The Interreg IVB North Sea Region Programme

Managing Adaptive REsponses to changing flood risk

MARE

The Lungegård lakes, transforming a fjord.

List of stakeholders

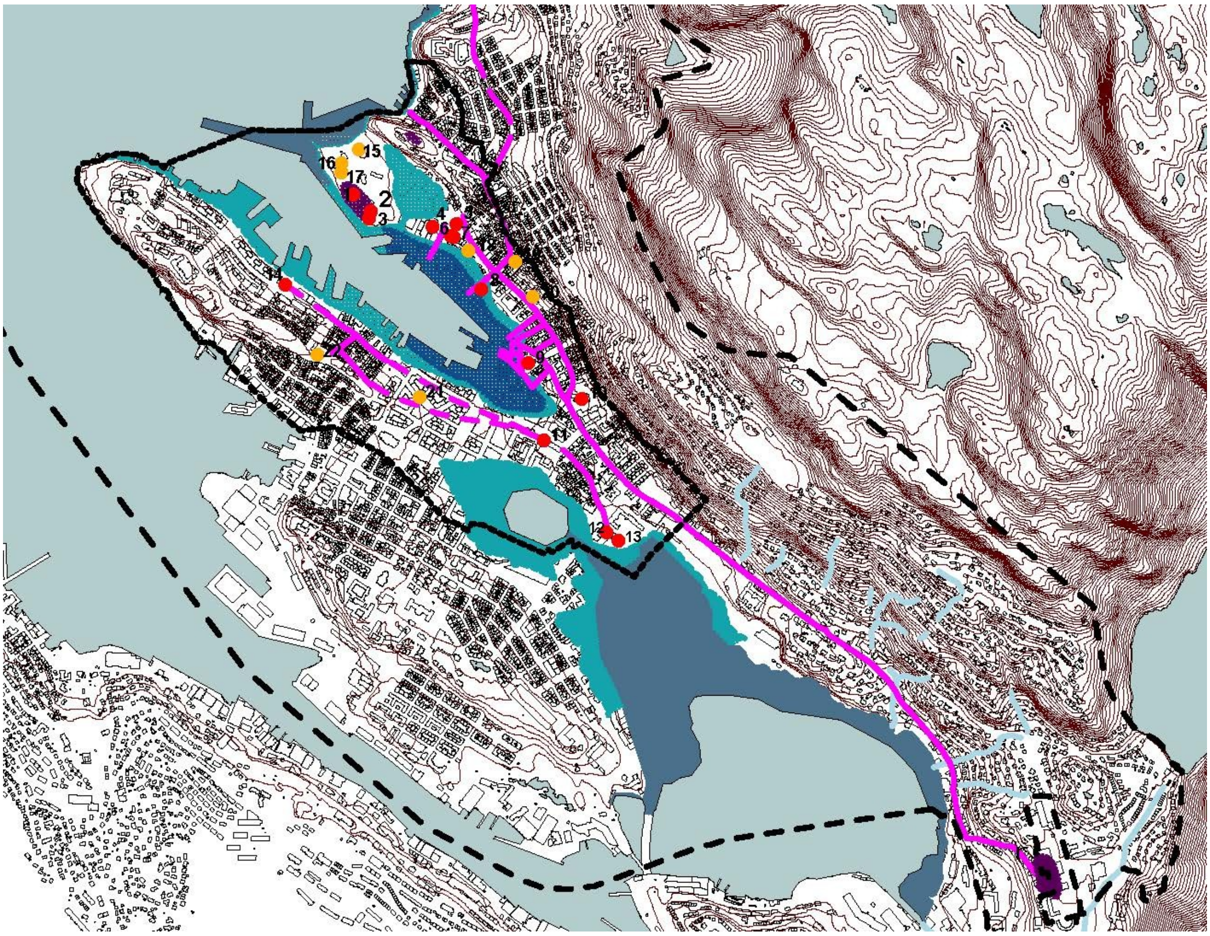
The stakeholders should be listed against the standard list. However the terms in the standard list should be used within the case study in order to enable readers to more easily understand

Ref. No.	Stakeholder	Developers		Long term ownership		Interest																									
						Regulators										Planning bodies										Knowledge development					
						Wild life		Heritage		Environment		Water quality		Water quantity		Emergency planning		Strategy planners		Development control		Building control		Road/Transport		Initiators		Create state of the art knowledge		knowledge maintenance	
		A	D	A	D	A	D	A	D	A	D	A	D	A	D	A	D	A	D	A	D	A	D	A	D	A	D	A	D	A	D
	Public authorities and water utility organisations																														
1	National Government												1		1																
	- Cultural Heritage							x	x																						
2	Provincial Government (County Hordaland)												3			X															
	- Environmental department						x				x		X				x														
	- Food safety authority									X	X	X	X													x	x			x	X
3	KLIF (Climate and Pollution Agency)											x	x					x	x	x	x					x	X			x	x
4	Norwegian Water Resources and Energy Directorate (NVE)									x			X		x		x		x		x									x	X
5	City of Bergen (divided by departments)																														
	-Agency for Fire and Rescue Services																														
	- Section for Civil Protection and Emergency Planning															X	X														
	- Department of Climate, Environment and Urban Development															x	x	x	x		x			x						x	

	- Agency for Water and Sewerage Works	x	x	x	x							x	x	x	x	x		x		x		x				x				x	X
	- Green Management Agency	x	x	x		x	x			x										x	x									x	X
	- Agency for Development Control and Private Plans/Agency for Planning and Geodata															x	x	x	x	x	x	x	x	x						x	X
	- Transport /roads (state- /county- and city level)	x	x	x	x										x		x			x				x	x					x	X
	- Agency for Cultural Heritage Management							x	x																						
	- BIR (waste management company)																														
6	Hordaland County (common to all municipalities in Hordaland)																														
	- Climate Advisory Panel																									x	x			x	X
	- Climate and natural resources					x	x					x		x		x	x	x	x							x	x			x	x
	- Water Region Hordaland									x	x	x	x	x	x											x	x			x	X
	- Wildlife, Inland fisheries, Outdoor Recreation					x	x			x		x		X																	
7	Civil Defence															x				x											
8	Infrastructure owners : gas, electricity, telecom, railway																														
9	Property owners	x		x	x																									x	X
10	Interest groups																														
	- Consultants, architects															x		x		x		x		x							
11	Knowledge institutions																														
	- Bjerknes Centre for Climate Reasearch/ The Norwegian Meteorological Institute											x		x		x		x		x		x						x		x	
12	Citizens, organisations and communities																														
	Nordnes SKOLE adoptation of Smålungeren																													x	x

Content

1 Introduction

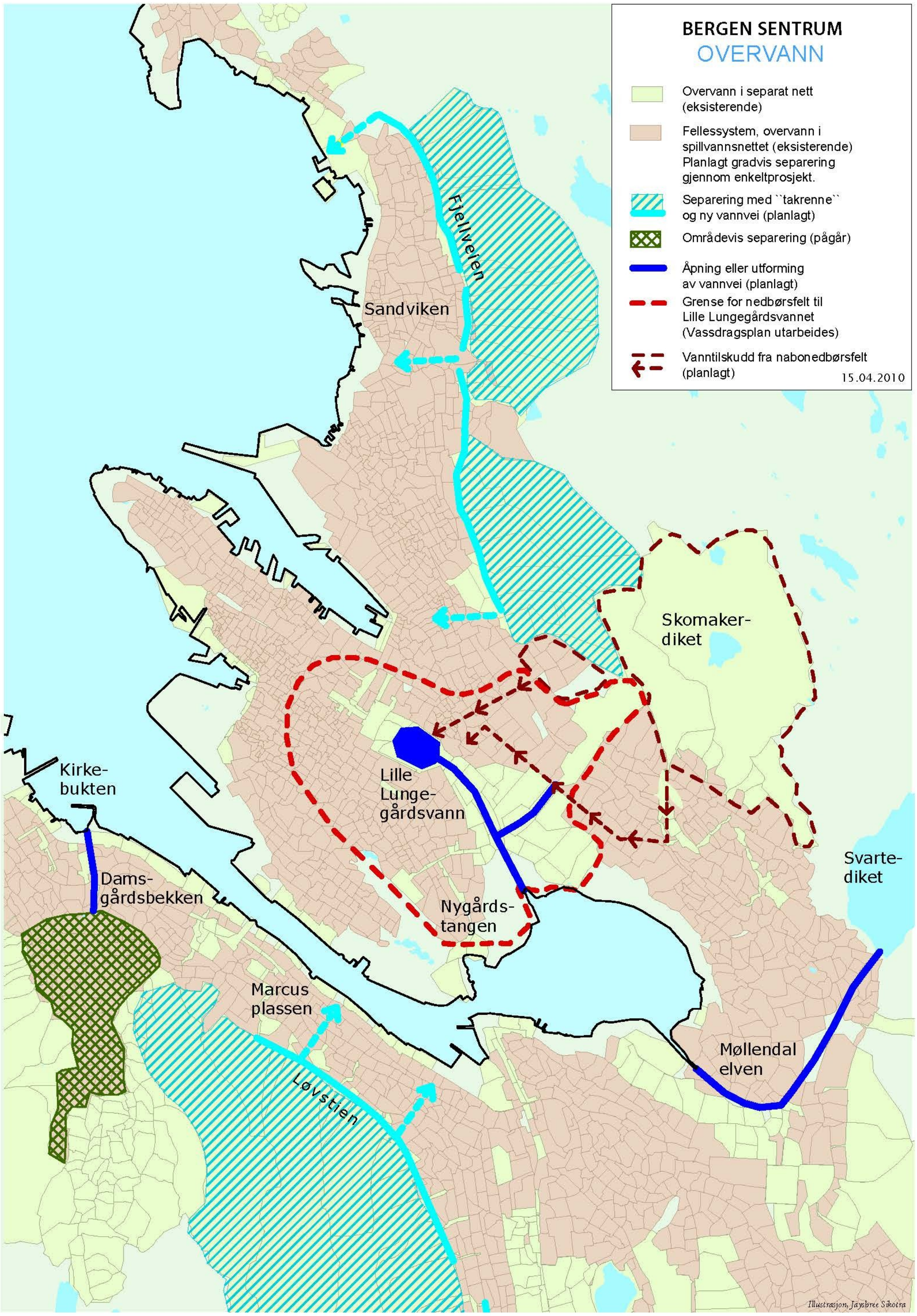


The City of Bergen is a historical port beside a sheltered fjord, surrounded by steep mountains in Western Norway. The city has a humid coastal climate with considerable amounts of precipitation. The mountain landscape creates short river systems with huge variations in water volumes. Large parts of the city centre are low-lying and vulnerable to spring tides and future rises in sea level.

The southern part of the city centre consists of reclaimed land in what was previously a fjord. The map above shows historical roads in pink, while the reclaimed land is marked in dark blue shades.

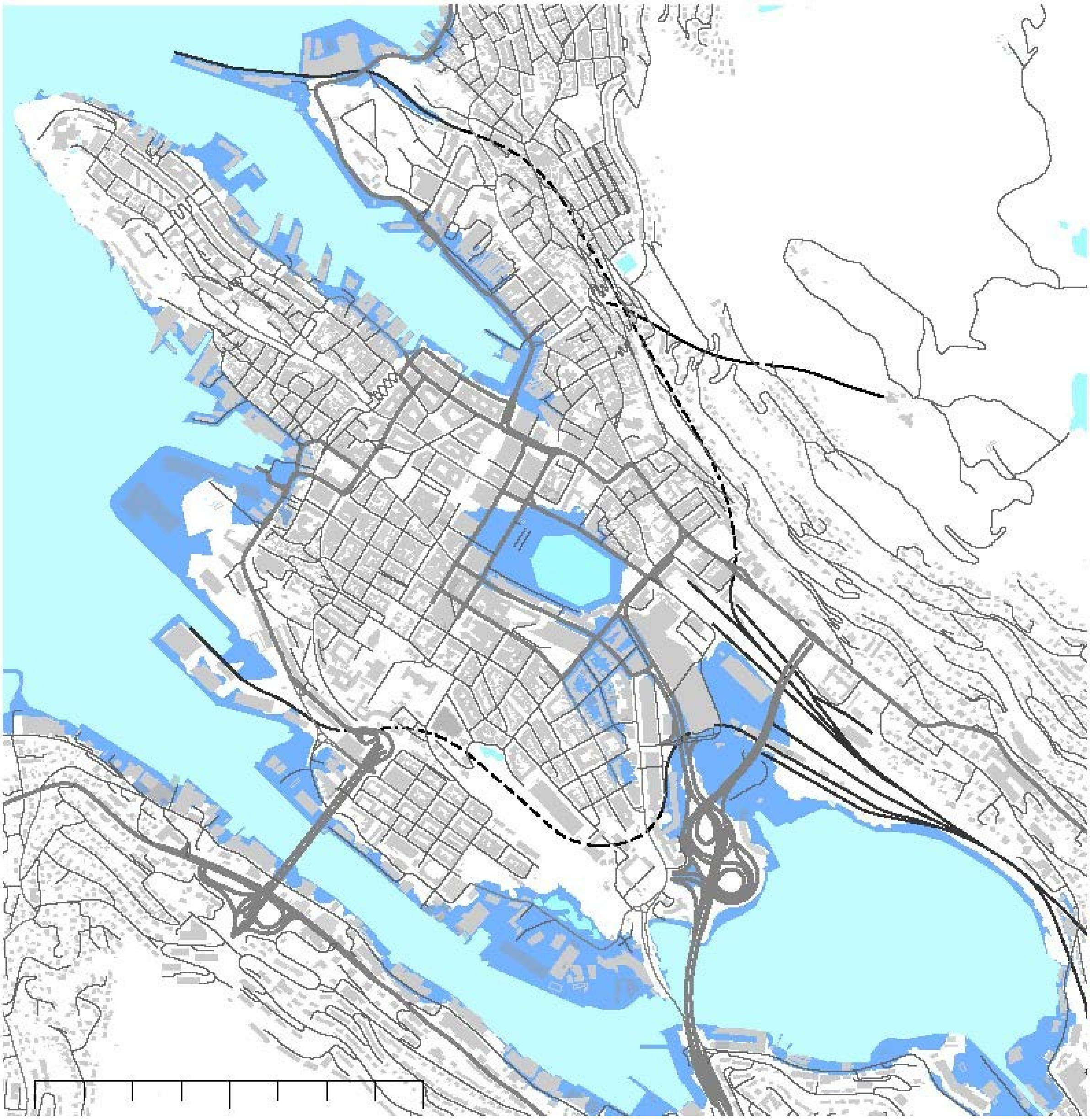
In 1925, the inner part of the fjord was designed as an urban lake connected by culverts to the sea, but odour problems caused by factors such as brackish water and pollution resulted in the connection to the sea being closed off in 1983. The lake is now a freshwater lake, but the water supply is insufficient and the conditions at the bottom of the lake are characterised by plenty of nutrients, a great deal of pollution and considerable historical sediments.

The map on the opposite page shows the surface water handling systems in the city centre. Areas shaded brown are areas that have common systems, where rainwater is routed through the sewage system, while areas shaded light green have separate systems for sewage and surface water. A long-term objective is to reduce the number of common systems and to reduce the inflow of rain water in the sewage systems. Turquoise arrows show plans to intercept the rain water from the mountains like a ‘drainpipe’ and route the water outside the common system.
The red dotted line shows the catchment area for Lille Lungegårdsvannet lake. Its water quality will be improved if as much rainwater as possible can be routed into the lake. The brown dotted lines illustrate the possibility of routing rainwater from adjacent catchment areas.



The map below shows that large parts of the city centre are situated less than 2.38 metres above sea level, which has previously been forecast to be the spring tide level in 2100. Large parts of the wastewater system are old common systems vulnerable to increased precipitation and rising sea levels. The operating expenses for treatment are disproportionately high, and the systems will not be able to handle the city's needs and address the safety risks associated with climate change.

Future changes in precipitation and sea levels in Western Norway have been analysed in separate sub-projects (see the list of references).



1.1 Aims and objectives

The goal is to transform what used to be an arm of the fjord and its associated catchment areas into a well-functioning, robust and sustainable watercourse that is an integral part of the city centre and its southward expansion.

A long-term objective is to separate the wastewater systems in the city centre, routing rainwater into open waterways, which will limit the precipitation load on the sewage system as much as possible.

The open water surfaces in the city must have an acceptable water quality. It may therefore become necessary to feed water in from adjacent catchment areas.

Rising sea levels and increased precipitation will have major consequences for the watercourse and for the area’s viability.

All elements of the watercourse must be dimensioned with regard to sustainability, climate change and flood control.

As an urban watercourse in a densely populated, built-up urban structure, it is crucial that the design meets high aesthetic requirements and that the water’s many attractive utility qualities are fully utilised in order to provide a good quality of experience in the urban spaces.

1.2 Background

1.3 Regulations, procedures and standards

The EU’s Water Framework Directive

The environmental objectives in the Water Framework Directive are to protect and, if necessary, to improve the state of the body of water in order to ensure sustainable use, which means that the water should not differ so much from its natural state that its ecosystems no longer function. This has been specified in more detail by the development of classification systems for the different types of water.

Bergen’s guidelines for handling surface water

The City of Bergen has developed guidelines for surface water facilities. When designing facilities for handling local surface water, every effort should be made to find solutions that improve the visual character of the area and enrich the local environment by highlighting the water and utilising it as an architectonic element. Running water is life-giving and can/should be utilised as an aesthetic element in gardens, parks and residential areas etc.

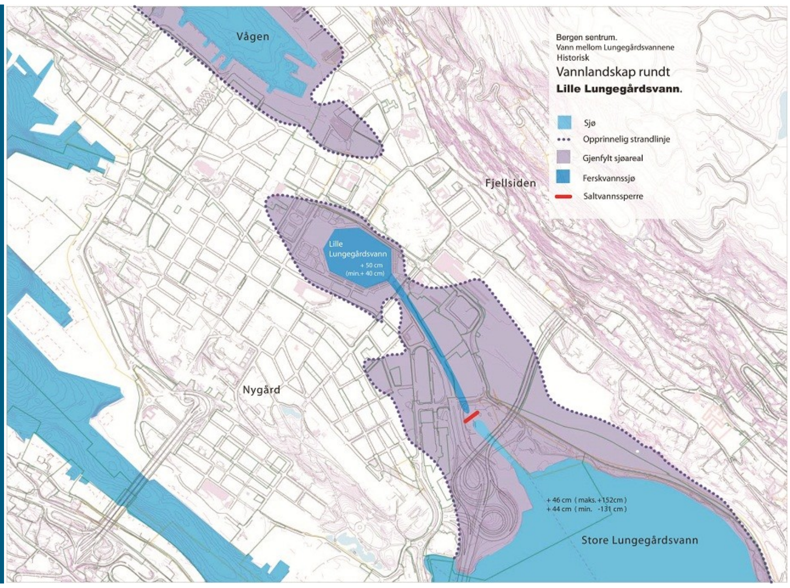
When choosing solutions for handling surface water in the city centre, solutions that reduce and retain runoff and reduce the content of pollutants in the surface water shall be used if possible. Examples of ways to achieve this include the use of more permeable and partially permeable surfaces, the use of partially permeable paving in streets, squares etc., the separation of clean/contaminated surface water, an increased use of retention basins where applicable, an increased use of open gutters in the urban landscape, and feeding downpipes etc. into the street/terrain and not directly into the water mains. Central barriers, avenues, parks etc. and infiltration surfaces along streets and squares may be modified to achieve a better infiltration of surface water.

Municipal plan for Bergen

In the land use part of the municipal master plan, it is a requirement for all zoning plans to include a water and sewerage framework plan. The framework plan shall stipulate the principles on which the solutions for the area will be based, the connection to the main, overriding system and give dimensions for and illustrate surface water handling and flood routes. Precipitation shall preferably be drained through filtration into the ground and open watercourses. Zoning plans shall identify and secure areas for surface water handling and describe how solutions can add new utility and visual qualities to public spaces.

Strategy programme for water between the Lungegård lakes

A policy document has been prepared and adopted for a programme called ‘Strategiprogram for vann mellom Lungegårdsvannene’ (Strategy programme for water between the Lungegård lakes). The strategy programme contains goals for how the Lungegård watercourse shall be developed into a sustainable, robust ‘backbone’ in the area, and the imminent city development towards Store Lungegårdsvannet lake. The strategy programme sets out guidelines for overall solutions for surface water handling, with an emphasis on high quality in design and use.



Zoning plan

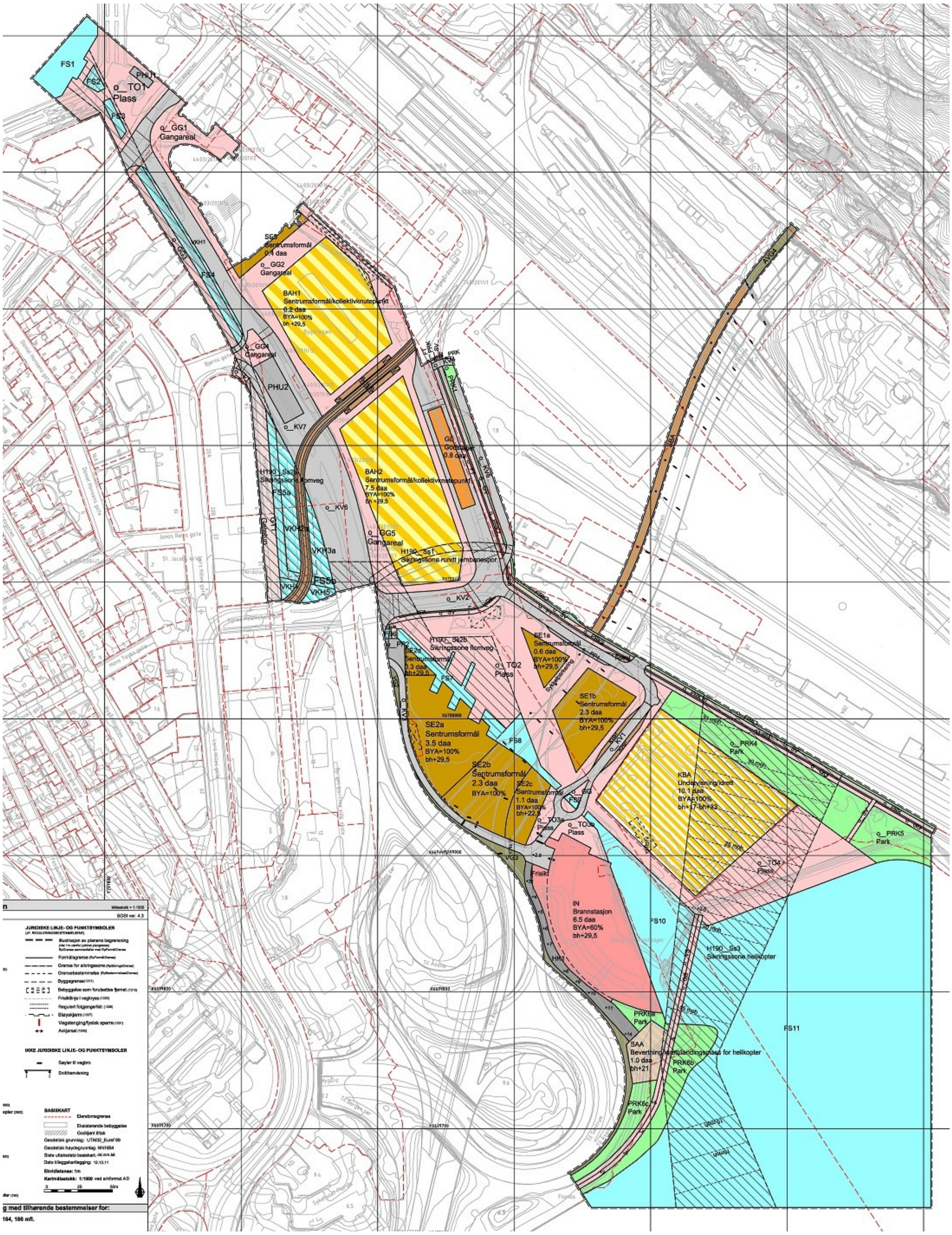
A draft zoning plan has been prepared for the Nygårdstangen area between the Lungegård lakes, and the plan will be distributed for public consultation in autumn 2012. The Nygårdstangen plan facilitates a coherent expansion of the city centre with a good design of urban spaces and streets, where watercourses and surface water handling are utilised as positive elements in the urban landscape in ‘Bergen, the Water City’.

It proposes the development of an attractive, spacious square in a central location in the area that will serve as a hub in the structure of urban spaces, where all the watercourses will meet and water will play a principal role.

The plan is based on a high utility value and solutions that are efficient in terms of land use, with the aim of achieving the best possible quality of experience in the urban spaces. The area is the city’s communication hub. It will become an active, diverse part of the city centre where elements at the opposite extremes of the urban spectrum can coexist, such as an outdoor swimming pool/area and a helicopter base.

It will be a challenge to find urban, robust solutions for the water areas that are efficient in terms of land use and yet are sustainable and of a high quality.

Extensive changes are being planned that include moving parking spaces to an underground facility beneath Lille Lungegårds lake and replacing the existing car park with new buildings. Planning work is therefore under way on the establishment of a parking facility beneath Lille Lungegårds lake.



Draft area zoning plan for Nygårdstangen, street level, consultation paper.

1.4 Timeline

June 1999 –first regulation plan is written for Nygårdstangen with open channel until halfway between the Lungegårds Lakes.

July 2007 – start-up of regulation change for the Nygårdstangen area.

December 2008 –The City Council confirms a planning program for regulation change and approves the strategy program for "Water between the Lungegårds Lakes". The main goal is to open a waterway along the whole profile between the lakes.

June 2012 – The City Council lays out the proposal for regulation change for the Nygårdstangen area to public hearing, and approves also the start-up of the regulation plan for the Little Lungegårds Lake to establish a parking facility under the water.

2 Details

2.1 Analysis and assessment

Overview of Nygårdstangen to the north.

The southern part of Bergen city centre is built on the landfill sites surrounding the brackish stretches of fjord, now known as Lille and Store Lungegårdsvann. This landfill has been home to the city's furtive activities and bleak transport areas. The area around Lille Lungegårdsvann has been

reconquered by a diversity of urban activities and has become the city's exclusive representation space with an open events arena and promenades, with high-quality design and landscaping.
The lake itself and the bottom of the lake have not yet received the same amount of attention, but are next in line. The problems concerning brackish water have come to an end and the lake is about to be developed into the core of a new urban waterway.

Extensive cleaning of the bottom sediments and securing an adequate supply of surface water from the urban area through separation of the sewage system are important elements in a long-term waterway plan that aims to establish a fresh, urban waterway in biological balance.
The reopening of the waterway from Lille Lungegårdsvann to the sea is the next stage of the plan.
The remodelling of the rest of the urban area, from a strained heavily trafficked area into an attractive modern city centre area towards Store Lungegårdsvann, will be based on water as the most important element.
The establishment of a climate-adapted flood route secured against rising sea levels constitutes the core of the environmental upgrading of the city's access road and public transport hub. The waterway will be designed as an attractive environmental thread through the new urban spaces to be built along the sea and the swimming complex that is already under construction. Understanding of the climate, modern urban ecology and the diverse qualities of water will form the basis for the design.

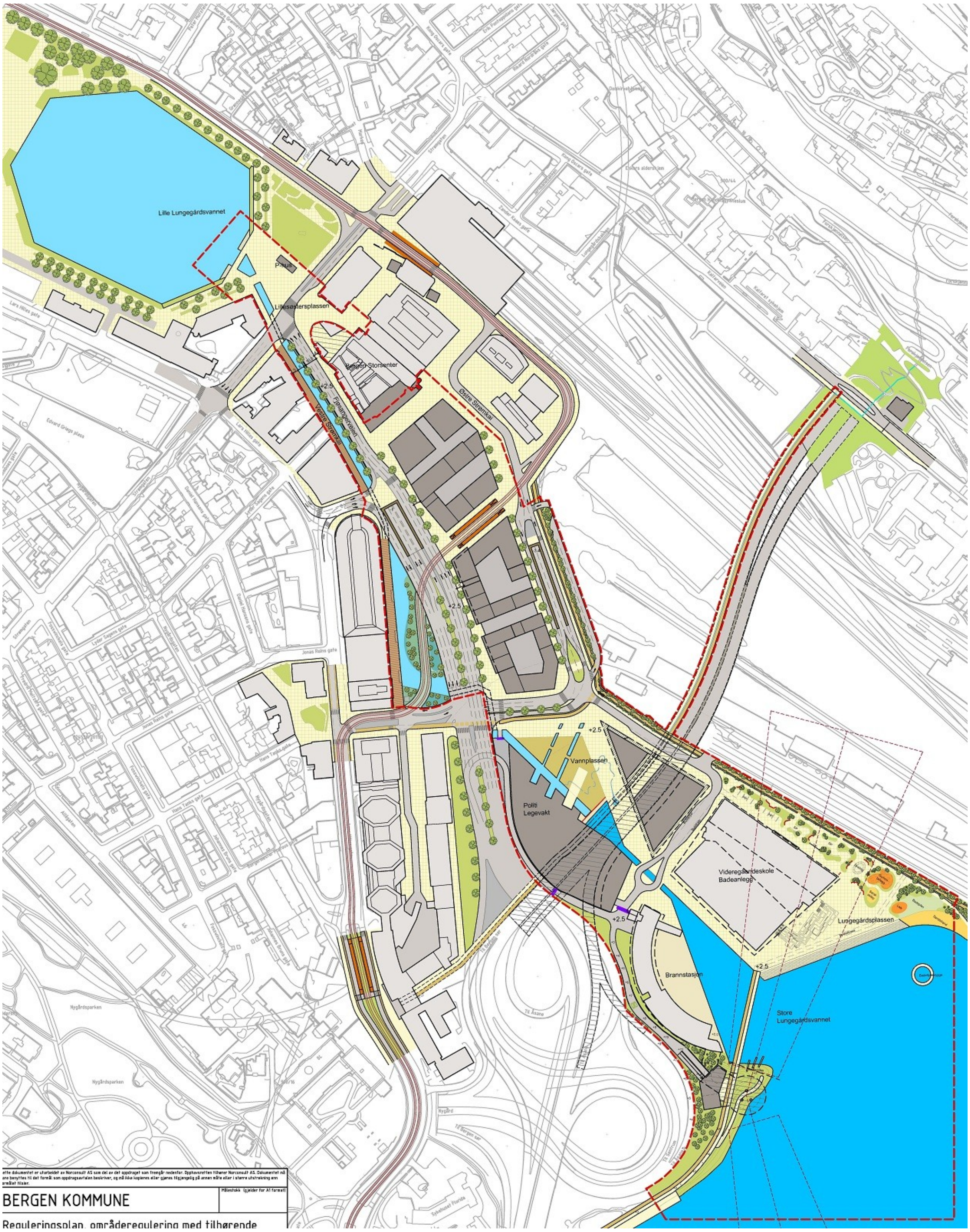
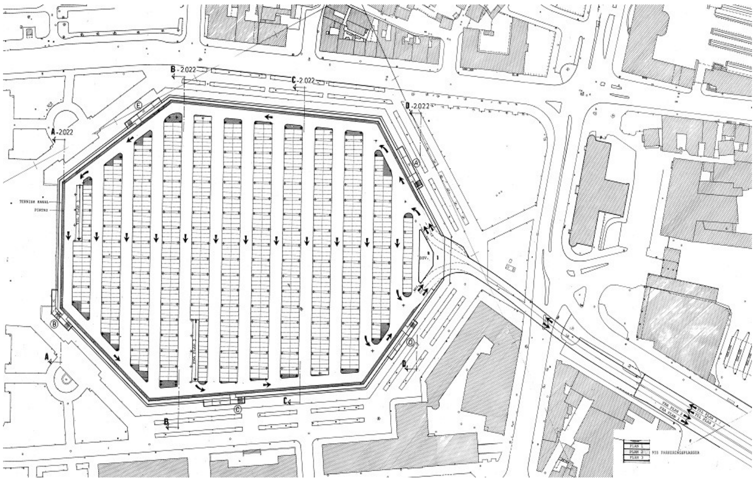
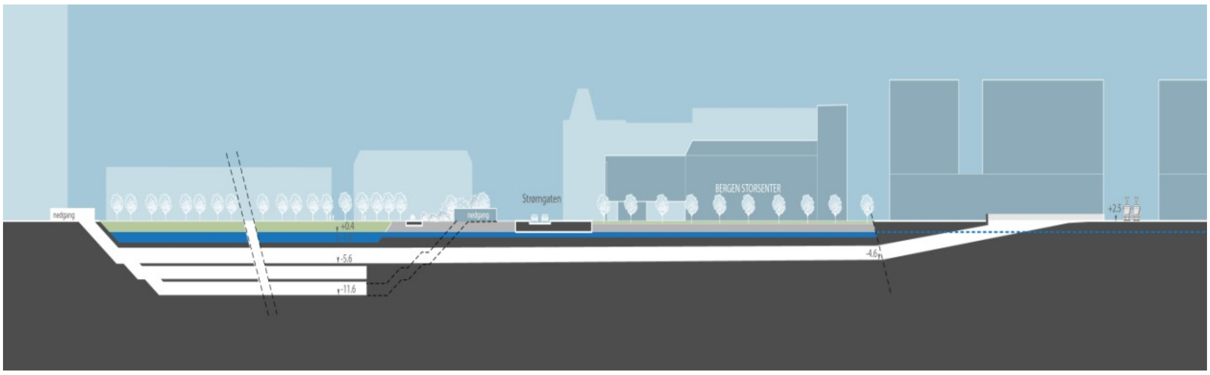


Illustration plan for the consultation paper.

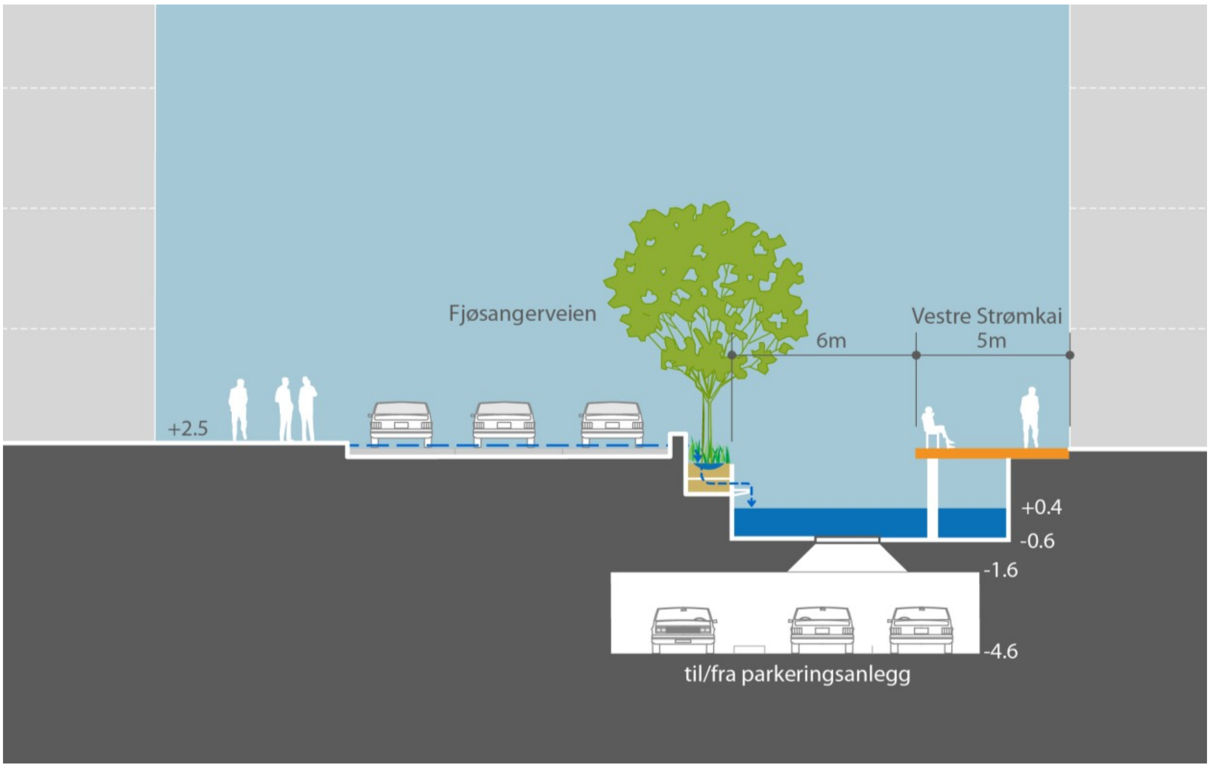


1976 draft for parking beneath Lille Lungegårdsvann.

A parking facility beneath Lille Lungegårdsvann has been proposed before. The parking facility could make it possible to clean up the pollution and create a healthy lake with attractions and activities, and a structure that could ensure retention capacity in the event of higher sea levels and increased precipitation. The entrance could provide space for the canal above and essential treatment plants.



Longitudinal section of Lille Lungegårdsvann, three-story parking facility and vehicle entrance with overlying canal.



Cross-section through vehicle entrance under the canal with a row of trees in a purification bed for road runoff and a wooden walkway for pedestrians.


View from Vestre Strømkai, with canal, purification bed and wooden walkway.

Water quality and treatment of surface water

Shallow areas that allow close contact with the water are an option for both Lillesøsterplassen and Vannplassen squares. Lille Lungegårdsvann and the Lungegård canal will both therefore require a water quality that corresponds to 'wading water' (the term is taken from the Danish report *Sundhetsaspekter ved regnbasert rekreativt vand i større byer* (Health aspects of rain-based recreational water in large cities) from the Danish Nature Agency). 'Wading water' is typically shallow pools, maximum 0.5 metres deep, where you only get water directly in your mouth if you fall over, or if you are playing and put wet fingers into your mouth.

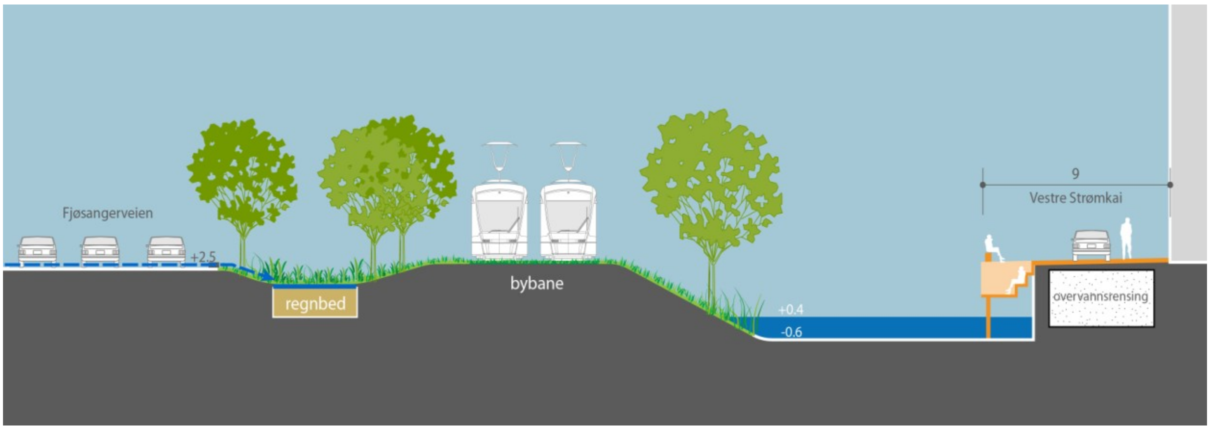
Treatment of road runoff

The Nygårdstangen area is heavily used by road traffic, and an objective for the area is that it should be able to serve as a trial area for testing possible treatment methods for the road water to enable it to be routed to the canal. The space available in the planning area for the treatment of contaminated surface water is very limited. In many places, road runoff can be routed to treatment/infiltration trenches along the road.

For areas where it is not possible to establish treatment trenches along the road, runoff must be routed to a 'central treatment facility'. In the plan, an area between the Fjøsangerveien road and the County Council's building has been allocated, partly for treatment purposes. The type, design and scale of treatment facilities must be assessed in more detail, and the chosen solution must be adapted so that it fits into the available area.

Other solutions could be closed filter pools, for example in an underground concrete structure. Rainbeds or bio-retention systems could also be used. A rainbed is a small, vegetation-covered depression in the terrain with an underlying filter layer consisting of soil/compost (40–50%) and suitable filter material (50–60%). Runoff is routed to the rainbed where it is filtered/treated. In the event of large inflows, the water is also retained through accumulation in the rainbed/depression.

Purification ponds are a commonly used solution for contaminated surface water in larger areas. These are open facilities that make the treatment process visible. Such facilities require a large amount of space, and during the work on the area zoning plan, it was decided that the main solution for the treatment of surface water shall not be based on purification ponds/wetland filters. Establishing some aquatic vegetation in the extended canal cross-section along Vestre Strømkai could be an option, which could be utilised to partly purify the canal water in periods of low/normal water flow.



Cross-section through treatment area and canal extension, with possible treatment volume under the walkway.

Basis for dimensioning surface water facilities

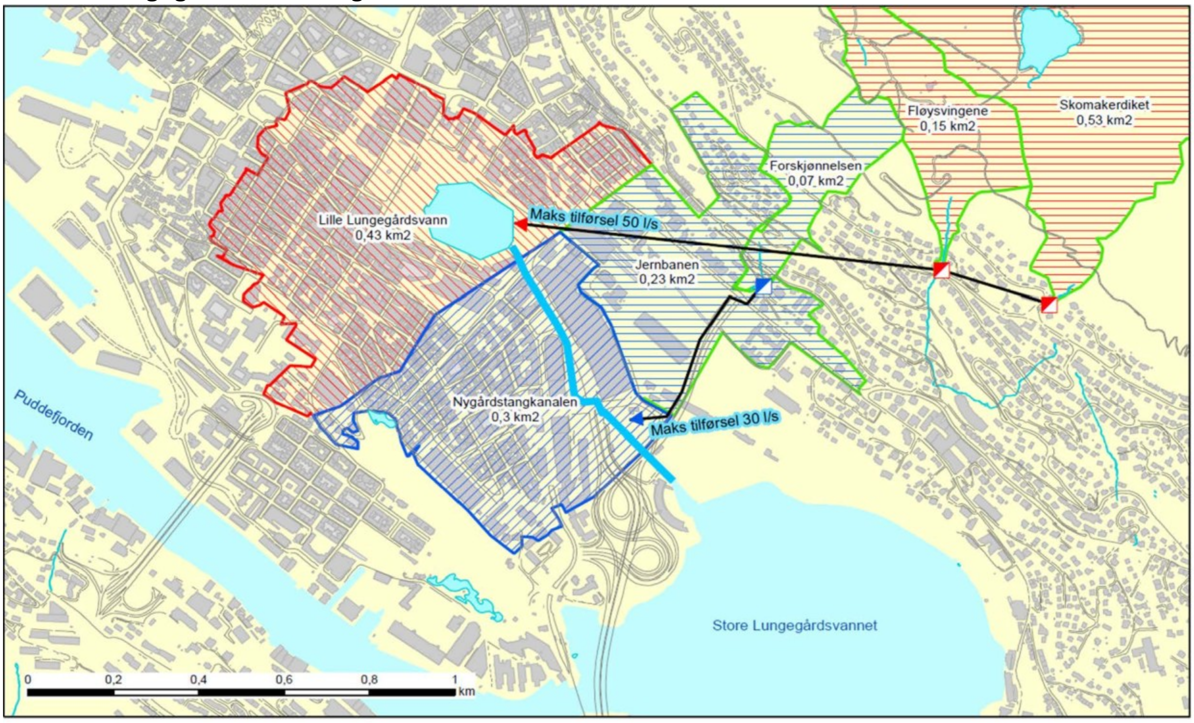
Precipitation data for Bergen city centre (Florida measuring station) have been used as a basis for calculating runoff. Climate prognoses and an expected future increase in precipitation have been taken into account by adding 40% to precipitation intensities taken from the IVF graphs. Precipitation intensities as stipulated in the table below shall be used when dimensioning surface water facilities:

	Nedbørintensitet (l/s.ha)		
Varighet t_k (min.)	Returperiode Z=100 år	Returperiode Z=10 år	Returperiode Z=1 år
3	560	400	250
5	470	340	210
10	295	225	160
15	220	170	125
20	185	140	100
30	140	110	85
45	115	90	70
60	100	80	55
90	93	70	48
120	82	60	42
360	46	35	25
720	38	28	18

THE CANAL SYSTEM

The canal's water level basically depends on the water level in Lille Lungegårdsvann, and it will normally have the same water level as the lake. This means a normal water level of contour line + 0.4, varying up to contour line + 1. At the same time, the water level will be affected by the sea water level in Store Lungegårdsvann, where a high water level can mean an additional accumulation back in the canal, as far as Lille Lungegårdsvann.

At the upper and lower ends of the canal, there are non-return systems that mean that seawater from Store Lungegårdsvann cannot flow back into the canal system, and that water from the canal cannot flow back into Lille Lungegårdvann. The canal level could then theoretically be higher than the water level in Lille Lungegårdsvann, and the canal's potential for accumulation could be utilised as a retention volume for inflow from adjacent areas in extreme situations when the sea water level in Store Lungegårdsvann is high.



Catchment area for Lille Lungegårdsvann and the Lungegård canal with possible inflow from adjacent catchment areas.

2.2 Problem definition

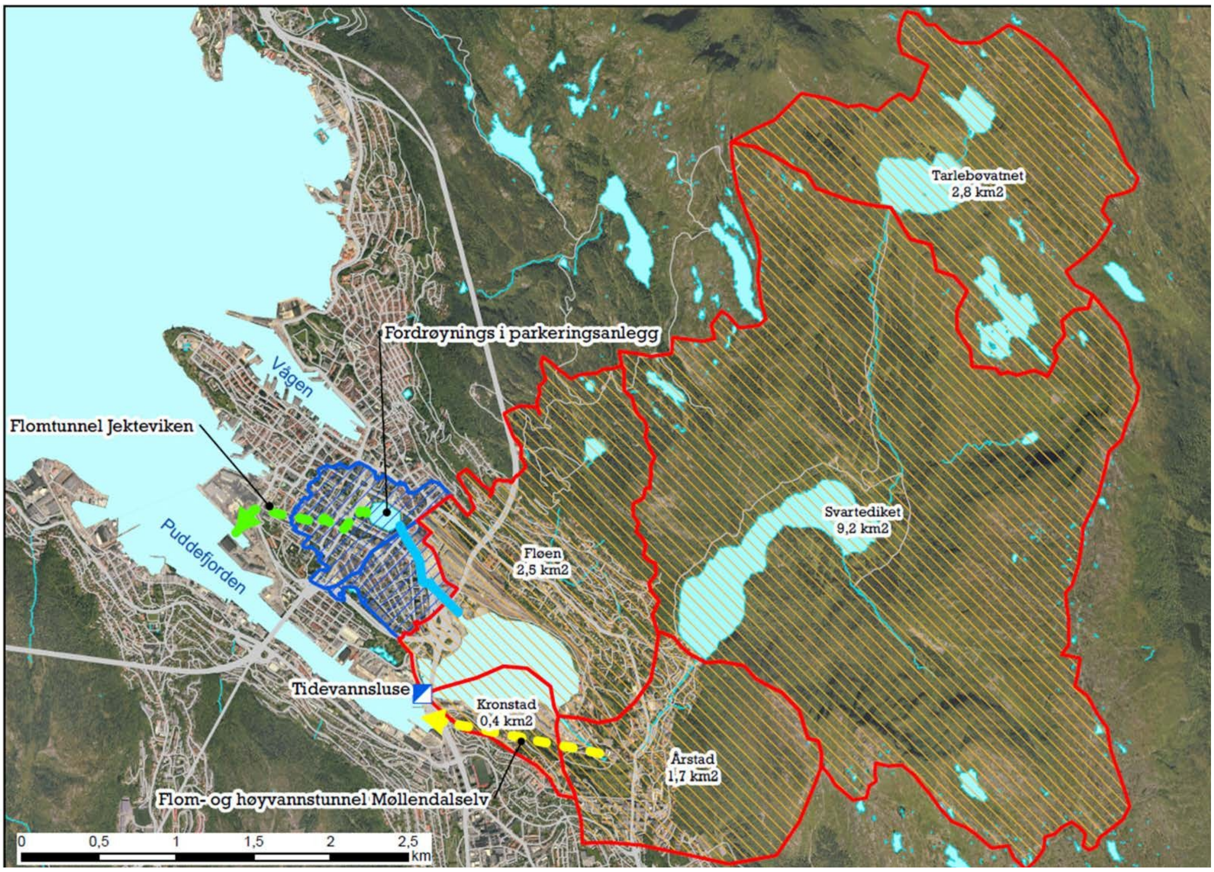
The objective for the Lungegård watercourse to become a robust, sustainable backbone in the central city area and the new expansion of the city centre requires an assessment of the long-term perspective of climate adaptation in relation to uncertainties, stages, changes and critical factors in the transformation process.

It is important that long-term dimensioning is analysed with regard to critical timings during the establishment phase, and any extra options or room for manoeuvre that may be available during a longer term perspective.

It would also be appropriate at this stage to assess the measures at Nygårdstangen in relation to the rest of the city centre, which will also need protection, particularly against rising sea levels.

2.3 Options considered

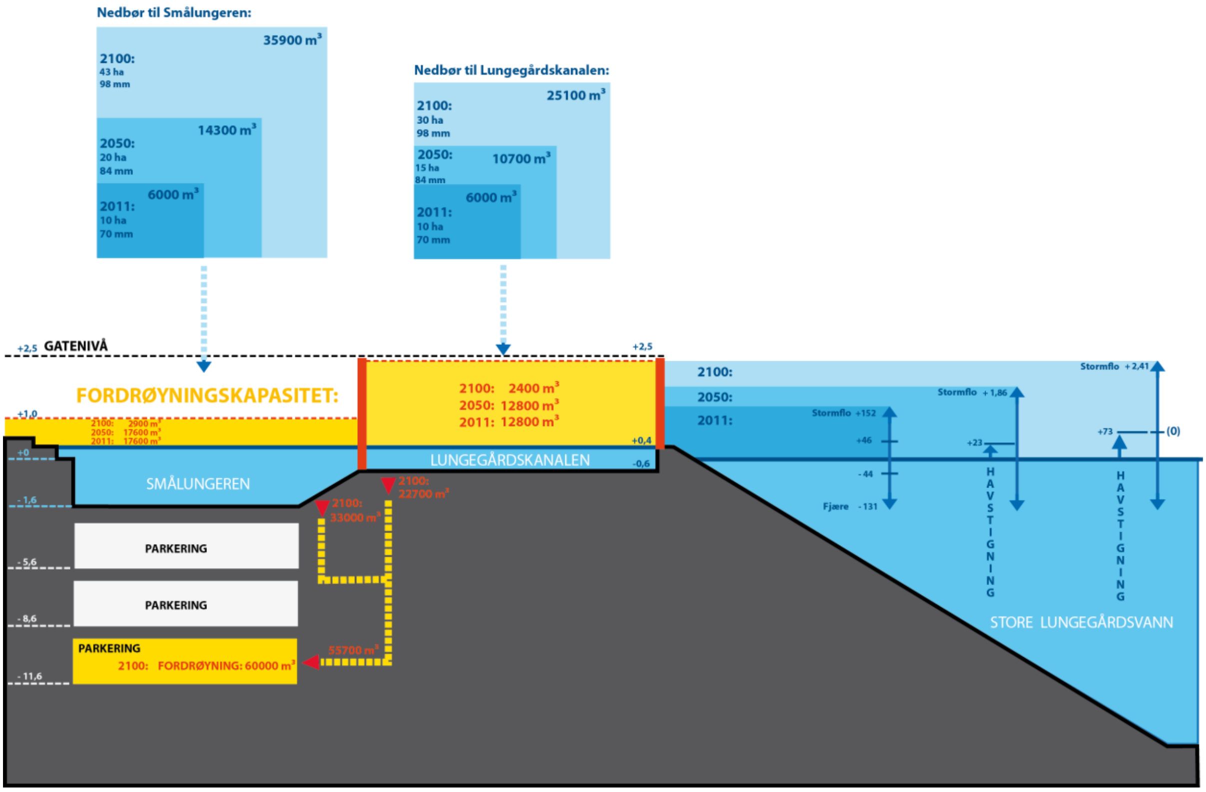
Estimated calculations of the precipitation increase and retention reduction have been carried out for two alternatives, one involving a non-return valve at Nygårdstangen and one involving a tidal sluice in the Nygårdsstrømmen sound.



Catchment area of Lille Lungegårdsvann (blue) and Store Lungegårdsvann (red).

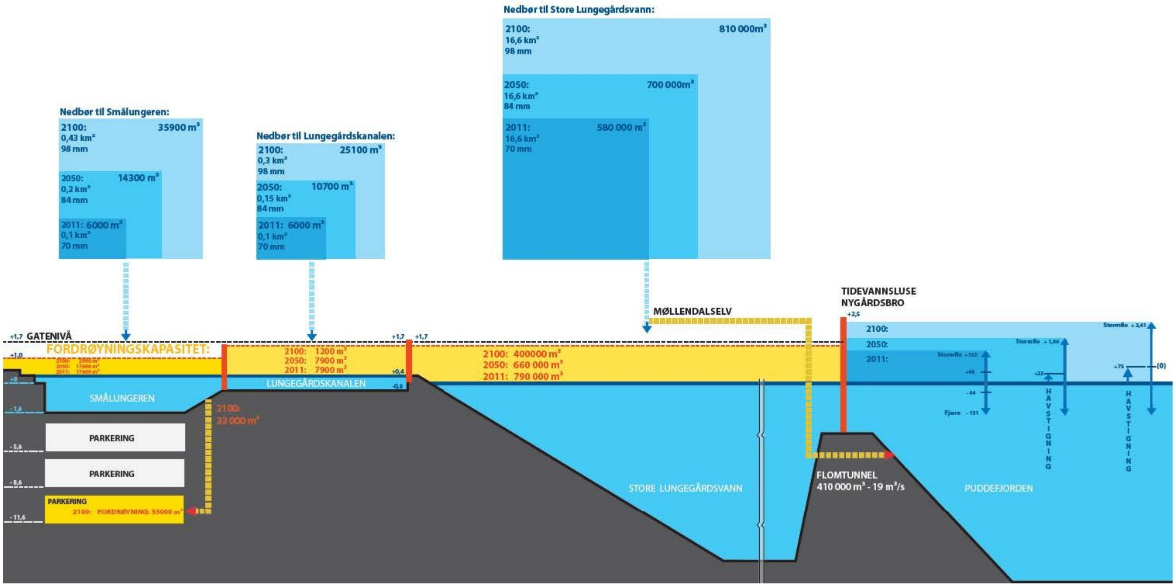
The map illustrates possible solutions for securing retention with a tidal sluice and/or retention in the parking facility, a possible flood tunnel for the Møllendalselven river (yellow) and possible pumps from the flood tunnel to the sea in Jekteviken (green).

Non-return valve (red) at Nygårdstangen and street level at contour line + 2.5 metres above sea level The table shows increases in precipitation (blue) in relation to changes in retention capacity (yellow) and rising sea levels.



Streetlevel +2,5 meters above sea.					2011	2050	2100
Sealevel rise						0.3m	0.90m
Precipitation intensity % of 1982-2002					100 %	120 %	140 %
	width m	length m	bottom moh	startlevel moh			
Retention volumes					volumes m3		
LL	171	171	-2	0,4	17600		
Channel		565		0,4	12800		
Total					30400		
Watershed Litle Lake					10 ha	20 ha	43 ha
Travel time					6 hours	6 hours	6 hours
Precipitation intensity					70 mm	84 mm	98 mm
Recharge					0.3 m3/s	0.7 m3/s	1.7 m3/s
Highest waterlevel					0.6 MOH	0.9 MOH	>2.0 MOH
Retention volume needed					6000	14300	35900
Retention volume available					17600	17600	2900
Required					0 m3	0 m3	33000
Watershed channel					10 ha	15 ha	30 ha
Travel time					6 hours	6 hours	6 hours
Precipitation intensity					70 mm	84 mm	98 mm
Recharge					0.3 m3/s	0.5 m3/s	1.2 m3/s
Highest waterlevel channel					1.4 MOH	2.2 MOH	>2.5 MOH
Retention volume needed					6000	10700	25100
Retention volume available					12800	12800	2400
Required					0 m3	0 m3	22700

Tidal sluice (red) by the Nygårdsbroen bridge. The table shows increases in precipitation (blue) in relation to changes in retention capacity (yellow) and rising sea levels.



Case 7 - stormflo - tidevannsluse Nygårdsbro		2011	2050	2100
Oppstuving Lungegårdskanalen	1,70			
Maks oppstuving Store Lungegårdsva	1,70			
Maks oppstuv. LiSmålungerene Lung	1,00	1,00	1,00	1,00
Sjøvannsnivå ved lukking sluse		-0,10	0,20	0,80
Middel høyvann		0,46	0,66	1,26
Overhøyde høyvannslukker Vannplassen		1,24	1,04	0,44
Nedbørintensitet, % av 1982 - 2002		100 %	120 %	140 %

Hovedelement	bredde	lengde	bunn	startnivå	volum	startnivå	volum	startnivå	volum
	m	*m*	*moh*	*moh*	*m³*	*moh*	*m³*	*moh*	*m³*
LiSmålungerene Lungegårdvann	171	171	-2,00	0,50	14 700	0,50	14 700	0,90	2 900
Lungegårdskanalen	9	170	-0,60	0,50	10 500	0,50	1 800	0,90	1 200
Maks nivå Store Lungegårdsvann	663	663		-0,10	791 200	0,20	659 400	0,80	395 600
Sum					**816 400**		**675 900**		**399 700**
Nedbør - avrenning									
Nedbørfelt				16,6 km²		16,6 km²		16,6 km²	
Varighet				6 timer		6 timer		6 timer	
Avrenningsfaktor				0,50		0,50		0,50	
Kapasitet til fordrøyning				4,6 m³/s km²		3,8 m³/s km²		2,2 m³/s km²	
Kapasitet nedbør til fordrøyning				98 mm		81 mm		48 mm	
Kapasitet tilrenning til fordrøyning				37,8 m³/s		31,3 m³/s		18,5 m³/s	
Intensitet, 6 timer - 100 årsflom				70 mm		84 mm		98 mm	
Intensitet, 6 timer - 100 årsflom				3,3 m³/s km²		3,9 m³/s km²		4,6 m³/s km²	
Snitt vannføring til Store Lungårdsvann, 6 timer - 100 årsflom				27,0 m³/s		32,4 m³/s		37,8 m³/s	
Volum til fordrøyning				582 660 m³		699 192 m³		815 724 m³	
Tilgjengelig fordrøyningsvolum				791 200 m³		659 400 m³		395 600 m³	
Behov for ytterligere fordrøyningsvolum				**0** m³		**39 792** m³		**420 124** m³	
KontroSmålungeren fordrøyningsvolum				816 400 m³		675 900 m³		399 700 m³	

Relevant measures for climate adaptation after 2050

If the sea level rises more than 20–30 cm, which is the expected increase by 2050, additional measures (or a combination of measures) must be implemented:

2050: Sea level rising 20–30 cm

- Based on its current level in Fjøsangerveien road, the Lungegård canal cannot withstand an increase in sea level. Possible measures may include raising the terrain to above 2.5–2.7 metres
- Building additional retention volume, for example under the Vannplassen square and/or in the parking facility by Lille Lungegårdsvann. In total, 56,000 m^3 will be required in 2100, which corresponds to a height of approximately 2.5 metres in the parking facility under the lake.

2100: Sea level rising 70–90 cm

This scale of sea level increase warrants completely different measures. Possible measures relevant for further assessment could be:

- Building a tidal sluice between Store Lungegårdsvann and the Puddefjord, possibly combined with options to transfer water from the Møllendalsbekken stream to outside the sluice
- Pumping surface water to Jekteviken
- Raising terrain
- Building dikes along Store Lungegårdsvann and pumping groundwater out
- Modifying the sewage system in Bergen city centre and increasing the water level in Lille Lungegårdsvann.

2.4 Selected option

The draft zoning plan will be distributed for public consultation in the autumn (2012) together with the initial consultation on the proposed planning programme for the zoning plan for the parking facility beneath Lille Lungegårdsvann. The environmental impact assessment shall clarify which retention solutions must be established if the parking facility is to be secured.

Additional assessments and comprehensive analyses are needed for the entire city centre. Based on the framework that is currently stipulated in the zoning plans for these two areas, climate adaptation measures have been proposed that will be able to secure the area for approximately 40 years.

2.5 Implementation

The area is being developed, and the solutions will be implemented alongside the various implementation stages.

2.6 Performance and effects of selected option

2.7 Difficulties encountered

3 Review

3.1 Discussion

3.2 Learning points

3.3 Conclusions

Flood prevention and safety measures against rising sea levels are topics that must be included as planning requirements at an early stage of the planning phase. In densely populated city structures with limited available space, the climate adaptation measures may be integrated with other functions and purposes, providing attractive and educational solutions in robust urban environments. It is a challenge to create transparent, self-explanatory solutions that can become part of people's everyday lives and form the basis for a general, broad understanding of the connection between public safety and the climate.

3.4 Recommendations

Sources

Bjerknessenteret for klimaforskning: Scenarios for future precipitation in the Western Norway (WestPrecip).

NERSC Special Report no. 89, Bjerknessenteret for klimaforskning, publikasjon nr. R101: Endringer i fortidens, dagens og framtidens havnivå med spesielt fokus på vestlandskysten (‘Changes in past, current and future sea levels with particular focus on the Western Norway coast’)

Nygårdstangen, forslag til områdereguleringsplan og konsekvensutredning, april 2012 (draft area zoning plan and environmental impact assessment).

Smålungeren, forslag til planprogram, april 2012 (draft planning programme)