

***ESPON Climate***  
Climate Change and Territorial Effects on Regions  
and Local Economies

Applied Research Project 2013/1/4

**Final Report**

**Annex 7**

**Case Study Coastal Aquifers**

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This report does not necessarily reflect the opinion of the members of the Monitoring Committee.

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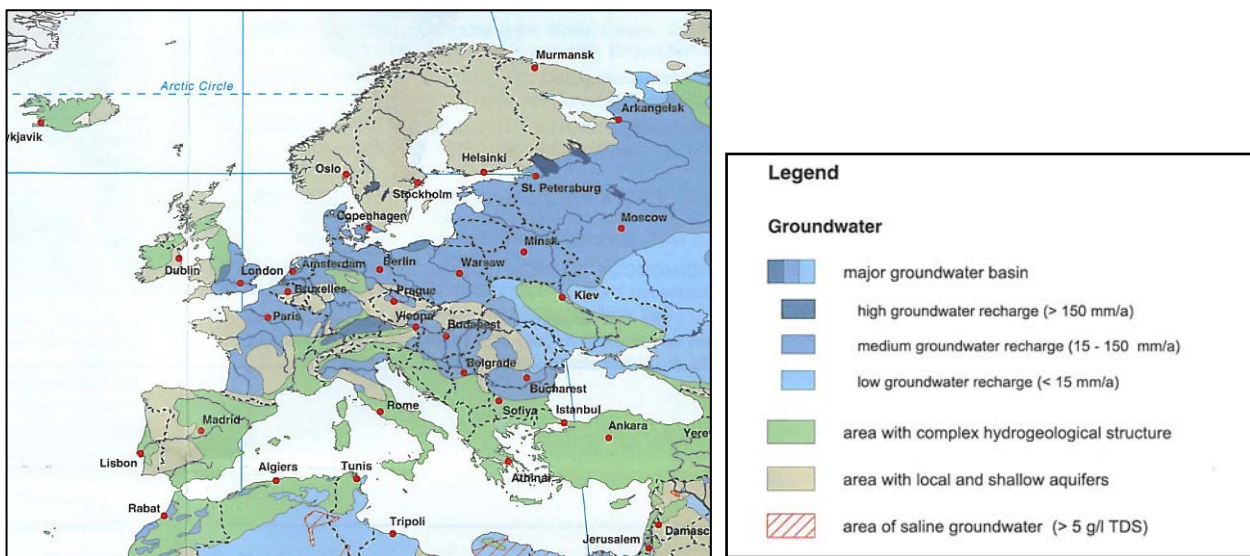
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## 1. Introduction

Freshwater is one of the most important natural resources for life. Water resources and water supply belongs to the critical infrastructure in a society and needs a special protection. In aquifers, in groundwater reservoirs, the water is well protected, better than surface water is, but even this water is at risk. The aquifers in Europe are not similar to each other, but they are unequal for example concerning the size, location or sensitivity for changes. Small, lowland aquifers lying close to settlement and rivers are highly vulnerable for all kind of changes. These aquifers need a special attention also concerning climate change.

The global groundwater resources are classified in different classes according to hydrogeological features (BGR 2004). Three groundwater classes can be found in Europe: 1) Major groundwater basins with medium recharge (15 – 150 mm/a) within the Central Europe sediment rock areas, 2) Areas with complex hydrogeological structures in the Mediterranean area and in the central parts of the British Isles, and 3) Areas with local and shallow aquifers for example in the Scandinavia, and in the mountain areas of Europe (Map 1).



Map 2: Groundwater resources in Europe. Source: BGR 2004.

International Groundwater Resources Assessment Centre (IGRAC) has published a report on "Global Overview of Saline Groundwater Occurrence and Genesis" (van Weert et al. 2009). In this report, saline groundwater bodies are divided in four main categories that are all found also in European coastal aquifers:

- Saline groundwater of marine origin
- Saline groundwater of terrestrial origin (natural)
- Saline groundwater of terrestrial origin (anthropogenic)
- Saline groundwater of mixed origin

Saline groundwater of marine origin includes both saline groundwater that have originated in past geological periods as well as salinity that is caused by recent phenomena like flooding, lateral seawater intrusion (often anthropogenic induced) and seawater spray. Salinisation due to evaporation and dissolution are of terrestrial origin. Anthropogenic salinisation may occur due to irrigation or pollution (e.g. road salt).

The report has also identified both natural and anthropogenic drivers affecting groundwater salinity. Climate change and its direct impacts on meteorological variables and indirect impact on sea level rise are one of the main drivers affecting groundwater salinity. Anthropogenic pressures (irrigation, groundwater abstraction, waste and waste water disposal) as well as other human activities that affect local and regional hydrological conditions (e.g. coastal protection, land reclamation) are also strong drivers causing groundwater salinity. Thus, the question on groundwater salinisation is very complex.

IGRAC has also defined Global Groundwater Regions (<http://www.igrac.nl>) that were used while describing the distribution of saline groundwater (van Weert et al. 2009). In Europe, three regions are defined: Baltic and Celtic shield, Lowlands of Europe, and Mountains of Central and Southern Europe. These areas correlate with areas of groundwater resources defined by the BGR (2004). The occurrences, origin and dimensions of shallow saline groundwater, current and potential threats, human responses as well as impact of climate change have been studied for each three regions separately.

Baltic and Celtic shield covers the Fennoscandia, Ireland, parts of UK, France, Estonia and Russia. The region is affected only very slightly by groundwater salinity but saline groundwater may locally be a threat to drinking water supply.

Lowlands of Europe covers the northern part of Central Europe (i.a. Denmark, the Netherlands, Belgium, and the Baltic states) and the Black Sea. Seawater intrusion, flooding and dissolution are all common within the area causing groundwater salinisation. The region is sensitive for rising seawater levels.

The coastal areas belonging to the region of the Mountains of Central and Southern Europe are affected by seawater intrusion. Irrigation and groundwater abstraction are significant factors posing a risk to groundwater quality. The coastal region is also very sensitive for rising sea levels.

## **2. Methodology**

Case study on coastal aquifers was aiming at to test the ESPON Climate -model generated by the ESPON Climate -project at the European level in coastal aquifers of Europe. The low-lying coastal aquifers have specific threats caused by the climate change. The location on the seashore makes them sensitive for all changes in sea water level. In worst case, the contamination of salt-water intrusion may severely affect coastal aquifers. The threats

concerning shallow groundwater aquifers or water supply infrastructure are serious because water supply is one of the most important requirements for living in a society.

Low-lying shallow aquifers located on the Baltic Sea (Finland), the North Sea (Norway and the Netherlands), the Mediterranean (Spain), the Atlantic Ocean (Scotland) and the Black Sea (Bulgaria) were selected for further studies. The vulnerability assessment was mainly based on European wide indicators generated by the ESPON Climate -project. Four sensitive indicators and three adaptive capacity indicators were specifically defined to better describe the vulnerability of coastal aquifers to climate change. In order to get information for these additional indicators from other countries than Finland, GTK sent a questionnaire to relevant bodies in representative countries (see appendix 1). Unfortunately, the questionnaire was answered poorly. Thus, only Finnish case study can provide adequate vulnerability assessment. The indicators presented in the questionnaire (appendix 1) have been developed further in the course of project. The updated description of developed indicators is given in chapters 3.3. 'Sensitivity', 3.4 'Impacts' and 3.5 'Adaptive Capacity'.

Limited number of information forced the coastal aquifer case study to concentrate on Finnish case study. The aquifers are generally small in size in Finland and in one NUTS 3 region there can be many small aquifers. The chosen NUTS 3 regions in the coastal area of South Finland for further studies are two: Uusimaa and Itä-Uusimaa.

### **3. Vulnerability assessment**

#### ***3.1 Main effect of climate change on coastal aquifers***

The main effect of climate change on coastal aquifers is changes in groundwater level. Both, the rise or fall in level of groundwater tables may affect the water supply in the area. In addition to that, over pumping may lead to salinisation of the groundwater. Climate change can also cause increasing number of heavy rainfall events that are connected to flash floods and intrusion of surface waters into the shallow coastal aquifers. Surface water may contain bacteria, high amount of organic carbon and other dissolved solids, which decreases the quality of the groundwater. Rising groundwater level make the coastal aquifers even more vulnerable to the sudden intrusion of surface waters.

#### ***3.2 Exposure to climate stimuli***

The eight regional exposure indicators and two triggered climate effect indicators chosen for the ESPON Climate -project were discussed and tested for the groundwater case study areas. Only eight out of the ten pan-European exposure indicators are relevant or important in the context of the case study on coastal aquifers. Those indicators are: 1) change in annual mean temperature, 2) decrease in number of frost days, 3) relative change in annual mean precipitation in winter months, 4) relative change in mean precipitation in summer months, 5) change in annual mean number of days with heavy rainfall, 6) relative change in annual mean evaporation, 7) change in annual mean number of days with snow cover and 8)



change in coastal flooding. These exposure indicators are linked to sensitivity indicators as shown in table 1 and discussed under chapter 3.4 'Impacts'.

#### **Change in annual mean temperature**

*Relevance:* Change in temperature influence groundwater recharge and quality indirectly through its impact on evapotranspiration and snow cover (and eventually on sea level rise).

*Indicator methodology:* The indicator is provided in the same way for the pan-European assessment as for the case study on coastal aquifers.

#### **Decrease in number of frost days**

*Relevance:* A decrease in number of frost days influences the formation of soil frost, which in turn has effect on the distribution of surface run-off and groundwater recharge. Indirect effects on groundwater are passed on through its influence on the snow cover.

*Indicator methodology:* The indicator is provided in the same way for the pan-European assessment as for the case study on coastal aquifers.

#### **Relative changes in annual mean precipitation in winter months**

*Relevance:* Change in precipitation has profound and direct impact on groundwater recharge. Generally, more precipitation means more recharge and less precipitation means less recharge (assuming that soil condition and evapotranspiration stay unchanged). While less precipitation might lead to low groundwater levels and water shortage, and contribute to droughts, more precipitation can lead to high groundwater levels and groundwater flooding. An increased fluctuation in groundwater levels can affect chemical and mechanical soil characteristics.

*Indicator methodology:* The indicator is provided in the same way for the pan-European assessment as for the case study on coastal aquifers.

#### **Relative change in annual mean precipitation in summer months**

*Relevance:* Change in precipitation has profound and direct impact on groundwater recharge. Generally, more precipitation means more recharge and less precipitation means less recharge (assuming that soil condition and evapotranspiration stay unchanged). While less precipitation might lead to low groundwater levels and water shortage, and contribute to droughts, more precipitation can lead to high groundwater levels and groundwater flooding. An increased fluctuation in groundwater levels can affect chemical and mechanical soil characteristics.

*Indicator methodology:* The indicator is provided in the same way for the pan-European assessment as for the case study on coastal aquifers.

#### **Change in annual mean number of days with heavy rainfall**

*Relevance:* During heavy rainfall events the relative share of surface runoff compared to groundwater recharge can increase. At the same time, the absolute increased groundwater recharge can enhance the transport of surface and soil contamination into the groundwater.

The occurrence of flash floods caused by heavy rainfall can affect infrastructure for water supply.

*Indicator methodology:* The indicator is provided in the same way for the pan-European assessment as for the case study on coastal aquifers.

### **Relative changes in annual mean evaporation**

*Relevance:* Together with surface runoff evaporation reduces the amount of precipitation that is available for infiltration into the ground and for groundwater recharge.

*Indicator methodology:* The indicator is provided in the same way for the pan-European assessment as for the case study on coastal aquifers.

### **Change in annual mean number of days with snow cover**

*Relevance:* The snow cover can store a remarkable amount of water, which is in turn not available for groundwater recharge, i.e. that part of precipitation that occurs as snow will not infiltrate into the ground directly, but melt or evaporate at a later stage. The melting snow contributes to recharge and surface runoff. The change in number of days with snow cover can only serve as a proxy for snow's influence, since it does not reveal the thickness of the snow cover nor the water equivalent.

*Indicator methodology:* The indicator is provided in the same way for the pan-European assessment as for the case study on coastal aquifers.

### **Change in coastal flooding**

*Relevance:* Similar like flash floods coastal flooding can affect infrastructure for water supply. Furthermore saltwater or brackish water might infiltrate into the groundwater or affect directly water intakes.

*Indicator methodology:* The indicator is provided in the same way for the pan-European assessment as for the case study on coastal aquifers.

## **3.3 Sensitivity**

The ESPON Climate -project had suggested several sensitivity indicators for each of the five sensitivity dimensions: physical, environmental, social, cultural and economic sensitivity. Three of the suggested European wide NUTS 3 level indicators were applicable directly for this case study. In addition to those, four sensitivity indicators were developed specifically for the case study on coastal aquifers: *Water intakes prone to flash floods* and *Water intakes prone to coastal flooding* representing physical sensitivity, *Percentage of groundwater yield from coastal aquifers* as an environmental sensitivity indicator and *Drinking water prices in coastal area* as an economic sensitivity indicator.

According to the project's methodology the impact indicator results from a multiplication of the sensitivity indicator with the exposure indicator. However, sensitivities that related to an exposure with a clear spatial extent (change in coastal flooding, change in areas prone to flash floods) the combination of sensitivity and exposure is done by spatial intersection.

Therefore the indicators *Water intakes prone to flash floods*, *Water intakes prone to coastal flooding*, *Settlements prone to coastal flooding*, *Coastal areas prone to coastal flooding* and *Population prone to coastal flooding* are introduced in chapter 3.4 'Impacts'.

#### **Percentage of groundwater yield from coastal aquifers (environmental sensitivity)**

*Relevance:* Percentage of groundwater yield from coastal aquifers from the total yield of all important aquifers in a NUTS 3 region reveals how critical the coastal aquifers can be for the region. These coastal aquifers can be even more important on local level.

*Existing studies* In Finland, there exists detailed statistical information on most of the aquifers (yield, quality etc.). Even the distance to the possible contamination sources is reported. However, the location of the aquifer in the shoreline is not documented. Thus, the information for the indicator was calculated especially for the purposes of this project.

*Indicator methodology:* The indicator is calculated as the percentage of water yield depending on coastal aquifers (aquifers located < 5 m above present mean sea level) of the total groundwater yield in a NUTS 3 area. If the coastal aquifer is surrounded by sea by all sides, the total yield is taken into account in the indicator calculation. If the aquifer is connected to the sea only by one side, 25% of the total yield is taken into account in the indicator calculation. In the calculation for the case study specific vulnerability, the indicator is not normalized, i.e. we assume 100% groundwater yield from coastal aquifers as the highest achievable value.

#### **Drinking water prices in coastal areas (economic sensitivity)**

*Relevance:* The availability of reasonable priced water is vitally important for households and industry in any region. This indicator shows the yearly value as end user product of the water extracted from the sensitive coastal aquifers.

*Existing studies:* EEA (2002) has reported prices from few European countries. Comprehensive and up-to-date information on water prices for households in Europe was not available.

*Indicator methodology:* This indicator is calculated from the yield depending on coastal aquifers (aquifers located < 5 m above present mean sea level) and the average customer price of water in the region or in the country. If the coastal aquifer is surrounded by sea by all sides, the total yield is taken into account in the indicator calculation. If the aquifer is connected to the sea only by one side, 25% of the total yield is taken into account in the indicator calculation. In order to compare the regional prices, the yearly price of threatened coastal water supply was calculated as share of the regional GDP (‰). The developed indicator was tested by using water prices presented by EEA (2002) and regional GDP's with fictive estimates of the groundwater yield in different countries. Because comprehensive dataset of water prices for Europe was not at our disposal, we assumed 2‰ as a (fictional) highest value for the normalization of the indicator.

### **3.4 Impacts**

As mentioned above, changes in groundwater tables may severely affect drinking or irrigation water supply. A pilot project in the city of Hanko located in the Uusimaa region,

Finland found out that sea level changes have a direct affect on shallow groundwater tables after a short time delay (Fig. 1, Backman et al. 2007). Changes in the groundwater table may also lead to contamination hazards, e.g. if the groundwater table rises close to the surface after prolonged or heavy rainfall events. Reduced summer precipitation and higher evapotranspiration leads to less groundwater recharge and consequently to a potential drying up of an aquifer. This may occur over longer periods in deeper aquifers but can also occur during a prolonged dry season in shallow aquifers. Thus, in addition to sea level changes, potential changes in rainfall patterns are also to be assessed.

The ESPON Climate -model calculates the impact indicators as combinations of exposure and sensitivity indicators. Impacts have the same dimensions as the sensitivity: physical, environmental, social, cultural and economic dimensions. For each impact indicator one sensitivity indicator and one or more exposure indicators are combined. The cultural sensitivity was not taken into the determination of the overall impact due to lack of information and its irrelevance to coastal aquifers. The combinations applicable for coastal aquifer case study are summarized in Table 1.

The single impact indicator values were normalized. However, while calculating the aggregated impact, the normalization was not used, only average value (this differs from general ESPON Climate –model).

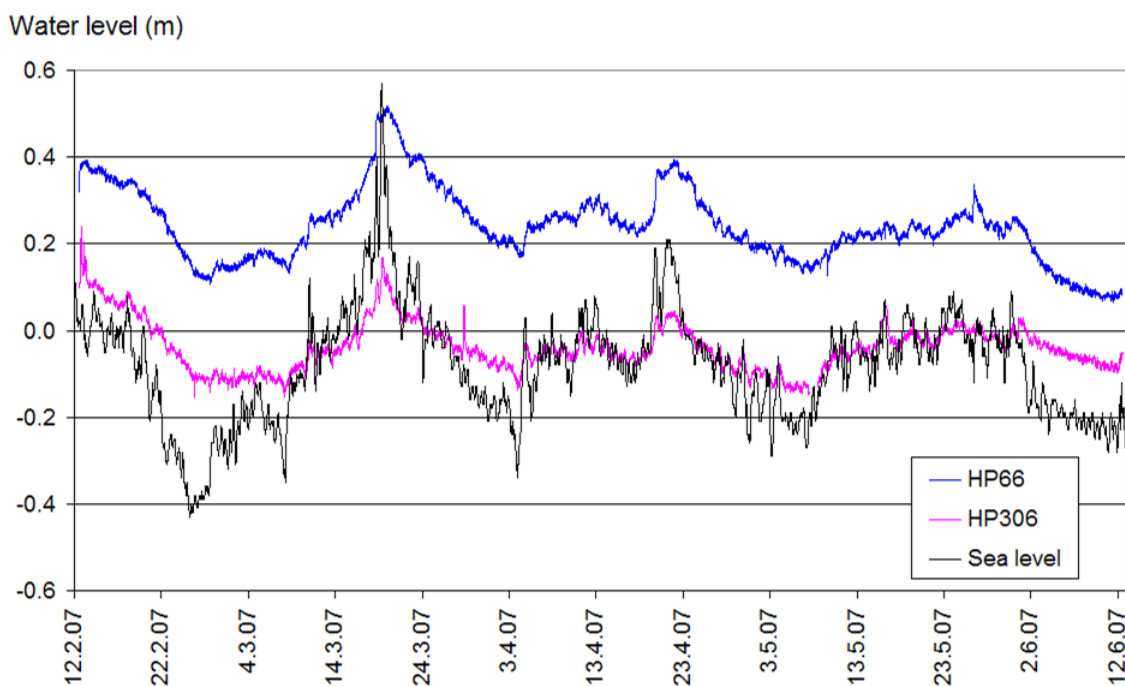


Figure 1: Fluctuation of sea level and groundwater level in an aquifer in the city of Hanko, Finland, during February – June 2007. Black line: sea level, blue and red lines: groundwater level in observation wells HP66 and HP306. Source: Backman et al. 2007.

Table 1: Exposure indicators and related sensitivity indicators. Linked indicators that will be used in model calculation are shown with a black dot. Black dots in parentheses ( ) indicate indirect effects of mean temperature to sensitivity through evapotranspiration and indirect effects of heavy rainfall on flash floods. Black dots in square brackets [ ] indicate number of frost days and number of days with snow cover, where the direction of impact (positive or negative) cannot be clearly identified within the applied methodology. These indicators are excluded from the final calculation. Cursive text indicates special sensitivity indicators defined for the case study.

	Change in annual mean temperature	Decrease in number of frost days	Change in mean winter precipitation	Change in mean summer precipitation	Change in number of heavy rainfall days	Change in annual mean evaporation	Change in number of days with snow cover	Change in coastal flooding
<b>Physical sensitivity</b>								
<i>Water intakes prone to flash floods</i>					(•)			
<i>Water intakes prone to coastal flooding</i>								•
Settlements prone to coastal flooding								•
<b>Environmental sensitivity</b>								
Coastal areas prone to coastal flooding								•
<i>Percentage of groundwater yield from coastal aquifers</i>	(•)	[•]	•	•		•	[•]	•
<b>Social sensitivity</b>								
Coastal population prone to coastal flooding								•
<b>Economic sensitivity</b>								
<i>Drinking water prices in coastal area</i>	(•)	[•]	•	•		•	[•]	•

### **Water intakes prone to flash floods (physical sensitivity)**

*Relevance:* Increasing number of heavy rainfall events may cause local flash floods and lead to infiltration of surface waters into shallow coastal aquifers. Relevant infrastructure for water supply might be directly negatively affected by flash floods.

*Existing studies:* In the climate change impact study for the water supply of the city of Porvoo located in the Itä-Uusimaa region, Finland, the effects of floods on water supply infrastructure was seen as critical (Nikula et al. 2008).

*Indicator methodology:* The change of the area potentially affected by flash floods under the given climate change scenarios was calculated in this project for the entire ESPON area. These data are intersected with the locations of water intakes that are located in coastal area (aquifers located <5 meters above sea level). The value of the indicator is given as percentage of the total number of water intakes located in flash flood prone coastal areas per NUTS 3 region. In the calculation for the case study specific vulnerability, the indicator is not normalized, i.e. we assume the highest change in flash flood impact would be an increase from 0% water intakes affected to 100% water intakes affected.

### **Water intakes prone to coastal flooding (physical sensitivity)**

*Relevance:* Coastal flooding can affect infrastructure for water supply. Furthermore, saltwater or brackish water might infiltrate into the groundwater or affect directly water intakes.

*Existing studies:* In the climate change impact study for the water supply of the city of Porvoo, Finland, the effects of floods on water supply infrastructure was seen as critical (Nikula et al. 2008).

*Indicator methodology:* The area additionally affected by coastal flooding under the given climate change scenarios was calculated in this project for the entire ESPON area. These data are intersected with the locations of water intakes. The value of the indicator is given as percentage of the total number of water intakes located in coastal flooding prone areas per NUTS 3 region. In the calculation for the case study specific vulnerability, the indicator is not normalized, i.e. we assume the highest change in coastal flooding impact would be an increase from 0% water intakes affected to 100% water intakes affected.

### **Settlements prone to coastal flooding (physical sensitivity)**

*Relevance:* The coastal areas with settlements are more sensitive to coastal flooding. Critical water supply infrastructure is located in settlement areas. Although the area is not relying on water supply from the coastal aquifer the water supply infrastructure may be occasionally be disturbed due to coastal flooding.

*Existing studies:* The impacts and adaptation measures to water supply and waste water systems are discussed in Finadapt—Climate change adaptation for hydrology and water resources (Silander et al. 2006). Increase of storm water discharged is documented, mainly due to heavy rain falls/flash floods but also due to storm surges.

*Indicator methodology:* The settlement area additionally affected by coastal flooding under the given climate change scenarios was calculated in this project for the entire ESPON area.

### **Coastal areas prone to coastal flooding (environmental sensitivity)**

*Relevance:* Aquifers threatened by the coastal flooding are vulnerable for salinisation. The temporary sea water flooding can have negative effects on the coastal aquifers.

*Existing studies:* Changes in water quality due to sea water flooding have been identified in the city of Hanko located in the Uusimaa region, Finland (Backman et al. 2007).

*Indicator methodology:* The area additionally affected by coastal flooding under the given climate change scenarios was calculated in this project for the entire ESPON area. The indicator is calculated as:

$$\frac{(\text{tot. area affected} + \text{rel. area affected})}{2}$$

### **Population prone to coastal flooding (social sensitivity)**

*Relevance:* The water supply of settlements located in coastal areas often relies on coastal aquifers. The population located in these areas is more vulnerable than those living in inlands.

*Indicator methodology:* The population additionally affected by coastal flooding under the given climate change scenarios was calculated in this project for the entire ESPON area.

## **3.5 Adaptive Capacity**

Interviews of local experts is the best way to estimate the adaption capacity in the municipality level, but the adaptive capacity indicators suggested for the ESPON Climate - project can be used at regional NUTS 3 level also in the case study. The best recognized adaptive capacity indicator for knowledge and awareness was the *Attitudes on climate change*. *Resources for technology* (expressed as R&D expenditure) and *Capacity for research* (expressed as R&D personnel) can be used as indicators for technological adaptive capacity. *Water infrastructure* is the key indicator of infrastructure adaptive capacity of the coastal aquifers. In addition to that, a new case study indicator, *Availability of alternative water sources*, is introduced. As an indicator for the institutional adaptive capacity new, case study specific indicator *National, regional and local climate change adaptation strategies* was chosen. *Income* as GDP per capita is an applicable proxy indicator for economic resources.

The relevance and methodology for the indicators for *Resources for technology*, *Capacity for research*, *Water infrastructure* and *GDP per capita* are described in the Scientific Report chapter 3.4 'Regional capacities to mitigate and adapt to climate change'

The single adaptive capacity indicator values were normalized. However, while calculating the aggregated adaptive capacity, the normalization was not used, only average value (this differs from general ESPON Climate –model).

### **Availability of alternative water sources**

*Relevance:* The availability of alternative water resources is a targeted indicator for adaptive capacity of a region to cope with reducing fresh water resources of shallow coastal aquifers. In some cases alternative water sources can be easily identified but desalinization technique or application of more distance water sources will increase the costs. In other cases there is a need to start planning alternative sources.

*Existing studies:* In Finland, aquifers are classified while they are mapped. The classification divides groundwater areas into three classes according to their priority:

Class I: groundwater area important for water supply

Class II: groundwater area suitable for water supply

Class III: other groundwater area

Class I aquifers are already in use. Class II aquifers are currently not needed but they can be used for water supply and are often indicated as alternative water sources. Class III aquifers need further investigations.

*Indicator methodology:* The indicator value is defined by ranking various alternative water sources that can be taken into use if shallow coastal aquifers are not useable in the future.

Indicator value	Explanation
0.2	Alternative water sources available with almost similar costs or slightly more expensive alternative water sources already available
0.3	Alternative water sources planned in detail
0.4	Alternative water sources planning started
0.5	No alternative water source plans available yet

### **National, regional and local climate change adaptation strategies**

*Relevance:* The existence of a local, regional or national climate change adaptation strategy is likely to increase adaptive capacity of a region. Usually national adaptation strategies have some relevance for the regional level and can thus act as encouraging factor and spur on political processes at the regional level. Regional and local adaptation strategies take more closely into account also the coastal problems related to the climate change. In the best case, the local or regional adaptation strategy has been developed to take into account the threats to the sensitive coastal aquifers.

*Existing studies:* In Finland, national but also some regional and local climate change adaptation strategies are available. National adaptation strategy, Finadapt, provides a specific report on climate change adaptation for hydrology and water resources (Silander et al. 2006).

*Indicator methodology:* The indicator value is defined by ranking of various climate change adaptation strategies.

Indicator value	Explanation
0.2	Local or regional adaptation strategy available for the most sensitive aquifers or regional adaptation strategy implemented



0.3	National adaptation strategy implemented
0.4	National adaptation strategy available
0.5	National adaptation strategy planned

### **3.6 Vulnerability**

The vulnerability is determined by as a combination of aggregated impact indicator and aggregated adaptive capacity indicator. This final result of the assessment has to be calculated for the different coastal NUTS 3 regions which were selected for this case study (see chapter 4).

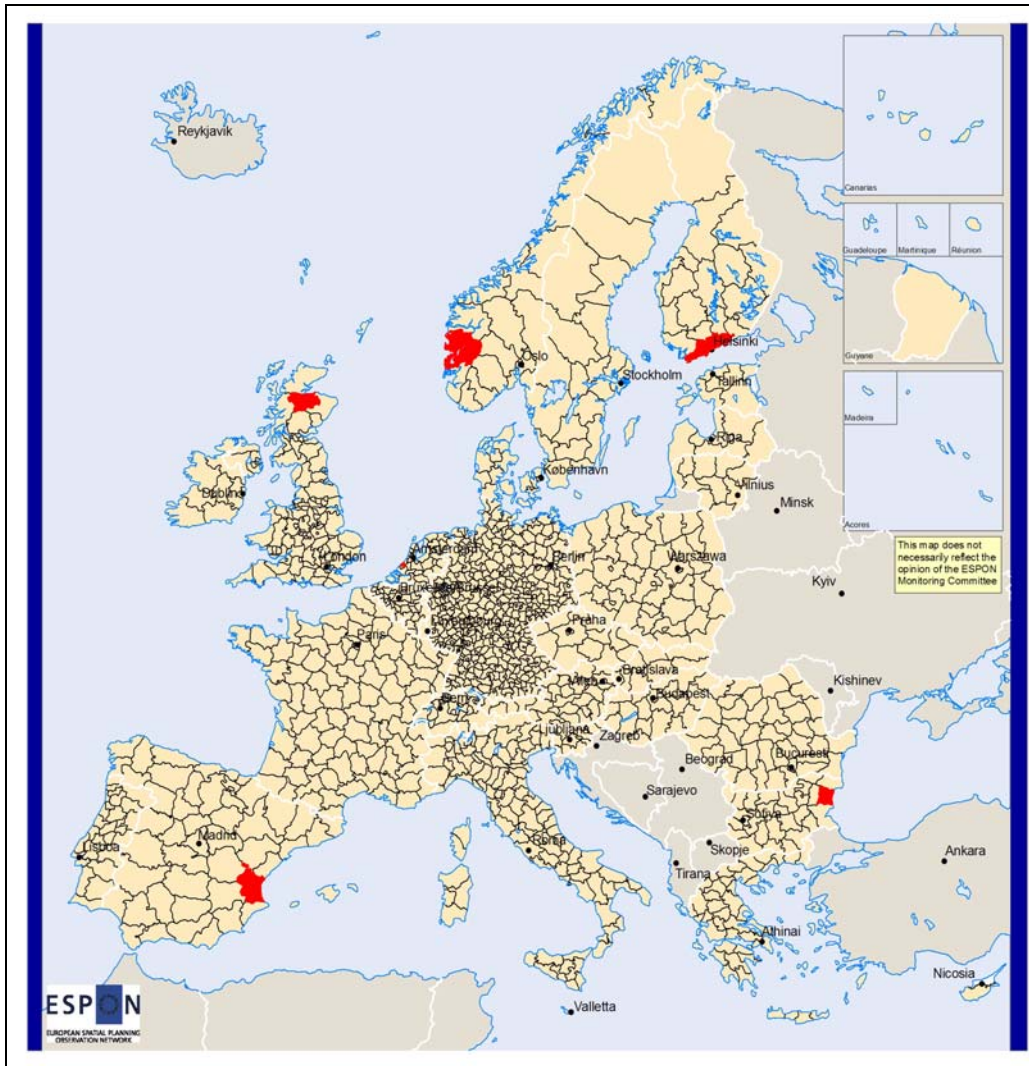
In order to estimate the vulnerability of the case study regions towards climate change, the ESPON Climate –model was used. The given values for exposure, impact and adaptive capacity indicators are presented in Appendix 2. Finally, the aggregated vulnerability is calculated if proper values for indicators existed.

## **4. European coastal aquifers**

Low-lying shallow aquifers located on the Baltic Sea (Finland), the North Sea (Norway and the Netherlands), the Mediterranean (Spain), the Atlantic Ocean (Scotland) and the Black Sea (Bulgaria) were selected for further studies. The NUTS 3 regions that were selected for testing the ESPON Climate –model were:

- Finland: "Uusimaa" (FI181) and "Itä-Uusimaa" (FI182)
- Norway: "Hordaland" (NO051)
- The Netherlands: "Agglomeratie s-Gravenhagen" (NL332)
- The UK: "Inverness and Nairn" (UKM42).
- Spain: "Valencia" (ES523)
- Bulgaria: "Varna" (BG131)

The selected case study areas are presented in Map 2. In Table 2, the location of case study regions within different INTERREG III regions is indicated.



Map 2: The selected NUTS 3 regions for coastal aquifer case study.

Table 2: Case study areas and their location in different European territorial co-operation areas

**Case Study on Coastal Aquifers**

European territorial cooperation	The Baltic Sea, Finland ('Uusimaa' and 'Itä-Uusimaa')	The North Sea coastal area, Norway ('Hordaland')	The North Sea coastal area, the Netherlands ('Agglomeratie s-Gravenhagen')	Atlantic Ocean coastal area, Scotland ('Inverness and Nairn')	Mediterranean coastal area, Spain ('Valencia')	The Black Sea coastal area, (Bulgaria ('Varna'))
<i>Interregional co-operation</i>						
Interreg IVC North	X	X				
Interreg IVC West			X	X		
Interreg IVC South					X	
Interreg IVC East						X
<i>Trans-national co-operation</i>						

Interreg IVB Northern Periphery				x		
Interreg IVB Atlantic Coast				x		
Interreg IVB Baltic Sea	x	x				
Interreg IVB North Sea		x	x	x		
Interreg IVB South West Europe					x	
Interreg IVB North West Europe			x	x		
Interreg IVB Mediterranean					x	
Interreg IVB South East Europe						x
<i>Cross-border co-operation</i>						
Interreg IVA Central Baltic	x					

#### 4.1 The Baltic Sea - Finland

The main effect of climate change on groundwater is changes in groundwater level in coastal aquifers. Both, the rise or fall in level of groundwater tables may affect the water supply in the area. In addition to that, over pumping may lead to salinisation of the groundwater. Climate change can also cause increasing number of heavy rainfall events that are connected to flash floods and intrusion of surface waters into the shallow coastal aquifers. Surface water may contain bacteria, high amount of organic carbon and other dissolved solids, which decreases the quality of the groundwater. Rising groundwater level make the coastal aquifers even more vulnerable to the sudden intrusion of surface waters (Fig. 2).



Figure 2: Groundwater table has risen to the surface in a shallow coastal aquifer in Hanko, South Finland. Photo: Samrit Luoma, GTK.

The methodology of the ESPON Climate -project was tested in different aquifers in coastal areas of the Baltic Sea in South Finland. Data was collected for precipitation, air

temperature, sea level, river gauges, groundwater level (in tubes and observation wells), groundwater yield of the aquifers, pumping rates from the production wells, main use of the water (drinking or irrigation water), amount of the water consumers, a forecast for the pumping, main land use of the catchment (aquifer), secondary land use of the catchment (aquifer) and land use in the vicinity of the aquifer (if remarkable), and especially the location of the aquifer concerning the present sea water level (above 5 m contour). Backup plans for water supply in future have been collected from municipalities if available.

Figure 3 shows the conceptual model of the climate change introduced effects to the coastal aquifers. Okkonen et al. (2010) developed a similar conceptual model for shallow unconfined aquifers in the boreal environment of Northern Finland. This kind of model shows the relationships between climatic drivers and hydrological and groundwater responses. In our case study, the most important climatic stimuli are increasing winter precipitation, increasing temperature and sea level rise. Evapotranspiration will increase especially in summer time. The amount of snow cover and the number of soil frost days are expected to decrease until year 2100. Surface runoff will increase in winter but decrease in summer. This will lead to increasing groundwater recharge in winter and decreasing recharge for summer months. Sea water intrusions may happen throughout the year. However, sea water intrusions are triggered mostly by over pumping. Finally, groundwater level will increase during winter period and decrease in summer. Water salinity can increase especially in summer. The conceptual model shows the long-term effects of the climate change. There is also a possible short term effect: Heavy rainfall events may lead to surface water intrusion into shallow aquifers and decrease the chemical and microbiological quality of the groundwater.

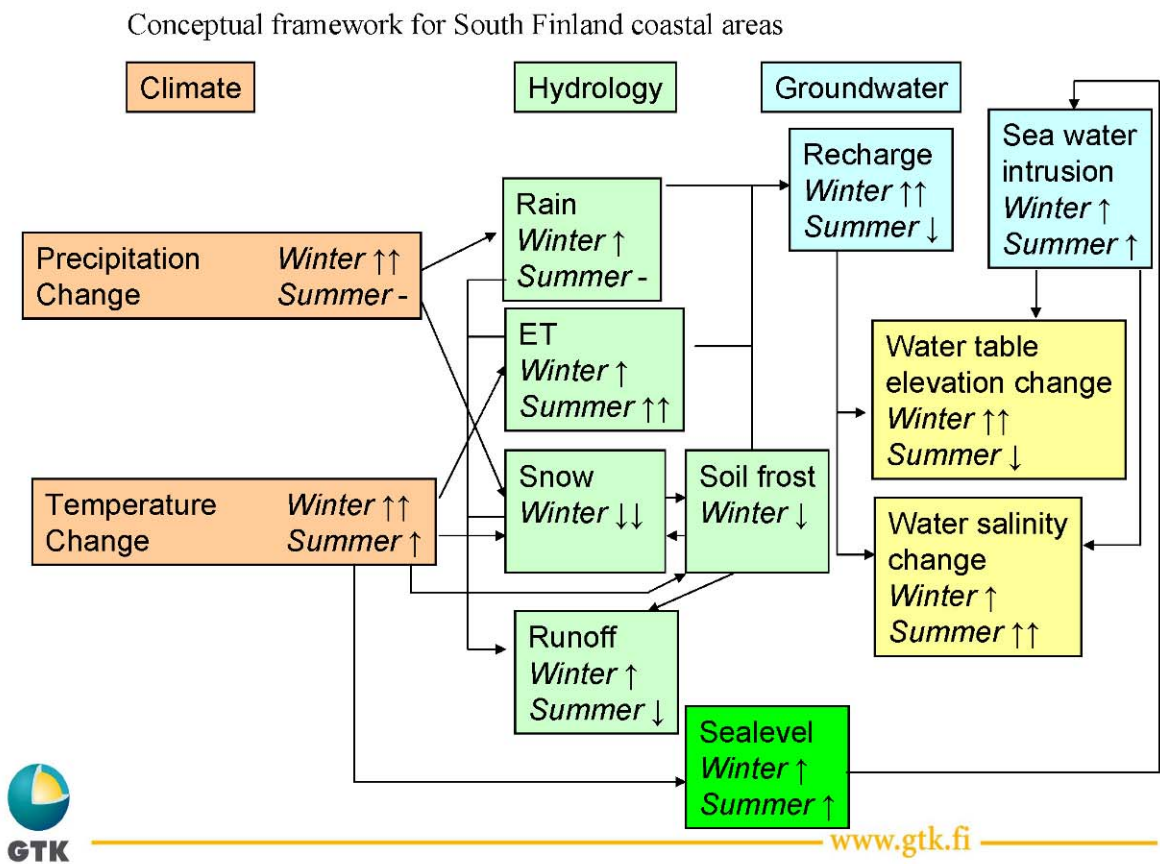


Figure 3: Conceptual framework for South Finland coastal areas.

### Exposure to climate stimuli

The eight regional exposure indicators and two triggered climate effect indicators chosen for the ESPON Climate -project were discussed and tested for the coastal aquifer case study areas. Not all of exposure indicators were relevant or important in the climate conditions of Northern Europe according to the conceptual model shown in figure 3. The result was that eight of those indicators were suitable for the groundwater case study as described in chapter 3.2. The exposure indicator values for the Uusimaa and the Itä-Uusimaa regions are summarized in Table 3.

Table 3: Exposure indicator values (1 = low, 5 = high, according to the methodology as described in the interim report of the ESPON Climate) for the Uusimaa and the Itä-Uusimaa regions. Change from today's average to 2071 – 2100.

Indicator	Uusimaa	Itä-Uusimaa
Change in annual mean temperature	4	4
Decrease in number of frost days	5	5
Relative change in annual mean precipitation in winter months	3	3
Relative change in annual mean precipitation summer months	1	1
Change in annual mean number of days with heavy rainfall	1	1
Relative change in annual mean evaporation	3	3
Change in annual mean number of days with snow cover	4	5
Change in coastal flooding	2	2

### **Sensitivity and impact**

Sea level rise is expected to continue throughout the project study period until year 2100 and far beyond. In the Baltic Sea region, sea level rise will exceed land uplift only during the last half of the modeled period and more negative effects can be expected closer to year 2100. Thus, most of the sensitivity indicators can be regarded as long-term implication indicators. However, increasing number of heavy rainfall events may cause local flash floods and lead to infiltration of surface waters into shallow coastal aquifers already in short run.

### Physical sensitivity and impact

The first indicator is the *Water intakes prone to flash floods*. The other physical indicator called the *Water intakes prone to coastal flooding* represents the pipelines and pumping stations that may be affected by elevating sea level and groundwater level in coastal area (Map 3).

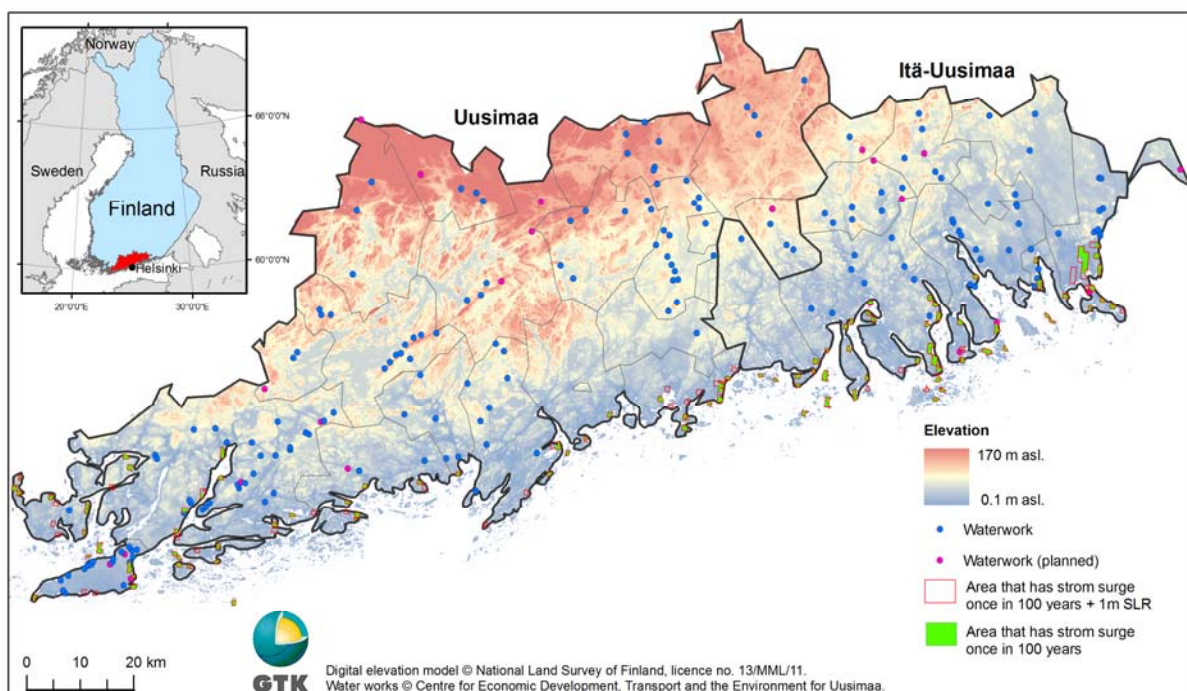
For both indicators, the total number of water intakes (current and planned) located in the NUTS 3 regions was calculated. In the Uusimaa region, there are 135 water intakes from which only four is located in areas currently prone to coastal flooding. No water intakes are located in areas which will have increase in coastal flooding. Thus, the indicator value is 0. In the Itä-Uusimaa region, six water intakes out of 63 are located in areas currently prone to coastal flooding. Two water intakes are located in areas with increase of coastal flooding, i.e. 3% of total number of water intakes. The indicator value is 0.030.



The total number of water intakes affected by flash floods is bigger. In the Uusimaa region, eight water intakes are located in area prone to flash floods. However, none of these water intakes is located in coastal areas. The indicator gets value 0. In the Itä-Uusimaa region, there exist eight water intakes that are located in area prone to flash floods. Three of them is located in coastal area, i.e. 4.7% of total number of water intakes. The indicator value is 0.047.

The third indicator to describe physical impact is the *Settlements sensitive for coastal flooding* (currently named in the Scientific Report as the *Settlements prone to coastal storm surges*). This indicator is calculated for the whole ESPON area. In the Uusimaa region, the indicator gets value 0.051 and in the Itä-Uusimaa region 0.021. The number of people and population density is higher in the Uusimaa region, also in the coastal area, and it is thus more sensitive to coastal flooding.

The aggregated physical impact is 0.017 in the Uusimaa region and 0,033 in the Itä-Uusimaa region. This means marginal physical impact for both regions.

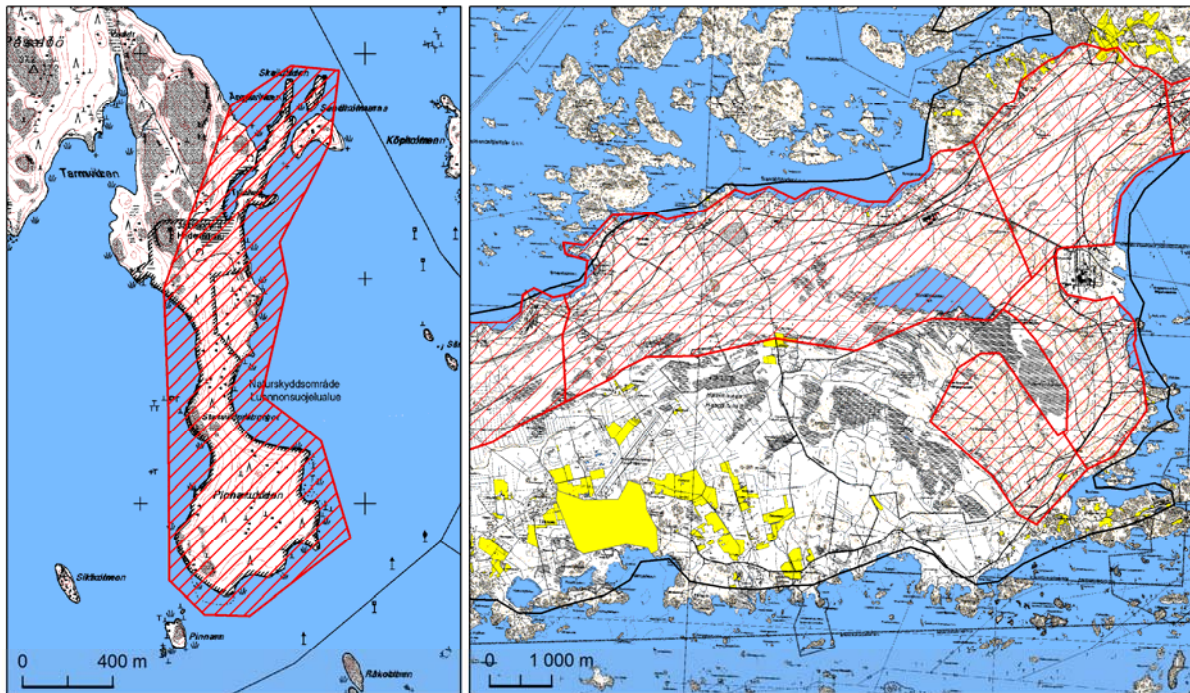


Map 3: Areas prone to coastal flooding and current and planned water intakes in the Uusimaa and the Itä-Uusimaa regions. Today's situation and situation after 1 m sea level rise without any time estimation.

### Environmental sensitivity and impact

The indicator *Coastal areas prone to coastal flooding* was applicable for this case study. The indicator was calculated according to formula described in chapter 3.4 'Impacts'. In the Uusimaa region, the indicator gets value 0.011 and in the Itä-Uusimaa region 0.019. The new

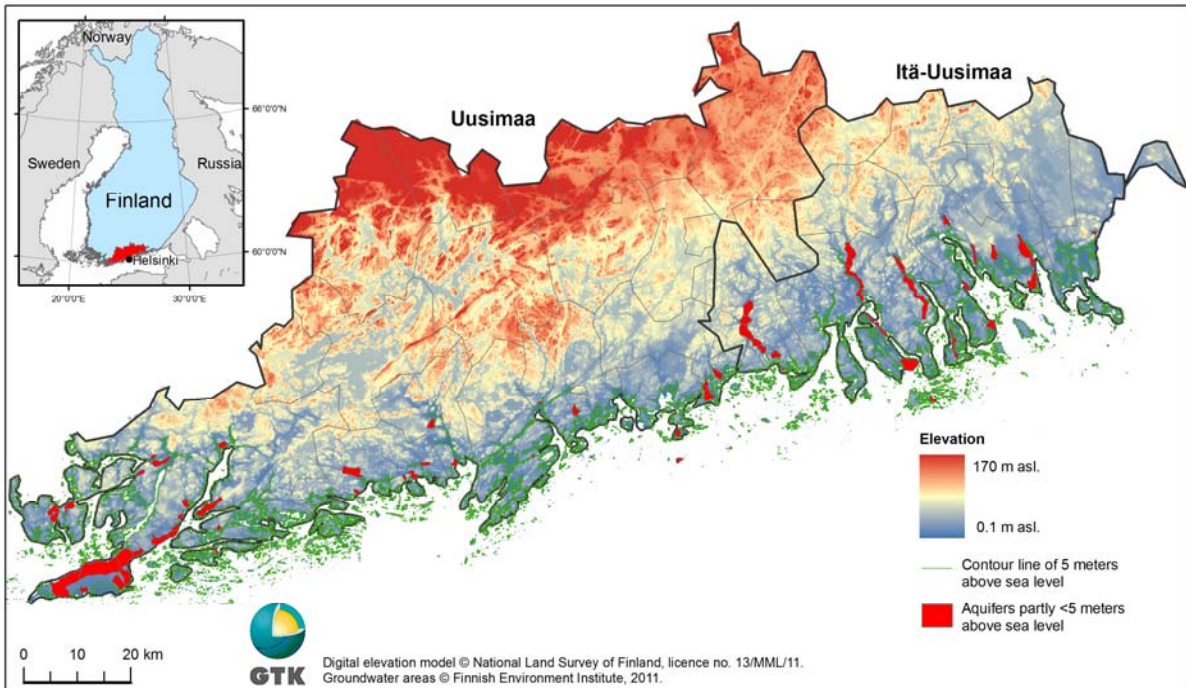
suggested environmental sensitivity indicator *Percentage of groundwater yield from coastal aquifers* (see chapter 3.3) is calculated as the percentage of water yield depending on coastal aquifers (aquifers located < 5 m above present mean sea level) of the total groundwater yield in a NUTS 3 region. If the coastal aquifer is surrounded by sea by all sides, the total yield is taken into account in the indicator calculation. If the aquifer is connected to the sea only by one side, 25% of the total yield is taken into account in the indicator calculation (Map 4).



Basemap © National Land Survey of Finland, licence no. 13/MML/11.  
Groundwater areas © Finnish Environment Institute, 2011.

*Map 4: Examples of coastal aquifers. If the aquifer is surrounded by the sea (left), the whole yield is taken into account in the water intakes prone to coastal flooding calculation. If the aquifer is connected to the sea only by one side (right), 25% of the total yield is taken into account in the indicator calculation.*





Map 5: The Uusimaa and the Itä-Uusimaa regions. Red areas: aquifers partly <5 m above sea level, green line: contour line of 5 meter above sea level. Today's situation.

There are 360 important groundwater aquifers in the Uusimaa NUTS 3 region, from which 29 are located in low-lying coastal area (Map 5). Total yield of all important aquifers of the Uusimaa region is 255 866 m<sup>3</sup>/d. Low-lying aquifers at coastal area have a yield of 15 320 m<sup>3</sup>/d. About 6% of freshwater resources are surrounded at least by one side by sea. Thus, the sensitivity indicator gets value 0.06.

In the Itä-Uusimaa NUTS 3 region, there are 140 important groundwater aquifers from which 22 are located in low-lying coastal area. Aquifers in the Itä-Uusimaa region are estimated to be replenished by 57 525 m<sup>3</sup> of water per day. The yield from low-lying aquifers at coastal area is 10 345 m<sup>3</sup>/d. About 18% of freshwater resources are surrounded at least by one side by sea. The sensitivity indicator gets value 0.18. The Itä-Uusimaa region is more dependent on coastal aquifers than the Uusimaa region.

The sensitivity indicator *Percentage of groundwater yield from coastal aquifers* is combined with exposure indicators: relative change in annual mean precipitation in winter months, relative change in annual mean precipitation summer months, relative change in annual mean evaporation and change in coastal flooding. In the Uusimaa region the impact indicator gets value 0 and in the Itä-Uusimaa region 0.001. Thus, the potential impact is marginal.

The aggregated environmental impact is 0.011 in the Uusimaa region and 0.021 in the Itä-Uusimaa region. This means marginal environmental impact for both regions.

### Social sensitivity and impact

Social impact is defined by indicator *Coastal population prone to coastal flooding*. In the Uusimaa region, indicator gets value 0.097 and in the Itä-Uusimaa region 0.007. The number of people and population density is higher in the Uusimaa region, also in the coastal area, and it is thus more sensitive to coastal flooding. However, this indicator does not take into account the dependency of the coastal population on coastal aquifers. In the Uusimaa region, the water supply of Helsinki metropolitan area is not depending on coastal aquifers and sensitivity is overestimated.

This is the only indicator describing social impact. Thus, no aggregated impact is calculated. The social impact is marginal in both regions.

### Cultural sensitivity and impact

Cultural sensitivity and impact indicators were not defined for coastal aquifer case studies due to lack of information and their irrelevance to coastal aquifer study.

### Economic sensitivity and impact

The suggested new case study specific economic sensitivity indicator *Drinking water prices in coastal area* can be calculated as the value of groundwater applied from the threatened shallow coastal aquifers (see chapter 3.3). The average duty of household freshwater in Finland is 0.90 €/m<sup>3</sup>. However, the household water prices in Europe vary greatly (Fig 4).

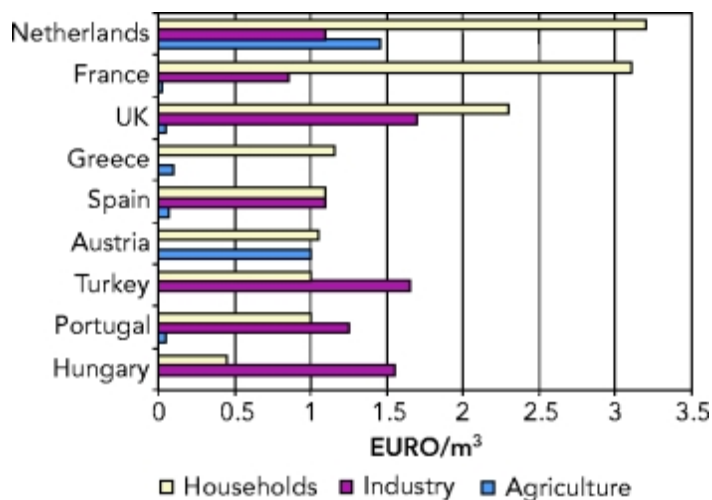


Figure 4: Agricultural, industrial and household water prices in late 1990s. Source: EEA 2002.

In the Uusimaa region, the sea level rise may affect groundwater yield of 15 320 m<sup>3</sup>/d. The estimated yearly value of the threatened coastal water supply is 15 320 m<sup>3</sup>/d x 0.90 €/m<sup>3</sup> x 365 = 5.0 M€. In the Itä-Uusimaa region, the sea level rise may affect 10 345 m<sup>3</sup>/d and the estimated yearly value is 10 345 m<sup>3</sup>/d x 0.90 €/m<sup>3</sup> x 365 = 3.4 M€. This indicator can be further developed by dividing the value of water by population or the regional GDP of the NUTS 3 region.

By dividing the share of yearly value of the threatened coastal water supply with the regional GDP, the following indicator values were given for the Uusimaa and the Itä-Uusimaa regions.

#### Uusimaa

- GDP (year 2007): 63 719 M € (Statistics Finland 2009)
  - Yearly price of threatened coastal water supply: 5.0 M€
- => 0.08 ‰ , indicator value 0.039

#### Itä-Uusimaa

- GDP (year 2007): 3 394 M € (Statistics Finland 2009)
  - Yearly price of threatened coastal water supply: 3.4 M€
- => 1 ‰ , indicator value 0.501

Economic sensitivity is higher in the Itä-Uusimaa region due to its stronger dependency on coastal aquifers. The sensitivity indicator *Drinking water prices in coastal area* is combined with exposure indicators: relative change in annual mean precipitation in winter months, relative change in annual mean precipitation summer months, relative change in annual mean evaporation and change in coastal flooding. In the Uusimaa region, the impact indicator gets value 0 and in the Itä-Uusimaa region 0.004. This is the only indicator describing economic impact. Thus, no aggregated impact is calculated. The economic impact is marginal in both regions.

#### Aggregated impact

The aggregated potential impact on coastal aquifers for the Uusimaa region is 0.028 and for the Itä-Uusimaa region 0.017. Thus, the impact is marginal for both regions. These values (non-normalized) are slightly lower than the non-normalized results of pan-European assessment for Finland. However, in either case the results indicate only marginal impacts. Only the economic impacts in the pan-European assessment for the Uusimaa region show a clearly stronger increase than in the case study specific assessment.

#### **Adaptive Capacity**

The question is how strongly long term sea level changes may affect local water supply, i.e. how depended is a local community on a coastal aquifer, based on the assessment mentioned above? In some parts of Finland, wells and water intakes in coastal aquifers already had to be shut down due to sea water intake. Currently it is still possible to use wells located further away from the sea shore, but is this trend sustainable? How high is thus the dependence on a specific aquifer? And how high is the awareness of a local supplier on these potential impacts? The discussion with the experts of Porvoon Vesi Ltd (water supply company of the city of Porvoo) in May 2010 revealed that these problems have been widely recognized at least in the Itä-Uusimaa region and there is an adaption strategy available for the city of Porvoo. The strategy is based on local KIHA model (Nikula et al. 2008).

Interviews of local experts is the best way to estimate the adaptation capacity in city level, but the adaptive capacity indicators suggested for the ESPON Climate project can be used at regional NUTS 3 level also in the case study. The best recognized adaptive capacity indicator for knowledge and awareness was the *Attitudes on climate change*. *Resources for technology* and *Capacity for research* can be used as indicators for technological adaptive capacity. *Water infrastructure* is the key indicator of infrastructure adaptive capacity of the coastal aquifers. In addition to that, a new case study indicator called *Availability of alternative water sources* is defined in the appendix. Two indicators were chosen for the institutional adaptive capacity: *Regional co-operation* that is important for examination of alternative water sources and *National, regional and local climate change adaptation strategies* (new indicator, see chapter 3.5). *Income* as GDP per capita is an applicable proxy indicator for economic resources.

Schmidt-Thomé & Schmidt-Thomé (2010) have discussed the Finnish National Strategy for Adaptation to Climate Change and they have also pointed out some aspects relative for water supply. Following cursive text is cited, partly shorten from this report:

*“Finland’s National Strategy for Adaptation to Climate Change” was adopted by the Finnish Parliament after it had submitted the National Climate Strategy in March 2001 (Finnish Ministry of Agriculture and Forestry 2005). It is implemented as a part of the new Energy and Climate Strategy of Finland that was revised in 2005 (Finnish Energy and Climate Strategy 2005). The propositions of the strategy are implemented through the principle of mainstreaming, meaning that involved sectors should cover adaptation issues within their current core tasks. The strategy describes the impacts of climate change in a sectoral manner. The elaboration process was accompanied by a public consultation process, conducted under the Ministry of Agriculture and Forestry and representatives of different ministries, together with the Finnish Meteorological Institute and the Finnish Environment Institute. The adaptation strategy, although having a progressive character, focused on sectoral separated approaches.*

*The five-year Climate Change Adaptation Research Programme (ISTO) enhances the search for solutions that support planning of adaptation measures. 15 research projects in different sectors are financed by this programme (ISTO 2006). One focus of climate change studies is on dissemination through a Climate Change Communication Programme (Finnish Climate Change Communications Programme 2002). The programme is part of the realisation of the aims of the National Energy and Climate Strategy. The Climate Change Adaptation Research Programme ISTO has produced useful information in support of the adaptation measures, but the limited resources have not allowed comprehensive studies on all relevant sectors.*

*An evaluation of the implementation of the Adaptation Strategy was conducted in winter 2008–2009 included a survey of how the measures presented in the strategy have been launched in different sectors. The evaluation revealed that understanding of the impacts of climate change and the need for adaptation measures has been recognized among decision*

makers. Some practical adaptation measures are being identified and plans have been made and partly launched for their implementation. The evaluation has also led to the development of a preliminary adaptation indicator.

The most advanced sector in the implementation of the Adaptation Strategy is the water resources management, where adaptation to climate change is already well integrated into the decision-making. In the transport sector, community planning and agriculture and forestry the implementation of the Adaptation Strategy has also proceeded quite well, but in most sectors the work is only in early stages (Ministry of Agriculture and Forestry 2009).

As a result of the National Adaptation Strategy all Finnish Ministries are responsible for designing concrete work plans to implement the Adaptation Strategy. The Finnish Ministry of Environment has, in cooperation with the Ministry of Agriculture and Forestry, identified a list of activities concerning climate change adaptation activities in the environment sector (Ministry of the Environment 2008).

For the use and protection of water reserves the list of activities includes i.a.:

- improvement of the hydrological monitoring and catchment area models in order to better forecast floods and droughts, as well development of the warning methods
- assessing the role of floods, increasing runoff and droughts in the raw water provision, as well as developing the preparedness of water management units by enhancing joint networks and backup systems
- re-evaluation of the existing permissions for water level regulation in the major catchment areas and, when required, increasing the flexibility of the regulation permissions

The Uusimaa region has started the development of a climate strategy that includes mitigation as well as adaptation as early as 2007. However, the strategy is not available yet. The regional strategy for the Uusimaa region (Uusimaa Regional Council 2010) addresses climate change only in terms of mitigation. The Itä-Uusimaa region has been planning a climate change strategy (Haanpää et al. 2009).

In the beginning of 2011, the regions of Uusimaa and Itä-Uusimaa were merged. This has far-reaching implications for the work in both regions. In the working programme for the joined region Uusimaa (Uusimaa Regional Council & Regional Council of Itä-Uusimaa 2010), climate change is dealt with as a cross cutting issue in conjunction with sustainable development. Climate change adaptation is not addressed specifically.

Adaptive capacity indicators are classified into five determinants in the Scientific Report. The values for adaptive capacity indicators were given as following:

Uusimaa

- Attitudes towards climate change (knowledge and awareness) => 0.202
- R&D personnel (technology) => 0.426
- R&D expenditure (technology) => 0.499
- Water exploitation index (infrastructure) => 0.043

- Availability of alternative water sources (infrastructure) => 0.40 (Alternative water sources planning started; case study specific indicator)
- National, regional and local climate change adaptation strategies (institutions) => 0.40 (National adaptation strategy available; case study specific indicator)
- Income per capita (economic resources) => 0.799

While estimating the availability of alternative water resources only those areas depending on coastal aquifers were taken into account. In the Uusimaa region, the water supply of Helsinki metropolitan area is not depending on coastal aquifers. The water supply is mainly organized by utilizing surface water (the Päijänne tunnel), and partly aquifers that are not located in coastal areas. In the city of Hanko, the alternative water resource for crisis situation is already available along with neighboring municipality Raasepori. However, this water resource is not sufficient for replacing the existing water supply constantly.

The local climate change adaptation strategy for water supply is currently under preparation in the city of Hanko. At the moment, national adaptation strategy is followed.

#### Itä-Uusimaa

- Attitudes towards climate change (knowledge and awareness) => 0.202
- R&D personnel (technology) => 0.426
- R&D expenditure (technology) => 0.499
- Water exploitation index (infrastructure) => 0.043
- Availability of alternative water sources (infrastructure) => 0.20 (Alternative water sources available; case study specific indicator)
- National, regional and local climate change adaptation strategies (institutions) => 0.20 (Local adaptation strategy available; case study specific indicator)
- Income per capita (economic resources) => 0.799

While estimating the availability of alternative water resources only those areas depending on coastal aquifers were taken into account. In the Itä-Uusimaa region, the city of Porvoo is depending on coastal aquifers. However, the city has already alternative water sources for crisis situation and existing coastal aquifers and water intakes have been protected for coastal and flash flooding. The local climate change adaptation for water supply exists for the city of Porvoo.

Aggregate adaptive capacity is 0.412 in the Uusimaa region and 0.374 in the Itä-Uusimaa region. Thus, both regions have good adaptive capacity towards the climate change impacts on coastal aquifers.

#### **Vulnerability**

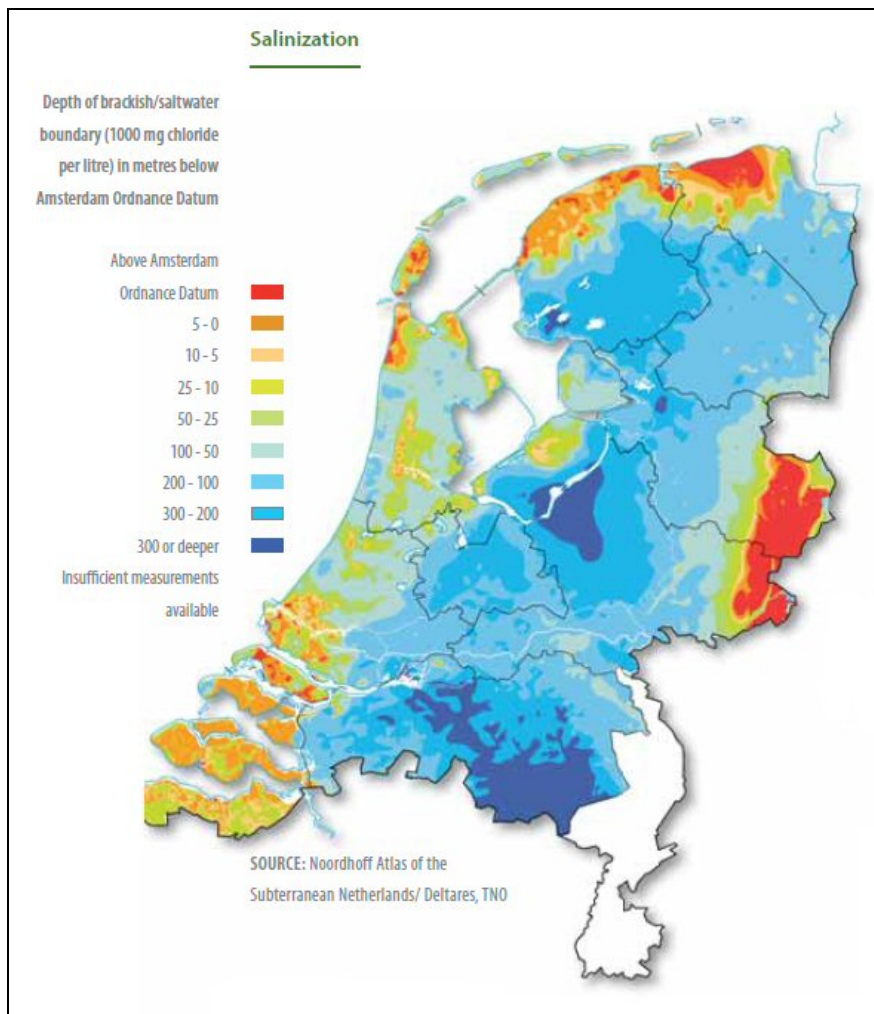
The vulnerability is determined by a combination of aggregated impact indicator and aggregated adaptive capacity indicator. The aggregated vulnerability normalized to pan-

European values is 0.024 in the Uusimaa region and 0.013 in the Itä-Uusimaa region. Thus, there is only a marginal impact of climate change on coastal aquifers within both regions.

#### ***4.2 The North Sea coastal area - Norway and the Netherlands***

The vulnerability assessment for low-lying shallow aquifer in the coastal area of the North Sea was made in Norway and in the Netherlands within one NUTS 3 region in both countries. In Norway, the coast of the North Sea is mainly rugged and steep from its topography. The low-lying shallow aquifers are completely lacking (Fringstad, Bjørn 2010, answers for the questionnaire). Even close to the coast, the terrain is well above sea level and the pressure of fresh groundwater pushes the fresh/salt water interface outwards. The water supply in municipalities along the coast have their water supplies from lakes in the hills behind, while the larger groundwater works serve towns and villages in the inland valleys. The islands located along the Norwegian coastline may be affected by sea level rise but no information was available from the islands. The Norwegian NUTS 3 region that was selected for testing is "Hordaland" (NO051), where the city of Bergen is located.

The landscape and the subsoil of the Netherlands have the characteristics of deltaic areas (Pastoors, Rien 2010, answers for the questionnaire). Thick unconsolidated sediments form good aquifers and the groundwater levels are shallow. A distinct feature of groundwater quality is the occurrence of brackish groundwater in large parts of the coastal zones already at present. In the Netherlands, the NUTS 3 region chosen for the CLIMATE-model was NL332 "Agglomeratie s-Gravenhagen" on the coastal dune area. Map 6 shows the depth of the salt water boundary in the Netherlands.



Map 6: Depth of brackish/saltwater boundary (1000 mg/L) in meters below Amsterdam Ordnance Datum. Source: Pastoors 2010. Today's situation.

### **Exposure to climate stimuli**

Norway belongs to the Northern climate change region of Europe (ESPON CLIMATE, Revised interim report, 22.3.2010). Within this region relative change in annual mean precipitation in summer months is insignificant. Change in annual mean temperature and relative change in annual mean precipitation in winter months will have strong increase. Change in annual mean number of days with heavy rainfall and relative change in annual mean evaporation will increase. Decrease in number of frost days and change in annual mean number of days with snow cover will have strong decrease.

The Netherlands belongs to the Northern-western climate change region of Europe (ESPON CLIMATE, Revised interim report, 22.3.2010). Within this region the relative change in annual mean evaporation and change in annual mean number of days with snow cover are insignificant. Change in annual mean temperature, relative change in annual mean precipitation in winter months and change in annual mean number of days with heavy rain fall will increase. Decrease in number of frost days and relative change in annual mean precipitation in summer months will decrease.



### ***Sensitivity and impact***

The sensitivity of low-lying shallow aquifers is especially high in the Netherlands and the problem of brackish or saline groundwater seepage will grow in future.

#### Physical sensitivity and impact

Data were not available for two case study specific physical indicators. The third indicator is the *Settlements sensitive for coastal flooding* (currently named in the Scientific Report as the *Settlements prone to coastal storm surges*). This indicator is calculated for the whole ESPON area. In Hordaland, Norway, the indicator gets value 0.054 and in Agglomeratie s-Gravenhagen, the Netherlands, 0.036. The physical impact is marginal. Compared to other case study areas these values are average.

#### Environmental sensitivity and impact

Data was not available for the case study specific environmental indicator. The indicator values were only available for indicator *Coastal areas prone to coastal flooding*. In Hordaland, Norway, the indicator gets value 0.005 and in Agglomeratie s-Gravenhagen 0.054. Mostly due to its steep topography, the coastal areas of Hordaland are not affected by coastal flooding. Comparing to other case study areas, Agglomeratie s-Gravenhagen has the biggest impact while reviewing this indicator.

#### Social sensitivity and impact

Data was available only for the Netherlandic NUTS 3 region. The indicator value for population sensitive to coastal flooding is 0.058. Change of potential impact of 100 year coastal storm surge event on population is marginal in "Agglomeratie s-Gravenhagen". Compared to other case study areas this value is average.

#### Economic sensitivity and impact

Data was not available for the case study specific economic indicator.

### ***Adaptive capacity***

Adaptive capacity varies from very good economic capacity to poor value for knowledge and awareness indicator.

#### Hordaland

- Attitudes towards climate change (knowledge and awareness) => not available
- R&D personnel (technology) => 0.623
- R&D expenditure (technology) => 0.756
- Water exploitation index (infrastructure) => 0.012
- Availability of alternative water sources (infrastructure) => not available (case study specific indicator)
- National, regional and local climate change adaptation strategies (institutions) => not available (case study specific indicator)
- Income per capita (economic resources) => 0.830

#### Agglomeration Copenhagen

- Attitudes towards climate change (knowledge and awareness) => 0.309
- R&D personnel (technology) => 0.788
- R&D expenditure (technology) => 0.773
- Water exploitation index (infrastructure) => 0.056
- Availability of alternative water sources (infrastructure) => not available (case study specific indicator)
- National, regional and local climate change adaptation strategies (institutions) => not available (case study specific indicator)
- Income per capita (economic resources) => 0.763

### **4.3 Atlantic Ocean coastal area - Scotland**

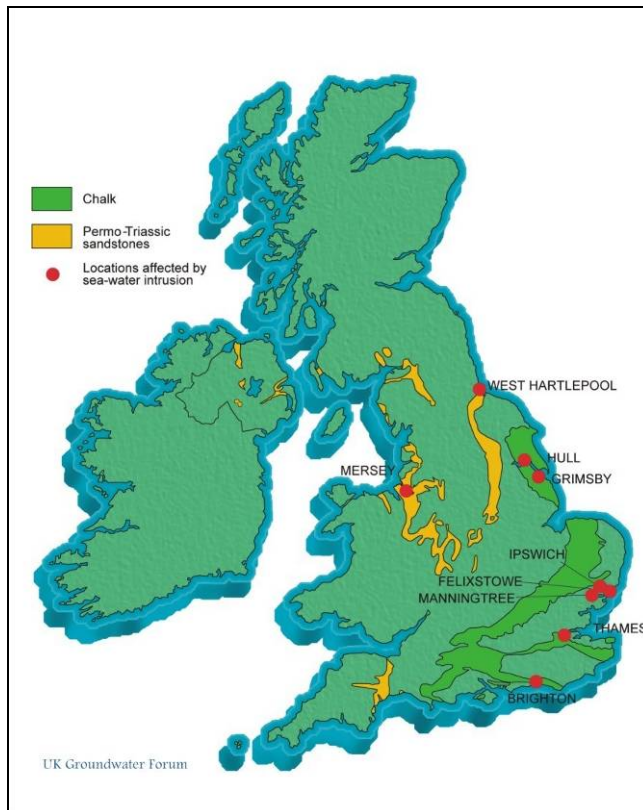
The UK Groundwater Forum (<http://www.groundwateruk.org>) provides information on groundwater. The impacts on groundwater of climate change have also been studied. The identified effects of climate change on groundwater in the UK include (*cursive text copied from the UK Groundwater Forum website*):

- *A long term decline in groundwater storage*
- *Increased frequency and severity of groundwater droughts*
- *Increased frequency and severity of groundwater-related floods*
- *Mobilisation of pollutants due to seasonally high water tables*
- *Saline intrusion in coastal aquifers due to sea level rise and resource reduction*

Thus, the reported effects on groundwater in the UK are similar to those identified for Finnish case study areas. It is also stated that climate change impacts may increase the cost of providing water supplies. However, no estimations for changes in costs are provided. One interesting point that has been brought out is the growing, more important role of groundwater in water supply in the future. Surface waters are assumed to be more sensitive to extreme climate change effects. The need for more detailed groundwater research in order to predict the impacts of climate (change) extremes is stressed.

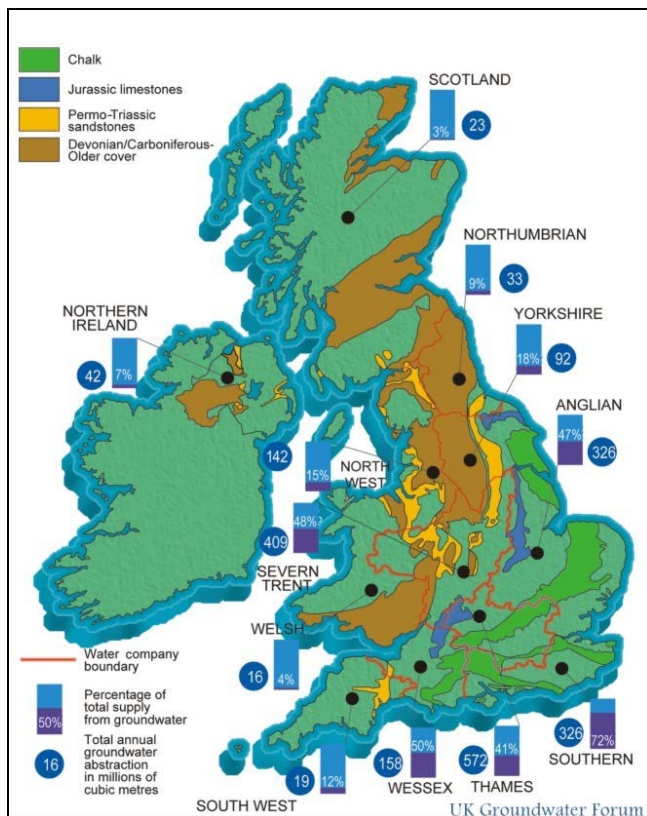
In order to address the growing demand on water resources and ensure the availability, some solutions have been presented by the UK Groundwater Forum. More efficient use of existing water supplies as well as development of new sources are the key options. The flexible transfer of water between regions needs further studies. Artificial recharge has been used only locally. Desalination and re-use of waste water if economically reasonable is also discussed.

Sea-water intrusion to coastal aquifers has occurred in the UK (Map 7) (British Geological Survey, 1998A). This is mainly due to extensive exploitation of a coastal aquifer.



*Map 7: Main areas of sea-water intrusions in Great-Britain. Source: UK Groundwater Forum 2011. Today's situation.*

Alluvial sands and gravels are not major aquifers in the UK. However, they can supply individual needs (British Geological Survey, 1998C). In Scotland, where water supplies are often derived from small, local aquifers (superficial deposits or fractured bedrock) springs may fail more frequently if summers become appreciably drier (Marsh, T. & Lewis, M. 2011). The use of groundwater varies greatly on the UK. In south-east parts of the UK, 72% of total water supply is from groundwater and annual groundwater abstraction is high (British Geological Survey, 1998B). In Scotland, the use of groundwater is limited. Only 3% of total water supply is from groundwater (Map 8). The annual groundwater abstraction is also much lower compared to southern parts of the UK. CLIMATE-model was tested in the NUTS 3 region "Inverness and Nairn" (UKM42).



Map 8: The use of groundwater in the UK. Source: UK Groundwater Forum 2011. Today's situation.

### **Exposure to climate stimuli**

Main parts of the UK belong to Northern-western climate change region of Europe (ESPON CLIMATE, Revised interim report, 22.3.2010). The central part of Scotland belongs to Northern-central climate change region. However, the Scottish coast is mainly Northern-western climate change region of Europe. Within this region the relative change in annual mean evaporation and change in annual mean number of days with snow cover are insignificant. Change in annual mean temperature, relative change in annual mean precipitation in winter months and change in annual mean number of days with heavy rain fall will increase. Decrease in number of frost days and relative change in annual mean precipitation in summer months will decrease.

### **Sensitivity and impact**

#### Physical sensitivity and impact

Data were not available for two case study specific physical indicators. The third indicator is the *Settlements sensitive for coastal flooding* (currently named in the Scientific Report as the *Settlements prone to coastal storm surges*). This indicator is calculated for the whole ESPON area. In Inverness and Nairn, the indicator gets value 0.109. Change of potential impact of 100 year coastal storm surge event on settlements is low. Compared to other case study areas this is the most sensitive region while considering the settlements prone to coastal flooding.

### Environmental sensitivity and impact

Data was not available for the case study specific environmental indicator. The indicator value was only available for *Coastal areas prone to coastal flooding*. In Inverness and Nairn, the indicator gets value 0.012. Compared to other case study areas this value is average.

### Social sensitivity and impact

In Inverness and Nairn, the indicator value for population sensitive to coastal flooding is 0.051. Change of potential impact of 100 year coastal storm surge event on population is marginal. Compared to other case study areas this value is average.

### Economic sensitivity and impact

Data was not available for the case study specific economic indicator.

### **Adaptive capacity**

Groundwater protection policy of Scotland has been published in 2009 (Scottish Environment Protection Agency, 2009). However, climate change and its potential impacts to groundwater quality and quantity are not discussed within this report. The report climate change adaptation in the UK, "How well prepared is the UK for climate change", also discussed the potential impacts to water supply (Adaptation Sub-Committee, 2010). Water resources and their efficient use are strongly presented in five priority areas that are described for early action. Knowledge and awareness indicator had a low value in "Inverness and Nairn". Also the adaptive capacity indicators for infrastructure, institutions and technology had low values for the area. Economic capacity was on average European level.

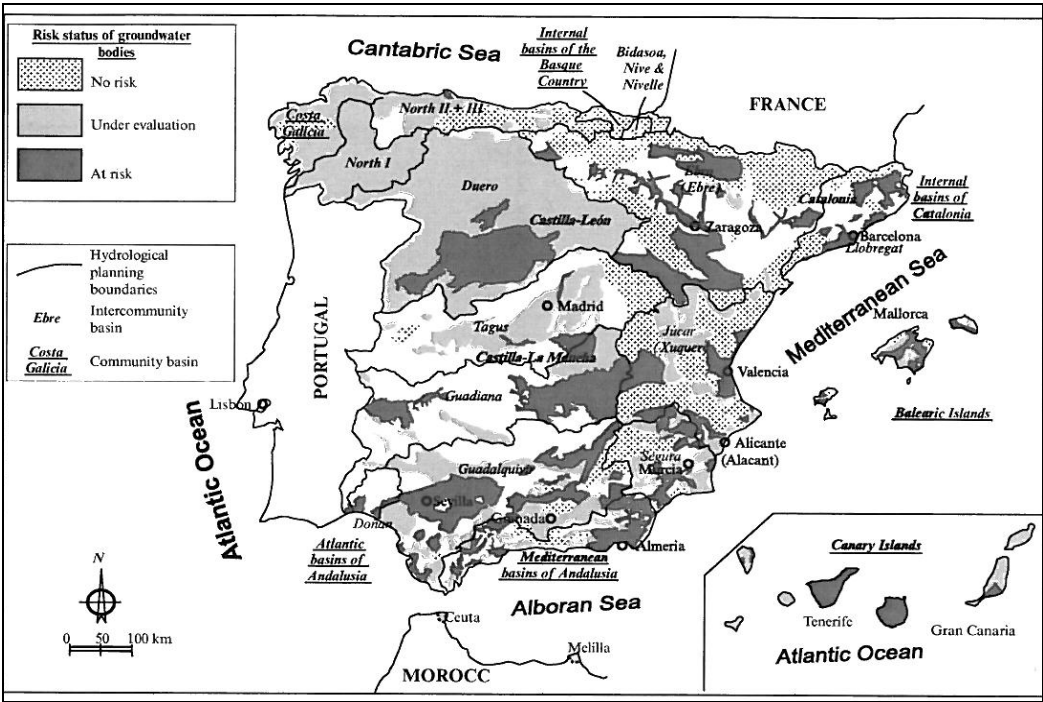
#### Inverness and Nairn

- Attitudes towards climate change (knowledge and awareness) => 0.300
- R&D personnel (technology) => 0.979
- R&D expenditure (technology) => 0.892
- Water exploitation index (infrastructure) => 0.232
- Availability of alternative water sources (infrastructure) => not available (case study specific indicator)
- National, regional and local climate change adaptation strategies (institutions) => not available (case study specific indicator)
- Income per capita (economic resources) => 0.842

### **4.4 Mediterranean coastal area - Spain**

Rocks of various age and type are represented in Spain. However, traditionally only high permeable geological formations, different sedimentary aquifers, are considered as aquifers in Spain. These aquifers are found in the area covering about 180 000 km<sup>2</sup>. Nowadays, even formations with lower permeability, such as igneous rocks and metamorphic rocks with

moderate permeability, are counted as aquifers. The estimate of total volume of water stored in Spain's aquifers varies between 150 000 and 300 000 Mm<sup>3</sup> (Custodio et al. 2009). Spain is the most arid country in Europe, however, it is a country with a large hydrogeological potential (Map 9). Spain's current total water use is about 37 500 Mm<sup>3</sup> /year or about one third of the total water resources (Llamas and Garrido 2007; Custodio et al. 2009). In Spain, as in many arid and semiarid countries, the main use for groundwater is irrigation with 75 %, domestic supply takes 20 % and industry only 5 % (Custodio et al. 2009). The share of groundwater use of the total water use varied from 15 to 25 % during the near past (Llamas and Garrido, 2007). There is not lack of aquifers in Spain, but there is a tradition to use more surface water on the water supply than groundwater.



Map 9: Classification of groundwater bodies in Spain according to the WFD status. Source: Custodio et al. 2009. Today's situation.

About 39 % (259) of the 699 groundwater bodies in Spain are classified to be at risk. The marine intrusion poses a risk for 72 of these 259 groundwater bodies (Molinero et al. 2007). Marine intrusion is mainly a consequence of freshwater aquifers over pumping. This is a very common phenomenon all over the Mediterranean basin, as well as in other areas with similar weather conditions and population. About 60 % of the Spanish coastal aquifers are contaminated by marine intrusion (EEA, 2009). The low-land alluvial aquifers close to settlement and river are the most sensitive groundwater bodies. ESPON Climate -model was tested in the NUTS 3 region "Valencia" (ES523).

**Exposure to climate stimuli**

Main parts of the Spanish coast belong to the Mediterranean climate change region of Europe (ESPON CLIMATE, Revised interim report, 22.3.2010). Within this region change in annual mean number of days with snow cover is insignificant. Change in annual mean

temperature will have strong increase. Relative change in annual mean precipitation in summer months will have strong decrease. Decrease in number of frost days, relative change in annual mean precipitation in winter months, change in annual mean number of days with heavy rainfall and relative change in annual mean evaporation will decrease.

### ***Sensitivity and impact***

#### Physical sensitivity and impact

Data were not available for two case study specific physical indicators. The third indicator is the *Settlements sensitive for coastal flooding* (currently named in the Scientific Report as the *Settlements prone to coastal storm surges*). This indicator is calculated for the whole ESPON area. In Valencia, the indicator gets value 0.091. Change of potential impact of 100 year coastal storm surge event on settlements is marginal. Compared to other case study areas this is the second most affected region while considering the settlements prone to coastal flooding.

#### Environmental sensitivity and impact

Data was not available for the case study specific environmental indicator. The indicator value was only available for *Coastal areas prone to coastal flooding*. In Valencia, the indicator gets value 0.020. Compared to other case study areas this value is average.

#### Social sensitivity and impact

In Valencia, the indicator value for population sensitive to coastal flooding is 0.133. Change of potential impact of 100 year coastal storm surge event on population showed low increase. Compared to other case study areas this is the most sensitive region while considering the population prone to coastal flooding.

#### Economic sensitivity and impact

Data was not available for the case study specific economic indicator.

### ***Adaptive capacity***

Adaption capacity indicators were on average European level except for water exploitation index, which indicated high usage of water resources.

#### Valencia

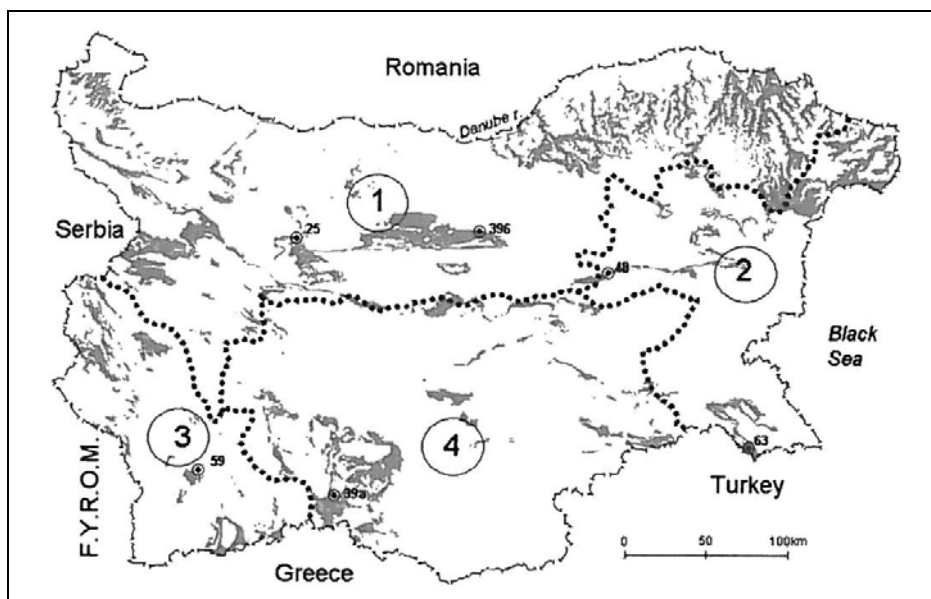
- Attitudes towards climate change (knowledge and awareness) => 0.182
- R&D personnel (technology) => 0.800
- R&D expenditure (technology) => 0.860
- Water exploitation index (infrastructure) => 0.722
- Availability of alternative water sources (infrastructure) => not available (case study specific indicator)
- National, regional and local climate change adaptation strategies (institutions) => not available (case study specific indicator)

- Income per capita (economic resources) => 0.842

#### 4.5 The Black Sea coastal area - Bulgaria

The Bulgaria is characterized by rather complicated geological structure. There is large variety of sedimentary, magmatic and metamorphic rocks and also volcanic-sedimentary rocks from the Precambrian to Quaternary age (Benderev et al. 2008). In parts of the rocks the porous, fractured and karst groundwater is formed.

The Black Sea coast area of Bulgaria has a typical platform structure, stratified, with very well defined aquifers separated by aquitards. The groundwater is accumulated in Neogene sands and sandstones, Palaeogene limestone and Mesozoic carbonate formations (Benderev et al. 2008). Alluvial aquifers are formed along the rivers and are superimposed over earlier formations. About 25 % of the 378 km long cost line is low-land and covered with sand. The country is divided in four hydrogeological zones (Map 10).



Map 10: Hydrogeological zones in Bulgaria. The zone number 2 is Black sea zone. Source: Benderev et al. 2008. Today's situation.

The annual mean groundwater recharge in 1977 – 2001 was about 6 km<sup>3</sup>, and in addition overlap shared by groundwater and surface water was also 6 km<sup>3</sup> (Earthtrends, 2003). Another estimate for potential groundwater was 3.3 km<sup>3</sup> by Knigh and Staneva (1996). The total water resources in Bulgaria were 21 km<sup>3</sup>. The annual withdrawal was in 1988 about 13.9 km<sup>3</sup> (Earthtrends, 2003). ESPON Climate -model was tested in the NUTS 3 region "Varna" (BG131).



### ***Exposure to climate stimuli***

Main part of Bulgarian coast in the Black Sea belongs to the Mediterranean climate change region of Europe (ESPON CLIMATE, Revised interim report, 22.3.2010). Within this region change in annual mean number of days with snow cover is insignificant. Change in annual mean temperature will have strong increase. Relative change in annual mean precipitation in summer months will have strong decrease. Decrease in number of frost days, relative change in annual mean precipitation in winter months, change in annual mean number of days with heavy rainfall and relative change in annual mean evaporation will decrease.

### ***Sensitivity and impact***

#### Physical sensitivity and impact

Data were not available for two case study specific physical indicators. The third indicator is the *Settlements sensitive for coastal flooding* (currently named in the Scientific Report as the *Settlements prone to coastal storm surges*). This indicator is calculated for the whole ESPON area. There is no change of potential impact of 100 year coastal storm surge event on settlements in Varna and the indicator gets value 0.

#### Environmental sensitivity and impact

Data was not available for the case study specific environmental indicator. The indicator value was only available for *Coastal areas prone to coastal flooding*. In Varna, the indicator gets value 0.011. Compared to other case study areas this value is average.

#### Social sensitivity and impact

In Varna, the indicator value for population sensitive to coastal flooding is 0.003. Change of potential impact of 100 year coastal storm surge event on population is marginal. Compared to other case study areas the sensitivity is very low.

#### Economic sensitivity and impact

Data was not available for the case study specific economic indicator.

### ***Adaptive capacity***

Economic and technological capacity is low at European level in "Varna" while knowledge, awareness and infrastructure indicators showed better adaptive capacity in this region.

Varna

- Attitudes towards climate change (knowledge and awareness) => 0.167
- R&D personnel (technology) => 0.939
- R&D expenditure (technology) => 0.969
- Water exploitation index (infrastructure) => 0.035
- Availability of alternative water sources (infrastructure) => not available (case study specific indicator)

- National, regional and local climate change adaptation strategies (institutions) => not available (case study specific indicator)
- Income per capita (economic resources) => 0.934

## 5. Conclusions

The purpose of the case study on coastal aquifer was to test the ESPON Climate –model within different case study areas. Detailed hydrological studies on aquifers were not able to carry out in the course of the project or studies on water supply and infrastructure within regions. Alongside with testing the indicators that were developed by the project for the whole ESPON area, the case study aimed at developing new indicators that will better describe the potential climate change impacts to coastal aquifers as well as the adaptive capacity of the regions.

The case study faced problems in getting information from different case study areas. Questionnaire was sent to few countries but they were answered poorly. Thus, the final testing of the ESPON Climate –model was only applicable for selected Finnish case study areas.

The case study used the exposure indicators that were provided by the project. No case study specific exposure indicators were made. Some of the impact indicators that were provided by the project for the whole ESPON area were also applicable for the case study, and four case study specific impact indicators were also developed. Two new case study specific adaptive capacity indicators were also developed in the course of the project, and five adaptive capacity indicators that were developed for the whole ESPON area were used.

The challenge of developing case study specific indicators was the lack of European wide data. The classification and valuation of indicators would have benefit if the variation between different countries and regions would have been available.

The ESPON area indicators showed differences between selected regions. Within more densely populated regions the investigated physical (settlements sensitive to coastal flooding) and social (population sensitive to coastal flooding) impacts for the coastal areas were higher. However, these indicators do not take into account whether the regions are depending on coastal aquifers. This also applies the investigated environmental impact. The coastal areas that are prone to coastal flooding don't necessarily correlate with coastal aquifer sensitivity. Coastal aquifers might not exist or regions are not using coastal aquifers for their water supply.

The ESPON wide adaptation capacity indicators were more applicable to coastal aquifer case study. The level of adaptation capacity in economic, knowledge and awareness, infrastructure and technology also reflect to adaptation capacity towards impacts on coastal aquifers. The difference between technological adaptation capacities within case study regions was noticeable. This applies also to economical and infrastructural adaptation capacities. More detailed information on region's adaptation capacity would have been achieved with case study specific indicators. Availability of alternative water sources within

coastal areas would tell more about the infrastructural preparedness of the region towards the potential impacts on coastal aquifers. The current situation on climate change adaptation strategies from the water supply point of view would best describe the region's institutional adaptation capacity.

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# APPENDIX 1 Questionnaire

## ESPON CLIMATE PROJECT

### CASE STUDY: COASTAL AQUIFERS

#### ADDITIONAL INFORMATION FROM COASTAL NUTS3 AREAS

GTK has carried out case study on two coastal NUTS3 areas in Finland: Uusimaa and Itä-Uusimaa. These areas will be discussed in detail in the project final report. In addition to that, our project should gather similar information from other coastal areas as well. That is why we ask you to try to find out information from two coastal NUTS3 areas in your country that are characterized by a shallow (sand and gravel) aquifer connected to the sea. We would be very pleased if you can find the following information or help us to find similar info from your country. Please send your answers as e-mail to [timo.tarvainen@gtk.fi](mailto:timo.tarvainen@gtk.fi) by 15 October. Johannes Klein and Philipp Schmidt-Thomé will give you advice with the questionnaire during the Budapest meeting.

Kind regards,

*Timo Tarvainen, Johannes Klein and Philipp Schmidt-Thomé*

#### PART 1: TWO COASTAL NUTS3 AREAS FROM YOUR COUNTRY

##### NUTS3 AREA NUMBER 1:

Name of the area: \_\_\_\_\_

NUTS3 identifier: \_\_\_\_\_

Are any coastal aquifers used for water extraction in this area or have those aquifers been used earlier?

\_\_\_\_\_  
\_\_\_\_\_

Are there any problems with using those aquifers?

\_\_\_\_\_  
\_\_\_\_\_

Are there any problems expected in the application of these coastal aquifers in the future because of the climate change?

\_\_\_\_\_  
\_\_\_\_\_

##### NUTS3 AREA NUMBER 2:

Name of the area: \_\_\_\_\_

NUTS3 identifier: \_\_\_\_\_

Are any coastal aquifers used for water extraction in this area or have those aquifers been used earlier?

\_\_\_\_\_  
\_\_\_\_\_

Are there any problems with using those aquifers?

---

---

Are there any problems expected in the application of these coastal aquifers in the future because of the climate change?

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**PART 2: CONCEPTUAL MODEL (OPTIONAL)**

The attached PowerPoint presentation shows the connections between climate change parameters, hydrology and groundwater in Southern Finland. If you wish, you can modify the conceptual model presented in the attached PowerPoint presentation to better describe the situation in your country.

Please choose (X)

- We have modified the conceptual model to present the situation in our country  
(Send the updated version as an attachment in your e-mail)
- The conceptual model made for Finland is applicable also for our country
- We did not have time or possibility to modify the conceptual model



### **PART 3: EXPOSURE INDICATORS AND SENSITIVITY INDICATORS**

The attached Excel file lists the exposure indicators (top) and sensitivity indicators (left) that we have found important for coastal aquifers in Finland. Most of the indicators are the same that were described in the technical report of our project. There are two additional sensitivity indicators (share of groundwater yield from coastal aquifers, value of water from coastal aquifers). The connections between exposure and sensitivity indicators are also shown in the table.

Please check the table and make changes if necessary.

Please choose (X)

- We have modified the indicator table to present the situation in our country  
(Send the updated version as an attachment in your e-mail)
- The indicator table made for Finland is applicable also for our country

**PART 4: NEW INDICATORS** Please fill in the yellow cells

Dimension: **Environmental sensitivity**

Indicator: *Percentage of groundwater yield from coastal aquifers*

Scale: NUTS3 region

Relevance: Percentage of groundwater yield from coastal aquifers from the total yield of all important aquifers in a NUTS3 region reveals how critical the coastal aquifers can be for the region. These coastal aquifers can be even more important on local level.

Existing studies: The yields of the important aquifers have often been investigated because this information is important for local and regional planning. E.g. aquifers in Itä-Uusimaa are estimated to be replenished by 57 525 m<sup>3</sup> of water per day. In low lying aquifers, close to the present sea shore, the water yield is about 10 345 m<sup>3</sup>/d. This means that about 18 % of the fresh water resources in Itä-Uusimaa Region are surrounded at least by one side by the Baltic Sea.

Indicator methodology: This indicator can be calculated as the percentage of water yield depending on coastal aquifers (< 5 m above present mean sea level) of the total groundwater yield in a NUTS3 area. If the coastal aquifer is surrounded by sea by all sides, the total yield is taken into account in the indicator calculation. If the aquifer is connected to the sea only by one side, 25% of the total yield is taken into account in the indicator calculation.

Parameters:

Parameter	Unit	Example: Uusimaa	NUTS3 area 1	NUTS3 area 2
Y1 = Yield from low lying aquifers at coastal area	m <sup>3</sup> /d	15 320		
Y2 = Total yield of all important aquifers	m <sup>3</sup> /d	255 866		

Formula

Indicator = 100 x Y1 / Y2 % (The indicator value will be re-scaled to 1 – 5 when more examples are available.)

NUTS3 area	Y1 m <sup>3</sup> /d	Y2 m <sup>3</sup> /d	Indicator value %
Example: Uusimaa	15320	255866	6%
Area 1			
Area 2			

Dimension: **Economic sensitivity**

Indicator: *Value of water from coastal aquifers*

Scale: NUTS3 region

Relevance: The availability of reasonable priced water is vitally important for households and industry in any region. This indicator shows the yearly value as end user product of the water extracted from the sensitive coastal aquifers.

Existing studies: The yield from coastal aquifers is the parameter that has been applied in the environmental indicator Percentage of groundwater yield from coastal aquifers. The average price of water is available at least in country level.

Indicator methodology: The indicator can be calculated as the value of groundwater applied from the threatened shallow coastal aquifers. This indicator can be calculated from the yield depending on coastal aquifers (< 5 m above present mean sea level) and the average customer price of water in the region or in the country. If the coastal aquifer is surrounded by sea by all sides, the total yield is taken into account in the indicator calculation. If the aquifer is connected to the sea only by one side, 25% of the total yield is taken into account in the indicator calculation.

Parameters:

Parameter	Unit	Example: Uusimaa	NUTS3 area 1:	NUTS3 area 2:
P = The average duty of household fresh water in region or in country	€/ m <sup>3</sup>	0.90		
Y = Yield from low lying aquifers at coastal area	m <sup>3</sup> /d	15 320		

Formula

Indicator = P x Y x 365 €

NUTS3 area	P €	Y m <sup>3</sup> /d	Indicator value €
Example: Uusimaa	0.90	15320	5.0 M€
Area 1			
Area 2			

The indicator value will be re-scaled to 1 – 5 when more examples are available.

Dimension: **Infrastructure adaptive capacity**

Indicator: *Availability of alternative water sources*

Scale: NUTS3 region

Relevance: The availability of alternative water resources is a targeted indicator for adaptive capacity of a region to cope with reducing fresh water resources of shallow coastal aquifers. In some cases alternative water sources can be easily identified but desalinization technique or application of more distance water sources will increase the costs. In other cases there is a need to start planning alternative sources.

Existing studies: There are some regional case studies. For example in Itä-Uusimaa there is a plan for an artificial groundwater intake and construction of related pipeline network

Indicator methodology: The indicator value is defined by ranking various alternative water sources that can be taken into use if shallow coastal aquifers are not useable in the future.

Parameters:

Parameter	Unit	Example: Uusimaa	NUTS3 area 1:	NUTS3 area 2:
The best alternative water sources for coastal aquifer problems		Other aquifers can be used for water extraction with higher costs		

Formula

Ranking

Indicator value	Explanation
5	Alternative water sources available with almost similar costs
4	More expensive alternative water sources already available
3	Alternative water sources planned in detail
2	Alternative water sources planning started
1	No alternative water source plans available yet

NUTS3 area	Indicator value
Example: Uusimaa	4
Area 1	
Area 2	

Dimension: **Institutional adaptive capacity**

Indicator: *National, regional and local climate change adaptation strategies*

Scale: NUTS3 region

Relevance: The existence of a local, regional or national adaptation strategy is likely to increase adaptive capacity of a region. Usually national adaptation strategies have some relevance for the regional level and can thus act as encouraging factor and spur on political processes at the regional level. Regional and local adaptation strategies take more closely into account also the coastal problems related to the climate change. In the best case the local or regional adaptation strategy has been developed to take into account the threats to the sensitive coastal aquifers.

Existing studies: An indicator for national adaptation strategies has been developed for the entire ESPON Climate project. More focused adaptation strategies are available for some regions such as Itä-Uusimaa in Finland.

Indicator methodology: The indicator value is defined by ranking of various climate change adaptation strategies

Parameters:

Parameter	Unit	Example: Itä-Uusimaa	NUTS3 area 1:	NUTS3 area 2:
The best climate change adaptation strategy available for coastal aquifer problems		Local adaptation strategy available for the most sensitive aquifers		

Formula: Ranking

Indicator value	Explanation
5	Local or regional adaptation strategy available for the most sensitive aquifers
4	Regional adaptation strategy implemented
3	National adaptation strategy implemented
2	National adaptation strategy available
1	National adaptation strategy planned

Itä-NUTS3 area	Indicator value
Itä-Uusimaa	5
Area 1	
Area 2	

## **APPENDIX 2 List of indicators**

### Exposure indicators

- Change in annual mean temperature
- Decrease in number of frost days
- Relative changes in annual mean precipitation in winter months
- Relative change in annual mean precipitation in summer months
- Change in annual mean number of days with heavy rainfall
- Relative changes in annual mean evaporation
- Change in annual mean number of days with snow cover
- Change in coastal flooding

### Sensitivity indicators

- Percentage of groundwater yield from coastal aquifers
- Drinking water prices in coastal area

### Impact indicators

- Water intakes prone to flash floods
- Water intakes prone to coastal flooding
- Settlements prone to coastal flooding
- Coastal areas prone to coastal flooding
- Coastal population prone to coastal flooding

### Adaptive capacity indicators

- Attitudes towards climate change (knowledge and awareness)
- R&D personnel (technology)
- R&D expenditure (technology)
- Water exploitation index (infrastructure)
- Availability of alternative water sources (infrastructure)
- National, regional and local climate change adaptation strategies (institutions)
- Income per capita (economic resources)

## APPENDIX 3 Coastal aquifer case study

ESPON Climate project. Coastal aquifers case study

19th April 2011

NUTS3	FI181	FI182	NO051	UKM42 (UKM62)	NL332	ES523	BG131 (BG331)
	Uusimaa (Finland)	Itä-Uusimaa (Finland)	Hordaland (Norway)	Inverness and Nairn (Scotland)	Agglomeratie s-Gravenhagen (Netherlands)	Valencia (Spain)	Varna (Bulgaria)
<b>Physical impact</b>							
Indicator 1:							
Potential impact (water intakes sensitive to flash floods)	0,000	0,047	x	x	x	x	x
Indicator 2:							
Potential impact (Water intake sensitive to coastal flooding)	0,000	0,030	x	x	x	x	x
Indicator 3:							
Potential impact (Settlements sensitive to coastal flooding)	0,051	0,021	0,054	0,109	0,036	0,091	0,000
Potential physical impact (average of 3 indicators)	0,017	0,033	(x)	(x)	(x)	(x)	(x)
<b>Environmental impact</b>							
Indicator 1							
Potential impact (Coastal areas sensitive to coastal flooding)	0,011	0,019	0,005	0,012	0,054	0,020	0,011
Indicator 2							
Exposure							
Decrease in number of frost days (no clear signal on impact, excluded)	-0,919	-0,926	-0,756	-0,740	-0,310	-0,227	-0,543
Change in mean winter precipit.	0,597	0,546	0,490	0,233	0,433	-0,670	-0,302
Change in mean summer precipit.	0,001	0,007	0,218	0,063	-0,352	-0,456	-0,460
Change in annual mean evaporation	0,590	0,562	0,222	0,224	0,096	-0,381	-0,243
Change: snow cover (no clear signal on impact, excluded)	-0,794	-0,813	-0,822	-0,187	-0,009	-0,008	-0,158
Coastal flooding (abs. area normalized)	0,028	0,021	0,030	0,034	0,005	0,084	0,017
Sensitivity							
Percentage of groundwater yield from coastal aquifers	0,060	0,180	x	x	x	x	x
Potential impact ((exp1*sens+.....exp5*sens)/5)	0,000	0,001	(x)	(x)	(x)	(x)	(x)
Potential environmental impact (average of 2 indicators)	0,011	0,021	(x)	(x)	(x)	(x)	(x)

ESPON Climate project. Coastal aquifers case study

19th April 2011

NUTS3	FI181	FI182	NO051	UKM42 (UKM62)	NL332	ES523	BG131 (BG331)
	Uusimaa (Finland)	Itä-Uusimaa (Finland)	Hordaland (Norway)	Inverness and Nairn (Scotland)	Agglomeratie s-Gravenhagen (Netherlands)	Valencia (Spain)	Varna (Bulgaria)
<b>Social impact</b>							
Indicator 1							
Potential impact (Population sensitive to coastal flooding)	0,097	0,007	(x)	0,051	0,058	0,133	0,003
Potential social impact	0,097	0,007	(x)	0,051	0,058	0,133	0,003
<b>Cultural impact</b>							
Potential cultural impact	Cultural sensitivity was excluded from the case study on coastal aquifers						
<b>Economic sensitivity</b>							
Indicator 1							
Exposure							
Decrease in number of frost days (no clear signal on impact, excluded)	-0,919	-0,926	-0,756	-0,740	-0,310	-0,227	-0,543
Change in mean winter precipit.	0,597	0,546	0,490	0,233	0,433	-0,670	-0,302
Change in mean summer precipit.	0,001	0,007	0,218	0,063	-0,352	-0,456	-0,460
Change in annual mean evaporation	0,590	0,562	0,222	0,224	0,096	-0,381	-0,243
Change: snow cover (no clear signal on impact, excluded)	-0,794	-0,813	-0,822	-0,187	-0,009	-0,008	-0,158
Coastal flooding (abs. area normalized)	0,028	0,021	0,030	0,034	0,005	0,084	0,017
Sensitivity							
Price of water from coastal aquifers	0,039	0,501	x	x	x	x	x
Potential impact ((exp1*sens+.....exp5*sens)/5)	0,000	0,004	(x)	(x)	(x)	(x)	(x)
Potential economic impact	0,000	0,004	(x)	(x)	(x)	(x)	(x)
<b>Aggregate Potential impact (Delphi weights)</b>	<b>0,028</b>	<b>0,017</b>	<b>(x)</b>	<b>(x)</b>	<b>(x)</b>	<b>(x)</b>	<b>(x)</b>
	The missing 10% of the cultural impact are compensated by increasing the 90% to 100% by deviding with 0,9.						



NUTS3	FI181	FI182	NO051	UKM42 (UKM62)	NL332 Agglomeratie s- Gravenhagen (Netherlands)	ES523	BG131 (BG331)
	Uusimaa (Finland)	Itä-Uusimaa (Finland)	Hordaland (Norway)	Inverness and Nairn (Scotland)		Valencia (Spain)	Varna (Bulgaria)
<b>Adaptation capacity</b>							
<b>Economic</b>							
Indicator 1							
Income per capita	0,740	0,799	0,830	0,842	0,763	0,842	0,934
<b>Knowledge and awareness</b>							
Indicator 1							
Attitudes towards climate change	0,202	0,202	x	0,300	0,309	0,182	0,167
<b>Infrastructure</b>							
Indicator 1							
Water exploitation index (EEA)	0,043	0,043	0,012	0,232	0,056	0,722	0,035
Indicator 2							
Availability of alternative water sources	0,400	0,200	x	x	x	x	x
Average infrastructure capacity	0,221	0,121	x	x	x	x	x
<b>Institutions</b>							
Indicator 1							
National, regional and local climate change adaptation strategies	0,400	0,200	x	x	x	x	x
<b>Technology</b>							
Indicator 1							
R&D personnel	0,426	0,426	0,623	0,979	0,788	0,800	0,939
Indicator 2							
R&D expenditure	0,499	0,499	0,756	0,892	0,773	0,860	0,969
Average technological capacity	0,463	0,463	0,690	0,936	0,780	0,830	0,954
<b>Aggregate Adaptive Capacity (Delphi weights)</b>	<b>0,412</b>	<b>0,374</b>	<b>(x)</b>	<b>(x)</b>	<b>(x)</b>	<b>(x)</b>	<b>(x)</b>
<b>Aggregate Vulnerability (imp*AC)</b>	<b>0,012</b>	<b>0,006</b>	<b>(x)</b>	<b>(x)</b>	<b>(x)</b>	<b>(x)</b>	<b>(x)</b>
<b>Aggregated Vulnerability normalized to pan-European values</b>	<b>0,024</b>	<b>0,013</b>					