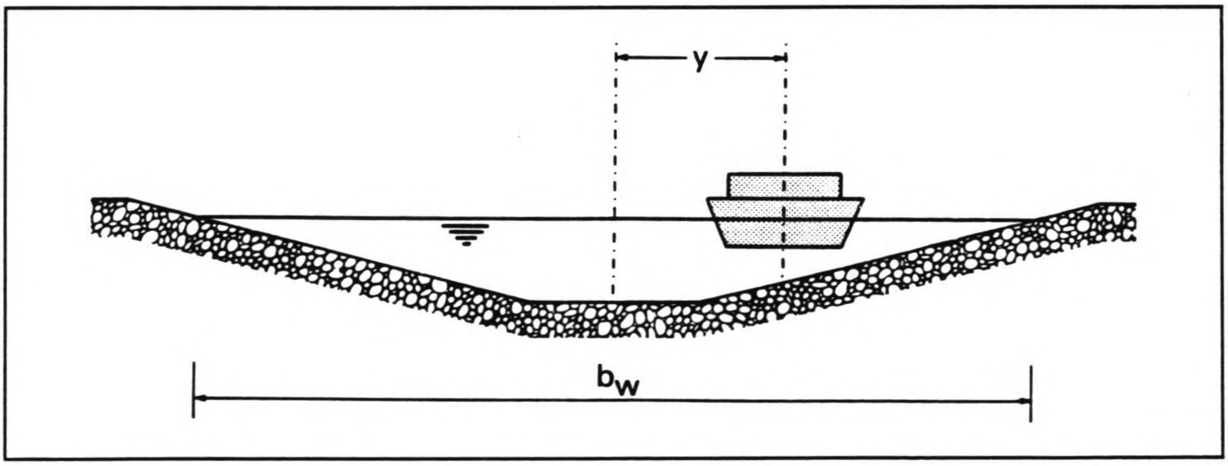


Figure 9.2 Sailing eccentricity y

The ship induced hydraulic loads can be subdivided in primary waves, secondary waves and screw race; see figure 9.3.

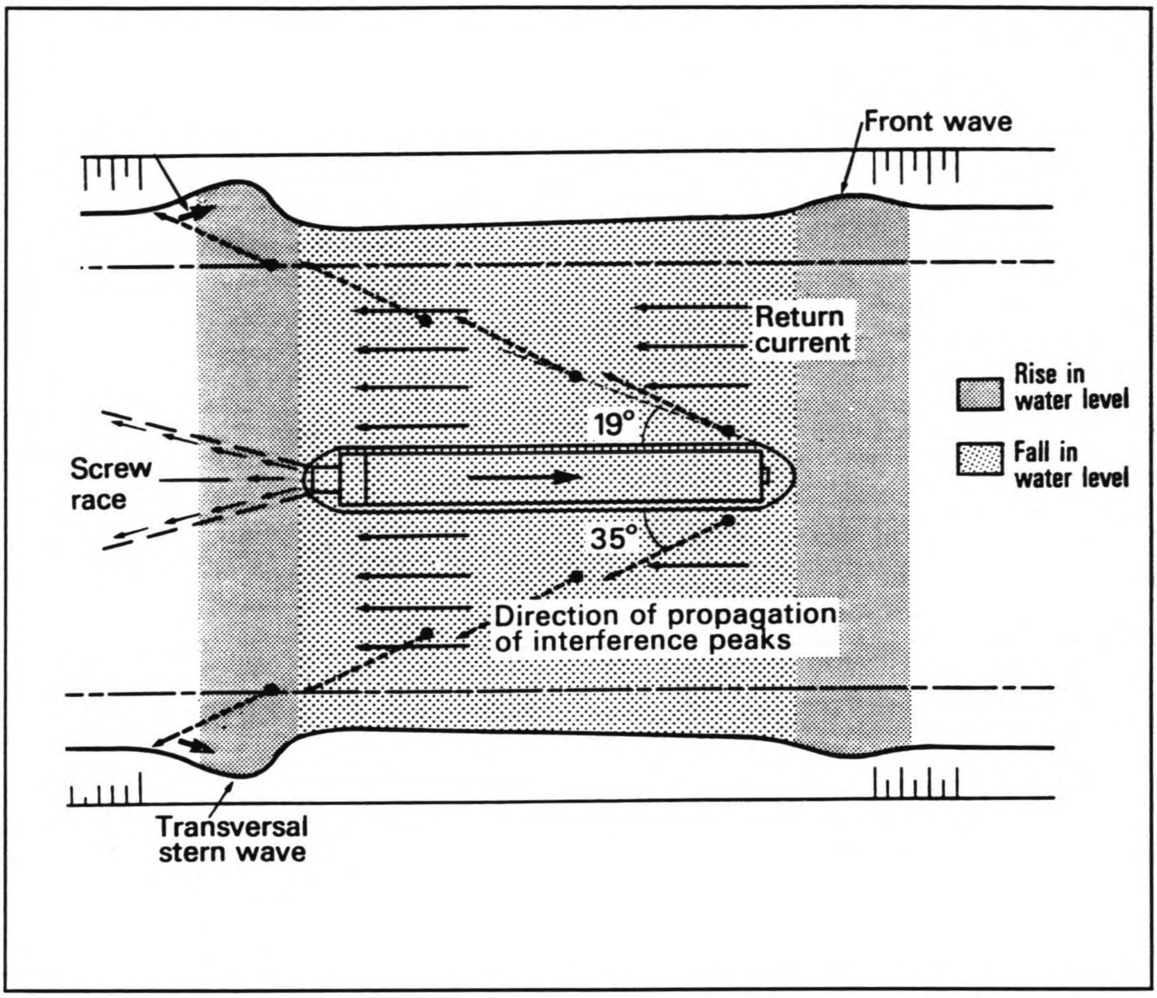


Figure 9.3 Ship induced watermotion

PRIMARY WAVES

The primary waves consists of the following phenomena:
-return current
-waterlevel depression
-frontwave
-transversal wave

The <u>return current</u> is generated by the sailing vessel and flows parallel but in opposite direction along the vessel. The average return current U has been calculated in chapter 7 and amounts 0.5 m/s. Due to the eccentricity of the sailing course a higher velocity will occur at the nearest bank. This maximum return current velocity Umax is calculated according to ref.[18]:

$$Umax = U * (1.5 - Ac'/Ac) = 0.7 \text{ m/s}$$

in which Ac' is the wet channel cross section between the centreline of the ship and the channel bank = $(½bw - y)h - ½h^2 *3 \approx 45 \text{ m}^2$

The velocity of the water flowing along the vessel also causes a depression of the waterlevel around the vessel. The average waterleveldepression Z was found to be 0.16 m. (see chapter 7) Also here the eccentricity of the sailing course causes a greater waterlevel depression at the nearest bank, which can be calculated with:

$$Zmax = Z * (2 - 2\, Ac'/Ac) = 0.26 \text{ m}$$

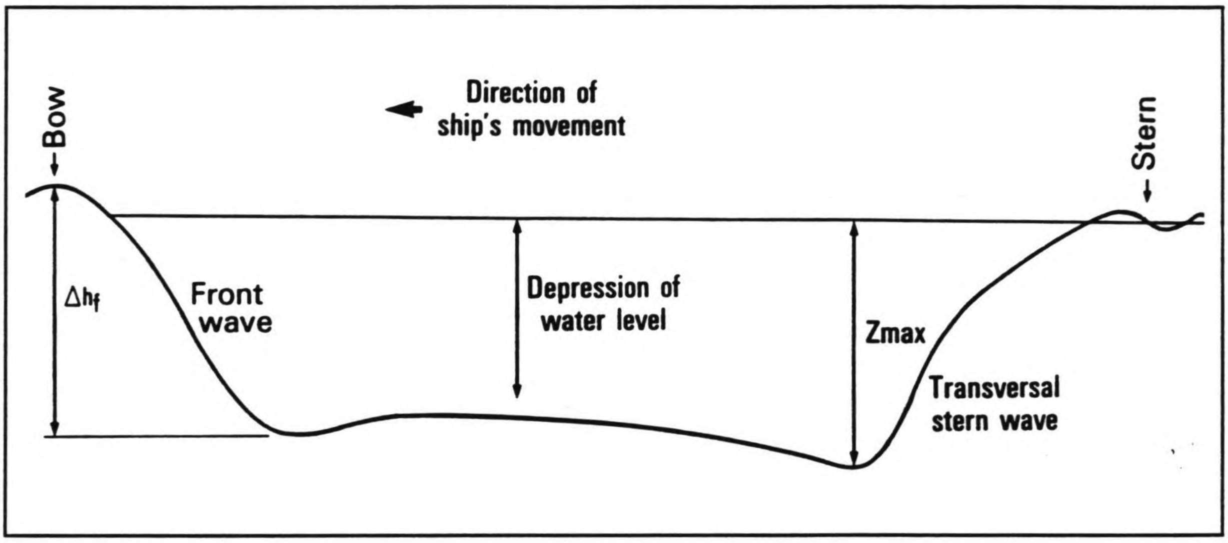


Figure 9.4 Primary waves

The transition between the undisturbed waterlevel in front of the vessel and the waterlevel depression beside the vessel is called the frontwave, see figure 9.4. Because the waterlevel is slightly pushed up at the bow, the frontwave is a bit higher than the waterlevel depression. Height of the frontwave:

$$Hf = 0.1 * Z + Zmax = 0.28 \text{ m}$$

The transition between the waterlevel depression and the waterlevel behind the ship is called the transversal stern wave Ht and has approximately the same height as the waterlevel depression Zmax.

$$Ht = Zmax = 0.26 \text{ m}$$

SECONDARY WAVES

Secondary waves are generated at the bow and stern of the ship and consist of transverse and diverging waves which together may form interference peaks. These peaks may cause significant loads on the embankments. These peaks propagate at an angle of about 55° with the channel bank. The height of these interference peaks Hi can be calculated with (ref.[18]):

$$Hi = h(s/h)^{-0.33}\,Fr^4$$

s = distance between the vessel's hull side and the channel embankment and amounts the bankclearance + three (=cotα) times the draught of the vessel (= 0.3·Bs + 3·Ts).
Fr = Froude number

For loaded vessels, sailing at economic speed:
s = 12 m.
$Fr = v_e/\sqrt{gh} = 0.48$ → Hi = 0.14 m

For unloaded vessels sailing at economic speed:
s = 6 m.
Fr = 0.52 → Hi = 0.24 m

For unloaded vessels sailing at maximum speed:
s = 6 m.
Fr = 0.65 → Hi = 0.50 m

Unloaded vessels produce significant higher secondary waves, when sailing at full speed heights of 0.5 m can be reached.
A design wave height of 0.5 m is taken.

SCREW RACE

The vessel's propeller generates a waterjet which may attack the bed or bank of the channel. The level of damage is proportional to both the screw race velocity and the duration. Screw race is a significant load at moorings, the locks and terminal berths, when vessels accelerate from zero or when vessels are manoeuvring at low speed. For ships underway the screw race velocities are less important as the level of damage is proportional to both the crew-race velocity and the duration over which the screw-race is attacking the area. Material will however be stirred up from the bottom.

SUMMARY OF HYDRAULIC LOADS

Returncurrent velocity	Umax = 0.7 [m/s]
Natural flow velocity	Vnat = 0.5 [m/s]
Design flow velocity	Vtot = 1.2 [m/s]
Front wave height	Hf = 0.28 [m]
Transversal wave height	Ht = 0.26 [m]
Interference peaks height	Hi = 0.50 [m]

9.2.4 EXISTING PROTECTION WORKS

According to RITES, at some places (no exact locations are mentioned) the existing waterway has already been provided with some bank protection works. Two types of protection are mentioned:
-A stone boulder construction; a bund of rather large stones (diameter upto about 40 cm), having a nearly vertical face and of which the part above waterlevel has been grouted with concrete.
-A retaining wall construction; concrete piles between which precast concrete panels are spanned. The piles are connected at the top by a concrete beam.
Figures of both protection works are given in figure 9.5.

9.2.5 OPTIONS FOR THE NEW REVETMENT

Five different types of revetment are considered. A description of each type is given and the dimensions are determined, followed by an evaluation in which the most promising solution will be selected.

The following revetment types are considered :

1-Rip-rap
2-Grouted stone
3-Concrete blocks on geotextile
4-Gabion mattress
5-Vertical wall

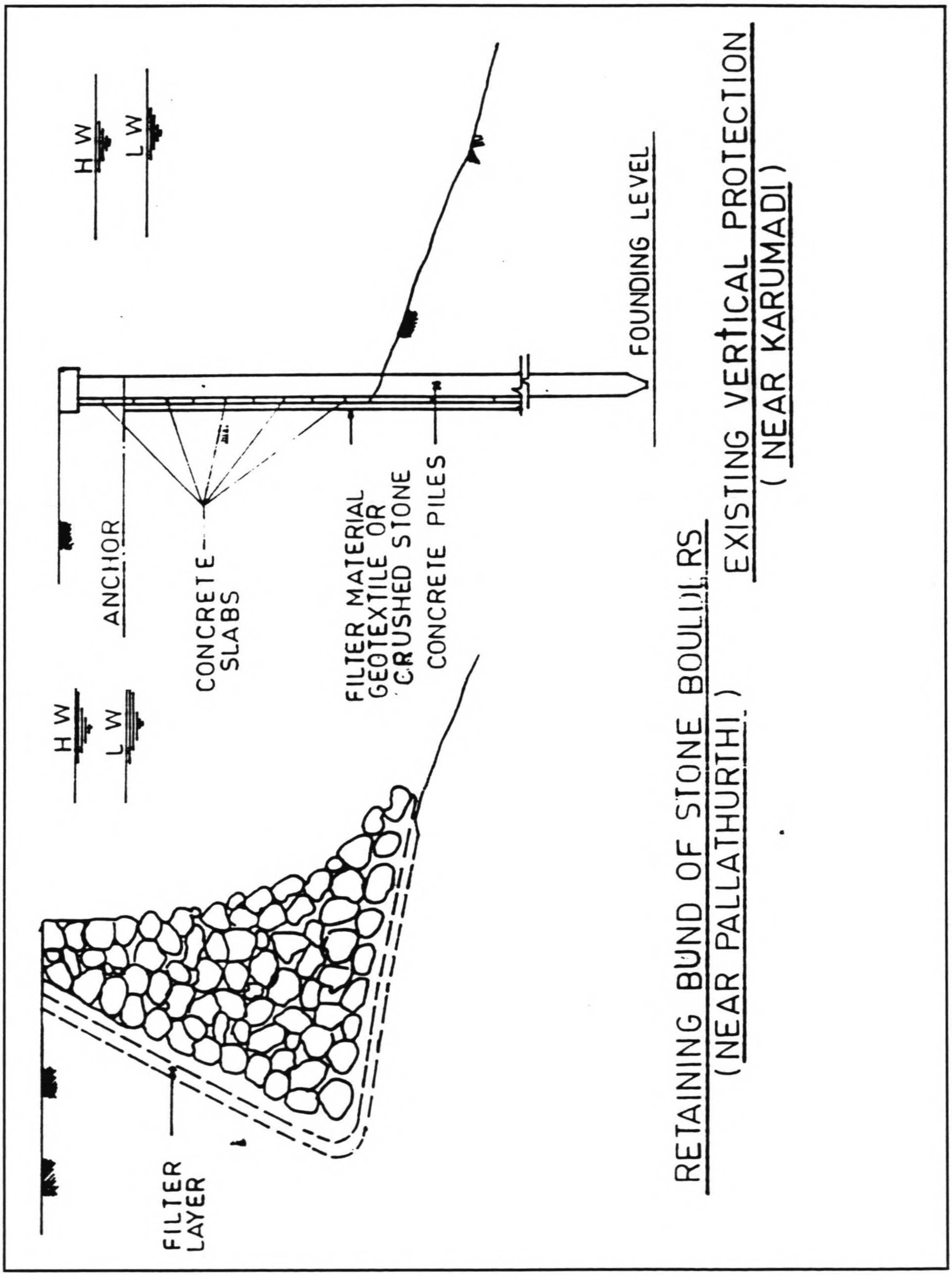
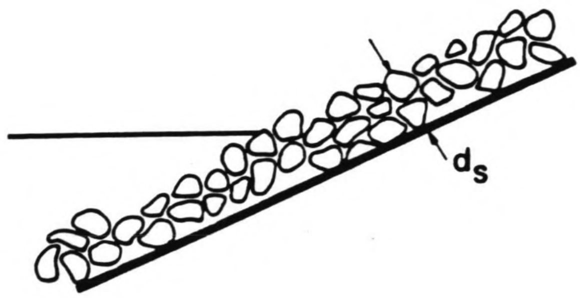


Figure 9.5 Existing protectionworks

1 Design of rip-rap revetment



rip rap revetment

The size of stone is characterised by the nominal diameter Dn50, where

Dn50 = (W50 / ρs)$^{0.33}$ [m], in which

ρs = density of the stone material [kg/m^3]
W50 = 50% value of the mass distribution curve of the stone [kg]

The design conditions are:

Design flow velocity Vtot = 1.2 [m/s]
Transversal wave height Ht = 0.26 [m]
Interference peaks height Hi = 0.50 [m]
Slope angle α = 19°
Density of the stone material Δs = 2630 [kg/m^3]
Relative mass Δ = (ρs - ρw)/ ρw = 1.63 ,then

CURRENT ATTACK

For the nominal diameter is found (after Isbazh):

Dn50 = 0.7 Vtot / (g Δ k) = 0.06 m ,in which

k = slope reduction coefficient = cos α (1-tan²α / tan²φs) $^{0.5}$ = 0.86
φs = angle of repose of stones = 40°

WAVE ATTACK

For transversal stern waves (after Laoyrie):

$Dn50 = Ht / (1.5 (\cot\alpha)^{1/3} \Delta) = 0.074$ m

For secondary waves (after Pilarczyk):

$Dn50 = Hi (\cos\beta)^{0.5} / 1.8 \Delta = 0.130$ m ,in which

β = angle of wave propagation normal to the bank = 55°

The secondary waves are the dominant load, so

Dn50 = 130 mm
W50min = 5.8 kg

The gradation of the whole coverlayer is estimated according to figure 9.6, the following guidelines were found:

W15min = 2.3 kg
W15max = 5.8 kg

W50min = 5.8 kg
W50max = 8.7 kg

W100min = 11.6 kg
W100max = 23.2 kg

geen bredere gradering?

Two layers of stone should be provided resulting in a total layer thickness of 1.5 to 1.8 times Dn50 = 234 mm

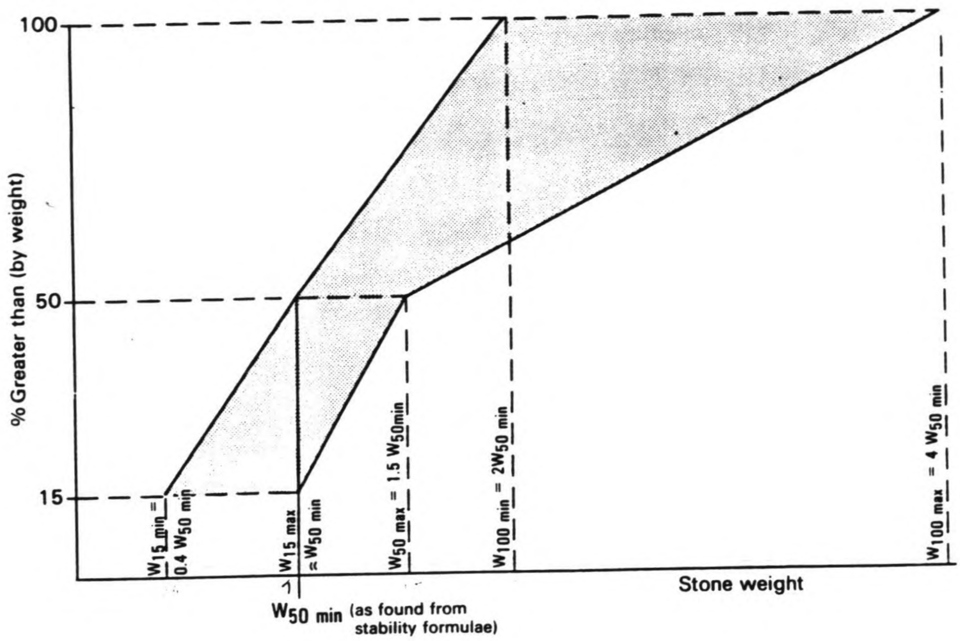


Figure 9.6 Gradation guideline for rip rap

ZONE OF WAVE ATTACK

Adopting that the lower part of the revetment has a Dn50 of 60 mm (to keep withstanding the currentattack), then the lower extend of the protection against wave attack can be estimated using figure 9.7 for transversal waves and figure 9.8 for secondary waves.

Transversal waves:	Ht / (Δ Dn50) = 2.6
	Rd' / Dn50 = 6
	Rd' = 0.4 m
Secondary waves:	Hi / (Δ Dn50) = 5.1
	Rd' / Dn50 = 11
	Rd' = 0.7 m

The lower extend of the coverlayer against wave attack is taken as 0.7 m below waterlevel.

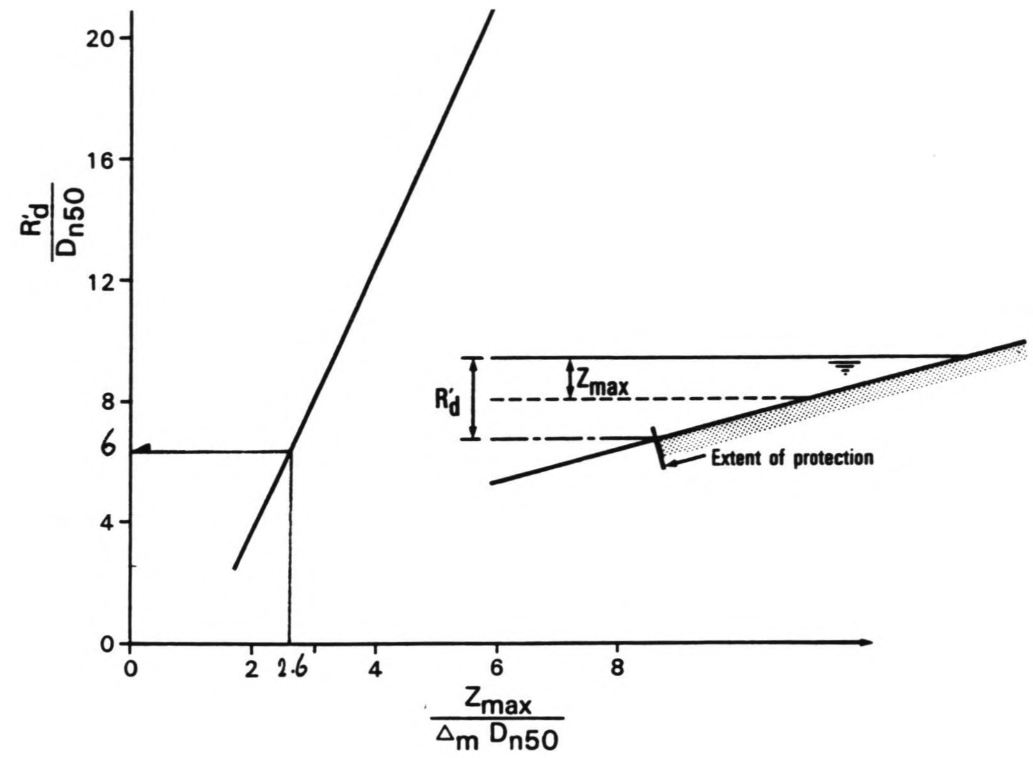


Figure 9.7 Lowest extend of protection against transversal waves

The upper extend of the coverlayer depends on the wave run-up height based on

wave and revetment characteristics. The effective run-up height R can be estimated using:

$R = R_n \, r_r \, r_ß$
$R_n = \mu H$,in which
R_n = run up on smooth slopes, defined as the vertical height above waterlevel.
r_r = reduction factor due to slope roughness ($\approx$ 0.6 for rip-rap)
$r_ß$ = reduction factor due to obligue wave attack = cos(ß-10); for $ß \leq 65°$
μ = wave breaking parameter $\approx$ 1.5

For the secondary waves: R = 1.5 * 0.50 * 0.6 * 0.7 = 0.3 m

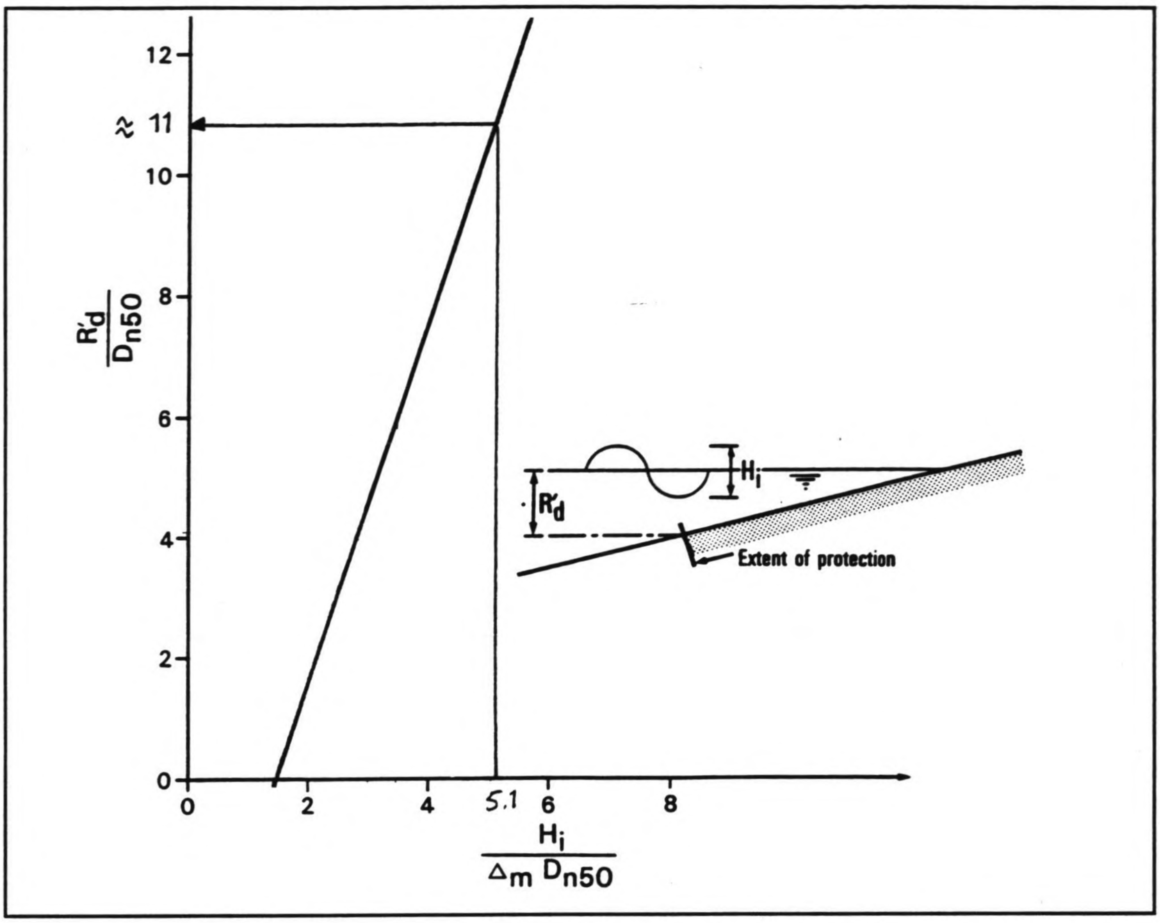


Figure 9.8 Lower extend of protection against secondary waves

Including a waterlevel fluctuation range of 1.0 m, the rip-rap revetment under wave attack should extend over a vertical distance of about 2 m (≈ 6 m along the slope).

2 Design of grouted stone coverlayer

When the stones of the coverlayer are grouted, a reduction in nominal stone diameter can be applied. Experience has shown that the following rules give reliable results (ref.[18]):

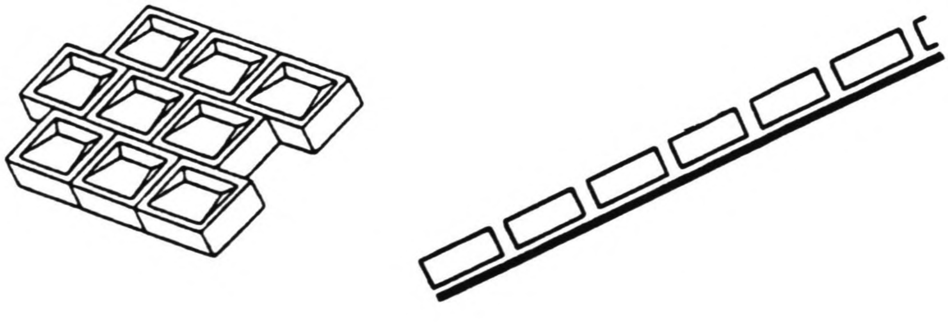
-For surface grouting (30% of the surface voids filled):
Dn50 (grout) = 0.9 Dn50 (loose)

-For pattern grouting (60% of the surface voids filled):
Dn50 (grout) = 0.6 Dn50 (loose)

grouted stone coverlayer

For the loose material the nominal diameter Dn50 of the rip-rap calculation can be used.

3 Design of concrete blocks on geotextile



concrete blocks on geotextile

For pitched concrete blocks current attack is no determinating load. Only wave attack is considered here. Thickness of the blocks can be calculated according to Pilarczyk:

$$Hs / \Delta D = \Theta \cos\alpha / \sqrt{\mu} \text{ ,in which}$$

D = thickness of the blocks [m]
Θ = strength coefficient
μ = wave breaking parameter ≈ 1.5
Δ = relative density of the concrete blocks = 1.40

Strength coefficient Θ depends on the type of wave, type of coverlayer and type of sublayers. An empirical value of Θ for concrete blocks connected by geotextile is 4.0 (ref.[18]).

D becomes then:

$$D = (0.50 \cdot \sqrt{1.5})/(1.40 \cdot 4 \cdot \cos 19^\circ) = 0.115 \text{ m. } (=115\text{mm})$$

The stability of concrete blocks under wave attack depends on:
-block weight
-block size and shape
-block permeability
-sublayer and filter permeability
-rate of interlocking

The stability of the construction is checked using the program ANAMOS and was found to be stable, having a safety coefficient R/S of 1.19. The calculation is presented in ANNEX E.

ZONE OF WAVE ATTACK

The upper extend of the revetment is determined by the wave run-up height:

$R = R_n\, r_r\, r_ß = 0.5$ m ,in which
$R_n = \mu H = 0.75$
$r_r = 0.95$
$r_ß = 0.7$
μ = wave breaking parameter ≈ 1.5

The lower extend is found using the general rule:

$$R_d / H = 0.8\mu + 0.5 \text{ ; for } \mu \leq 2.5$$
$$R_d = 0.9 \text{ m}$$

Including 1 m waterlevel variation, the revetment extends over a distance along the slope of 2.5*3 = 7.5 meters.

4 Gabion mattress

The thickness of the gabion mattress tm is related to the used stone size (Dn50). Two layers of stone is considered sufficient, resulting in a thickness tm of: $t_m = 1.8 \cdot Dn50$

Subjected to wave attack tm can be calculated with (Pilarczyk):

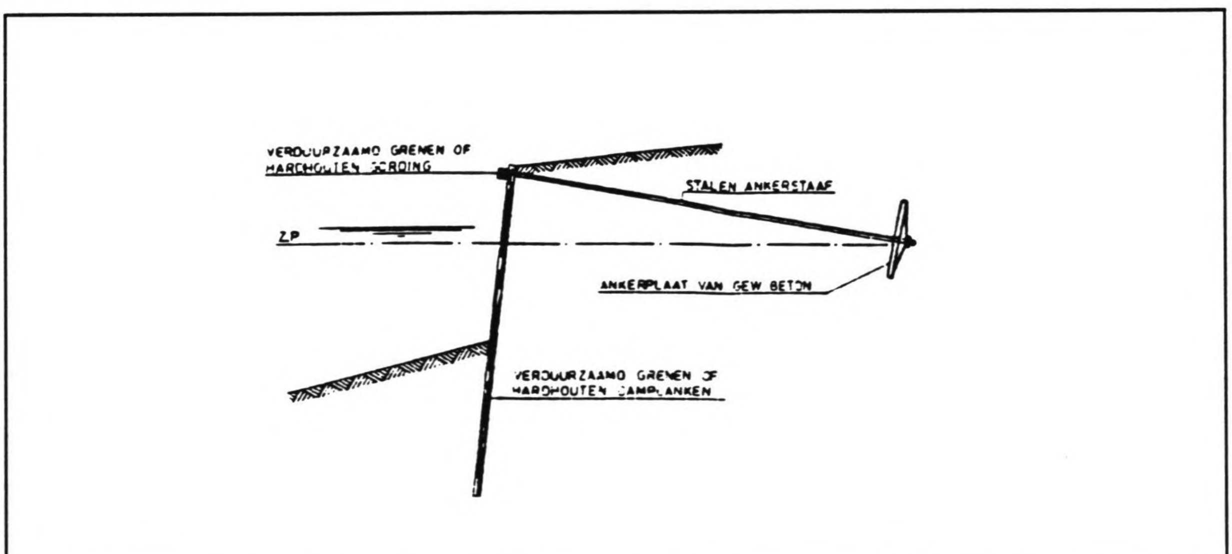
$$tm = H / 4 \cdot (1-n) \cdot \Delta \cdot (\cot\alpha)^{1/3} \quad \text{,for } \cot\alpha \geq 3 \text{ ,in which}$$

n = porosity of the stones ≈ 0.4

For common quarry stones $(1-n)\cdot\Delta \approx 1$ and thus $t_m = 0.09$ m (= 90 mm).

Only when the current velocity exceeds 3 m/s or the wave height exceeds 1 m a granular sublayer is required. The gabion can be placed directly on the filter (geotextile).

5 Vertical wall



vertical wall

A vertical wall has to withstand the hydraulic loads as well as the imposed soil pressure. It is very important that the upper extend of the construction is high enough to prevent erosion of the soil behind the structure due to overtopping waves. Also sufficient depth is required to obtain enough reaction force and to prevent loss of soil underneath the structure. The reaction force against the soil pressure can also be obtained by an anchor behind the wall. Loss of soil particles through the construction can be prevented by a filter or geotextile behind the wall.

9.2.6 EVALUATION AND SELECTION OF REVETMENT

The vertical wall or cofferdam is very expensive to construct (about US$ 800.-/m1, and we are talking about 30 kilometres of waterway !), and difficult to maintain and repair. This type of bankprotection is easily damaged by vessels. The major advantage of this type of construction is the reduction in landacquisition of about 10 meters at each side of the channel (profit: 20 m * 1.4 US$/m² = 28.- US$/m). It might be a preferable option at places where land acquisition is not or hardly possible.

The gabion mattress is very sensitive to damages, especially the wire-netting. This structure has no 'self restoring' possibilities in a way that other parts of the construction replace the failed part; break down of (a part of) the wire structure will initiate the loss of function of the whole revetment. The construction requires proper and careful maintenance.

Concrete blocks on geotextile requires professional execution and is expensive. Also maintenance and repair has to be carried out properly and correctly. Loss of an element will reduce the strength of the whole construction and quick replacement of the element is therefore required. The construction requires proper and careful maintenance.

The rip rap construction (whether or not grouted) is relatively cheap (about 350 US$/m), easy to construct and to maintain and has a 'self restoring' capacity. It is however liable to damage by human action (theft and vandalism). Grouting of the stones is a solution when this problem occurs.
In figure 9.10 an example of a rip rap revetment which will fit well into the surroundings is shown.

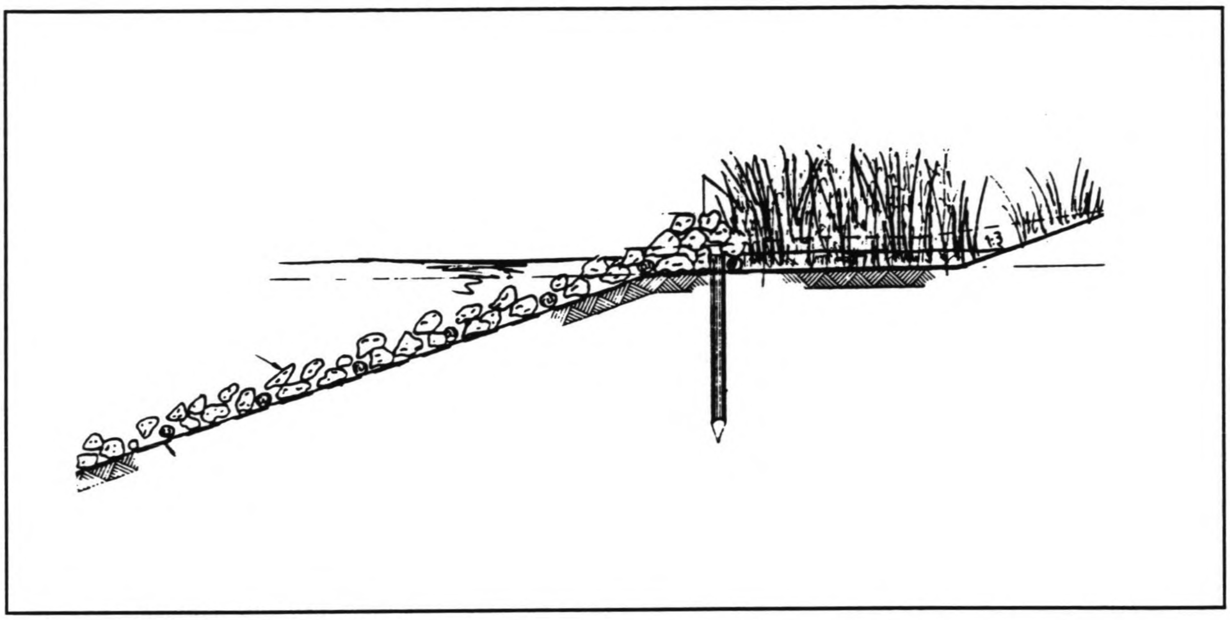


Figure 9.10 selected rip rap revetment

Cost estimate

For the cost estimate of the revetment works the rip rap construction is considered. Investment cost of this type of construction is approximately US$ 350 per meter. Total investment cost then becomes (two sides):
30,000 m * 2 * 350 = 21,000,000 US$
Applying an economic lifetime of 50 years results in an annual cost of about
0.101 * 21,000,000 = 2,120,000 US$
Annual costs of maintenance and repair is assessed at 2% per year and becomes then 420,000 US$.

9.3 AIDS TO NAVIGATION

In the selected system, Large Rhine Vessels (having a length of 110 m, a beam of 11.4 m and a payload of 2,250 tons), will continuously sail at the waterway. In view of safety of navigation, an appropriate channel marking system is required.

Description of the navigation route

The characteristics of the navigation route are as follows:

From km 0 to km 62, the navigation route follows the wide kayals and lakes between Cochin and Punnamada. Width of the waterway here varies from 1,000 to 4,000 m. Along most part of this route enough depth is already available and no dredging is required. From km 7 to 8; km 21 to 22 and from km 49 to 62 however, the navigation route has to be deepened. The vessels must be able to follow this deepened fairway. Also ferries cross this part of the waterwayroute at Cochin, Pannavally, Vaikom and Thanneermukkom.

From km 62 to km 91, the waterway has to be adapted to the required channel profile and the fairway is confined by the channel embankments. The low lying embankments are densely inhabited and overgrown with tall palmtrees; therefore riverbranches, creeks and river outfalls into the channel are generally difficult to distinguish.
(Visibility, currents and winds will not cause much problems as already outlined in chapter 3.)

Aids to Navigation (shipborne)

To keep regular contact with offices, terminals and other ships, a system of ship radio is necessary. This radio system can also give information about new or missing buoys, obstructions, temporary works, etc. Radio masts along the waterway have to be installed.
Because the vessels also navigate at night, the vessels must be provided with radar which is an excellent tool of position fixing.

Aids to navigation (shorebased)

The system must be laid out for visual navigation at day and night, which calls for light buoys and -beacons at appropriate locations and intervals.
All buoys and beacons must be provided with radar reflectors to enable detection by night at all times. An appropriate average distance interval for the locations of these buoys and beacons, considering the length of the selected vessel (L_s = 110 m.), is (according to Dutch practice) about 750 m.

Additional marks and illumination are required at bridges, locks, crossings of ferries and other danger points and obstacles.

Buoys

The (light)buoys which are applied from km 0 to km 62, mark the navigational route in relative wide waters. For good visibility at daytime their size should not be too small; a diameter of about 2 meters is required.
Only steel buoys should be used, because they can easily and relatively cheap be repaired. Buoys made of plastic are vulnerable and repair is a major problem.

For the illumination of the buoys and beacons several methods can be applied; the buoys can be:
-gaslighted,
-battery lighted,

-solar panel powered
Gas lighted buoys are easy to maintain and energy supply is generally no problem. Battery lighted buoys are very widely used but batteries must be properly available. Solar panel powered buoys are more sophisticated than the other methods, however, they are also more liable to more expensive and less available parts, theft and vandalism.
Gaslighted allumination is selected as the most appropriate solution.

Beacons and signs

The shorebased (lighted) beacons consists of a steel support structure for the light which also contains a radarreflector and the powersupply, for instance a gastank. To improve its visibility, which may be hampered by the dense vegetation, an elevated platform is recommended.
Signs at the left and at the right bank are required to give information about navigational conditions of the channel. Good visibility is very important, so the colour, illumination and elevation above groundlevel must be considered carefully. A good policy is to locate the signs near local houses, so that they can be guarded and the risk of theft and vandalism will be reduced.

<u>Cost estimate</u>

Lightbuoys
A light buoy having the following characteristics is considered:
A 2 m diameter steel body, skirt keel type, complete with marks,radar reflector, allumination, with chain and anchor for 5 to 10 m waterdepth.
The investment costs of such a buoy is approximately US$ 25,000
Annual depreciation cost is approximately US$ 2,000

For the waterway route between Cochin and Punnamada (two sides) approximately (62,000 / 750) * 2 ≈ 165 light buoys are required. Annual costs amount to:
165 * 2,000 = US$ 330,000

Beacons
A beacon having the following characteristics is considered:
A steel pipe structure (flash) light beacon, height 4m.
Investment cost of a beacon is approximately US$ 14,000
Annual depreciation cost is approximately US$ 1,000

For the route between Punnamada and Trikkunnapuzha (two sides) approximately (29,000 / 750) * 2 ≈ 77 beacons are required, annual cost is then:
77 * 1,000 = US$ 77,000

Signs
Lighted signs having a steel pipe support structure with mounting frame, a 1 m^2

square signboard of galvanized steel, lantern bracket, battery and solar panel, epoxy painted for tropical conditions and a height of 4 m. are considered.
Investment cost per sign is approximately US$ 7,000
Annual depreciation cost is approximately US$ 400

When signs are placed with an average interval of 1 km. along the entire route (except for the very wide stretch from km 30 to km 62), approximately (60,000 / 1,000) * 2 ≈ 120 signs are required. Annual depreciation cost becomes then about US$ 48,000

Maintenance
Concerning maintenance of the aids to navigation the following must be considered:
Buoys should at least be inspected once every month to check the position and functioning. Also the buoy must be cleaned and marine growth has to be removed. Broken parts must be replaced (and therefore each service vessel shall carry a number of spare parts).

For shore beacons the same procedure is applicable as for buoys, including the removal of vegetation.

9.4 NAUTICAL MANAGEMENT OF THE WATERWAY ROUTE

It is preferable that the directorate involved with the traffic and waterway control has its own patrol service. One or more boats must be available. Echosoundings have to be made regularly in the channel, revetments, buoys, beacons, kilometersigns and gauges have to be maintained. It is also important to make waterway maps of the routing.

To keep regular contact with offices, terminals and other ships, a system of ship radio is necessary. This radio system can also give information about new or missing buoys, obstructions, temporary works, etc. Radio masts along the waterway have to be installed.

Also night navigation is applied, requiring navigation with radar or permanently installed navigation lights to mark the channel.
Radar requires special attention to buoys, beacons and bank alignments; they must give a good radar echo at all times.

The amount of maintenance dredging in the new waterway is very difficult to determine beforehand. A dredger of suitable capacity should be stationed in the waterway, at least during the first years of operation until a reliable determination of the maintenance dredging can be made.

9.5 ESTIMATE OF TOTAL COST PER TON

Many of the cost components of the transportsystem have already been estimated, i.e. cost of:
-vessels and crew
-fuel and oil
-locks
-capital and maintenance dredging
-land acquisition
-loading- and unloading equipment
-quay structures
-revetments
-aids to navigation

Costs which also have to be taken into account are cost of:
-construction of a new bridge at Karumadi and demolition of the old one
-the conveyor belt including gallery structure from Trikkunnapuzha to the Kayamkulam power plant site
-administration, overhead and profits (15% of total annual cost).

The transportsystem has been designed for an annual throughput of 10 mmtpa. The estimate of the total cost per ton is presented in table 9.1 and amounts then to US$ 3.2 / ton.

In case only 8 million tons is transported with the same transport system; the number of vessel calls can be reduced with 20% (3,556 in stead of 4,445 calls per year). This can be achieved by reducing the sailing speed of the IWT-fleet. As a consequence the berth occupancy factor will reduce. However, the same transport system components will be applied and a saving of costs is only obtained by a slight reduction in fuel- and maintenance costs. When transporting 8 million tons per year, the total costs per ton are assessed at US$ 4.0 / ton cont.wk1 ESTIMATE OF TOTAL COST PER TON FOR THE SELECTED OPTION (LARGE RHINE VESSEL)

DAY AND NIGHT NAVIGATION

throughput 10,000,000 ton			TOTAL COST ESTIMATES		YEAR: 1993 CURRENCY: US $		
	LARGE RHINE VESSEL (2,250 ton)						
Item	Quantity	Unit	Rate (US$)	Subtotals mil.US$	Cap.Rec. factor	Maint. + Repair (mil.US$)	Yearly subtotal (mil.US$)
Vessels	19	each	1,700,000	32.3	0.106	3.23	6.65
Pushboats		each		0.0			
Barges		each		0.0			
Labour	114	men/year	1,500				0.17
Locks	2	each	5,800,000	11.6	0.101	0.604	1.78
Land acquisition	869,000	m2	1.4	1.2	0.101		0.12
Capital Dredging	7,000,000	m3	4.6	32.2	0.101		3.25
Maintenance Dredging	1,400,000	m3/year	2.6				3.64
Loading Berths	2	each					
Quay structure	253	m	10,500	2.7	0.101		0.27
Vessel loaders	2	each	750,000	1.5	0.106	0.15	0.31
Unloading Berths	6	each					
Quay structure	759	m	10,500	8.0	0.101		0.80
Vessel unloaders	5	each	3,500,000	17.5	0.106	1.75	3.61
Fuel + oil	39,446,000	KWh	0.044				1.74
New bridge	1	each	6000000	6	0.101		0.606
Conveyor belt	4000	m	4000	16	0.101		1.616
Revetments	60000	m	350	21	0.101	0.42	2.541
Aids to navigation							
buoys	165	each	25000	4.125		0.33	0.33
beacons	77	each	14000	1.078		0.077	0.077
signs	120	each	7000	0.84		0.048	0.048
ANNUAL SUBTOTAL							27.6
ADMINISTRATION, OVERHEAD AND PROFIT:							4.1
TOTAL INVESTMENT COST		US$		155.9856			
TOTAL ANNUAL COST		US$/year					31.7
TOTAL TRANSPORT COST:		**US$/ton**					**3.2**

Table 9.1a Total cost per ton estimate Throughput 10 mmtpa

cont.wk1 ESTIMATE OF TOTAL COST PER TON FOR THE SELECTED OPTION (LARGE RHINE VESSEL)

DAY AND NIGHT NAVIGATION

throughput 8,000,000 ton	TOTAL COST ESTIMATES				YEAR: 1993 CURRENCY: US $		
	LARGE RHINE VESSEL (2,250 ton)						
Item	Quantity	Unit	Rate (US$)	Subtotals mil.US$	Cap.Rec. factor	Maint. + Repair (mil.US$)	Yearly subtotal (mil.US$)
Vessels	19	each	1,700,000	32.3	0.106	3.23	6.65
Pushboats		each		0.0			
Barges		each		0.0			
Labour	114	men/year	1,500				0.17
Locks	2	each	5,800,000	11.6	0.101	0.604	1.78
Land acquisition	869,000	m2	1.4	1.2	0.101		0.12
Capital Dredging	7,000,000	m3	4.6	32.2	0.101		3.25
Maintenance Dredging	1,400,000	m3/year	2.6				3.64
Loading Berths	2	each					
Quay structure	253	m	10,500	2.7	0.101		0.27
Vessel loaders	2	each	750,000	1.5	0.106	0.15	0.31
Unloading Berths	6	each					
Quay structure	759	m	10,500	8.0	0.101		0.80
Vessel unloaders	5	each	3,500,000	17.5	0.106	1.75	3.61
Fuel + oil	39,446,000	KWh	0.044				1.74
New bridge	1	each	6000000	6	0.101		0.606
Conveyor belt	4000	m	4000	16	0.101		1.616
Revetments	60000	m	350	21	0.101	0.42	2.541
Aids to navigation							
buoys	165	each	25000	4.125		0.33	0.33
beacons	77	each	14000	1.078		0.077	0.077
signs	120	each	7000	0.84		0.048	0.048
ANNUAL SUBTOTAL							27.6
ADMINISTRATION, OVERHEAD AND PROFIT:							4.1
TOTAL INVESTMENT COST		US$		155.9856			
TOTAL ANNUAL COST		US$/year					31.7
TOTAL TRANSPORT COST:		**US$/ton**					**4.0**

Table 9.2b Total cost per ton estimate Throughput 8 mmtpa

10 MAIN ASSUMPTIONS

During this study several assumptions were made due to the limited information available. In further studies these assumptions have to be studied more in detail. The main assumptions will be mentioned and discussed below:

-number of operational days per year is 350
-for day and night navigation the number of operational hours per day is 20
-a berth occupancy factor of 0.8 is considered
-the rate of annual maintenance dredging is 20% of the amount of capital dredging
-economic lifetime of vessels and mechanical works is 30 years
-economical lifetime of civil works is 50 years
-the economic sailing speed is applied for the whole trip

Furthermore a discussion about the following items will be given:

-the other traffic is left out of consideration because only the costs directly related to the transportation of coal is considered
-costs of land acquisition
-the number of vessels required
-the alignment (bends) and cross profile of the existing waterway
-arrival pattern of the vessels and resulting port waiting times
-dimensions of the locks
-vessel characteristics
-labour
-the selected rip-rap revetment
-drift angle due to wind influence

<u>number of working days per year</u>

The assumption concerning the number of operational (workable) days of 350 is based on the occurring weather conditions. There are however more circumstances we have to consider. Indian conditions and circumstances are less appropriate than those in Western countries. Considered must be: national holidays, strikes and a more frequent break-down of the whole transportsystem. 350 days per year may be overestimated !

<u>20 working hours per day</u>

If the system will be operational day and night, 20 working hours per day is assumed. A margin of 4 hours per day is however rather high and margins are already included in most of the other system components. 24 hours might be better !

berth occupancy factor

A berth occupancy factor of 0.8 is assumed in the calculations of the transportsystem characteristics. However the system will probably less regular than assumed and a factor of 0.8 might be too high.

rate of maintenance dredging

The rate of maintenance dredging is assumed to be 20% of the amount of capital dredging. This has already been discussed in chapter 7 (page 47) and detailed survey is required in further studies.

economic lifetime

An economic lifetime of 30 years is assumed for the vessels and the mechanical (handling) equipment and 50 years is assumed for all civil works. However, the vessels built in India are of lower steel quality and maintenance (also of the civil works !) is expected not to be carried out properly. A shorter lifetime might be more appropriate.

sailing speed over the total trip

In the study the calculated economic sailing speed is assumed for the whole trip. In further studies a more detailed distinction between sailing speed of loaded and empty vessels and of sailing on the narrow and the wide reaches should be made.

other traffic

The vessels and countrycrafts already plying on the waterway were left out of consideration because only costs directly related to the transportation of coal is taken into account. However, for most of the crafts sailing on the waterway will become impossible due to the influence of the large IWT vessels (wavebuilding). Solutions must be found and additional costs must be beared by the coal transport system.

costs of land acquisition

Cost of land acquisition is taken at 1.4 US$/m². It may however be expected that the prices of land along the waterway will raise when plans for channel improvement are made public. Furthermore the waterway embankments are densely inhabited and many people will have to be relocated, inducing additional costs and many protests of the inhabitants !

number of vessels required

In the estimate of costs only the number of required operational vessels was taken into account. However, also spare vessels are required to carry out maintenance and repair without loss of transportcapacity. For this maintenance and repair also a shipyard (dock) will be required.

number of buoys required

In fact the same as mentioned for the number of vessels required counts for the buoys and beacons. Also here spares must be included.

alignment of the existing waterway

About the waterway alignment little information is available. This is mainly due to the fact that the coastal area we are considering is a military zone and no detailed maps are available. Nevertheless a detailed survey is required to obtain reliable information. One of the boundary condition of the study was that the fairway-route follows the existing West Coast Canal. Other routes, following less densely populated areas may be more advantageous.

cross profile of the existing waterway

The cross profile of the existing waterway applied is rather schematic because little information was available. In further studies a detailed morphological survey of the fairway is recommended.

bends along the fairway

According to RITES the route contains no sharp bends. Apart from the fact that this statement might not be correct, the influence of bends on the design channel cross profile is left out of consideration. This has been done because very little information was available and the influence on the amount of dredging is negligible. When detailed survey of the waterway is carried out, the influence of bends must also be considered.

arrival pattern and port waiting times

In the transportsystem calculations a regular system is assumed. This will however not be experienced in reality. In this stage of the study it is difficult to determine the expected arrival pattern of the IWT vessels. This arrival pattern as well as the distribution of the port service time has a great influence on the additional waiting time of the vessels.
For the Large Rhine Vessel (2,250 tons), day and night option, two arrival patterns will be considered:

i) a semi-regular- (Erlang 2-) and
ii) a random (N.E.D.) distribution of inter arrival times.

For both patterns the waiting time will be estimated at the loading- and unloading terminal. The service (loading/unloading) time is considered semi-regular (Erlang 2) distributed having an average of 1.5 hours at the loading terminal and 5.0 hours at the unloading terminal.
The estimate of the waiting times for both arrival patterns is presented in table 10.1
The waiting-time factor is taken from "Port development" a handbook for planners in developing countries, submitted by the United Nations.

ESTIMATE OF EXPECTED WAITING TIMES AT THE TERMINALS

Erlang-2 Interarrivaltime distribution / Erlang-2 Servicetime distribution

LOADING TERMINAL

Utilization (b.o.f.)	Berths	Average Service Time (hours)	Waiting-time Factor (in units of servicetime)	Waiting Time (hours)
0.75	2	1.5	0.58	0.87
0.80	2	1.5	0.83	1.24

UNLOADING TERMINAL

Utilization (b.o.f.)	Berths	Average Service Time (hours)	Waiting-time Factor (in units of servicetime)	Waiting Time (hours)
0.75	6	5	0.11	0.55
0.80	6	5	0.19	0.95

Random (N.E.D.) Interarrivaltime distribution / Erlang-2 Servicetime distribution

LOADING TERMINAL

Utilization (b.o.f.)	Berths	Average Service Time (hours)	Waiting-time Factor (in units of servicetime)	Waiting Time (hours)
0.75	2	1.5	1.00	1.50
0.80	2	1.5	1.40	2.10

UNLOADING TERMINAL

Utilization (b.o.f.)	Berths	Average Service Time (hours)	Waiting-time Factor (in units of servicetime)	Waiting Time (hours)
0.75	6	5	0.22	1.10
0.80	6	5	0.34	1.70

Table 10.1 Estimate of waiting times

As can be seen from table 10.1, the arrival pattern has a great influence on the waiting time of the vessels. In the study a waiting time of 1 hour at the loading terminal and 2 hours at the unloading terminal was assumed. It can be concluded that in further studies the arrival pattern must be studied in more detail to get a better estimation of the expected waiting times.

<u>dimensions of the locks</u>

The dimensions of the lock chambers are estimated according to Bouwmeester (ref.[6]). The resulting dimensions are somewhat overestimated. Further, when more than one lock is required (two for instance), a large lock containing two vessels will be cheaper than two separate locks containing each one vessel. A further optimization is required in further studies.

vessel characteristics

In the study European standards are assumed concerning the vessel characteristics. At the moment however, vessels built in India (Port of Goa) do have a maximum payload of about 1,700 to 2,000 tons only. Further the ratio between length and beam of the vessel is less than in Europe resulting in a higher resistance and hence a lower economic sailing speed.

labour

For day and night navigation two shifts each consisting of three men is assumed. According to latest information however, the number of men required has to be twice as much (union regulations).

the selected rip-rap revetment

The most favourite option for the slope-protectionworks was found to be the rip-rap revetment. The main disadvantage of this type of revetment, the stones could be stolen, is a much more serious problem than assumed. The stones will be used for house building and the revetment is expected to be disappeared soon. Other options must be considered.

drift angle due to wind influence

In order to estimate the drift angle due to wind influence, a design cross wind speed of 6 m/s is taken. For the wide less protected reach between Cochin and Punnamada (km 0 to 61), a higher design cross wind might be more appropriate. The estimate of the design cross wind speed is in fact also related to the number of days the transportsystem has to be operational. The more days, the higher the design wind speed under which the vessels must be able to sail safely must be. A cross wind speed at open sea $\leq$ 10 m/s will occur for 98% of the year and may be considered as a maximum. Resulting drift angle of the Large Rhine Vessel becomes then about 6°.

11 CONCLUSIONS AND RECOMMENDATIONS

10.1 CONCLUSIONS

The existing waterway route from Cochin to the projected powerplant site at Kayamkulam following the West Coast Canal, contains many restrictions and is in the present conditions absolutely not suitable for the transportation of the ultimate projected coal throughput of 8.06 million tons per year.

Based on a comparative costs evaluation, the best option for the transportation of the ultimate projected coal throughput of 8.06 mmtpa from the coal (un)loading terminal at Cochin Port to the projected thermal powerstation at Kayamkulam by IWT using the existing waterway route of the West Coast Canal is the use of IWT vessels having a payload of 2,250 tons. The unloading terminal will be located at Trikkunnapuzha and the coal will be transported further by conveyor belt over a distance of about 4 km.
Improvement of the waterway transport system to transport the ultimate projected coal throughput, requires the deletion of the existing locks at Trikkunnapuzha from the system, the construction of new locks at Thanneermukkom, the construction of a new bridge at Karumadi, channel bank protection works, aids to navigation and extensive capital dredging works.

Total resulting coal transportation costs in case 8 million tons per year is transported amounts to US$ 4.0 per ton.

11.2 RECOMMENDATIONS

After improvement of the waterway, transportation of the ultimate coal throughput is possible by IWT. However, environmental impacts and reliability aspects may result this option to be less attractive. Comparison with other options is required.

The Indian Government is exploring the possibilities of improving inland waterway transport on the West Coast Canal. It may be possible to combine several interests concerning the improvement of the waterway route. This provides possibilities for further cooperation and costs sharing.

If the transportation of the coal by IWT is found to be a promising option, further detailed survey is required to review the present study.
Especially survey is required to:
-The possibilities of removal of lock systems, i.e. the changing of (parts of) the backwatersystem into a more salt/brackish system,
-The rate of siltation in the new channel,
-The environmental and socio-economical impacts due to the introduction of IWT coal transport on the region.

A further optimisation of the IWT transportsystem may be found in the possibilities of other routes;

11.3 CRITICAL REMARKS

Lack of reliable data

For this project, having such an enormous impact on the hydrological, environmental and social conditions of the area, the quantity and quality of data and information is very limited.

Country craft traffic

In the wide reaches between Cochin and Alappuzha the country traffic will not experience serious navigational problems due to the introduction of IWT coal transport. In the canal reach between Alappuzha and Kayamkulam Kayal however, serious operational problems may occur.
Sailing on the canal will be almost impossible for the small country crafts because of the coal vessel's wavepatterns and the small freeboards of these country crafts.

Water management problems

The Kerala backwaters form a very complex hydraulic-ecological system in which human intervention will cause significant effects. Improvement of any component of the (wet) infrastructure can cause a deterioration of others. Great care should therefore be given to the impact of each project component on the whole system.

Waterway improvement

Many of the canals going to be used by the transport system were originally designed for small slow moving country boats and not for the self propelled coal vessels. The banks on both sides are mostly densely populated and widening them to adapt them to the coal barges may therefore be very difficult.
Dredging the backwaters is a delicate subject and possibly not permitted for ecological reasons.

Salt water intrusion

The waterbarrier at Thanneermukkom was built to separate the fresh watersystem of Kuttanad from the salt waterbasin of Cochin during the dry non-monsoon period (november-june). The operation of the locks causes a penetration of salt water into the fresh water reach caused by the exchange flow of fresh and salt water due to the difference in density. During the dry period at least 8/12 * 4,445 = 2,963 vessel calls are taking place; this means 2* 6,800 = 5,926 lock operations.

Water exchange per lock operation (= water content of the lockbasin - waterdisplacement of the vessel) = 6,780 - 2,980 = 3,800 cubic meters.
This may result in a salt water intrusion during the dry period of 22.5 million cubic meters.

12 SUMMARY

The demand for electric power in India has been growing steeply during the past decade particularly in the rapid industrialising southern regions and power shortages are frequently experienced. In order to cope with this problem, several coal burning power stations will be constructed along the west coast of India. One of the projected sites for a power station is at Kayamkulam, supplied by coal from Talcher mines in the north east.
The Central Electricity Authority established that the least coal transport costs from Talcher (Port of Paradip) to the coastal power stations is by means of sea transport.
Different coal unloading locations have been put forward for consideration for the Kayamkulam powerplant. One of these locations is at the existing port of Cochin (110 km north of Kayamkulam). Furthermore several ways for transporting the coal from the coal unloading terminal at Cochin to the powerplant site have been considered : slurry pipe, rail and inland waterway transport.

In the assessment of alternatives concerning the coal transport scenarios for the Kayamkulam powerplant it has been required to perform a more detailed assessment of the option by which coal will be unloaded at the existing port of Cochin and further transported by Inland Waterway Transport (IWT) to the Kayamkulam plant site.

The objective of this study is to assess constraints and opportunities concerning the transportation of the projected coal throughput of 8.06 million tons per year from the coal unloading terminal at Cochin to the projected powerstation at Kayamkulam by IWT using the existing West Coast Canal; and to select the most promising scenario for this transport system on basis of technical feasibility and costs.

To meet the objective an inventory of the existing situation has been made and constraints and bottlenecks have been identified. Main constraints are the inadequate waterway dimensions and the restricted dimensions of the existing locks at Thanneermukkom and Trikkunnapuzha.
It is concluded that the existing waterway is not suitable for the transportation of the required throughput of 8.06 million tons per year.

Improvement scenarios have been generated and it is concluded that feasibility of the transport scenario requires the deletion of the existing locks at Trikkunnapuzha from the system, the construction of new locks at Thanneermukkom and extensive capital dredging works.

Several options for the coal carrying vessels have been considered i.e.:
-self propelled vessels, ranging from 600 to 2,250 tons
-push formations, ranging from 3,500 to 11,200 tons.

These options have been analyzed with respect to the required
-waterway improvements
-loading- and unloading terminal
-fleet composition
Further, a distinction has been made between daytime only and day and night navigation.

Costs for each option have been determined in order to make a comparison between the options.
Based on these analyses, the preferred option for the transportation of the required throughput of 8 mmtpa, is the use of self propelled IWT vessels having a payload of 2,250 tons. The total coal transportation cost for the 8 mmtpa are estimated to be US$ 4.0 per ton.

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LIST OF SYMBOLS

SYMBOL	UNIT	DESCRIPTION
b	m	beam of vessel
b_b	m	bottom width of channel
b_w	m	waterlevel width of channel
c	N/m^2	cohesion factor
c_b	-	block coefficient
c_d	-	resistance coefficient
d	m	draught of vessel
g	m/s^2	acceleration of gravity
h	m	waterdepth
v_{cr} $(=v_{gr})$	m/s	critical sailing speed
v_e	m/s	economic sailing speed
v_s	m/s	sailing speed
A	m^2	dredging cross profile
A_c	m^2	wet channel cross section
A_s	m^2	wet midship cross section
A_{so}	m^2	wet ship's hull surface
B	m	vessel beam
C	vessels/yr	lock throughput capacity
D	m	channel depth
F_r	-	Froude number
F_s	N	propulsive force
H	m	wave height
Hi	m	interference peak wave height
Hf	m	front wave height
Ht	m	transversal wave height
L	m	vessel length
L_u	m	barge unit length
M	kg	mass
P_s	W	propulsive power
R	m	bend radius
$R_{d'}$	m	vertical extend of wave attack
T	m	vessel draught
T_l	m	vessel draught loaded
T_u	m	vessel draught ballasted
U	m/s	average return flow velocity

V	m/s	current velocity
W	N	weight
Z	m	average waterlevel drop
U_{max}	m/s	maximum return flow velocity
Z_{max}	m	maximum waterlevel drop
α	deg.	slope angle
ß	deg.	drift angle
ϕ	deg.	angle of repose
μ	-	efficiency coefficient
ρw	kg/m^3	specific mass of water
ρs	kg/m^3	specific mass of stone
Δ	-	relative mass

ANNEX A VESSEL CHARACTERISTICS

VESSEL OPTIONS

In order to derive vessel and barge options and sizes use was made of the 'Proposal of standardisation of waterways' by the Permanent International Association of Navigation Congresses (PIANC/CEMT-classification).

See table A1

VESSEL PAYLOAD

The total waterdisplacement of a vessel is not equal to the contents obtained by multiplication of length (L), breath (B) and draught (T). The vessel's hullshape isn't a rectangular box. The order in which the hullshape matches this box shape is expressed by the 'block-coefficient' cb.
For self propelled cargo vessels cb = 0.85 ,and
for push barges cb = 0.90

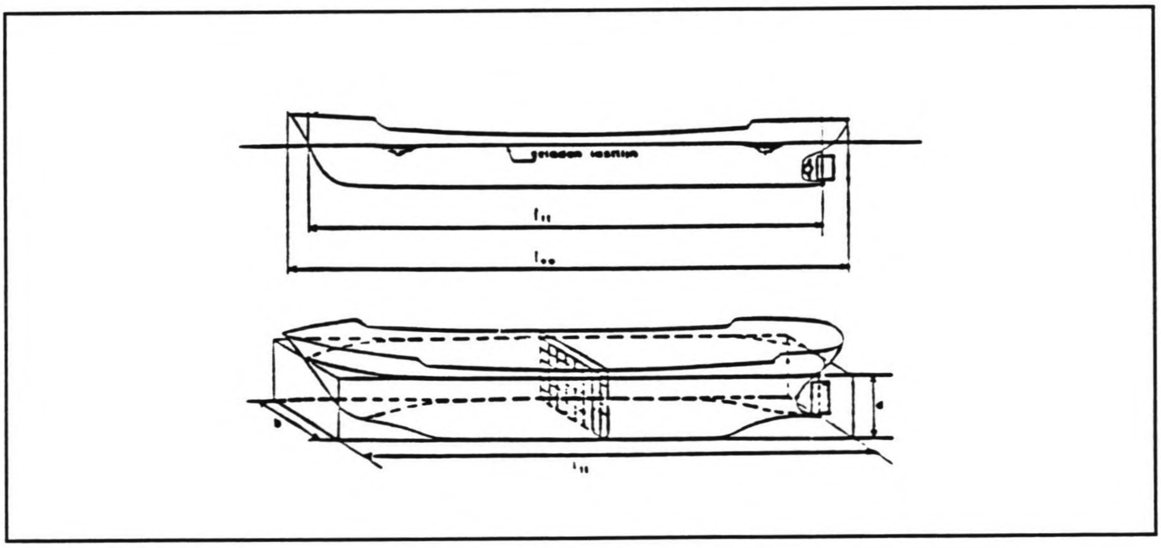


figure A1 vessel hull shape

The total waterdisplacement will not only benefit the carrying load but also the vessel's own weight.
The ratio payload-waterdisplacement is expressed by the load-coefficient cl which is:

- 0.75 for self propelled cargo vessels, and
- 0.80 for push barges.

Assuming water of 1,000 kg/m3 (=1 ton/m3);
the vessel's payload becomes then :

Payload = L * B * T * cb * cl [ton]

SAILING SPEED AND PRIMARY WATERMOVEMENT

Around a sailing vessel there will be a watermovement opposite to the sailing direction (conservation of mass and energy) which increases with the sailing speed. This so called returnflow also causes a waterleveldrop around the ship. These two phenomena together are called the primary watermovement. Due to the waterleveldrop the sailing vessel's keelclearance will be reduced.

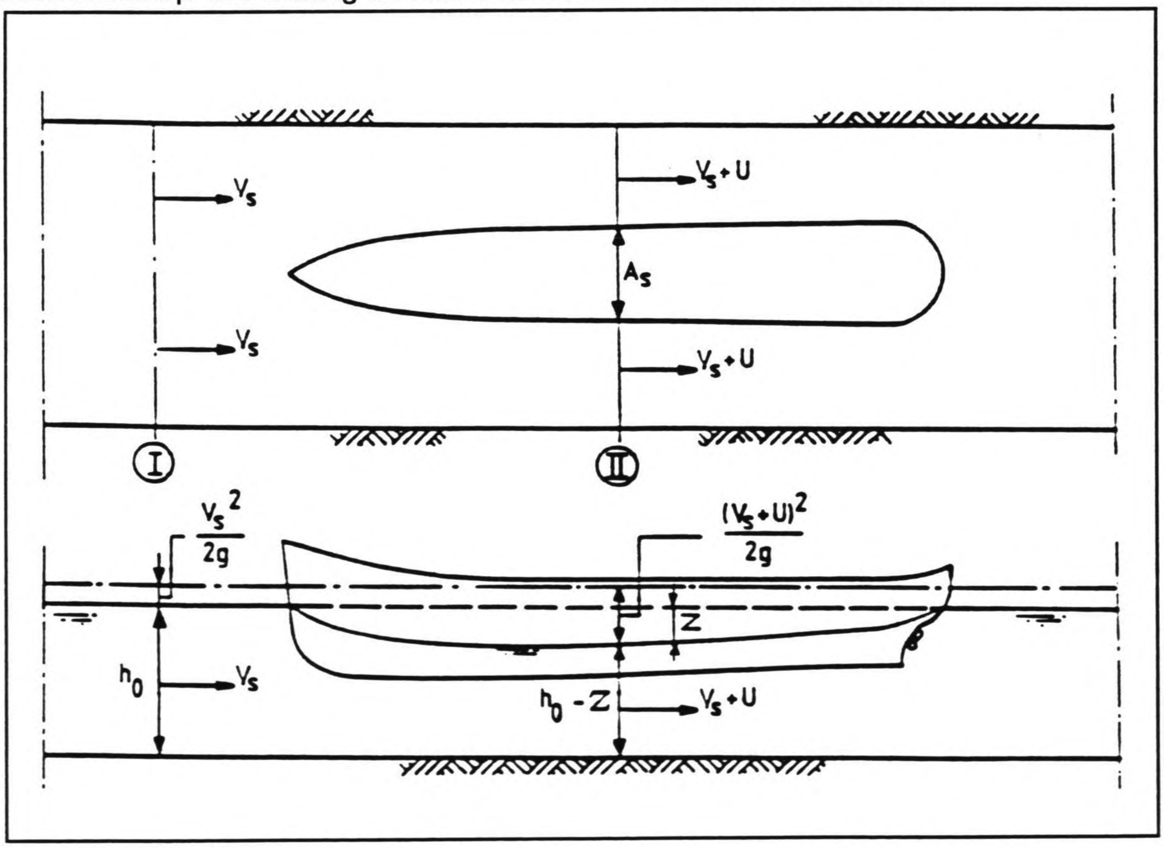


figure A2 primary watermovement

Vs = vessel speed
U = return flow
Z = waterlevel drop

Primary watermovement

The watermovement around a sailing vessel is very complicated and has a strongly three- dimensional character. In order to make preliminary calculations, one-dimensional calculation methods like Bouwmeester's method or Schijf's method (1953) can be used.

In confined waters the critical vessel speed depends on the blockage ratio expressed by Ac / As, in which
Ac = wet cross section of the canal (m^2)
As = wet midship cross section (m^2)

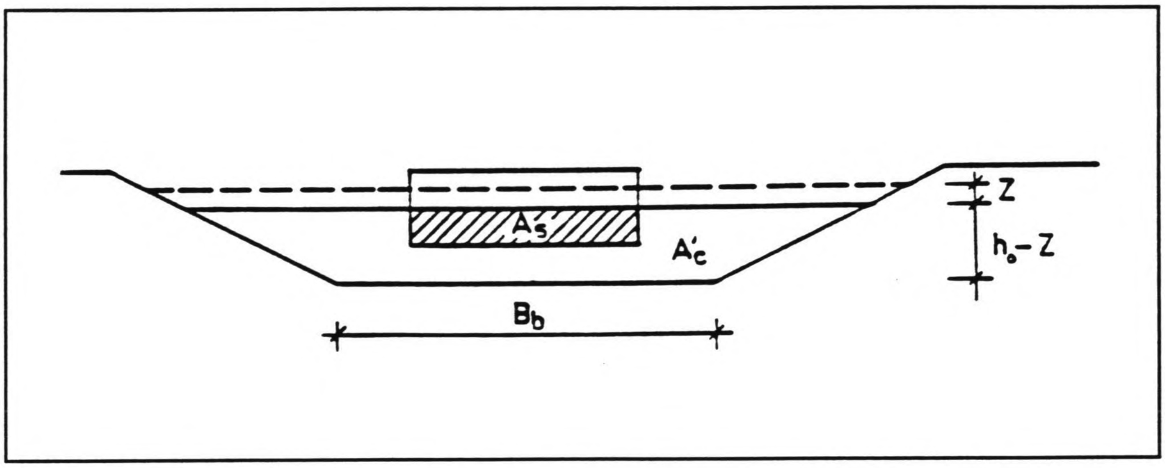


figure A3 cross profile

When vessel- and waterway dimensions and thus the blockage ratio As/Ac is known, the maximum vessel speed vcr can be calculated using Schijf's diagram. See figure A5.

The propulsive power required to reach this maximum (critical) speed is excessively high and very uneconomical. Also wavebuilding and hence bank attack is of considerable extent. Therefore the vessel speed will be limited to an economic speed which is approximately 0.80 times the maximum speed.

ve = 0.80·vcr (m/s) in which ve = economic vessel speed

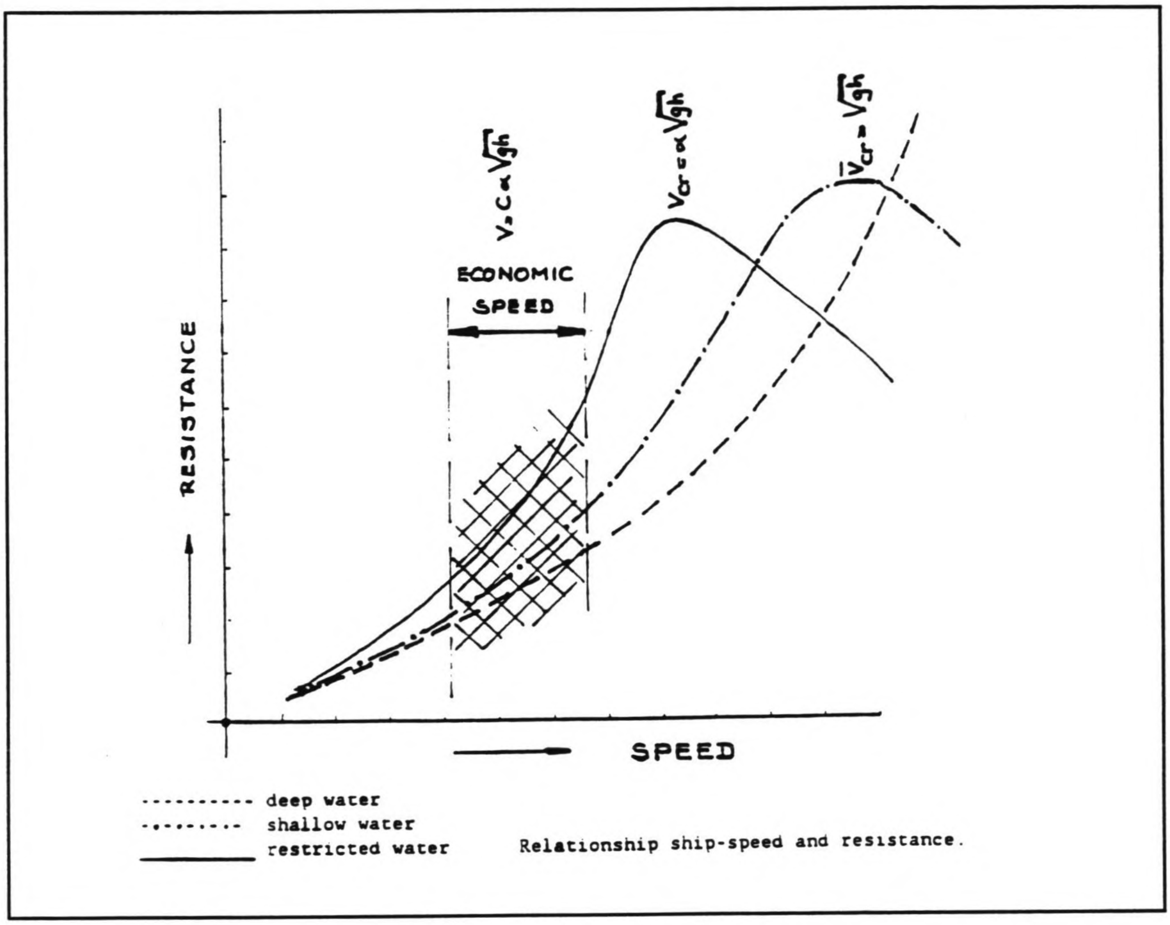


figure A4 relation vessel speed and resistance

Waterleveldrop (Z) and returnflow (U) is calculated according to Tuck's formulae (ref.[6] and [9]):

$$\frac{U}{\sqrt{gh}} = \frac{As/Ac}{1 - As/Ac - Fr^2} Fr$$

$$\frac{Z}{h} = \frac{As/Ac}{1 - As/Ac - Fr^2} Fr^2$$

THEORETICALLY REQUIRED PROPULSIVE POWER

The required propulsive power has been calculated according to Bouwmeester's impulse method (ref.[6]); the propulsive force is determined by the equilibrium of forces acting on the ship, i.e. the hydrostatic pressure at the bow and at the stern. Assuming that the waterleveldrop is still present at the ship's stern, the required propulsive force becomes:

$$Fs = \rho w\ g\ \{(cd\ (vs + U)^2 / 2g) + Z\}\ As \qquad [N]$$

ρw = mass of water [kg/m³]
cd = resistance coefficient
vs = vessel sailing speed [m/s]

This relation is applicable for push barges, when the propeller is located at some distance behind the barges. Concerning conventional vessels however, the propeller is situated underneath the required propulsive force can be determined with:

$$Fs = \rho w\ g\ cd\ \{(vs + U)^2 / 2g\}\ b[Z + d] \qquad [N]$$

Resistance coefficient cd is expressed by $cd = \tau\ (d/h)^2$

in which $\tau \approx 0.8$ for conventional vessels and, due to its sloping bow
$\tau \approx 0.1$ for pushtows

The required propulsive power Ps becomes:

$$Ps = Fs\ (vs + U)/\mu \qquad [W]$$

in which μ is an efficiency coefficient. For pushbarges Bouwmeester found a value of 0.45 For conventional vessels, Drost in 1986 found based on field experiments the following relation for μ :

$$\mu = 0.067\ d + 0.098\ d^2\ \{1-Ps/Pmax\}$$

in which Ps/Pmax gives the ratio between required - and installed power. A practical value of 0.8 is used.

CLASSIFICATION DIFFERENCES					
CLASS		ACCESSIBILITY			
	E.C.M.T.	FRANCE	F.R.G.	THE NETHERLANDS	BELGIUM
I	barge	barge	barge	barge	barge
II	Campinois	Campinois	Campinois	II = Campinois IIa = Hague vessel	Campinois
III	DEK	Two-barge unit	DEK	DEK	DEK
IV	RHK	Pushed unit of one GR barge	RHK	RHK	RHK
V	GR	Pushed unit of two barges, reduced draught	Va = GR Vb = two-barge pushed unit	GR	GR
VI	GR	Two-barge pushed unit	VI = four-barge pushed unit VIa = six-barge pushed unit	Four-barge pushed unit	Four-barge pushed unit

Barge = also known as spits
RHK = Rhine-Herne-Canal standard vessel
DEK = Dortmund-Ems-Canal standard vessel
GR = Large Rhine vessel

Association Internationale Permanente des Congres de Navigation

Permanent International Association of Navigation Congresses

PROPOSITION DE STANDARDISATION DES VOIES NAVIGABLES

PROPOSAL OF STANDARDISATION OF WATERWAYS

Classes de voies navigables / Classes of navigable waterways	Automoteurs et chalands / Motor vessels and barges — Type de bateau: Caractéristiques générales / Type of vessel: General characteristics					Convois poussés / Pushed units — Type de convoi: Caractéristiques générales / Type of pusher: General characteristics					Barges de poussage / Push lighters — Type de barge: Caractéristiques générales / Type of barge: General characteristics				Hauteur minimale sous les ponts / Minimum height under bridges
	Dénomination / Designation	Longueur / Length	Largeur / Beam	Tir. d'eau / Draft	Tonnage / Tonnage	Dénomination / Designation	Longueur / Length	Largeur / Beam	Tir. d'eau / Draft	Tonnage / Tonnage	Dénomination / Designation	Longueur / Length	Largeur / Beam	Tir. d'eau / Draft	
(1)		m	m	m	T		m	m	m	T		m	m	m	m (4)
I	Péniche / Barge	38.50	5.05	2.20	250 - 400										4.00
II	Kast Campinois / Campine-Barge	50 - 55	6.60	2.50	400 - 650										4.50
III	D.E.K.	67 - 80	8.20	2.50	650 - 1000										5.00
IV	R.H.K.	80 - 85	9.50	2.50	1000 - 1500	1 barge E I	85	9.50	2.50	1 240	Europe I	70.00	9.50	2.50	5.25
V a	Grande Rhénane / Large Rhine vessels	95 - 110	11.40 (2)	2.80	1500 - 3000	1 barge E II	95 - 110	11.40	2.80	1 850	Europe II	76.50	11.40 (2)	2.80	7.00
V b						2 barges E II	172 - 185	11.40	2.80	3 760					
VI a						4 barges E II a	185 - 195	22.80	4.50 (3)	8 000 12 000	Europe II a	76.50	11.40 (2)	3.90	9.10
VI b						6 barges E II a	270	22.80	4.50 (3)	12 000 18 000					
							195	34.20	4.50 (3)	12 000 18 000					

1) La classe d'une voie navigable est déterminée par les dimensions horizontales des bateaux ou convois-poussés.
2) Sur le bassin du Danube, cette largeur est généralement de 11 m.
3) Tient compte des développements futurs.
4) Tient compte d'une marge de sécurité entre le tirant d'air du bateau et la hauteur libre des ponts. En cas de transport fluvio-maritime ou de conteneurs, les hauteurs libres devront être adaptées.

1) The class of a waterway is determinated by the horizontal dimensions of the vessels or pushed units.
2) In the Danubian basin, this beam usually is 11 m.
3) Takes into account the future developments.
4) Takes into account a security clearance between the draft of the vessel and the height under the bridges. In case of coastal or container traffic, the height under the bridges should be checked.

Table A1 Vessel classification

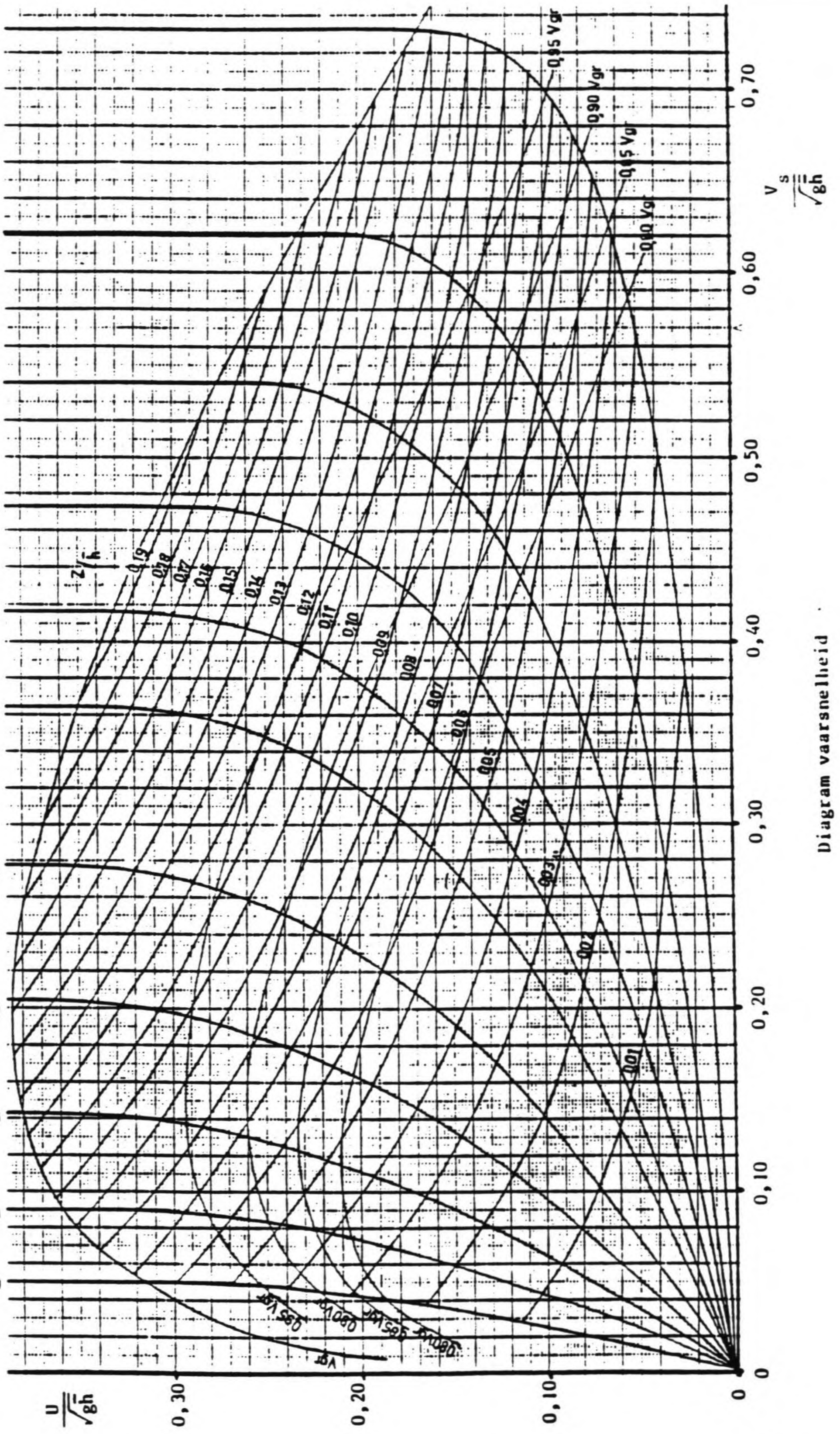


Figure A5 Schijf's Diagram

ANNEX B ESTIMATE OF CHANNEL CROSS PROFILE

Hydraulic phenomena as they occur during navigation in confined waters determine the minimum dimensions for channels for certain vessel characteristics. These phenomena have a significant effect on the speed and manoeuvrability.

Due to these phenomena the sailing vessel is subjected to squat, trim and critical speed. These largely determine the actual speed, ease of navigation and the possibilities of encountering and overtaking capabilities of the vessels.

REQUIRED CHANNEL DEPTH

The required channel depth is determined by :
- draught of the (design-) vessel and
- keelclearance

Keel clearance is defined as the distance between the bottom of the waterway bed and the deepest part of the ship while in rest. This keel clearance is needed for the following reasons :
- speed
- manoeuvring
- avoiding the ship's bottom from hitting the waterway bed.

Waterleveldrop (squat) and trim reduce the keelclearance of the sailing barge considerably. In this study the increase of draught is taken equal to the average waterleveldrop of the sailing ship.

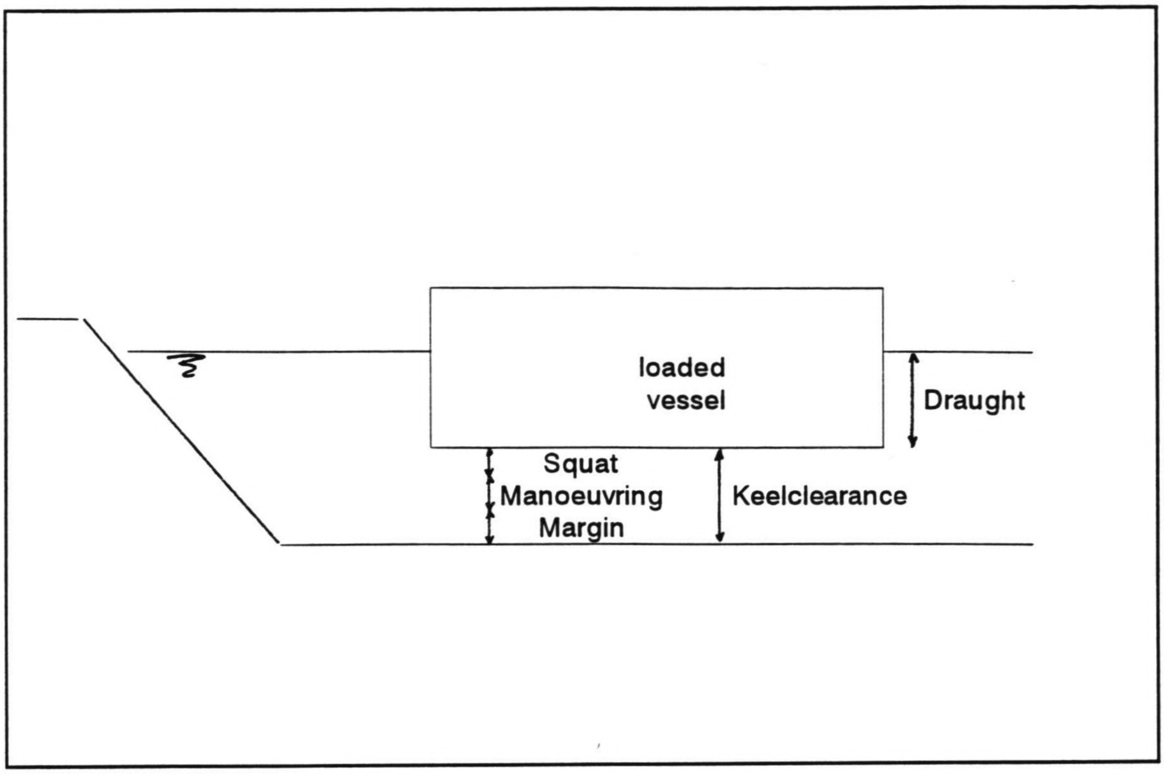


figure B1 channel depth components

Channel depth expressed in draught of the vessel T then becomes:

-draught	1	
-squat	0.05	
-manoeuvring	0.2	
-margin	0.1	+

Channel depth =	1.35 T	

REQUIRED CHANNEL WIDTH

Traffic situation:

The governing traffic situation is assumed as two encountering IWT vessels.

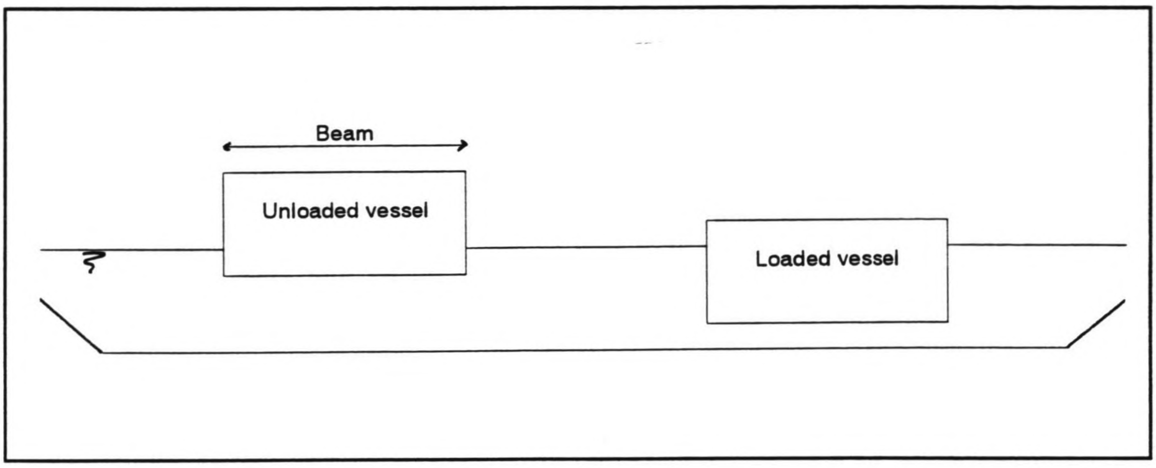


figure B2 determining traffic situation

Nautical demands

For a vessel sailing in confined waters it is almost impossible to maintain a straight course parallel to the channel axis because of the disturbing influence of bank suction, other ships, wind (unloaded vessels) and cross currents. The ship will sail with a certain average drift angle. For self propelled vessels is this drift angle taken at 2 degrees; push barges are, as a result of their square hull shape, less course-stable and therefore a drift angle of 4 degrees is taken.
Therefore the actual width required is more than only the vessels beam (B).

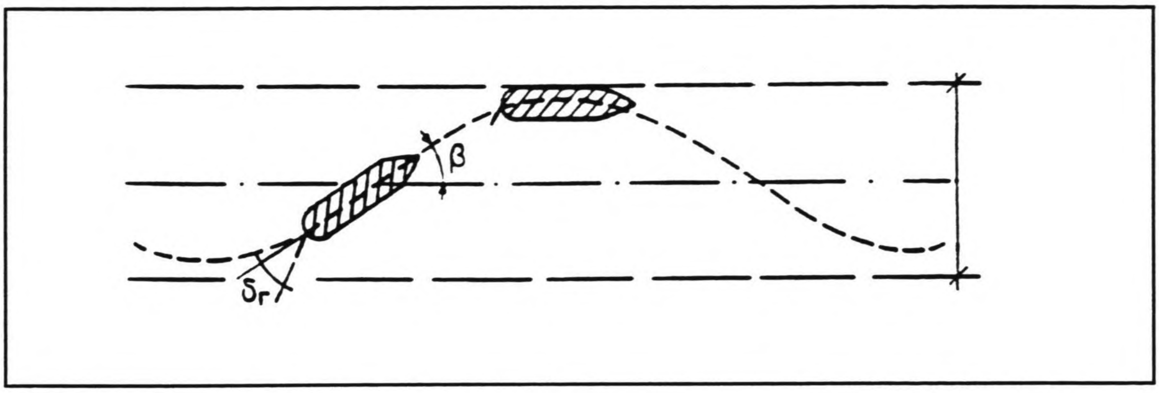


figure B3 path width

safety distance between lanes
When two vessels encounter on a (straight) channel a minimum distance between their lanes is required to prevent the ships from hitting each other. This separation lane is usually recommended to be in the order of 1.0 to 1.5 times the vessel's beam.

windinfluence
Drift angle due to wind influence is calculated by,

$$\beta = \alpha \left(\frac{W}{V}\right)^2$$

in which ß = drift angle due to wind influence [deg.]
α = empirical coefficient
0.5 for self propelled vessels (ref.[6])
1.0 for push barges (ref.[10])
w = wind speed perpendicular to channel axis [m/s]
v = vessel speed [m/s]

In 80 % of the year the windspeed on open sea will be less than about 8 m/s. Along large parts of the waterway (esp. km 60 - km 91), the channel banks are overgrown with palmtrees reducing the wind influence.
A design cross wind of 6 m/s will be taken. With a preliminary vessel speed of 3 m/s, ß becomes then 4*α [degrees].

Extra path width due to a drift angle is then:

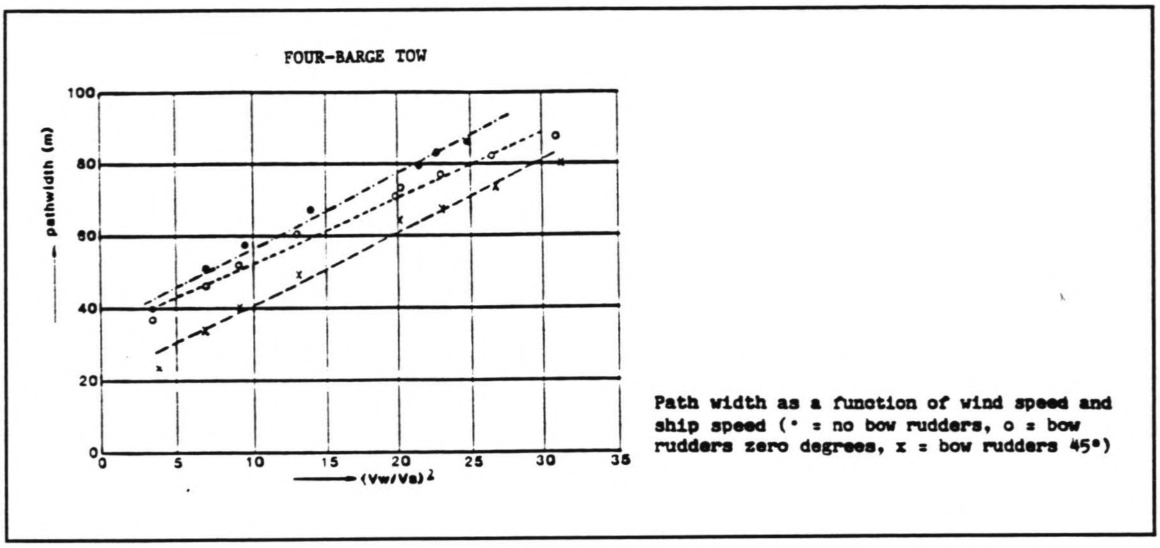


figure B4 path width as a function of wind speed

$$\Delta B = L \cdot \sin\beta$$

in which L = shiplength.

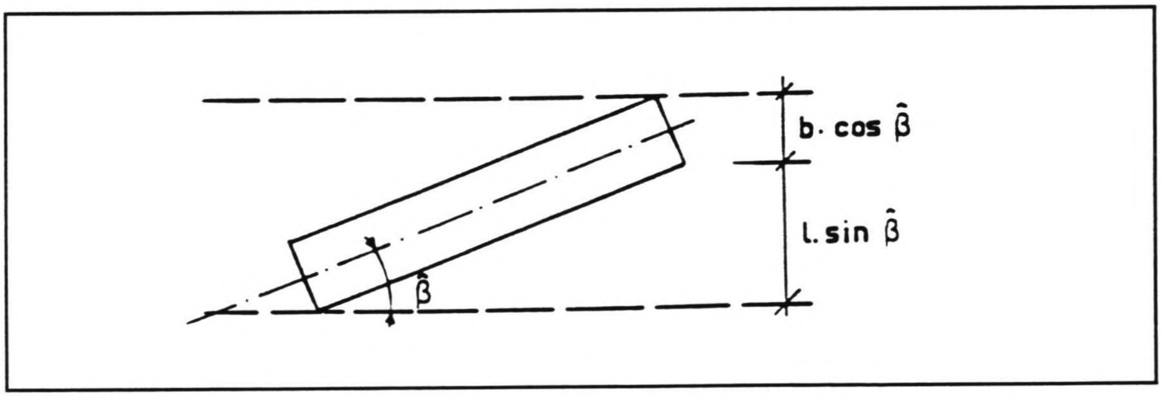


figure B5 driftangle and pathwidth

Windinfluence is only taken into account for the unloaded vessel.

The unloaded vessel has less draught and therefore some slope profit is obtained (see figure B6).

Slope profit = { Draught loaded vessel - Draught unloaded vessel } * cotan(slope angle)

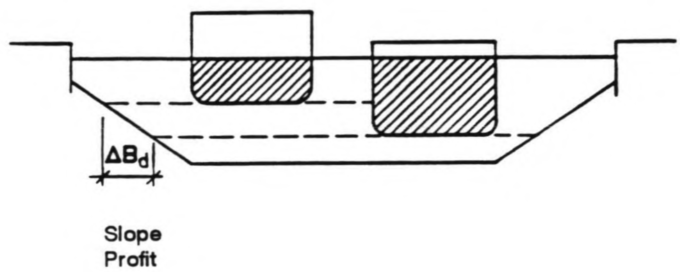


figure B6 slope profit

bankclearance
A bank clearance of 0.3 times the vessel beam for self propelled vessels and 0.5 times for push barges will be taken to reduce bank suction effects.

safety margin
An extra safety margin of 0.5 *B for only day navigation and 1.0 *B for night navigation is taken.

bend pathwidth
When a vessel sails on a curved section of the waterway the ship's centerline will deviate from the tangent of the bend radius. This centerline will point towards the inner bend. This results in an drift angle between centerline and tangent. This drift angle is the result of an equilibrium between all forces that act upon the hull during the rotation through a bend. This drift angle decreases with an increasing vessel velocity, with decreasing depth and with larger bend radii. Also the draught and wind are of influence.

Additional required pathwidth becomes then (see also figure B8):
$L * \sin ß$, with (based on field experiments) $ß \approx L^2 / R$

No detailed information is available about the present bends. The effects of additional widening at bends is not included in the present study.

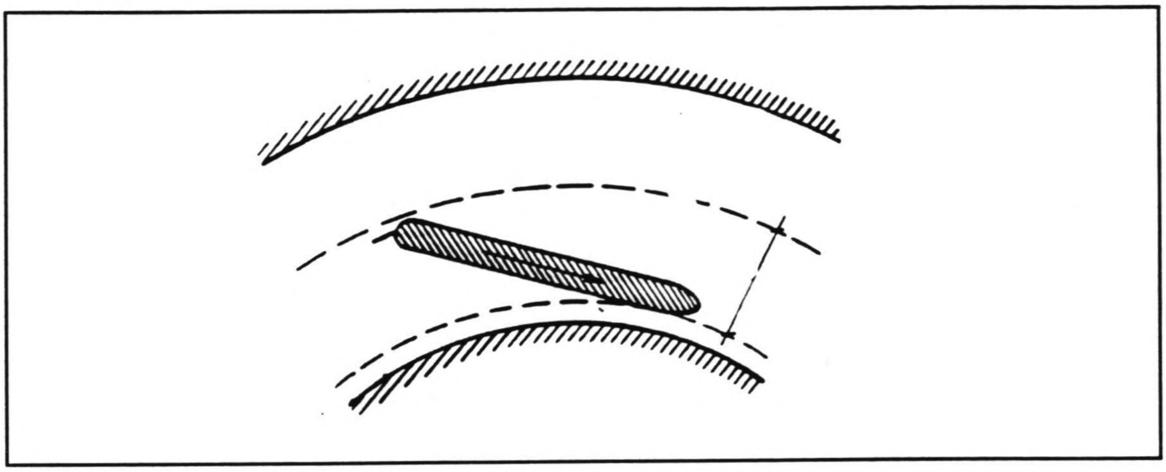


figure B7 vessel sailing through a curve

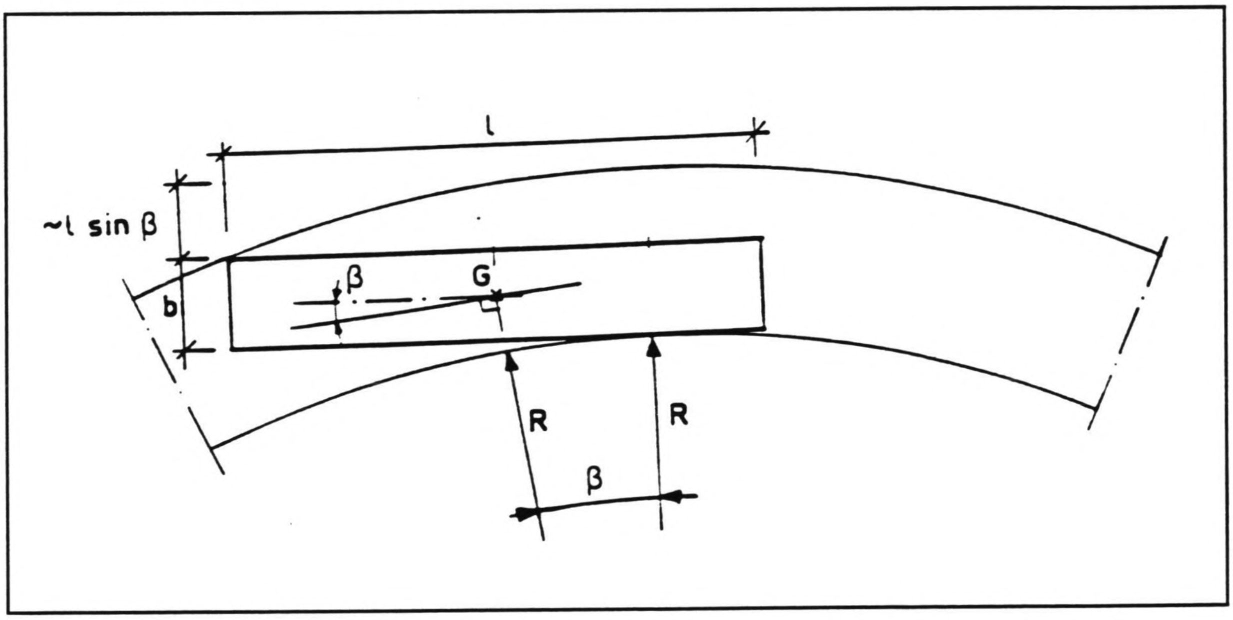


figure B8 required pathwidth in curve

Calculated channel cross profiles for the vessel options are presented in tables 7.3 and 7.4

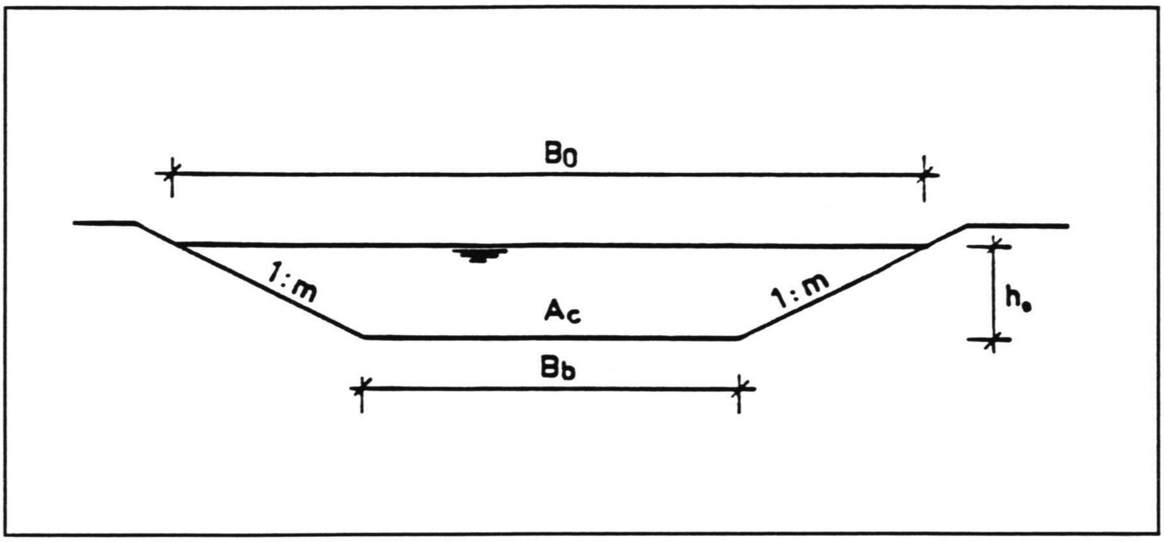


figure B9 channel cross profile

ANNEX C TRANSPORT SYSTEM CALCULATIONS

To calculate and obtain the main system characteristics of the vessel options, a spreadsheet program has been made. Calculations are made for daytime only-and day-and-night navigation. A description of the main components of the calculation is given below.

Each transport system (= vessel option) has to transport 10 million ton of coal per year. Travel distance from the IWT-loading terminal at Cochin to the IWT-unloading terminal at Trikkunnapuzha is 91 km. Sailing speed is according to ANNEX A and sailing speed calculation output in tables 7.3 and 7.4

Shifts at the terminals are considered working 10 hrs. When shifts are changed some time is inefficiently used resulting in extra (waiting) time.

Loading- and unloading rates based on practical experience are given in table C1. The vessels are loaded at Cochin by a continuous loader having an efficiency coefficient of 0.9. The vessels are unloaded at Trikkunnapuzha by portal grabbing cranes having an efficiency coefficient of 0.6 due to the very low capacities when the vessel is almost unloaded.

Resulting trip time then consists of the total sailing time, the lock cycle time and the time in port at the loading - and unloading terminal.

Per year the number of trips becomes then:
(number of working hours per year) / (trip time)

Resulting annual throughput per vessel is the payload times the number of trips per year. The design annual throughput is 10 mmtpa and the number of vessels required to accomplish this throughput can be determined.

A berth occupancy factor of about 0.8 is considered for this scheduled transport system from which the number of required berths can be determined.

Calculation outputs for the vessel options are given in table 7.5 and 7.6 for daytime navigation only and in table 7.7 and 7.8 for day-and-night-navigation.

	unit	SELF PROPELLED VESSELS				BARGE FORMATIONS	
vessel payload	ton	600	1000	1300	2250	3500 (2*1750)	7000 (4*1750)
length	m	55	75	85	110	185	185
beam	m	6.6	8.2	9.5	11.4	11.4	22.8
draught	m	2.5	2.5	2.5	2.8	2.8	2.8
IWT LOADING TERMINAL							
(continuous loader)							
rated loading capacity	t/h	700	1000	1500	1700	1700	2000
effective loading capacity	t/h	630	900	1350	1530	1530	1800
number of berths		6	4	3	2	2	2
IWT UNLOADING TERMINAL							
(grabbing crane)							
rated unloading capacity	t/h	500	500	750	750	1000	1500
effective unloading capacity	t/h	300	300	450	450	600	900
number of berths		11	10	7	6	4	3

Table C1 Loading- and unloading rates

ANNEX D ESTIMATE OF AMOUNT OF DREDGING

When the design cross profile as well as the existing waterway profile is known, the quantity of dredging can be calculated.
Three situations can be distinguished:

Situation 1

The existing profile is wider but less deep than required.

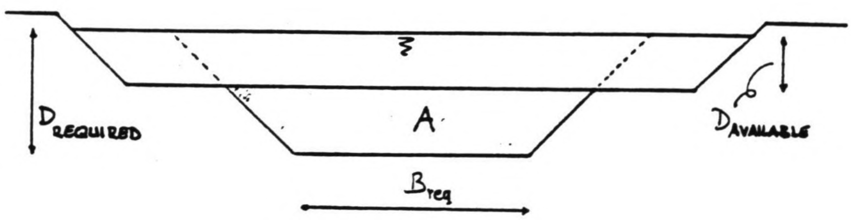


figure D1 situation 1

Dredging quantity is then : A * stretchlength (cum.)
in which

$A = B_{req.} * (D_{req.} - D_{available}) + (D_{req.} - D_{available})^2 * slope_{req.}$
B = Bottom width

Situation 2

The existing profile is less wide and more shallow than required.

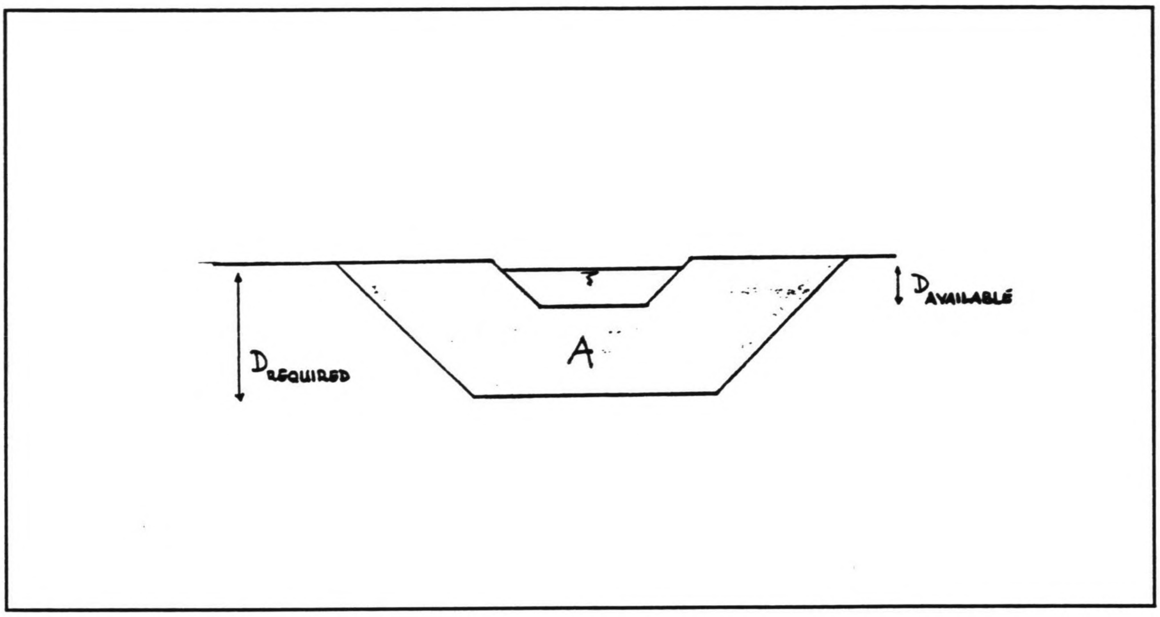


figure D2 situation 2

Now $A = A_{req.} - A_{available}$

Situation 3

The available profile is less wide but deeper than required.

$$\text{Now } A = 2*\{0.5(B_{req.} - B_{av.})*(D_{req.} + a) + (D_{req.} + a)^2*slope_{av.} - (D_{req.} + a)^2*slope_{req.}$$
$$= (B_{req.} - B_{av.})*(D_{req.} + a) + 2(D_{req.} + a)^2*(slope_{av.} - slope_{req.})$$

B is here the toplevel width [m]
a is the height of the banks above waterlevel = 0.5 m

For calculating the total dredging quantities for the channel profiles a spreadsheet program was made.

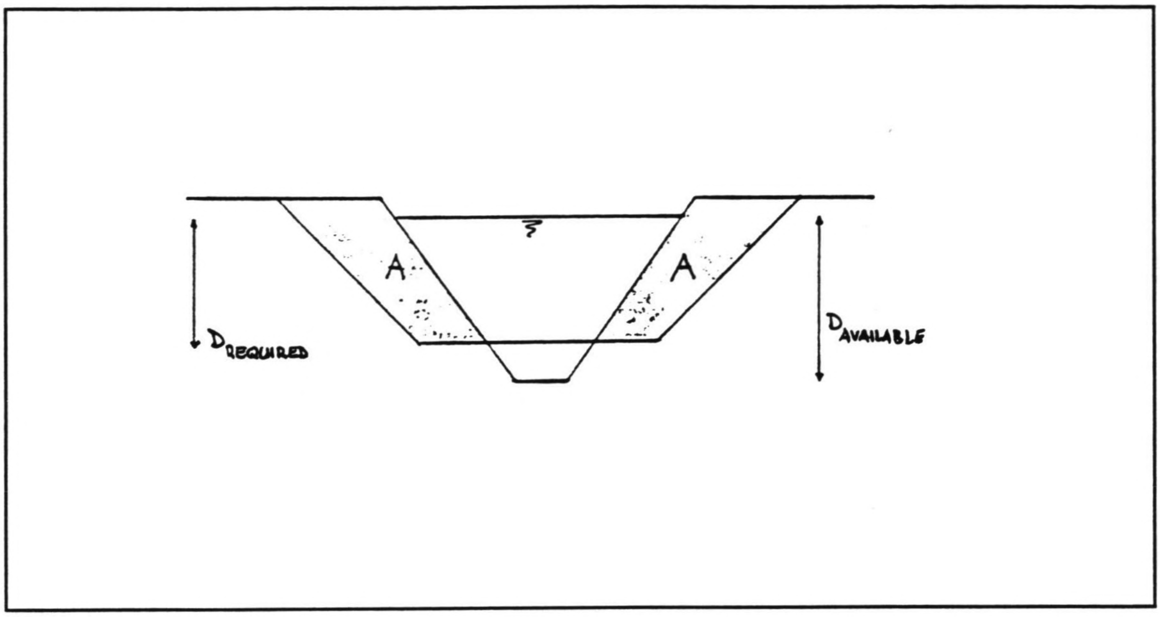


figure D3 situation 3

Stretchwise calculation outputs of dredging quantities are given in tables D1 to D10.
The calculation of amount of land acquisition is given in table D11

LIST OF TABLES REQUIRED DREDGING CALCULATIONS

dre1.wk

REQUIRED DREDGING FOR CHANNEL-PROFILE CAMPINE BARGE (payload 600 t)

DAYTIME NAVIGATION ONLY

CHAINAGE (km.)		AVAILABLE PROFILE				REQUIRED PROFILE				REQUIRED DREDGING
from	to	WIDTH (m.) (average)	DEPTH (m.) (average)	SLOPE (arctan)	A (m2)	WIDTH (m.) at bottom	DEPTH (m.)	SLOPE (arctan)	A (m2) dredge cross section	(cu.m.)
0.00	7.00	1000.00	4.00	10.00	4343	21.00	3.40	3.00	128	0
7.00	7.50	1000.00	2.00	10.00	2463	21.00	3.40	3.00	128	17,640
7.50	21.00	1000.00	4.00	10.00	4343	21.00	3.40	3.00	128	0
21.00	22.00	1000.00	1.00	10.00	1493	21.00	3.40	3.00	128	67,680
22.00	30.00	1000.00	4.00	10.00	4343	21.00	3.40	3.00	128	0
30.00	49.00	3000.00	4.00	10.00	13343	21.00	3.40	3.00	128	0
49.00	62.00	3000.00	1.00	5.00	4496	21.00	3.40	3.00	128	879,840
62.00	65.00	55.00	1.50	2.50	105	21.00	3.40	3.00	128	152,190
65.00	73.00	100.00	5.00	5.00	426	21.00	3.40	3.00	128	0
73.00	75.00	25.00	1.00	10.00	30	21.00	3.40	3.00	128	195,060
75.00	84.00	25.00	2.00	5.00	44	21.00	3.40	3.00	128	754,020
84.00	91.00	35.00	1.50	5.00	60	21.00	3.40	3.00	128	472,710
									TOTAL DREDGING :	**2,539,140** cu.m.

DAY AND NIGHT NAVIGATION

CHAINAGE (km.)		AVAILABLE PROFILE				REQUIRED PROFILE				REQUIRED DREDGING
from	to	WIDTH (m.) (average)	DEPTH (m.) (average)	SLOPE (arctan)	A (m2)	WIDTH (m.) at bottom	DEPTH (m.)	SLOPE (arctan)	A (m2) dredge cross section	(cu.m.)
0.00	7.00	1000.00	4.00	10.00	4343	25.00	3.40	3.00	143	0
7.00	7.50	1000.00	2.00	10.00	2463	25.00	3.40	3.00	143	20,440
7.50	21.00	1000.00	4.00	10.00	4343	25.00	3.40	3.00	143	0
21.00	22.00	1000.00	1.00	10.00	1493	25.00	3.40	3.00	143	77,280
22.00	30.00	1000.00	4.00	10.00	4343	25.00	3.40	3.00	143	0
30.00	49.00	3000.00	4.00	10.00	13343	25.00	3.40	3.00	143	0
49.00	62.00	3000.00	1.00	5.00	4496	25.00	3.40	3.00	143	1,004,640
62.00	65.00	55.00	1.50	2.50	105	25.00	3.40	3.00	143	174,990
65.00	73.00	100.00	5.00	5.00	426	25.00	3.40	3.00	143	0
73.00	75.00	25.00	1.00	10.00	30	25.00	3.40	3.00	143	226,260
75.00	84.00	25.00	2.00	5.00	44	25.00	3.40	3.00	143	894,420
84.00	91.00	35.00	1.50	5.00	60	25.00	3.40	3.00	143	581,910
									TOTAL DREDGING :	**2,979,940** cu.m.

Table D1 Required dredging for 'Campine barge'

dre2.wk

REQUIRED DREDGING FOR CHANNEL–PROFILE "DORTMUND–EEMS–CANAL VESSEL" (payload 1000 t)

DAYTIME NAVIGATION ONLY

CHAINAGE (km.) from	to	AVAILABLE PROFILE WIDTH (m.) (average)	DEPTH (m.) (average)	SLOPE (arctan)	A (m2)	REQUIRED PROFILE WIDTH (m.) at bottom	DEPTH (m.)	SLOPE (arctan)	A (m2) dredge cross section	REQUIRED DREDGING (cu.m.)
0.00	7.00	1000.00	4.00	10.00	4343	30.00	3.40	3.00	163	0
7.00	7.50	1000.00	2.00	10.00	2463	30.00	3.40	3.00	163	23,940
7.50	21.00	1000.00	4.00	10.00	4343	30.00	3.40	3.00	163	0
21.00	22.00	1000.00	1.00	10.00	1493	30.00	3.40	3.00	163	89,280
22.00	30.00	1000.00	4.00	10.00	4343	30.00	3.40	3.00	163	0
30.00	49.00	3000.00	4.00	10.00	13343	30.00	3.40	3.00	163	0
49.00	62.00	3000.00	1.00	5.00	4496	30.00	3.40	3.00	163	1,160,640
62.00	65.00	55.00	1.50	2.50	105	30.00	3.40	3.00	163	203,490
65.00	73.00	100.00	5.00	5.00	426	30.00	3.40	3.00	163	0
73.00	75.00	25.00	1.00	10.00	30	30.00	3.40	3.00	163	265,260
75.00	84.00	25.00	2.00	5.00	44	30.00	3.40	3.00	163	1,069,920
84.00	91.00	35.00	1.50	5.00	60	30.00	3.40	3.00	163	718,410
									TOTAL DREDGING :	3,530,940 cu.m.

DAY AND NIGHT NAVIGATION

CHAINAGE (km.) from	to	AVAILABLE PROFILE WIDTH (m.) (average)	DEPTH (m.) (average)	SLOPE (arctan)	A (m2)	REQUIRED PROFILE WIDTH (m.) at bottom	DEPTH (m.)	SLOPE (arctan)	A (m2) dredge cross section	REQUIRED DREDGING (cu.m.)
0.00	7.00	1000.00	4.00	10.00	4343	34.00	3.40	3.00	178	0
7.00	7.50	1000.00	2.00	10.00	2463	34.00	3.40	3.00	178	26,740
7.50	21.00	1000.00	4.00	10.00	4343	34.00	3.40	3.00	178	0
21.00	22.00	1000.00	1.00	10.00	1493	34.00	3.40	3.00	178	98,880
22.00	30.00	1000.00	4.00	10.00	4343	34.00	3.40	3.00	178	0
30.00	49.00	3000.00	4.00	10.00	13343	34.00	3.40	3.00	178	0
49.00	62.00	3000.00	1.00	5.00	4496	34.00	3.40	3.00	178	1,285,440
62.00	65.00	55.00	1.50	2.50	105	34.00	3.40	3.00	178	226,290
65.00	73.00	100.00	5.00	5.00	426	34.00	3.40	3.00	178	0
73.00	75.00	25.00	1.00	10.00	30	34.00	3.40	3.00	178	296,460
75.00	84.00	25.00	2.00	5.00	44	34.00	3.40	3.00	178	1,210,320
84.00	91.00	35.00	1.50	5.00	60	34.00	3.40	3.00	178	827,610
									TOTAL DREDGING :	3,971,740 cu.m.

Table D2 Required dredging for 'Dortmund-Eems-Canal vessel'

dre3.wk

REQUIRED DREDGING FOR CHANNEL-PROFILE "RHINE-HERNE CAN. VESSEL" (payload 1300 t)

DAYTIME NAVIGATION ONLY

CHAINAGE (km.)		AVAILABLE PROFILE				REQUIRED PROFILE				REQUIRED DREDGING
from	to	WIDTH (m.) (average)	DEPTH (m.) (average)	SLOPE (arctan)	A (m2)	WIDTH (m.) at bottom	DEPTH (m.)	SLOPE (arctan)	A (m2) dredge cross section	(cu.m.)
0.00	7.00	1000.00	4.00	10.00	4343	36.00	3.40	3.00	186	0
7.00	7.50	1000.00	2.00	10.00	2463	36.00	3.40	3.00	186	28,140
7.50	21.00	1000.00	4.00	10.00	4343	36.00	3.40	3.00	186	0
21.00	22.00	1000.00	1.00	10.00	1493	36.00	3.40	3.00	186	103,680
22.00	30.00	1000.00	4.00	10.00	4343	36.00	3.40	3.00	186	0
30.00	49.00	3000.00	4.00	10.00	13343	36.00	3.40	3.00	186	0
49.00	62.00	3000.00	1.00	5.00	4496	36.00	3.40	3.00	186	1,347,840
62.00	65.00	55.00	1.50	2.50	105	36.00	3.40	3.00	186	243,090
65.00	73.00	100.00	5.00	5.00	426	36.00	3.40	3.00	186	0
73.00	75.00	25.00	1.00	10.00	30	36.00	3.40	3.00	186	312,060
75.00	84.00	25.00	2.00	5.00	44	36.00	3.40	3.00	186	1,280,520
84.00	91.00	35.00	1.50	5.00	60	36.00	3.40	3.00	186	882,210
									TOTAL DREDGING :	**4,197,540** cu.m.

DAY AND NIGHT NAVIGATION

CHAINAGE (km.)		AVAILABLE PROFILE				REQUIRED PROFILE				REQUIRED DREDGING
from	to	WIDTH (m.) (average)	DEPTH (m.) (average)	SLOPE (arctan)	A (m2)	WIDTH (m.) at bottom	DEPTH (m.)	SLOPE (arctan)	A (m2) dredge cross section	(cu.m.)
0.00	7.00	1000.00	4.00	10.00	4343	41.00	3.40	3.00	206	0
7.00	7.50	1000.00	2.00	10.00	2463	41.00	3.40	3.00	206	31,640
7.50	21.00	1000.00	4.00	10.00	4343	41.00	3.40	3.00	206	0
21.00	22.00	1000.00	1.00	10.00	1493	41.00	3.40	3.00	206	115,680
22.00	30.00	1000.00	4.00	10.00	4343	41.00	3.40	3.00	206	0
30.00	49.00	3000.00	4.00	10.00	13343	41.00	3.40	3.00	206	0
49.00	62.00	3000.00	1.00	5.00	4496	41.00	3.40	3.00	206	1,503,840
62.00	65.00	55.00	1.50	2.50	105	41.00	3.40	3.00	206	301,590
65.00	73.00	100.00	5.00	5.00	426	41.00	3.40	3.00	206	0
73.00	75.00	25.00	1.00	10.00	30	41.00	3.40	3.00	206	351,060
75.00	84.00	25.00	2.00	5.00	44	41.00	3.40	3.00	206	1,456,020
84.00	91.00	35.00	1.50	5.00	60	41.00	3.40	3.00	206	1,018,710
									TOTAL DREDGING :	**4,778,540** cu.m.

Table D3 Required dredging for 'Rhine-Herne-Canal vessel'

dre4.wk

REQUIRED DREDGING FOR CHANNEL-PROFILE LARGE RHINE VESSEL (payload 2250 t)

DAYTIME NAVIGATION ONLY

CHAINAGE (km.) from	to	AVAILABLE PROFILE WIDTH (m.) (average)	DEPTH (m.) (average)	SLOPE (arctan)	A (m2)	REQUIRED PROFILE WIDTH (m.) at bed level	DEPTH (m.)	SLOPE (arctan)	A (m2) dredge cross section	REQUIRED DREDGING (cu.m.)
0.00	7.00	1000.00	4.00	10.00	4343	45.00	3.80	3.00	249	0
7.00	7.50	1000.00	2.00	10.00	2463	45.00	3.80	3.00	249	45,360
7.50	21.00	1000.00	4.00	10.00	4343	45.00	3.80	3.00	249	0
21.00	22.00	1000.00	1.00	10.00	1493	45.00	3.80	3.00	249	149,520
22.00	30.00	1000.00	4.00	10.00	4343	45.00	3.80	3.00	249	0
30.00	49.00	3000.00	4.00	10.00	13343	45.00	3.80	3.00	249	0
49.00	62.00	3000.00	1.00	5.00	4496	45.00	3.80	3.00	249	1,943,760
62.00	65.00	55.00	1.50	2.50	105	45.00	3.80	3.00	249	431,910
65.00	73.00	100.00	5.00	5.00	426	45.00	3.80	3.00	249	0
73.00	75.00	25.00	1.00	10.00	30	45.00	3.80	3.00	249	437,940
75.00	84.00	25.00	2.00	5.00	44	45.00	3.80	3.00	249	1,846,980
84.00	91.00	35.00	1.50	5.00	60	45.00	3.80	3.00	249	1,322,790
									TOTAL DREDGING :	**6,178,260** cu.m.

DAY AND NIGHT NAVIGATION

CHAINAGE (km.) from	to	AVAILABLE PROFILE WIDTH (m.) (average)	DEPTH (m.) (average)	SLOPE (arctan)	A (m2)	REQUIRED PROFILE WIDTH (m.) at bed level	DEPTH (m.)	SLOPE (arctan)	A (m2) dredge cross section	REQUIRED DREDGING (cu.m.)
0.00	7.00	1000.00	4.00	10.00	4343	51.00	3.80	3.00	275	0
7.00	7.50	1000.00	2.00	10.00	2463	51.00	3.80	3.00	275	50,760
7.50	21.00	1000.00	4.00	10.00	4343	51.00	3.80	3.00	275	0
21.00	22.00	1000.00	1.00	10.00	1493	51.00	3.80	3.00	275	166,320
22.00	30.00	1000.00	4.00	10.00	4343	51.00	3.80	3.00	275	0
30.00	49.00	3000.00	4.00	10.00	13343	51.00	3.80	3.00	275	0
49.00	62.00	3000.00	1.00	5.00	4496	51.00	3.80	3.00	275	2,162,160
62.00	65.00	55.00	1.50	2.50	105	51.00	3.80	3.00	275	509,310
65.00	73.00	100.00	5.00	5.00	426	51.00	3.80	3.00	275	0
73.00	75.00	25.00	1.00	10.00	30	51.00	3.80	3.00	275	489,540
75.00	84.00	25.00	2.00	5.00	44	51.00	3.80	3.00	275	2,079,180
84.00	91.00	35.00	1.50	5.00	60	51.00	3.80	3.00	275	1,503,390
									TOTAL DREDGING :	**6,960,660** cu.m.

Table D4 Required dredging for 'Large Rhine vessel'

dre5.wk

REQUIRED DREDGING FOR CHANNEL–PROFILE 2 * 1 BARGE FORMATION ; DRAUGHT 2.8 M. (payload 3500 t)

ONLY DAY NAVIGATION

CHAINAGE (km.) from	to	AVAILABLE PROFILE WIDTH (m.) (average)	DEPTH (m.) (average)	SLOPE (arctan)	A (m2)	REQUIRED PROFILE WIDTH (m.) at bottom	DEPTH (m.)	SLOPE (arctan)	A (m2) dredge cross section	REQUIRED DREDGING (cu.m.)
0.00	7.00	1000.00	4.00	10.00	4343	83.00	3.80	3.00	412	0
7.00	7.50	1000.00	2.00	10.00	2463	83.00	3.80	3.00	412	79,560
7.50	21.00	1000.00	4.00	10.00	4343	83.00	3.80	3.00	412	0
21.00	22.00	1000.00	1.00	10.00	1493	83.00	3.80	3.00	412	255,920
22.00	30.00	1000.00	4.00	10.00	4343	83.00	3.80	3.00	412	0
30.00	49.00	3000.00	4.00	10.00	13343	83.00	3.80	3.00	412	0
49.00	62.00	3000.00	1.00	5.00	4496	83.00	3.80	3.00	412	3,326,960
62.00	65.00	55.00	1.50	2.50	105	83.00	3.80	3.00	412	922,110
65.00	73.00	100.00	5.00	5.00	426	83.00	3.80	3.00	412	0
73.00	75.00	25.00	1.00	10.00	30	83.00	3.80	3.00	412	764,740
75.00	84.00	25.00	2.00	5.00	44	83.00	3.80	3.00	412	3,317,580
84.00	91.00	35.00	1.50	5.00	60	83.00	3.80	3.00	412	2,466,590
									TOTAL DREDGING :	**11,133,460** cu.m.

DAY AND NIGHT NAVIGATION

CHAINAGE (km.) from	to	AVAILABLE PROFILE WIDTH (m.) (average)	DEPTH (m.) (average)	SLOPE (arctan)	A (m2)	REQUIRED PROFILE WIDTH (m.) at bottom	DEPTH (m.)	SLOPE (arctan)	A (m2) dredge cross section	REQUIRED DREDGING (cu.m.)
0.00	7.00	1000.00	4.00	10.00	4343	88.00	3.80	3.00	434	0
7.00	7.50	1000.00	2.00	10.00	2463	88.00	3.80	3.00	434	84,060
7.50	21.00	1000.00	4.00	10.00	4343	88.00	3.80	3.00	434	0
21.00	22.00	1000.00	1.00	10.00	1493	88.00	3.80	3.00	434	269,920
22.00	30.00	1000.00	4.00	10.00	4343	88.00	3.80	3.00	434	0
30.00	49.00	3000.00	4.00	10.00	13343	88.00	3.80	3.00	434	0
49.00	62.00	3000.00	1.00	5.00	4496	88.00	3.80	3.00	434	3,508,960
62.00	65.00	55.00	1.50	2.50	105	88.00	3.80	3.00	434	986,610
65.00	73.00	100.00	5.00	5.00	426	88.00	3.80	3.00	434	0
73.00	75.00	25.00	1.00	10.00	30	88.00	3.80	3.00	434	807,740
75.00	84.00	25.00	2.00	5.00	44	88.00	3.80	3.00	434	3,511,080
84.00	91.00	35.00	1.50	5.00	60	88.00	3.80	3.00	434	2,617,090
									TOTAL DREDGING :	**11,785,460** cu.m.

Table D5 Required dredging for 2*1 Barge formation (D=2.8m)

dre6.wk

REQUIRED DREDGING FOR CHANNEL–PROFILE 1 * 2 – BARGE FORMATION ; DRAUGHT 2.8 M. (payload 3500 t)

DAYTIME NAVIGATION ONLY

CHAINAGE (km.) from	to	AVAILABLE PROFILE WIDTH (m.) (average)	DEPTH (m.) (average)	SLOPE (arctan)	A (m2)	REQUIRED PROFILE WIDTH (m.) at bottom	DEPTH (m.)	SLOPE (arctan)	A (m2) dredge cross section	REQUIRED DREDGING (cu.m.)
0.00	7.00	1000.00	4.00	10.00	4343	96.00	3.80	3.00	468	0
7.00	7.50	1000.00	2.00	10.00	2463	96.00	3.80	3.00	468	91,260
7.50	21.00	1000.00	4.00	10.00	4343	96.00	3.80	3.00	468	0
21.00	22.00	1000.00	1.00	10.00	1493	96.00	3.80	3.00	468	292,320
22.00	30.00	1000.00	4.00	10.00	4343	96.00	3.80	3.00	468	0
30.00	49.00	3000.00	4.00	10.00	13343	96.00	3.80	3.00	468	0
49.00	62.00	3000.00	1.00	5.00	4496	96.00	3.80	3.00	468	3,800,160
62.00	65.00	55.00	1.50	2.50	105	96.00	3.80	3.00	468	1,089,810
65.00	73.00	100.00	5.00	5.00	426	96.00	3.80	3.00	468	0
73.00	75.00	25.00	1.00	10.00	30	96.00	3.80	3.00	468	876,540
75.00	84.00	25.00	2.00	5.00	44	96.00	3.80	3.00	468	3,820,680
84.00	91.00	35.00	1.50	5.00	60	96.00	3.80	3.00	468	2,857,890

TOTAL DREDGING : **12,828,660** cu.m.

DAY AND NIGHT NAVIGATION

CHAINAGE (km.) from	to	AVAILABLE PROFILE WIDTH (m.) (average)	DEPTH (m.) (average)	SLOPE (arctan)	A (m2)	REQUIRED PROFILE WIDTH (m.) at bottom	DEPTH (m.)	SLOPE (arctan)	A (m2) dredge cross section	REQUIRED DREDGING (cu.m.)
0.00	7.00	1000.00	4.00	10.00	4343	107.00	3.80	3.00	516	0
7.00	7.50	1000.00	2.00	10.00	2463	107.00	3.80	3.00	516	101,160
7.50	21.00	1000.00	4.00	10.00	4343	107.00	3.80	3.00	516	0
21.00	22.00	1000.00	1.00	10.00	1493	107.00	3.80	3.00	516	323,120
22.00	30.00	1000.00	4.00	10.00	4343	107.00	3.80	3.00	516	0
30.00	49.00	3000.00	4.00	10.00	13343	107.00	3.80	3.00	516	0
49.00	62.00	3000.00	1.00	5.00	4496	107.00	3.80	3.00	516	4,200,560
62.00	65.00	55.00	1.50	2.50	105	107.00	3.80	3.00	516	1,231,710
65.00	73.00	100.00	5.00	5.00	426	107.00	3.80	3.00	516	832,480
73.00	75.00	25.00	1.00	10.00	30	107.00	3.80	3.00	516	971,140
75.00	84.00	25.00	2.00	5.00	44	107.00	3.80	3.00	516	4,246,380
84.00	91.00	35.00	1.50	5.00	60	107.00	3.80	3.00	516	3,188,990

TOTAL DREDGING : **15,095,540** cu.m.

Table D6 Required dredging for 1*2 Barge formation (D = 2.8m)

dre7.wk

REQUIRED DREDGING FOR CHANNEL-PROFILE 2 * 2 – BARGE FORMATION ; DRAUGHT 2.8 M. (payload 7,000 t)

DAYTIME NAVIGATION ONLY

CHAINAGE (km.)		AVAILABLE PROFILE				REQUIRED PROFILE				REQUIRED DREDGING
from	to	WIDTH (m.) (average)	DEPTH (m.) (average)	SLOPE (arctan)	A (m2)	WIDTH (m.) at bottom	DEPTH (m.)	SLOPE (arctan)	A (m2) dredge cross section	(cu.m.)
0.00	7.00	1000.00	4.00	10.00	4343	140.00	3.80	3.00	657	0
7.00	7.50	1000.00	2.00	10.00	2463	140.00	3.80	3.00	657	130,860
7.50	21.00	1000.00	4.00	10.00	4343	140.00	3.80	3.00	657	0
21.00	22.00	1000.00	1.00	10.00	1493	140.00	3.80	3.00	657	415,520
22.00	30.00	1000.00	4.00	10.00	4343	140.00	3.80	3.00	657	0
30.00	49.00	3000.00	4.00	10.00	13343	140.00	3.80	3.00	657	0
49.00	62.00	3000.00	1.00	5.00	4496	140.00	3.80	3.00	657	5,401,760
62.00	65.00	55.00	1.50	2.50	105	140.00	3.80	3.00	657	1,657,410
65.00	73.00	100.00	5.00	5.00	426	140.00	3.80	3.00	657	2,758,880
73.00	75.00	25.00	1.00	10.00	30	140.00	3.80	3.00	657	1,254,940
75.00	84.00	25.00	2.00	5.00	44	140.00	3.80	3.00	657	5,523,480
84.00	91.00	35.00	1.50	5.00	60	140.00	3.80	3.00	657	4,182,290

TOTAL DREDGING : **21,325,140** cu.m.

DAY AND NIGHT NAVIGATION

CHAINAGE (km.)		AVAILABLE PROFILE				REQUIRED PROFILE				REQUIRED DREDGING
from	to	WIDTH (m.) (average)	DEPTH (m.) (average)	SLOPE (arctan)	A (m2)	WIDTH (m.) at bottom	DEPTH (m.)	SLOPE (arctan)	A (m2) dredge cross section	(cu.m.)
0.00	7.00	1000.00	4.00	10.00	4343	151.00	3.80	3.00	705	0
7.00	7.50	1000.00	2.00	10.00	2463	151.00	3.80	3.00	705	140,760
7.50	21.00	1000.00	4.00	10.00	4343	151.00	3.80	3.00	705	0
21.00	22.00	1000.00	1.00	10.00	1493	151.00	3.80	3.00	705	446,320
22.00	30.00	1000.00	4.00	10.00	4343	151.00	3.80	3.00	705	0
30.00	49.00	3000.00	4.00	10.00	13343	151.00	3.80	3.00	705	0
49.00	62.00	3000.00	1.00	5.00	4496	151.00	3.80	3.00	705	5,802,160
62.00	65.00	55.00	1.50	2.50	105	151.00	3.80	3.00	705	1,799,310
65.00	73.00	100.00	5.00	5.00	426	151.00	3.80	3.00	705	3,137,280
73.00	75.00	25.00	1.00	10.00	30	151.00	3.80	3.00	705	1,349,540
75.00	84.00	25.00	2.00	5.00	44	151.00	3.80	3.00	705	5,949,180
84.00	91.00	35.00	1.50	5.00	60	151.00	3.80	3.00	705	4,513,390

TOTAL DREDGING : **23,137,940** cu.m.

Table D7 Required dredging for 2*2 Barge formation (D=2.8m)

dre8.wk

REQUIRED DREDGING FOR CHANNEL-PROFILE 2 * 1 - BARGE FORMATION ; DRAUGHT 4.5 M. (payload 5,600 t)

DAY NAVIGATION ONLY

CHAINAGE (km.) from	to	AVAILABLE PROFILE WIDTH (m.) (average)	DEPTH (m.) (average)	SLOPE (arctan)	A (m2)	REQUIRED PROFILE WIDTH (m.) at bottom	DEPTH (m.)	SLOPE (arctan)	A (m2) dredge cross section	REQUIRED DREDGING (cu.m.)
0.00	7.00	1000.00	4.00	10.00	4343	75.00	6.10	3.00	626	1,195,110
7.00	7.50	1000.00	2.00	10.00	2463	75.00	6.10	3.00	626	178,965
7.50	21.00	1000.00	4.00	10.00	4343	75.00	6.10	3.00	626	2,304,855
21.00	22.00	1000.00	1.00	10.00	1493	75.00	6.10	3.00	626	460,530
22.00	30.00	1000.00	4.00	10.00	4343	75.00	6.10	3.00	626	1,365,840
30.00	49.00	3000.00	4.00	10.00	13343	75.00	6.10	3.00	626	3,243,870
49.00	62.00	3000.00	1.00	5.00	4496	75.00	6.10	3.00	626	5,986,890
62.00	65.00	55.00	1.50	2.50	105	75.00	6.10	3.00	626	1,562,040
65.00	73.00	100.00	5.00	5.00	426	75.00	6.10	3.00	626	1,595,440
73.00	75.00	25.00	1.00	10.00	30	75.00	6.10	3.00	626	1,191,360
75.00	84.00	25.00	2.00	5.00	44	75.00	6.10	3.00	626	5,237,370
84.00	91.00	35.00	1.50	5.00	60	75.00	6.10	3.00	626	3,959,760

TOTAL DREDGING : **28,282,030** cu.m.

DAY AND NIGHT NAVIGATION

CHAINAGE (km.) from	to	AVAILABLE PROFILE WIDTH (m.) (average)	DEPTH (m.) (average)	SLOPE (arctan)	A (m2)	REQUIRED PROFILE WIDTH (m.) at bottom	DEPTH (m.)	SLOPE (arctan)	A (m2) dredge cross section	REQUIRED DREDGING (cu.m.)
0.00	7.00	1000.00	4.00	10.00	4343	80.00	6.10	3.00	659	1,268,610
7.00	7.50	1000.00	2.00	10.00	2463	80.00	6.10	3.00	659	189,215
7.50	21.00	1000.00	4.00	10.00	4343	80.00	6.10	3.00	659	2,446,605
21.00	22.00	1000.00	1.00	10.00	1493	80.00	6.10	3.00	659	486,030
22.00	30.00	1000.00	4.00	10.00	4343	80.00	6.10	3.00	659	1,449,840
30.00	49.00	3000.00	4.00	10.00	13343	80.00	6.10	3.00	659	3,443,370
49.00	62.00	3000.00	1.00	5.00	4496	80.00	6.10	3.00	659	6,318,390
62.00	65.00	55.00	1.50	2.50	105	80.00	6.10	3.00	659	1,661,040
65.00	73.00	100.00	5.00	5.00	426	80.00	6.10	3.00	659	1,859,440
73.00	75.00	25.00	1.00	10.00	30	80.00	6.10	3.00	659	1,257,360
75.00	84.00	25.00	2.00	5.00	44	80.00	6.10	3.00	659	5,534,370
84.00	91.00	35.00	1.50	5.00	60	80.00	6.10	3.00	659	4,190,760

TOTAL DREDGING : **30,105,030** cu.m.

Table D8 Required dredging for 2*1 Barge formation (D=4.5m)

dre9.wk

REQUIRED DREDGING FOR CHANNEL-PROFILE 1 * 2 - BARGE FORMATION ; DRAUGHT 4.5 M. (payload 5,600 t)

DAYTIME NAVIGATION ONLY

CHAINAGE (km.)		AVAILABLE PROFILE				REQUIRED PROFILE				
from	to	WIDTH (m.) (average)	DEPTH (m.) (average)	SLOPE (arctan)	A (m2)	WIDTH (m.) at bottom	DEPTH (m.)	SLOPE (arctan)	A (m2) dredge cross section	REQUIRED DREDGING (cu.m.)
0.00	7.00	1000.00	4.00	10.00	4343	88.00	6.10	3.00	711	1,386,210
7.00	7.50	1000.00	2.00	10.00	2463	88.00	6.10	3.00	711	205,615
7.50	21.00	1000.00	4.00	10.00	4343	88.00	6.10	3.00	711	2,673,405
21.00	22.00	1000.00	1.00	10.00	1493	88.00	6.10	3.00	711	526,830
22.00	30.00	1000.00	4.00	10.00	4343	88.00	6.10	3.00	711	1,584,240
30.00	49.00	3000.00	4.00	10.00	13343	88.00	6.10	3.00	711	3,762,570
49.00	62.00	3000.00	1.00	5.00	4496	88.00	6.10	3.00	711	6,848,790
62.00	65.00	55.00	1.50	2.50	105	88.00	6.10	3.00	711	1,819,440
65.00	73.00	100.00	5.00	5.00	426	88.00	6.10	3.00	711	2,281,840
73.00	75.00	25.00	1.00	10.00	30	88.00	6.10	3.00	711	1,362,960
75.00	84.00	25.00	2.00	5.00	44	88.00	6.10	3.00	711	6,009,570
84.00	91.00	35.00	1.50	5.00	60	88.00	6.10	3.00	711	4,560,360

TOTAL DREDGING : **33,021,830** cu.m.

DAY AND NIGHT NAVIGATION

CHAINAGE (km.)		AVAILABLE PROFILE				REQUIRED PROFILE				
from	to	WIDTH (m.) (average)	DEPTH (m.) (average)	SLOPE (arctan)	A (m2)	WIDTH (m.) at bottom	DEPTH (m.)	SLOPE (arctan)	A (m2) dredge cross section	REQUIRED DREDGING (cu.m.)
0.00	7.00	1000.00	4.00	10.00	4343	98.00	6.10	3.00	777	1,533,210
7.00	7.50	1000.00	2.00	10.00	2463	98.00	6.10	3.00	777	226,115
7.50	21.00	1000.00	4.00	10.00	4343	98.00	6.10	3.00	777	2,956,905
21.00	22.00	1000.00	1.00	10.00	1493	98.00	6.10	3.00	777	577,830
22.00	30.00	1000.00	4.00	10.00	4343	98.00	6.10	3.00	777	1,752,240
30.00	49.00	3000.00	4.00	10.00	13343	98.00	6.10	3.00	777	4,161,570
49.00	62.00	3000.00	1.00	5.00	4496	98.00	6.10	3.00	777	7,511,790
62.00	65.00	55.00	1.50	2.50	105	98.00	6.10	3.00	777	2,017,440
65.00	73.00	100.00	5.00	5.00	426	98.00	6.10	3.00	777	2,809,840
73.00	75.00	25.00	1.00	10.00	30	98.00	6.10	3.00	777	1,494,960
75.00	84.00	25.00	2.00	5.00	44	98.00	6.10	3.00	777	6,603,570
84.00	91.00	35.00	1.50	5.00	60	98.00	6.10	3.00	777	5,022,360

TOTAL DREDGING : **36,667,830** cu.m.

Table D9 Required dredging for 1*2 Barge formation (D=4.5m)

dre10.wk

REQUIRED DREDGING FOR CHANNEL-PROFILE 2 * 2 - BARGE FORMATION ; DRAUGHT 4.5 M. (payload 11,200 t)

DAYTIME NAVIGATION ONLY

CHAINAGE (km.) from	to	AVAILABLE PROFILE WIDTH (m.) (average)	DEPTH (m.) (average)	SLOPE (arctan)	A (m2)	REQUIRED PROFILE WIDTH (m.) at bottom	DEPTH (m.)	SLOPE (arctan)	A (m2) dredge cross section	REQUIRED DREDGING (cu.m.)
0.00	7.00	1000.00	4.00	10.00	4343	132.00	6.10	3.00	1002	2,033,010
7.00	7.50	1000.00	2.00	10.00	2463	132.00	6.10	3.00	1002	295,815
7.50	21.00	1000.00	4.00	10.00	4343	132.00	6.10	3.00	1002	3,920,805
21.00	22.00	1000.00	1.00	10.00	1493	132.00	6.10	3.00	1002	751,230
22.00	30.00	1000.00	4.00	10.00	4343	132.00	6.10	3.00	1002	2,323,440
30.00	49.00	3000.00	4.00	10.00	13343	132.00	6.10	3.00	1002	5,518,170
49.00	62.00	3000.00	1.00	5.00	4496	132.00	6.10	3.00	1002	9,765,990
62.00	65.00	55.00	1.50	2.50	105	132.00	6.10	3.00	1002	2,690,640
65.00	73.00	100.00	5.00	5.00	426	132.00	6.10	3.00	1002	4,605,040
73.00	75.00	25.00	1.00	10.00	30	132.00	6.10	3.00	1002	1,943,760
75.00	84.00	25.00	2.00	5.00	44	132.00	6.10	3.00	1002	8,623,170
84.00	91.00	35.00	1.50	5.00	60	132.00	6.10	3.00	1002	6,593,160

TOTAL DREDGING : **49,064,230** cu.m.

DAY AND NIGHT NAVIGATION

CHAINAGE (km.) from	to	AVAILABLE PROFILE WIDTH (m.) (average)	DEPTH (m.) (average)	SLOPE (arctan)	A (m2)	REQUIRED PROFILE WIDTH (m.) at bottom	DEPTH (m.)	SLOPE (arctan)	A (m2) dredge cross section	REQUIRED DREDGING (cu.m.)
0.00	7.00	1000.00	4.00	10.00	4343	143.00	6.10	3.00	1074	2,194,710
7.00	7.50	1000.00	2.00	10.00	2463	143.00	6.10	3.00	1074	318,365
7.50	21.00	1000.00	4.00	10.00	4343	143.00	6.10	3.00	1074	4,232,655
21.00	22.00	1000.00	1.00	10.00	1493	143.00	6.10	3.00	1074	807,330
22.00	30.00	1000.00	4.00	10.00	4343	143.00	6.10	3.00	1074	2,508,240
30.00	49.00	3000.00	4.00	10.00	13343	143.00	6.10	3.00	1074	5,957,070
49.00	62.00	3000.00	1.00	5.00	4496	143.00	6.10	3.00	1074	10,495,290
62.00	65.00	55.00	1.50	2.50	105	143.00	6.10	3.00	1074	2,908,440
65.00	73.00	100.00	5.00	5.00	426	143.00	6.10	3.00	1074	5,185,840
73.00	75.00	25.00	1.00	10.00	30	143.00	6.10	3.00	1074	2,088,960
75.00	84.00	25.00	2.00	5.00	44	143.00	6.10	3.00	1074	9,276,570
84.00	91.00	35.00	1.50	5.00	60	143.00	6.10	3.00	1074	7,101,360

TOTAL DREDGING : **53,074,830** cu.m.

Table D10 Required dredging for 2*2 Barge formation (D=4.5m)

calculation of land acquisition

ac.wk1 CALCULATION OF AMOUNT OF LAND ACQUISITION

STRETCHWISE LAND ACQUISITION (*1,000 m2) FOR :

WATERWAY				CAMPINE BARGE		D.E.K.		RHINE-HERNE VESSEL		LARGE RHINE VESSEL	
STRETCH (km.) from	to	AVAILABLE WIDTH (m.) (average)		daytime only	day and night	daytime only	day and night	daytime only	day and night	daytime only	day and night
			REQUIRED WIDTH : (m)	43	46	51	55	57	62	69	74
0	7	1000		0	0	0	0	0	0	0	0
7	8	1000		0	0	0	0	0	0	0	0
8	21	1000		0	0	0	0	0	0	0	0
21	22	1000		0	0	0	0	0	0	0	0
22	30	1000		0	0	0	0	0	0	0	0
30	49	3000		0	0	0	0	0	0	0	0
49	62	3000		0	0	0	0	0	0	0	0
62	65	55		0	0	0	0	6	21	42	57
65	73	100		0	0	0	0	0	0	0	0
73	75	25		36	42	52	60	64	74	88	98
75	84	25		162	189	234	270	288	333	396	441
84	91	35	+	56	77	112	140	154	189	238	273
TOTAL LAND ACQUISATION (*1000 m2) =				**254**	**308**	**398**	**470**	**512**	**617**	**764**	**869**

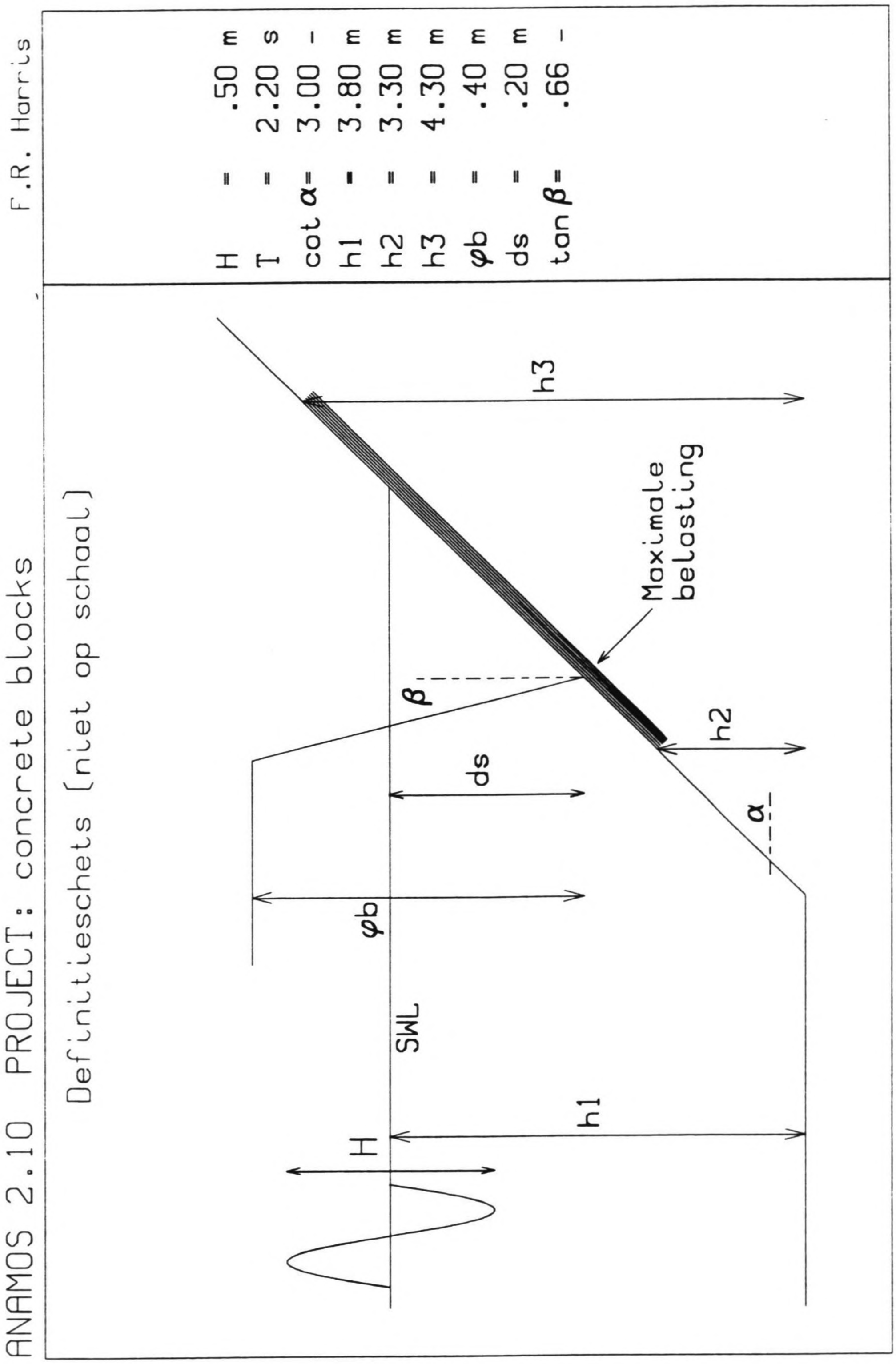
STRETCHWISE LAND ACQUISITION (*1,000 m2) FOR :

DRAUGHT : 2.8 m

WATERWAY				2*1 PUSHTOW		1*2 PUSHTOW		2*2 PUSHTOW	
STRETCH (km.) from	to	AVAILABLE WIDTH (m.) (average)		daytime only	day and night	daytime only	day and night	daytime only	day and night
			REQUIRED WIDTH : (m)	106	111	119	130	163	174
0	7	1000		0	0	0	0	0	0
7	8	1000		0	0	0	0	0	0
8	21	1000		0	0	0	0	0	0
21	22	1000		0	0	0	0	0	0
22	30	1000		0	0	0	0	0	0
30	49	3000		0	0	0	0	0	0
49	62	3000		0	0	0	0	0	0
62	65	55		153	168	192	225	324	357
65	73	100		48	88	152	240	504	592
73	75	25		162	172	188	210	276	298
75	84	25		729	774	846	945	1242	1341
84	91	35	+	497	532	588	665	896	973
TOTAL LAND ACQUISATION (*1000 m2) =				**1,589**	**1,734**	**1,966**	**2,285**	**3,242**	**3,561**

Table D11 Calculation of amount of land acquisition

ANNEX E STABILITY CALCULATION OF CONCRETE BLOCKS REVETMENT USING THE PROGRAM 'ANAMOS'



```
ANAMOS 2.10  PROJECT: concrete blocks

INVOERGEGEVENS
--------------

GOLVEN
      Significante golfhoogte          :  Hs      =   .500 m
      Periode (van piek spectrum)      :  Tp      =  2.200 s
      Waterstand tov. de teen          :  h1      =  3.800 m

TALUD
      Helling                          :  cot(α)  =  3.000 -
      Wrijvingscoeff. toplaag/ondergr:    ft      =   .100 -
      Nivo ondergrens zetting          :  h2      =  3.300 m
      Nivo bovengrens zetting          :  h3      =  4.300 m

CONSTRUCTIETYPE

      niet ingewassen dichte blokken
      ==================================================
      filter
      ==================================================
      geotextiel
      ==================================================
      basis

DICHTE BLOKKEN
      Breedte (langs het talud)        :  B       =   .500 m
      Lengte (evenwijdig dijkas)       :  L       =   .500 m
      Dikte                            :  D       =   .100 m
      Spleetbreedte                    :  s       =  1.500 mm
      Soortelijke massa                :  sm      = 2450.0 kg/m3
      Onderlinge wrijving              :  fwg     =   .500 -

FILTER
      Laagdikte                        :  b       =   .050 m
      Karakteristieke korreldiameter   :  D15     =  2.000 mm
      Porositeit                       :  n       =   .300 -

GEOTEXTIEL ONDER FILTER
      Dikte van het geotextiel           : Tg     =  2.000 mm
      Karakteristieke openingengrootte   : O90    =   .300 mm
      Coefficienten in machtsrelatie:
      q  = specifiek debiet (m/s)
      i  = verhang over geotextiel (i = Φ/Tg)
      In de relatie  q = k*i^m is:
                                          k       = 10.000 mm/s
                                          m       =   .500 -
```

Zie volgende bladzijde

ANAMOS 2.10 PROJECT: concrete blocks

VERVOLG INVOERGEGEVENS

BASIS

Karakteristieke korreldiameter	:	D50	=	.300	mm
	:	D90	=	.500	mm
Porositeit	:	nb	=	.350	-

```
ANAMOS 2.10  PROJECT: concrete blocks

TUSSENRESULTATEN
________________

CONSTRUCTIE
                    Forchheimer coefficienten          doorlatendheid
                       a (s/m)           b (s2/m2)            k (m/s)
     Toplaag          349.227        169.680*10^3            .0016
     Filter            88.798       1245.894                 .0108

     Geotextiel tussen basis en filter    :  k               =   .010 m/s
                                          :  m               =   .500 -

     Leklengte                            :  LAMBDA          =   .183 m
     Lekhoogte                            :  lambda          =   .058 m

BELASTING
     Golfsteilheid                        :  Hs/Lo           =   .066 -
     Brekerparameter                      :  ksi-o           =  1.295 -
     Belastingsparameter                  :  Hs/(delta*D)    =  3.627 -

     Voor de berekening van de blokbeweging wordt in dit geval gerekend met
     Hs. De bijbehorende belastingparameters zijn:
     Hoogte stijghoogtefront              :  Φb              =   .404 m
     Helling stijghoogtefront             :  tan(ß)          =   .661 -
     Diepte zwaarste golfaanval tov. SWL  :  ds              =   .200 m
     Hoogte freatische lijn               :  zf              =   .203 m
     Maximaal stijghoogteverschil toplaag :  Φw              =   .132 m
     Invloedsfactor wrijving              :  Γs1             =  1.206 -
     Invloedsfactor massatraagheid        :  Γ2              =   .000 -
     Invloedsfactor toestroming           :  Γ3              =   .000 -
```

```
ANAMOS 2.10   PROJECT: concrete blocks

EINDRESULTATEN
--------------

STABILITEIT TOPLAAG
      Belasting                            :   S       =   .132 m
      Sterkte                              :   R       =   .158 m
      Blokbeweging                         :   Y       =   .000 m
      Conclusie:
      De constructie is stabiel.
      H = Hs is maatgevend.

STABILITEIT TEGEN AFSCHUIVING
      Stabiliteitsfactor                   :   Γ_a     =   .000 -
      Kracht op teen                       :   Fteen   =   1.24 kN/m'

STABILITEIT GRENSVLAK BASIS-FILTER

      Het grensvlak is stabiel, want Df15 < 5 * Db90.
```

ANAMOS 2.10 PROJECT: concrete blocks

GEVOELIGHEID VAN DE RESULTATEN

DE WAARDE VAN DE INVOERPARAMETERS

In onderstaande tabel worden de eindresultaten gegeven behorende bij de invoergegevens die alleen verschillen in de waarde van de parameter in de eerste kolom. Deze parameter is in de nieuwe berekening 10% groter gekozen dan in de oorspronkelijke invoer.

			TOPLAAG		GRENSVLAK
			R/S	Y/D	icr/imax
Oorspronkelijke resultaten:			1.19	.00	nvt
10% verhoogde invoerparameter:					
Golfhoogte	Hs		-	-	-
Golfperiode	Tp	*	1.18	.00	nvt
Taludhelling	cot(α)		1.18	.00	nvt
Waterdiepte	h1		1.20	.00	nvt
Blokdikte	D		1.26	.00	nvt
Blokoppervlak	B*L		1.19	.00	nvt
Spleetbreedte	s		1.22	.00	nvt
Filterlaagdikte	bf		1.16	.00	nvt
Filterkorrel	Df15		1.16	.00	nvt

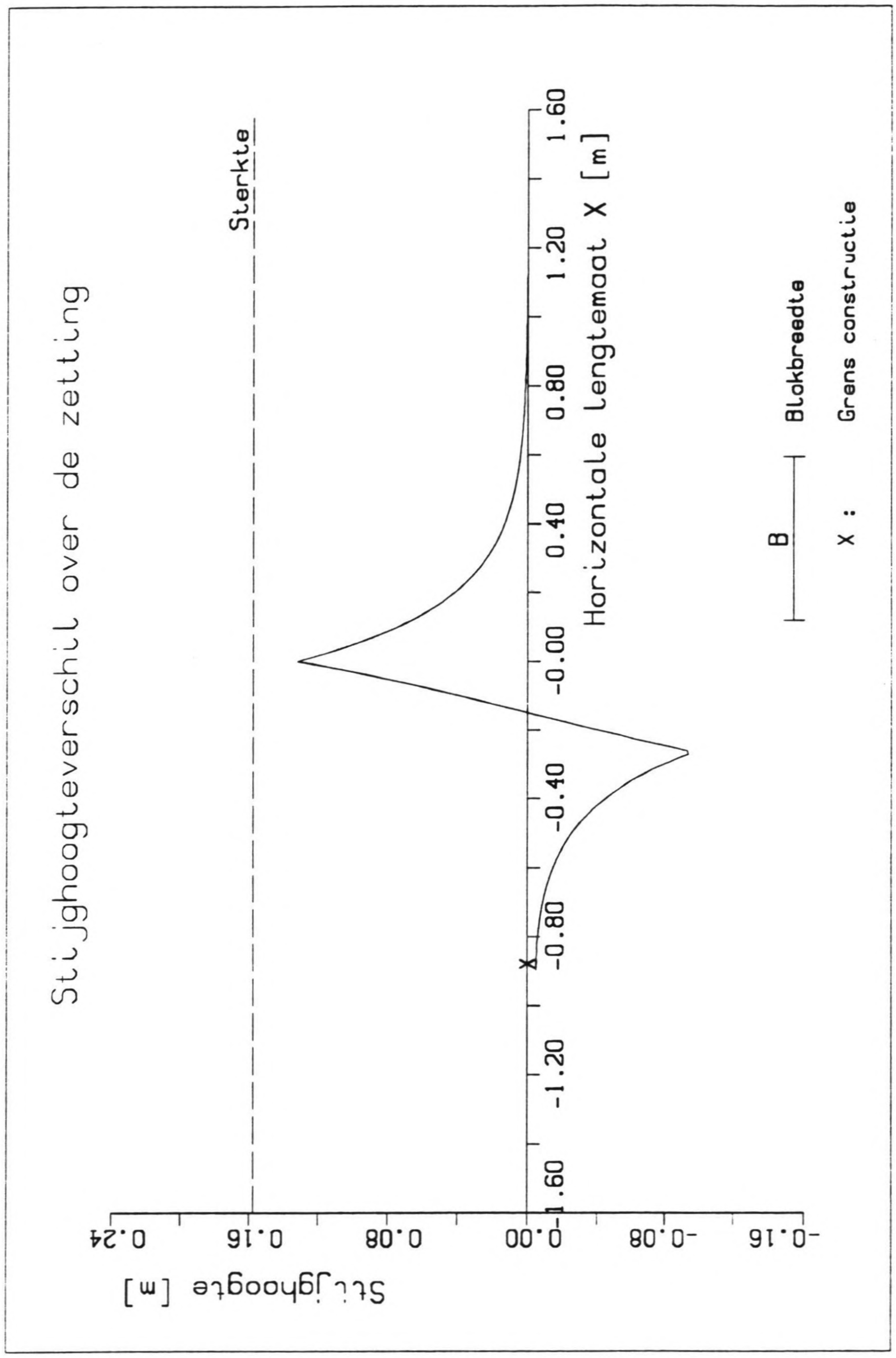
DE AANWEZIGHEID VAN CONSTRUCTIEONDERDELEN

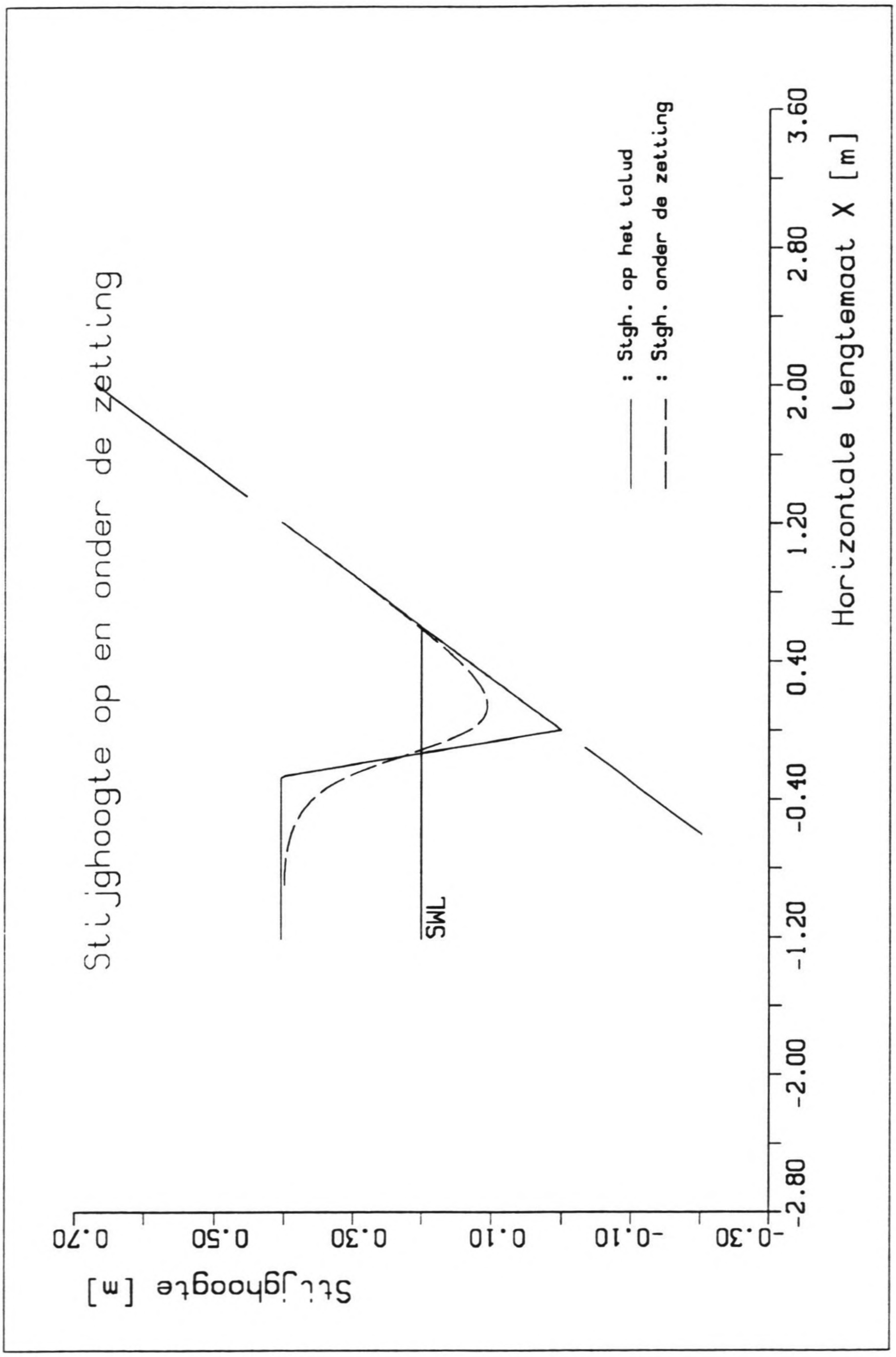
In onderstaande tabel worden de eindresultaten gegeven behorende bij de invoergegevens die alleen verschillen in de aanwezigheid van het constructieonderdeel in de eerste kolom. Dit constructieonderdeel is in de nieuwe berekening weggelaten ten opzichte van de oorspronkelijke.

	TOPLAAG		GRENSVLAK
	R/S	Y/D	icr/imax
Oorspronkelijke resultaten:	1.19	.00	nvt
Weggelaten constructieonderdeel:			
Geotextiel onder het filter	1.19	.00	nvt

Betekenis '*': Er treden waarschuwing(en) bij op.

Betekenis '-': de parameter kan niet 10% groter gekozen worden, omdat anders de maximum grens behorende bij die parameter overschreden wordt.


ANAMOS 2.10 PROJECT: concrete blocks
F.R. Harris
Stijghoogteverschil over de zetting
Sterkte
Stijghoogte [m]
0.24
0.16
0.08
0.00
-0.08
-0.16
-1.60
-1.20
-0.80
-0.40
-0.00
0.40
0.80
1.20
1.60
Horizontale Lengtemaat X [m]
B
Blokbreedte
X :
Grens constructie


ANAMOS 2.10 PROJECT: concrete blocks
F.R. Harris
Stijghoogte op en onder de zetting
: Stgh. op het talud
: Stgh. onder de zetting
SWL
Stijghoogte [m]
0.70
0.50
0.30
0.10
-0.10
-0.30
Horizontale lengtemaat X [m]
-2.80
-2.00
-1.20
-0.40
0.40
1.20
2.00
2.80
3.60