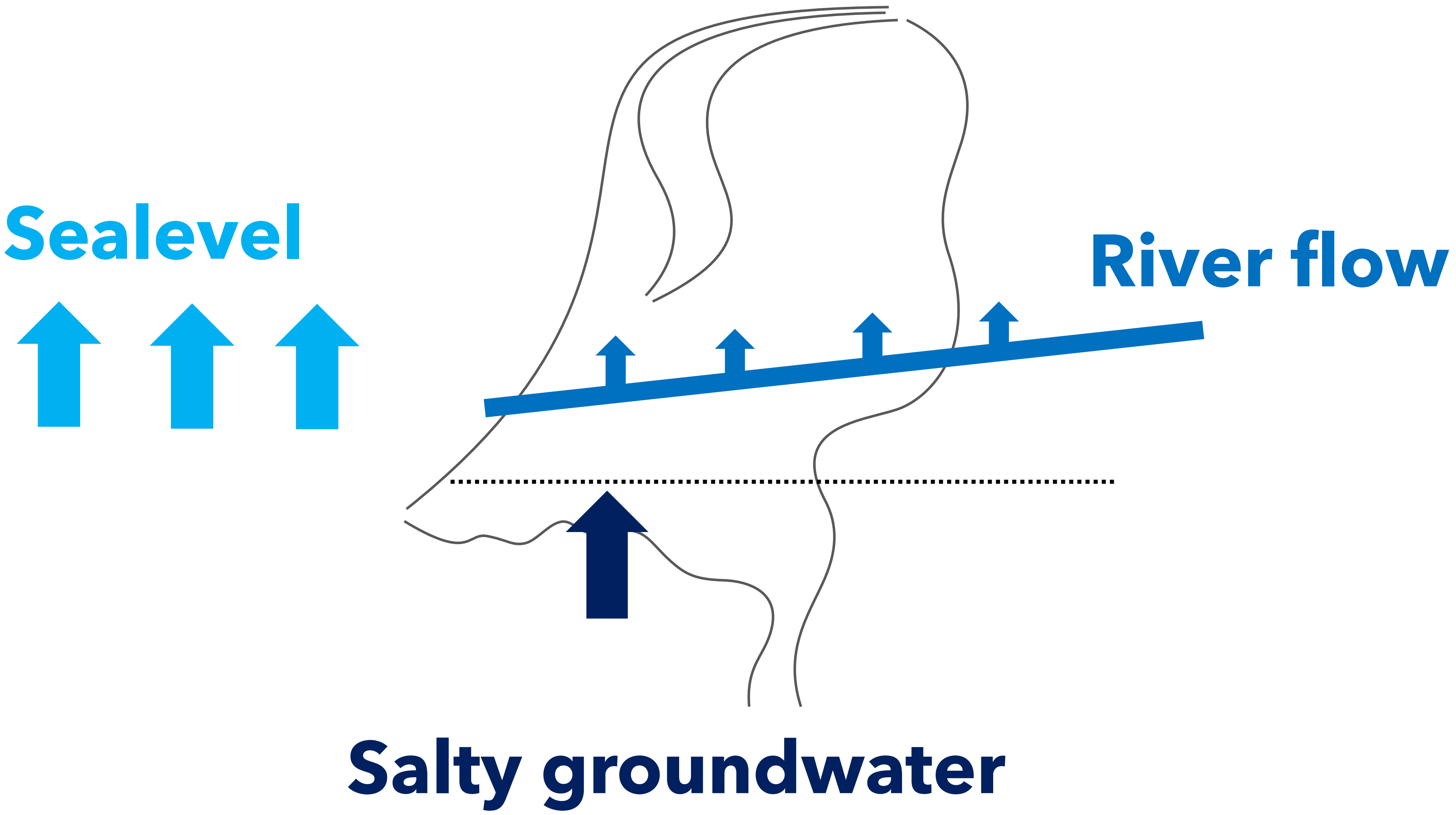
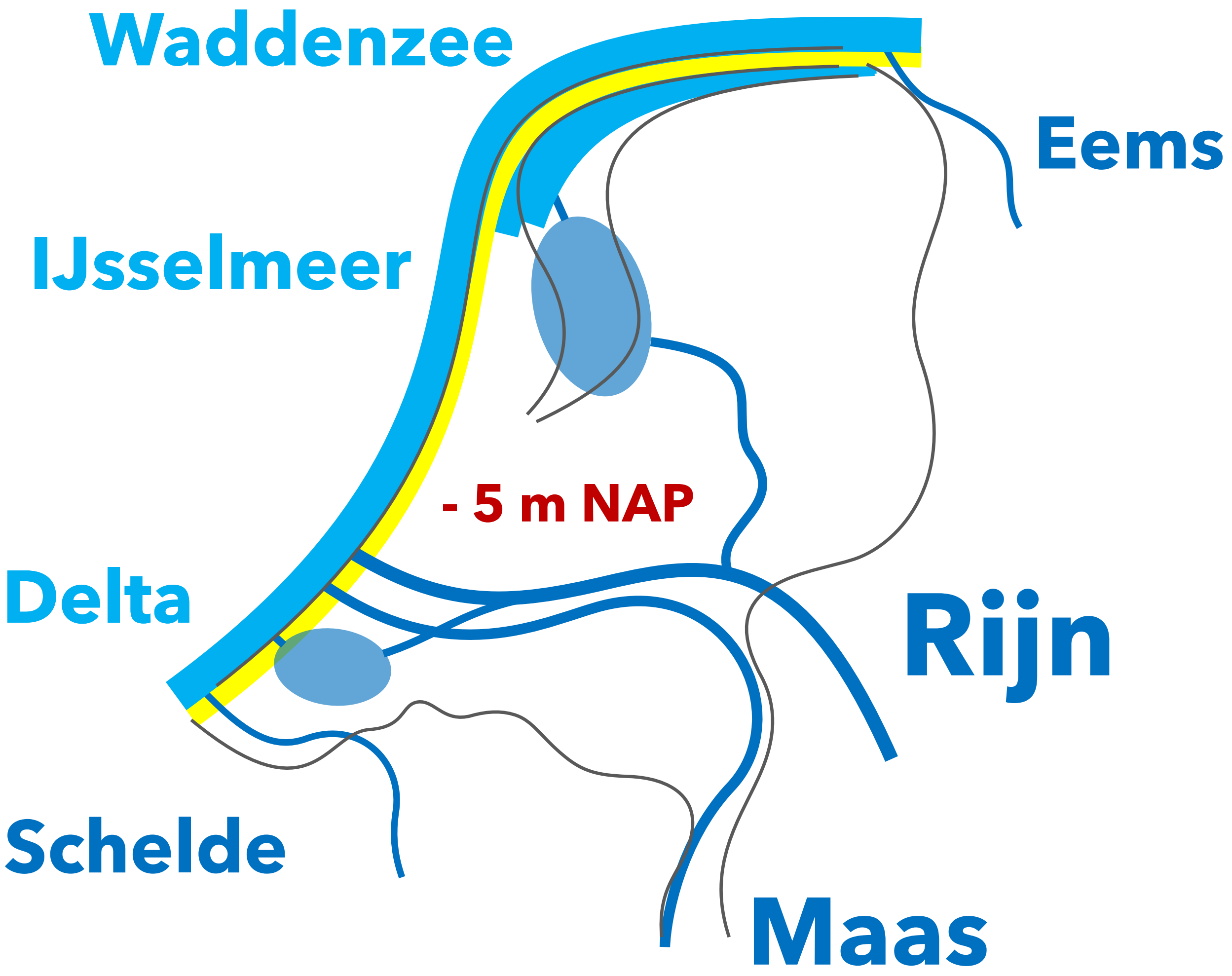
Nieuwe Hollandse Bosvariant


Sea Level Rise 10 meter
Nieuwe Hollandse Bosvariant

Three Threats

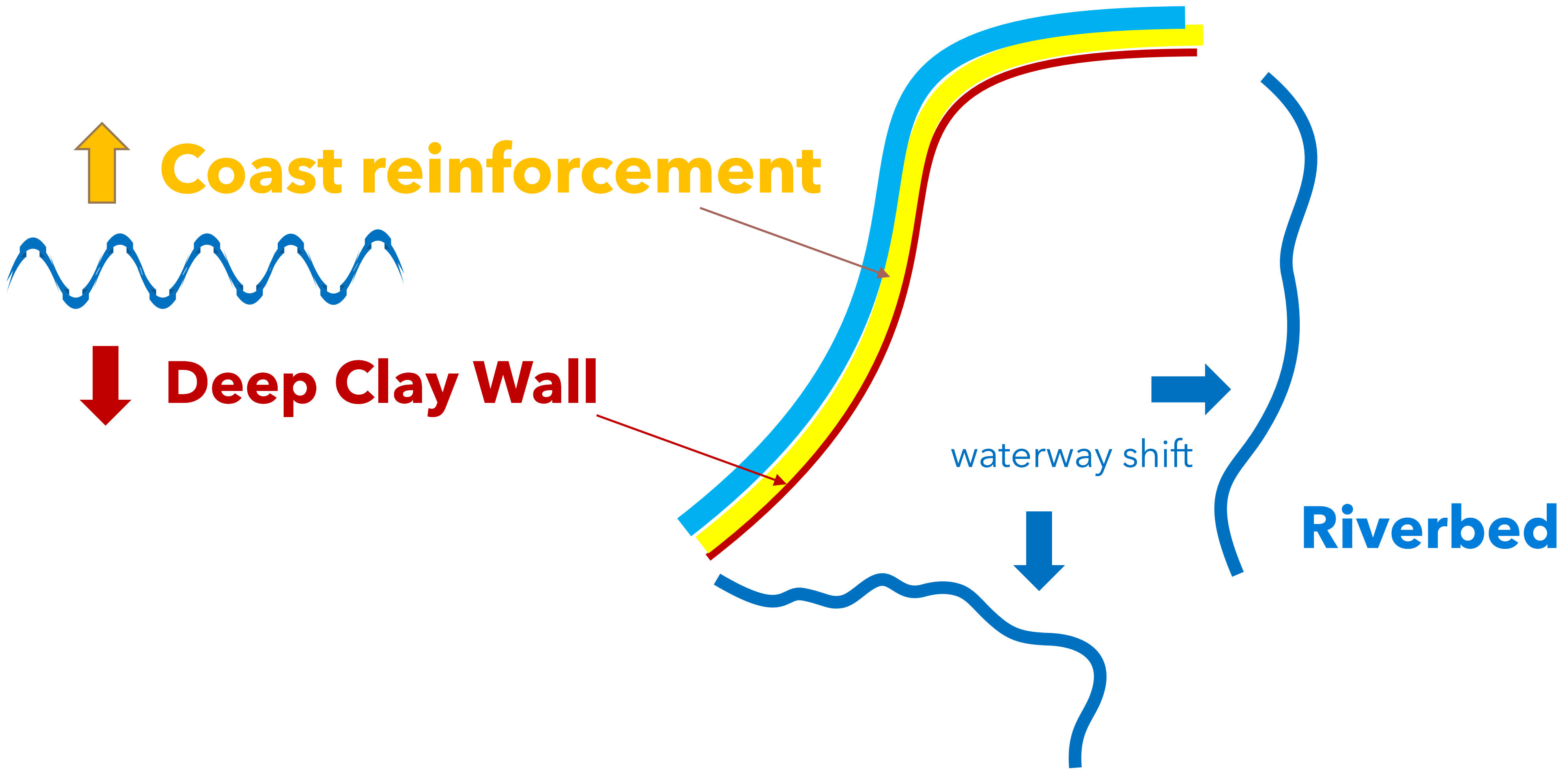


Current situation



How to keep dry feet?

Three future proof interventions



Coast Reinforcement

Enclosured coastline

Coastal widening

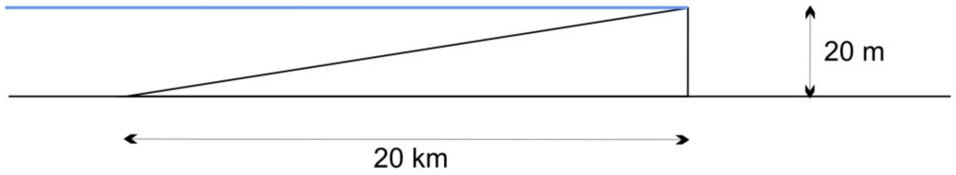
Upward beachrise

Sweet water lakes
nearby coastal towns →

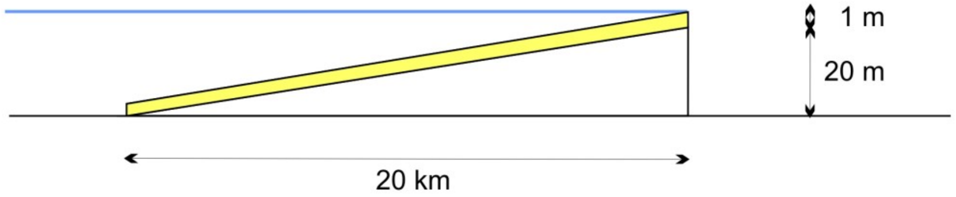
Coastal widening 5 till 10 km →

Sluices Rotterdam, Amsterdam, Den Helder →

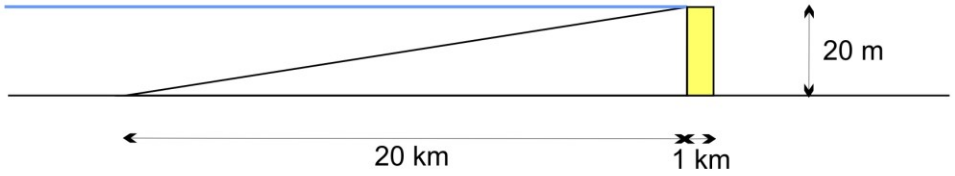
Seaward protection of coastline
with natural sandy sea beach



Natural slope of coastal fundament 1 : 1000



Sea level rise: supplementation Q = 20 km x 1 m



Coastal widening: supplementation Q = 20 m x 1 km

Beach nourishment

Length of coastline: 400 km
Sea level rise: 1 meter
Supplementation: 20.000 m3 /m1
Total quantity of sand: 8 billion m3

Length of coastline: 400 km
Sea level rise: 10 meter
Supplementation: 200.000 m3 /m1
Total quantity of sand: 80 billion m3

Plus extra sand for dune elevation
Approx 10 m high x 500 m width
Total quantity of sand: 2 billion m3

Seaward protection of coastline
with hard sea barrier (dike)

Quantification

. Seaside slope 1 : 20 and landside slope 1 : 10
. Dike height 10 m + NAP (new sea level)
. Sea level rise 10 m
. Total 20 m
. Super safety dike: crown 500 m width
. Dike width ca 1 km (400 slope + 500 top/crown + 200 slope)
. So: (10 + 10) x 500 + 0,5 x (10 + 10) x 600 = 16.000 m3
. Total 16.000 m3 x 400 km = 16.000 x 400.000 = **6,4** billion m3

Seaward protection of coastline
with natural sandy sea beach

Quantification

. Total **82** billion m3

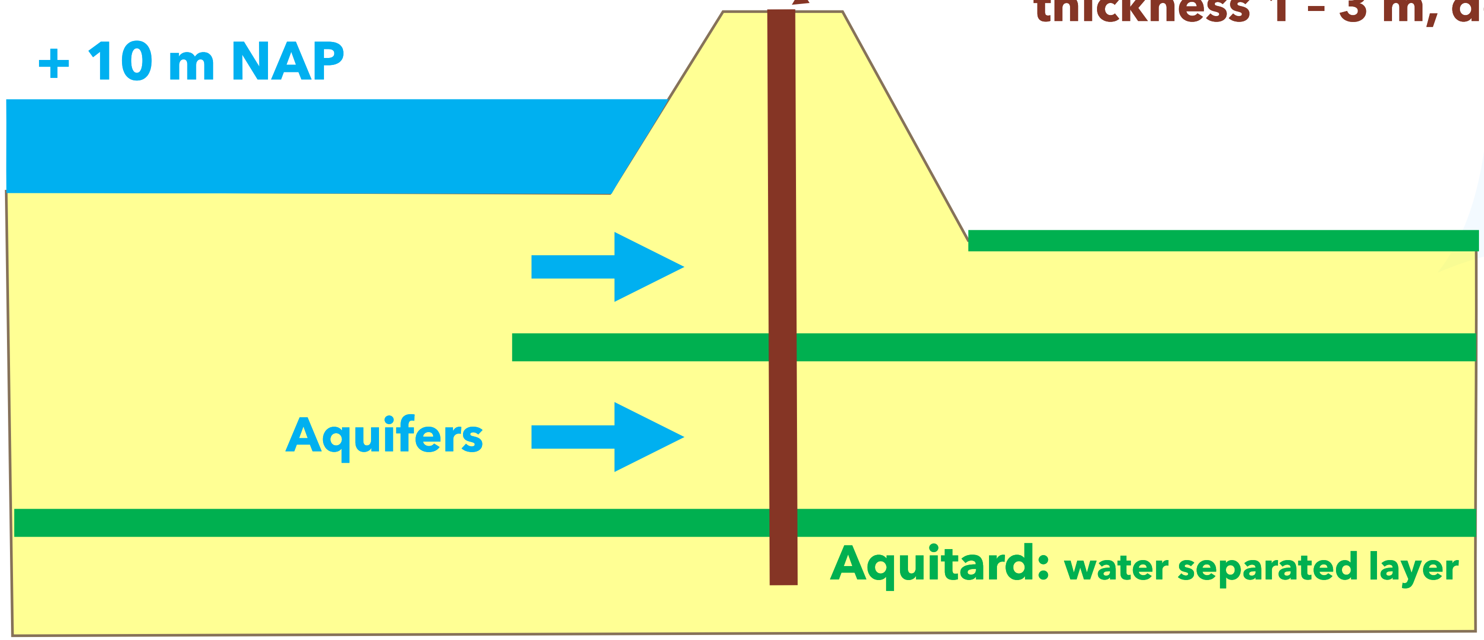
Deep Clay Coastline

Slurry wall of clay deep into the ground

Invulnerable of brackish/saline seepage

Deep Clay Wall = seepage barrier

thickness 1 – 3 m, depth 20 – 60 m



Deep Clay Coastline   Dutch seepage-free

Characteristics

. diapraghm walls of solid clay (water blocking)

. thickness 1 - 3 meter

. depth of 10 – 20 m to 50 - 60 meter

. length approx 400 km

Construction process

. Digging of trench

. Temporary filled with bentonite (swalling viscous clay)

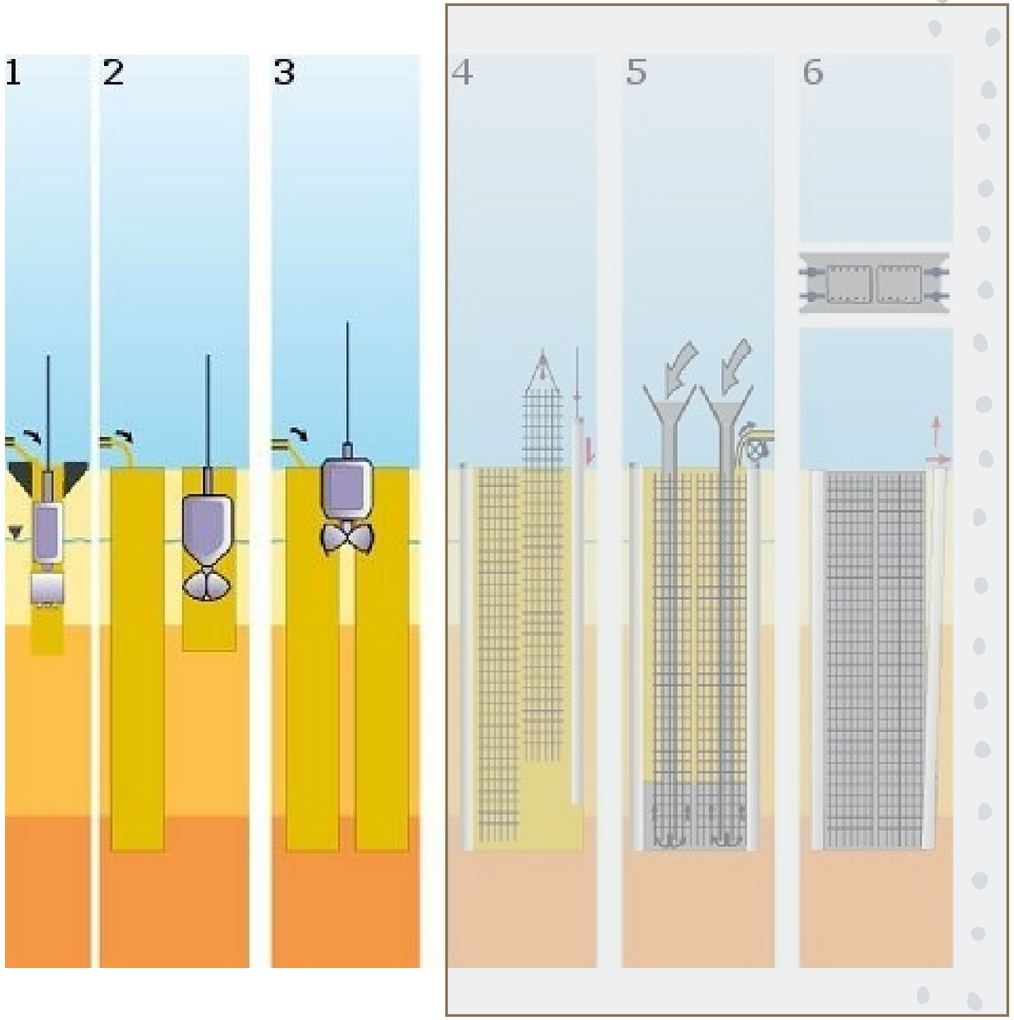
. Pouring of solid clay (in stead of normally concrete)

Seepage barrier costs

. depth average 25 m x thickness 3 m = 75 m3 /m1

. Coastline 400 km: 400 x 75 = 30 million m3

. Costs: 30 euro/m3 -> 1 billion euro

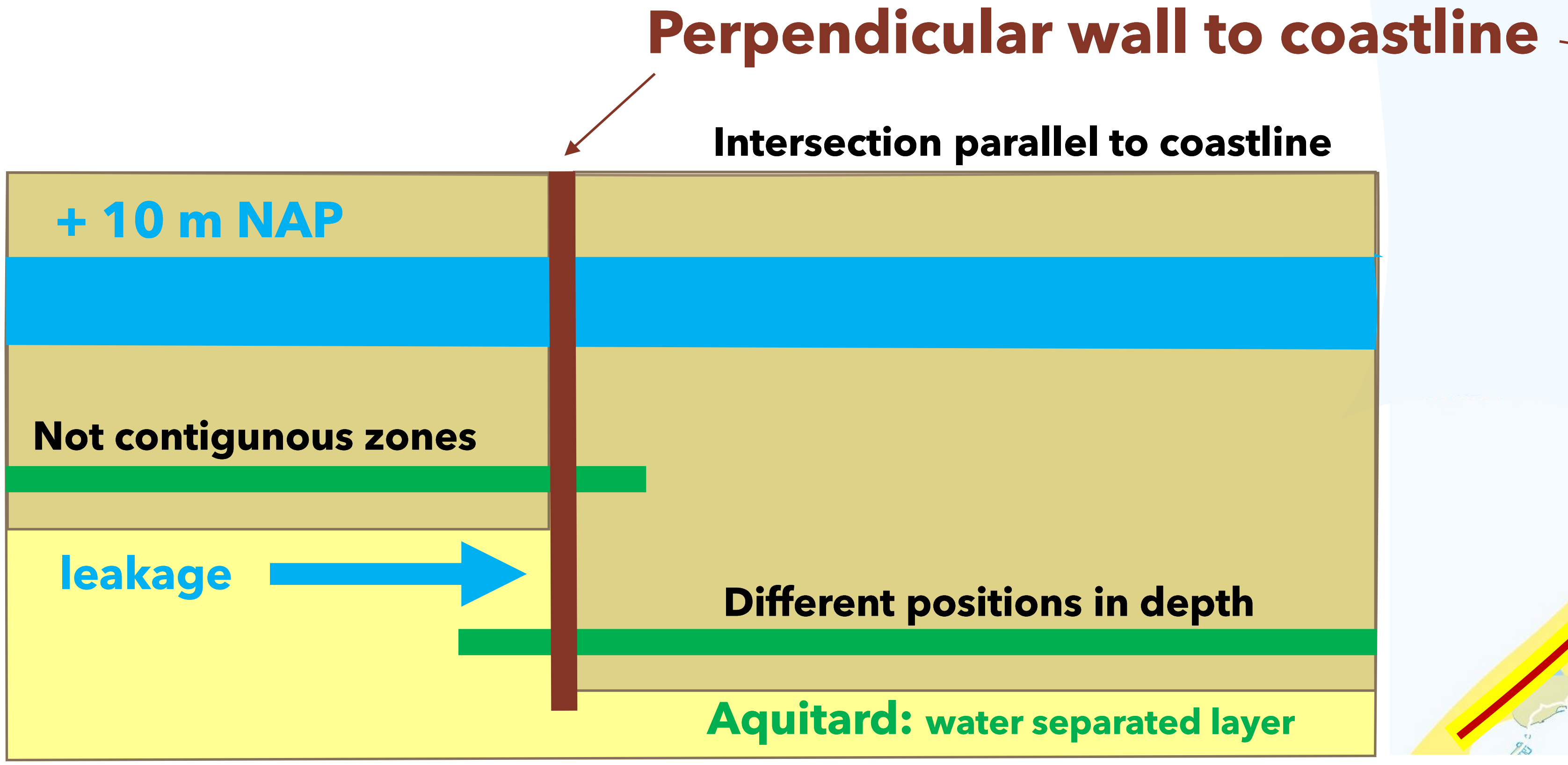


pouring of clay in stead of reinforcement concrete

Deep Clay Coastline (additionally)

Deep walls also perpendicular to coastline

Compartmentalization along coastline



Sweet water balance

Sweet water Dutch household demand – supply (capacity in billions m3) Masterplan in worst case even without supply Rijn and Maas									
supply	year period		driest summer		driest summer		year period		demand
	autonomous	masterplan	autonomous	masterplan	masterplan	autonomous	masterplan	autonomous	
Rijn	70	-	21	-	0,6	0,6	1	1	housekeeping
Maas	8	-	0,7	-	2,7	2,7	5	5	industrial
divers	3	5	3	5	3,3	3,3	3	3	level control
Oosterschelde				2	-	6,1	-	12	flushing of rivers
Waddenzee				10	-	4,7	-	9	salinaziation
rain	35	35			8,6	8,6	20	20	evaporation
total	**116**	**40**	**25**	**17**	**15**	**26**	**30**	**51**	total

divers: small rivers 0,5; draining -> NL 0,5; ground water extraction 0,8; waterpurification 1,2; reservoir IJsselmeer/weirs (dams, stuwpanden) 2,0

Oosterschelde and Waddenzee: sweet water basins: 350 + 2400 km2; maximum level difference 4 m

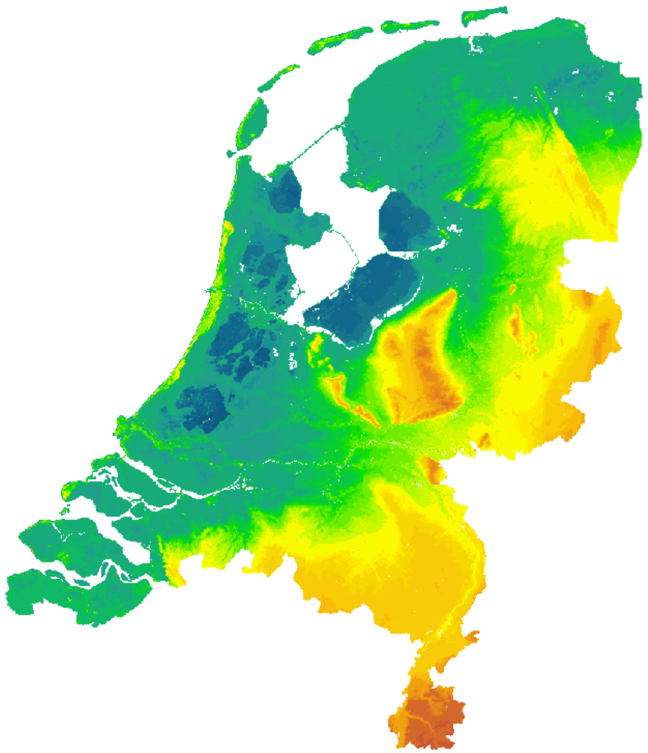
Source: De Waterhuishouding van Nederland 1e nota, 1968 met vooruitzicht naar 2000.

Riverbed shifting

Shift to high-land trajectory

National border as natural location

Rijn-*to*-Dollard and Maas-*to*-Westerschelde

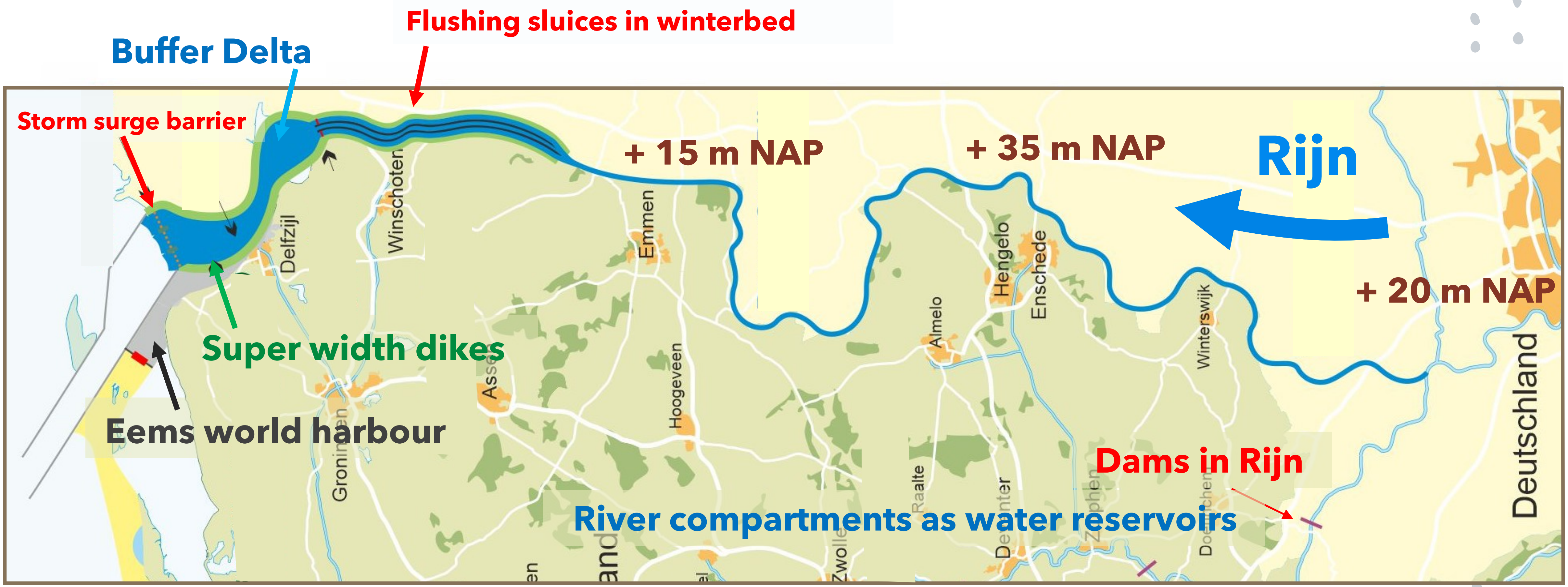


Riverbed Maas

Riverbed Rijn

Dollard

Wesel



Riverbed shifting

Arguments for shifting rivers to borderline?

- High land present along the borderline
- Bufferdelta available in Westerschelde and Dollard
- Meandering borderline adresses to buffering riverwater
- Borderzone is less urbanized
- National border as natural location
- Sharing costs with neighboring countries
- Future proof position till approx 20 – 30 m sea level rise

Riverbed shifting to Dollard

Issues:

- Limited river gradient between Wesel and Dollard
- Flat land northwart of Emmen
- Winterbed required to be small (land use)
- No salt intrusion in summertime
- Sufficient draft as inland waterway

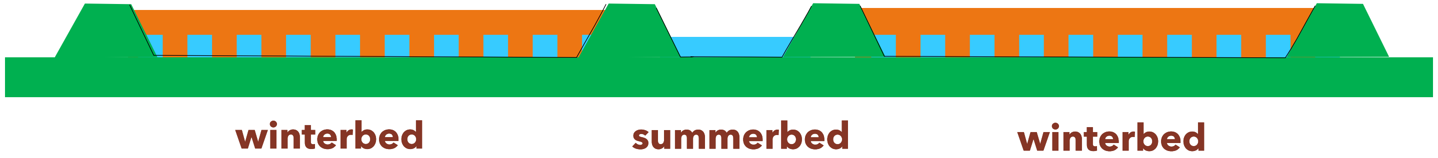
What kind of solutions conceivable?

- Winterbed bottom as depth as summerbed
- Moveable seabarrier (weir) in winterbed
- In winter time to open, in summer time closed

Flushing sluices in winterbed

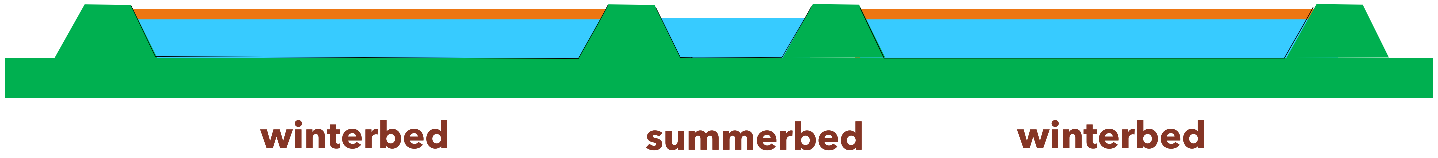
Summer time

Flushing sluice closed
no salt intrusion



Winter time

Flushing sluice open
high water river discharge



winterbed as depth as summerbed: maximum water discharge at minimal landuse

Riverbed dimensioning

Issue:

. Dimensioning in width and depth of summerbed and winterbed?

What kind of parameters are required?

. flow rate (debiet) in summer and winter:

  . upstream water level

  . downstream sea level

  . river distance

. current speed: (iterative process)

  . river gradient (verhang)

  . depth

  . roughnous factor soil

Current speed: $v = \sqrt{g.d.I} / c$

in with d = waterdepth and I = river gradient in m/m

and c = roughnous factor soil = 0,005 (sand with ridges and stones)

Riverbed dimensioning

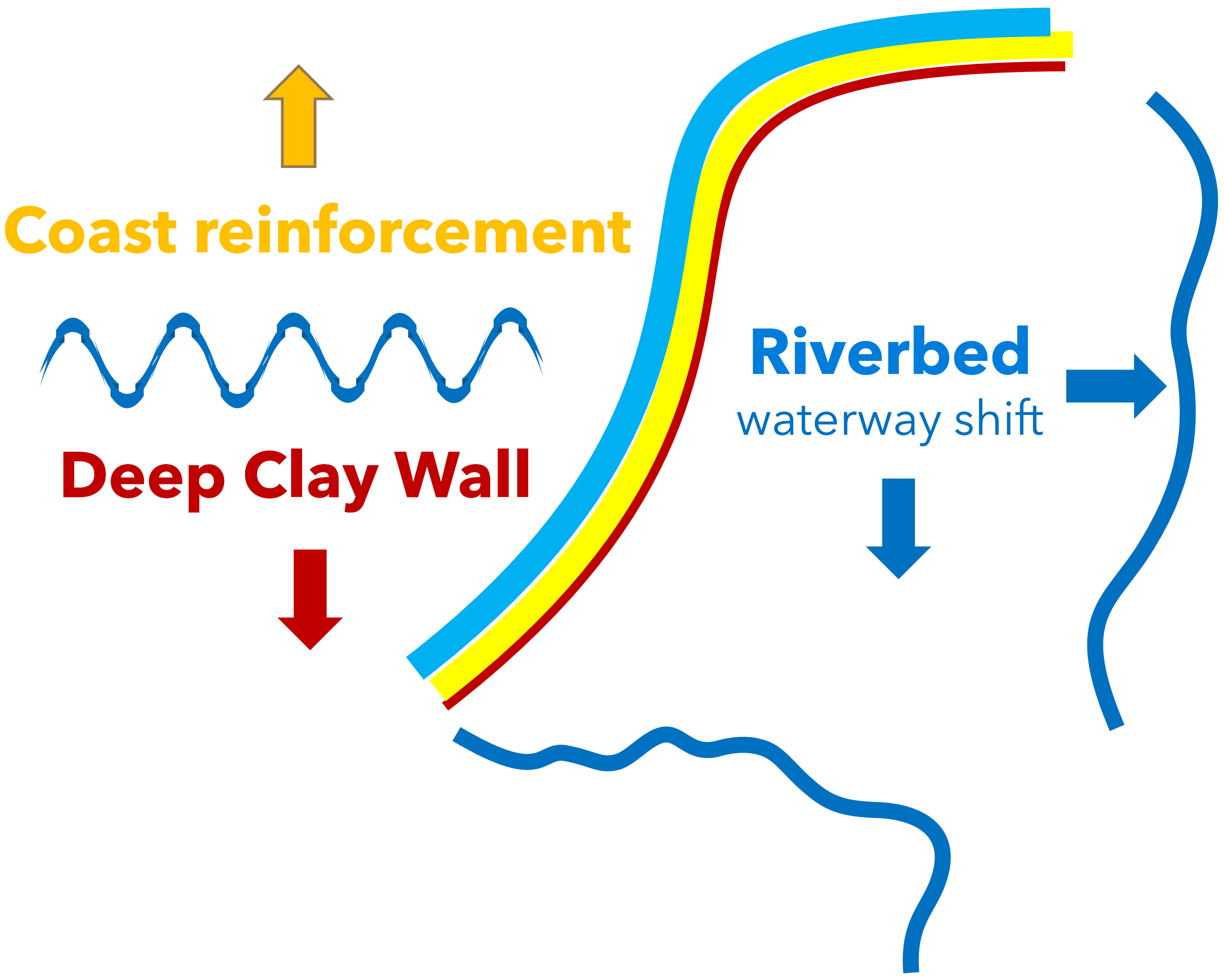
River profile and flow rate Bosse GrensRijn (border river the Netherlands- Germany)															
Traject		distance	water level relative to NAP		river gradiënt	bed						intersection	speed	discharge	
			upstream	down stream		location	height relative to NAP			depth	width			calculation	norm
							land	bottom	water level						
Wesel – Nieuweschans	**summerbed**	225 km	**12 m**	**10 m**	0,009 m/km	Emmerich	20 m	0 m	**12 m**	**12**	**500**	6.000	**0,46**	2.760	2.200
	summerbed					Winterswijk	40 m	- 0,5 m	11,5 m	12	500	6.000	0,46	2.760	2.200
	summerbed					Enschede	35 m	- 1 m	11 m	12	500	6.000	0,46	2.760	2.200
	summerbed					Emmen	15 m	- 1,5 m	10,5 m	12	500	6.000	0,46	2.760	2.200
	summerbed					Ter Apel	10 m	- 2 m	10 m	12	500	6.000	0,46	2.760	2.200
	summerbed					Nieuweschans	- 2 m	- 2 m	**10 m**	**12**	**500**	6.000	**0,46**	2.760	2.200
Wesel - Nieuweschans	**winterbed**	225 km	**18 m**	**10 m**	0,035 m/km	Emmerich	20 m	6 m	**18 m**	**12**	**2.500**	30.000	**0,83**	27.400	22.000
	summerbed									6	500	3.000	0,83		
	winterbed					Winterswijk	40 m	4 m	16 m	12	2.500	30.000	0,83	26.800	22.000
	summerbed									4,5	500	2.250	0,83		
	summerbed					Enschede	35 m	2 m	14 m	12	2.500	30.000	0,83	26.150	22.000
	summerbed									3	500	1.500	0,83		
	winterbed					Emmen	15 m	0 m	12 m	12	2.500	30.000	0,83	25.500	22.000
	summerbed									1,5	500	750	0,83		
	winterbed					Ter Apel	10 m	- 2 m	10 m	12	2.500	30.000	0,83	24.900	22.000
	summerbed											inclusive			
	winterbed					Nieuweschans	- 2 m	- 2 m	**10 m**	**12**	**2.500**	30.000	**0,83**	24.900	22.000
	summerbed											inclusive			

Current speed: v = √ g.d.I /c in with d = waterdepth and I = river gradient in m/m and c = roughnous factor soil = 0,005 (sand with ridges and stones)

Riverbed dimensioning

River profile and flow rate Bosse GrensMaas (border river the Netherlands - België)															
traject		distance	water level relative to NAP		river gradiënt	bed						intersection	speed	discharge	
			upstream	down stream		location	height relative to NAP			depth	width			calculation	norm
							land	bottom	water level						
Maasbracht - Antwerpen	**summerbed**	180 km	**20 m**	**10 m**	0,055 m/km	Maasbracht	30 m	15 m	**20 m**	**5**	**80**	400	**0,73**	292	200
	summerbed					Baarle-Nassau	20 m	7 m	12 m	5	80	400	0,73	292	200
	summerbed					Antwerpen	15 m	- 1 m	4 m	**5**	**80**	400	**0,73**	292	200
Maasbracht - Antwerpen	winterbed	180 km	**26 m**	**10 m**	0,089 m/km	Maasbracht	30 m	20 m	**26 m**	**6**	**600**	3.600	**1,05**	4.200	3.800
	summerbed									5	80	400	1,05		
	summerbed					Baarle-Nassau	20 m	12 m	18 m	6	600	3.600	1,05	4.200	3.800
	summerbed									5	80	400	1,05		
	summerbed					Antwerpen	15 m	4 m	**10 m**	**6**	**600**	3.600	**1,05**	4.200	3.800
	summerbed									5	80	400	1,05		
Current speed: v = √ g.d.I /c in with d = waterdepth and I = river gradient in m/m and c = roughnous factor soil = 0,005 (sand with ridges and stones)															

Overview



Coast reinforcement
Deep Clay Wall
Riverbed
waterway shift

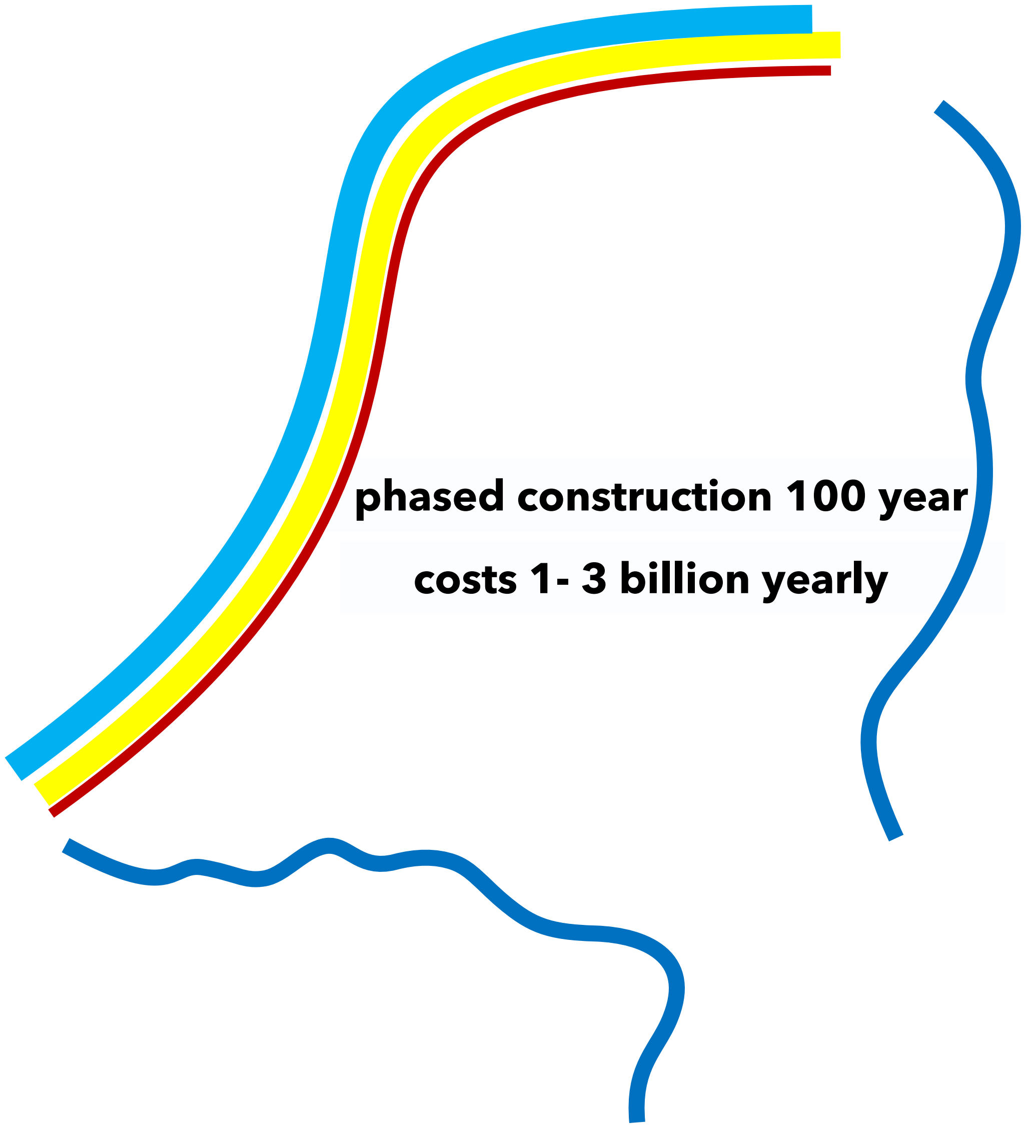
Nieuwe Hollandse Bosvariant
Bosse Zee- en Rivierlinie
Zeespiegel + 10 m NAP
Stormvloedkering
Eems wereldhaven
Bufferdelta
Superbrede dijken langs Dollard
Spuisluizen in winterbed
Bosse GrensRijn
Bosse Zeelinie
Nieuwe Zeewering + 25 m NAP
met binnenbaaien bij badplaatsen
en onderlangse leemkade
Zoetwater binnenbaaien + 5 m NAP
bij oud-Hollandse badplaatsen
voor recreatieve beleving
Leemkade onderlangs zeewering
tot horizontale kleilagen 10 - 60 m diep
als zoutwaterkerende kwelwand
Zeesluizen bij Rotterdam,
Amsterdam en de Waddenzee
Nederland
Dam IJssel
Dam Rijn
Dam Waal
Dammen
Rivierpanden als spaarbekkens
Dam Maas
Deutschland
Bosse GrensMaas
Stormvloedkering
Bufferdelta
Superbrede dijken
langs Westerschelde
België/la Belgique
Dokkum
Leeuwarden
Groningen
Delfzijl
Harlingen
Drachten
Sneek
Assen
Heerenveen
Den Helder
Emmen
Hoogeveen
Meppel
Enkhuizen
Emmeloord
Alkmaar
Hoorn
Kampen
Lelystad
Zwolle
Raalte
Amsterdam
Haarlem
Almere
Almelo
Hengelo
Enschede
Deventer
Apeldoorn
Hilversum
Leiden
Alphen a/d Rijn
Amersfoort
Utrecht
Zutphen
Den Haag
Gouda
Ede
Arnhem
Doetinchem
Winterswijk
Rotterdam
Gorinchem
Nijmegen
Dordrecht
Oss
's-Hertogenbosch
Breda
Tilburg
Middelburg
Vlissingen
Goes
Bergen o. Z.
Roosendaal
Helmond
Eindhoven
Venlo
Terneuzen
Hulst
Weert
Roermond
Heerlen
Maastricht
10 km

Cost menu (indication)

Conclusion: deep clay wall 1- 2 billion; sandshore 200 billion or seawall 25 billion; estuaria 13 billion
shifting Maas 17 billion; shifting Rijn 145 billion or with limited discharge 30 billion

Cost menu Nieuwe Hollandse Bosvariant 10 meter sea level rise (in euro)								
cost element		length	specification	quantity		costs		
		km	dimensioning (H x Br) in m	per km	total	unit	per km	total
Deep Wall	clay wand	350	40 x 3	120 10^3	42 10^6	30 /m3	3,6 10^6	1,3 10^9
seasluices			R'dam, A'dam, D'Helder 3 st			1 10^9 /st		3 10^9
Sandshore	sand talud	350	20 km fundament:10 x 20.000	200 10^6	70 10^9	3 /m3	600 10^6	**210 10^9**
Seawall	stone talud	350	slope 1 : 20: ½ x 15 x 300	2,25 10^6	0,8 10^9	13 /m3	29 10^6	10 10^9
Land gain	sandcrown	350	per 500 m seaward: 20 x 500	10 10^6	3,5 10^9	3 /m3	30 10^6	11 10^9
Estuaria	sealevee	200	Westerschelde + Dollard				65 10^6	13 10^9
IJsselvlecht	digging	125	summer/winterbed: 2x(5 x 100 / 5 x 500)	5 10^6	0,6 10^9	10 /m3	50 10^6	6 10^9
Maas	digging	180	summer/winterbed: 5 x 80 / 6 x 600	6,1 10^6	1,1 10^9	10 /m3	61 10^6	11 10^9
Maas	divers	180	landpurchase, riverbed, infra	0,6 10^6	108 10^6	50 /m2	30 10^6	6 10^9
Rijn	digging	225	summer/winterbed: 12 x 500 / 12 x 2500	52 10^6	11,7 10^9	10 /m3	520 10^6	**117 10^9**
Rijn	divers	225	landpurchase, riverbed, infra	2,5 10^6	562 10^6	50 /m2	125 10^6	29 10^9

Social costs



phased construction 100 year

costs 1- 3 billion yearly

acceptable and affordable

Phased and adaptive process

Phase A   Southwestern Delta   no regret interventions
limited sea level rise 1 – 2 meter

. A1 Nieuwe Waterweg closing off including lock

. A2 Oosterspuischelde
- flushing sluices Oosterscheldedam
- river buffer in Oosterschelde
- sweet water reservoir Oosterschelde

. A3 Deep clay wall along southwestern coastline

Phased and adaptive process

Phase B   Northwestern Delta   far-reaching interventions

advancing sea level rise 2 – 3 meter

. B1 IJssel increasing of river capacity
- artificial inland delta or inverted delta
- interweaving of (braided) river branches

. B2 Waddenbekken
- enclosure of Waddenzee
- flushing sluices
- river buffer and sweet water reservoir

. B3 Deep clay wall along northwestern coastline

Discharge distribution

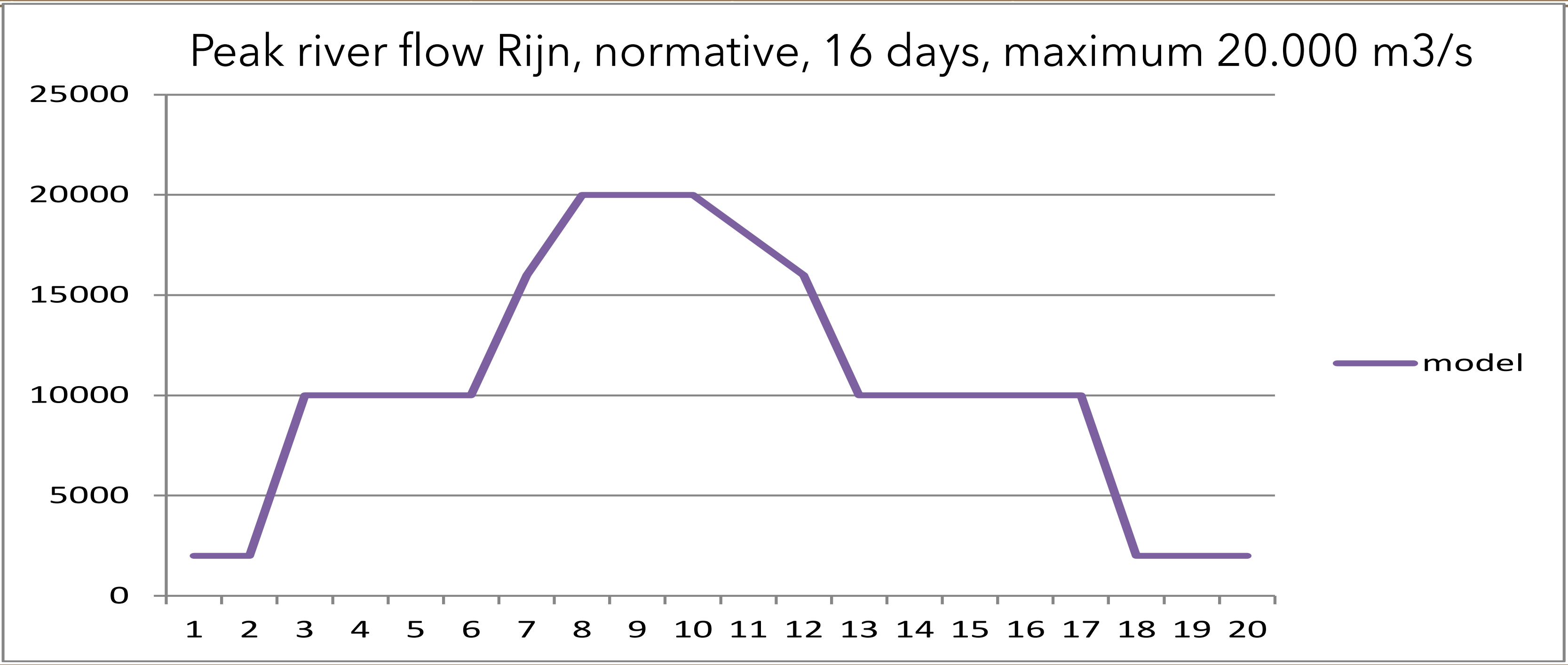
Conclusion: peak capacity IJssel actual 3.500 m3/s -> masterplan 10.000 m3/s -> contribution 70 %
BovenRijn: discharge only 17 days/year > 4.500 m3/s; average discharge only 2.400 m3/s

Discharge distribution BovenRijn in m3/s (year average 2400 m3/s, year discharge 75 10^9 m3)								
River	**length km**	**summer bed m**	**winter bed m**	**side riverbed falls dry**	**groyne-strand falls dry**	**groynes flooded**	**winterbed flooded**	**winterdike maximum**
BovenRijn level				+ **7** m NAP	+ **9** m NAP	+ **12** m NAP	+ **15** m NAP	+ **18** m NAP
BovenRijn	10	400	850	1000 (100%)	2000 (100%)	4000 (100%)	8000 (100%)	16000 (100%)
Waal/Merwede	110	300	550	813 (81%)	1450 (73%)	2680 (67%)	5300 (67%)	10000 (64%)
NederRijn/Lek	120	150	400	30 (3%)	250 (12%)	756 (19%)	1500 (19%)	3500 (21%)
IJssel	125	100	500	157 (16%)	300 (15%)	561 (14%)	1100 (14%)	2500 (15%)
Bron: Watersysteem rapportage Rijntakken 1990 - 2015								

Flushing and Buffer capacity

Conclusion: prolonged peak Rijn discharge 16 days -> discharge total 15 . 10^9 m^3

Flushing capacity and Buffer capacity Delta en Waddenzee related to maximum Rijn discharge (20.000 m3/s)



Prolonged peak discharge: (2 days x 20.000 m3/s + 4 days x 15.000 + 6 days x 10.000 + 4 days x 5.000) x 24 x 3600 = 15 10^9 m3

Flushing and Buffer capacity

Conclusion: prolonged peak Rijn discharge 16 days -> discharge total 15 . 10^9 m^3
-> area Waddenzee/IJsselmeer 2400 km^2 -> level rise 4 m without sea flushing

Flushing capacity and Buffer capacity Delta en Waddenzee related to maximum Rijn discharge (20.000 m3/s)							
6-hour period	**flushing capacity**		**v = 3 m/s**	**low tide (6 hours)**	**buffer capacity (per 6 hour)**		**high tide (6 hours)**
	b x h	**opening**	**flow**	**discharge**	**area**	**level rise**	**charge**
	m	m2	m3/s	m3	km2	m	m3
Haringvliet	960 x 6	5.760	17.280	0,4 10^9	100	0,90	0,4 10^9
Oosterschelde	2688 x 9	24.200	72.600	1,5 10^9	350		
IJsselmeer	300 x 4	1.200	3.600	0,08 10^9	1100	0,11	
Waddenzee	20.000 x 5	100.000	300.000	6,5 10^9	2400		
Prolonged peak discharge: (2 days x 20.000 m3/s + 4 days x 15.000 + 6 days x 10.000 + 4 days x 5.000) x 24 x 3600 = 15 10^9 m3							

Phased and adaptive process

Phase C East and Southside more drastic interventions

advancing sea level rise > 3 meter

. C1 Maasbed shifting to Belgian border

. C2 Rijnbed shifting to German border

Option I: all discharge of Rijn to Dollard

- maximum 20.000 m3/s

Option II: discharge to Dollard without peak flow

- maximum 4.500 m3/s
- peak flow temporary to Waddenzee

Phased and adaptive process

Phase C East and Southside more drastic interventions

advancing sea level rise > 3 meter

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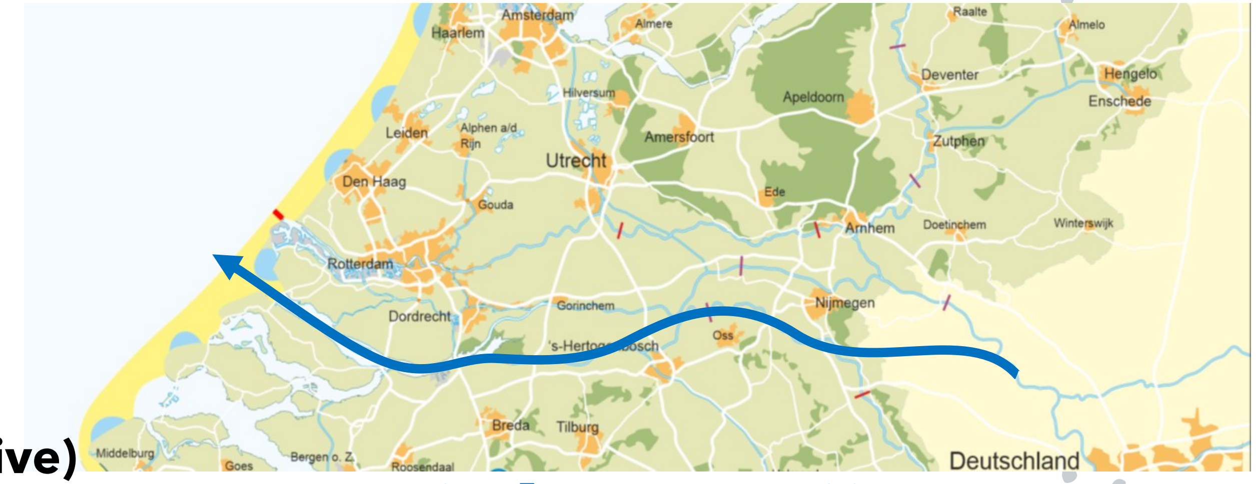
Option I: all discharge of Rijn to Dollard

- maximum 20.000 m3/s

Option II: discharge to Dollard without peak flow

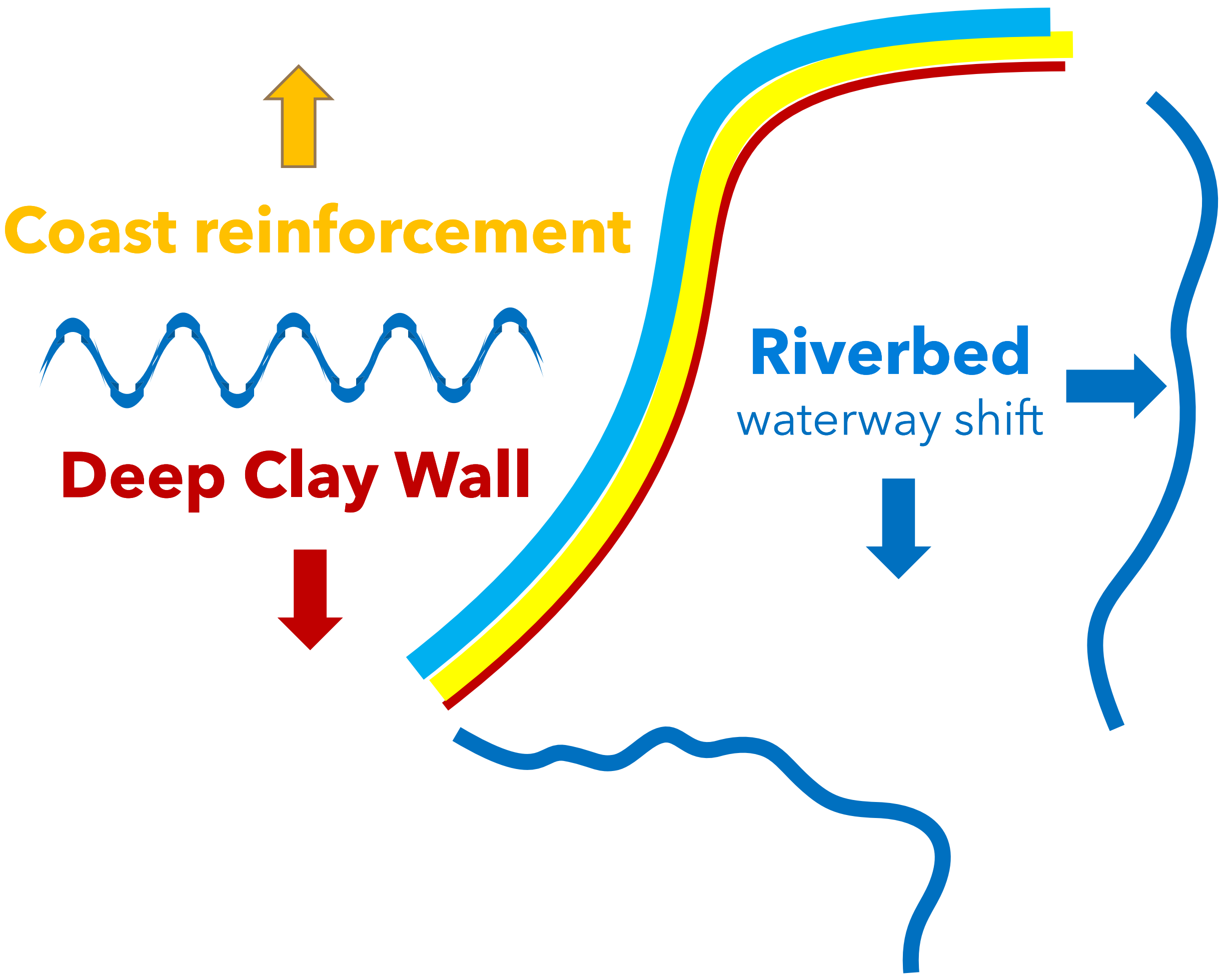
- maximum 4.500 m3/s
- peak flow temporary to Waddenzee

. C3 Highway Rijn river as Brabants by-pass **(alternative)**



Highway Rijn

Overview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Superbrede dijken langs Dollard
Delfzijl
Spuisluizen in winterbed
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Harlingen
Drachten
Winschoten
Bosse GrensRijn
Sneek
Assen
Heerenveen
Den Helder
Bosse Zeelinie
Nieuwe Zeewering + 25 m NAP
met binnenbaaien bij badplaatsen
en onderlangse leemkade
Nederland
Emmen
Enkhuizen
Emmeloord
Alkmaar
Hoorn
Meppel
Hoogeveen
Zoetwater binnenbaaien + 5 m NAP
bij oud-Hollandse badplaatsen
voor recreatieve beleving
Kampen
Lelystad
Zwolle
Bosse GrensRijn
Dam IJssel
Raalte
Leemkade onderlangs zeewering
tot horizontale kleilagen 10 - 60 m diep
als zoutwaterkerende kwelwand
Amsterdam
Haarlem
Almere
Almelo
Deventer
Hengelo
Enschede
Hilversum
Apeldoorn
Zeesluizen bij Rotterdam,
Amsterdam en de Waddenzee
Leiden
Alphen a/d Rijn
Utrecht
Amersfoort
Zutphen
Den Haag
Ede
Gouda
Dam Rijn
Arnhem
Doetinchem
Winterswijk
Rotterdam
Dam Waal
Dammen
Gorinchem
Nijmegen
Bosse GrensRijn
Dordrecht
Oss
's-Hertogenbosch
Rivierpanden als spaarbekkens
Breda
Tilburg
Dam Maas
Deutschland
Middelburg
Goes
Bergen o. Z.
Roosendaal
Helmond
Vlissingen
Eindhoven
Bosse GrensMaas
Venlo
Terneuzen
Hulst
Stormvloedkering
Bufferdelta
Weert
Roermond
Superbrede dijken
langs Westerschelde
Bosse GrensMaas
België/la Belgique
Heerlen
10 km
Maastricht