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Abstract

This publication reports on the main findings the entire TOLERATE project, which was an integrated natural science – social science project for the assessment of climate changed induced changes of extreme weather events and their social-economic consequences at a regional level. It includes regional projections of changes in climate conditions in Finland, with special reference to (short) periods with extremely abundant and extreme scant precipitation respectively. Based on these projections changes in river flood risks are assessed for two water shed areas by means of hydrological models. The resulting flood maps for events with different return times are subsequently evaluated with respect to their direct damage cost and with respect to the overall macro-economic impacts in the region. With the aid of a group decision support system alternative flood risk mitigation options (investment alternatives) were preliminary explored with the aim to arrive at a ranking of alternatives based on a mix of criteria.

Key words: adaptation, climate change, cost-benefit analysis, decision support, flood risk, hazard economics, regional climate scenario

JEL classes: D81, H43, O18, Q54, R11

Tiivistelmä

Tässä julkaisussa esitellään keskeiset tulokset TOLERATE – projektista, joka oli luonnon- ja yhteiskuntatieteellinen projekti, jossa arvioitiin ilmastonmuutoksesta aiheutuvia äärimmäisiä sääolosuhteita ja niiden sosio-ekonomisia vaikutuksia alueellisella tasolla. Tarkasteluun sisältyvät laskelmat Suomen ilmasto-olosuhteiden alueellisista muutoksista ja erityisesti tutkittiin (lyhyitä) ajanjaksoja, jolloin sademäärät olivat poikkeuksellisen runsaita tai vähäisiä. Näiden laskelmaarvioiden pohjalta laskettiin jokien tulvariskit kahdella vesistön valuma-alueella hydrologisten mallien avulla. Työn tuloksena syntyneiden erilaisten sääilmiöiden tulvakarttojen avulla arvioitiin suorien tulvavahinkojen määrät sekä kokonaistaloudelliset vaikutukset alueelle ottaen huomioon tulvan ajallisen keston. Asiantuntijaistunnon avulla kehiteltiin alustavasti tulvariskien pienentämistoimenpiteitä (ratkaisuvaihtoehtoja) tavoitteena luokitella vaihtoehtoja eri arvosteluperusteiden yhdistelmän perusteella.

Avainsanat: sopeutuminen, ilmastonmuutos, kustannus-hyötyanalyysi, päätöksenteon tuki, tulvariski, katastrofien taloustiede, alueellinen ilmastoskenaario

JEL-luokat: D81, H43, O18, Q54, R11

Summary

Introduction

The initiative to this study followed from one of the conclusions of the FINADAPT study[1], namely that for a proper assessment of the economic consequences of climate change more attention should be paid to extreme events, which are possibly exacerbated by climate change. In Finland the most significant damaging processes resulting from extreme weather events are floods and droughts. The TOLERATE[2] study therefore concentrates on disruptions caused by those events in particular, with a primary focus on floods. In addition the study pays some attention to the effects of prolonged absence of precipitation.

Two flood prone areas, the cities of Pori and Salo were selected. For these areas current and future flood probabilities are assessed, while accounting for the impacts of climate change on precipitation patterns and volumes. The considered time span is 2005–2050. Subsequently, for various levels of flooding the direct and indirect damage was assessed by linking spatial flood data (i.e. GIS based) with spatial data on real estate and economic activity in the flood prone areas. Also the demographic and economic development for the period 2005–2050 was reviewed. In this way the influence of climate change on flood risk could be distinguished from the influence of socio-economic factors. The propagation of the direct damage and of the first order indirect damage cost throughout the regional economy was assessed as well. Finally, the socio-economic cost-benefit profiles of various flood protection measures were reviewed by means of a multi-criteria analysis approach in the setting of group decision making framework. In this way it was tried to reflect stakeholder involvement in local climate change adaptation policy making. In addition to the elaborate analysis of flood risk cases the report deals briefly with drought and the influence of larger volatility of precipitation on the wholesale electricity prices in Nordic countries.

A new study area in economics

Economic impact assessment of major hazards is still very much in a development stage, both in terms of theoretical underpinning and in terms of modelling for applied cost-benefit analysis. For given types and graveness categories of events direct cost of damage to man made and natural capital can be evaluated fairly accurately, provided the location of the initial impacts (flood, storm, etc.) can be determined with sufficient precision. Accurate GIS data bases and applications, which are able to combine data on natural conditions (elevation,

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[1] See http://www.ymparisto.fi/default.asp?contentid=227544&lan=FI&clan=en

[2] TOLERATE stands for: TOwards LEvels of Required Adaptation To cope with Extreme weather events.

soil type, etc.) with societal data (building stock, economic activity, accessibility, etc.), are extremely helpful for identifying vulnerabilities and for evaluation of the direct cost. After a few replications of such exercises it should be possible to apply adequately representative unit cost figures (i.e. per hectare by type of land use and/or degree of building density). This would create a good basis for generation of replicable and reliable cost-benefit assessments against reasonable cost. Yet, for comprehensive cost-benefit analysis also the induced effects on the regional economy over a longer time span (~10 years or more) should be assessed. In this respect it should be realised that – notwithstanding the progress made in the past two decades – modelling of the induced effects of hazards is still in a relatively infant stage. Furthermore, the assessment of the net benefits of alternative solutions, which reduce the exposure to and/or the consequences of hazards, adds further complications due to the uncertainties, varying views on discounting, and the inclusion of (originally) non-monetised effects.

Meteorological and hydrological simulation results

Extremes of daily and monthly precipitation were assessed for so-called return times of 10, 20, 50, 100 and 500 years. According to multi-model mean estimates based on 19 global climate models, annual mean warming in Finland by the period 2020–2049, compared to the period 1971–2000, is about 2±1°C, virtually regardless of the emission scenario. The corresponding annual mean precipitation change is about 7±5 %. The increase in precipitation is expected to be the largest in winter months (approx. +9% compared to current climate, with a 90% probability interval of +2% ~ +16%), whereas also the change in daily average temperature is the largest during the winter (+2.9 degrees compared to current climate, with a 90% probability interval lying between +1.6 degrees and +4.2 degrees). The latter effect means that a bigger part of the precipitation during winter will come as rain or at least will melt soon after reaching the ground.

Hydrological model simulation indicated an increase of flooding risk in the city of Pori, but a decrease in the city of Salo for floods caused by high river discharges. In both cases sea level rise is increasing the risk of flooding. According to hydrological simulations the 100 year flood in Pori increases by 0% ~15 % in terms of discharge in the period 2020-2049 as compared to 1971–2000 in case of strongly modified regulation. The flood might also last a little longer, maybe one or two days more for a 250 year event. The simulations made for Salo indicate that, the floods in the period 2020–2049 would decrease considerably, i.e. by -15%~-30% for a 100 year event.

Flood maps and damage estimates are based on flood mapping, which are produced by means of hydraulic models, in this case a 1-D model. The limitation of a one-dimensional (1-D) flow model should be kept in mind when inspecting the modelling results. Only one water level is calculated for each cross section. This is problematical in cases like Pori, where vast low-lying areas are protected by embankments. The water level in the flooded embanked areas is assumed to be level with the water surface slope in the main river channel. This is not the case in reality, since inundating water may have different flow routes and downstream boundary conditions. Realistic modelling of embankment breach would require two-dimensional modelling. An attempt to reach the universal solution would require multiple case studies, since breaches in different locations cause different impacts. The knowledge about the most vulnerable spots in the embankments would require geotechnical analysis.

Expected direct costs

Of all the flood prone areas in Finland the city area of Pori clearly stands out as the case where the most social-economic damage could occur. According to the simulation exercises in this study the costs of river flooding in Pori in the next few decades could easily cause damages of 40 million to 50 million euro with the current (2008) level of protection. Worst case situations for floods with a return time of 50 years may even cause damages of just over 100 million euro. The probability that a flood with a return time of 50 years will occur at least once in the next 45 years is about 0.64. A flood with a return time of 250 years, of which the probability of occurrence in the next 45 years is approximately 0.18, is expected to cause very considerable damage of up to 380 million euro. These cost concern only damage to residential and non-residential buildings and the first order cost of suspended production in flooded areas. A summary of direct damage ranges is provided in table S1 below.

When comparing results for present and future climate the direct costs of floods go up by about 15% when applying future climate conditions. However, the impact of economic growth is much larger, being in the order of magnitude of 50% in the considered time span (2005–2050). On the other hand over longer time spans it is also possible to avoid building in the most risky areas and to take precautionary measures for existing buildings, notably in shallower parts of flood prone areas.

Table S1 *Direct costs of material damage and first order indirect damage of production interruptions and temporary residence for R50 and R250 floods in all three flood prone areas (costs rounded off at million euros)*

	Direct Cost – material damage (buildings, interior, equipment) and cleaning cost (in million euro)			
	Current climate		Future Climate	
	R=50	R=250	R=50	R=250
Homes	81	169	91	194
Apartments	13	53	16	67
Shops & offices	5	30	7	38
Other buildings	7	41	9	50
Auxiliary buildings	1	2	1	2
TOTAL direct cost	**107**	**294**	**123**	**350**
of which buildings	*98*	*270*	*113*	*323*
	First order indirect Cost – suspension of production and temporary residence (in million euro)			
	Current climate		Future climate	
	R=50	R=250	R=50	R=250
Households (homes + apartments)	7	9	13	15
Companies	3	5	13	16
TOTAL first order indirect cost	**10**	**14**	**25**	**32**

Regional economic impacts

The direct costs mentioned above represent mainly loss of capital and only a modest fraction is loss of income. Therefore these overall direct cost not necessarily show up that way in the regional economic accounts. The repair work usually causes a boom in some sectors, possibly for over a year. The consequence is that the regional GDP might first even go up, provided the repair is predominantly carried out by inhabitants from the same region. It is likely that the demand surge for building repair displaces ongoing and about to be started building activities. It depends on various factors, such as available labour supply and available building supplies after the extreme event, to what extent displacement will actually take place. If there is a lot of labour hired from outside the region, whereas wages surge due to scarcity, the result can be a significant outflow of income to other regions. In subsequent years directly after the repair boom the economy may do less well due to the repayment of the funding of the repairs, and due to higher insurance premiums. Together this causes reduced purchasing power and affects the entire (regional) economy via (reduced) household consumption. The extent to which real estate and other capital goods are insured has significant influence on how the regional economy recovers. Higher insurance coverage promotes quicker recovery. Also the functioning of the labour market and the re-establishment of trade contacts in crippled product markets are important ingredients for better resilience. They depend on transparency and up-to-date information provision. Table S2 summarizes the results.

Table S2 Influences of different assumptions on accumulated cost

cumulated effect (12 year) in mln €		**CC**	**FC**	difference to default	
default	stepwise displacement	346	380		
	high displacement	366	404		
	low displacement	228	239		
Less insurance less substitution	stepwise displacement	368	402	6 %	6 %
	high displacement	389	427	6 %	6 %
	low displacement	253	265	11 %	11 %
slow repair (no cap.corr.)	stepwise displacement	326	357	-6 %	-6 %
	high displacement	361	398	-1 %	-1 %
	low displacement	222	233	-3 %	-3 %
higher I/O multiplier	Stepwise displacement	377	411	9 %	8 %
	high displacement	398	436	9 %	8 %
	low displacement	259	271	14 %	13 %

Decision making

In the preparatory phase of the TOLERATE study was hypothesized that in principle the assessment of the risks of floods, including the reinforcement effects of climate change as well as possible flood protection measures, could be under-stood as an optimal control problem. Yet, already in that phase it was also indicated that most probably such an optimal control approach would not be feasible in a strict sense, but rather works as a metaphor and helps to systemise the comparison of alternative strategies. The decision making simulation exercise carried out during the study exemplifies this point. Not only is there uncertainty regarding a part of the information, but there is also uncertainty about the way different interest groups conjecture the overall problem. A part of the latter uncertainty can be somewhat relieved by providing better and more accessible information. However, partly the uncertainty may be fundamental, because the stakeholders are facing limitations in their capacity to evaluate all information. Furthermore, the choices ahead may involve trade-offs that are very hard to monetise if at all, whereas the stake-holders may even change opinion several times. Obviously, this is does not mean that a cost-benefit assessment loses its significance, as stakeholders still want to know what are the economic consequences of stressing as such non-monetised features.

Precipitation variability and droughts

Calculation exercises to test the economic implications of higher volatility of the filling rates of electric power hydro reservoirs show that, even though the basic effect of the changes in average weather conditions seems to be a modest lowering in the price, the increase in price swings due to increased volatility of weather conditions are easily 3 to 5 times larger than the generic effect of a slightly lower price. Even though these price swings are of a temporary nature, the return to the reference level may take considerable time and thereby the transfer of wealth between producers and users can rise to considerable levels. In this respect it should also be realised that over a time span of several decades a few periods with overrepresentation of dry or wet years should be accounted for. All in all it means that risks of investments in generation capacity are somewhat rising as a result of the climate change induced enlargement of the hydro volatility. Possibly, over time adapted water system management regimes may alleviate that effect.

Analysis of simulations by seven regional climate models, all downscaling the same global climate model simulation for the end of the 21st century showed that projected changes in the length of meteorological droughts vary in sign from model to model in Finland in summer. Lapland was the only region for which consistent increases in the length of dry periods were projected, while elsewhere in Finland the models disagreed on the sign of the change. In winter the longest periods without precipitation were projected to become shorter in most of Finland. On the other hand, heavy precipitation events are expected to increase in intensity in all seasons. It should be noted that these climate scenarios were applied as mean changes; possible changes in inter-annual variability were not investigated and scenarios based on downscaling of a wider range of global models also remain to be examined.

The Wells' self-calibrating Palmer Drought Severity Index (SC-PDSI) was used to review the occurrence of severe drought in Finland. Several summers in the 1940s stood out as extremely dry. Analysis of three global climate model simulations for the end of the 21st century showed that changes in the frequency of droughts are spatially variable in Finland. Northern Lapland was the only region for which consistent increases in the frequency of summer drought and decreases in the frequency of wet summers were projected, while large parts of central Finland experienced a shift to more frequent wet conditions at the end of the 21st century. It should be noted that these few climate scenarios were applied as mean changes; possible changes in inter-annual variability and seasonality were not investigated and scenarios based on a wider range of global climate models as well as higher resolution regional models also remain to be examined. Besides, SC-PDSI exhibits several obvious limitations, not the least with respect to application to the Nordic climate.

The preliminary estimates of summer PDSI reported here have also been compared to estimates of the operational Finnish Forest Fire Index during the period 1961–1997. Years of high forest fire risk tend to coincide with the drier years defined by the PDSI. Furthermore, a cursory examination of actual forest fire statistics indicates that the summer PDSI values correlate reasonably well to the number of 20th century forest fires in Finland. Future work could expand on this preliminary exercise with SC-PDSI and establish the relationship between SC-PDSI and impacts of drought in Finland, possibly in combination with other drought-related indices.

Tiivistelmä

Johdanto

Tämän tutkimuksen aloite lähti yhdestä FINADAPT-tutkimuksen[3] johtopäätöksestä, jonka mukaan ilmastonmuutoksen taloudellisten vaikutusten asianmukainen arviointi edellyttää lisähuomion kiinnittämistä äärimmäisiin ilmiöihin, joita ilmastonmuutos saattaa voimistaa. Suomessa tulvat ja kuivuus ovat merkittävimmät äärimmäisistä ilmastotapahtumista johtuvat, haittaa aiheuttavat prosessit. TOLERATE[4]-tutkimuksessa keskityttiin sen vuoksi lähinnä näiden tapahtumien aiheuttamaan haittaan, erityisesti tulviin. Lisäksi tutkimuksessa kiinnitettiin jonkin verran huomiota sateen pitkäaikaisen puuttumisen aiheuttamiin vaikutuksiin.

Tutkimuskohteeksi valittiin kaksi tulville altista aluetta, Porin ja Salon kaupungit. Näiden alueiden nykyisiä ja tulevia tulvien todennäköisyyksiä arvioitiin ottaen huomion ilmastonmuutoksen vaikutukset sateisuuteen. Tutkimus kattaa aikavälin 2005–2050. Eritasoisten tulvien aiheuttamia välittömiä ja välillisiä vahinkoja arvioitiin linkittämällä tulvia koskevat paikkatietojärjestelmään (GIS) pohjautuvat tiedot tulville alttiiden alueiden kiinteistöjä ja taloudellista toimintaa koskeviin vastaaviin tietoihin. Myös kauden 2005–2050 demografista ja taloudellista kehitystä tarkasteltiin. Näin ilmastonmuutoksen vaikutus tulvariskiin pystyttiin erottamaan sosioekonomisten tekijöiden vaikutuksesta. Lisäksi arvioitiin välittömien vahinkojen ja ensimmäisen asteen välillisten vahinkojen leviämistä koko alueellisessa taloudessa. Lopuksi tarkasteltiin erilaisten tulvasuojelutoimenpiteiden sosioekonomisia kustannus–hyötyprofiileja monikriteerianalyysina ryhmäpäätöksenteon kannalta. Tässä pyrittiin ottamaan huomioon sidosryhmien osallistuminen ilmastonmuutokseen sopeutumista koskevaan paikalliseen päätöksentekoon. Tulvariskien kattavan analysoinnin lisäksi raportissa käsitellään lyhyesti kuivuutta ja sadannan suuremman vaihtelevuuden vaikutuksia sähkön tukkuhintoihin Pohjoismaissa.

Taloustieteen uusi tutkimusalue

Merkittävien vaarojen taloudellisten vaikutusten arviointi on vielä kehityksensä alkuvaiheessa sekä teoreettisen tutkimuksen että sovelletun kustannus-hyötyanalyysin mallintamisen osalta. Tietyntyyppisten ja tiettyihin vakavuusluokkiin kuuluvien tapahtumien välittömät kustannukset rakennetulle ja rakentamattomalle ympäristölle pystytään arvioimaan melko hyvin, jos alkuperäisten vaikutusten (tulva, myrsky jne.) sijainti pystytään määrittämään riittävän tarkasti.

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[3] Katso http://www.ymparisto.fi/default.asp?contentid=227544&lan=FI&clan=fi

[4] TOLERATE on lyhenne sanoista TOwards LEvels of Required Adaptation To cope with Extreme weather events (suom. Kohti äärimmäisten olosuhteiden edellyttämää sopeuttamisastetta).

Täsmälliset GIS-tietokannat ja -sovellukset, joissa pystytään yhdistelemään luonnonolosuhteita (korkeus, maaperätyyppi jne.) koskevia tietoja yhteiskunnallisten tietojen kanssa (rakennuskanta, taloudellinen toiminta, saavutettavuus jne.), ovat erittäin hyödyllisiä, kun halutaan tunnistaa haavoittuvuuksia ja arvioida välittömiä kustannuksia. Muutaman tällaisen arvioinnin jälkeen pystytään todennäköisesti käyttämään riittävän edustavia yksikkökustannusarvoja (esimerkiksi hehtaaria kohden maan käyttötyypin ja/tai rakennustiheyden mukaan). Näin saataisiin luotua hyvä perusta toistettavissa olevien ja luotettavien kustannus-hyötyarvioiden luomiselle kohtuullisin kustannuksin. Kattavassa kustannus-hyötyanalyysissa tulisi kuitenkin arvioida myös seurannaisvaikutuksia, joita alueelliselle taloudelle syntyy pidemmällä aikavälillä (vähintään noin 10 vuotta). Tältä osin on syytä huomata, että viimeisten kahden vuosikymmenen aikana tapahtuneesta kehityksestä huolimatta vaarojen seurannaisvaikutusten mallintaminen on edelleen melko alkuvaiheessa. Vaihtoehtoisten, alistumista ja/tai vaarojen seurauksia vähentävien ratkaisujen nettohyötyjen arviointia vaikeuttavat myös epävarmuudesta, eri diskonttaustavoista ja (alunperin) ei-rahamääräisten vaikutusten mukaan ottamisesta aiheutuvat ongelmat.

Meteorologisen ja hydrologisen simulaation tulokset

Vuorokauden ja kuukauden sademäärien ääriarvoja arvioitiin havaintojen nojalla 10, 20, 50, 100 ja 500 vuoden toistuvuusajoilla. Yhteensä 19 maailmanlaajuisen ilmastomallin tulosten keskiarvon perusteella keskimääräinen lämpeneminen Suomessa ajanjaksoon 2020–2049 mennessä on noin 2±1 °C ajanjaksoon 1971–2000 verrattuna käytännössä päästöskenaariosta riippumatta. Vastaava vuotuisen sadannan muutos on noin 7±5 %. Sadannan kasvun odotetaan olevan suurempi talvikuukausina (noin +9 % nykyiseen ilmastoon verrattuna; 90 %:n todennäköisyydellä välillä +2 %...+16 %), ja myös keskilämpötilan muutos on suurin talvikuukausina (+2,9 astetta nykyiseen ilmastoon verrattuna, 90 %:n todennäköisyydellä +1,6...+4,2 astetta). Lämpenemisen myötä entistä suurempi osa talviajan sadannasta tulee vetenä tai ainakin sulaa pian maahan satamisen jälkeen. Toisaalta kesällä rankkasateet voimistuvat enemmän kuin mitä koko vuodenajan sadesumma kasvaa.

Hydrologisella mallilla tehtyjen simulointien mukaan tulvat lisääntyvät Porissa, mutta vähenevät Salossa. Merenpinnan nousu kasvattaa tulvariskiä molemmissa tapauksissa. Hydrologisen simulaation perusteella keskimäärin kerran 100 vuodessa toistuvan tulvan virtaama kasvaa Porissa 0–15 prosentilla 2020–49 mennessä, jos säännöstelyä muutetaan voimakkaasti. Tulva voi myös kestää hieman pidempään, 250 vuoden toistuvuusajan tulvalle ehkä päivän tai kaksi kauemmin. Saloa koskevista simulaatioista käy ilmi, että tulvat vähenisivät jaksolla 2020–2049 huomattavasti eli -15 %...-30 % 100 vuoden tapahtumaa kohden.

Tulvakartat ja vahinkoarviot perustuvat tulvien kartoitukseen, joka tuotetaan hydraulisten mallien, tässä tapauksessa yksiulotteisen (1-D) mallin avulla. Yksiulotteisen mallinnuksen rajoitukset on syytä pitää mielessä tuloksia tarkasteltaessa; jokaista poikkileikkausta kohden on laskettu vain yksi vedenpinnan taso. Tämä aiheuttaa ongelmia Porin kaltaisissa tapauksissa, joissa laajoja matalalla olevia alueita suojataan pengerten avulla. Pengerretyille alueille tulvineen veden pinnan oletetaan olevan samalla tasolla kuin pääjokikanavan vedenpinta. Todellisuudessa näin ei kuitenkaan ole, koska tulvaveden virtausreitit ja alajuoksun rajaehdot voivat olla erilaiset. Pengerten murtumisen realistiseen mallintamiseen tarvittaisiinkin kaksiulotteista mallinnusta. Yleispätevän ratkaisun etsimiseen tarvittaisiin useita tapaustutkimuksia, koska murtumat aiheuttavat eri paikoissa erilaisia vaikutuksia. Pengerten haavoittuvaisimpien kohtien tunnistamiseen tarvittaisiin geoteknistä analyysia.

Odotettavissa olevat välittömät kustannukset

Porin kaupunki erottuu Suomen muista tulva-alttiista alueista, koska mahdolliset sosioekonomiset vahingot ovat suurimmat juuri siellä. Tässä tutkimuksessa tehtyjen simulaatioiden perusteella joen tulviminen Porissa seuraavien parin vuosikymmenen aikana voisi aiheuttaa hyvinkin 40–50 miljoonan euron vahingot nykyisellä (2008) suojelun tasolla. Huonoimmassa tapauksessa 50 vuoden toistuvuusajan tulvat voisivat aiheuttaa jopa hieman yli 100 miljoonan euron vahingot. Todennäköisyys, että seuraavien 45 vuoden aikana tapahtuu vähintään kerran tulva, jonka toistuvuusaika on 50 vuotta, on noin 0,64. Toistuvuusajaltaan 250 vuoden tulvan todennäköisyys seuraavien 45 vuoden kuluessa on noin 0,18, ja sen odotetaan aiheuttavan erittäin merkittäviä vahinkoja, joiden kokonaismäärä voi olla jopa 380 miljoonaa euroa. Nämä kustannukset sisältävät ainoastaan asunnoille ja muille rakennuksille aiheutuvat vahingot ja tulva-alueiden tuotannon keskeytymisestä aiheutuvat kustannukset. Taulukossa S1 on esitetty välittömien kustannusten vaihteluvälit.

Nykyisen ja tulevan ilmaston kustannuksia vertaamalla käy ilmi, että tulvien välittömät kustannukset kasvavat tulevissa ilmasto-olosuhteissa noin 15 %. Taloudellisen kasvun vaikutus on kuitenkin huomattavasti suurempi eli noin 50 % tarkasteltavalla ajanjaksolla (v. 2005 – v. 2050)). Pitkällä aikavälillä voidaan toisaalta myös välttää rakentamista alueille, joilla riski on kaikkein suurin, ja toteuttaa myös olemassa olevien rakennusten suojelutoimenpiteitä etenkin tulva-alttiiden alueiden matalimmissa osissa.

Taulukko S1 Aineellisista vahingoista aiheutuvat välittömät kustannukset ja tuotannonkeskeytysten ja tilapäisasuntojen ensimmäisen asteen kustannukset R50- ja R250-tulville kaikilla kolmella tulva-alttiilla alueella (kustannukset pyöristetty miljoonan euron tarkkuuteen)

	Välittömät kustannukset – aineelliset vahingot (rakennukset, irtaimisto, laitteet) ja siivouskustannukset (miljoonaa euroa)			
	Nykyinen ilmasto		Tuleva ilmasto	
	R=50	R=250	R=50	R=250
Omakotitalot	81	169	91	194
Osakehuoneistot	13	53	16	67
Liikkeet ja toimistot	5	30	7	38
Muut rakennukset	7	41	9	50
Apurakennukset	1	2	1	2
Välittömät kustannukset YHTEENSÄ	**107**	**294**	**123**	**350**
mistä rakennukset	*98*	*270*	*113*	*323*
	Ensimmäisen asteen välilliset kustannukset – tuotannon keskeytys ja tilapäisasuminen (miljoonaa euroa)			
	Nykyinen ilmasto		Tuleva ilmasto	
	R=50	R=250	R=50	R=250
Kotitaloudet (omakotitalot ja osakehuoneistot)	7	9	13	15
Yritykset	3	5	13	16
Ensimmäisen asteen välilliset kustannukset YHTEENSÄ	**10**	**14**	**25**	**32**

Vaikutukset alueelliseen talouteen

Edellä mainitut välittömät kustannukset johtuvat pääasiassa pääoman menetyksistä, ja niissä on mukana vain hieman tulonmenetystä. Nämä välittömät kokonaiskustannukset eivät näin ollen tulekaan sellaisenaan näkyviin aluetalouden kirjanpidossa. Korjaustyöt aiheuttavat yleensä joidenkin toimialojen kukoistuksen mahdollisesti yli vuoden ajaksi. Tästä johtuen alueen BKT voi aluksi jopa kasvaa, jos korjaustöitä tekevät pääasiassa saman alueen asukkaat. Korjausrakentamisen kysynnän voimakas kasvu korvaa todennäköisesti käynnissä ja alkamassa olevaa rakennustoimintaa. Todellisen siirtymän voimakkuuteen vaikuttavat useat tekijät, kuten äärimmäisen tapahtuman jälkeen käytettävissä oleva työvoima ja saatavana olevat rakennusmateriaalit. Jos iso osa työvoimasta palkataan alueen ulkopuolelta ja palkat samalla nousevat työvoiman niukkuuden vuoksi, seurauksena voi olla merkittävä tulovirta muille alueille. Talouden tila voi heti korjausbuumin jälkeisinä vuosina olla heikompi korjauskustannusten takaisinmaksun ja korkeampien vakuutusmaksujen vuoksi. Näiden tekijöiden yhteisvaikutuksena ostovoima vähenee, mikä vaikuttaa kotitalouksien kulutuksen (vähenemisen) kautta koko (alueen) talouteen. Kiinteistöjen ja muiden pääomahyödykkeiden vakuutusaste vaikuttaa merkittävästi aluetalouden toipumiseen. Suurempi vakuutusaste nopeuttaa toipumista. Myös hyvin toimivat työmarkkinat ja häiriytyneiden tuotemarkkinoiden nopea elvyttäminen ovat tärkeitä tekijöitä, jotka parantavat palautumiskykyä. Ne riippuvat avoimuudesta ja ajantasaisten tietojen tarjoamisesta. Tulosten yhteenveto on taulukossa S2.

Taulukko S2 Eri oletusten vaikutukset kumulatiivisiin kustannuksiin

kumulatiivinen vaikutus (12 vuotta), milj. €		**nyk. ilmasto**	**tuleva ilmasto**	ero oletukseen	
oletus	asteittainen siirtymä	346	380		
	suuri siirtymä	366	404		
	vähäinen siirtymä	228	239		
Vähemmän vakuutuksia	asteittainen siirtymä	368	402	6 %	6 %
vähemmän korvaamista	suuri siirtymä	389	427	6 %	6 %
	vähäinen siirtymä	253	265	11 %	11 %
hidas korjaus	asteittainen siirtymä	326	357	-6 %	-6 %
(ei kapasiteettikorj.)	suuri siirtymä	361	398	-1 %	-1 %
	vähäinen siirtymä	222	233	-3 %	-3 %
suurempi panos-tuotoskerroin	asteittainen siirtymä	377	411	9 %	8 %
	suuri siirtymä	398	436	9 %	8 %
	vähäinen siirtymä	259	271	14 %	13 %

Päätöksenteko

TOLERATE-tutkimuksen valmisteluvaiheessa hypoteesina oli, että tulvariskien arviointia, ilmastonmuutoksen voimistavat vaikutukset sekä mahdolliset tulvasuojatoimenpiteet mukaan lukien, voidaan pitää optimointiongelmana. Kuitenkin jo tuossa vaiheessa todettiin myös, että optimointiongelmaan perustuva lähestymistapa ei tiukasti ottaen olisi toteuttamiskelpoinen, vaan että sitä voidaan käyttää pikemminkin ajatusmallina, joka auttaa systematisoimaan vaihtoehtoisten strategioiden vertailua. Tutkimuksen aikana tehty päätöksentekosimulaatioarvio käy esimerkiksi tästä seikasta. Tietoihin liittyy epävarmuutta, samoin siihen, mitä otaksumia eri eturyhmillä on ongelman suhteen. Näistä jälkimmäiseen liittyvää epävarmuutta pystytään poistamaan jossakin määrin tarjoamalla käyttöön parempia ja helpommin käytettäviä tietoja. Epävarmuus voi kuitenkin olla osittain ominaista, koska sidosryhmien kyky arvioida kaikkia tietoja on rajallinen. Tehtäviin valintoihin voi myös liittyä kompromisseja, joiden rahamääräistä arvoa on vaikea tai mahdotonta määrittää, ja sidosryhmien kanta voi lisäksi muuttua useita kertoja. Tästä ei tietenkään seuraa, ettei kustannus-hyötyanalyysilla olisi merkitystä, sillä sidosryhmät haluavat edellä esitetystä huolimatta tietää, mitä taloudellisia vaikutuksia sinällään ei-rahamääräisten asioiden painottamisella on.

Sadannan vaihtelu ja kuivuus

Vesivoimavarantojen täyttymisnopeuksien suuremman vaihtelevuuden taloudellisia vaikutuksia arvioitiin testausmielessä. Laskelmista kävi ilmi, että vaikka keskimääräisten sääolosuhteiden muutokset näyttäisivätkin laskevan jonkin verran hintoja, sääolosuhteiden vaihtelevuuden kasvun aiheuttama hintavaihtelu voi olla 3–5 kertaa suurempi kuin hieman alhaisemman hinnan yleinen vaikutus. Vaikka nämä hintavaihtelut ovat luonteeltaan tilapäisiä, paluu viitetasolle voi viedä huomattavan pitkään, jolloin tuottajien ja käyttäjien välillä voi tapahtua merkittävää varallisuuden siirtymistä. Tältä osin on myös syytä huomata, että useiden vuosikymmenien ajanjaksolla on odotettavissa muutamia jaksoja, joina vähäsateiset tai runsassateiset vuodet ovat yliedustettuina. Kaiken kaikkiaan ilmastonmuutoksesta johtuva vesivoiman saatavuuden vaihtelevuuden kasvu lisää jonkin verran tuotantokapasiteetin investointiin liittyviä riskejä. Mukautetut vesijärjestelmien hallintamallit voivat mahdollisesti ajan mittaan lieventää tätä vaikutusta.

Tutkittaessa seitsemän alueellisen mallin simulaatiota, jotka saivat reuna-arvotietonsa yhdestä ja samasta maailmanlaajuisesta mallista, kävi ilmi, että kesällä pitkien sateettomien jaksojen muutokset vaihtelivat suuresti mallikokeesta toiseen. Lappi oli ainoa alue, jolle useimmat mallit ennustivat sateettomien jaksojen pitenevän kesällä tämän vuosisadan aikana; muulla mallit ovat erimielisiä muutoksen suunnasta. Talvella sateettomien jaksojen ennustetaan lyhenevän lähes koko maassa. Toisaalta rankkasateet voimistuvat kaikkina vuodenaikoina. On syytä huomata, että tarkasteltavina olivat keskimääräiset muutokset. Mahdollisia vuosien välisen vaihtelun muutoksia ei tutkittu, ei myöskään sellaisia alueellisia mallisimulaatioita, jotka saisivat reuna-arvotietonsa useista maailmanlaajuisista malleista.

Wellsin itsekalibroituvan Palmerin kuivuusindeksin (SC-PDSI) avulla tarkasteltiin vakavan kuivuuden esiintymistä Suomessa. Useat 1940-luvun kesät olivat erittäin kuivia. Tutkittaessa kolmen maailmanlaajuisen mallin 2000-luvun loppua koskevia ilmastoskenaarioita kävi ilmi, että eri kuivuusluokkien esiintymistiheyden muutokset vaihtelevat Suomessa alueellisesti. Pohjois-Lappi oli ainoa alue, jolle ennustettiin kuivuusjaksojen esiintymistiheyden kasvua kesällä ja samalla runsassateisten kesien harvenemista. Muualla Suomessa tapahtui 2000-luvun lopussa siirtymä kohti useammin toistuvia runsassateisia olosuhteita. On syytä huomata, että tarkasteltavana oli vain kolme ilmastomallia ja että SC-PDSI:ssä on useita ilmeisiä rajoituksia, jotka liittyvät muun muassa sen soveltuvuuteen pohjoismaiseen ilmastoon.

Tässä raportoitujen kesäajan PDSI-tietojen alustavia arvioita verrattiin myös Suomen käytössä olevaan metsäpaloindeksiin vuosilta 1961–1997. Vuodet, joina metsäpalon riski oli suuri, olivat yleensä samat kuin PDSI:llä määritetyt. Todellisten metsäpalotilastojen lyhyessä tarkastelussa kävi myös ilmi, että kesien PDSI-arvot korreloivat melko hyvin Suomen 1900-luvun metsäpalojen määrän kanssa. Tulevissa tutkimuksissa tätä alustavaa arviota voitaisiin laajentaa SC-PDSI:llä ja tutkimalla SC-PDSI:n ja Suomen kuivuuden vaikutusten välistä suhdetta mahdollisesti yhdessä muiden kuivuuteen liittyvien indeksien kanssa.

Contents

1 Introduction

1.1 Background and rationale of the study

One of the outcomes of the FINADAPT study[5] was that *gradual* long-term changes in future climate most probably do not significantly affect the Finnish economy at the macro level, apart from possibly more profound changes in foreign trade conditions (Perrels et al, 2005). To this could be added that there also hard to quantify risks that the gradual changes in temperatures and precipitation eventually trigger dramatic changes in ecosystems. Furthermore, the various sector studies of FINADAPT (e.g. Silander et al 2005, Kirkinen et al 2005, Saarelainen 2005) showed that extreme weather conditions are capable of causing substantial damage and of incurring significant costs, at least at a local level. Increase in the occurrence and/or severity of extreme weather events may have a substantial non-linear multiplier effect on the costs incurred (Allianz Group/WWF 2005). Extreme weather events are an integral part of natural climatic variability. However, there is growing concern that future anthropogenic climate change may be associated with increases in the frequency and/or magnitude of such events (IPCC, 2007).

In the light of the above considerations, it becomes evident that estimates of economic impacts based purely on projected average changes in climate conditions could provide a misleading picture for decision making. If these changes in mean climate are accompanied by more frequent and/or more intense extreme weather events, the resilience of local and regional infrastructure and even of the regional economy at large is more seriously put to test[6]. In the case of especially severe individual events, extremes that are clustered in time, or multiple extremes occurring in different places, misjudgement of the resilience and consequential ill-suited risk strategies may lead to disruptions of the regional economy for protracted time periods (e.g. months). Avoidance of such disruptions, or at least a reduction in their severity and likelihood, almost certainly pays off. On the basis of these premises the TOLERATE project was formulated, where TOLERATE stands for 'TOwards LEvels of Required Adaptation To cope with Extreme weather events'.

In Finland the most significant damaging processes resulting from extreme weather events are floods and droughts. The TOLERATE study therefore concentrates on disruptions caused by those events in particular with a primary

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[5] Assessing the adaptive capacity of the Finnish environment and society under a changing climate, see: http://www.ymparisto.fi/default.asp?contentid=227544&lan=FI&clan=en

[6] For a definition of extreme events and economic resilience see section 2.4.

focus on floods. In addition the study pays some attention to the effects of prolonged absence of precipitation.

1.2 Project objectives and overall approach

The notion of a *required level of adaptation to avoid unacceptable disruption* is in essence what the study is aiming at. Given the overall objective of getting a better understanding of required levels of adaptation the study purports to answer the following questions:

a. What is the current likelihood of disruptive extreme weather events that exceed a given threshold level of damage (to be defined in this study), and will the frequency and/or magnitude of such events increase up to 2050 with a changing climate?

b. What are the impacts of weather-induced disruptions of different magnitudes in different sectors, in terms of damage to the capital stock as well as loss of production, when applying so-called event tree analysis?

c. What kind of damage can be experienced by the regional population, in terms of loss of property, loss of employability, as well as loss of social networks and quality of life?

d. To what extent are current trends in economy, technology and institutional organisation aggravating the sensitivity of the studied sectors?

e. What are cost-effective alternatives to lower the risk of disruptions (at various levels) for various sectors, while recognising spill-over effects of measures between sectors?

f. What could be the role of public authorities and the insurance and financial sector regarding the promotion of adequate risk management (land use, market development, schooling & training, etc.)?

According to the original plan emphasis was to be put on questions a., b, e and f, whereas questions c and d would receive some attention. However, over the course of the project it seemed worthwhile to pay also sufficient attention to question c, whereas question e. was treated more cautiously.

The stepwise description of the study in the next section focuses on the assessment of flooding risks, but in the study and also in this report some attention is paid to the impacts of drought.

The project structure and a summary of the proposal are presented in Appendix 1.

1.3 Structure of the report

The questions formulated in §1.2 were operationalised by selecting two flood prone areas, being the cities of Pori and Salo. For these areas current and future flood probabilities are assessed, while accounting for the impacts of climate change on precipitation patterns and volumes. The considered time span is 2005-2050. Subsequently, for various levels of flooding the direct and indirect damage was assessed by linking spatial flood data with spatial data on real estate and economic activity in the flood prone areas. Also the demographic and economic development for the period 2005-2050 was reviewed. In this way the influence of climate change on flood risk could be distinguished from the influence of socio-economic factors. The propagation of the direct damage and of the first order indirect damage cost across the regional economy was assessed as well. Finally, the socio-economic cost-benefit profiles of various flood protection measures were reviewed by means of a multi-criteria analysis approach in the setting of group decision making framework. In this way it was tried to reflect stakeholder involvement in local climate change adaptation policy making. In addition to the elaborate analysis of flood risk cases the report deals briefly with drought and the influence of larger volatility of precipitation on the wholesale electricity prices in Nordic countries.

The next chapter (2) first a general review is given of economic assessments of extreme events. The chapter also explains the logic behind the approach in this study. The simulations for temperature and precipitation in current and future climate are presented in chapter 3. Subsequently, in chapter 4 the hydrological simulations are presented. The output from chapter 3 functions as input for the simulations discussed in chapter 4. The economic assessment of the flood risks in Pori is presented in chapter 5, whereas chapter 6 presents a summary of the evaluation of alternative protection measures. The theme of chapter 6 is discussed in full in a separate report (Molarius et al, 2008). Chapter 7 deals with some other issues related to extreme abundant or scarce precipitation. Overall conclusions are presented in chapter 8. Further details on the study structure, terminology, and certain calculations are provided in various Appendices.

2 Socio-economic implications of extreme events and its analysis

2.1 Types of extreme events and the role of climate change

Many extreme events have their origin in natural phenomena such as extreme rainfall and flooding, severe drought and forest fires, earthquakes, volcanic eruptions, storms, etcetera. In addition there are man made extreme events, either as an accident (such as in traffic or industry) or intently in war situations or through terrorist actions. In the context of climate change the first group is of relevance, since changes in the climate are expected to affect the occurrence probability of several types of extreme events. However, even though the changes in occurrence level or severity of extreme events have natural causes, the extent to which the consequences for mankind are aggravated is heavily influenced by human activity (IPCC, 2007), e.g. how cities are allowed to expand, how river systems are managed, and whether and how incentives for risk handling are developed. On the other hand gradual changes in the climate can affect the occurrence of man made extreme events. For example, an increase in the number of thaw-frost cycles in winter may increase the probability of road traffic accidents. The interaction between natural and manmade factors will also feature in this study, notably chapter 5, but also elsewhere in the report.

Please observe that an extreme event is understood as a phenomenon which is localised in space and time. Therefore, in the context of this report radical – possibly disastrous – biological or ecological changes, such as invading species and illnesses, are not included in the definition of extreme event. Rapid shifts in eco-system equilibria are also an issue in climate change, but the more or less permanent character of the new state of the system requires another analysis than for the peak events studied here. Next to localisation in space and time it is also important to consider that extreme events cannot be predicted exactly, neither in terms of their timing nor in terms of their severity[7]. At best probability distributions are known regarding their occurrence over time in certain regions.

It is fair to say that there is one other important subdivision between the various kinds of extreme events. In principle, storms (hurricanes, etc.), floods and earthquakes do allow for recapturing the space lost or damaged soon after the event. In the case of droughts one of the functionalities of the land (soil quality) has crucially eroded, but may recover over a somewhat longer time span (i.e.

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[7] . Historical evidence and geological and geographical knowledge helps to delimit the risks in space. Furthermore, for several extreme events short term forecasts (i.e. several days to weeks ahead) can be made. This ties in with the development of early warning systems.

5~10 years). On the other hand in the case of volcanic eruptions, notably larger ones, recapture takes easily decades.

Climate change affects precipitation amounts and patterns, as well as temperatures (IPCC, 2007). As a consequence hydrological systems around the world are affected. Similarly soils are affected, either directly through changed climatic conditions or indirectly due to changed hydrology. A third weather phenomenon that is expected to change is storms, both in terms of frequency and of ferocity. All three phenomena are studied in Finland in conjunction with climate change (see chapter 3 of this report; and e.g. Venäläinen et al, 2007a and 2007b; Silander et al, 2004; Ollila et al 2000).

Compared to other European countries Finland is expected not to suffer extremely in economic terms from changed weather conditions on its own territory (Perrels et al, 2005). However, since the sum of the economic effects caused by gradual changes in climate seem to cancel each other out (ignoring induced effects from changes abroad[8]) the effects of extreme effects could be relatively important for Finland. Furthermore, solutions for the amelioration of the consequences of extreme events will often tie in with solutions for other aspects of climate change policy, notably in urban planning, new buildings and renovation.

Up to now the knowledge and information about the occurrence and consequences of floods in Finland is further developed than with respect to droughts and storms. International information suggests that in the long run the amount of damage of floods and droughts could be at the same level (Kundzewicz et al, 2007; Schneider et al, 2007), but this may vary between areas around the globe and also within Finland. As regards costs of floods in Finland the historical *average annual* cost level has been in the order of magnitude of a few million Euros (Vehviläinen et al, 2005). Without intensified policies and management this may go up to 20 to 30 million Euro per year over a couple of decades. For droughts the corresponding estimates are clearly lower (0.5 mln; Silander and Järvinen, 2004), but also much less reliable or incomplete. Neither is their systematic information about possible increased risks of enhanced erosion, as a consequence of consecutively occurring drought and extreme rainfall. For example, in the Swedish national assessment of costs of climate change (SOU 2007–60) is warned for a significant increase in cost risks due to landslides, whereas this issue has so far received limited attention in Finland.

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[8] Generally spoken economic effects of climate change in one country due to (extreme) events in other countries has been not been analysed thoroughly up to now. The IMPLIFIN project in Finland tries to provide basic material on the basis of which such a study may become possible (Carter and Kankaanpää, 2008).

Admittedly, in the past decade Sweden has already experienced more and more severe landslide accidents than Finland.

The annual averaged figures regarding costs are only of limited value, since the resilience of the economy is tested due to the occasional high peak in cost (i.e. at least tenths of millions of Euros) in conjunction with the localised occurrence of these costs. To date these features have received relatively little attention in terms of assessing the eventual economic implications of such regional shocks in costs. The bulk of the economic literature on the economic implications of climate change is based on gradual changes in weather conditions (e.g. Tol, 2002a and 2002b; Fankhauser, 1995). Stern (2007, notably section 5.4) devotes some attention to the significance of extreme events with special reference to the extent that it raises conventional estimates of macro-economic costs of climate change. However, notwithstanding the importance of providing a place to extreme events in the overall long term economic assessment, it is still an approach based on generalised assumptions and aggregated figures. The literature on thorough (regional) economic impact assessment is quite recent, still in a nascent state of development, modest in size and scattered over various journals, partly outside the economic literature proper[9]. This issue will be touched upon in section 2.4.

2.2 Historical experience and evidence of floods in Finland

Flooding of rivers in Finland occurs regularly. In most cases these floods occur in sparsely populated areas and cause only rather little economic damage. Larger floods with significant (local) economic ramifications have been rare. An exceptionally large flood (flooded area 1400 km^2) occurred in 1899, with an estimated cost of 30 million euro (Ollila et al, 2000). In the spring of 1988 there was a somewhat larger flood in Central Finland. Since the year 2000 various floods occurred (Silander et al 2006). In the spring of 2005, 100 people had to be evacuated in the municipality of Kittilä (Lapland). In the same year also Ivalo (Lapland) suffered from spring floods. In smaller river systems, such as the Vantaa river in 2004, also a few summertime floods occurred due to extreme downpour. The order of magnitude of the damages of each of these floods was several million Euro, possibly up to ten million.

Next to river flooding sea level rise in combination with storm surge can cause trouble in various seaside built-up areas. Occasionally harbour areas have been flooded in South and South-west Finland. The harbour area of the city of Turku became flooded in 2002, limiting its use for various days. Along the coastline of the Helsinki metropolitan area there are pockets of residential areas which can

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[9] E.g. economic journals: Economic Systems Research, Ecological Economics; other journals: Environmental Hazards, Journal of Environmental Management, Disaster Prevention and Management – an international journal.

get flooded in case of considerable (+2.5 m.) sea level rise. In January 2005 flooding occurred along several places along the coast, including some key areas in downtown Helsinki near the Southern harbour. The estimated costs amounted to approx. 20 million Euro.

A third type of flooding typically occurs in larger built-up areas, when extreme downpour results in water volumes that cannot anymore be handled by the sewer system. Events of this kind with noticeable amounts of damage occurred in Vaasa in 2003 (Lonka and Raivio, 2003) and in Pori in 2007 (Mikkelsen, 2008). For the latter case a total cost estimate of 20 million euro is given.

Of the two case study areas of this report, the cities of Pori and Salo, Pori has experienced a number of floods, some of them with notable damage (Koskinen 2006). In 1899, the most extreme flooding year in the past two centuries, many areas in the Kokemäki river basin experienced flooding, including Pori. In that time damage to agriculture constituted the main part of the total 'bill'. Also in 1924, 1936, 1951 and 1974/75 various areas in Pori experienced flooding. Especially in 1951 quite some areas suffered flooding. In 1981/82 and 2004/05 the flood threats were high, but eventually actual flooding remained at modest levels.

As regards Pori there exists estimates of the damage from the 2007 summer downpour case (Koskinen, 2006; Mikkelsen, 2008). Furthermore, in Koskinen (2006) an assessment is made of the possible total damage to real estate for various flood categories. When the current dikes would hold, damage levels are expected to remain well under 10 million Euros. If dikes fail costs easily surpass 50 million Euro and according to the 2006 report may surpass 200 million Euro in truly large floods. In the latter case losses due to interruptions in production and dilapidated stocks are estimated at 15 to 20 million Euro. The direct cost estimates are based on GIS-linked matching of flood depths and real estate locations, combined with a building type specific unit cost figure (Euro/m^2). The production cost estimates are based on a confidential questionnaire among companies. For comparison, the market value of the building stock in Pori can be estimated to be in the order of magnitude of 4 to 5 billion Euro. The GDP of Pori can be rated at about 1.5 billion Euro (2005).

The influence of climate change on the above mentioned levels of damages is expected to be notable if no further measures would be taken. However, the extent of the cost increases varies significantly across areas. In the city of Pori the effect of climate change on the likelihood of floods is significant *if no further measures are taken*. Consequently, in combination with the effects of economic growth expected direct cost (i.e. damage to real estate and infrastructure) can increase very substantially (i.e. with hundreds of percents rather than tens of percents). In combination with the possible scale of the floods, this makes Pori the economically most significant place in Finland in terms of flood risks and the enhanced effect of climate change.

The above cited cost estimates of floods in Finland are problematic since they are mixing up different kinds of costs. For example, damage to real estate can amount to impressive cost figures at aggregate levels and nonetheless have limited influence on regional or national economic performance, if production capacity and purchasing power are not so much affected. Both in Finland and abroad cost assessments of floods and other extreme events has been usually confined to direct material damage to real estate and physical infrastructure, sometimes extended to estimates of the value of suspended production in affected companies. More recently there is still small but growing body of literature about the economics of disasters and alternative methods to assess regional and national economic impacts. This will be further discussed in section 2.4.

2.3 A scenario perspective – climate change amidst other effects

Most if not all cost assessments of floods based on simulations of possible floods refer to the *current* built environment and the *current* structure of the economy. This practice entails both over- and underestimation features. On the one hand economic growth usually means that the value per m^2 of real estate is going up (short run effects of business cycles are ignored in this context). Furthermore, even with a constant population the total amount of floor space, both of dwelling and of service sector buildings, tend to go up with growing levels of wealth. As a consequence even with constant flooding probabilities expected values of damage will go up, other things being equal[10].

There are however counter effects possible. The first one is that future town planning takes better account of the flood risks. This could mean that the floor space in flood prone areas is not anymore growing or in the long run it might even result in a reduction of floor space in flood prone areas. Also technological development may result in reduced exposure to actual damage, e.g. due to building specific measures, new materials, etc. Admittedly, accounting for the influence of technical development is not exactly anymore a strict interpretation of a baseline. To a lesser extent the same could be said about changes in urban planning practices. Yet, in both cases it is still assumed that no large investments or other changes in flood protection are realised.

These counter effects are especially relevant in long run assessments, when both economic and demographic development start to have very significant cumulated

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[10] For some areas also changes in the natural environment due to geological and geographical changes need to be included. For example, land uplift has a significant effect for Finland even over the course of half a century.

impacts. If scenarios extent well beyond 25 years even significant parts of the long lasting capital stock have become renewed or replaced, and consequently there is simply an ever increasing manoeuvring space in decision making. In this way risks can be reduced without much explicit policy effort and hence the difference between a baseline and somewhat diverting pathways (e.g. due to learning) are getting blurred.

Apart from the above mentioned factors that affect the share of the population and the capital stock that is exposed to damage, there are also institutional dynamics which can affect the ability of a society to deal adequately with a disaster, both in economic and in social terms. For example, the share of the capital stock in North-America and the European Union which is at least partly insured against damages from extreme weather events is much larger than elsewhere (SwissRe, 2003). Also early warning systems – a mixture between technology and reliable institutions – can make a significant difference in losses. Institutional readiness for dealing with disasters can be associated with a certain level of material wealth of a society. Nevertheless, there is by no means a perfect correlation, since also social and spatial equity, institutional reliability, and community spirit affect the institutional readiness with respect to handling disasters (prevention, relief, reconstruction, etc.)

2.4 Socio-economic assessment of extreme events

2.4.1 A young field of study

As extreme events by their very nature upset economic functions and relations, they constitute a challenge regarding both ex ante and ex post economic assessments of extreme events. The challenges ex ante have to do with the uncertainty of the size and timing of the event of its direct implications as well as with the uncertainty regarding the responsiveness of the economy under extreme conditions. The challenges with ex post assessment have to do with the difficulty to collect data from an area where most stakeholders would not tend to prioritise the collection and provision of the necessary data. Supposedly these challenges have indeed held back the development of economic theories of socio-economic implications of extreme events, including their operationalisation. In fact only in the last ten years starts to emerge in earnest a body of literature on this subject (for overviews see e.g. Okuyama 2007, and Rose 2007)[11].

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[11] It is fair to say that at the same time there is also emerging a broader interest in economic resilience, e.g. in relation to small states (Briguglio et al, 2008) and regional economies (Reggiani et al, 2001; Hill et al, 2008) and regarding robustness of macro economic policy (OECD, 2008).

A few concepts are worthwhile to introduce. First, the term *economic resilience* is often used in connection to recovery from disasters. The concept 'resilience' has its origins in natural science, but in economics is to be understood as the capacity to recover once the shock, i.e. disaster, has taken place, and in such a way that at some point (in the not too distant) future the original economic development path (growth rate) is resumed. In other words a resilient economy succeeds in returning to its original equilibrium pathway within a reasonable time span. Rose (2007) distinguishes this concept further into *static economic resilience* and *dynamic economic resilience*. The former term indicates the economic impacts at the very initial stage, i.e. in the first days or week after a disaster a part of the local production is suspended and a part of the local demand is retracted or relocated. These (re)actions simply emerge due to lack of availability, access, or presence. In a much longer lasting next stage the local economy (and beyond) starts to adapt to the new limits in local production capacity by price adaptations, relocation of production, search for new demand, recruitment of specialist personnel (e.g. in the building sector). If the dynamic resilience of the economy is high, the recovery time (the return to the baseline development path) is rather short and (virtually) complete.

It should be noted that resilience is by most authors explained as ability to recover, and is *not* about withstanding the extreme event. The latter aspect is often referred to as *vulnerability*. Of course proactive measures, such as improved flood protection, are important as well to reduce total expected costs, but they not necessarily improve resilience. The combination of proactive policy and resilience together can be termed *adaptive capacity*. If proactive policies lead to a lower occurrence probability of a disaster but at the same time to a higher share of the economy exposed to a disaster risk, the resilience of the economy, at least the static one, is even reduced. For example, there are many large booming cities around the world where economic growth materialises through business area developments in flood prone – but protected – areas (Nicholls et al 2006). Adequate land use policies and planning constitutes an important cornerstone of enabling proactive behaviour. Similarly, well functioning insurance systems are a very important factor in dynamic resilience. Some redundancy in key infrastructure (power systems, roads) is important for the static resilience.

Last but least it is important to realise that policy efforts aimed to improve adaptive capacity may have lock in effects, might not be helpful in other (combinations of) extreme events, and also generally compete with use of scarce resources for other important public purposes. For example, a flood risk in a certain area could be dealt with by reinforcing dikes and raising the redundancy in key infrastructure. However, if in the future the likelihood is increasing that floods are preceded by droughts, the result might be that the effective protection level has not much increased (if at all), while appreciably more damage to infrastructure is experienced (and hence a possible reduction in static resilience).

2.4.2 Approaches for overall economic impact assessment of disasters

Three basic types of assessment methods have been put forward and to some extent applied, being:

a. input-output models

b. general equilibrium models

c. econometric simulation models

For all these models applies the proviso that *first and foremost* adequate data and the appropriate scale of analysis are to be ensured. As defined in §2.1 extreme events are localised events, which means that often regional economic models are called for or an economic model with multiple geographical layers. Extreme events often hit some sectors much more severe than other ones, which points at the need for sufficient disaggregation by sector. Last but not least, there should be sufficient information about the duration of the exceptional state of the area, with at least some disaggregation by sub-area and sector.

Nowadays in many cases natural science simulation of the unfolding of the extreme event is linked to a GIS application, to which subsequently GIS based layers of economic and social information on real estate, infrastructure and land use can be added. This provides a good basis to fulfil the provisos mentioned above.

Input-output models allow for direct description of limitations in deliveries caused by the extreme event. The induced effects of these limitation to the entire (regional) economy can than be analysed. However, since the technical coefficients in an input-output model are normally fixed. A standard input-output model will tend to overstate the loss in production. On the other hand it may miss out on malfunctioning of sectors due to impaired infrastructure. To overcome this kind of problems adapted input-output models which account for physically impaired markets have been developed (e.g. Steenge and and Bočkarjova, 2007). Also adapted CGE models that account for random loss of capital stock and imperfect information have been developed. Hallegatte has been developing several models explicitly dealing disequilibrium situations, such as demand surge in labour and product markets (e.g. Hallegatte et al, 2008). In this project a mixture of a heuristic (for initial reactions and allocation by sector) and a regional input-output model has been used.

2.5 The approach in the TOLERATE study

The eventual regional socio-economic effects stemming from flooding and drought have their origins in weather phenomena. However, the pathways from causes to effects are complicated, and include for example cross-relations, feedbacks, and – at best partly understood – interactions between physical and man made systems.

Since the ultimate purpose of the TOLERATE study is to provide insights, which are useful for policy preparations for adaptation to climate change, it is important to obtain better understanding to what extent the various interlinked systems respond automatically to climate change and to what extent targeted efforts are needed. Furthermore, as regards automatic responses it is important to know whether these responses are adequate, in the right direction although insufficient, or even enlarging vulnerability instead of decreasing it. Both with respect to auto-responses and with respect to policy induced responses it is also important to check whether problems are transferred to another time period or another sector or area.

The study focuses on the period 2005–2050. Roughly speaking the following sequence of events can be distinguished with respect to socio-economic impacts of inland flooding. The relevance of the various characteristics per step may vary by area and event:

1. *Elevated levels of precipitation:*
    a. Extreme downpours / cloud breaches (very localised and short lived events, impacts depend on surface and groundwater levels, type of area, and drainage capacity);
    b. Prolonged periods of elevated precipitation levels (leading to high water levels in an entire river system) -> step 2.
2. *Hydrological features that mitigate or enhance the probability of flooding:*
    a. The natural buffer capacity in the river system (i.e. lakes, swamps),
    b. The natural speed of the flow,
    c. Effects of canalisation (lowering the retention capacity and/or increasing the flow speed),
    d. Water level regulation protocols,
    e. Sea water level effects in and near the river mouth, and
    f. Man made flooding defences (dykes, designated buffer zones).
3. *Land use changes that affect the cost of flooding events:*

   a. Increases in the fixed capital located in areas prone to flooding (e.g. more real estate, more infrastructure, switch from extensive to intensive farming),
      i. due to new investments, and
      ii. due to price rises of existing capital;
   b. Economic production activities in the considered area (changes in the economic and demographic structure),
   c. Rearrangements in land use (allowed and used functions)
      i. declaration of nature refuge areas,
      ii. reservations for residential and industrial areas,
      iii. presence of hazardous substances (waste, stocks) in flood prone areas, and
      iv. physical interventions due to new infrastructure or landscaping which affect the exposure probabilities for parts of the (originally) prone areas.

4. *Anticipatory and remediation measures:*
   a. Zoning policies in spatial planning, including restrictions where and how to build,
   b. Water flow and water quality monitoring and forecasting systems,
   c. Water level regulation evaluation cycles,
   d. Flooding defences (permanent/make shift),
   e. Overflow buffer areas to prevent flooding in other (downstream) areas with economic values,
   f. Education of target groups,
   g. Introducing price mechanisms (insurance) to incite anticipatory behaviour and improve investment decision making, and
   h. Flood crisis plans (to handle evacuations, temporary reinforcements, public communication, etc.).

Only after analysing all these four layers and their possible changes and interactions over time for a study area, sets of alternative scenarios can be made, which include also the most plausible trade-offs.

Similar layered structured sequences of events can be specified for extreme downpours, coastal flooding and droughts (in Appendix 6 causal flow figures are presented for river floods and droughts respectively). The identification of sequential structures serves two purposes. On the one hand it assists in mapping out the causal relations, whereas the identification also shows for what entities scenarios have to be made (or at least scenario assumptions have to be made as part of a larger scenario). As regards steps 1 and 2 the specification of scenarios of the natural environment (climate, hydrology) are required. For step 2 this includes also some man made elements (hydrological engineering, water level regulation regime). Step 3 requires socio-economic scenarios about location specific economic and demographic developments, including possible sector specific changes in vulnerability for either flooding or droughts. Finally, the relevance of options in step 4 can be influenced by trends in governance approaches (e.g. planned vs. market driven).

It was illustrated in the previous section that there is a need for three types of scenarios, covering the natural environment, socio-economic developments in a spatial context, and the governance context respectively. Each scenario is typically related with one or at most two steps in the event sequence structure, whereas within the chosen time frame (2005-2050) the relations across the scenario types are either very weak (natural environment – other two scenario types[12]) or relatively weak and rather indefinite (localised socio-economic trends – governance approaches[13]).

In the table below the event sequence steps are linked to required types of scenarios and for each scenario a brief description of its elements as well as the responsible consortium partners are indicated. This table provides at the same time an outline for the structure of chapter 3, in which the choices and specifications are discussed. The scenario parts are numbered I.a to IV and discussed below the table. In principle at least one set of scenarios has to be

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[12] For the period up to 2050 it is generally assumed that effects of differences in economic growth and mitigation efforts have very little differential effects on the course of climate change (in the same period), see e.g. Carter et al. 2005.

[13] No doubt that at national or EU level the main characteristics of governance approaches affect the composition and level of economic development, but whether a certain spatial lay-out decades ahead would be essentially different for similar socio-economic developments but different governance approaches is hard to say. For example, governance (or lack thereof) of spatial dynamics varies significantly across EU Member States, and nevertheless spatial structures and their developments exhibit many similarities across the EU, only the intensity and pace of change seem to vary.

specified for each study area, even though the figures may be partly similar or even identical.

Table 2.1 Types of scenario needed by event sequence step

Steps in the event sequence (see §2.1)	**Scenarios for the natural environment**		**Scenarios for location specific economic development**			**Governance approach**
	Climate	Climate and geophysical features	Economy & demography	Land use features	Technology & volatility	
1	I.a					
2	I.b	II.a				II.b (water regulation)
3	I.c		III.a	III.b	III.c	
4						IV

Clarification of the scenario parts:

I.a/b/c

For selected study areas it concerns the production of key climate indicators (e.g. monthly average precipitation and temperatures, as well as those for extremes of various typical return periods) for recent past/current climate (RPCC) and for enhanced (future) climate (FC). In addition for both RPCC and FC for given combinations of average and extreme temperature and precipitation additional indicators are produced (I.c) to facilitate assessment of water use responses of various sectors. This refers in particular to drought.

The FC figures are based on the use of an ensemble of simulations from different models in order to improve the handling of probability distributions of projected weather events.

II.a/b

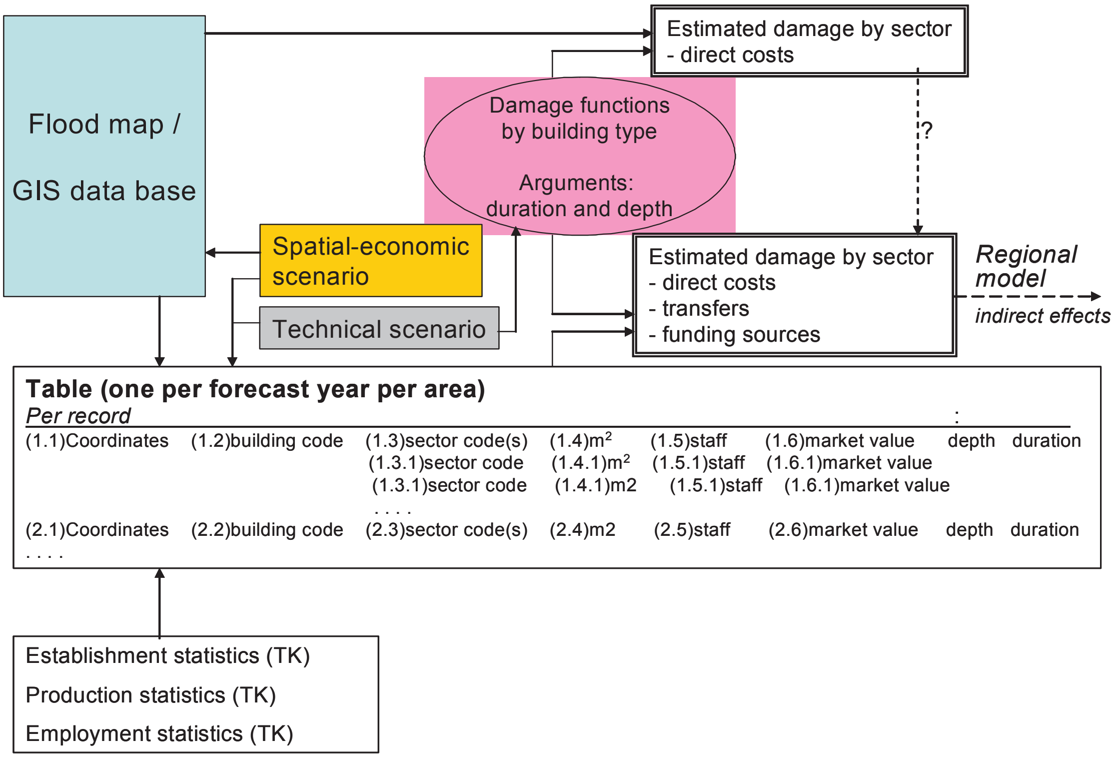
Based on the input from IL water discharge profiles for extreme events with typical return periods are produced for some key locations in selected water systems. Apart from the climate scenarios (I) this requires specification of the physical environment of the selected water systems up to 2050. Even though many natural parts may be assumed constant (or at a constant pace of change) (II.a), the state of hydrological engineering and of the water level regulation regime needs to be specified up to 2050 (II.b). The problem is that a part of the future choices made will be triggered by climate change induced changes in water discharge profiles. Therefore hydrological scenario output consists of versions without changes in engineering and regulation. Hydrological scenarios show whether there are changes in the water balance, and thereby provide an indication for the need for changes in the regulation regime. In case the results indicate that changes in the regulation regime are recommendable, a verbal description of plausible changes can be added. As regards hydraulic scenarios the default case is that dyke levels are not increased in upcoming years and consequently that water is flowing quickly to the city and away from there in case of floods.

Each flood event, based on present climate or hydrological climate change scenario respectively, can be described with several spatial flood maps (each representing a flood with a certain duration).This information can be combined with spatial building stock and land use scenario information. Eventually the output of II.a/b is synthesized in collections of flood maps of selected areas, each accompanied with a linking table of the affected areas in which flooding indicators (duration, depth, etc.) are combined with real estate information (GIS code, real estate value, activity, value added of activity, volatility indicators for flooding, etc.). Figure 2.1 (next page) shows the linkage between steps 2 and 3 in detail.

III.a/b/c

Point of departure is the current statistical characterisations of the study areas (employment and value added by sector, population, dwelling stock, utilitarian building stock, etc.). From national/regional scenarios for economic growth and regional projections on population and dwellings regional scenarios are constructed for the regional/local changes in the number and volume of dwellings and other buildings (III.a). This information is joined with spatial planning maps of the selected areas in order to downscale the regional changes in the building stock to the areas prone to flooding (III.b). For droughts the regional information level (seutukunta / maakunta) will usually suffice regarding economic and geographical changes (III.a/b). Furthermore, for selected sectors (infrastructure, buildings, agriculture) possible significant changes in vulnerability to flooding or drought are checked (III.c).

Figure 2.1 The linkage between scenario parts II and III (and steps 2 and 3) – the example of flooding



Even though scenario part III.a can still depend for a good part on systematic quantitative data and assessments, scenario part III as a whole is to a significant part dependent on reasoned choices rather than entirely quantitative analysis. Furthermore, for scenario parts III and IV rather different scenarios could be drawn up, each of them roughly equally plausible. In order to ensure that the output of the project has sufficient credibility to various decision makers, which are involved in the implementation of adaptations measures, reflection of the scenarios in cooperation with the stakeholders is recommendable.

In regional economic terms in this step is eventually checked to what extent the economic development according to a baseline is disturbed by the occurrence of extreme weather event(s) in the region. This is illustrated in figures 2.2a and 2.2b below.

In figure 2.2a is depicted a hypothetical default regional GDP development (as an index) from 2005 to 2050. This is the baseline which is assumed to be realised in absence of significant shocks. Imagine that an extraordinary flood occurs sometime in the period considered. Such a flood causes direct damage to buildings and other capital stock and causes some degree of temporary and/or lasting fall-out of regional production.

The figures contain two cases. In one case (T_shock2025) the flood does not cause permanent fall-out of production. Furthermore, it is assumed that the current national damage compensation systems are still in place. This means that the region succeeds to get back to its original default growth path. The overall social-economic costs for the region are in this case represented by the area between the default growth path and the T_shock2025 growth path.

In the other case (P_shock2030) the initial downward impact on the economy is as large as in the other example, however in this case the regional economy does not succeed in getting back to its original (default) growth path. A possible reason could be that some of the damaged production capacity is not compensated by new or repaired capacity. In that case the overall social-economic costs for the region are in this case represented by the area between the default growth path and the P_shock2025 growth path. Obviously this area is much larger as it continues over the entire remainder of the period after the extreme event.

In the study the actually projected deviations from the default growth paths are probably somewhere in between the options shown here. The extreme events have a small probability. For the impact of the regional economy we need to know the overall risk of damage of flooding, i.e. the compound value at risk of a range of flood levels (each representing different return times) for current and future climate situations. The differences in expected net costs of extreme events when comparing current and future climate conditions indicates the expected value of the impacts of climate change.

In the last phase (IV) measures are assessed that can reduce the effects of extreme events. The net costs of these measures can be compared with the expected net costs of extreme events. It is possible that some measures are worth carrying out regardless of the extent of enhancement of extreme events due to climate change, i.e. they may even be worth doing in current climate conditions.

Figure 2.2a. Illustrative development of regional GDP according a baseline (default) and two deviations from that baseline due to an external shock (extreme weather event)

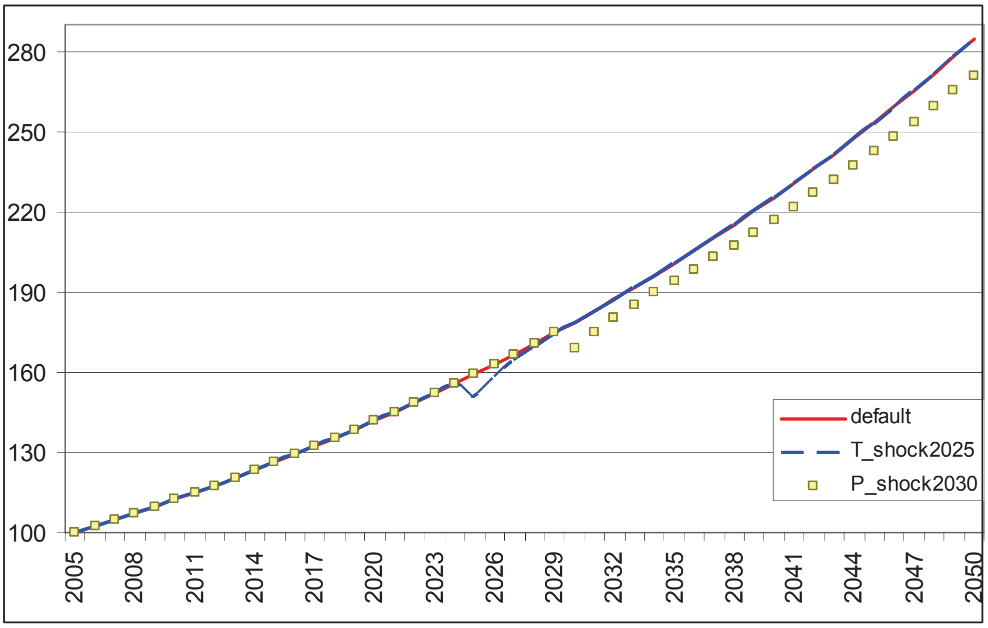
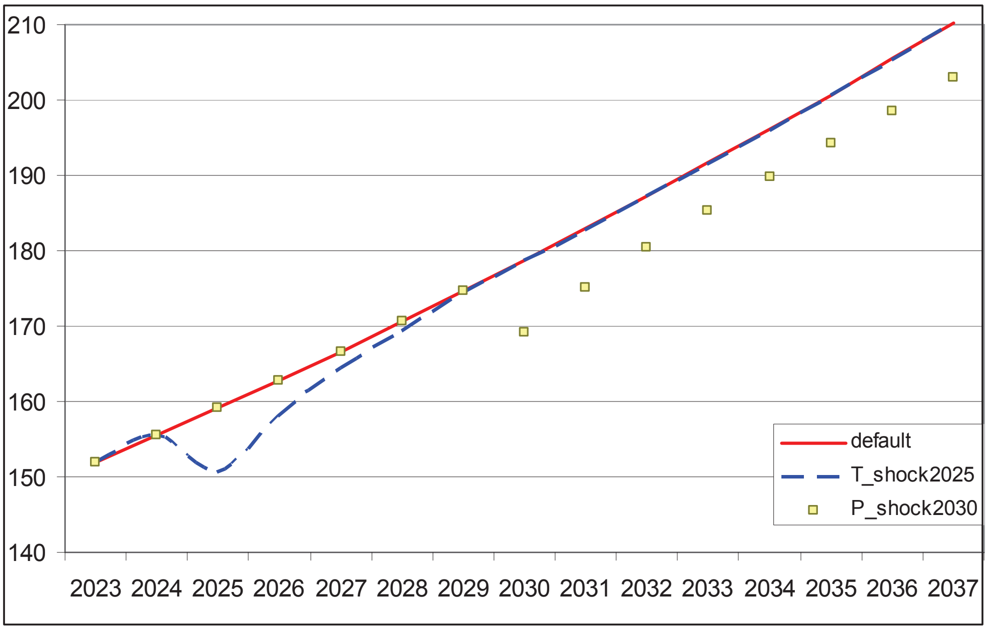


Figure 2.2b. Illustrative development of regional GDP according a baseline (default) and two deviations from that baseline due to an external shock (extreme weather event) – detail of figure 2.2a



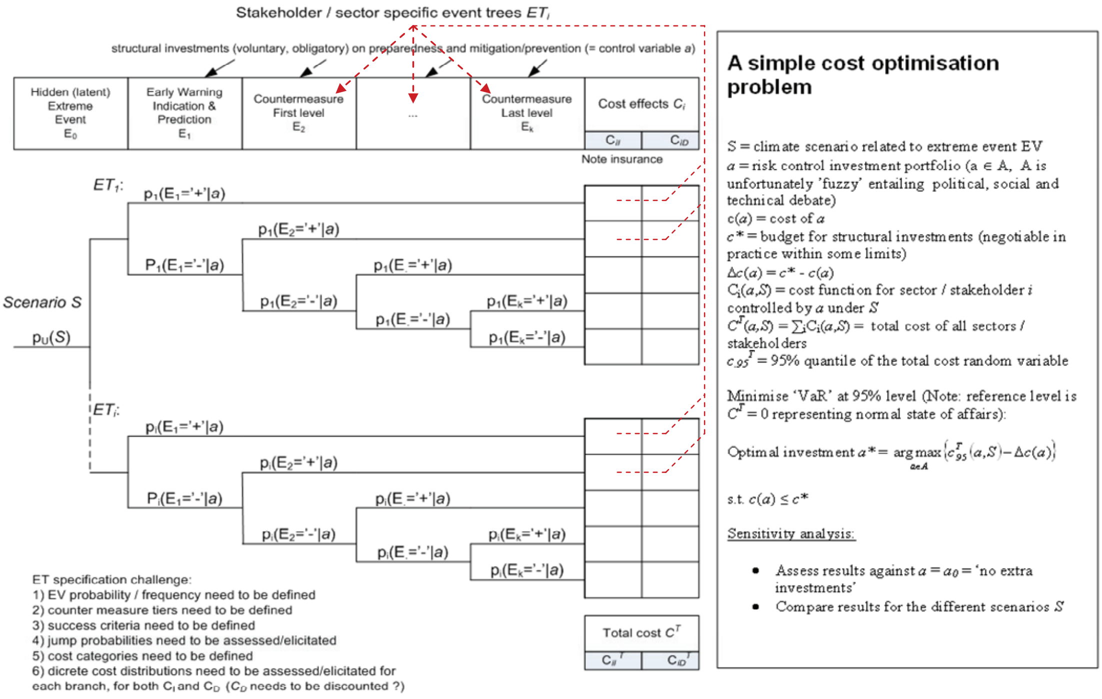
IV

Since the societal feasibility and eventual pay-off of cost reducing measures also depends on the kind of governance regime, which is prevailing at regional and national level, some key features of that regime have to be specified. An example is the extent to which or the conditions under which market based (price signal led) instruments are preferred over more prescriptive instruments, such as often used in spatial planning. The assumed governance context supposedly determines the initial selection of relevant measures to be included in a more or less formal analysis of alternative packages of measures for a certain scenario and projected economic impact (without planned adaptation efforts). The overall in the project can be understood as an *optimal control problem*. However, it should be realised that this functions in the first place *as a metaphor*, providing conceptual guidelines how to design the analysis properly and in a structure which is tractable and replicable.

The evaluation of measures and packages of measures depends on the likelihoods of alternative events and their impacts. Eventually in many of these cases one has to consider as set of trade-offs between alternative packages (and in this case perhaps also between various categories of extreme events).

This summarised below in figure 2.3 on the next page. In which an event tree analysis is linked to trade-off table.

Figure 2.3 *An event tree analysis flow chart for a selected scenario and selected remedial measures and a trade-off table with a hypothetical distribution of impacts by sector and effect type in two regimes (measure packages)*



ET specification challenge:
1) EV probability / frequency need to be defined
2) counter measure tiers need to be defined
3) success criteria need to be defined
4) jump probabilities need to be assessed/elicitated
5) cost categories need to be defined
6) dicrete cost distributions need to be assessed/elicitated for each branch, for both C_I and C_D (C_D needs to be discounted ?)

A simple cost optimisation problem

S = climate scenario related to extreme event EV
a = risk control investment portfolio ($a \in A$, A is unfortunately 'fuzzy' entailing political, social and technical debate)
$c(a)$ = cost of a
c^* = budget for structural investments (negotiable in practice within some limits)
$\Delta c(a) = c^* - c(a)$
$C_i(a,S)$ = cost function for sector / stakeholder i controlled by a under S
$C^T(a,S) = \sum_i C_i(a,S)$ = total cost of all sectors / stakeholders
$c_{.95}^T$ = 95% quantile of the total cost random variable

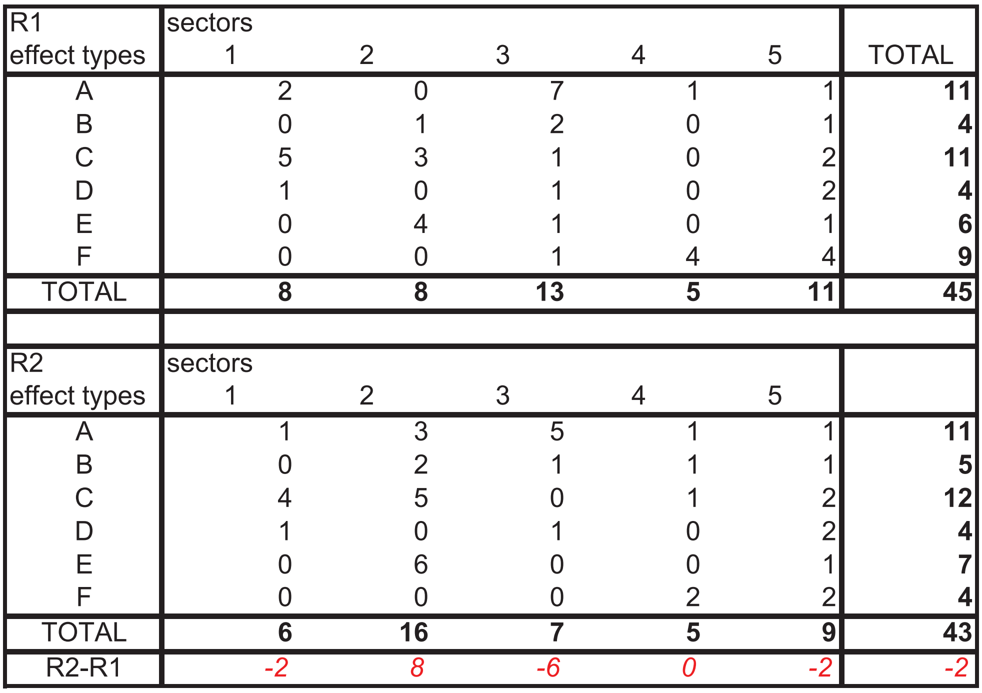
Minimise 'VaR' at 95% level (Note: reference level is $C^T = 0$ representing normal state of affairs):

Optimal investment $a^* = \underset{a \in A}{\arg\max} \{c_{95}^T(a,S) - \Delta c(a)\}$

s.t. $c(a) \le c^*$

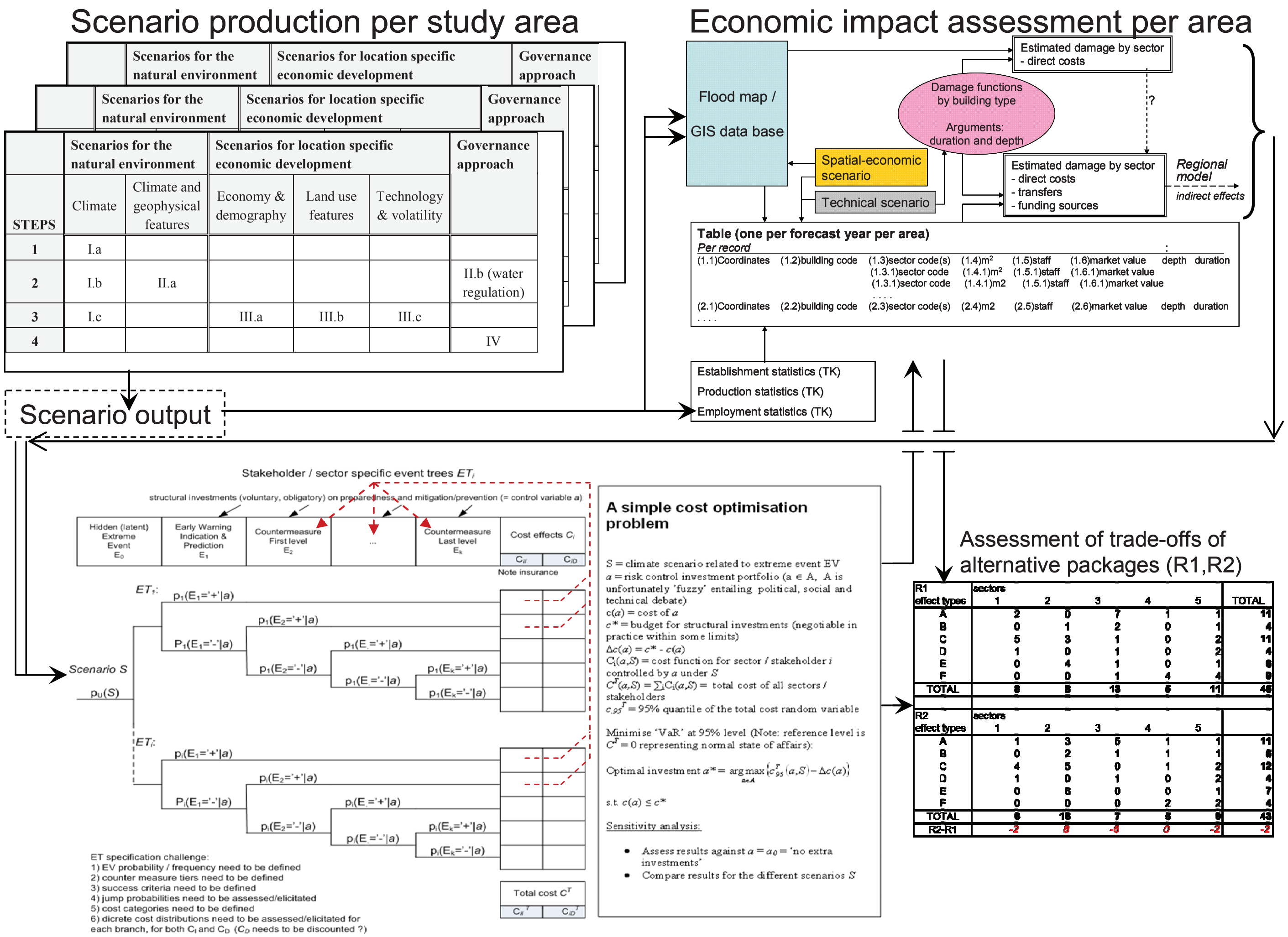
Sensitivity analysis:

- Assess results against $a = a_0$ = 'no extra investments'
- Compare results for the different scenarios S



R1 effect types	sectors 1	2	3	4	5	TOTAL
A	2	0	7	1	1	**11**
B	0	1	2	0	1	**4**
C	5	3	1	0	2	**11**
D	1	0	1	0	2	**4**
E	0	4	1	0	1	**6**
F	0	0	1	4	4	**9**
TOTAL	**8**	**8**	**13**	**5**	**11**	**45**
R2 effect types	sectors 1	2	3	4	5	
A	1	3	5	1	1	**11**
B	0	2	1	1	1	**5**
C	4	5	0	1	2	**12**
D	1	0	1	0	2	**4**
E	0	6	0	0	1	**7**
F	0	0	0	2	2	**4**
TOTAL	**6**	**16**	**7**	**5**	**9**	**43**
R2-R1	*-2*	*8*	*-6*	*0*	*-2*	*-2*

Figure 2.4 A synthesizing overview of the assessment framework



STEPS	Scenarios for the natural environment		Scenarios for location specific economic development			Governance approach
	Climate	Climate and geophysical features	Economy & demography	Land use features	Technology & volatility	
1	I.a					
2	I.b	II.a				II.b (water regulation)
3	I.c		III.a	III.b	III.c	
4						IV

Table (one per forecast year per area)

Per record

(1.1)Coordinates	(1.2)building code	(1.3)sector code(s)	(1.4)m^2	(1.5)staff	(1.6)market value	depth	duration
		(1.3.1)sector code	(1.4.1)m^2	(1.5.1)staff	(1.6.1)market value		
		(1.3.1)sector code	(1.4.1)m2	(1.5.1)staff	(1.6.1)market value		
		. . . .					
(2.1)Coordinates	(2.2)building code	(2.3)sector code(s)	(2.4)m2	(2.5)staff	(2.6)market value	depth	duration
. . . .							

ET specification challenge:
1) EV probability / frequency need to be defined
2) counter measure tiers need to be defined
3) success criteria need to be defined
4) jump probabilities need to be assessed/elicitated
5) cost categories need to be defined
6) dicrete cost distributions need to be assessed/elicitated for each branch, for both C_I and C_D (C_D needs to be discounted ?)

A simple cost optimisation problem

S = climate scenario related to extreme event EV
a = risk control investment portfolio (a ∈ A, A is unfortunately 'fuzzy' entailing political, social and technical debate)
$c(a)$ = cost of a
c^* = budget for structural investments (negotiable in practice within some limits)
$\Delta c(a) = c^* - c(a)$
$C_i(a,S)$ = cost function for sector / stakeholder i controlled by a under S
$C^T(a,S) = \sum_i C_i(a,S)$ = total cost of all sectors / stakeholders
$c_{.95}^T$ = 95% quantile of the total cost random variable

Minimise 'VaR' at 95% level (Note: reference level is $C^T = 0$ representing normal state of affairs):

Optimal investment $a^* = \underset{a \in A}{\arg\max}\{c_{95}^T(a,S) - \Delta c(a)\}$

s.t. $c(a) \le c^*$

Sensitivity analysis:

- Assess results against $a = a_0$ = 'no extra investments'
- Compare results for the different scenarios S

R1 effect types	sectors 1	2	3	4	5	TOTAL
A	2	0	7	1	1	11
B	0	1	2	0	1	4
C	5	3	1	0	2	11
D	1	0	1	0	2	4
E	0	4	1	0	1	6
F	0	0	1	4	4	9
TOTAL	8	8	13	5	11	45

R2 effect types	sectors 1	2	3	4	5	
A	1	3	5	1	1	11
B	0	2	1	1	1	5
C	4	5	0	1	2	12
D	1	0	1	0	2	4
E	0	6	0	0	1	7
F	0	0	0	2	2	4
TOTAL	6	16	7	5	9	43
R2-R1	-2	8	-6	0	-2	-2

3 Climate change and extreme weather events

3.1 General introduction

During the last century, the annual mean surface air temperature increased by 0.8±0.3°C as a European average (Luterbacher at al., 2004) and by 0.74°C (0.56°C to 0.92°C) as a global average (IPCC, 2007). At the same time, widespread precipitation increases over mid- and high-latitude land areas of the Northern Hemisphere during the period 1901–2005 have been observed (Trenberth *et al*., 2007). Increasing trends in heavy precipitation events have generally dominated over the last three to five decades, especially during wintertime. In Finland, however, no significant long-term nationwide trend in the annual mean precipitation during the 20th century has been observed (Tuomenvirta 2004), although annual precipitation amounts measured at drainage level in Finland were generally larger in 1991–2000 than in 1961–1990 (Hyvärinen and Korhonen, 2003). This was due to wintertime increases rather than to summertime changes. Similarly, heavy precipitation events in Finland have increased in magnitude during winter without any clear summertime trends, according to observational studies by Haylock and Goodess (2004), Moberg et al (2006) and Kilpeläinen et al (2008).

As a result of human activities altering the composition of the atmosphere, a global warming of about 0.2°C per decade is projected for the next two decades (IPCC, 2007). These projections of future climate change are based, from a socio-economic and technological point of view, on four narrative storylines of the future world, as defined in the Intergovernmental Panel on Climate Change (IPCC) Special Report on Emissions Scenarios (SRES – Nakićenović and Swart, 2000). For each of the habitable continental regions of the globe, the projected warming over 2000 to 2050 resulting from the SRES emissions scenarios is greater than the global average and exceeds the natural variability and the observed warming over the past century. Continued greenhouse gas emissions at or above current rates would cause further warming and induce many changes in the global hydrological and energy cycles during the 21st century that would very likely be larger than those observed during the 20th century. Best estimates and likely ranges for globally average surface air warming at the end of the 21st century range from 1.8°C (likely range is 1.1°C to 2.9°C) for the low SRES scenario (B1) to 4.0°C (likely range is 2.4°C to 6.4°C) for the high scenario (A1FI).

Increases in the amount of precipitation are very likely at high latitudes. Poleward of 50°, mean precipitation is projected to grow due to the increase in water vapour in the atmosphere and the resulting increase in vapour transport from lower latitudes. Climate models suggest that changes in mean precipitation amount, even where robust, will rise above natural variability more slowly than the temperature signal. A tendency for an increase in heavy daily rainfall events is projected in many regions, including some in which the mean rainfall is predicted to decrease. (IPCC, 2007)

The greatest threat posed by climate change to the society will be manifested locally via changes in regional extreme weather and climate events. In Northern Europe (48–75N, 10W–40E) it was assessed by IPCC (2007) that the probability of an extremely wet season will increase almost tenfold by the period 2080–2099 for winter and twofold for summer; an extreme season was defined as one having a frequency of 5% in 1980–1990 i.e. occurring once in the recent 20-year period. Similarly, the frequency of a correspondingly defined warm season was projected to increase from 5% to about 80–90%, whereas the probability of a dry season was anticipated to decrease in that area (Christensen et al. 2007).

In various sectors of the society, more information is needed about the contemporary and future probability of extreme climate events in order to avoid intolerable damage resulting from extreme weather events, such as prolonged excess or shortfall of precipitation. Especially the knowledge about the frequency of extreme and rare weather and climate events is still to a large extent inadequate. Inherently, rare events are so few and occur so randomly both in observational past and simulated future time series that long-term trends in their frequency and intensity are difficult to be identified.

In the following we will consider the production of key climate indicators related to flood (e.g. monthly average precipitation and temperatures, as well as those for extremes of various return periods) for recent past/current climate (RPCC) and for future climate (FC) for selected study areas within the time period 2020–2049. The RPCC figures are based on observations and the FC figures are constructed using an ensemble of simulations from different climate models. Drought will be considered in Section 7.2.

3.2 Methods and Data

3.2.1 Challenges of observations

As a part of the on-going Finnish Climate Change Adaptation Research Programme ISTO, return levels of various climate variables have been computed based on the measurements made at up to 12 observing stations in different parts of the country (Table 3.1), considering return periods of 10, 20, 50, 100 and 500 years (Venäläinen *et al.* 2007a).Among others, calculations were made for monthly, 14 days, five days, and daily precipitation sums. In addition, six hour precipitation values were examined in Jokioinen and Sodankylä. The return levels were estimated by means of the so-called "peak over threshold" (POT) method (Coles 2001), utilizing the extRemes toolkit software package developed in the National Center of Atmospheric Research (NCAR) (e.g., Gilleland *et al.* 2005; Katz *et al.* 2005). Statistical analysis Detailed description of the return period calculations is given in Venäläinen et al. (2007a). Some of the findings are illustrated by Venäläinen et al. (2007b) and Jylhä et al. (2007), and results for not very uncommon precipitation events, those with a 10-year return period, are discussed more closely by Venäläinen et al. (2009).

In Finland most of the daily data converted into digital form cover three to five decades. Observations of monthly precipitation amounts are available for longer time intervals. In addition to the measurements made at the 12 stations, return levels of monthly precipitation were also assessed using all available monthly precipitation data in Finland, recorded at more than 200 stations. In that analysis all the observations were put together to get an estimate about the recurrence anywhere in Finland, whereas the analysis based on the 12 stations described the probability of occurrence in a certain site.

Thirdly, precipitation data in 1961–2007 on a 10x10 km grid (Venäläinen et al., 2005) were employed to assess return period of area-averaged daily precipitation sums. The area considered, 60.75–62.75N, 22.75–25.25E, approximated the Kokemäki drainage basin.

Table 3.1 The meteorological stations (name and a running number) and the time periods of data for monthly and daily precipitation (in years) in estimates of 20-year return levels

Station name	No.	Monthly precipitation	Daily precipitation
Helsinki	1	1844–2004	1958–2006
Turku	2	1950–2006	1950–2006
Jokioinen	3	1902–2004	1959–2006
Utti	4	1945–2004	1959–2006
Jyväskylä	5	1945–2004	1950–2006
Kauhava	6	1909–2004	1959–2006
Joensuu	7	1933–2004	1947–1999
Oulu	8	1953–2004	1959–2006
Kuusamo	9	1908–2004	1959–1999
Sodankylä	10	1907–2004	1947–2006
Muonio	11	1909–2004	1959–2006
Ivalo	12	1946–2004	1957–2000

Source: Venäläinen et al, 2007a

The relatively short periods of observational time series (Table 3.1) make it difficult to estimate return levels of very extreme phenomena, i.e. those having return periods of several hundreds of years. Further challenges are caused by climate change that tends to make the time series non-stationary. This is a major problem for temperature variables. On the other hand, measurement errors, such as that due to the wind drift on an open measurement site, may have a large influence on recorded precipitation amounts. This is the case especially with snowfall.

3.2.2 Challenges of future model projections

Projections for the future climate are not based on an-extrapolation of observed temporal trends but on modelling of the climate system on the ground of the laws of physics. A global climate model, or a coupled atmosphere-ocean general circulation model (AOGCM), consists of submodels simulating the atmosphere, oceans, soil, snow cover, vegetation etc. Likewise simulated are interactions among these subsystems, including fluxes of heat, moisture and momentum between the surface and the atmosphere. The primary goal of climate modelling is to assess how sensitive the climate system is to external disturbances, such as human-induced changes in atmospheric composition, and what kind of temporal and spatial climate response patterns may be expected. For a given externally-imposed disturbance, or radiative forcing, variations in the climate change patterns from one model simulation to another ensue from differences in model design, and to some extent, from random effects due to internal climate variability. Accordingly, magnitude of the projected changes in heavy precipitation and other climatic variables, and sometimes the sign of the change as well, are subject to a number of uncertainty sources. These include future evolution of atmospheric emissions, natural variations of climate and a multitude of aspects in modelling the climate system and its interactions at different spatial and temporal scales.

The AOGCM experiments simulate the climate response to past and assumed future changes in atmospheric composition. Projections of climate changes are based, from a sosio-economic and technological point of view, on four narrative storylines of the future world, as defined in the Intergovernmental Panel on Climate Change (IPCC) Special Report on Emissions Scenarios (SRES – Nakićenović and Swart, 2000). The storylines, labeled A1, A2, B1 and B2, represent different demographic, social, economic, technological, and environmental developments during the 21st century. These forces drive GHG and aerosol emissions and their evolution. Three alternative developments of energy technologies were represented for A1: fossil intensive (A1FI), predominantly non-fossil (A1T) and balanced across energy sources (A1T). Each storyline was quantified by a number of scenarios, among which six illustrative marker scenarios were selected, one for A1FI, A1T, A1B, A2, B1 and B2, respectively.

Because of the relatively coarse horizontal resolution of GCMs, various regionalisation – or downscaling – techniques have been developed by which results from GCMs are utilized to produce more detailed regional information. The methods include high or variable resolution atmospheric general circulation models (AGCMs), regional climate models (RCMs) and statistical/empirical downscaling (IPCC, 2007). Regionalisation is generally regarded as most useful in studies dealing with areas of complex topography and land-water distribution and in research into future climate extremes. Accordingly, RCMs operating at a resolution of 25–50 km are often used to project changes in the occurrence of heavy precipitation and other extreme or rare meteorological events. However, climate data produced by regionalisation are inherently influenced by the GCM employed. For practical reasons the number of GCMs used to drive a RCM is restricted, typically two or three at most. Consequently, even when utilizing output from several RCMs, there is a risk of not fully covering the uncertainty in the future climate.

3.2.3 The use of model ensembles and downscaling to Finland and Finnish regions

An unprecedented set of coordinated, standard experiments performed by 14 AOGCM modelling groups from 10 countries using 23 global climate models has been collected into the so-called "WCRP CMIP3 multi-model dataset" (Meehl et al. 2007) and utilized to prepare the Fourth Assessment Report (AR4) of the Intergovernmental Panel on Climate Change (IPCC). Climate changes scenarios for Finland within the ISTO program are based on simulations performed with a subset of these experiments, consisting of 19 global models (Table 3.2). The selection of the GCMs was made based on the following criteria:

- Model simulations are available at least for the A1B and B1, or for the A1B and A2 emission scenarios.
- The geographical distribution of continents and oceans is realistic over the European and North-Atlantic region.
- The model performance in describing the current climate in Finland is satisfactory.

Table 3.2. The global climate model experiments considered here, with the model acronym and country of origin. The asterisks indicate three individual models, output of which are utilized for hydrological simulations in Section 4.3.

Model	**Country**
BCCR_BCM2	Norway
CGCM3.1(T47)	Canada
CGCM3.1(T63)	Canada
CNRM-CM3	France
CSIRO-Mk3.5	Japan
GFDL-CM2.0	USA
GFDL-CM2.1	USA
GISS-ER	USA
INM-CM3.0	Russia
IPSL-CM4	France
MIROC3.2(hires)	Japan
MIROC3.2(medres)	Japan
ECHO-G	Germany/Korea
*ECHAM5/MPI-OM	Germany
MRI_CGCM2.3.2	Japan
*NCAR_CCSM3	USA
NCAR_PCM1	USA
*UKMO_HADCM3	UK
UKMO_HADGEM	UK

For model documentations, see Randall et al, 2007

For the SRES A1B, A2 and B1 scenarios, simulations were available in the CMIP3 data archive for most of the models. For the remaining three scenarios (A1FI, A1T and B2), no simulations have been performed. Surrogate data for the non-existing model simulations have been produced by applying a pattern-scaling method (Ruosteenoja et al., 2007). Model projections are presented for the 30-year time span 2020–2049, relative to the baseline period 1971–2000. In addition to the individual model results, best estimates and 90% probability intervals of the changes were constructed for each SRES scenario. The best estimates are simply ensembles or multi-means of the 19 GCMs. The probability intervals were constructed by fitting a normal distribution to the set of projections calculated by the various GCMs and then defined as mean±1.645×standard deviation of the GCM simulations (Ruosteenoja and Jylhä, 2007). Besides maps, an effective method to condense the model-derived information is to represent it as spatial averages. Therefore, most of the results to be presented here are area-weighted spatial means over the grid boxes inside the given region.

In hydrological simulations in Section 4.3, climate projections based on a small subset of individual GCMs was utilized in addition to the multi-model mean projections. The subset consisted of the following three GCMs: MPI_ECHAM5, NCAR_CCSM3 and UKMO_HadCM3.

Regional climate model experiments employed here to provide dynamically downscaled climate change scenarios of heavy precipitation and dry spells are listed in Table 3.3. Most RCMs contained an atmospheric component only, although in two of them a submodel for the Baltic Sea was utilized. The sea surface data and atmospheric lateral boundary values were mainly derived from the global HadAM3H climate model, applying the IPCC-SRES A2 scenario. Some simulations were also conducted for the B2 scenario, and a few RCMs additionally regionalized information from an alternative general circulation model, ECHAM4/OPYC. All the RCMs contributed to the EU project PRUDENCE (Christensen et al., 2007) and/or to the Nordic project Climate and Energy (CE).

Table 3.3 The regional climate model experiments considered here, with the following characteristics defined: the model acronym; country of origin; acronym of the driving GCM (see the footnotes) and the SRES scenarios employed, together with the number of ensemble simulations (in parentheses).

Model	**Country**	**Driving GCM – SRES scenario (# of runs)**
CHRM	Switzerland	H-A2
CLM	Germany	H-A2
HadRM3H	UK	H-A2
HadRM3P	UK	HP-A2(3), HP-B2
HIRHAM (dk)	Denmark	H-A2(3), E’-A2(3), E’-B2
HIRHAM (no)	Norway	H-A2, H-B2
RACMO2[1]	Netherlands	H-A2
RCA3	Sweden	E-A2, E-B2
RCAO	Sweden	H-A2, H-B2, E-A2, E-B2
REMO[2]	Germany	H-A2

[1] Indicates not available for the entire domain.

[2] Denotes not used for summer and autumn. Acronyms in col. 2: H stands for the HadAM3H AGCM, HP for the HadAM3P AGCM, and E and E’ for two parallel runs by the ECHAM4/OPYC3 AOGCM.

Climate scenarios inferred from downscaling of solely two GCMs may comprise only a small subset of possible future evolutions. It is therefore essential to put the projections into the perspective of a wider range of plausible scenarios. For that purpose as well, we utilize the GCM-based climate change scenarios discussed above.

3.3 Results

3.3.1 Recurrence of excess precipitation events based on observations

20-year recurrence levels, i.e. the levels exceeded on average once in two decades, are shown in Fig. 3.1 for monthly, 14-day, 5-day and daily precipitation totals at the twelve Finnish stations. In southern and western Finland (stations no. 1–6), the best estimates and the 95% confidence intervals (in parentheses) for the 20-year return level of monthly precipitation varied between 149 (147–157) mm and 164 (153–182) mm. For daily precipitation amount the 20-year return period varied between 54 (46–63) mm and 67 (54–80) mm in southern and western Finland. The differences between the stations are caused partly by general climatological features, by micrometeorological conditions and by random effects. The return levels at the northern stations were typically somewhat lower than those at the southern stations; the annual mean precipitation in Finland generally decreases from the south to the north as well. The influence of random effects (coincidence) increases when return levels of longer periods are considered, as can be inferred based on Fig. 3.2. The rarer the event, the larger the variation of level estimates among the twelve sites.

According to our estimates based on all available data from more than 200 stations, once in two decades the monthly precipitation somewhere in Finland exceeds about 260 mm. That return level is much higher than the corresponding value for a fixed location. The difference demonstrates the lower likelihood of an extreme event at a certain site compared with the probability that such an event occur somewhere in the country. Expectedly as well, the return level estimates for domain-averaged daily precipitation amounts over an area approximating the Kokemäki drainage basin are lower than those at single stations (Fig. 3.3).

Figure 3.1. The 20-year return level estimates (mm) for monthly, 14-day, 5-day and daily precipitation amounts at 12 measurement stations. The dots give the maximum likelihood estimates and the error bars depict the 90% confidence intervals. See Table 3.1 for the stations.

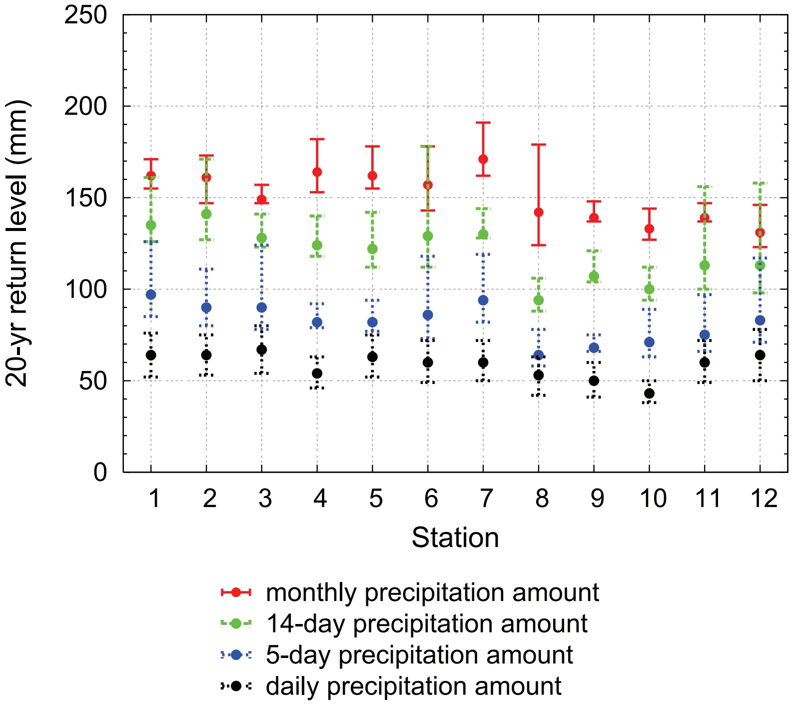


Figure 3.2. *The variation of the maximum likelihood return level estimates among the studied 12 stations versus the return period for daily (left) and monthly (right) precipitation amounts. Shown are (from bottom to top) the minimum, the 1st quartile, the mean, the 3rd quartile, and the maximum (Venäläinen et al. 2007b).*

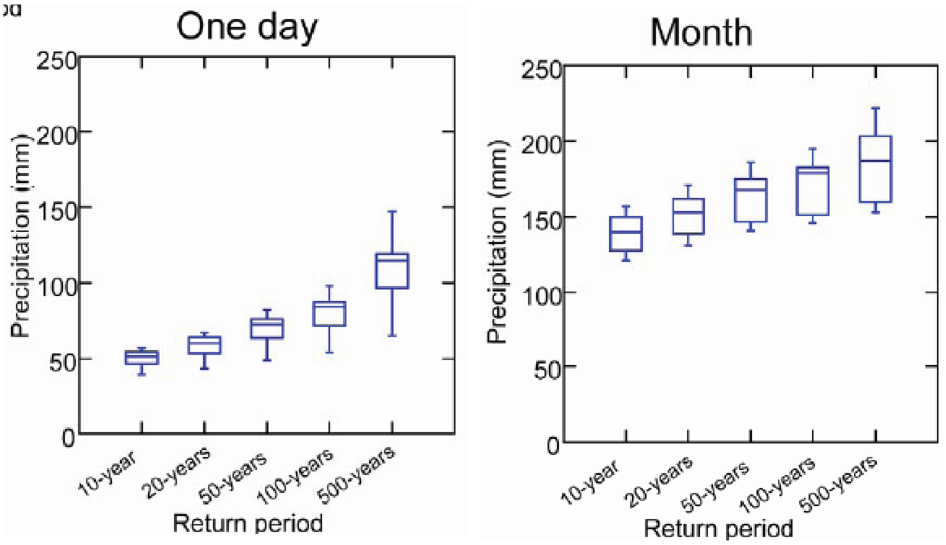


Figure 3.3. *The 20-year return level estimates for domain-averaged daily precipitation amounts over the area of 60.75-62.75N, 22.75-25.25E based on observations in 1961-2007. The solid line gives the maximum likelihood estimates and the dashed lines depict the 90% confidence interval.*

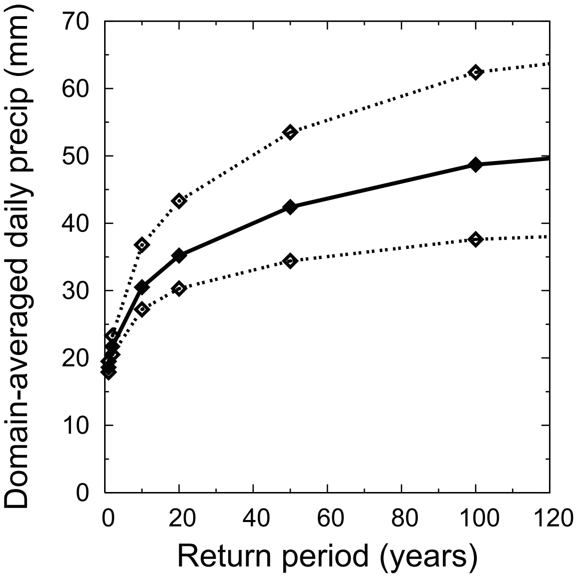
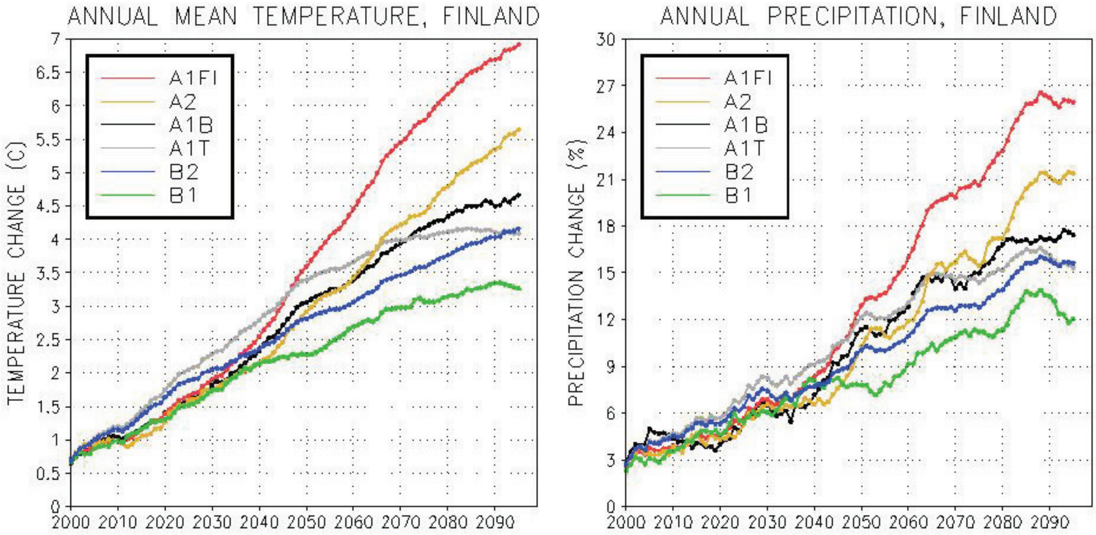


Figure 3.4 Temporal evolution of projected changes of the annual mean temperature (left panel, unit ºC) and precipitation (right panel, unit %) in Finland during the 21st century, relative to the mean of the baseline period 1971–2000. The curves represent 9-year running means of the estimates given by 19 GCMs, separately for six SRES emission scenarios (see legend). (Based on Ruosteenoja and Jylhä, 2007)



3.3.2 Mean climate scenarios

Annual mean temperature and precipitation, averaged over the 19 GCMs, were projected to increase virtually monotonously in Finland during the 21st century (Ruosteenoja and Jylhä, 2007). Up to the year 2040, all the six SRES scenarios studied (A1B, A1FI, A1T, A2, B1 and B2) yield quite similar projections (Fig. 3.4). Only in the second half of the century the projections deviate markedly. These projections only include the uncertainty due to future greenhouse gas emissions. In addition to that, projections given by the various models diverge quite a lot because of differences in model formulation and internal climate variability.

Based on the projections, annual mean warming by the period 2020–2049, compared to the period 1971–2000, is about 2±1°C, almost regardless of the emission scenario (Fig. 3.5). The corresponding annual mean precipitation change is about 7±5%. Both the warming and the precipitation increase are slightly stronger in northern Finland than those in the south (Figs. 3.6–3.7). The projected seasonal mean precipitation responses indicated an almost certain increase in winter, but in the other seasons there is a small probability of even a reduction for the period considered. Warming, as well, is projected to be strongest in winter (Figs. 3.5, 3.7–3.8). Compared to the 90% probability intervals arising from natural variability and differences in model formulation, the deviations due to the different emission scenarios is very small (Fig. 3.5).

Figure 3.5. Seasonal and annual mean temperature (in °C, left panel) and precipitation (in %, right panel) responses in Finland to the SRES A1B, B1 and A2 forcing. Means of the responses simulated by the 19 GCMs are denoted by open circles, 90% probability intervals (mean ±1.645 × the standard deviation of the simulations) of the change by vertical bars. All changes are given for the period 2020–2049, relative to the baseline period 1971–2000.

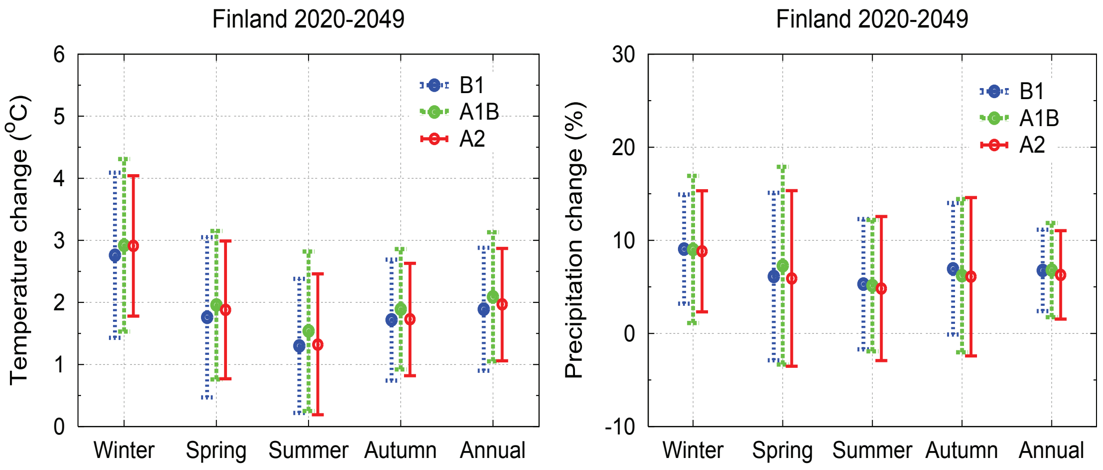


Figure 3.6. Spatial distribution of projected changes in annual mean temperature (left panel, unit ºC) and precipitation (right panel, unit %) for the A1B scenario, computed as the multi-model mean difference between 2020-2049 and 1971-2000.

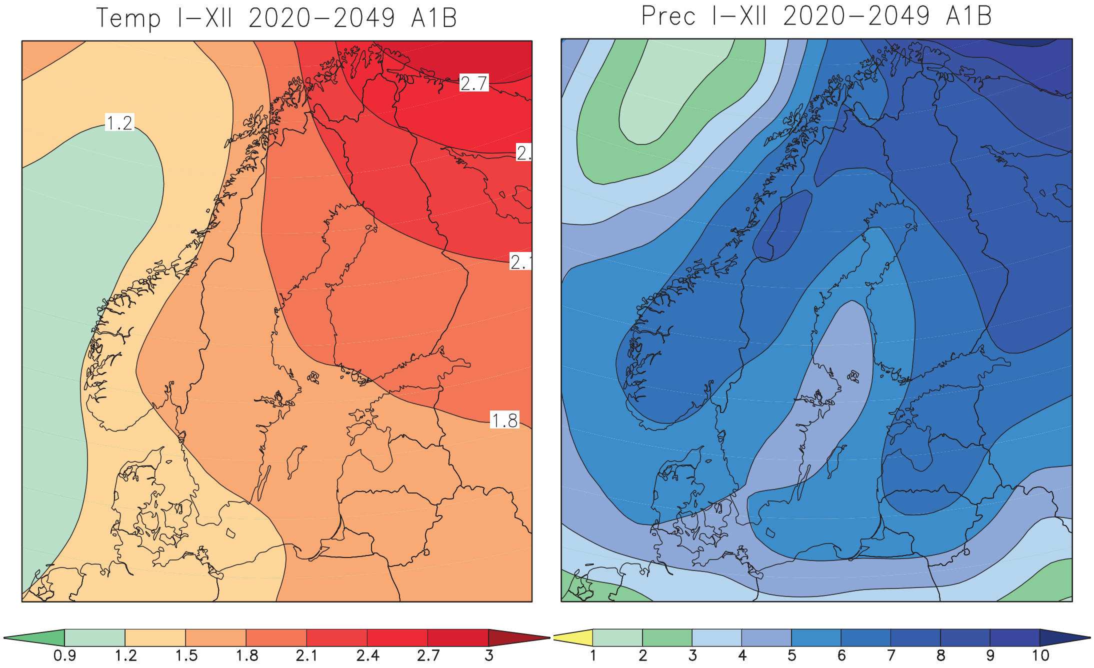


Figure 3.7. Same as Fig. 3.7, but separately for southern and northern Finland and the whole country under the A1B scenario.

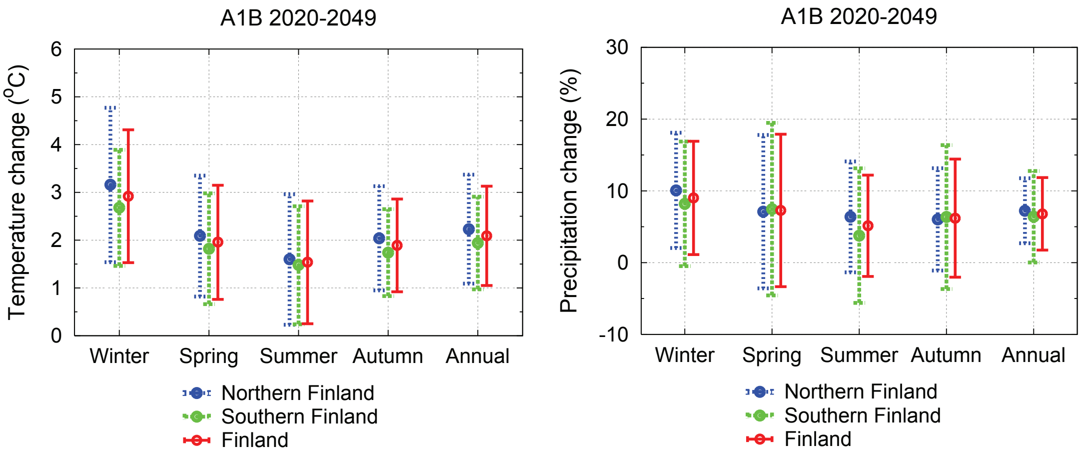
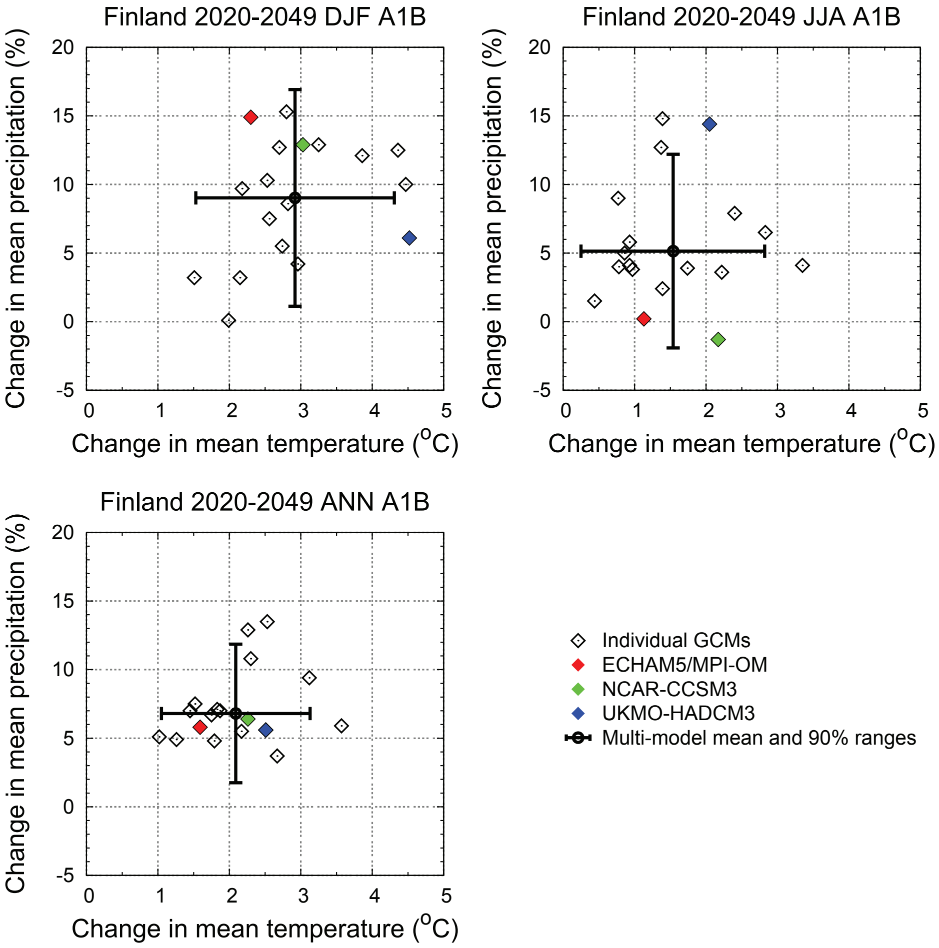


Figure 3.8. *Temperature and precipitation responses to the SRES A1B forcing in Finland. Symbols: individual model results; large black cross: 19-model mean changes together with 90% probability intervals (mean ±1.645 × the standard deviation of the simulations). The subset of three models is shown by coloured symbols. All changes are given for the period 2020-2049, relative to the baseline period 1971-2000.*



3.3.3 Projections of heavy precipitation

A trend towards heavier one-day precipitation amounts was consistent across all regional climate model simulations considered, irrespective of the SRES scenario and the driving GCM (Fig. 3.9). In summer and, according to most model experiments, also in spring and autumn, the 30-year averages of the greatest seasonal one-day precipitation (R1d) tended to increase more (in %) than the mean precipitation (*P*). Several experiments with negligible changes or even decreases in *P* nonetheless yielded increases in R1d. In winter the situation was vice versa: the one-day extremes tended to increase less (in %) than the mean precipitation. There was a close correlation between the projected changes in R1d and *P* in winter and summer but less so in the remaining seasons.

The differences between the A2 and B2 scenarios were rather small compared to the spread among the model results (Fig. 3.9). In general, the RCM-based projections were mainly scattered around the projections given by the driving GCMs. The ECHAM4/OPYC-driven RCM simulations projected larger changes in winter R1d and *P* than the HadAM3H-driven ones. This appears to be related to different responses in the wintertime atmospheric circulation in the two GCMs (e.g., Räisänen et al., 2004). In other seasons the lateral boundary conditions had a smaller effect on the projected changes in R1d.

In addition to the scenarios of seasonal mean precipitation and one-day extremes, constructed using output of the RCMs, Fig. 3.9 also shows the 90% intervals of changes in *P* on the basis of the 19 GCMs discussed previously. A comparison of the GCM-based and RCM-based results indicates that the set of the RCM experiments employed here actually produced a rather wide range of estimates for *P*. Although most of the RCM-based projections of *P* fell inside the GCM-based intervals, there was a tendency towards larger increases in winter, and smaller increases (or even decreases) in summer and autumn, compared to the GCM-derived ranges. In spring the scatter of the RCM-based projections was wider than the GCM-based intervals at both ends.

As a first attempt to approximately put the RCM-based projections of the indices into the context of the 90% probability intervals given by the extensive set of GCMs, Table 3.4 was constructed. It simply shows the ranges across the RCM-H and RCM-E simulations for the A2 scenario, provided that the RCM-based minimum (maximum) change in *P* differed by less than 5% from the GCM-based 5th percentile (95th percentile) and the relationship between *P* and the index was strongly linear. However, if the mean precipitation responses derived from the two sets of model data deviated more notably or if there were for example some outliers among the RCM projections, a new index value roughly corresponding to the percentile was estimated on the basis of the scatter diagram in Fig. 3.9. This estimate is shown in italics in Table 3.4 but only if it deviated more than 5% from the original RCM-based value.

It appeared that the RCM-H and RCM-E simulations together produced a rather wide variety of projections for R1d in Finland under the A2 emission scenario (Table 3.4). The procedure utilizing the GCM-based probability intervals of the *P* response actually suggested a bit narrower range of estimates than the RCM experiments themselves. The wide RCM-based ranges may in part be explained with differences in wintertime atmospheric circulation and summertime Baltic Sea warming in the driven GCMs.

Figure 3.9. *Projected area-averaged changes (%) in the 30-year means of the greatest 1-day precipitation total (R1d) in winter (DJF), spring (MAM), summer (JJA) and autumn (SON) by 2071–2100, relative to the baseline period 1961-1990, as a function of the seasonal mean precipitation changes in Finland. The small solid (open) triangles pointing downward refer to the H/HP-A2 (H/HP-B2) runs, the larger one denoting to the A2 experiments by the driven HadAM3H. The solid (open) triangles pointing upward refer to the E-A2 (E-B2) runs. The horizontal solid (dashed) bars below each scatter diagram indicate the best estimate and the 90% interval of the precipitation change for the A2 (B2) scenario based on 19 GCMs.*

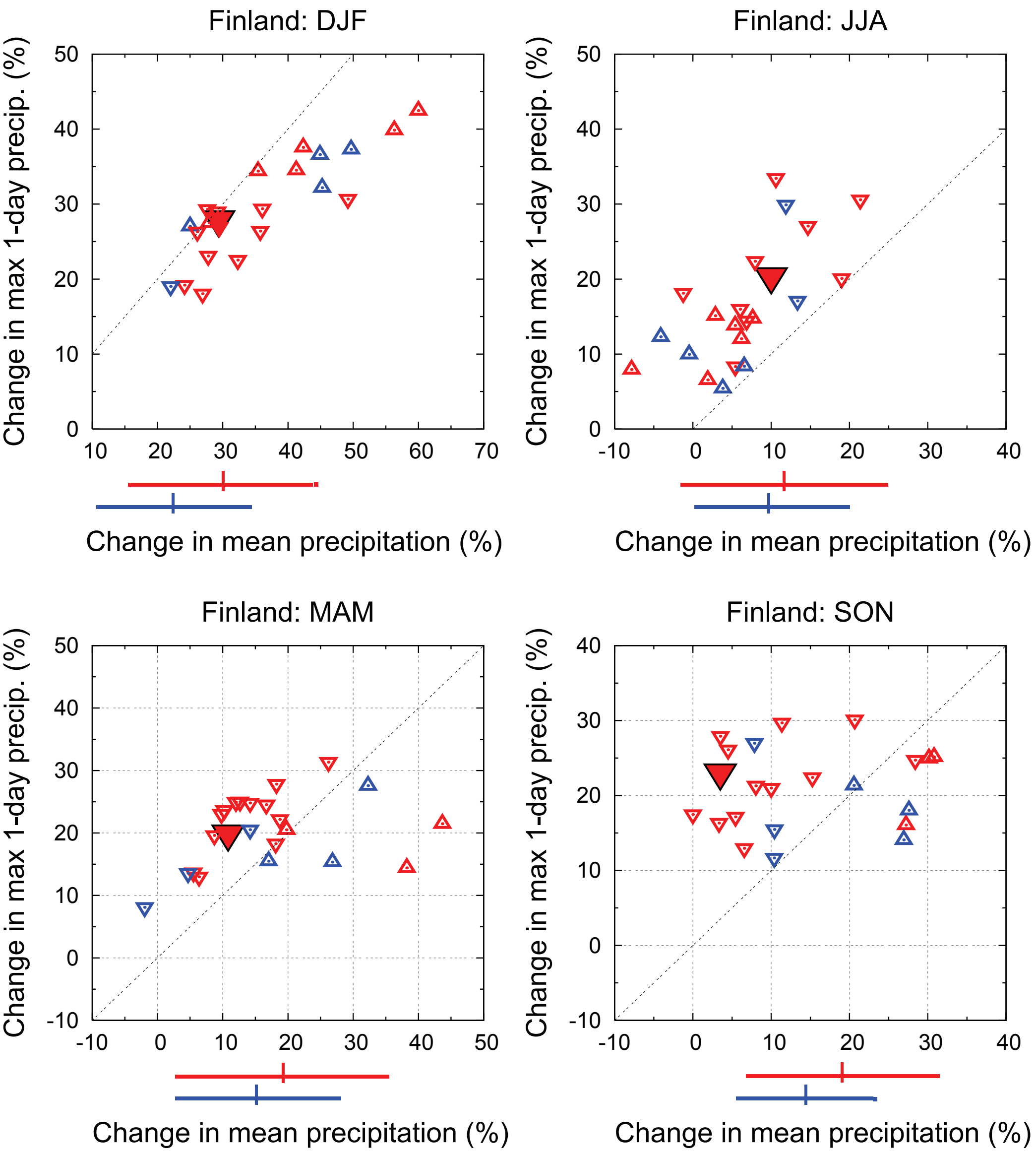


Table 3.4. Estimated area-averaged mean changes in precipitation-related indices in Finland by the time period 2071–2100 under the A2 emission scenario. The indices are the maximum one-day precipitation total (R1d) and maximum number of consecutive dry days (CDD). The values given in the normal font are derived from the RCM-H-A2 and RCM-E-A2 simulations, those in italics are estimates using the GCM-based 90% probability intervals of mean temperature and precipitation responses (shown in the top of the table). The estimates in italics for R1d and CDD are shown only if the RCM-based low and high limits for the indices deviate more than 5% from the simple GCM-based estimates. The index ranges are given with intervals of 5%.

2071–2100	**DJF**	**MAM**	**JJA**	**SON**
P (%)	*16–44*	*3–35*	-1–24	*7–30*
T (°)	*5.1–9.6*	*2.7–7.0*	*0.7–6.0*	*2.6–6.5*
R1d (%)	15–40/*35*	15–30	5–35	10–30
CDD (%)	-30/-20–0	-30–10	-20–20	-5/-10–15

Rough estimates of the changes in heavy precipitation by the period 2020–2049 may be obtained with the aid of linear interpolation in time of the values in Table 3.4 for R1d, that is, by approximately halving them. An alternative is to utilize the finding according to which increases in the one-day extremes are larger (in %) than the mean precipitation in summer and smaller in winter (Fig. 3.9 together with Fig. 3.5). The resulting estimates for the changes in the 30-year seasonal averages of the greatest one-day precipitation amount are of order of 10%. More extreme precipitation events, those occurring more seldom than the "average extremes", were not considered here. Obviously, they are very strongly affected by random effects. However, increases in the "average extremes" add to risks of the more rare precipitation events.

3.4 Conclusions

According to multi-model mean estimates based on 19 global climate models, annual mean warming in Finland by the period 2020–2049, compared to the period 1971–2000, is about 2±1°C, virtually regardless of the emission scenario. The corresponding annual mean precipitation change is about 7±5 %. Both the warming and the precipitation increase are stronger in winter than in summer. The projections of summertime mean precipitation by 2020–2049 are subject to a rather low signal-to-noise ratio.

Changes in heavy precipitation in Finland by the end of the 21st century were analyzed based on experiments performed with a set of regional climate models.

Increases in the maximum one-day precipitation totals were projected in all seasons. Particularly in summer the one-day extremes tended to increase more (in %) than the mean precipitation.

4 Climate change and hydrology

4.1 General introduction

One of the most frequent environmental hazards in Finland is flooding. Nonetheless, floods are less common in Finland than elsewhere in Europe, because rainstorms are usually not as severe as in Central and Southern Europe and differences in elevation are not as large as in some countries. Furthermore, Finland's many lakes and marshes play an important role in storing excess water. Yet, various types and magnitudes of floods do occur in the country. Typically, floods are caused by snowmelt, heavy rainfall, characteristic ice jams seen in northern climates, wave extremes and, very seldom, dam failures.

Floods always cause some amount of damage; between 1974 and 1998 the annual damage from flooding in Finland was over one million Euros. In 1988, a major spring flood alone caused 4–5 million Euros in damage. In 1899, an exceptional flood, with a recurrence interval estimated to be at least 250 years, caused nearly 30 million Euros in damage, as the flood waters covered over 1400 km^2.

In a project called the Extreme Flood project, the regional environment centres estimated flood damage for almost 400 risk areas. According to these estimates, the damage costs from extreme floods (occurring simultaneously) in the whole country would be between 500 and 600 million Euros. Only in the city of Pori river flood damage may be over 200 million Euros. A heavy rainfall event, in August 2007, in the city of Pori caused local flooding. Within three hours it rained in some places more than 100 mm, thereby causing 20 million Euros damage. The Kokemäki river (Kokemäenjoki) in the city of Pori is also sensitive to ice jamming. The Greater Helsinki area is sensitive to coastal flooding. As an example, strong winds in January 2005 raised sea level on the southern coast by around 80 cm in eight hours and water level rose to around 1,5 metres above the average sea level, setting a new record for the period back to 1904 when observations began damage was estimated to be between 15 and 20 million euro.

According to the estimates used, climate change would affect flooding so that (Silander et. al. 2006):

- In southern and central Finland, snowmelt floods will decrease.
- In northern Finland, snowmelt floods will increase.
- In the large central lakes of some river systems, flooding will increase.

- Large precipitation events are projected to increase, and resulting flood events can be expected to increase in the whole country, accordingly, especially in rivers.

- Changes in flood risk in coastal areas during this century will depend on the rate of global sea level rise compared to the rate of concurrent local land uplift, (Pori 5,6 mm/y and Salo 3,6 mm/y relative to sea level, used land uplift model is NKG2005LU "the postglacial land uplift model", where relative sea level rise is 1,32 mm/y).

It has been estimated, that by the year 2100 the 1-in-100 years flood would increase in southern and middle Finland by about 15% and the 1-in-20 years flood by about 10% (Silander et al, 2006). In northern Finland these floods would slightly increase in the near future, but by the end of the century there would be no change in these floods in comparison to recent/current weather conditions. In the long run, snowmelt floods decrease while precipitation induced floods increase.

4.2 The study regions

In flooding in winter time there is a risk for slush ice flooding. If the discharge is large and the river is free of ice, the fast flow speed prevents the ice cover from forming and the water is supercooled. When the supercooled water meets an obstacle such as a rock its flow speed decreases and the water freezes as frazil ice or anchor ice to rock and other bottom material. The slush ice decreases the discharge capacity of the river in which case even a smaller discharge can raise the water level quickly to flood heights and cause significant damages. It is possible that slush floods cause a more significant flood risk than just floods caused by large discharges. The risks for slush floods increases in the future when discharges are often large during winter and ice covers are often missing. The risk for slush flood production is however not evaluated in this study.

The city of Pori. The regulation of the large lakes upstream of River Kokemäenjoki affects the magnitude of floods in Pori. Current regulation practice means that water levels are drawn down during winter and early spring to make room for the floods caused by snow melt in late spring. When the climate warms there is less snow and consequently the spring floods decrease while winter runoff increases. Managing the drawdown of the upstream water system increases discharges during winter in the Kokemäki river and this increases the winter floods, and consequently these can become the largest floods (instead of the spring floods).

In the simulations the lakes were regulated with an operating rule where outflow from lake depends on water level and date. When simulating the reference period the operating rules corresponded on average to present regulation practices. When simulating the climate change situation the operating rules were modified since the present regulation practices do not work well in the changed climate. Two different operating rules were tested. In the slightly modified regulation the current regulations limits were upheld as much as possible, but winter and spring drawdown of water levels was not done quite as deep as before. In the strongly modified regulation the spring draw down is not done at all during winters with large runoffs. In additions the water levels during autumn are lowered slightly to make more storage capacity for winter floods. The strongly modified regulation results in on average smaller floods in Pori than the slightly modified regulation, because the outflows are smaller during winter when most of the worst floods in Pori occur.

The city of Salo. The non-regulated river Uskelanjoki flows through the city of Salo. During winter floods, frazil ice may cause the floods to become much worse than they otherwise would be. Floods can especially spread to industrial areas with high value added manufacturing.

4.3 Hydrological simulations

The hydrological scenarios about the effects of climate change to the floods of Pori and Salo by 2020–2049 were simulated by the Finnish Environment Institutes Watershed Simulation and Forecasting System (WSFS) (Vehviläinen et al. 2005).

The WSFS is a conceptual hydrological model, used for operational flood forecasting and for research purposes. The system is based on watershed model, which is originally the HBV-model and simulates the hydrological cycle using standard meteorological data. The model simulates the whole land area of Finland, including cross-boundary watersheds, total of 390 000 km^2. The inputs of the model are precipitation and temperature and the simulated components of hydrological cycle are snow accumulation and melt, soil moisture, evaporation, ground water, runoff and discharges and water levels of main rivers and lakes. (Vehviläinen et al. 2005)

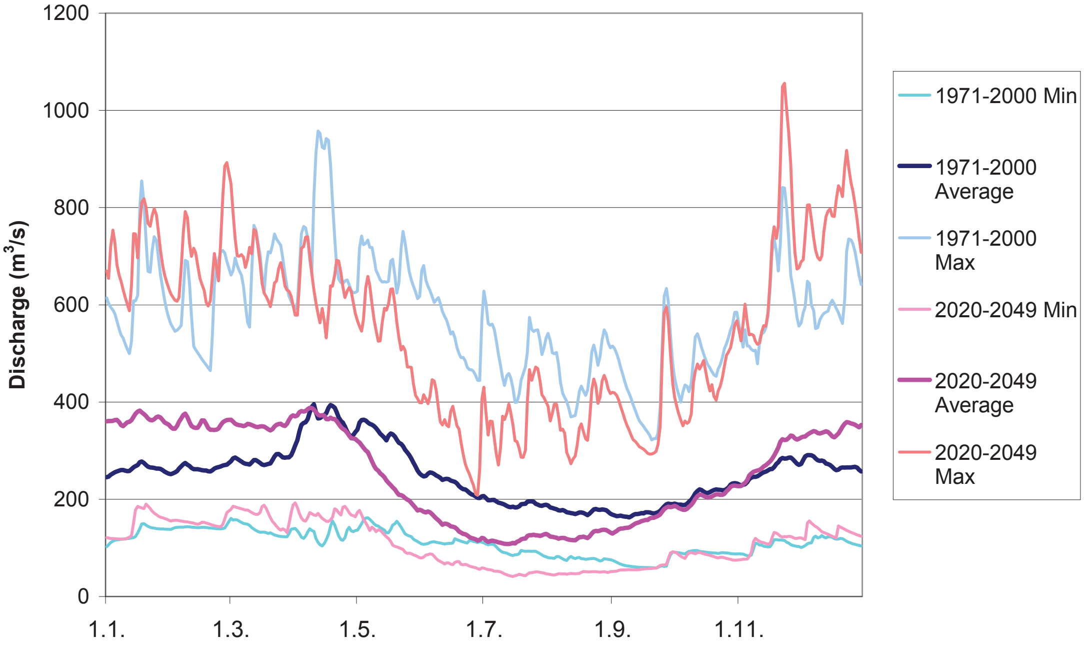
The changes in floods were evaluated by simulating 30 years of daily discharges with the WSFS and yearly maximums were picked from this data. The Gumbel frequency distribution was fitted to the yearly maximums and based on this the flood magnitudes for each return period were estimated. 100 and 250 year flood magnitudes were examined. The same calculations were done first for the reference period 1971–2000 using observed temperatures and precipitations and then for the period 2020–2049 and these results were then compared. Climate change was taken into account in the simulations by changing the observed temperatures and precipitation with delta-change approach according to climate scenarios from global climate models.

The climate scenarios were obtained from the Finnish Meteorological Institute (FMI) (Ruosteenoja 2007). The time period under study was 2020–2049 and the reference period to what the results were compared was 1971–2000. In this study, 12 climate scenarios were used to take into account the uncertainties related to climate change. One so called mean scenario, which was an average of 19 global model with A1B emission scenario calculated by FMI, was selected for the further evaluations. The A1B emission scenario the estimated future emissions of greenhouse gases are quite intermediate compared with the other SRES emission scenarios (IPCC 2007).

4.3.1 Pori

The timing of the floods will change due to climate change (Fig 4.1). In the reference period 1971–2000 most of the largest floods in Pori occurred during spring in March to May, while in 2020–2049 most of the largest floods were during winter or autumn. Spring floods were not among the largest simulated floods in 2020-49 in Pori.

Figure 4.1 Maximum, average and minimum discharges of the simulated 30 year period in 1971–2000 and 2020–2049 in Pori.

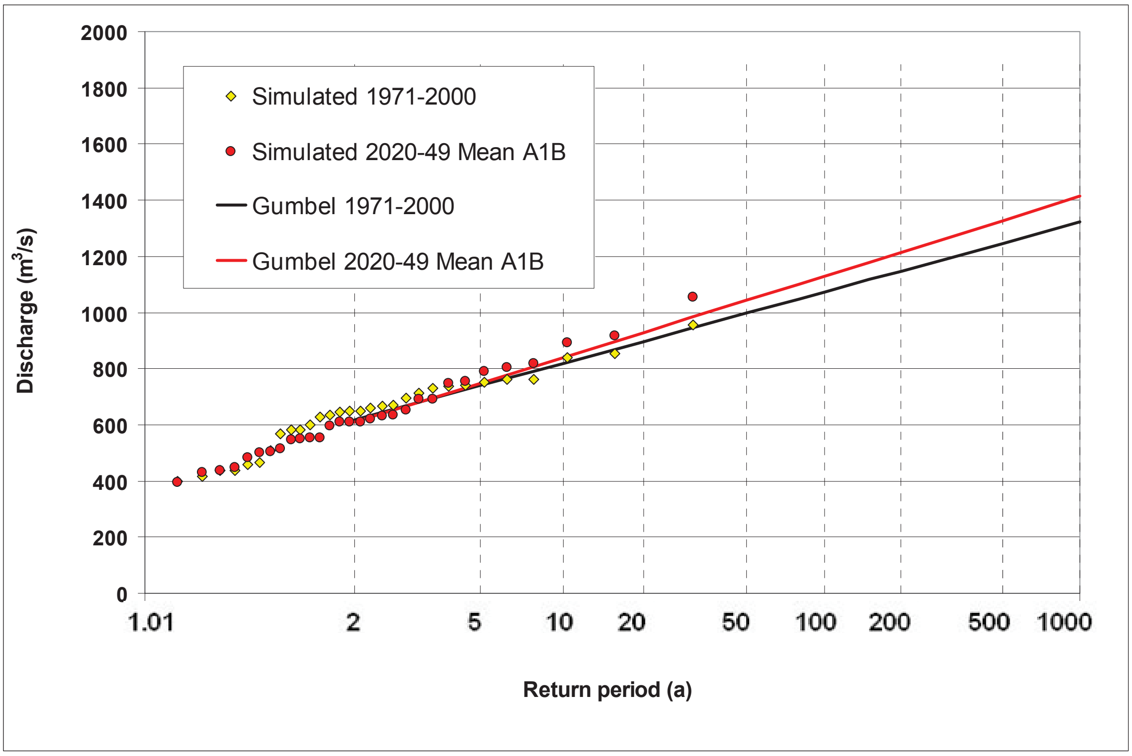


The changes in floods in Pori from the period 1971–2000 to the priod 2020–2049 based on 30 year simulations while applying a Gumbel distribution can be seen in Table 4.1 and Figure 4.2. Min is the minimum of the 12 simulations and Max is the maximum. Mean A1B represents the results from the so called mean scenario with emission scenario A1B. The further evaluation of the hydraulic modelling was done with the values of the last column in Table 4.1, which are the results form the mean scenario with the strongly modified regulation. In this scenario the 100 year flood in Pori increases by 5.3 % and the 250 year flood by 6.0% by 2020–2049 in terms of discharge.

Table 4.1. Results for Pori

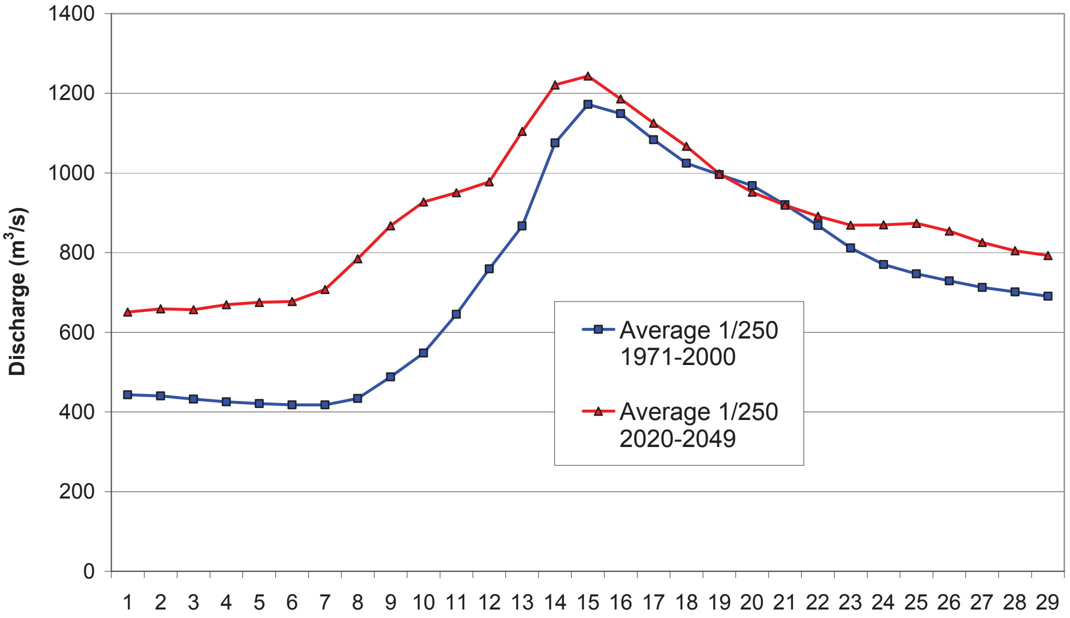
	Change in 2020–49 compared with 1971–2000			
Gumbel	**Slighly modified regulation**	**Strongly modified regulation**		
Return period	**Mean A1B**	**Min**	**Max**	**Mean A1B**
250	9.0%	2.0%	14.3%	**6.0%**
100	8.3%	0.9%	12.9%	**5.3%**

Figure 4.2 The simulated yearly maximum discharges and Gumbel estimate for Pori.



The length and shape of the floods in Pori was estimated by choosing the three largest floods of each simulation period, scaling their maximum values to the 100 or 250 year flood (Gumbel) magnitude and taking an average of these three floods for each day. With this estimation method the length of the flood increases. For example in 2002–2049 the discharge is over 800 m3/s for 20 days, while in the reference period the discharge is over this value for 11 days. This is only one method to estimate the shape of the flood and different methods would produce floods with different shapes.

Figure 4.3 The shape of the250 year flood hydrograph in 1971-2000 and in 2020–2049.



4.3.2 Salo

The timing of the floods is similar in Salo as in Pori. In the reference periods most floods are spring floods, but in 2020–2049 most simulated floods are winter or autumn floods (Fig 4.4). During winter floods, frazil ice may cause the floods to become much worse than they otherwise would be.

In the simulations made for Salo the floods in the period 2020–2049 decreased considerably compared with the floods in the reference period (Table 4.2, Fig 4.5). This was due to the decreased amount of snow and the decrease of fast snow melt floods. The simulations did not include the possible larger increases of extreme precipitations. Many climate model results indicate that rare extreme precipitations may increase much more than the average precipitations. The effect of increasing extreme precipitation was studied by separately increasing by 50% those daily precipitation which were over 30 mm. In this simulation the floods were slightly larger, but the floods in 2020–2040 still decreased from the reference period. This was because the change increased mainly summer precipitations but summer floods were not the largest floods in the region. These results are sensitive to for example the weather of the reference period, the parameters of the snow and watershed model and the method used in the evaluation of flood magnitudes and the results should not be considered with caution.

Figure 4.4 *Maximum, average and minimum discharges of the simulated 30 year period in 1971–2000 and 2020–2049 in Salo.*

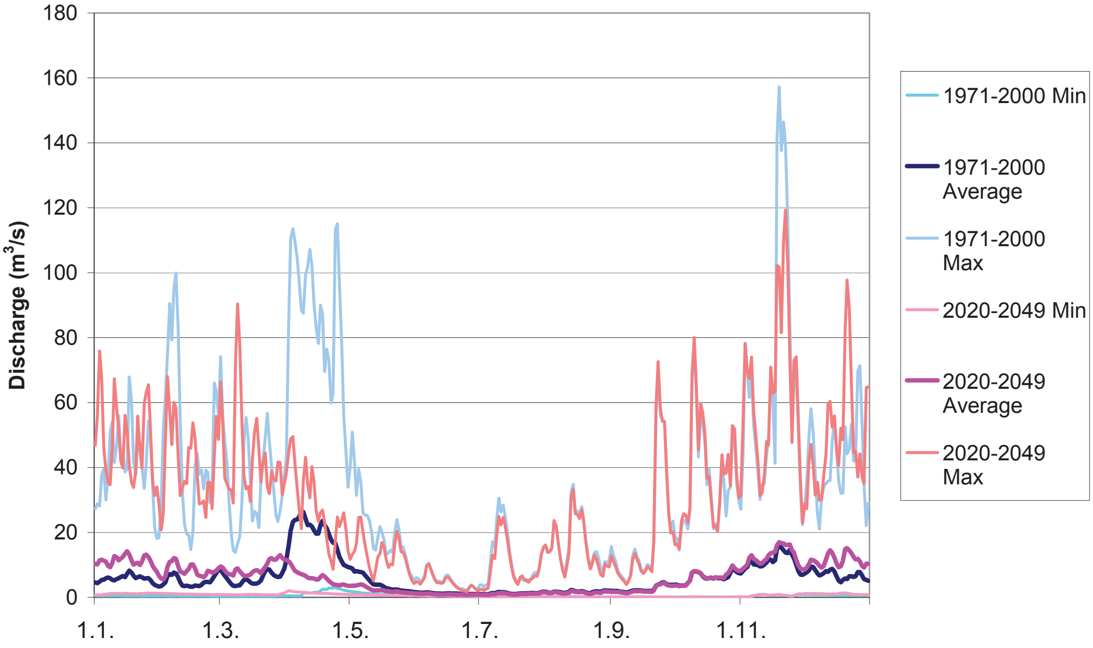
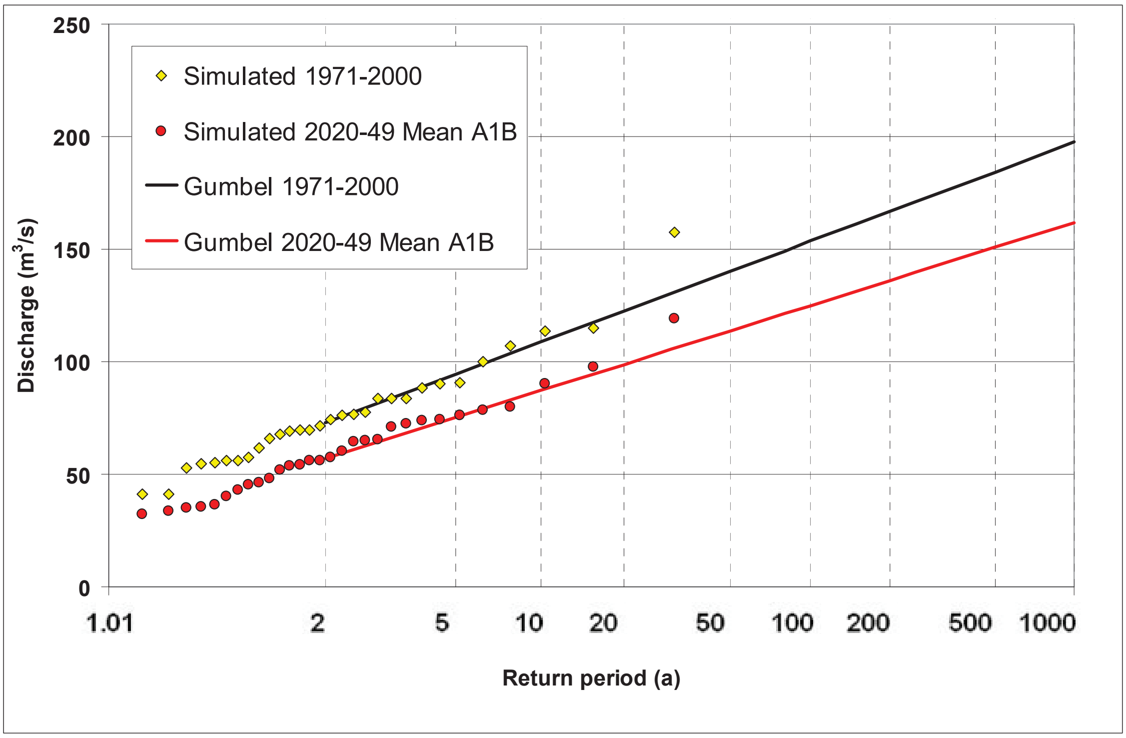


Table 4.2 *Results for Salo*

Gumbel	**Change in 2020–49 compared with 1971–2000**			
				Extereme precipitations (over 30 mm/d) +50%
Return period	**Min**	**Max**	**Mean A1B**	**Mean A1B**
250	-27.7%	-15.0%	-18.4%	**-12.6%**
100	-28.1%	-15.3%	-18.7%	**-13.2%**

Figure 4.5. The simulated yearly maximum discharges and Gumbel estimate for Salo



4.4 Hydraulic simulations

4.4.1 Hydraulic modelling

There are several factors that must be taken into consideration when estimating water levels in a river reach. Flow from the upstream is described with a discharge hydrograph. It represents the amount of water flowing in to the reach per time unit. Another obligatory boundary condition must be given for the most downstream point of the reach. In the case of rivers flowing to the sea it is reasonable to use time series of observed sea levels if available. The shape and bed surface of the river reach are also important, since they specify how the incoming flow is conveyed before the downstream boundary.

Modelling of river flow may be performed in different ways and the choice of model should rely on the desired results as well as the available information about the study area. In flood inundation studies both one- and two-dimensional hydraulic models are used. The dimension refers to number of flow directions. In one-dimensional model the channel is usually described with cross sections and the flow is perpendicular to cross sections. In two-dimensional model the topography is usually described with elevation points forming either a raster or an irregular triangular network. The flow velocity is calculated for each point and its direction may vary in a horizontal plane. When comparing the flooded areas achieved with calibrated one- and two-dimensional models, the differences between the model results may be small (Horritt & Bates 2002). However, the inundation process where water is flooding from channel to floodplain is hard to describe realistically with one-dimensional model. This is even harder, if floodplain is separated from channel with embankments. This is the case for example in Pori.

The model used in this study was one-dimensional HEC-RAS 4.0b (USACE 2002). It is widely used and well documented. The model is capable to simulate steady and unsteady flow in a complicated channel network with diverging and converging reaches and structures like bridges and weirs. Flow calculation is based on the conservation of mass and momentum. The continuity (conservation of mass) may be expressed with equation 4.1 (USACE 2002):

$$\frac{\partial A_T}{\partial t} + \frac{\partial Q}{\partial x} - q_t = 0 \qquad (4.1)$$

Where A_T is cross-sectional area, t is time, Q is flow, x is distance along the channel and q_t is possible lateral inflow per time unit.

The equation used to calculate the momentum is presented in equation 4.2 (USACE 2002):

$$\frac{\partial Q}{\partial t} + \frac{\partial (QV)}{\partial x} + gA\left(\frac{\partial z}{\partial x} + S_f\right) = 0 \qquad (4.2)$$

Where V is velocity, g is acceleration of gravity, $\partial z/\partial x$ water surface slope and S_f is friction slope which is calculated with equation:

$$S_f = \frac{Q|Q|n^2}{R^{4/3}A^2} \qquad (4.3)$$

Where n is Manning friction coefficient and R hydraulic radius.

The Manning friction coefficient is left for model calibration whereas channel geometry, inflow discharge and downstream water elevation are considered fixed. The abovementioned one-dimensional unsteady flow equations are solved by four-point implicit scheme.

4.4.2 Flood mapping and building registers

Flood mapping is performed in a GIS software with imported flow model results. The Finnish flood mapping procedure is widely described and instructed by Sane et al. (2006). It is possible to fix the HEC-RAS model geometry directly to a co-ordinate system and import the simulation results easily to a ArcGIS (ESRI 2000) with HEC-GeoRAS software (USACE 2005). Despite of the import method, flood mapping procedure goes simply by creating an elevation model about the terrain and a similar surface about the simulated water levels. In this procedure the water levels are interpolated continuously between the model cross sections. Flooding is defined by calculating the difference between the water surface and the terrain. Positive results are interpreted as wet areas (Fig 4.6) (see also §5.3.1 and §5.3.2).

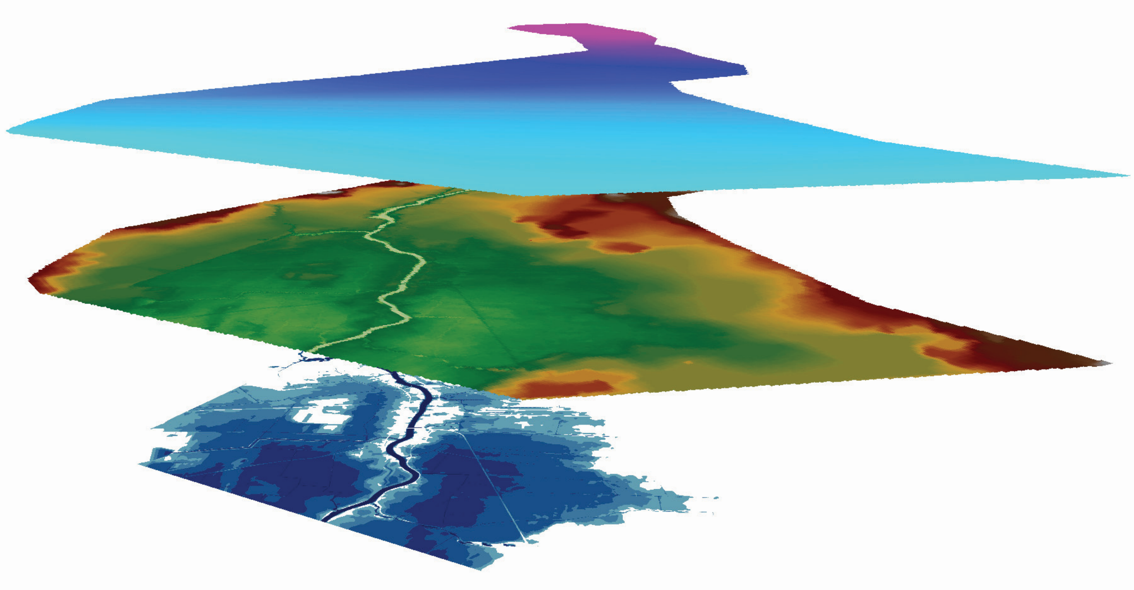


Figure 4.6 Flood mapping procedure (Sane et al. 2006)

Building information (RHR) is a part of the Population Information System maintained by the Population Register Centre. It contains information about over three million buildings and it is maintained and checked in close cooperation with municipal building supervision authorities and local register offices (VRK 2008). The most important information in this system for the flood damage analysis are the location of the building, floor area, construction material and number of people. The information is available as point shape file. On both Salo and Pori, the building information system data was combined with the domain of the hydraulic model. Points in the intersecting area were labelled to have a water level later in the analysis. To incorporate the water level into a building, each building point was given a river station number from the hydraulic model. Since model cross sections were numbered according to river length, a surface was created from the model cross sections and building points were interpolated onto this surface (Fig. 4.7).

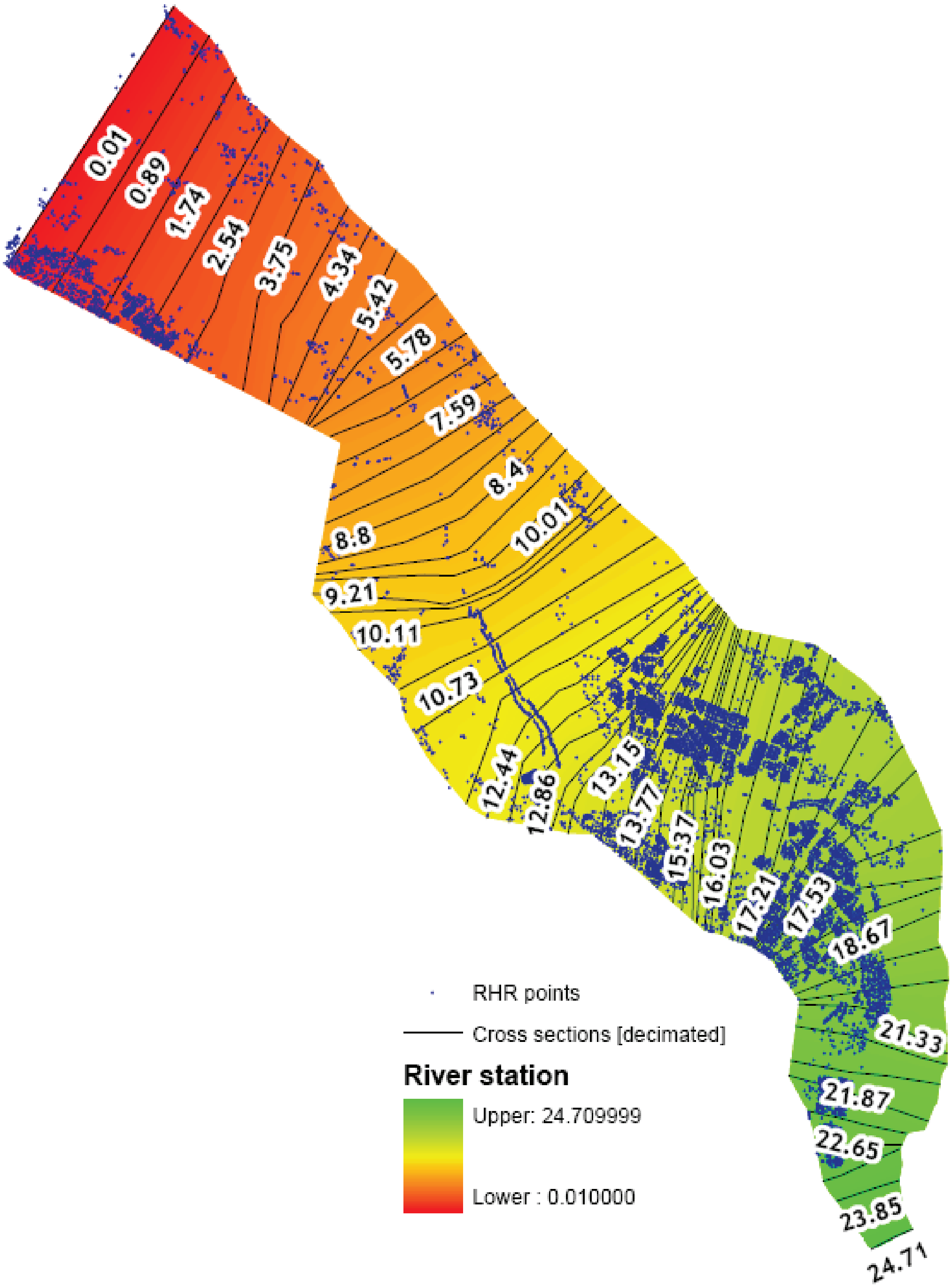


Figure 4.7 Interpolation of cross section numbers to building register (Pori case)

4.4.3 Model simulations

The model for Kokemäenjoki (Pori) was created in the 'Porin tulvat project' (Koskinen 2006). The model covers the downstream reaches of the river in the area of Pori. In addition to main the reaches Luotsinmäenhaara and Raumanjuopa also minor reaches between abovementioned reaches were included, as well as flow routes in the delta area. The total number of cross sections was 490 with an average distance of 100 meter ranging from 10 to 400 meter. This makes the total length of the reaches 50 km. The underwater parts of the cross sections were established with echo sounding device, whereas floodplain sections were obtained from the elevation data of city of Pori. For some locations a national elevation model produced by the National Land Survey of Finland. The resolution of this elevation model is 10 meter. The model calibration was based on the water level observations at Seikku sawmill. Each calibration set was about seven days and they were chosen from ice-free periods. The discharge curve was chosen to be as fluctuating as possible as well as to contain as high peak discharge as possible.

The flow model for river Uskelanjoki (Salo) was created in EXTREFLOOD-project (Selin 2006). The river reach under study was about 4 km in length and located around the city centre of Salo. River was described with 22 cross sections and bridges crossing the rivers were added into the model. The average distance between cross sections was 290 meter varying from 20 to 800 meter. The model was calibrated with observed water levels and using observed sea level and discharge as boundary conditions. The elevation model used in flood mapping procedure was a new DEM based on laser scanning. Salo is one of the pilot areas for the new national elevation model work. The resolution of the model was 2.5 metres and its advantage is good vertical accuracy.

Simulations were performed as unsteady flow simulations. While the upstream discharge varied against time, the downstream sea level was expected to be constant. Discharge hydrographs were obtained from hydrological scenarios and they were calculated with four sea levels varying from N60+0.5 to N60+2.0 metres. Hydrographs for Salo and Pori are presented in Figures 4.2, 4.3 and 4.4. The sea levels used in this study differs significantly from the mean sea levels. For example, according to the Finnish Marine Research Institute the mean sea level is around N60-0.23 meter in Pori. The effects of sea level variations are discussed more elaborately in Appendix 3.

4.5 Results

In both cases the impact of the sea level was significant. This is demonstrated in in Figures 4.10 and 4.11, sea level – flood area diagrams with various discharge scenarios for Salo and Pori respectively. Compared to the magnitude of the discharge, the sea level has a larger influence on the resulting flooded area. With the mean water level the water covers around 13 km² of the study area in Pori. When inspecting the water covered area with zero discharge and sea level N60+0.0 meter the water covered area is 13.5 km². Even with this tolerable sea level the GIS-analysis already produces wet areas behind the embankments. These areas are counted as flood area.

Table 4.3 The increase of the highest water level in some locations in Pori when moving from 1971–2000 scenario to 2020–2049 scenario.

		HQ 1/250				HQ 1/100				HQ 1/50			
Location	**River km**	**N60+ 2.0 m**	**N60+ 1.5 m**	**N60+ 1.0 m**	**N60+ 0.5 m**	**N60+ 2.00 m**	**N60+ 1.5 m**	**N60+ 1.0 m**	**N60+ 0.5 m**	**N60+ 2.00 m**	**N60+ 1.5 m**	**N60+ 1.0 m**	**N60+ 0.5 m**
	208	0.05	0.07	0.09	0.10	0.05	0.07	0.09	0.10	0.02	0.03	0.03	0.04
Pormestarinsilta	224	0.07	0.08	0.09	0.11	0.05	0.07	0.08	0.09	0.02	0.04	0.04	0.06
Kirjurinluoto	230	0.08	0.09	0.11	0.12	0.06	0.08	0.09	0.10	0.03	0.04	0.05	0.06
Linnansilta	235	0.07	0.09	0.11	0.12	0.06	0.08	0.09	0.10	0.04	0.04	0.05	0.06
Lukkarinsanta	255	0.08	0.10	0.12	0.13	0.07	0.08	0.10	0.11	0.03	0.05	0.05	0.07
Kalaholma	273	0.09	0.11	0.13	0.14	0.08	0.09	0.10	0.11	0.04	0.05	0.06	0.07
Koivistonluoto	284	0.10	0.12	0.13	0.14	0.08	0.10	0.11	0.12	0.05	0.05	0.06	0.08
Metallinkylä	297	0.11	0.13	0.15	0.16	0.09	0.10	0.11	0.12	0.05	0.06	0.07	0.08

Table 4.4 The decrease of the highest water level in some locations in Salo when moving from 1971–2000 scenario to 2020–2049 scenario.

		HQ 1/250				HQ 1/100				HQ 1/50			
Location	**River km**	**N60+ 2.0 m**	**N60+ 1.5 m**	**N60+ 1.0 m**	**N60+ 0.5 m**	**N60+ 2.00 m**	**N60+ 1.5 m**	**N60+ 1.0 m**	**N60+ 0.5 m**	**N60+ 2.00 m**	**N60+ 1.5 m**	**N60+ 1.0 m**	**N60+ 0.5 m**
Lammassaari	2139	-0.01	-0.04	-0.11	-0.16	-0.01	-0.04	-0.10	-0.14	-0.01	-0.03	-0.07	-0.11
Sokerisilta	3131	-0.06	-0.11	-0.17	-0.22	-0.05	-0.10	-0.17	-0.21	-0.04	-0.08	-0.14	-0.20
Rautatiesilta	4193	-0.15	-0.21	-0.26	-0.30	-0.13	-0.20	-0.25	-0.29	-0.10	-0.15	-0.23	-0.27
Mariansilta	4401	-0.16	-0.22	-0.27	-0.31	-0.15	-0.21	-0.26	-0.30	-0.12	-0.17	-0.24	-0.29
Marketplace	4523	-0.19	-0.25	-0.29	-0.32	-0.17	-0.22	-0.27	-0.31	-0.13	-0.19	-0.25	-0.29
Salonsilta	4665	-0.18	-0.24	-0.29	-0.32	-0.17	-0.23	-0.28	-0.32	-0.13	-0.18	-0.26	-0.29
Moisio	5063	-0.24	-0.30	-0.33	-0.35	-0.23	-0.28	-0.32	-0.35	-0.18	-0.23	-0.29	-0.32

Figure 4.8 *Flooded area in mean water level (cyan), sea level N60+1.0 m, the present HQ 1/50 discharge*

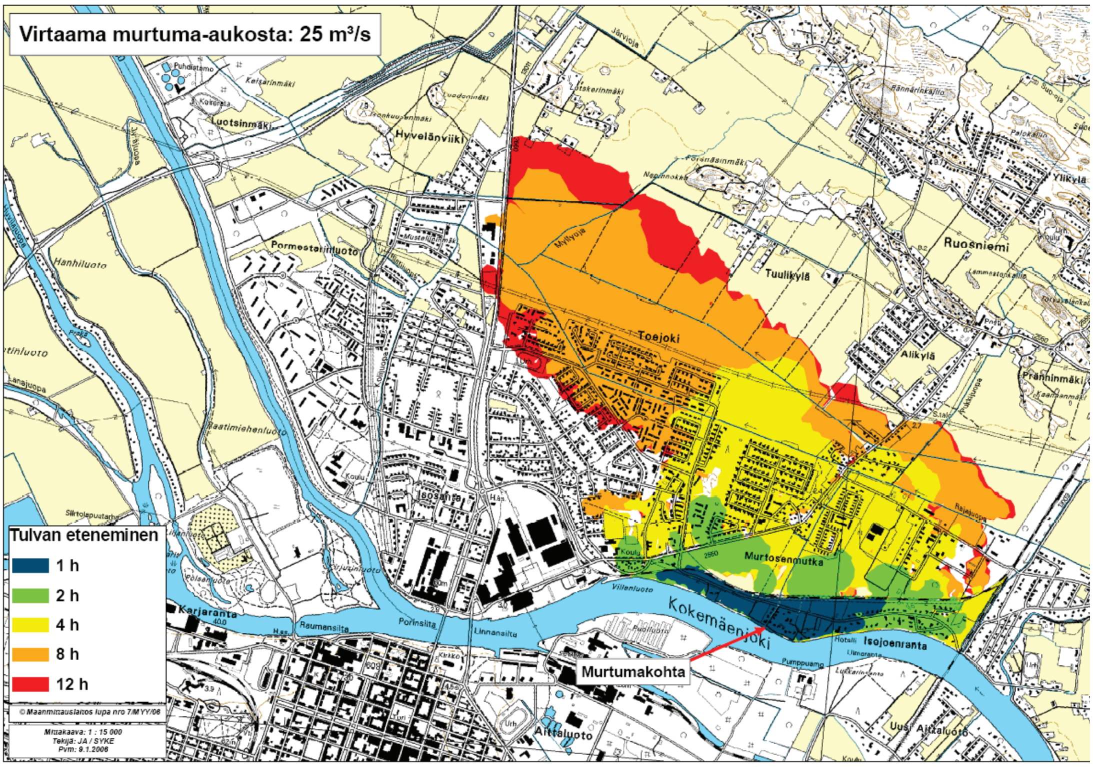


Figure 4.9 *Flooded area in mean water level (cyan), sea level N60+2.0 m, the present HQ 1/250 discharge.*

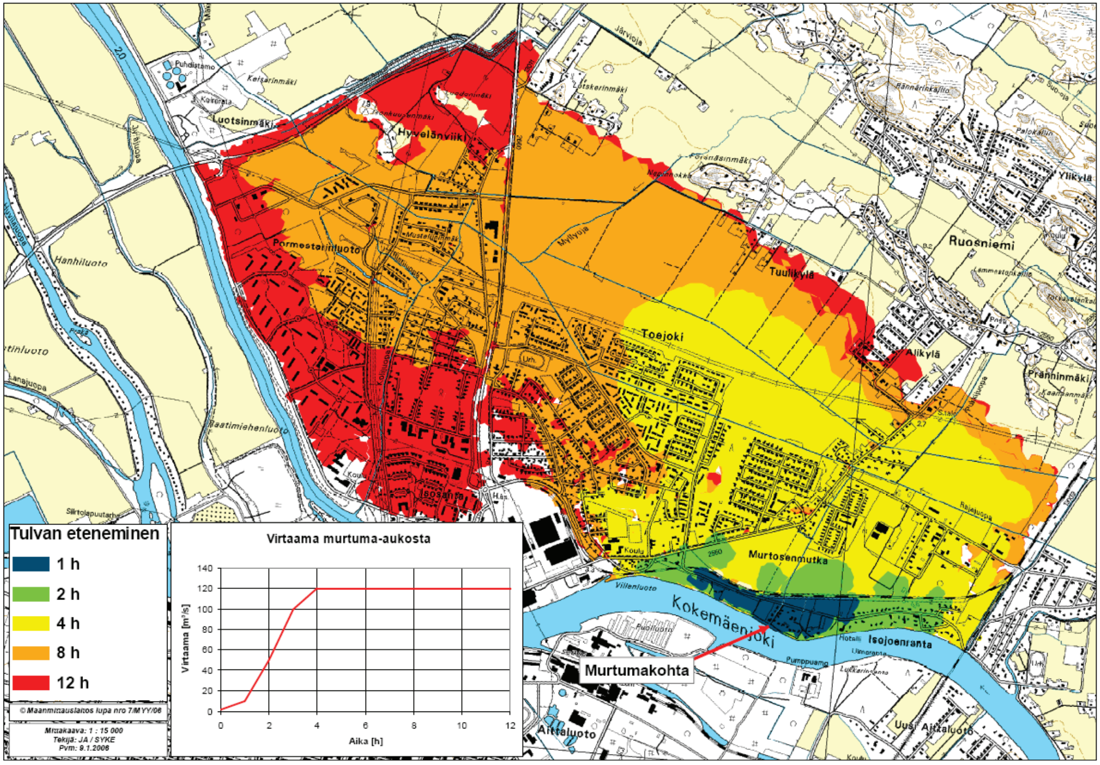


Figure 4.10 Flooded area in high water situation in Salo with different sea levels and discharge scenarios

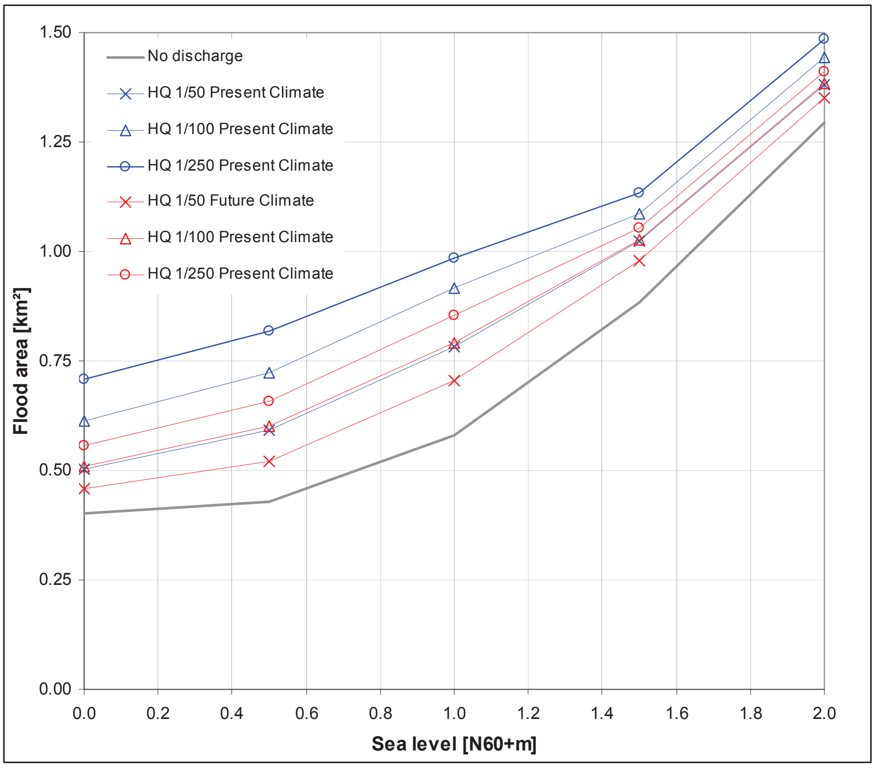
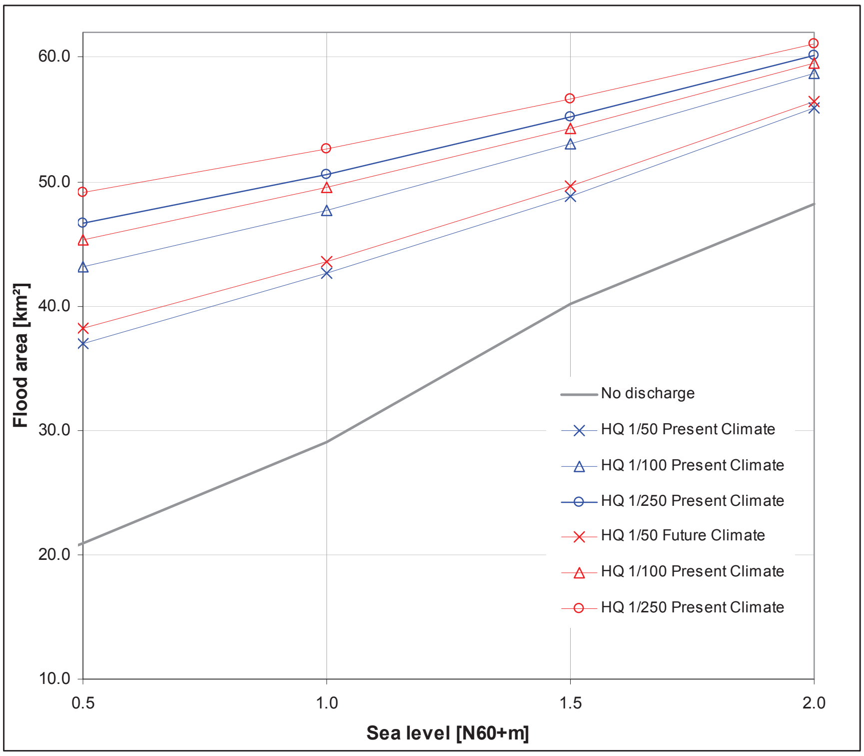


Figure 4.11 Flooded area in high water situation in Pori with different sea levels and discharge scenarios



4.6 Uncertainties and research needs

Hydrological model simulation indicated an increase of the flooding risks in the city of Pori, but a decrease in the city of Salo. In both cases sea level rise is increasing risk of flooding. The 100 year flood in Pori according to hydrological simulations increases 0–15% by 2020–2049, with strongly modified regulation. The flood might also last a little longer, maybe one or two days for a 250 year event. The simulations made for Salo indicate that, the flood risks in the period 2020–2049 would decrease considerably by approximately -15% ~ -30% for a 100 year event.

The limitation of a one-dimensional flow model should be kept in mind when inspecting the hydraulic modelling results: Only one water level is calculated for each cross section. This is problematical in cases like Pori, where vast low-lying areas are protected by embankments. The results above present the worst possible flood area, if embankments are breached in every flood protected area. The water level in the protected areas is consistent with the water surface slope in the main river channel. This is not the case in reality, since inundating water may have different flow route and downstream boundary conditions.

Realistic modelling of embankment breach would require two-dimensional modelling. Even there, an attempt to reach the universal solution would require multiple case studies, since breaches in different locations cause different impacts. The knowledge about the most vulnerable spots in the embankments would re-quire geotechnical analysis. There were not enough resources for these in this project. However, when comparing the one-dimensional results of the two-dimensional embankment breach simulations calculated in the 'Porin tulvat project', the water covered areas were quite similar in these two modelling approaches (Fig. 4.12). There were significant differences in the water levels in the flooded areas, though. For example the assumed breach location does have a large impact on simulated water levels throughout the study area.

The influence of boundary conditions is significant for the results, as it may be seen from the results. This uncertainty is very often neglected as pointed out by Pappenberger et al. (2007). There is need for a tool to study different uncertainties influencing the model simulation results.

These simulations concentrated only on ice-free periods. Both study areas are potential ice jam locations and climate change may have adverse effects on river ice phenomena. Both study areas contain drainage systems that are flowing to river or sea. In flood situation they would probably bank up water and cause flooding from sewer system and gather water inside the drainage areas.

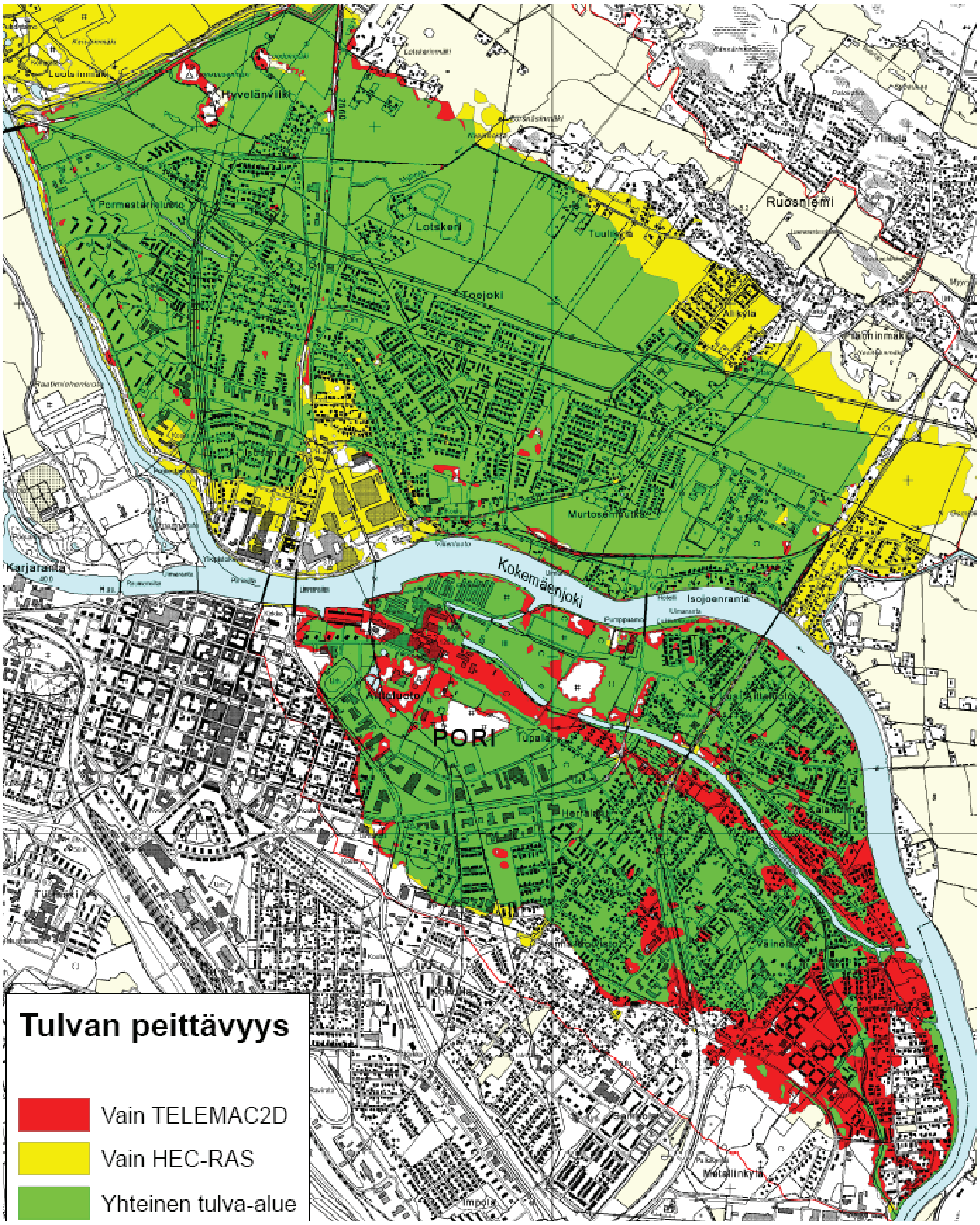


Figure 4.12 The intersection and subtraction of 1D- and 2D-simulation results in Pori. The analysis is made on the basis of inundated area regardless of the water depth. Embankment breach locations are pointed out with arrows. Simulated scenarios are from Porin tulvat –project (1D: stationary HQ 1/250 discharge with N60+1.4 m sea level, 2D: inflow discharge of 120 m³/s after 12 hours).

5 Socio-economic appraisal of floods

5.1 General introduction

Floods were simulated for the cities of Pori and Salo. Since for Salo a reduction in flood risk was foreseen, whereas also the overall expected damage is usually quite limited, the analysis of economic impact propagation concentrated on the Pori case.

Flood damages include all kinds of losses which are caused by a flood event. Damages can concern humans, buildings and other structures as well as the environment, ecological and cultural objects, and the economy. Some of these losses can be measured in monetary terms (tangible), while other impacts can't be expressed easily in monetary terms (intangible). Flood damages can result from direct contact with water or indirectly, due to lack of access or lack of inputs (e.g. electricity or clean water). From these direct, first order indirect effects, and higher order induced economic effects evolve. The latter category includes effects such as spatial substitution of demand and price effects due to sudden new scarcities and imperfect information. This division is summarised in table 5.1.

Damage functions are usually used to illustrate only direct tangible damages which have often large impacts on total damages. Nevertheless indirect and intangible damages should also be taken into account when flood effects are specified.

Table 5.1 Direct, indirect, tangible and intangible flood impacts with examples

	Tangible	**Intangible**
Direct	- buildings - equipment, furniture, etc. - infrastructure	- loss of life - health effects* - loss of ecological goods
Indirect (1st and higher order)	- loss of economic production - traffic disruption - emergency costs	- inconvenience of post-flood recovery - increased vulnerability of survivors

*) This has both tangible and intangible aspects; e.g. medical costs and loss of production hours due to illness and injury are tangible.

Source: Messnet et al. 2007

Direct tangible damages can be further classified into different sub-categories (for example buildings, equipment, and infrastructure). Depending on what is the desired accuracy of the research and on how detailed available data are, these categories can be further sub-divided. The selection of subcategories depends also on the size of the study area. Some damage categories may dominate the total damage count, but also (seemingly) minor issues are recommended to take account at least approximately.

In this study the focus is on *tangible damages*. Direct tangible damages include the estimated repair cost of residential and non-residential buildings, as well as replacement cost of interiors, equipment, and stocks. Also indirect tangible damages are considered, both the first order and the higher order effects. Considered first order indirect effects are suspended production in the flooded area and evacuation (temporary housing) of households who used to live in the flooded area. These first order cost are also presented in the tables in §5.3.2. Non-tangible damages may have economic ramifications as well. For example, if there is lack of trust in timely and complete recovery of the affected region, the result may be lack of willingness to invest, and in turn this can deepen and prolong the economic crisis even further.

Flood characteristics, which largely determine the extent of damage, are water depth, flood duration and flooded area. According to Mickelsson (2008) velocity of the flow in the flooded area is also an important factor. To this we wish to add contamination of the water and freezing just after the flood occurs. The possible effects of contamination (which can take many forms) were not assessed in this study.

In the case of Pori the flood simulations are assumed to take place in January. Next to the physical flood simulations, based on climate and river management scenarios, projections were made for regional economic growth, the regional population development, and a building stock. These projections will be explained in section 5.2. The direct cost calculations via the matching of economic and geographical information is explained in section 5.3. The results of the direct cost and first order indirect cost are summarised in section 5.4. The assessment of the higher order economic effects is presented in section 5.5. It has been carried out by means of an input-output system (see section 2.4 for a short discussion on the theoretical difficulties to assess economic effects of disasters). Section 5.6 reviews briefly the currently known options for enhanced flood protection policy in Pori. The section also contains a simplified cost-benefit analysis. Section 5.7 puts the results in wider context, seeks for options to generalise information and provides a step-up to chapter 6, where flood protection policy evaluation is discussed more at length.

5.2 Regional socio-economic and spatial scenarios in Pori

Prospective calculations for the period 2005–2050 were made for the population, the housing stock and gross annual dwelling production, the service building stock (shops, offices), and the regional GDP. The population forecasts are directly taken from Statistics Finland (Tilastokeskus, 2007). The housing forecast is based on the simulated stock development carried out for the KulMaKunta study (Perrels et al, 2006). The projections are quite near to those assumed in the Pori city plan (which however runs not further than 2025). The projections for the service building stock were based on estimation of surface-GDP elasticities and the regional GDP projections made in this study. The projection of the GDP of the Satakunta province has been derived from national projections by means of shift-share analysis. The national GDP projections are carried out by VATT in the framework of the National Energy & Climate Strategy (TEM, 2008). More background information is provided in Annex 4, whereas the key results are presented below.

The population of the Pori region (approx. 137 000) is expected to start a slow decrease in the next decade. For Pori proper (approx. 76 000) this is expected to start a few years later. However, despite a constant or even slightly contracting population the number of households will still increase, notably up to 2030, due to a higher share of elderly. This means that up to 2030 there will be still a need for additional dwellings, after that the need for newly built houses would mainly depend on the need to replace obsolete homes (table 5.2). In the Pori city plan a higher number of new dwellings is indicated for the period 2005–2025 (approx. 4100 as compared to 3300 in this study). Yet, the higher figure denotes (gross) production of dwellings, not net additions to the stock. From these projections can also be inferred that the lay-out and locations of the residential areas in 2050 will be to a very large extent be decided upon before 2020.

Table 5.2 Summary of the dwelling stock projections for Pori

Total number of dwellings in Pori and Pori region (seutukunta)

	Pori			**Pori region**		
	2005	*2015*	*2025*	*2005*	*2015*	*2025*
detached	16069	16564	16746	11660	12183	12446
terraced	3878	4202	4411	2755	3026	3176
apartments	17547	18993	19654	2842	3152	3342
TOTAL	37494	39759	40811	17257	18361	18964

Additions to the dwelling stock by period in Pori

Pori	**2005-2010**	**2010-2020**	**2020-2030**	**2030-2040**
detached	253	359	34	0
terraced	159	301	125	0
apartment	728	1315	75	0
TOTAL	1139	1975	233	0

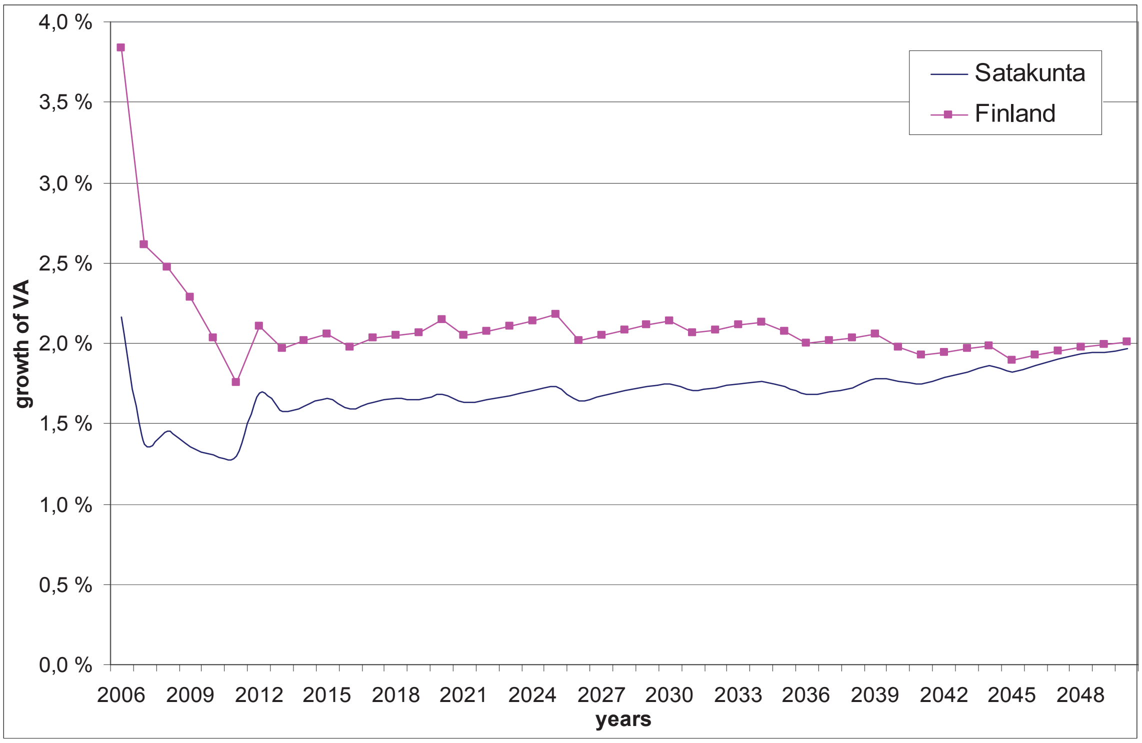
Source: Perrels et al, 2006

The growth in the non-residential building stock depends mainly on economic growth, changes in economic structure and productivity per square metre. In this case only the net increase in floor space up to estimated. For offices this is estimated at +5% in 2020 and +10% in 2040. The corresponding projections for retail floor space are +7% in 2020 and +14% in 2040. The actual building activity regarding non-residential buildings can be expected to be larger due to replacement and renovations.

The above presented projections about the volume changes in the building stock leave still a lot of leeway as regards the extent to which these changes are realised in flood prone areas. According to the Pori city plan ('Yleiskaava - kantakaupunki'), which runs up to 2025, a part of the building production can be expected to be realised in the flood prone areas even though mostly in those parts which would flood only in case of very extreme flooding situations.

The growth of the GDP of the Satakunta province is projected to be somewhat lower than the national average, but the difference is diminishing over time. The year to year variations are attributable to the applied shift-share analysis which retains cyclical components. The aggregate growth for the entire period 2005–2050 amounts to 114%.

Figure 5.3 Economic growth projections for the province of Satakunta and a comparison with Finland overall



Maps of Pori were presented in chapter 4. The flood prone areas in downtown Pori can be divided in a northern side, where it concerns mostly residential areas and a southern side (just east of the city centre), where it concerns both residential and non-residential areas (service buildings and industrial areas). According to the Pori city plan 30%~40% of newly built dwellings in the period 2005–2025 may be located in flood prone areas (the northern side). Also some of the new service buildings will be in flood prone areas, but in this case the share could be smaller.

5.3 Direct costs and first order indirect costs of floods in Pori

5.3.1 From flooding information to building damage

The river Kokemäenjoki in the Pori area is divided into 55 sections, which all have a measurement point for the water level in that section[14]. The database on real estate information of Pori (and the other study areas) has been obtained from the building registry (RHR) managed by the Centre of Population Registration (Väestörekisterikeskus). The used database represents the situation of 31 March 2007. Of each (registered) building in Pori a set of key data are known, such as its coordinates, address, floor area, type of building, current use, number of residents, and principal building material. The location of the flooded area can than be matched with the location of the buildings.

The water level in the affected buildings at subsequent points in time is measured as the difference between the water level of the appropriate[15] river section and the local elevation at the building spot[16]. As the decisive water level the peak level in the river section (for the considered period) is chosen.

In order to get an idea of the kind of economic activities that may get interrupted due to flooding, the business establishments as contained in the enterprise register of Statistics Finland were linked to the building register by means of the street address. The purpose of the use of the buildings is registered in the RHR as well. Calculations are made for three flooded areas applying two flood level situations. The areas were specified in an earlier research by Koskinen (2006). One flood area is located along the southern shoreline of the river Kokemäenjoki near the centre of Pori. The other two areas area located more or less opposite of

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[14] The level is expressed in reference to a normalised sea water level.

[15] Appropriate means usually the nearest section under a certain angle.

[16] That elevation uses obviously the same reference as the river water level measurement. However the data come from different sources. In the EXTREFLOOD II project has been addressed that for this and other reasons there are inaccuracies in the elevation data which are large enough (i.e. 10~20 cm) to add a fairly significant amount of uncertainty about which building would just get flooded and which just not. A new national elevation measurement project has just started.

the southern flood area along the northern embankments. More downstream are more flood risk areas, but they do not entail residential or business areas (with the exception of the harbour area at the river mouth).

Buildings have been classified in five categories:

- detached, semi-detached and terraced houses
- apartments (in multi-story buildings)
- shops and offices, which includes shops, shopping malls, department stores, restaurants, offices and institutional buildings
- auxiliary buildings, including saunas, garages, sheds and private warehouses
- other buildings, such as mills, theatres, museums, etc.

The water level of the river Kokemäenjoki is simulated for every day in a future January[17] for every consecutive river section in Pori by SYKE. Water level of the flood peak is chosen to define flood damages. The maximum water depth in every flooded building is the difference between the water level of the river and ground elevation at the building spot[18]. This method of measurement leads to assumption that when flood happens in certain area water can spread over whole flooded area, which is defined by SYKE and there is no embankment to stop it. It is also assumed that when for example river dyke collapses, water level in the river doesn't decline and water spread quickly and it reaches its maximum level. If for example dyke collapses after the flood peak, the water depth used to define damages, is too high. Buildings are linked to the information of the nearest river pole and geography of the area is not taken into account.

5.3.2 Calculation approach for the appraisal of building damage

Damage calculations are made for three different areas. These areas are defined in previous research (Koskinen 2006, 62–63). One flood risk area lies south of the river in between Linna Bridge and Koivistonluoto near the city centre of Pori. The second area is north side in between road to Vaasa and Railway Bridge and the third, neighbouring, area lies between the northern river arm and the main road to Vaasa. Flood for these areas can be caused by collapse of the dykes or overflow of the dykes, which erodes dykes and often leads to collapse.

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[17] As explained in chapters 3 and 4, for the period 2020–2050 under changing climate conditions extreme runoff situations seem most likely to happen in January.

[18] If the building is standing on a slope, this may still entail uncertainty about flooding.

Unit costs of damages to four different building types are represented in table 5.3. Damage estimations are made by Helsinki university of Technology (Mickelsson, 2008) and unit costs represent potential damages of building and fixtures caused by clean water. These costs are rough generalisations because real damages depend on the quality of the building and the fittings. Mickelsson also considered effects in case of polluted water (not shown in table 5.3). The cost effect of polluted water hovers between a 10% and 20% addition to the unit-cost level of a clean water flooding. A water level inside a building of less than 30cm is assumed to cause only minor cost, mostly comprising of cleaning cost, etc. If the water level inside a building rises up to 30cm~60cm the floor and lowest part of the walls get wet, and consequently repair cost start to increase. If the water level rises over 60cm, walls will need more extensive repair and the probability that fittings get damaged increases quickly. The flood duration is considered to be at least several days when the water level in the building reaches over 5cm. The variation in the duration of the flooded state of buildings varies considerably across the flood risk areas, i.e. from days to weeks, depending on the extremity of the flood, the profile of the local terrain, and technical features of the building. The water level in the flooded area is assumed to decline at the same pace as it does in the river after the passing of the flood peak. In the calculations regarding direct damage to buildings only water depth in the building is taken into account by multiplying flooded floor space per building category by the applicable unit-cost as listed in table 5.3. Duration of the flood plays a role in assessing the indirect costs, such as production interruptions and temporary residence (see below). The calculations can be summarised as follows:

$$DC_{acT} = \sum_{i,w} S_{aiw} \cdot u_{iw} \tag{5.1}$$

where *DC* denotes direct cost, *S* flooded surface area, and *u* cost per square metre (unit-cost). The subscript *c* refers to current or future climate, while subscripts *a* and *T* refer to city area and flood return category respectively. The subscript *i* denotes building category and *w* water depth (category).

Table 5.3 Unit costs of residential and non-residential buildings, €/m2

Building category (i)	**Water depth categories (w)**		
	5–30cm	**30–60cm**	**Over 60cm**
Homes (excl. apartments)	35	260	740
Apartments	30	270	885
Shops and offices	40	370	1550
Auxiliary buildings	35	330	1390
Others	10	30	50

5.3.3 Calculation approach for the appraisal of 1st order indirect costs

The indirect costs are subdivided between indirect first order cost and higher order induced cost. The former indirect cost category comprises the estimated direct losses of production days in production establishments, which are inaccessible during the flood and possible following repair time. Also temporary housing costs belong to this category. The latter category, higher order induced cost, represents the overall macro-economic economic impact on the region

Loss of production, expressed in loss of revenues, is estimated from the yearly revenues of the companies. The used extraction from the company register doesn't include branches for which spatial substitution of demand, also within the city perimeters, is easy and quickly to realise and consequently for the city as a whole these sectors may suffer much less production loss (at least for this reason). Therefore retail trade, hotels and restaurants, and transport (support) services (in buildings) are not included. Admittedly for some shops, some transport facilitators and hotels this exclusion will create some underestimation of the cost[19]. It should be stressed that the direct cost of building damage occurring in these sectors is accounted for (see §5.3.2).

The loss of production days is based on the number of days that a building is estimated to have at least some water on its floor(s), augmented by an average of 14 days for cleaning and repair. Only those production establishments are included in which the maximum water level in the building exceeds 10cm. In practice there are large variations in the recovery periods of buildings. The variation correlates to some extent with water height and flood duration, but even more with building specific features (not observed in the data sets). It was beyond the scope of this study to attempt to differentiate recovery times in a reliable way. The number of lost production days divided by the number of annual production days and multiplied by the annual revenues provides an indication of the lost revenues.

Households of affected buildings, including those living in non-flooded but inaccessible apartments, incur cost due to the need for temporary housing. Only a rough estimate can be made applying the assumption that all temporary displaced households have to pay a fee of 75 euro per day for the temporary housing. On the one hand the number of households using priced services could be lower due to assistance, which is free of charge (relatives, friends, charities, etc.). On the other hand scarcity may drive up prices or at least oblige a part of the displaced to use more expensive services and/or incur other extra cost, such as for extra travel and new clothing, etc.

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[19] The inclusion of the category hotels is due to its close combination with restaurants.

$$IC_{acT} = \sum_{i,w} (N_{aci} \cdot h + p_i \cdot S_{aci} \cdot 1/D_i) \cdot d_{cT} \tag{5.2}$$

N denotes the number of displaces households and h the cost of temporary housing (and related cost). D_i stands for the number of annual production days in sector I, while d_{cT} represents the duration of the flood of return time T in climate regime c (current or future).

Now the total direct and first order indirect cost amount simply to the following.

$$C_{acT} = DC_{acT} + IC_{acT} \tag{5.3}$$

CacT, after attribution to sectors based on the building information, is used as the basis for the calculations for the higher order induced effects (§5.4).

5.3.4 Results of the cost calculations for Pori

As indicated above the costs were assessed per flooding area (3 in total) for two levels of flooding, i.e. floods with a return time of 50 and 250 years respectively, both in current and future climate conditions. The difference between the cost levels in current and future climate indicates the impact of climate change, *other things being equal*. The proviso means that economic growth and changes in building stock are not taken into account in the results shown in table 5.4. That is done in a next step.

For a flood with a return time of 50 years in combination with a sea water level of +100cm above normal the material damage to buildings, interior and equipment is rated at approx. 107 million euro in current climate and at approx. 123 million euro in future climate. This means an increase of about 15%. For indirect first order costs the (rough) estimates are rated at about 11 and 14 million euro respectively. This means an increase by about 27%.

A more extreme flood with a return time of 250 years (but with the same sea water level as for the R50 case) is expected to cause appreciably more damage. The total damage to buildings, interior and equipment in current climate is rated at approx. 294 million euro, whereas the cost level in future climate is expected to rise to approx. 350 million euro. This implies an increase of about 19%. For indirect first order costs the (rough) estimates for the heavier flood are rated at about 25 and 32 million euro respectively. This means an increase by about 26%.

The sea water level could still be somewhat higher but a combination of events with sea water levels beyond +140cm would be truly extremely rare. Another possible combination of events is a sharp and sustained drop in temperature just after the flooding occurred. Even though the return time of such a combined event is well beyond 1000 years, it should be realised that the very high cost level of this case (i.e. two to three times the reported figures for the R250 case) still implies that the tail of the flood event distribution beyond R250 should not entirely be neglected.

Table 5.4 Direct costs of material damage and first order indirect damage of production interruptions and temporary residence for R50 and R250 floods in all three flood prone areas (costs rounded off at million euros)

	Direct Cost – material damage (buildings, interior, equipment) and cleaning cost (in million euro)			
	Current climate		Future Climate	
	R=50	R=250	R=50	R=250
Homes	81	169	91	194
Apartments	13	53	16	67
Shops & offices	5	30	7	38
Other buildings	7	41	9	50
Auxiliary buildings	1	2	1	2
TOTAL direct cost	**107**	**294**	**123**	**350**
of which buildings	*98*	*270*	*113*	*323*
	First order indirect Cost – suspension of production and temporary residence (in million euro)			
	Current climate		Future climate	
	R=50	R=250	R=50	R=250
Households (homes + apartments)	7	9	13	15
Companies	3	5	13	16
TOTAL first order indirect cost	**10**	**14**	**25**	**32**

The influence of economic growth and the development of the building stock are not so easy to integrate, not the least since the two are also interrelated, e.g. via productivity growth per unit of floor space. Furthermore, as time passes by there is ever more leeway with respect to the location of the additions and reductions of the building stock. In the tentative calculations presented below the assumptions are used as mentioned in §5.2 regarding the changes in the building stock and the geographical distribution thereof.

On the basis of the Pori City plan 2025 it can be tentatively estimated that at most 200 homes might be built in areas where floods with return times of over 100 years could reach. In quite some cases water levels in building may stay moderate though, implying moderate unit-cost (table 5.3). All in all in the above presented case of flood rated at a 250 years return time (table 5.4) the estimated addition to the dwelling stock in flood prone areas could increase the direct costs incurred by households by approximately 3% to 5%[20]. For production establishments the stock addition effect is probably even smaller.

The influence of economic growth is channelled both via capital accumulation and via higher productivity per unit of floor space. The capital accumulation effect can be subdivided into more floor space (expansion of the stock) and more value per unit floor space (augmentation of the stock, including interior and equipment). The augmentation effect is related to the higher productivity per unit of floor space. The expansion and the augmentation effects are relevant with respect to material damage of buildings and equipment. The productivity effect is relevant with respect to suspension of production in flooded buildings.

Given the projected growth figures of regional GDP and given the estimated net addition in floor space a net growth in value per square metre (in real terms) could be estimated for subsequent years. As a rough *average* for the period under consideration (2005–2050) an increase of 50% is estimated. In 2020 the increase in value per square metre would amount to 20% and in 2050 to 88%. Obviously the impact of economic growth is dominating all other effects on the direct costs of flooding.

Averaged estimated contributions to changes in real undiscounted cost of flooding in the Pori region by type of influence for the period 2020–2050:

- Economic growth +50% – the figure depends strongly on the estimated growth rate and the time span, e.g. in the Pori case for the applied growth rate it varies between approx. + 20% in 2020 and +88% in 2050).
- Climate change +15%~+20% – depending on how to weigh in different return times.
- Building stock -10%~+10% – depending on how spatial plans and building spatial planning technology are developing, this factor seems harder to quantify; in Pori with a stable population and moderate economic growth the influence seems limited, if there are large changes in the population and in the economic structure the significance of this factor can increase appreciably).

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[20] . Simply in terms of numbers of homes exposed to flood risk the increase is approximately 8%, but the unit-cost (per m^2) can be expected to be below average, hence a tentative estimate of 3%-5%.

$$E(C_{tacT}) = P_T(A_T \geq 1 \mid t = 45) \cdot \left(DC_{tacT} + IC_{tacT}\right) \tag{5.4}$$

C_{tacT} stands for the total cost of a flood with a return time T in area a in climate regime c in a future year t. A_T denotes the number of flood events with return time T. Due to climate change a flood with a given return time will be heavier in the future than in current climate, so $E(C_{a,c=f,T}) > E(C_{a,c=c,T})$. Furthermore, economic growth and discounting should be considered as well. Therefore equations 5.2 and 5.3 are to be reformulated as follows:

$$DC_{tacT} = \frac{\sum_{i,w} S_{taiw} \cdot e^{g.(1-\vartheta)} u_{iw}}{(1+r)^t} \tag{5.5}$$

$$IC_{tacT} = \frac{\sum_{i,w} (N_{taci} \cdot h_t + p_{tiT} \cdot S_{aciT} \cdot 1/D_i) \cdot d_{cT}}{(1+r)^t} \tag{5.6}$$

where $e^{g.(1-\vartheta)}$ is the economic growth rate in the period t_0-t as it is affecting the value (productivity) of floor space, while corrected for the elasticity of floor space with respect to economic growth ϑ. In other words in as far as economic growth is not translated in additional floor space, it is assumed to be accommodated by an increase of the value per m^2 (in fact mirroring the productivity development of real estate). The discount rate is denoted by r, where $0 \leq r \leq L$, and L being some country or case specific upper limit of the applicable discount rate.

The expected total cost of a certain dimension of a flood, $E(C_{t,a,c,T})$, can now be compared with the expected total costs of alternative flood protection schemes which are just capable of protecting up to the flood dimension as assumed in the expected total cost. It will be shown in chapter six that the decision making process is based on broader notions than minimising present value of net costs of floods and protection measures. Furthermore, the above figures represent direct and first order indirect cost, but they do not give much information on the ultimate regional economic effect. Regional economic effects of extreme events will be discusses below in the section 5.4.

5.4 Induced socio-economic impacts at the regional level – case Pori

5.4.1 The various pathways from the initial damage to eventual effects

As was shown in the previous sections initial economic effects of a flood come from damaged capital stock of business and households (and its implied repair costs), suspended production due to damaged capital stock, and extra cost and/or displaced expenditures of households due to temporary housing and its follow-up costs.

Starting from this initial situation one has to consider how the local economy recovers from the shock. The repair is preceded by cleaning up. The resumption of production and the return from temporary housing depend on the finishing date of the repairs. The scale of the damage in relation to the scale of the economy and population, and more in particular the capacity of the building sector, is important here. For cleaning up (incl. drying) various sorts of equipment are necessary of which the availability is not limitless, even not at a national scale. Consequently, the larger the scale of the damage (e.g. number of buildings) the higher the likelihood will be that there is shortage of cleaning-up capacity. The result is queuing, i.e. prolonged time lapses until repair and resumption of production, as well as an upward pressure on prices for cleaning-up services and equipment. Yet, it is not sure how much prices will be affected, as also cultural characteristics (norms and values) play a role (Okuyama 2007; Munasinghe, 2007).

Similar capacity restrictions, potentially with much larger cost consequences, can also occur with respect to the repair work proper. If the construction sector suffers from underutilisation of its equipment and labour force the repair boom will cause less price rises and less crowding out of other building projects. The re-employment of unemployed construction workers is in that case a positive stimulus for the economy. In case of an already fully utilised capacity in the construction sector higher price rises are likely, as is increased displacement of other ongoing or planned construction work, and a larger inflow of (temporary) construction workers from other regions or even from abroad. In that case the stimulus effect of the repair boom can be overshadowed by the price rises (with knock-on effects on current and future consumption budgets) and the transfer of wage income to other regions.

Another important influence factor is the funding basis of the repairs (and other costs). The options are funding from current income, from accrued savings, from a bank loan, and last but not least from an insurance pay-out. Funding out of current income has a limited capacity and implies also that other consumer demand is reduced in other sectors than construction services and materials. Combined with price rises and leakage to other regions, the net effect would be reduction in the regional GDP. The other funding options do not affect consumer demand in the investment year, but reduce purchasing power to some extent in future years due to loan costs, forgone capital income from spent savings, and increased insurance premiums. If the greater part of the damaged objects was insured, the flood will cause a massive pay-out among insurance companies. In turn these have to restore their capital base by increasing the premiums. Other sources of reduction of purchasing power in the base year (investment year) constitute the first order indirect cost for companies and households and the financing cost of the repairs. All in all in the first year private consumption (except the purchase of construction services and products) reduces due to displacement inside consumer budget allocation and due to income reductions stemming from production losses (affecting incomes of self-employed and paid-out profits). In the following years the purchasing power is lower due to the extra financing cost of households themselves and due to the extra financing cost of companies which are assumed to reduce profits (and hence capital income).

5.4.2 The estimated induced economic impacts in Pori

On the basis of the consideration described in the previous section a heuristic was made. Furthermore, the input-output table for the province of Satakunta was used to assess multiplier effects. As regards the funding of construction and repair work of commercial buildings it was assumed that 85% of the incurred costs are covered by insurance pay-out, whereas the remaining 15% is split 50/50 between coverage from bank loans and from current income respectively. Loss of stocks was assumed to be covered for only 50% by insurance, as indeed in practice there are more limitations on the insurability of stocks. The remainder of the replacement of those stocks was assumed to be funded either by a loan (25%) or from current income (25%). As regards losses due to suspension of production it was assumed that 50% of those losses would be eventually recovered by temporal or spatial substitution[21].

For construction and repair work of residential buildings and for temporary housing cost the same division between insurance (85%), loans (7.5%) and current income (7.5%) was applied. However, for replacement of interior and equipment only 50% coverage by insurance pay-out was applied, among others because policies often apply high amortisation rates (i.e. limited lifetimes) of such goods. Furthermore, home interiors tend to be underinsured. The costs that are not covered by insurance are either covered from current income (¼ of the remainder), from accrued savings (¼ of the remainder), and from bank loans (½

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[21] During the TOLERATE project a questionnaire was sent around to gather information about for example these substitution effects. Approximately ⅓ of the respondents indicated that suspension of production could be wholly or partly compensated by increased production elsewhere. A similar share of respondents indicated that after resumption of production a part of the loss could be recaptured by means of overtime work. These shares concerned partly overlapping groups, therefore a share of 50% was used to cover both substitution options together.

of the remainder). Both for companies and households a real interest rate of 5% was applied with respect to their bank loans.

Last but not least the insurance companies have to restore their level of invested capital by raising premiums. Hence both companies and households incur extra annual cost of higher premiums, whereas insurance companies have lower income from capital. However, as the restoration of the capital proceeds, this income loss is gradually fading away.

At the moment unemployment in the province of Satakunta and the Pori area is above the national average. However, the local age structure is such that many unemployed move even sooner into retirement age than overall in Finland, whereas new cohorts of young employable people are getting smaller. Over a longer time span it seems therefore reasonable to assume that there is no abundance of labour in the region. Beyond 2020 a shortage may even become more likely. Yet, in the calculations such imbalances have not been considered.

Regardless of the state of the labour and the building market the amount of repair and construction work caused by the flood is very large in comparison to the size of the market for construction work in the province of Satakunta. In comparison with the current level of regional production value (~ turnover) of that sector the shock is roughly between 8% and 16% in case of a flood with a return time of 50 years and the shock is roughly between 45% and 55% in case of a flood with a return time of 250 years. This means that notably in case of a flood with a return time of 250 years (R250) the displacement effect with respect to other ongoing and planned construction work will be truly significant. In the calculations stages of 25%, 50% and 75% displacement[22] can be applied. For the R250 case all these stages will be applied as alternatives, whereas for the R50 case only the 25% and 50% seem to be relevant.

The key effects at the macro-economic level are:

- the enlarged demand for construction work and construction materials
- the extent to which repair activities are displacing other building activities
- the sources of finance of that repair and the related reduction of capital income of the insurance sector depending on the pay out
- the reductions in purchasing power and the forced changes in allocation of consumer spending

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[22] The share of the value of the repairs that displaces an equal amount of construction activity elsewhere in the region.

The figures 5.1 and 5.2 provide the results for a recovery scenario after a R250 flood in current and future climate conditions, in which the displacement of other building activities is stepwise getting less. An alternative would be to assume that displacement is low right from the start, e.g. due to substantial re-employment of unemployed and (recently) retired workers or due to influx of construction workers from other regions. The other extreme would be that the displacement effect remains high throughout the repair period (3 years at maximum). In the R50 flood case (not shown in figures 5.1. and 5.2) displacement is supposed to be lower throughout the recover period. This means that the effect of the repair boom is relatively larger, resulting in a *net* extra impulse of 25 million euro in year 1 and 11 million euro in year 2. Subsequently a period of small negative impulses follows.

Obviously the repair activities cause a significant boom in the economy. In the figures 5.1 and 5.2 is assumed that the boom does not cause price rises, even though the displacement is high in year 1 (75%) and fairly high in year 2 (50%). The overall recovery takes however a longer time, since consumption remains slightly repressed due to long term extra cost of higher insurance premiums and long term cost of loans for repairs. Since the insurance sector has used a part of its capital to pay out the damage, it incurs a capital income loss that lasts up to the point where the extra premiums, charged after in the years after the flood, have restored the original capital. The amounts in figures 5.1 and 5.2 can be regarded as estimates of absolute losses of regional GDP.

Figure 5.1 Regional economic impacts – current climate

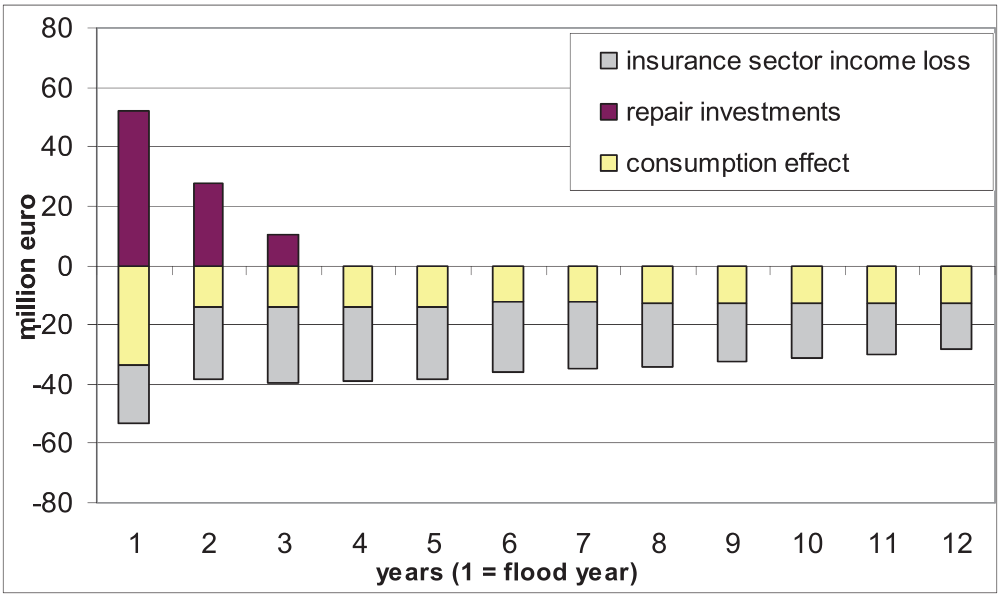
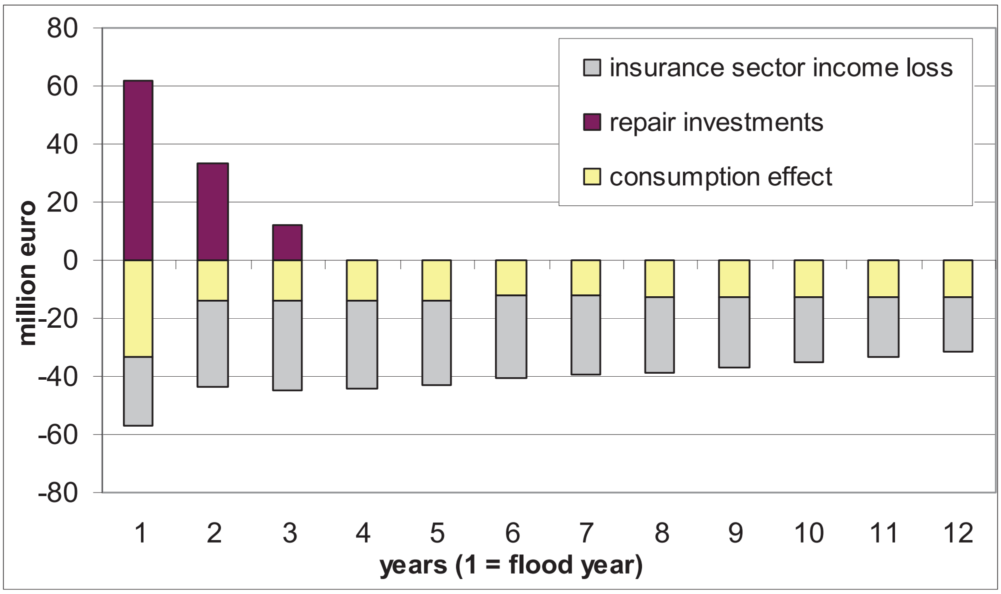


Figure 5.2 Regional economic impacts – future climate



In figure 5.3 the various development pathways in current (CC) and future (FC) climate are depicted for the R250 case in Pori assuming low displacement (profile 3), high displacement (profile 2), and stepwise diminishing replacement (profile 1), which is regarded as the most plausible one.

Figure 5.3 Regional economic impacts with different repair response rates in current and future climate

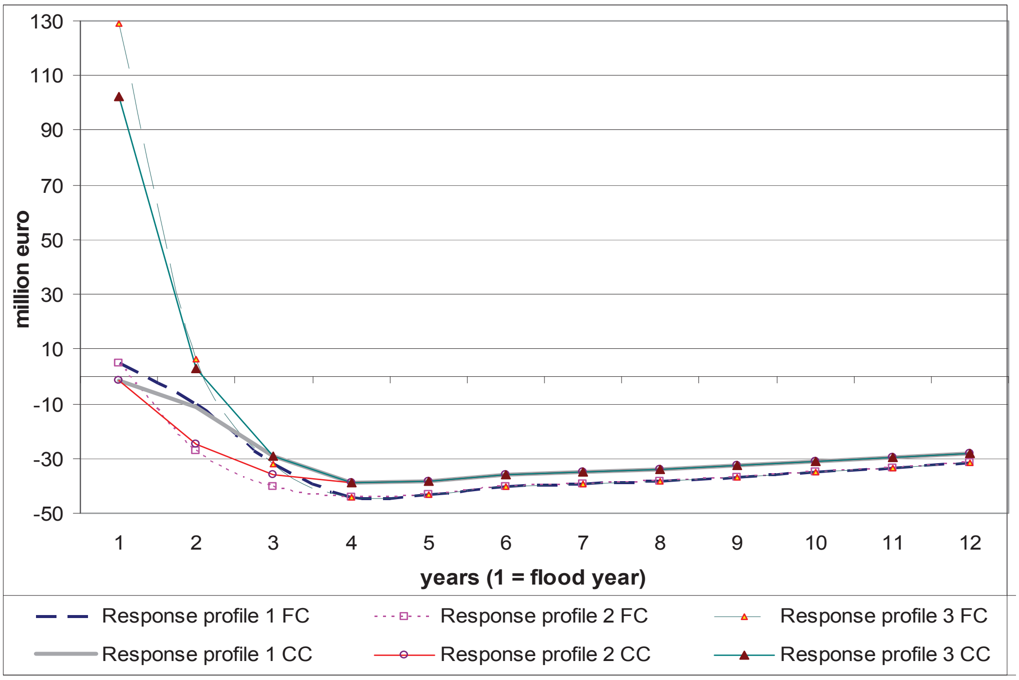
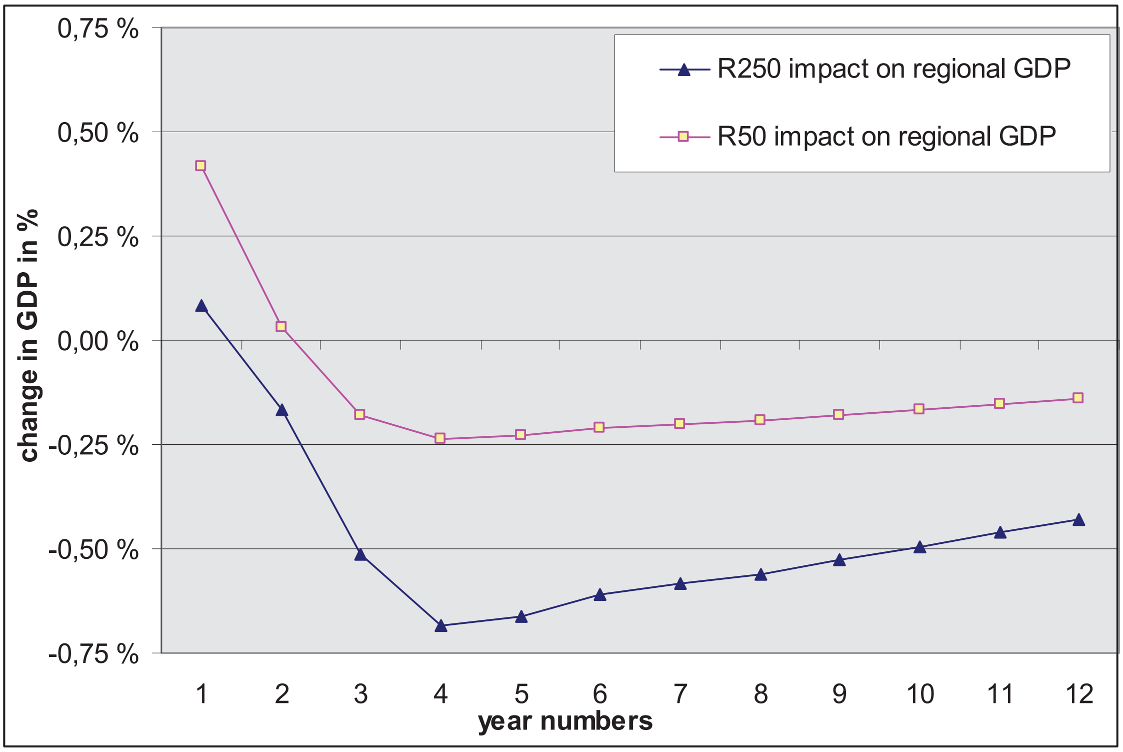


Figure 5.4 provides an impression of the impact in terms of a percentage deviation from the baseline development of GDP for both the R50 and R250 case in future climate. In this figure the expected economic growth rate (approx. 1.7%) is taken into account. The differences with the curves for current climate are small (see also figure 5.3) and therefore not both climate regimes are shown. The overall value of cumulative loss (or gain) of welfare is represented by the surface area between the curves and the x-axis.(0.00% line). From this can be inferred that the cumulative welfare loss caused by a R250 flood is over three times larger than that of a R50 flood. It will also take longer before the setback has been totally compensated.

Figure 5.4 Deviation from baseline regional GDP in the first 12 years after the flood in future climate conditions (based on input-output heuristic; no dynamic productivity and capital stock effects)



In the above assessment demand surge effects have not been accounted for. Hallegatte et al (2007) has been assessing the prices of reconstruction work in the aftermath of extreme events in the USA. The price increases depend on the accessibility of the affected area and on the extent of (sudden) surplus demand. As a rough average rises of 25%~30% can be mentioned. The cases cannot be straightaway compared with the Pori case, whereas no actual observations are available for Finnish cases. With the necessary caution it could be expected that demand surge effects are mild in the R50 case and consequently price effects would probably remain under 10%. In the R250 case prices might indeed rise by

30% or more, whereas a part of the extra cost leak away to other areas. With these results in mind it is understandable that staggering of repair work could be seen as an economically relevant option, as it reduces overall cost and diminishes the losses for the regional economy. Obviously this has to be balanced against the material and immaterial costs of delaying some repairs.

A sensitivity analysis was carried out with respect to the degree of displacement of other building activities. In addition to these basic alternatives influences of other effects were tested, being:

- less insurance and less substitution,
- a slower pace of repair, and
- a higher input-output multiplier.

The sensitivity analysis (table 5.5) shows that a reduction in the insurance coverage results in larger accumulated losses. The various alternative displacement scenarios indicate that it pays off to try to keep markets working, in other word to keep people and companies up-to-date informed after the flood took place. It also hints at the value of sufficient flexibility in regional and inter-regional labour markets. The effect of slower repair is slightly favourable, notably when the markets are working well. Of course there are plenty of reasons why it pays off for most constructions to be repaired as soon as possible. On the other hand it does show that priority setting may actually save some money. Possibly not everything needs to be repaired immediately. Furthermore, in some cases more thorough refurbishment may be more beneficial than simply restoring the old situation, even if that would involve some delay.

In this example the accumulated macro-economic impacts in a period of 12 years happen to be approximately as large as the initial direct cost. One should however realise that these figures represent different concepts of ‘cost’ (direct outlays versus loss of GDP) and refer to different time frames. The exercise also shows that the responsiveness and resilience of the local economy do make a difference. Starting from a default level – in this simulated case – high resilience means 30% less macro-economic cost and low resilience 30% more macro-economic cost (when measured as accumulated loss in local GDP). Resilience not only relates to good prevention, but also to good rescue services, good institutions (i.e. the spread of insurance) and some redundancy in infrastructure.

Table 5.5 Influences of different assumptions on accumulated cost

cumulated effect (12 year) in mln €		**CC**	**FC**	difference to default	
default	stepwise displacement	346	380		
	high displacement	366	404		
	low displacement	228	239		
less insurance	stepwise displacement	368	402	6 %	6 %
less substitution	high displacement	389	427	6 %	6 %
	low displacement	253	265	11 %	11 %
slow repair	stepwise displacement	326	357	-6 %	-6 %
(no cap.corr.)	high displacement	361	398	-1 %	-1 %
	low displacement	222	233	-3 %	-3 %
higher I/O	Stepwise displacement	377	411	9 %	8 %
multiplier	high displacement	398	436	9 %	8 %
	low displacement	259	271	14 %	13 %

5.5 Generalisation of the results

As regards the assessment of damage and direct and induced economic impacts the approach for the Pori case study was intently carried out at a quite detailed level. This provides a basis for deciding in what steps less detailed approximations can be used without losing much reliability regarding the results. Streamlining the assessment methods will help to promote their uptake by local and regional authorities and by sector specialists.

For example, for the damage per m^2 in buildings series of default figures have become available for different buildings and different water heights. In combination with appropriate data on building density (per hectare or km^2) this would enable a quick assessment of damage cost in built-up areas. For infrastructure much less general or generalised information is as yet available. Furthermore, apart from the material damage to the infrastructure itself, the extent to which the (local) malfunctioning is hampering other functions (public services, commercial production, residences) in the risk area (and beyond) is very important. It is an example of first order indirect damage. This study did not include effects on public health. Neither did it include possible effects on overall confidence in the local economy. Both types of effects are hard to quantify in terms of impacts on GDP and household income level, but in particular circumstances may well have noticeable effects in the medium to long run. Obviously for a lot of aspects generalisation of findings and application of default unit-costs, ratios, etc. for these effects is still far away.

Accurate GIS data bases and applications, which are able to combine data on natural conditions (elevation, soil type, etc.) with societal data (building stock, economic activity, accessibility, etc.), are extremely helpful for identifying vulnerabilities and for evaluation of the direct cost. After a few replications of such exercises it should be possible to apply adequately representative unit cost figures (i.e. per hectare by type of land use and/or degree of building density). This would create a good basis for generation of replicable and reliable cost-benefit assessments against reasonable cost.

5.6 Conclusions

As regards quantifying cost of climate change induced or enhanced extreme events flooding is a relatively well studied phenomenon in Finland. There are quite some river systems and coastal areas where flooding can occur, even though for different reasons. Of all the flood prone areas in Finland the city area of Pori clearly stands out as the case where the most social-economic damage could occur. Costs of river flooding in Pori in the next few decades could easily cause damages of 40 million to 50 million euro with the current level of protection. Worst case situations for floods with a return time of 50 years may even cause damages of just over 100 million euro. The probability that a flood with a return time of 50 years will occur at least once in the next 45 years is about 0.64. A flood with a return time of 250 years, of which the probability of occurrence in the next 45 years is approximately 0.18, is expected to cause very considerable damage of up to 380 million euro.

When comparing results for present and future climate the direct costs of floods go up by about 15%. However, the impact of economic growth is much larger, being in the order of magnitude of 50%. On the other hand over longer time spans it also possible to avoid building in the most risky areas and to take precautionary measures for existing buildings, notably in shallower parts of flood prone areas.

The direct costs mentioned above not necessarily show up that way in the regional economic accounts. The repair work usually causes a boom in some sectors, possibly for over a year. The consequence is that the regional GDP might first even go up, provided the repair is predominantly carried out by employees from the same region. On the other hand if there is a lot of labour hired from outside the region, whereas wages surge due to scarcity, the result can be a significant outflow to other regions. In subsequent years directly after the repair boom the economy may do less well due to the repayment of funding of the repairs, and due to higher insurance premiums. Together this has causes reduced purchasing power and affects the entire (regional) economy via (reduced) household consumption. The extent to which real estate and other capital goods are insured has significant influence on how the regional economy recovers. Higher insurance coverage promotes quicker recovery. Also the functioning of the labour market and the re-establishment of trade contacts in crippled goods markets are important ingredients for better resilience. They depend on transparency and up-to-date information provision.

As regards the interpretation of the economic effects it should be realised that the initial damage estimates do not include damage of infrastructure, neither the spill-over effects of malfunctioning infrastructure. The study neither includes social-psychological effects (confidence), nor health effects. The role of institutions, norms, etc. is hinted at, e.g. in relation to attempts to promote or re-establish well functioning product and labour markets, but was not taken into account in the actual cost assessment.

6 Evaluating flood protection measures

6.1 General introduction

If the pondering of flood protection alternatives (or of any other hazard protection scheme) would be purely an investment optimisation decision, a cost-benefit analysis would suffice which would include probabilities of extreme events at several levels of flood protection. Such a cost-benefit analysis could be based either on the direct and first order indirect cost of floods, the costs of flood protection, and occurrence probabilities of the costs in relation to different flood protection levels. In that case cost of damage and avoidance cost of damage are straightaway compared. An alternative, wider scoped, approach would be to calculate the regional economic impacts of alternative flood scenarios in conjunction with different flood protection levels. Subsequently the implied cumulative losses in GDP over a certain time period can be compared for the different scenarios, while accounting for differences in probability of occurrence. In the latter case is not only accounted for the induced effects of flood damage, but also the induced effects of investment in (extra) flood protection.

Yet, floods and other natural hazards entail also other effects, such as on public health and the environment. Often these effects can only be partially monetised, whereas monetisation as the only way of impact representation may be frowned upon by a part of the interest groups. Furthermore, also the alternative hazard reducing investment options can have non-economic effects, such as on the environment, the landscape and local access levels (barrier effects). Some of these effects, even though originally ‘non-economic’ by themselves, may have economic implications. For example, changes in the local landscape and access levels can affect the value of real estate in (parts of) the study area.

Next to the role of non-economic effects in the evaluation of hazard reduction options, there are two other reasons why a cost-benefit analysis (of either of the above mentioned type) of a few investment alternatives can be unsatisfactory. Firstly, the distribution of impacts of natural hazards and the distribution of impacts of funding hazard reduction investment can be quite different in terms of spread over socio-economic groups. Basically, it is possible to apply weighing methods to deal with these issues, but in that case the problem moves to the choice of the weights (which can be – partly – neutralised by doing sensitivity analysis). One way or the other the judgement of equity effects requires involvement of relevant interest groups.

A second reason for extending the analysis beyond a cost-benefit analysis is based on insights from behavioural economics, and more in particular ‘Prospect theory’ (Tversky and Kahneman, 1992). The key point is in this case that most people appear to have a different priority setting with respect risk taking, than the choices that would follow from application of economic optimisation based on expected values. In the case of hazards both the feature of uncertainty in conjunction with very large effects and the feature of putting more weight on negative than on positive effects have an influence. The combined effect is that a survey among possibly affected households and (small) businesses would tend to result in a choice for higher protection standards than what a purely economic analysis would indicate as economically optimal option.

In the TOLERATE study an exploratory multi-criteria assessment (MCA) was made which involved representatives from various stakeholders. The MCA was constructed as an extended cost-benefit analysis. As regards the monetary information it used the direct and first order indirect cost of floods, the costs of flood protection, and occurrence probabilities of the costs in relation to different flood protection levels. It should be stressed that it was an exploratory assessment only, based on the Pori case. A part of the information in the MCA was far too sketchy for any official decision support analysis, whereas also the participation of interest groups was rather patchy compared to what would have been the case in an official assessment. A full report of the exercise can be found in Molarius et al (2008). In the next section a summary will be provided of the exercise. Lessons, needs for further development, and conclusions are presented in §6.3.

6.2 A summary of the exploratory MCA for Pori

As it concerned only a small first test of this approach the delineation of the assessment and the invitation of the stakeholders needed to be done by the researchers in a pragmatic way (quick and low cost). In real world decision-making situations, the definitions of the points of departure and the decision-making framework are important and should be subject to some degree of interaction with the involved interest groups. Agenda setting, when exclusively done by a limited number of bureaucrats or technocrats or for which only a subset of interest groups is consulted, may lead to exclusion of relevant alternatives and/or to erosion of the credibility of the decision-making process among the public.

Another essential task is the identification of the relevant stakeholder groups[23]. Since this exercise concerned only a test, diversity in opinions was needed, but it

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[23] Another selection feature could have been the extent of experience with flood (as a professional, in one's living environment, in the own dwelling). As part of the TOLERATE project a questionnaire distributed in three flood prone areas in Finland showed that respondents that had experience with floods were systematically more cautious or pessimistic with respect to the expected efforts and duration of the recovery after a flood.

was not necessary to insist on complete representation. There were even simple technical reasons, such as workable size of the group, which did put some tentative upper limit on the number of participants. The eventual set of participants turned out to be sufficiently diverse.

The advance information sent to the participants consisted of an invitation (also explaining the context of the exercise), an agenda for the day, and a compact collection of overhead material of state of the art knowledge and the basic solutions to be discussed. The expert session started with a rehearsal of the basic information and procedures of the day.

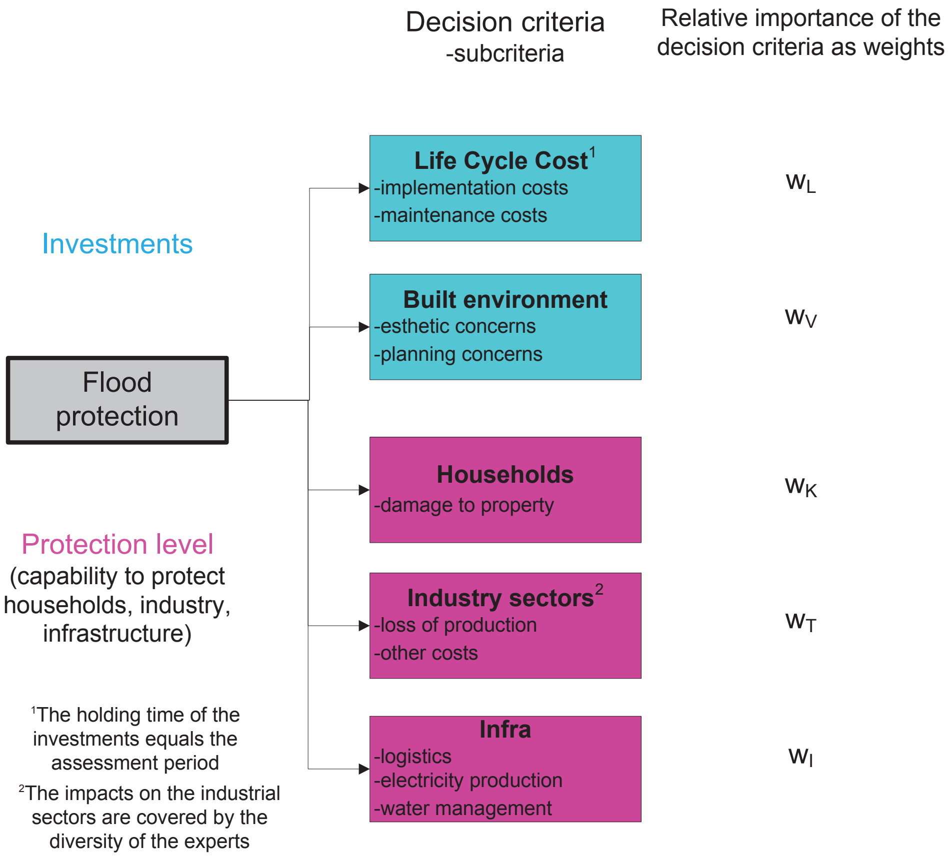
The aim of the session was to consider different flood protection strategies and different stakeholders’ opinions about these strategies. Multiple Criteria Decision Analysis (MCDA) and a value tree presentation (Keeney and Raiffa, 1993; Keeney, 1992) were used to structure the opinions. The principal idea in MCDA is to present the different *decision criteria* in a tree structure to aid the decision process. The set of criteria should reflect which features the decision makers find important when making the decisions. First the *decision alternatives* to be considered are chosen. Then all decision alternatives are assessed with regard to each criterion separately, one at a time. Every alternative receives thus a *value* with regard of each criterion. Next the criteria are weighed against each other according to their relative importance. Finally, the *aggregate value* of each alternative is calculated as the weighed sum of its values with respect to the criteria. If the decision maker has given all preference statements according to his true values, which is not a trivial task, the decision maker prefers the alternative that receives the highest aggregate value.

A computer system was used to facilitate the session. In order to collect the opinions of all participants in an efficient way, the participants had laptop computers connected via the Internet to their disposal. Using a Group Decision Support System software called GroupSystems ThinkTank, the participants were able to give both numerical and verbal input throughout the process. Web-HIPRE, a dedicated MCDA software package, was used for the MCDA presentation and calculation.

The most significant framing of the decision problem was made by pre-defining the *decision criteria and their sub-criteria*, shown in the form of a value tree in Figure 6.1. The value tree comprises of five decision criteria broadly representing protection and use of resources. The red shading is associated with the three protection-criteria, whereas blue with the two resource-criteria. The protection is measured in terms of the capability to mitigate the adverse consequences of a flood event for the stakeholders can be alleviated.

The outcome of the decision on the investment-criteria (use of resources) is deterministic: the investments incurred by selecting a protection level entail the use resources that have a, more or less, fixed net present value for the investment period considered, i.e. 45 years. Also the impacts on the built environment are deterministic – some impacts having a positive sign, e.g. providing opportunities for innovative land use.

Figure 6.1 The value tree and weights denoting the relative importance of the decision criteria. The sub criteria in the boxes are the main dimension used in defining the respective scales.



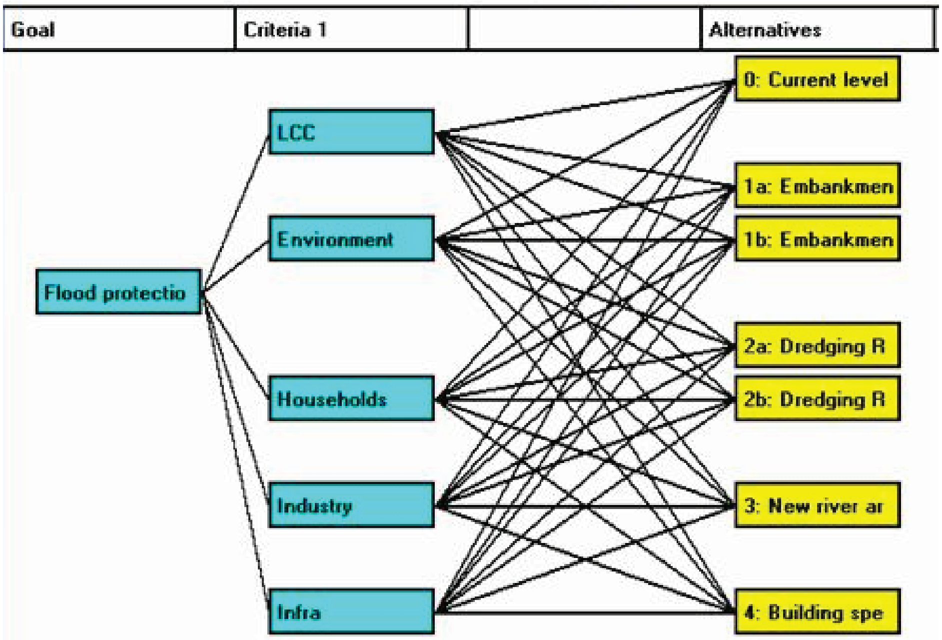
The decision outcomes with respect to the protection-criteria are uncertain: the benefits of flood control will materialise only with the occurrence of the flood. Thus, all protection benefits are anticipatory at the moment of decision-making. It should be noted that in the decision-making simulation the damage levels per return time category (R50 and R250) were not discounted nor weighted by the different probabilities of occurrence of R50 and R250 events in the considered time span (2005-2050). The direct and first order indirect costs as shown in table 5.4 were presented to the participants. Also flood maps for the R50 and R250 event simulations (such as in figures 4.8 and 4.9) were shown.

Figure 6.2 shows the value tree defined for the expert session together with an indication of the analysis phases. The analysis phases were:

1. Review of the flood protection alternatives (decision alternatives),
2. Assessment of the value of the alternatives with regard to each decision criterion, and
3. Weighing of the criteria according to their relative importance.

The value tree was input to the Web-Hipre tool (www.hipre.hut.fi).

Figure 6.2 Decision model of the expert session with analysis phases indicated



The protection solutions where discussed based on pre-defined description that were fitted to the situation in Pori:

0. Current protection level (some repair of current low embankment)
1. (Mainly) Stronger embankments
    1.a. protection level up to R 50
    1.b. protection level up to R250
2. (Mainly) Dredging
    2.a. protection level up to R50
    2.b. protection level up to R 250
3. New river arm
4. Building or building block specific protection

In this phase each protection alternative is scored against each decision criterion. The participants were asked to give scores from 1 to 10 where 10 is given for best performance. A 1 denotes the worst possible score. The scores were then scaled to a 0-to-1 scale, which is the standard format in a MCDA process. The mean values across the participants were used to represent the group opinion. After the numerical assessments, the participants were asked to write down the rationale behind their assessments. Basically, scoring cannot be performed unless the experts review the performances of the alternatives jointly and decide upon their relative performance. In the study, the performance was been rescaled into four pre-defined protection levels. These performance levels are 'Full protection against R50 and R250 floods', 'Full protection against R50 floods', 'Improved protection for selected buildings', and 'Current control level'.

In this phase the relative importance of the five criteria is defined (see Figure 2) and the overall score of each alternative is computed. The participants were asked to assess the relative importance of the criteria by distributing 100 points according to their opinion. The question asked is: how many points would you distribute to the changes from worst to best on the criteria, the points reflecting the relative importance of the changes? Again, the participants were asked to give the rationale behind the scores directly after the assessments. The weights were then normalised to sum up to one and mean values of the weights were calculated to represent the group opinion. In fact, by specifying the weights w_L, w_V, w_K, w_T, w_I, the performances of alternatives on the different decision criteria are made commensurable: the weights (normalised weights w_i) adjust the criterion-specific scores of an alternative ($s_i(a)$) such that they can be summed up to a single value $V(a)$ score depicting the overall goodness or value of the alternative a as given by

$$V(a) = \sum_{i=1}^{5} w_i s_i(a) \quad w_i \in [0,1], \sum_{i=1}^{5} w_i = 1,\ s_i(a) \in [0,1] \forall a \tag{6.1}$$

The additive form for the value function entails that the decision-maker / expert shows mutual preferential independence: the preference of one alternative over another on any criterion does not depend on the levels of performances shown by the alternatives on any other criteria.

It is expected that the ratings, weightings, and therefore the values of the experts will vary a lot depending on the expert's inclination to be optimistic or pessimistic as to the occurrence of a flooding, and to the extent he/she is involved in the consequences of the flood. It should be kept in mind that the probabilities of experiencing a 1/50 or a 1/250 flooding are 0.16 and 0.58, respectively, during the planning horizon of 45 years.

The one day session concludes with an overall evaluation round of the day. Participants could provide written and oral feedback on the procedures, the usefulness, particularly interesting features, weaknesses, etc.

6.3 An impression of the kind of results produced by the MCA test

In the overall assessment the eventual group average weights of the decision criteria at group level were as follows (total adding up to 1):

- life cycle cost (resource use): 0.231
- living environment (resource use and quality): 0.126
- households (protection): 0.222
- business sector (protection): 0.145
- infrastructure (protection): 0.277

As stated before the weight for infrastructure can be regarded as possibly on the high side, whereas the weight for business sectors seems to be on the low side, e.g. think of possible consequences for employment. A fairly widely shared opinion among the experts was that companies have better possibilities to prevent flood damages than households.

The group judgement of the performance scores per flood protection alternative can be obtained by applying the product sum of the above weights and the respective scores per criterion per protection alternative. Figure 6.3 shows the summary scores per flood protection alternative. The majority of the experts believes that the classical flood protection measures, such as dikes and dredging, are the best alternatives. According to the results those flood protection measures which can prevent R250 flood damages are slightly preferred over protection measures which can prevent only the damages of R50 floods. This preference results despite the fact that the measures necessary to arrive at the R250 protection level are clearly more expensive. However, when taking account of the inaccuracy and imprecision of parts of the analyses both flood protection levels deserve further attention. For both protection levels dredging and dikes are the prominent alternatives, even though also the construction of a new river arm was considered as a good alternative, provided it also succeeds to prevent R250 flood damages[24].

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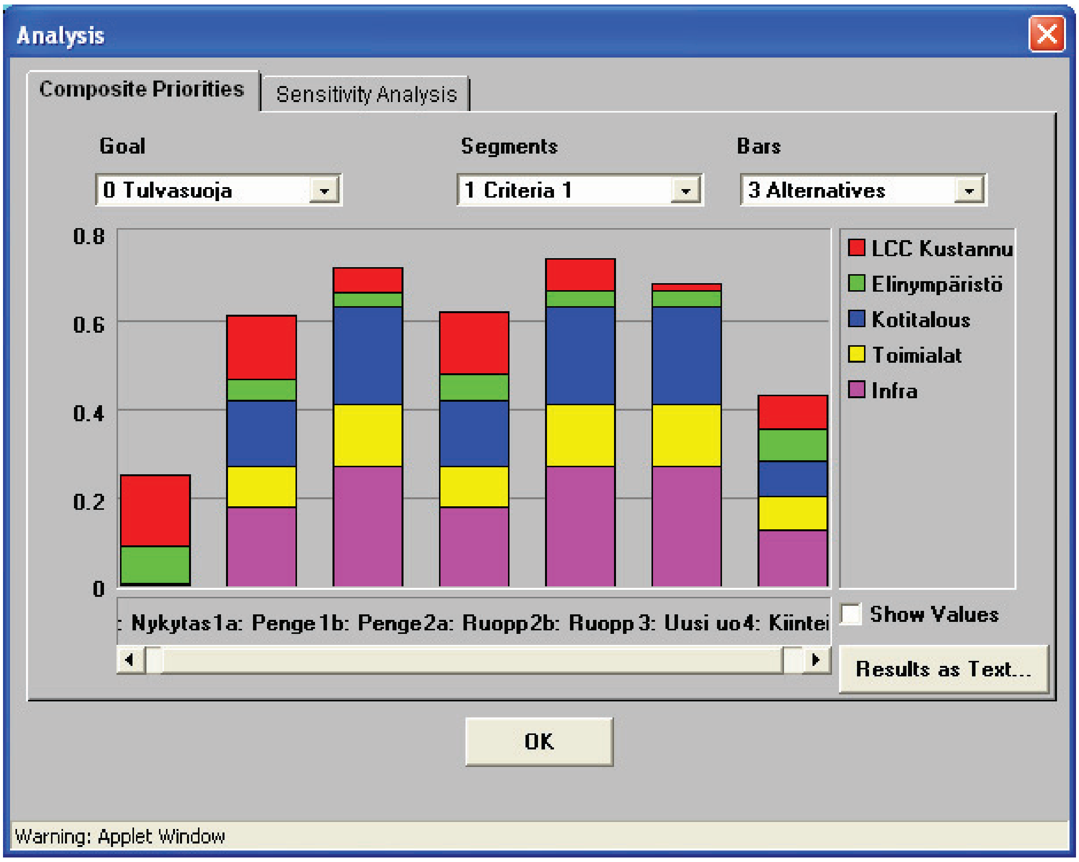
[24] Unlike the options dike reinforcement and dredging the new river arm not necessarily has only negative landscape and ecological effects. It creates all kinds of new potential.

Figure 6.3 Normalised total group scores per flood protection alternative



Goal: 0 Tulvasuoja

Segments: 1 Criteria 1

Bars: 3 Alternatives

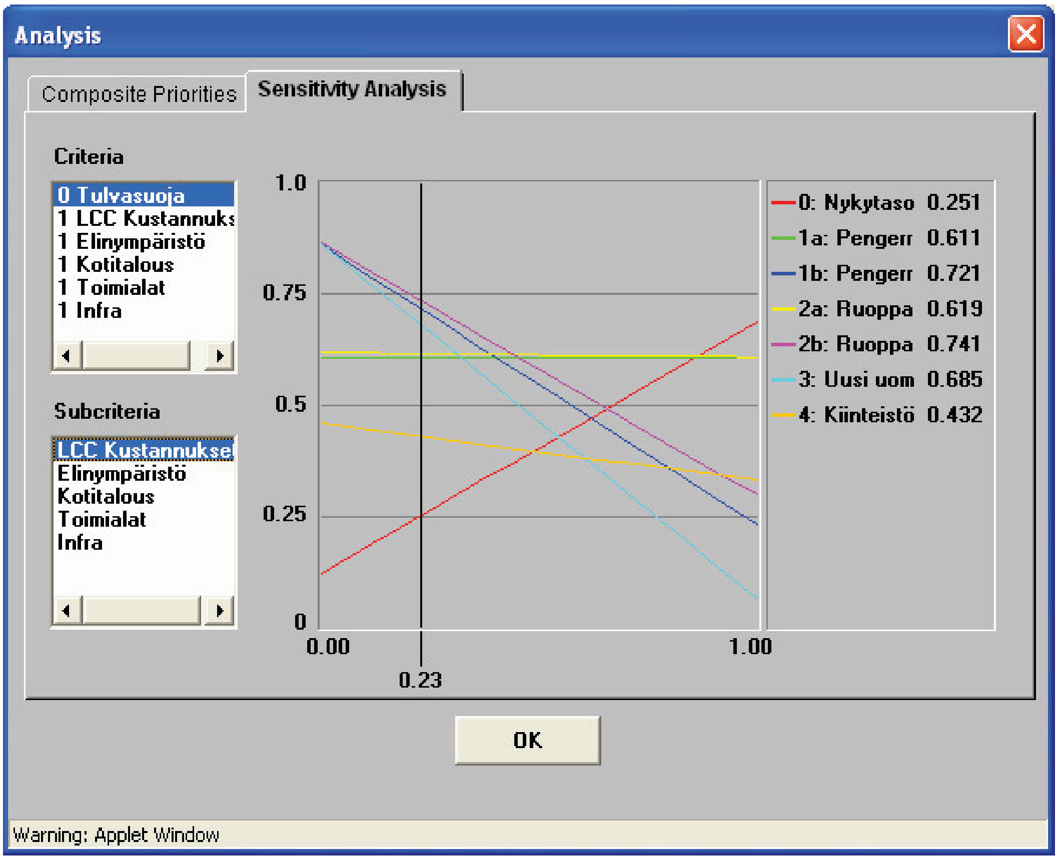
Warning: Applet Window

By manipulating the weights per sub-criterion a sensitivity analysis can be performed. Below is discussed the effect of varying the weights of lifecycle cost of which the effects are also shown in figure 6.4.

The zero-option may get relevant only, if people would attach an extremely high value to (own) money in the nearby future (e.g. LCC weight > 0.8 instead of the average in the MCA test, being 0.233 (see previous page)). This fits well with the general notion that willingness to pay for risk reduction improves when wealth levels are rising (Morone and Ozdemir, 2006). Even though we are uncertain about the representative value of the weights, it's unlikely that LCC would get more than 80% of the weight sum.

On the other hand the resulting weight of costs in this study (0.231) is possibly low. One argument for this is that we have not been considering a portfolio of all kinds of useful public expenditures (schooling, medical care, etc.) with which this project has to compete over public budget money. In the discussion round between the subsequent decision steps this balancing of the overall public budget was mentioned however. On the other hand we neither formally involved preferences about cost sharing between levels of government, etc.

Figure 6.4 Implications of varying the weight of lifecycle cost for the scores of the and rankings of the flood protection solutions



Assuming that relevant weight scores would be between 0.2[25] and 0.7, there are 3 patches:

1. between weight 0.20–0.45: options 2b (and given other uncertainties) 1b are superior;
2. between weight 0.45–0.80: options 2a and (and given other uncertainties) 1a are superior
3. for a weight >0.80: option 0 would be preferred, but this seems to be an irrelevant range

Assuming that other, not yet handled, dimensions (such as impact on city planning) would not greatly upset the results, the societal discussion would circle around dikes and dredging. If (current) money counts appreciably the 'A'-variant (R50 protection level) would be preferred, otherwise the 'B' variant (R250

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[25] A weight of 0.2 would mean that 80% of the weight (importance) is attributed to other criteria than cost. Vice versa, a weight of 0.8 would mean that the other criteria together would count for only 20%.

protection level). The choice between dredging and dikes is than probably decided by other factors, or new cost estimates make the differences larger. It should be kept in mind however that the new river arm could nevertheless become a relevant option, e.g. when embedded in a wider context of city planning. Similarly, building specific measures might still be relevant, e.g. in combination with R50 dredging or dikes,

6.4 Lessons and conclusions

As was expected the decision-making simulation exercise did not provide strong guidelines regarding preferred options. Nevertheless the results indicate that in a real world exercise there would most probably be broad support for a significant improvement of the protection level. However, the extent of the improvement and the preferred type of solution would need a more elaborate assessment in which the participants would be involved in an earlier stage and would be better informed (over time). Among others participants should have a say in the definition of evaluation criteria and the identification of solution alternatives to be included in the comparison.

The exercise also indicated that there are some risks for societal disputes about prefer-able solutions. In first instance it seems that investment costs are not necessarily problematic, but the impacts of different solutions on the living environment can be a source of misunderstanding and dispute. Consequently these impacts should be assessed thoroughly for all alternative solutions. Another risk related to the interpretation of the effects on the living environment is that of choosing the zero-alternative as a kind of deadlock compromise.

Even though participants had rather varying opinions on how such a decision-making exercise should be carried out, a majority was of the opinion that this is a useful and all in all a quite effective (compact) way to engage a larger collection of interest groups in the evaluation and decision making regarding significant public projects

In the preparatory phase of the TOLERATE study was hypothesized that in principle the assessment of the risks of floods, including the reinforcement effects of climate change as well as possible flood protection measures, could be understood as an optimal control problem. Already in that phase it was indicated that most probably such an optimal control approach would not be feasible in a strict sense, but rather works as a metaphor and helps to systemise the comparison of alternative strategies. The decision making simulation exercise discussed here exemplifies this point. Not only is there uncertainty regarding a part of the information, but there is also uncertainty about the way different interest groups conjecture the overall problem. A part of the latter uncertainty can be somewhat relieved by providing better and more accessible information.

However, partly the uncertainty may be fundamental, because the stakeholders are facing limitations in their capacity to evaluate all information. Furthermore, the choices ahead may involve trade-offs that are very hard to monetise if at all, whereas the stakeholders may even change opinion several times. Obviously, this is does not mean that a cost-benefit assessment loses its significance, as stakeholders still want to know what are the economic consequences of stressing as such non-monetised features.

7 Possible other effects of extremely high or low precipitation

7.1 Implications for electricity production

The electricity production in the Nordic electricity system consists on average for about 50% of hydro power. Simulations of future precipitation patterns in Norway, Sweden and Finland indicate that up to 2050 annual electricity production from hydro power could increase easily by several percent and possibly by 10% (Gabrielsen 2005). On the other hand the seasonal precipitation patterns are expected to show larger year-to-year variation, i.e. be less predictable (Bye et al, 2006; Gabrielsen et al, 2005). Average winter temperatures are expected to rise significantly and hence demand for space heating will be less (for a given building stock) (Kirkkinen et al, 2005; Gabrielsen et al, 2005). Further improvement of building insulation and in combination with utilisation of the passive solar potential as part of greenhouse gas emission reduction policies can be expected to enhance the climate change induced reduction in demand for space heating. The production cost of electricity based on hydro power tends to be lower than of any other production type. Furthermore, as it is free of greenhouse gas emissions, it does not create additional cost of emission right such as fossil fuel based power does. All in all *in absence of any other factor* the impact of climate change on Nordic electricity systems in the next three to four decades would be:

1. The average annual share of hydro power in the total generation mix would increase somewhat.

2. The slightly increased abundance in hydro power in conjunction with lower (average) demand, notably in winter, would have a downward effect on the wholesale price of electricity, this effect may be further leveraged due to avoided cost of emission rights.

3. The higher volatility in the availability of hydro power and the worsened predictability of hydro power availability represents a risk premium which is to be hedged against and may also create a need to build slightly more reserve capacity, thus resulting in a lower overall capital utilisation rate; all in all the consequence is an upward pressure on the wholesale price of electricity.

The above mentioned effects will however mix in with other factors, such as the development of total capacity and total demand in the Nordpool area[26], the functionality and capacity of the main power links within the Nordpool regions, the expected extension of power links with Western-Europe and the Baltic, and the developments in the European emission trade system (EU-ETS). For example, the increase of link capacity with Western-Europe can be expected to raise wholesale prices in the Nordpool area.

Gabrielsen et al (2005) used the RegClim model to assess impacts of climate change on electricity demand, on electric power supply from hydro and wind sources, and on resulting changes in wholesale power prices *when all other factors are kept constant*. The availability of hydro power in Finland may increase relatively more than in Sweden and Norway. In absolute terms it would amount to 1.5~2 TWh extra hydro production by 2040 (for a given hydro generation capacity). Yet, for the Nordpool area as a whole the changes in Norway (approx. 10% more water inflow by 2040) are decisive with respect to e.g. wholesale prices. The climate change induced addition may amount to 25~30 TWh *more* hydro production compared to the precipitation regime of the recent past. The RegClim model simulations show a decrease of electricity demand due to temperature changes of about 4% for Finland (by 2040). For Norway and Sweden the reduction is estimated at about 3%. The simulated demand and supply effects were subsequently used for assessing the effect on the wholesale price per market area. For Finland a first order price reduction of € 2.40/MWh results. However, the lower price invokes some extra demand, whereas there are also other factors to count for in a long term scenario, such as increased net export to Western Europe. Consequently, the simulated eventual price reduction was rated at € 1.70 per MWh.

In Honkatukia et al (2008) several functions were estimated for the day-ahead price in the Finnish market area of Nordpool. The function[27] which contained most information about the status of the system (hydro filling rate, temperature, utilisation rate of the installed generation capacity) was used for an alternative check of the climate change induced price effect by translating the temperature changes, hydro filling, and their impacts on overall capacity utilisation into model input. An average price reduction of € 2.10/MWh results, when using the model version representing annual demand (as distinct from demand by season). In this case no secondary demand effect due to lower prices is taken into account.

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[26] The Nordpool area comprises of the electric power systems of Norway, Sweden, Finland and Denmark.

[27] An AR(1 2 5)-GARCH model with the day ahead power price as dependent variable and the prices of emission rights and natural gas, the utilisation rate of Finnish production capacity, cross-border power links, the hydro filling rate, the temperature, and weekend and holiday dummies as explanatory variables. Most variables were transformed into their natural logarithm form. See Appendix 5 for calculation details.

Please note that these simulated price changes not necessarily reflect strategic behaviour regarding investments in new capacity, which would tend to get postponed. Without such changes in strategic investment behaviour the benefits of price reductions would accrue to the power sales companies and/or the final consumers of electricity. By postponing investments the power production sector can recapture a part of these transfers, provided such behaviour does not cause new (competing) entrants at the production side.

Bye et al (2006) assessed the impact of the volatility of hydro power capacity on wholesale prices in the Nordpool area. The developed model seems to be capable to approximately reproduce the strong price swings in connection with the low hydro levels in autumn/winter 2002/2003. Very low hydro filling levels (for a given season) may lead to 100% higher prices in extreme circumstances. These price effects owing to volatility are much larger than the price effects of changes in average conditions presented above, i.e. an order of magnitude of 10 to 20 Euro extra per MWh in case of low hydro filling instead something in the neighbourhood of a reduction of 2 Euro per MWh for the effect of changes in average weather conditions.

By applying the estimated function for winter periods from Honkatukia et al (2008) a crude assessment was made of the size of the price effect of volatility (figure 7.1 and Appendix 5). An already tight winter situation was extra stressed by reducing hydro availability and conversely in a situation with moderate demand and sufficient hydro capacity more hydro was added. The simulated extra tightness resulted in a price mark-up of approximately 7 Euro per MWh on top of a price varying between € 46/MWh and € 53/MWh. Conversely, in case of hydro abundance a price reduction of about 5 to 6 Euro per MWh was calculated, getting the system price close to € 40/MWh in some cases. In principle by choosing other combinations even larger variations in price could be generated.

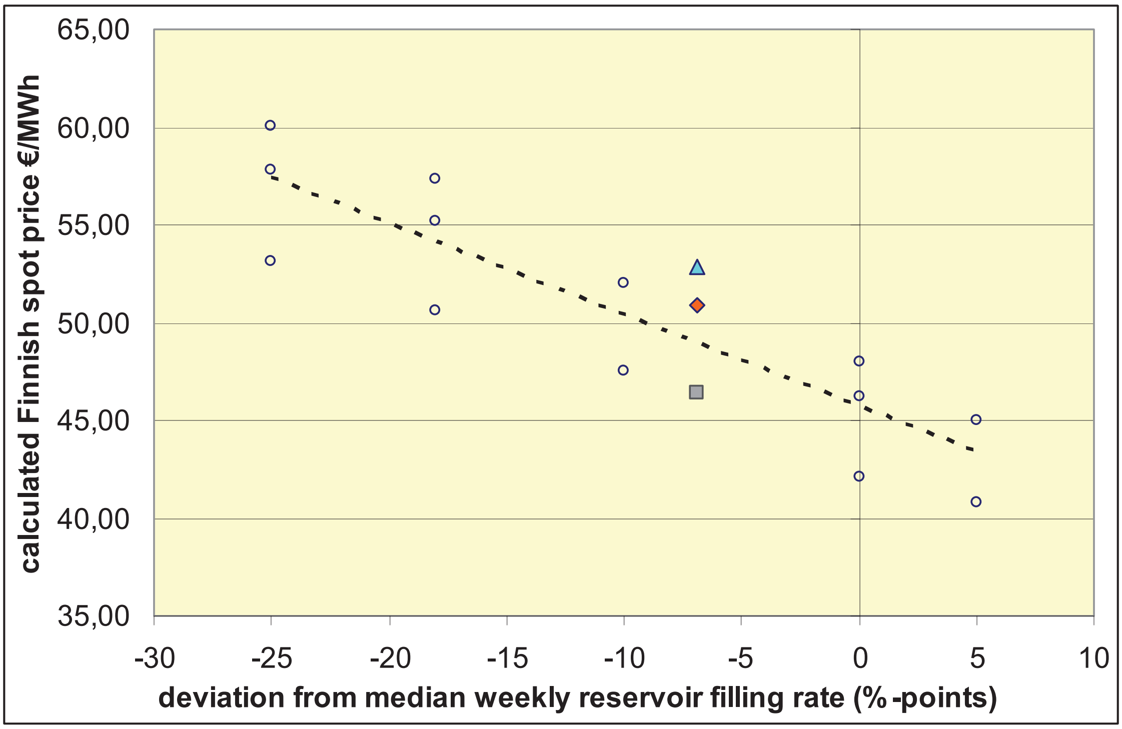


Figure 7.1 *Impacts of different reservoir filling rates in the Nordpool area on Finnish spot price in conjunction with different reference load levels and temperatures*

Both volatility exercises show that even though the basic effect of the changes in average weather conditions seems to be a modest lowering in the price, the increase in price swings due to increased volatility of weather conditions are easily 3 to 5 times larger. Admittedly, these price swings are of a temporary nature, but in some cases the return to the reference level can take considerable time and thereby the transfer of wealth between producers and users can rise to very considerable levels. In this respect it should also be realised that over a time span of several decades a few periods with overrepresentation of dry or wet years should be accounted for. This means that investment risks are rising. The ultimate implications for wholesale and retail power prices depend on the ways the increased risks are mitigated. The options are hedging (via supply derivatives), more reserve capacity, more exchange capacity with other areas, and hedging at the demand side (a wider portfolio of DSM and flexible pricing).

7.2 Low/no-precipitation periods

Dry spells, or prolonged periods with little rain, decrease surface and ground water level, thereby having adverse effects on the environment and various sectors of the society, e.g., agriculture, hydropower generation and forestry. Summer 2006 in Finland was exceptionally dry, with less than 25% of the average precipitation sum in the vicinity of the Bothnia Bay and in the Helsinki metropolitan area. At the station Helsinki Kaisaniemi during June-August, it rained only 35 mm, the smallest summer rainfall amount ever recorded since the onset of the precipitation measurements there in 1845. Among numerous consequences of the wide-spread drought, the risk of forest fires in Finland and the surroundings was larger than usually.

In the following, observations will be used to assess 20-year return levels for durations of spells with only a small amount of precipitation (*DS20*). Secondly, we will present multi-model mean projections for changes in the average summer maximum number of consecutive dry days (*CDD*), discussing the level of agreement between the models.

7.2.1 Recurrence of dry spells based on observations

Daily observations at twelve stations in Finland (Table 3.1) were utilized to examine *DS20*.. We considered several thresholds (10, 25, 50, 100, 200 mm) of the accumulated precipitation sum and picked out the longest spells per year to achieve these thresholds. The 20-year return levels were assessed applying the so-called “peak over threshold” (POT) approach, discussed in Section 3.2.1.

According to the observations, on average once in two decades there is likely to be a period of about 50–60 days with the precipitation sum of consecutive days remaining below 10 mm (Fig. 7.2). The variations between the different stations are very small for the threshold of 10 mm but increase rapidly with the increasing upper limit of accumulated precipitation amount (Fig. 7.3). Considering the best estimates, one can see that the 20-year return level for 25 mm of rain at one station may be almost as large as the return level for 50 mm at another location. The quite large differences between the stations for the high thresholds may be partly caused by spatial variations of climate, although in contrast to heavy precipitation, no clear south-to-north gradient could be found. However, the relatively short periods of data, about 50 years, increased the uncertainty.

Figure 7.2 *The 20-year return level estimates (days) for the duration of spells with a small amount of precipitation, as a function of the accumulated precipitation thresholds (in mm), at 12 measurement stations. The dots give the maximum likelihood estimates and the error bars depict the 90% confidence intervals. See Table 3.1 for the stations.*

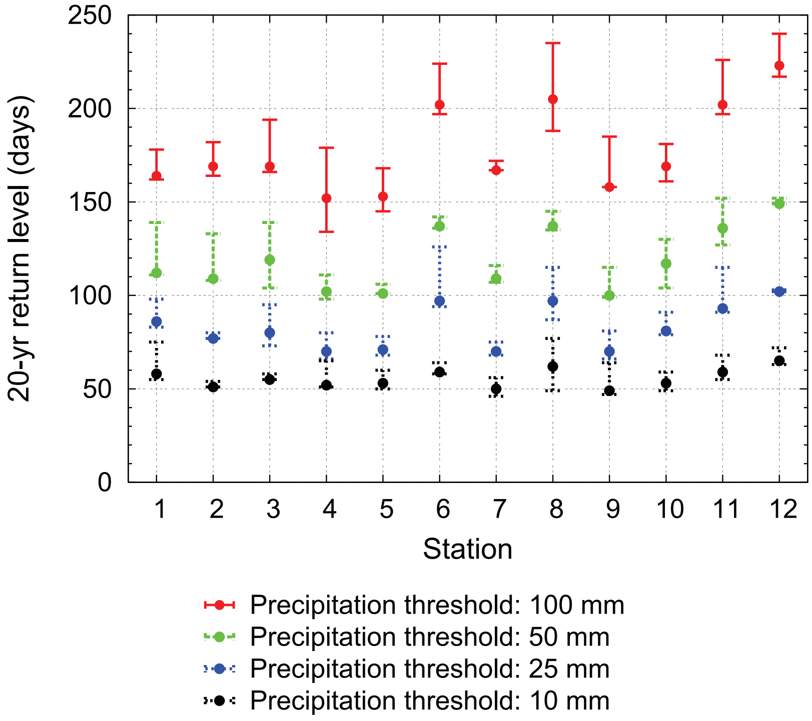
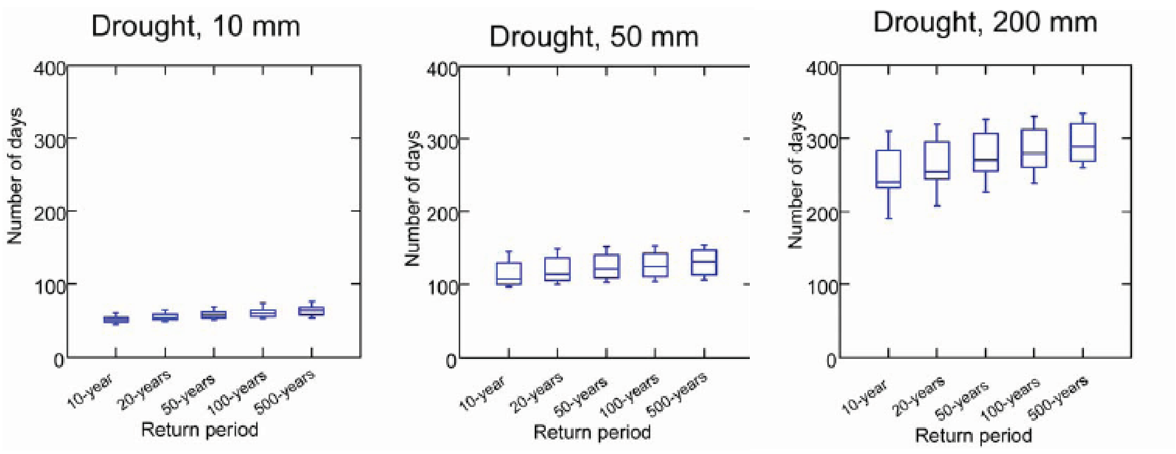


Figure 7.3 *The variation of the maximum likelihood return level estimates among the studied 12 stations versus the return period for the length of dry spell lengths in case of 10, 50 and 200 mm drought, i.e. the precipitation of consecutive days remained below those threshold. See Fig. 3.2 for details (Venäläinen et al. 2007b).*

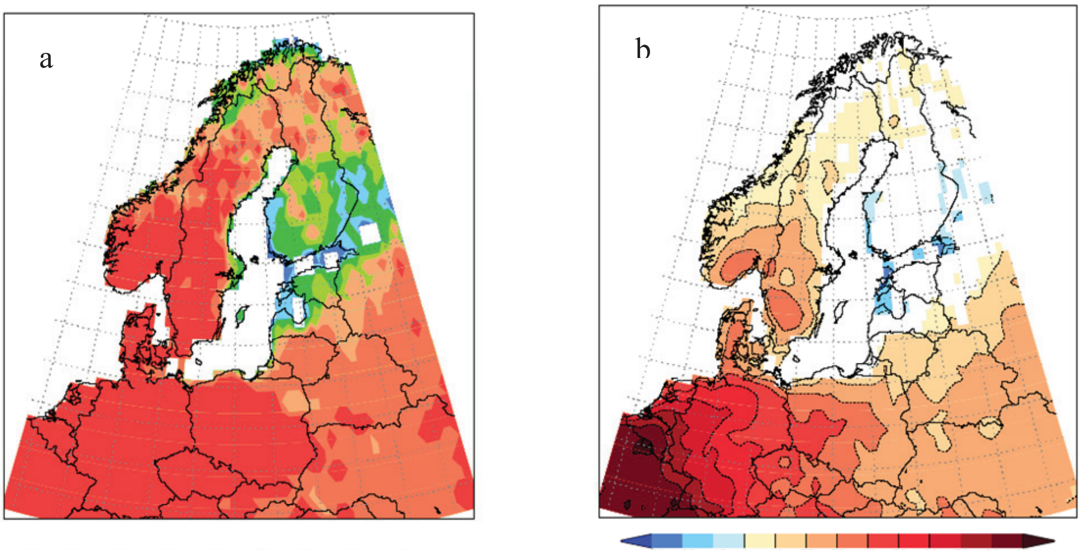


7.2.2 Occurrence of dry spells based on model projections

On the southern and western coast of the Baltic Sea, all seven RCM-H-A2 simulations agreed on an increase in the 30-year mean of the summer maximum number of consecutive dry days (*CDD*) by the end of this century (Fig. 7.4). In southern and central Finland, however, about half of the models suggested an increase in *CDD* and the rest a decrease or no change. Because of the disagreement on the sign of the change (and a low signal-to-noise ratio), wide areas in Figure 7.3b are not shaded with colour. It is noteworthy that in northern Finland the models agreed on longer summer dry spells, although the sign of the change of the country-average was uncertain (see Table 3.4).

In winter the longest periods without precipitation were projected to become shorter in most of Finland (not shown), and the sign of the country-averaged change was negative (Table 3.4 in Ch.3). Only in north-eastern areas of the country about half of the models suggested an increase and the rest a reduction or no change in *CDD*. In spring and autumn, as well as on annual basis, most RCMs agreed on a slight increase in CDD in southern and central Finland, but in northern Finland the longest dry spells were projected to remain practically unchanged or become shorter. Consequently, the sign of the country-averaged annual, spring, autumn (and summer, see above) mean changes remained uncertain. In general, *CDD* had a tendency to decrease with increasing seasonal and annual mean precipitation.

Figure 7.4 Projected changes in the 30-year mean of the summer (JJA) maximum number of consecutive dry days (CDD) by 2071-2100, compared to 1961-1990, based on PRUDENCE RCM simulations with A2 radiative forcing scenario.



a) The number of models indicating a positive change.
b) Multi-model mean change (%); in white land areas three out of seven models disagree on the sign of the change. (Jylhä et al. 2007)

7.3 Drought conditions under historical and future climate

7.3.1 Introduction

The Palmer Drought Severity Index (PDSI) is a regional drought index developed by Palmer (1965) for describing meteorological drought in the United States[28]. Using readily available climatologic input data on monthly temperature and precipitation in combination with information on soil water holding capacity, it classifies the soil moisture condition into classes from extremely wet to extreme drought (Table 7.1). The index is calculated as the sum of a fraction of the previous index value and the current moisture anomaly from a value "climatologically appropriate for existing conditions" (Palmer 1965). It uses a representation of the water balance that allows for evapotranspiration losses when the potential evapotranspiration is larger then the precipitation, and water losses through run-off when precipitation exceeds the storage capacity of the soil.

Table 7.1 Soil moisture classification by values of the Palmer Drought Severity Index (PDSI).

PDSI value	***Classification***
≥ 4.00	Extremely wet
2.00 – 3.99	Very wet
1.00 – 2.99	Moderately wet
1.00 – 1.99	Slightly wet
0.50 – 0.99	Incipient wet
-0.49 – 0.49	Near normal
-0.99 – -0.50	Incipient dry spell
-1.99 – -1.00	Mild drought
-2.99 – -2.00	Moderate drought
-3.99 – -3.00	Severe drought
≤ -4.00	Extreme drought

The original index uses several empirical parameters that were calibrated with data from a limited number of stations in the United States. Wells et al. (2004) developed the index further by introducing a self-calibration algorithm that determines these parameters dynamically. Wells' self-calibrating Palmer Drought Severity Index (SC-PDSI) is reported to behave consistently over diverse

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[28] Some authors contend that the index describes hydrological or agricultural drought rather than meteorological drought, because it includes a soil component (e.g. Briffa et al. 1994; Quiring and Papakryiakou 2003).

climatologic regions (van der Schrier et al. 2006). Although developed for the United States, PDSI has also been applied in global (Dai et al. 2004) and European (Briffa et al. 1994; van der Schrier et al. 2006) analyses; however, an application of the index specifically for Finnish or Nordic conditions has not yet been conducted.

7.3.2 Data and methods

Gridded data for Europe on soil water holding capacity from Groenendijk (1989) were interpolated from their original resolution of 0.5º x 0.5º to 10' x 10' (approximately 9.3 x 18.6 km at 60°N) using bilinear interpolation. Monthly mean air temperature and precipitation for the period 1901–2000 were extracted from the CRU-TS 1.2 gridded European data set at a spatial resolution of 10' x 10' (Mitchell et al. 2003; New et al. 2002). Scenarios for the 21st century were constructed using out-puts from three coupled Atmosphere-Ocean General Circulation Model (AOGCM) simulations – HadCM3, CSIRO-Mk2 and NCAR/PCM – for the SRES A2 scenario of greenhouse gas and aerosol emissions. The simulated changes between the periods 1961–1990 and 2071–2100 were combined with the observed de-trended time-series[29], thus constructing scenarios that reproduce the observed time series of inter-annual variability while representing the future trends in temperature and precipitation from AOGCMs (modified from Mitchell et al. 2003).

SC-PDSI was used in this study to assess the summer moisture conditions in Finland and the Nordic region. The calculations were conducted with a modified version of the computer code by Nathan Wells[30]. Potential evapo-transpiration (PET) was estimated from mean monthly temperature and day length using the Thornthwaite method (Thornthwaite 1948). Latitude was used to estimate the day length, whereby locations north of 55°N were assumed to have the same day length as locations at 55°N to avoid unrealistic values at high latitudes (van der Schrier et al. 2006; van der Schrier, pers. comm.). The algorithm requires the definition of a climatological "normal" period from which deviations are calibrated to fall into the drought classes. We used the complete period 1901–2000 as the normal period following the approach of van der Schrier (2006). Although calculated on a monthly time-step, the index was analysed only for the summer months, June–August, to reduce the effect of a possible bias as the calculations do not account for snow or frost.

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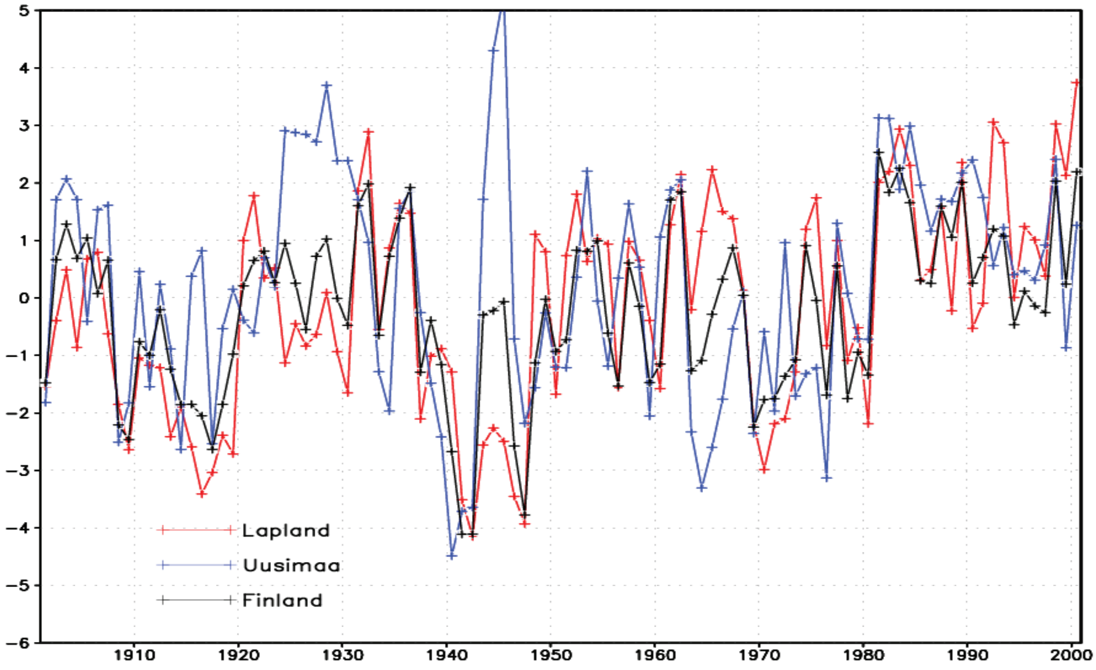
[29] Removing the 20th century global warming trend that can be attributed, in part, to anthropogenic forcing (cf. Hegerl et al. 2007).

[30] Source code downloaded from http://nadss.unl.edu/downloads.

7.3.3 Results

Summer moisture conditions in Finland, as depicted by the June-August averages of SC-PDSI, have a strong inter-annual variability throughout the 20th century with exceptionally dry periods in the 1940s. Spatially averaged values[31] for all land grid cells in Finland give the driest summers in the years 1941, 1942, 1947 (Fig. 7.5). In Uusimaa in southern Finland, the three driest summers are 1940, 1941 and 1942 and in Lapland, in the north, 1941, 1942 and 1947. Other summers with dry SC-PDSI values are 1964 and 1977 in Uusimaa and 1917, 1918 and 1970 in Lapland. The last 20 years of the simulation, 1981-2000, shows distinctly wetter summers with no summer being classified as dry in Lapland or for the Finnish average, and only one summer (1999) falling into the class "incipient dry spell".

Figure 7.5 SC-PDSI values for June–August 1901–2000 averaged over Uusimaa, Lapland and Finland as a whole. Negative values indicate drought conditions. Note that values averaged over larger regions indicate drought in relative terms and are not directly comparable between different regions[31].



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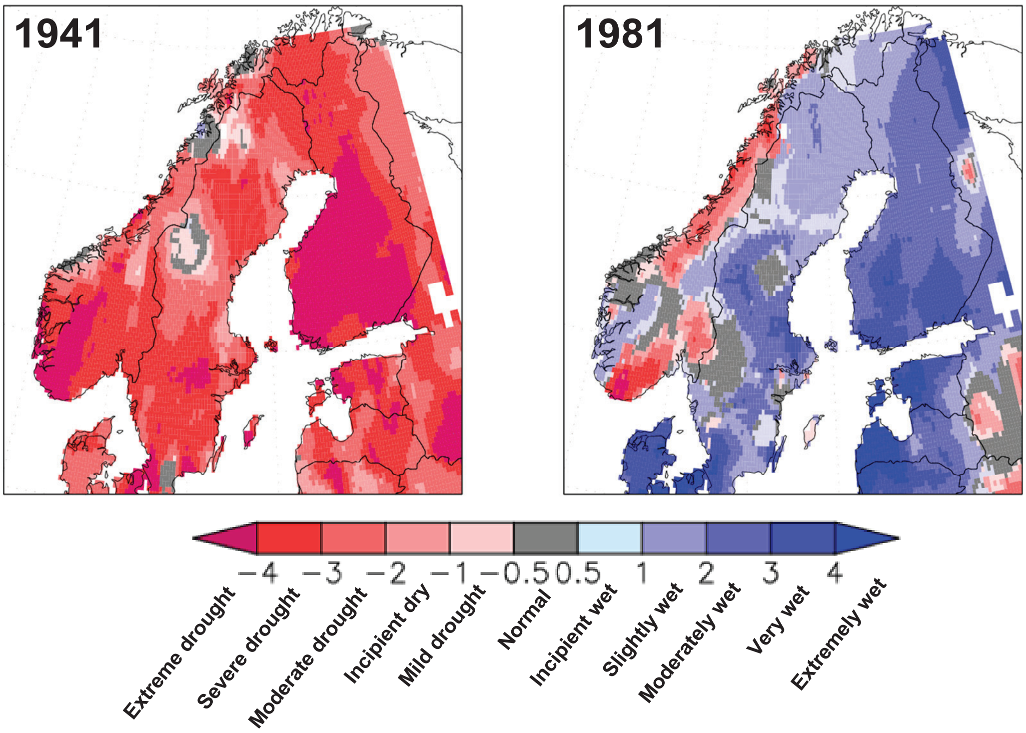
[31] The PDSI was designed to be applied at sites. Given the regional heterogeneity in patterns of moisture conditions, spatial averaging of the index has the effect of reducing its absolute magnitude, with moister conditions in some areas offsetting drier conditions in others. Therefore, values averaged over regions of different sizes are not directly comparable in absolute terms, though comparisons of temporal variations for any one region are still perfectly valid.

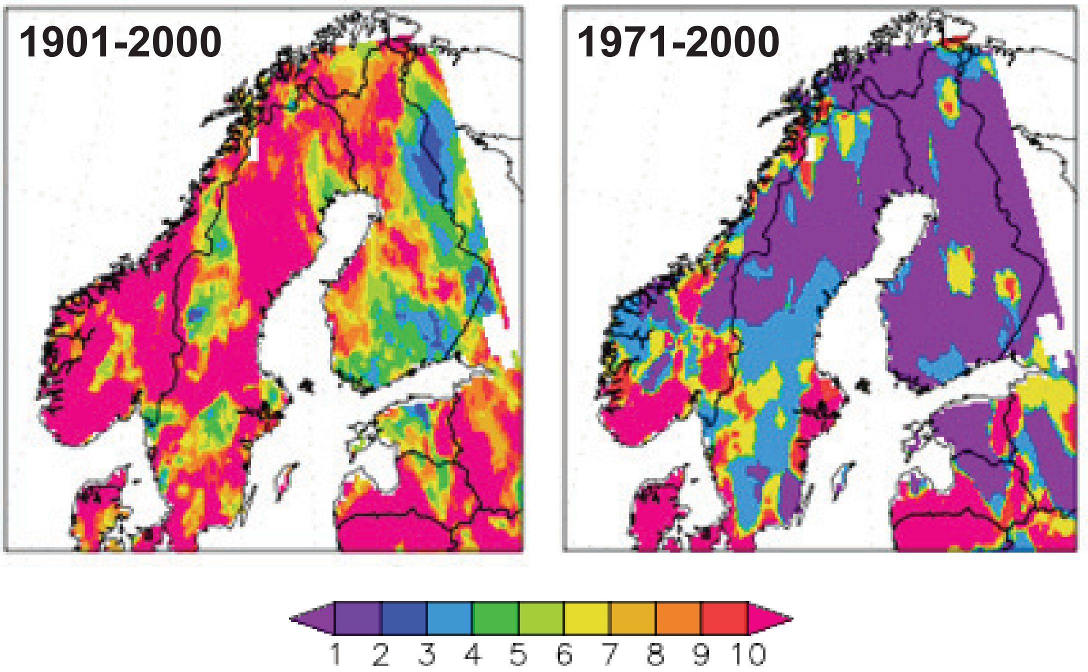
The driest summer of the 20th century, 1941, exhibits extreme drought conditions over large parts of southern and central Finland, while the remainder of the country is classified as experiencing severe or moderate drought (Fig. 7.6, left). The typical wet summer of 1981 has moderately or very wet conditions over much of the country, with localised extremely wet pockets in south-west Finland and on the border of Pirkanmaa and Pohjanmaa (Fig. 7.6, right).

Figure 7.6 Gridded June-August SC-PDSI in a dry year 1941 (left) and in a wet year 1981 (right).



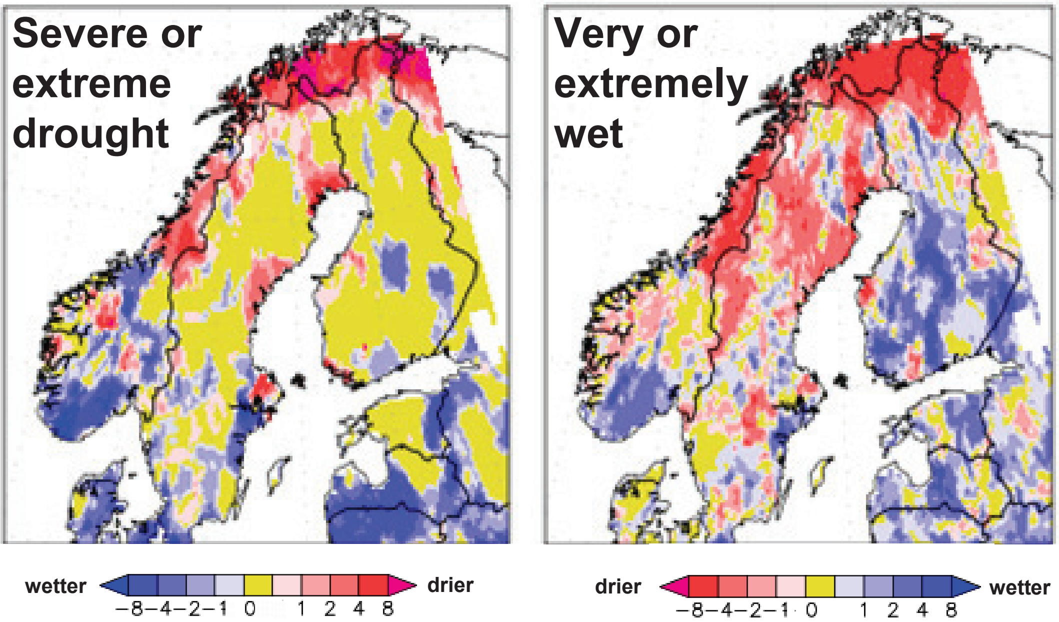
Throughout the 20th century, the regions with the most frequent drought conditions were in central Finland, large parts of Lapland and along the west coast (Fig. 7.7). Nearly all extreme droughts of the 20th century are estimated to have occurred before 1971 (not shown) and there are also fewer severe droughts in most areas since 1971 (Fig.7.7, right). Areas with the most frequent occurrences of conditions classified as very or extremely wet during the 20th century are in Lapland (south of Lake Inari) and the regions of Uusimaa and Häme (not shown).

Figure 7.7 Frequency, in percent, of summer (June-August) droughts classified as extreme or severe for the periods 1901–2000 (left) and 1971–2000 (right).



Estimates of index values under projected future climate based on three AOGCMs for the SRES A2 emission scenario show no clear sign of change between the periods 1971-2000 and 2071-2100 when averaged over Finland as a whole or over Uusimaa (not shown). However, Lapland shows a clear increase in the frequency of summer droughts. This is illustrated in Fig. 7.8 (left) for the HadCM3 scenario. The frequency of severe or extreme drought shows little change over large areas of Finland, localised declines in parts of southern Lapland, central, eastern and southern Finland, but sharp increases in northernmost Lapland and smaller increases in parts of western Finland. In contrast, the spatial pattern of changes in the frequency of wet summers shows increases over large areas of the country except northern Lapland and small areas in western, central and eastern Finland (Fig. 7.8, right)

Figure 7.8 Change in the number of summers classified as severely or extremely dry (left) and wet (right) projected for 2071–2100 relative to 1971–2000 (HadCM3 A2 scenario).



7.3.4 Conclusions

The analysis with the SC-PDSI enabled the identification of locations and years during the 20th century with exceptionally dry summers. Several summers in the 1940s stood out as extremely dry, an observation also made by Heino (1994; cited by Silander and Järvinen 2004) for several stations in Finland based on daily precipitation data, and Kajosaari (1968; cited by Silander and Järvinen 2004) who commented on the exceptionally dry conditions of the early 1940s in water bodies in central Finland. Analysis of a limited number of climate scenarios for the end of the 21st century showed that changes in the frequency of droughts are spatially variable in Finland. Northern Lapland was the only region for which consistent increases in the frequency of all drought classes and decreases in the frequency of wet classes were projected, while large parts of central Finland experienced a shift to more frequent wet conditions at the end of the 21st century. It should be noted that these few climate scenarios were applied as mean changes; possible changes in inter-annual variability and seasonality were not investigated and scenarios based on a wider range of AOGCMs as well as higher resolution models also remain to be examined.

SC-PDSI exhibits several obvious limitations. First, the use of only monthly climate data precludes consideration of how extreme weather events might affect moisture conditions. For example, extreme precipitation events on an hourly or daily timescale, with rates exceeding the maximum percolation rate of a soil may lead to runoff even if there is overall moisture capacity in the soil. The Thornthwaite method for estimating PET used in the calculation of SC-PDSI can differ from estimates of alternative methods. The sensitivity of the index to the use of alternative PET calculation methods remains to be tested for Finnish conditions. Snow and frozen soil is not taken into ac-count in the calculations; rather, all precipitation is assumed to be rain. This implies that index results are flawed during the winter and the biases in water storage that result can be carried through to the summer. Van der Schrier et al. (2007) included a simple snow-accumulation and snowmelt model in the water balance calculations and conducted simulations for the European Alps. They found that differences between simulations with and without the snow model were largest in high altitude locations but relatively small elsewhere. In principle, a similar model could be applied in northern Europe, but would need to be calibrated to regional conditions.

The preliminary estimates of summer PDSI reported here have also been compared to estimates of the operational Finnish Forest Fire Index during the period 1961–1997 (Ari Venäläinen, personal communication). Years of high forest fire risk tend to coincide with the drier years defined by the PDSI (coefficient of determination, R2 = 0.46). Furthermore, a cursory examination of actual forest fire statistics indicates that the summer PDSI values correlate reasonably well to the number of 20th century forest fires in Finland (Heikki Suvanto, personal communication). Outside Finland, a close relationship has been demonstrated between the PDSI and the occurrence of large forest fires (Wright and Agee 2004) and area burnt (Balling et al. 1992). PDSI has also been related to tree growth (Orwig and Abrams 1997), agricultural yields (Quiring and Papakryiakou 2003) and soil moisture variation (Mika et al. 2005). Future work could expand on this and establish the relation-ship between SC-PDSI and impacts of drought in Finland, possibly in combination with other drought-related indices.

8 Conclusions

Economic impact assessment of major hazards is still very much in a development stage, both in terms of theoretical underpinning and in terms of modelling for applied cost-benefit analysis. For given types and graveness categories of events direct cost of damage to man made and natural capital can be evaluated fairly accurately, provided the location of the initial impacts (flood, storm, etc.) can be determined with sufficient precision. Accurate GIS data bases and applications, which are able to combine data on natural conditions (elevation, soil type, etc.) with societal data (building stock, economic activity, accessibility, etc.), are extremely helpful for identifying vulnerabilities and for evaluation of the direct cost. After a few replications of such exercises it should be possible to apply adequately representative unit cost figures (i.e. per hectare by type of land use and/or degree of building density). This would create a good basis for generation of replicable and reliable cost-benefit assessments against reasonable cost. Yet, for comprehensive cost-benefit analysis also the induced effects on the regional economy over a longer time span (~10 years or more) should be assessed. In this respect should be realised that – notwithstanding the progress made in the past two decades – modelling of the induced effects of hazards is still in a relatively infant stage. Furthermore, the assessment of the net benefits of alternative solutions, which reduce the exposure to and/or the consequences of hazards, adds further complications due to the uncertainties, varying views on discounting, and the inclusion of (originally) non-monetised effects.

Extremes of daily and monthly precipitation were assessed for so-called return times of 10, 20, 50, 100 and 500 years. According to multi-model mean estimates based on 19 global climate models, annual mean warming in Finland by the period 2020–2049, compared to the period 1971–2000, is about 2±1°C, virtually regardless of the emission scenario. The corresponding annual mean precipitation change is about 7±5 %. The increase in precipitation is expected to be the largest in winter months (approx. +9% compared to current climate, with a 90% probability interval of +2%~+16%), whereas also the change in daily average temperature is the largest during the winter (+2.9 degrees compared to current climate, with a 90% probability interval lying between +1.6 degrees and +4.2 degrees). The latter effect means that a bigger part of the precipitation during winter will come as rain or at least will melt soon after reaching the ground.

Hydrological model simulation indicated an increasing of flooding in the city of Pori, but decrease in the city of Salo. In both cases sea level rise is increasing risk of flooding. The 100 year flood in Pori according to hydrological simulations increases 0–15 % by 2020–2049, with strongly modified regulation. The flood might also last a little longer, maybe one or two days more for a 250 year event. The simulations made for Salo indicate that, the floods in the period 2020–2049 would decrease considerably, i.e. by -15%~-30% for a 100 year event.

Flood maps and damage estimates are based on flood mapping, which are produced by means of hydraulic models, in this case a 1-D model. The limitation of a one-dimensional (1-D) flow model should be kept in mind when inspecting the modelling results: Only one water level is calculated for each cross section. This is problematical in cases like Pori, where vast low-lying areas are protected by embankments. The water level in the flooded embanked areas is assumed to be level with the water surface slope in the main river channel. This is not the case in reality, since inundating water may have different flow route and downstream boundary conditions. Realistic modelling of embankment breach would require two-dimensional modelling. An attempt to reach the universal solution would require multiple case studies, since breaches in different locations cause different impacts. The knowledge about the most vulnerable spots in the embankments would require geotechnical analysis.

Of all the flood prone areas in Finland the city area of Pori clearly stands out as the case where the most social-economic damage could occur. According to the simulation exercises in this study costs of river flooding in Pori in the next few decades could easily cause damages of 40 million to 50 million euro with the *current (2008) level* of protection. Worst case situations for floods with a return time of 50 years may even cause damages of just over 100 million euro. The probability that a flood with a return time of 50 years will occur at least once in the next 45 years is about 0.64. A flood with a return time of 250 years, of which the probability of occurrence in the next 45 years is approximately 0.18, is expected to cause very considerable damage of up to 380 million euro. These cost concern only damage to residential and non-residential buildings and the first order cost of suspended production in flooded areas.

When comparing results for present and future climate the direct costs of floods go up by about 15% when applying future climate conditions. However, the impact of economic growth is much larger, being in the order of magnitude of 50% in the considered time span. On the other hand over longer time spans it also possible to avoid building in the most risky areas and to take precautionary measures for existing buildings, notably in shallower parts of flood prone areas.

The direct costs mentioned above represent mainly loss of capital and only a modest fraction is loss of income. Therefore these overall direct cost not necessarily show up that way in the regional economic accounts. The repair work usually causes a boom in some sectors, possibly for over a year. The consequence is that the regional GDP might first even go up, provided the repair is predominantly carried out by inhabitants from the same region. On the other hand if there is a lot of labour hired from outside the region, whereas wages surge due to scarcity, the result can be a significant outflow of income to other regions. In subsequent years directly after the repair boom the economy may do less well due to the repayment of the funding of the repairs, and due to higher insurance premiums. Together this causes reduced purchasing power and affects the entire (regional) economy via (reduced) household consumption. The extent to which real estate and other capital goods are insured has significant influence on how the regional economy recovers. Higher insurance coverage promotes quicker recovery. Also the functioning of the labour market and the re-establishment of trade contacts in crippled product markets are important ingredients for better resilience. They depend on transparency and up-to-date information provision.

In the preparatory phase of the TOLERATE study was hypothesized that in principle the assessment of the risks of floods, including the reinforcement effects of climate change as well as possible flood protection measures, could be under-stood as an optimal control problem. Yet, already in that phase it was also indicated that most probably such an optimal control approach would not be feasible in a strict sense, but rather works *as a metaphor* and helps to systemise the comparison of alternative strategies. The decision making simulation exercise carried out during the study exemplifies this point. Not only is there uncertainty regarding a part of the information, but there is also uncertainty about the way different interest groups conjecture the overall problem. A part of the latter uncertainty can be somewhat relieved by providing better and more accessible information. However, partly the uncertainty may be fundamental, because the stakeholders are facing limitations in their capacity to evaluate all information. Furthermore, the choices ahead may involve trade-offs that are very hard to monetise if at all, whereas the stake-holders may even change opinion several times. Obviously, this is does not mean that a cost-benefit assessment loses its significance, as stakeholders still want to know what are the economic consequences of stressing as such non-monetised features.

Calculation exercises to test the economic implications of higher volatility of the filling rates of electric power hydro reservoirs show that, even though the basic effect of the changes in average weather conditions seems to be a modest lowering in the price, the increase in price swings due to increased volatility of weather conditions are easily 3 to 5 times larger than the generic effect of a slightly lower price. Even though these price swings are of a temporary nature, the return to the reference level may take considerable time and thereby the transfer of wealth between producers and users can rise to considerable levels. In this respect it should also be realised that over a time span of several decades a few periods with overrepresentation of dry or wet years should be accounted for. All in all it means that risks of investments in generation capacity are somewhat rising as a result of the climate change induced enlargement of the hydro volatility. Possibly, over time adapted water system management regimes may alleviate that effect.

Analysis of a limited number of climate scenarios for the end of the 21st century showed that changes in the frequency of droughts are spatially variable in Finland. Northern Lapland was the only region for which consistent increases in the frequency of all drought classes and decreases in the frequency of wet classes were projected, while large parts of central Finland experienced a shift to more frequent wet conditions at the end of the 21st century. It should be noted that these few climate scenarios were applied as mean changes; possible changes in inter-annual variability and seasonality were not investigated and scenarios based on a wider range of AOGCMs as well as higher resolution models also remain to be examined.

The Wells' self-calibrating Palmer Drought Severity Index (SC-PDSI) was used to review the occurrence of severe drought in Finland. Several summers in the 1940s stood out as extremely dry. Analysis of a limited number of climate scenarios for the end of the 21st century showed that changes in the frequency of droughts are spatially variable in Finland. Northern Lapland was the only region for which consistent increases in the frequency of all drought classes and decreases in the frequency of wet classes were projected, while large parts of central Finland experienced a shift to more frequent wet conditions at the end of the 21st century. It should be noted that these few climate scenarios were applied as mean changes; possible changes in inter-annual variability and seasonality were not investigated and scenarios based on a wider range of AOGCMs as well as higher resolution models also remain to be examined. SC-PDSI exhibits several obvious limitations, not the least with respect to application to the Nordic climate.

The preliminary estimates of summer PDSI reported here have also been compared to estimates of the operational Finnish Forest Fire Index during the period 1961–1997. Years of high forest fire risk tend to coincide with the drier years defined by the PDSI. Furthermore, a cursory examination of actual forest fire statistics indicates that the summer PDSI values correlate reasonably well to the number of 20th century forest fires in Finland. Future work could expand on this preliminary exercise with SC-PDSI and establish the relationship between SC-PDSI and impacts of drought in Finland, possibly in combination with other drought-related indices.

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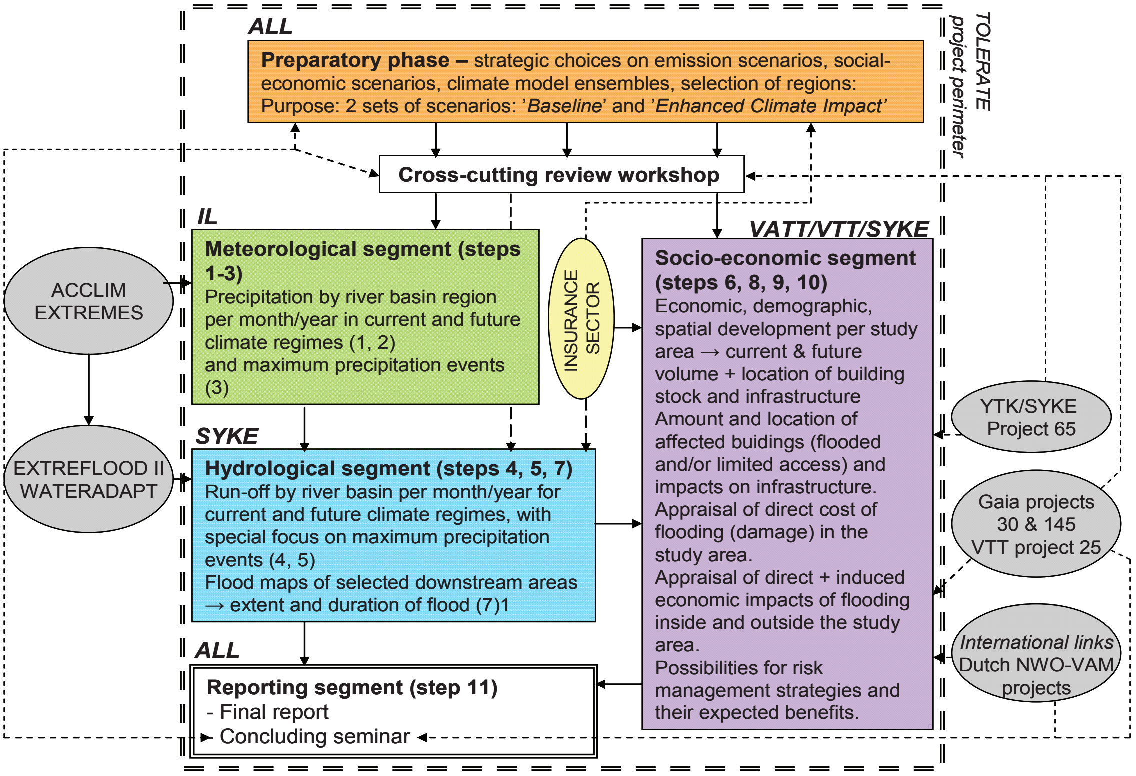
Appendix 1 – The work packages of the TOLERATE study

Figure A1. Study structure



The five main segments contain the following steps:

1. A preparatory step for strategic choices regarding long term time frames, emission scenarios, climate simulations ensembles, socio-economic scenarios, selection of study regions, etc. it can be tentatively indicated that the study will not look (much) beyond the year 2050 and will probably use the SRES A1-B scenario as point of departure for both the emission and socio-economic scenarios; the selection of study areas will be made in close co-operation with related cluster projects EXTREFLOOD II and ACCLIM with the aim to cover the same areas; this phase should produce two sets of scenarios, *baseline* and *enhanced climate impact*, per selected area; this step concludes with a cross-cutting review workshop involving also the projects with which information is to be exchanged and has the purpose to prevent mismatches in timing and contents and facilitate the latest updates prior to actual analytical 'take-off';

   parties involved: all;

2. Simulations of the precipitation per period (monthly and longer) per area in current (baseline) climate conditions[1], i.e. the baseline (input from ACCLIM); the simulations employ statistical methods applied on historical hydrological and climatologic time series from recent decades, on the bases of the resulting observed weather extremes, a baseline scenario will be defined representing the present-day situation regarding weather events; this step also produces complementary output on prolonged spells without precipitation;

   parties involved: IL

3. Simulations of the precipitation per period (monthly and longer) per area in future (enhanced) climate conditions for the period 2020–2050[32] (input from ACCLIM); detailed, regional scenarios of future changed climate (for example, in the 2040s) will be represented by calculating the frequency of weather extremes (defined in the same way as those used in the baseline analysis) using projections from different climate models, this analysis may also make use of results of later modelled periods (e.g. 2070–2099) for which new multiple (ensemble) climate model simulations become available; this step also produces complementary output on prolonged spells without precipitation based on the same simulations;

   parties involved: IL

4. Attribution calculations for maximum precipitation events (one or more days) in consecutive standard periods in current and future climate conditions (input from RATU and ACCLIM); given a certain threshold level (which may vary by season and area), the distribution of precipitation-free spells with a potential to cause drought is (tentatively) identified for current and future climate conditions;

   parties involved: IL and to some extent SYKE

5. Simulations of the run-off in the river basin for baseline and enhanced climate conditions with a predetermined (current or updated) regulation regime given the precipitation output of steps 1-3; the existing hydrological forecasting system of SYKE will be used for calculating flood frequencies and discharge curves; (and conversely periods with very low runoff);

   parties involved: SYKE;

6. Mapping of the flooding extent based on calculated water levels and durations of the flood in the study areas, employing output of step 4 and accounting for

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[32] In relation to the FINADAPT-scenarios (Carter et al. 2005) 'current' would 'present day' 1970–2000, whereas future can be distinguished in 'near term' (1990–2020) and 'mid term' (2020–2050)

possible other impacts (e.g. storm induced sea level rise on outflow capacity) (input from EXTREFLOOD II); existing hydraulic models of SYKE will be used to calculate water levels and to produce vector based flood extent maps;

parties involved: SYKE;

7. Determining the changes in spatial lay-out/land-use and in the building and infrastructure stock expressed in m^2 floor area by type of building, hectares of industrial or agricultural area, metres of infrastructure, based on economic scenarios per region, output-floor space ratios and infrastructure plans; possibly input from YTK/SYKE Environmental cluster project 65 (on urban form); for the drought assessment, sensitive locations per selected region (industries, farms, etc.) will be identified;

   parties involved: VATT, SYKE, municipalities;

8. Description of the flooding situation in the study area by means of a flood mapping application, impacts are expressed in terms of: land area affected (ha), amount of buildings affected (m^2 floor area and function), amount of obstructed infrastructure, amount of flooded industrial area (input from EXTREFLOOD II);

   parties involved: SYKE;

9. Assessment of the need for clean-up and repair, of the consequent impacts on the time lag up to resumption of production/use of buildings, infrastructure and other production facilities, and of the possible implication for temporary and permanent change of production locations (input from Gaia projects 30 and 145);

   parties involved: VATT, VTT, SYKE;

10. Assessment of overall direct and induced costs and benefits inside and outside the study area; this involves regional input-output modelling, also infrastructure productivity analysis can be used if necessary; similarly impacts on selected drought sensitive sectors will be assessed (e.g. irrigation cost; reduced harvests, etc.);

    parties involved: VATT;

11. Assessment of loss reduction options for activities inside flood prone area, as well as for drought prone sectors, and their implications for the preceding assessment steps (5–9) (inputs from the insurance sector, Gaia projects 30 and 145, Dutch NOW-VAM projects);

    parties involved: VATT, VTT

12. Drafting of the final report and a concluding seminar, including international participation.

    parties involved: all.

Appendix 2 – Glossary of terms

Current climate:

It refers to the statistical characteristics of weather phenomena such as annual precipitation, daily temperatures per month, maximum daytime temperatures per month, thickness of snow cover, etc. based on a complete series of observations for the recent past (1970–2000) from the observation stations in the selected study area. These statistical characteristics include average, standard deviation and other moments of distribution. On the basis of these statistical characteristics can be inferred what for example the probability is that the amount of precipitation in a particular season exceeds a certain amount.

In TOLERATE regionalised climate indicators will be used (instead of national ones), provided by the Finnish Meteorological Institute.

Future climate:

It refers to the statistical characteristics of weather phenomena such as annual precipitation, daily temperatures per month, maximum daytime temperatures per month, thickness of snow cover, etc. for a future period, e.g. 2020-2050, *while accounting for the influences of climate change*. The change in climate may mean that some or several of these figures may change. The statistical characteristics include average, standard deviation and other moments of distribution. On the basis of these statistical characteristics can be inferred what for example the probability is that the amount of precipitation in a particular season exceeds a certain amount and whether a changed climate exacerbates the occurrence and/or severity of such extreme amounts.

Extreme weather event

An extreme weather event, such as a large flood or a severe drought is the result of an exceptional constellation of weather characteristics in a certain area. For example, the virtual absence of precipitation in late spring and summer in combination with above average temperatures in the same period will result in significant or even severe drought in those areas where irrigation is impossible or insignificant. The severity of the situation can be further aggravated if groundwater levels were already relatively low prior to the drought, e.g. due non-completed recovery from an earlier drought.

The Finnish Meteorological Institute terms weather phenomena (such as temperatures) as ‘exceptional’ when their probability of occurrence on a given day is less than once in 30 years given the typical distribution of that day.

The indication ‘less than once in XX years’ (where XX is e.g. 10, 30, 100, 250 or whatever) is referred to as *the return time*.

Model ensemble

For the assessment of future climate weather statistics one has to rely on model simulations that account for expected changes in the climate system. However, due to the uncertainties in the modelling usually the simulations from a collection of models, a so-called *model ensemble*, is used as the basis to assess the extent that weather characteristics change over time.

Damage function

In principle the actual flood damage will vary from building to building for a host of reasons. Factors are building material, elevation of the ground floor, presence of basements, affected surface area, local water depth, etc. etc. On the basis of observations in various countries (including Finland) it can be assessed what are the principal factors that largely determine the amount of damage (in € per m^2). The resulting damage function can than be applied to the building stock (in m^2) affected by a (simulated) flood in order to obtain an estimate (median value) for the aggregate direct damage to buildings. This sum includes repair and clean-up costs as well as partial compensation for equipment and interior.

Risk

Risk is the expected value of the damage that a possible event could cause, being the product of the occurrence probability of such an event within a certain time span and the value of the projected damage of such an event. Both the occurrence of the event and the extent of damage realised can be regarded as stochastic (distributed according to a probability distribution).

Uncertainty

Uncertainty can refer to:

- An exceptional but possible damaging event of which the likelihood of occurrence is unknown (apart from that it is larger than zero),
- An exceptional but possible damaging event of which the likelihood of very large damage is unknown (apart from that it is larger than zero), or
- events of which we are as yet unaware.

The difference compared to ‘risk’ is that no likelihood can be attached to the event and hence no expected value produced. This makes it difficult to assess it in terms of cost-benefit analysis of possible measures. A way out of this could be found by assessing via surveys what the stakeholders (e.g. inhabitants or tax payers or whoever) are prepared to pay to arrive at a level of uncertainty that is perceived as ‘manageable’.

Value at risk

This refers to the value of real estate and of economic activities on or in that real estate, which is exposed to a certain risk of an extreme weather event. Value at risk hence not only encompasses direct damage to buildings and equipment, but also losses incurred from suspension of production.

Volatility

Volatility refers to the degree of variability in realised and simulated outcomes.

Vulnerability

Vulnerability refers to the sensitivity for damage. For example, a vulnerable building may mean that even with rather modest levels of flooding already high damage cost could be incurred.

Governance

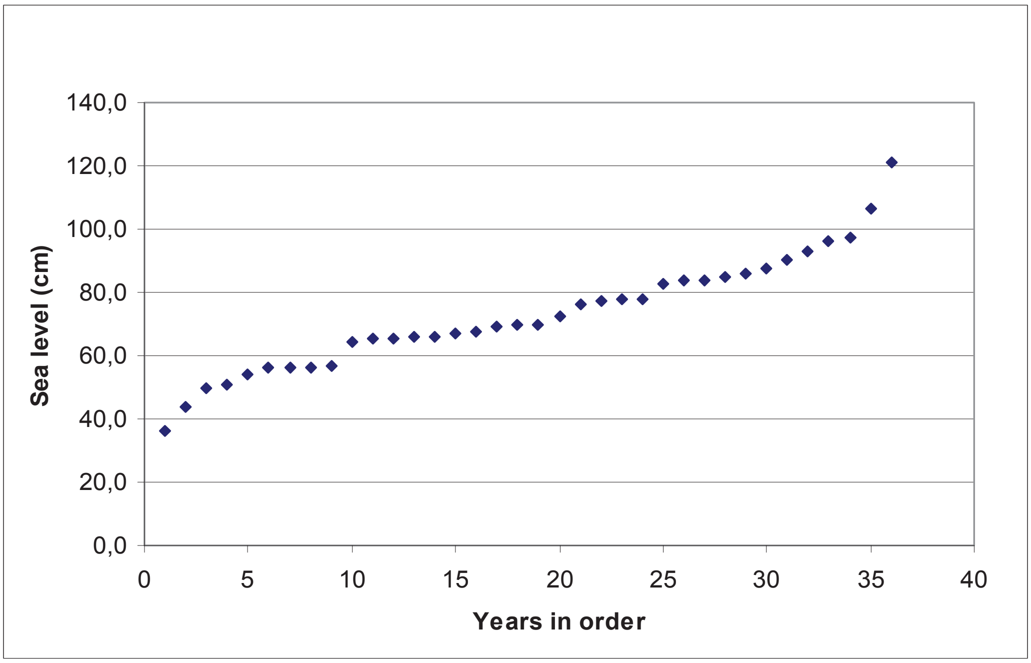
With governance is meant here the whole constellation of decision making, implementation, and control and feedback, as well as the philosophy or guidelines according to which the constellation is run.

Appendix 3 – Sea level variation and its impacts

The sea level is measured close to the city of Pori with the mareograph of Mäntyluoto (http://www.fimr.fi/). Daily means of the sea level are calculated as a mean of hourly observations. Often the annual maximum sea level occurs in December and the annual minimum in April-May. The geodetic levelling system used here is called **theoretical mean water (MW).** It is a forecast for the long-term mean value of the sea level, made for practical purposes (http://www.fimr.fi/). In Hanko the annual maximum sea level has increased by 10-20 cm in one hundred years (Johansson ym. 2001, 2004).

Daily observation from Mäntyluoto were available for the period 1971–2000, which was enough to carry out a statistical analysis (Hawkes et. al. 2002) and compare river and sea levels in order to calculate joint probabilities of river flow and storm surge. All sea levels were change to MW-system prior to statistical analysis, one year data was and it was copied from the previous year. The water level station was chosen to be as far downstream as possible without being sea level influenced and to have as few missing data as possible. It was selected Harjavalta station (station 3510450, SYKE Hertta system 10.7.2007, daily average discharges).

Figure A3.1. Annual maximum sea levels in the Mäntyluoto from years 1971–2006 in coordinate system MW2007. Each point represents one year. Figure show that only in one year water level have exceeded 120 cm.



Pearson product moment correlation between sea level and river discharges in the Kokemäenjoki river was 0.2, as 0 indicates no linear correlation (maximum 1), used data from 1971–2000. Correlation is low partly due to regulation of reservoirs, but exists as Northern Atlantic Oscillation is influencing both discharges in Finland and the Baltic Sea. The river Kokemäenjoki is large, thus duration of flood event is several days as quite often sea level gains it's maximum value within a day. In this study events were assumed to be independent, so no joint probabilities were used when analyzing impact of climate change.

Sea level was analyzed and maximum daily sea level value was used in analysis. Johnson SU, Lognormal and General Extreme Value distribution were seen the most appropriate reliable, based on following statistical tests Anderson Darlingin, Kolmogorov Smirnovin and Chi-Squared, while analyzing accurately the highest sea levels. Here we used Johnson SU-distribution.

Distribution had shape parameter γ -5,9771, shape parameter σ 5,1366 and scale parameter λ 70,214 and location parameter ξ -106,31 (Bowman et.al. 1983). Only location parameter was expected to be chaining when water level is chaniign, this is not exactly thrue as Johansson (2001) showed that distribution is lowly changing. Probability that sea level in the Mäntyluoto is 100 cm in MW2007 was 0,0006 and in MW2034 it would be 0,0002 due to land uplift and climate change induced sea level rise. Without sea level rise risk would be even lower.

Appendix 4 – The calculation of the induced economic effects

The direct and first order indirect impacts as reported in table 5.4 are allocated to two sectors, being companies and households. For companies the following cost are distinguished: (1) lost production days, (2) damaged or lost stocks, and (3) repairs (of equipment and buildings). For households the cost categories are: (1) temporary residence, (2) damaged or lost interior, and (3) repair of homes. Subsequently for companies a further distinction is made between that part of the damage incurred by companies that did not compensate production losses by increasing production in other locations or later on and that part of the companies that uses those compensation options. In a next step both for companies and households a further distinction is made between the part of the damage covered by insurance and the remainder, which is to be compensated from savings, loans or current income.

Assumptions about degree of spatial and temporal substitution is based on a survey among companies, held during the TOLERATE study. Also from the literature some indications can be found about spatial and temporal substitution. As regard insurance coverage is assumed that 50% of the value of the stocks is effectively insured and 85% of the repair cost of buildings and equipment. For households is assumed that costs of repairs and of temporary residence is covered for 85% by insurance. For damage to interior the assumed coverage is 50%.

The uncompensated lost production and 50% of the cost of repairs is paid out of current company income (i.e. reduces profit). The remainder of the costs not covered by insurance is financed by loans (with a runtime of 5 years and a real interest rate of 5%). For households is assumed that half of the costs not covered by insurance are paid out of loans. The remainder is 50/50 divided over payment out of savings and from current income.

It also assumed that insurance companies wish to replenish their capital after the substantial pay-out. This is indeed an option which is often actually chosen by insurance companies (Savijoki, 2008). This is done through a small rise in flood insurance premiums. In the calculations is assumed that annually 2.5% of the pay-out is recaptured by premium increases. Furthermore, overtime the extra return on investment generated via the increased premium income further promotes the recovery of the capital.

On the basis of these assumptions can be calculated what are the real expenditure effects for companies and households and the extent to which other household expenditures are displaced (so a reallocation over budget items due the need to fund the repairs). The loss of company profit is assumed to affect aggregate household income. For the assessment of the effects of household expenditures an average household from Satakunta has been applied. The reallocation has been assessed by means of a VATT consumption model (also used in the KulMaKunta study). The rescaled and reallocated household budget is compared with the original budget per expenditure category and the vector of differences is used in a linked system with a regional input-output model to assess the impacts on production. The overall average multiplier effect is about 1.4.

In order to assess the temporary boom effect of repairs alternative displacement rates have been assumed (25%, 50%, 75% and an alternative where it stepwise drops from 75% to 25%). High displacement means that X% of the repair value crowds out other building production in the same year.

Table A4.1 *Allocation of costs by category for companies and households*

			R=250; M1 >>>>>>		**R=50; M1 >>>>>>**	
companies			CC (d=23)	FC (d=30)	CC (d=37)	FC (d=44)
lost production days	- ***without*** temporal or spatial compensation		6,30	8,20	1,70	2,35
	- ***with*** temporal or spatial compensation		6,30	8,20	1,70	2,35
lost stocks	- ***without*** insurance compensation		4,95	5,70	1,15	1,25
	- ***with*** insurance compensation		4,95	5,70	1,15	1,25
repairs	- ***without*** insurance compensation		10,58	13,17	1,67	2,27
assume production reduced by 40%	- - of which with production limitations		*5,29*	*6,58*	*0,83*	*1,13*
	- ***with*** insurance compensation		59,93	74,61	9,46	12,84
assume production reduced by 20%	- - of which with production limitations		*23,97*	*29,85*	*3,78*	*5,13*
	lost company income		11,59	14,8	2,5	3,5
T = 5 yearsn costs for funding extra debts		i = 5%	2,56	3,1	0,5	0,6
2,5% of payout	insurance premium effect		*1,62*	*2,0*	*0,3*	*0,4*
	of which in Satakunta (15%)		0,24	0,30	0,04	0,05
Satakunta	annual company income loss	year 1	14,39	18,2	3,1	4,1
Satakunta	annual company income loss	year 2-5	2,80	3,37	0,54	0,65
			R=250; M1 >>>>>>		**R=50; M1 >>>>>>**	
households			CC (d=23)	FC (d=30)	CC (d=37)	FC (d=44)
repairs	- ***without*** insurance compensation		33,45	39,34	14,15	16,05
	- ***with*** insurance compensation		189,56	222,93	80,17	90,92
interior	- ***without*** insurance compensation		6,95	8,05	3,15	3,55
	- ***with*** insurance compensation		6,95	8,05	3,15	3,55
temporary residence	- ***without*** insurance compensation		1,92	2,31	1,10	1,34
	- ***with*** insurance compensation		10,88	13,09	6,21	7,57
	repairs paid from current income		10,58	12,43	4,60	5,23
	repairs paid from savings		10,58	12,43	4,60	5,23
	loss of savings income due to repairs and temp. cons compensation		1,15	1,29	0,67	0,72
T = 7 years	loan cost funding extra debts		4,08	4,79	1,77	2,02
2,5% of payout	insurance premium effect		*5,18*	*6,10*	*2,24*	*2,55*
	of which in Satakunta (15%)		0,78	0,92	0,34	0,38
Satakunta	year 1	annual purchasing power displacement	15,44	18,13	6,71	7,63
Satakunta	year 2-7	annual purchasing power displacement	4,86	5,71	2,11	2,40
	building sector investment shock		276,8	330,4	98,4	114,0

Appendix 5 – The calculation of the impact of hydro filling volatility on the Nordpool Finland area electricity price

The empirical method is AR-GARCH with as much as possible logarithmic transformations.[33] The general form of the estimated equation is:

$$\begin{aligned}
&p_t^{elec} = a + [\mathrm{b}^{ETS} \times \ln(p_{t-1}^{ETS}) + b^{ETS} \times \ln(p_{t-1}^{coal})] + \\
&\left[\mathrm{b}^{tm_t} \times \ln(tmcap_t) + \mathrm{b}^{pc_t} \times \ln(pcap_t) + \mathrm{b}^{pc_{t\text{-}1}} \times \ln(pcap_{t-1}) + \mathrm{b}^{dr_t} \times \ln(dresfil_{t-1}) + \mathrm{b}^{tmp_t} \times \ln(dtemp_t)\right] \\
&+[\mathrm{b}^{wknd} \times wknd + \mathrm{b}^{hld} \times hld] + \eta_t
\end{aligned}$$

The first line of the equation contains a constant and the prices of emission permits (in EU-ETS) and the monthly price of import coal (Baltic Sea area). The second line concerns the variables describing the state of the electricity generation system (load factor, etc.). Here, $tmcap_t$ indicates the utilisation of the transmission capacity between Finland and Sweden at time *t*, $pcap_t$ indicates the utilisation of the Finnish production capacity. Variables $dresfil_{t-1}$ and $dtemp_t$ denote the deviations from the long term median Nordic weekly reservoir filling rates and average daily temperatures respectively. On the third line the weekend and holiday dummies are added, whereas the error term η_t includes the AR(1 2 5) - GARCH(1) processes.

Please note that the deviation from the long term historical temperature is in the default situation positive (period 1970-2000 vs. current levels).

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[33] For variables that can include negative values a conditional formulation was included to avoid division by zero when using the natural logarithm.

moderately high load of production capacity

	H0	**H1**	**H2**	**H3**	**H4**	**H5**
impsutil	0,136	0,136	0,136	0,136	0,136	0,136
ets07[t-1]	19	19	19	19	19	19
hydrodev[t-1]	**-6,9**	-10	-18	-25	-0,1	5,1
prcautdt-1	**0,7**	0,71	0,74	0,765	0,68	0,66
prcautd	**0,7**	0,71	0,74	0,765	0,68	0,66
pdcoal	18,44	18,44	18,44	18,44	18,44	18,44
devtemp	0,7	0,7	0,7	0,7	0,7	0,7
weekend	0,285	0,285	0,285	0,285	0,285	0,285
holi	0,02	0,02	0,02	0,02	0,02	0,02

moderately high load of production capacity; and slightly lower average temperature

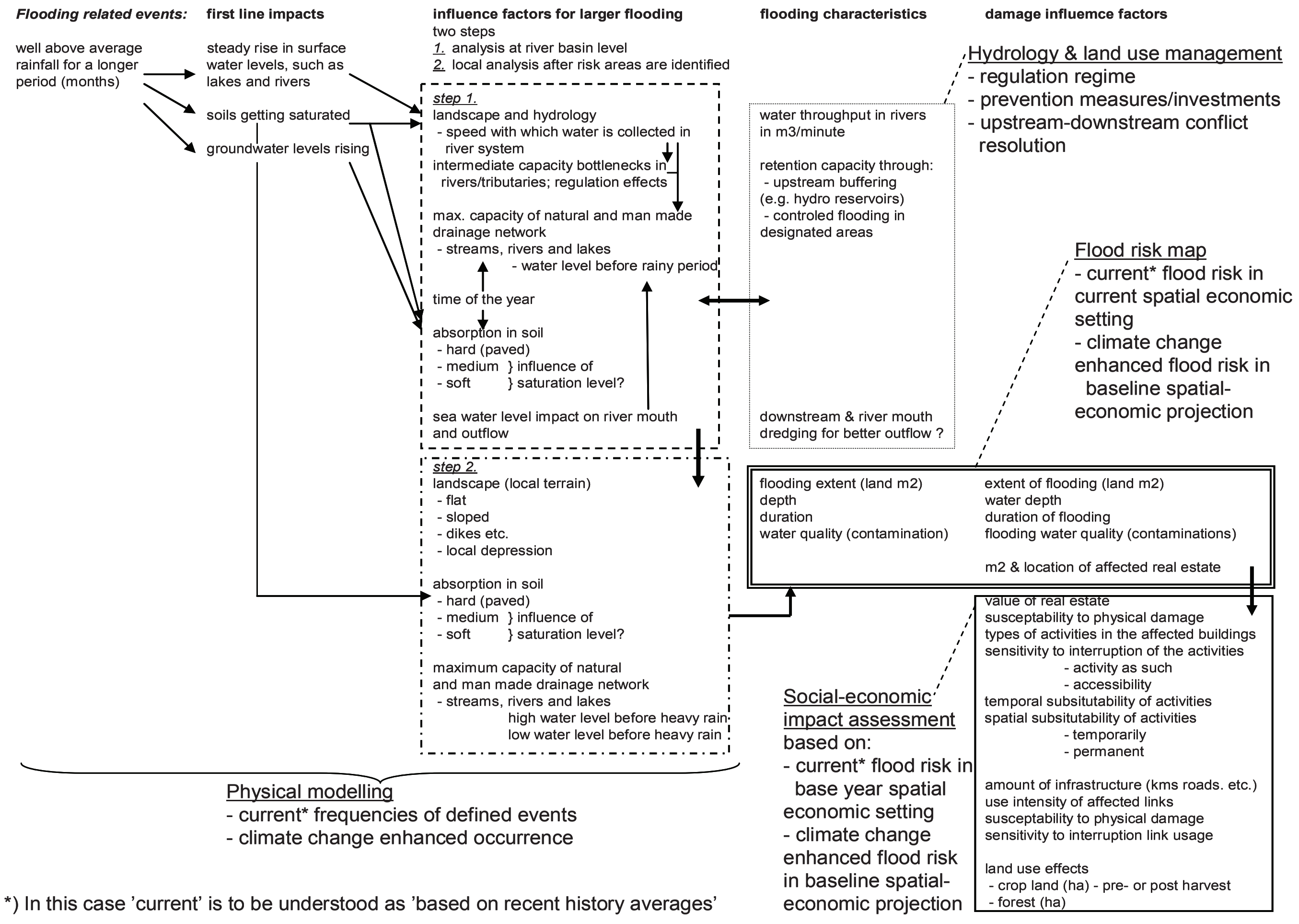
	H6	**H7**	**H8**	**H9**	**H10**	**H11**	**H12**	**H13**	**H14**	**H15**
impsutil	0,136	0,136	0,136	0,136	0,136	0,136	0,136	0,136	0,136	0,136
ets07[t-1]	19	19	19	19	19	19	19	19	19	19
hydrodev[t-1]	**-6,9**	-10	-18	-25	-0,1	5,1	**-6,9**	-18	-25	-0,1
prcautdt-1	**0,75**	0,76	0,79	0,815	0,73	0,71	**0,75**	0,79	0,815	0,73
prcautd	**0,75**	0,76	0,79	0,815	0,73	0,71	**0,75**	0,79	0,815	0,73
pdcoal	18,44	18,44	18,44	18,44	18,44	18,44	18,44	18,44	18,44	18,44
devtemp	0,7	0,7	0,7	0,7	0,7	0,7	**0,01**	0,01	0,01	0,01
weekend	0,285	0,285	0,285	0,285	0,285	0,285	0,285	0,285	0,285	0,285
holi	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02

Parameters for winter period function

Variable	**winter months 2005 &2006**
a	3.071**
$\ln(p_{t-1}^{ETS})$	0.401**
$\ln(p_{t-1}^{coal})$	0.008
$\ln(tmcap_t)$	0.004
$\ln(pcap_t)$	1.681**
$\ln(pcap_{t-1})$	-0.356**
$\ln(dresfil_{t-1})$	-0.014
$\ln(dtemp_t)$	-0.009*
weekend	0.012
holiday	-0.122**
AR[t-1]	-0.538**
AR[t-2]	-0.231**
AR[t-5]	-0.115**
ARCH0	0.003**
ARCH1	1.43**
n	378
Total R^2	0.82

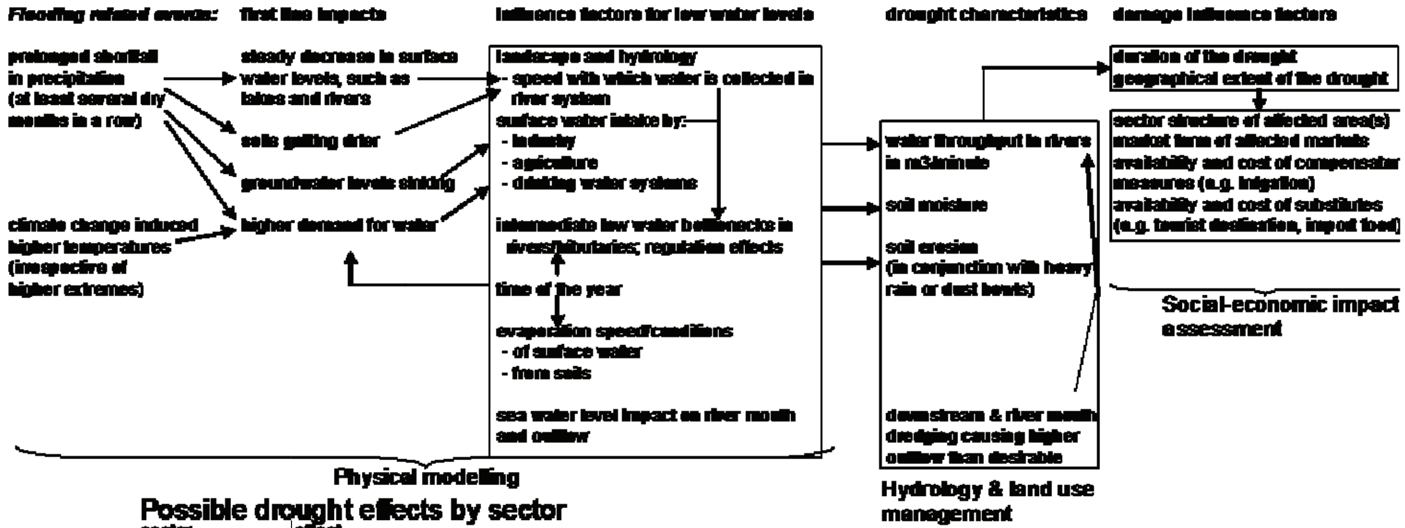
Appendix 6 – Causal structure for river flood and drought

Figure A 2.1. Causal flows for flooding events caused by long term excess precipitation



*) In this case 'current' is to be understood as 'based on recent history averages'

Figure A 2.2 Causal flows for drought events caused by long term low precipitation levels



Possible drought effects by sector

sector	effect
agriculture	reduced growth / smaller harvests extra cost of irrigation
forestry	slower growth (which has however limited short term implications I suppose) Increased risks for forest fires - higher forest fire prevention and mitigation cost - higher losses of wood volume due forest fires
transport	possible limitations in inland navigation (Saima channel) possibly increased use of bicycles (and less travel by car / public transport)
tourism	possibly more outdoor leisure activities (and less indoor) possibly restrictions on swimming due to degraded water quality (in summer) more domestic holidays (and less abroad) the combined impact of the previous 3 points can be larger stress on nature in some areas (that attract a growing number of tourists)
energy	less hydro production capacity -> higher electricity prices (especially if the same situation prevails in Norway and Sweden) more electricity demand due to increased cooling need in summer (-> higher electricity prices)
health	possibly increased mortality due to higher summer temperatures (heat waves)

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