THEME ENV.2012.6.1-1

EUPORIAS

(Grant Agreement 308291)

European Provision Of Regional Impact Assessment on a

Seasonal-to-decadal timescale

Deliverable *D11.2*

White paper on sector specific vulnerabilities

EUPORIAS

Deliverable Title	*White paper on sector specific vulnerabilities*	
Brief Description	*Sectors to be focussed on are Energy, Tourism, Water, Health, Transport, Food Security and Agriculture, and East Africa Disaster Risk Reduction*	
WP number	11	
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Creation Date Version Number Version Date	16/11/15 V2 30/11/15	
Deliverable Due Date Actual Delivery Date	30/11/15 30/11/15	
Nature of the Deliverable	x	*R - Report*
		P - Prototype
		D - Demonstrator
		O - Other
Dissemination Level/ Audience	x	*PU - Public*
		PP - Restricted to other programme participants, including the Commission services
		RE - Restricted to a group specified by the consortium, including the Commission services
		CO - Confidential, only for members of the consortium, including the Commission services

Version	Date	Modified by	Comments
V1	16/11/2015	Daniel Funk	
V2	30/11/2015	Daniel Funk	Pete Falloon, Laurent Pouget, Carlo Buontempo

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1. Executive Summary

Sector-specific vulnerability to climate variability is very valuable information for users and providers of seasonal- to decadal (S2D) climate information to enhance the constructive development and thus the usability of climate service products. Established climate-related vulnerability assessment frameworks generally pursue a top-down approach. The matter of analysis is the potential impact of a well-defined hazard on a system of concern. Vulnerability is assessed by the outcome i.e. the quantification of impacts (usually economic losses, damages or fatalities). They are a function of the related pre-defined hazard which is characterized by its magnitude-frequency relation. Challenges for the vulnerability assessment of economic sectors to S2D climate events originate from the inherent role of climate for economic sectors: climate may affect economic sectors as hazard, resource, production- or regulation factor. Climate impacts may therefore be very indirect and modified by interconnected systems (e.g. watersheds, eco-systems) or by decision-making processes (DMP's) or rather temporal scope of decision-making. Beyond that, climate itself is a statistical description of mean climate conditions for a specific region. Climate events are generally defined by the means and extremes of weather statistics which are in turn dependent on the chosen time period. Both, the sophisticated role of climate for economic systems as well as the definition of climate events decoupled from affected systems challenges the common top-down approach. Effects of meteorological defined climate events may not be relevant for or accordingly may be far beyond a critical threshold of an affected system. Or in turn, climate events which are critical for affected systems do not necessarily correlate with climatological extremes.

For that reason a concept for a vulnerability assessment framework is developed for the context of the EUPORIAS project. The EUPORIAS approach is a user-cantered approach, using top-down (vulnerability as outcome) as well as bottom-up (vulnerability as state) approaches and is generally based on qualitative data (surveys, interviews, etc.). It thus pursues a systemic approach to provide comparability of different vulnerabilities which is more relevant for organizational decision-makers than spatial comparability of a single vulnerability. The starting point is the climate-sensitive *'critical situation'* which requires a decision" which is defined by the user. From this basis the related *'critical climate conditions'* are assessed and *'climate information needs'* are derived. This mainly refers to the critical period of time of the climate event or sequence of events. This critical period of time may be assessed by the resilience (time) of the system of concern or the response time of an interconnected system (i.e. top-down approach using a bottom-up methodology) or alternatively, by the critical time-frame of decision-making processes (bottom-up approach). The focus of the exposure assessment is on the identification of the critical climate event and especially its time-scale. The concept is tested on the specific problems from the EUPORIAS prototypes and case-studies. Commonalities and differences between these examples are discussed and classification systems are developed which can serve as preliminary indicators to assess cross-sectoral vulnerability to climate variability in the context of S2D climate service provision. Indicators for the assessment of vulnerability mainly refer to characteristics of decision-making processes as well as the potential (structural) usability of S2D climate service information for decision-makers. The outputs are qualitative *vulnerability profiles* for the problem of each prototype and case-study with a preliminary unnormalized and unweighted ranking of the degree of vulnerability.

One major findings of this study is the realization that decision-making processes is a very sensitive factor which significantly influences (i) the determination of threshold which define critical situations; (ii) the characteristics of buffer functions and thus the temporal scale of critical climate conditions and (iii) the specification of *climate information* needs and thus their potential usability (value) for decision-making. Thus, decision-making processes should be considered in detail when assessing sector-specific vulnerabilities in the context of climate information.

The second-major finding is the classification system of '*climate-impact types*' which classifies sector-specific problems in a systemic way. This system proves to be a promising concept because (i) it reflects and thus differentiates the cause for the climate relevance of a specific problem (compositions of buffer factors; (ii) it integrates DMP's which proved to be a significant factor; (iii) it indicates a potential usability of S2D climate service products and thus integrates coping options, and (vi) it is a systemic approach which goes beyond the established 'snap-shot' of vulnerability assessments.

2. Project Objectives

With this deliverable, the project has contributed to the achievement of the following objectives (DOW, Section B1.1):

No.	Objective	Yes	No
1	Develop and deliver reliable and trusted impact prediction systems for a number of carefully selected case studies. These will provide working examples of end to end climate-to-impacts-decision making services operation on S2D timescales.		x
2	Assess and document key knowledge gaps and vulnerabilities of important sectors (e.g., water, energy, health, transport, agriculture, tourism), along with the needs of specific users within these sectors, through close collaboration with project stakeholders.	x	
3	Develop a set of standard tools tailored to the needs of stakeholders for calibrating, downscaling, and modelling sector-specific impacts on S2D timescales.		x
4	Develop techniques to map the meteorological variables from the prediction systems provided by the WMO GPCs (two of which (Met Office and MeteoFrance) are partners in the project) into variables which are directly relevant to the needs of specific stakeholders.		x
5	Develop a knowledge-sharing protocol necessary to promote the use of these technologies. This will include making uncertain information fit into the decision support systems used by stakeholders to take decisions on the S2D horizon. This objective will place Europe at the forefront of the implementation of the GFCS, through the GFCS's ambitions to develop climate services research, a climate services information system and a user interface platform.	x	
6	Assess and document the current marketability of climate services in Europe and demonstrate how climate services on S2D time horizons can be made useful to end users.		x

3. Detailed Report

3.1 Concept for EUPORIAS' sector-specific vulnerability assessment

3.1.1 Introduction

The successful provision of climate service products from seasonal to decadal (S2D) forecasts to sector-specific users is dependent on the individual user needs and problem characteristics. Climate forecasts require an impact on decision making to have any value (Rodwell and Doblas-Reyes 2006). In this context, the knowledge of sector-specific vulnerabilities to S2D climate variability is very valuable information for both, climate service producers and users. For climate service producers this information helps to specify climate service products for individual user needs but simultaneously keeping them general to make them useful for other users with similar problems. For climate service users this information helps to assess their priorities of climate information needs as well as the potential usability of available climate service products. Thus, vulnerability information may also help to close the gap between the provision and use of S2D climate information (Goddard, Aitchellouche et al. 2010).

The presented vulnerability assessment framework intends to pick up these issues, asking: *in which ways are specific sectors vulnerable to climate variability and change and to which extent can S2D climate information possibly help to reduce these vulnerabilities?* The focus will be shifted from the climate event to the system of concern and using a bottom-up approach to tackle the problem-specific requirements on climate information.

The purpose of the suggested vulnerability assessment framework (VAF) is to identify and characterize sector-specific vulnerabilities in such way to provide valuable information for decision makers with respect to the use of S2D climate service products. Furthermore, there is a need to apply established concepts and methods on vulnerability assessments to make the results comparable and scientifically sound.

The report is structured in 4 parts. *Part 1* gives a short introduction on vulnerability and assessment concepts. It presents the major challenges of established concepts and presents an alternative assessment framework to assess vulnerabilities of economic sectors to climate variability in the context of S2D climate service provision. In *part 2* examples from the EUPORIAS prototypes and case-studies are presented to which the assessment framework is applied. In *part 3* the examples are analyzed and discussed. *Part 4* is dedicated to the actual sector-specific vulnerability assessment. Indicator-fields are identified and applied to the problems from the prototypes and case-studies. The outputs are vulnerability profiles for each prototype and case-study which can be found in the appendix.

3.1.2 Climate vulnerability - definitions and assessment concepts

Referring to the climate (change) context vulnerability is defined according IPCC as: "*The degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change, including climate variability and extremes"* (Carter, Jones et al. 2007). Vulnerability is often determined by the exposure, sensitivity and coping capacity of a specified system to a specific hazard (Brooks 2003, Füssel 2007, Preston and Stafford-Smith 2009). According to the IPCC **exposure** is defined as “the nature and degree to which a system is exposed to significant climatic variations” (McCarthy, Canziani et al. 2001). **Sensitivity** is “the degree to which a system is affected, either adversely or beneficially, by climate variability or change” (Parry, Canziani et al. 2007) and the **adaptive or coping capacity** is regarded as “the ability of a system to adjust to climate change (including climate variability and extremes) to moderate potential damages, to take advantage of opportunities, or to cope with the consequences” (Parry, Canziani et al. 2007).

Whilst the basic determinants of vulnerability are relatively consistent across research domains the conceptualizations do significantly vary between disciplines according the relation of vulnerability components. In the *biophysical perspective* the analytical focus is on the exposure to a hazard and the sensitivity of the system of concern, whereas coping capacity is normally not accounted (Soares, Gagnon et al. 2012). The most classical biophysical approach is the ‘Risk-Hazard Approach’. They key aspect of this approach is the hazard which is a potentially damaging physical event that is characterized by its location, intensity, frequency and probability. The vulnerability denotes the relationship between the severity of the hazard and the degree of the caused damage. Vulnerability is thus considered as ‘end-point’ (Füssel 2007). Vulnerability assessment methods are mainly ‘top-down’ and research-driven analysing the potential biophysical impact of a specified hazard (e.g. climate change) (Soares, Gagnon et al. 2012).

In the *social perspective* vulnerability is considered as pre-existing conditions of the system of concern and thus a system inherent characteristic and exposure is regarded as external element. The focus here is on differential sensitivities and capacity to adapt across various social groups within a system of concern (Soares, Gagnon et al. 2012) at which vulnerability is not a function of hazard severity or probability of occurrence but to a certain extent at least hazard specific (Brooks 2003). The most prominent approach is the ‘Political Economy Approach’ which focus the analysis on people, asking for the most vulnerable and the reasons. Vulnerability is here the state of social groups or individuals and their ability to cope with or adapt to external stress and is determined by the availability of and access to resources. Vulnerability is thus considered as ‘starting-point’ (Adger and Kelly 1999). Vulnerability assessment methods are mainly ‘bottom-up’ and research/stakeholder-driven analysing the vulnerability to a specified hazard (e.g. climate change) considering feasible adaptations (Soares, Gagnon et al. 2012).

Integrated approaches try to combine ‘internal factors’ of a vulnerable system with its exposure to ‘external hazards’. Prominent concepts are the ‘hazard-of-place model by Cutter (1993, 2003) and the ‘coupled vulnerability framework’ by Turner et al (2003). Vulnerability assessment methods are mainly ‘bottom-up’ and highly stakeholder-driven analysing recommended adaptations for reducing vulnerability to a specified hazard (e.g. climate change) (Soares, Gagnon et al. 2012).

The methodical implementation of most vulnerability concepts implies the assessment of vulnerability components by using indicators representing exposure, sensitivity and coping capacity. Different techniques are used to normalize weight and combine indicators to make them comparable. Output is often vulnerability maps on variable scales showing spatial differences in vulnerability (e.g. Schröter, Polsky et al. 2005).

3.1.3 EUPORIAS vulnerability assessment needs

Referring to vulnerability information needs in the context of S2D climate service provision the assessment of sector-specific vulnerability obviously requires an integrated approach. A detailed knowledge of climate phenomena or conditions which may have a relevant potential impact on a specific system of concern is required to be able to provide meaningful and usable climate forecasts. On the other hand, climate forecasts have no value if they have no impact on decision-making. Consequently, the structure and susceptibility of the affected system and especially interlinked decision-making processes need to be known to get the entire scope of vulnerability.

Consequently, the implementation of established vulnerability assessment concepts for the purpose of EUPORIAS implies two fundamental challenges:

(1) **The pre-determination of a climate 'hazard'**. This aspect is very central and implies a row of problems which all result in the problem of pre-determining a climate hazard.

   a) **The role of climate goes beyond the concept of a 'hazard'**. For climate-sensitive sectors climate may act as (i) *hazard* (system damaging), as (ii) *resource* (system controlling) or as (iii) *production factor* (system modifying) (comp. Sussman and Freed 2008, Van Bergen, Soonawala et al. 2008).

   b) **Climate does not have to be the actual 'hazard'**. Referring to a) the effect of climate on the system of concern is often indirect and modified and delayed by interconnected systems. Thus, climate is often not the actual hazard but (only) a relevant stressor. Consequently, not all extreme weather and climate events necessarily have extreme impacts; not all extreme impacts require extreme climate events; and a potential impact doesn't need to be extreme to require a decision.

   c) **Climate events are no discrete events**. Since climate is defined *"[…] as the average weather or more rigorously, as the statistical description in terms of the mean and variability of relevant quantities over a period of time ranging from months to thousands or millions of years […]*" (IPCC 2001), climate are not discrete events and mean and extreme values strongly depend on the specified period of time. Consequently, referring to a)+b) the use of climate extremes (i.e. extreme values of a 30-year period) is arbitrary with respect to relevant impacts on the system of concern.

(2) **Provision of vulnerability information**. Vulnerability information should help climate service producers to develop sector-specific products with problem-specific usability. On the other hand it should help decision-makers to prioritize climate-related vulnerabilities. Both aspects require vulnerability indicators which enable both a comparison of different vulnerabilities and its spatial characteristics.

Summarizing the problems above it can be concluded that **critical climate events and their scales are problem-specific**. Critical climate conditions and especially their scale are dependent on specific problems, the climate-impact pathway (modification of the climate signal) and decision-making processes which define local thresholds. For this reason it doesn't make much sense to pre-determine a climate hazard to assess sector-specific vulnerabilities. Looking for 'vulnerability to climate variability' is therefore sometimes misleading and only justified by the context of S2D climate forecast provision.

3.1.4 EUPORIAS Vulnerability Assessment Framework

Strategy

The basic assumption is that the *types* of climate impacts on economic systems (climate-impact pathways) are in general known since climate-sensitive sectors have to cope with climate influence and impacts on a regular basis. Consequently, decision-makers know rather well when a situation influenced by climate or weather becomes critical (i.e. lower limits) in terms of a decision is required. However, the intensity of climate events as well as the potential consequences (degree of risk) may be unfamiliar and surprising due to the low frequency of extreme climate events and the relatively faster changing vulnerability of the affected systems. Starting with the identification of such system-specific critical situations the influence of climate can be assessed and the characterization of critical climate conditions can be determined. Using the knowledge of decision-making processes and critical climate conditions respective climate information needs can be derived (e.g. spatial and temporal resolutions and timing of provision). This approach is aligned to prevailing concepts of climate service product development and dissemination (Goddard, Aitchellouche et al. 2010, Kirchhoff, Lemos et al. 2013) as well as to specific examples like PICSA (Walker_Institut 2006) or the research project 'Agricultural Extreme Weather and Risk Management Possibilities' (Gömann, Bender et al. 2015). The main attributes of vulnerability considered in this study will be the impact and usability of S2D climate forecasts for decision-makers of specific sectors.

A crucial part of this approach is the consideration of decision-making processes (DMP's). DMP's are considered as crucial for the definition of relevant thresholds characterizing critical situations as well as for the determination of climate information needs and the usability of S2D climate forecasts.

Scope

The primary scope of this study is the identification of problem-specific vulnerabilities with respect to climate variability on a seasonal to decadal scale to enhance the provision of S2D climate services to users with focus on the EUPORIAS prototypes and case-studies.

Of secondary importance is the development of a vulnerability assessment framework for sector-specific vulnerabilities to climate variability. This implies appropriate definitions for the terms 'vulnerability' and its components 'exposure', 'sensitivity' and 'coping capacity' for the context of climate information provision as well as a preliminary identification of indicators to describe and assess vulnerability.

Assessment concept

For the EUPORIAS VA an integrated approach to vulnerability is suggested. As global conceptual framework for the EUPORIAS VA, the CSIRO framework (Preston and Stafford-Smith 2009) and especially the UKCIP guide to climate change adaption (Brown, Gawith et al. 2011) may be taken as conceptual basis, since these concepts integrate biophysical and socio-economic dimensions of vulnerability and consider important aspects from risk management and policy sciences and support planning and decision-making under uncertainty.

Identification S2D climate exposures

To identify system-specific vulnerabilities relevant on S2D climate scales a 5-step approach is used for the EUPORIAS VA: (i) determination and delineation of the system of concern; (ii) identification of the system-specific critical situation (hazard and interlinked decision-making processes); (iii) identification of the system-specific buffer systems which cause a climatic relevance of the critical situation; (iv) derivation of the critical climate conditions and its specific scale in dependence on the buffer systems and decision-making processes; (v) assessment of the vulnerability attributes (here: criticality of decision-making processes and usability of S2D climate information). Figure 1 gives a schematic overview of this methodical approach.

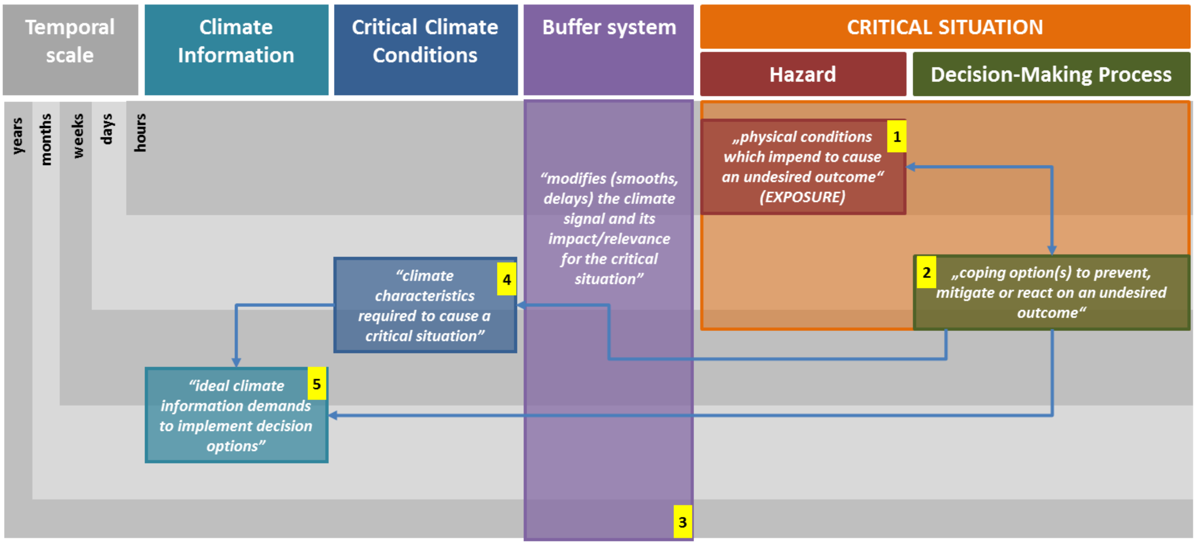

Figure 1: 5-step approach for identification of the system-specific vulnerabilities.

Determination of the 'system of concern': *the 'system of concern' is the considered system being analysed*. The system of concern is characterized and delineated by its physical boundaries and/or organizational boundaries defined by the scope of decision-makers. Thus, a decision-maker has to be identified, his reach of decision-making as well success criteria which define the scope of decision-making.

Identification of the 'critical situation': *the critical situation is defined as a situation at which a climate impact requires a decision or a situation at which a decision is significantly influenced by climate conditions.* The critical situation is characterized by physical climate-conditioned circumstances (thresholds, ranges, etc.) which may cause disadvantageous consequences for the system of concern ('*hazard*'). Interlinked decision options determine and/or characterize a critical threshold of the physical circumstances determining the point at which a decision has to be made or a coping measure has to be initiated.

Identification of 'buffer systems': *a 'buffer system' is an interconnected system which gives a 'climatic relevance' to the critical situation*. The 'climatic relevance' refers to the temporal (and spatial) scale of climate conditions relevant for the critical situation. Thus, the 'buffer system' is the reason for the temporal (and spatial) aggregation of climate parameters. Buffer systems may be of physical nature (e.g. ecosystems, catchments, etc.) or anthropogenic nature (technical or organizational systems).

Derivation of the 'critical climate conditions': '*critical climate conditions' are those climate conditions which are representative for the causation of the identified critical situation*. The focus is on impact relevant characteristics (e.g. role of distribution and extreme values) and especially the temporal dimension (i.e. critical scale).

Derivation of 'climate information': *'climate information' characterizes the format of which climate forecasts are required to be usable*. Attributes of decision-making processes relevant for the critical situation do have influence on this, determining temporal and spatial resolution as well as decision lead-times to initiate appropriate coping measures.

Assessing vulnerability

In the context of climate service provision the usability of climate services for the decision-maker as well as the impact on decision-making are crucial factors to assess the success of a climate service product. In the context of a vulnerability assessment a system can be considered as vulnerable when an impending climate event has a potential significant (negative) impact. Information on such a climate event would have significant impact on decision-making in order to cope with the impact or the consequences. However, if this climate information is not available (for technical reasons) or not usable (information has no value) by the decision-maker the vulnerability of the system to this climate event would increase significantly since appropriate coping measures cannot be initiated or only to a limited extend.

Thus, vulnerability in the context of climate services is basically related to the ability to activate the available coping capacity and the relevance of the climate event (or information) for the respective decision-making process required to initiate coping measures.

Consequently, three vulnerability attributes will be analysed to assess vulnerability for this study:

1. Relevance of climate on decision-making.
2. Criticality of decision-making processes for a specific critical situation.
3. Usability of S2D climate forecast information for the specific critical situation.

3.1.5 Methods and data

The EUPORIAS assessment framework will be applied to the examples from the climate service prototypes and case-studies developed in the context of the EUPORIAS project. Thus, the problems anticipated by the prototypes and case-studies will be analysed following the 5-step approach presented above. The assessment approach will be an integrated approach using both, top-down and bottom-up methods to gather respective information. The top-down information basically refers to literature research to get an understanding of general system understanding, cause-effect relationships, organizational structures and thresholds. The bottom-up information refers to the interviews conducted by WP12 as well as questionnaires and oral questioning of partners and stakeholders related to the prototypes and case-studies. Altogether ten prototypes/case-studies covering seven sectors have been analysed (Table 1).

Table 1: EUPORIAS prototypes and case-studies

Name	Abbreviation	Type	Sector	Partner	Location
Strengthening the European energy network using climate services	**RESILIENCE**	Prototype	Energy	IC3, EDF, Vortex	North Sea Region
River flow forecasts for water resource management	**RIFF**	Prototype	Water	Météo France, EPTB	Seine Basin, France
Land management tool	**LMTool**	Prototype	Agriculture	Met Office, CDE	Devon, England
Winter conditions for UK transport	**SPRINT**	Prototype	Transport	Met Office, DoT	UK
Hydrologic multi-model seasonal forecasting system	**HSFS**	Prototype	Water, Energy	SMHI, ELSFORSK	Ångerman Basin, Sweden
Livelihood Early Assessment and Protection	**LEAP**	Prototype	Food security	ENEA, WFP	Ethiopia
Seasonal Outlook Streamflow for the River Rhine	**SOSRHINE**	Case-study	Water	DWD, BfG	Rhine Basin, Germany
Seasonal Climate predictions for Water Reservoirs management in Spain	**S-ClimWaRe**	Case-study	Water	CETaqua, AEMET, DHI	Ebro Basin, Spain
A seasonal forecasting system for snowfall and snow depth in France's Alps ski resorts	**PROSNOW**	Case-study	Tourism	TEC	French Alps
A decision-support service for temperature related mortality in Europe	**CMTool**	Case-study	Health	WHO IC3	Europe

3.2 Examples from the EUPORIAS prototypes and case-studies

3.2.1 RESILIENCE

Introduction

Scope of prototype

The primary aim of the RESILIENCE prototype ('Strengthening the efficiency and security of energy networks') is to facilitate and strengthen energy management by having a more robust knowledge of the future variability of wind power. The highest priority for the energy network is to maintain a balanced system to avoid black-outs. However, the rapidly evolving energy system is in an increasingly vulnerable position due to the growth of highly variable wind power contributing to the total energy supply.

Scope of vulnerability analysis

With respect to power production the focus of RESILIENCE is on wind power and related decision-making processes. Wind power is a rapidly growing but highly variable power generation in European grids especially with respect to the North Seas Countries Offshore Grid Initiative (NSCOGI) where off-shore wind power constitutes a significant contribution to power production. The need for climate information on wind to enhance decision-making is therefore desired. The focus of this vulnerability analysis will therefore be on wind power production and problems of grid integration.

System of concern

The system of concern in the context of RESILIENCE comprises the North Seas Countries Offshore Grid Initiative (NSCOGI) which is a collaboration of the EU member states and Norway. It interconnects the countries of the North Sea Region and provides connection and integration of off-shore wind energy with on-shore power plants using especially hydroelectricity as storage for off-shore excess wind energy (E3G 2006-2015). It is the task of the grid-operators to actively manage the balance of supply and demand. Thus, the attribute of concern is the net power output (supply) which is the fundamental basis to meet the power demand to keep the system stable. A balanced system at economic conditions can be considered as success criteria for the system of concern.

Critical situations

The general hazard is a black-out caused by a significant discrepancy of power supply and demand. Small discrepancies can be balanced by changing the speed of alternators which is assumed to be constant in permanent regimes. A technical guiding value can thus be expressed in the frequency of alternators which is at 50 Hz. A specific deviation (which is system dependent) from this value may cause a disconnection of power generators from the system causing chain reactions and consequently black outs (Dubus 2015).

Wind speed for power production is challenging to manage since it is highly variable and often fluctuates over very short time periods comprising hours and even minutes and thus difficult to predict. This has consequences for the production of wind power, which is consequently very variable in space and time and can cause problems for the integrity of the grid (i.e. the power quality, the system security and system stability). Grid operator's task is to maintain the balance between the total supply of electrical power generated by all power plants feeding into the system and the aggregated demand (Ayodele, Jimoh et al. 2012).

Short-term variability of wind power

Hazard: In large highly interconnected power systems, short-term variability of wind power in the range of seconds to minutes are hardly felt by the system and thus pose no crucial problems (van Hulle, Fichaux et al. 2010). Such variabilities are automatically balanced by primary and secondary reserves, which comprise spinning reserves (power plants in part load operation mode) and standing reserves (rapidly starting plants). Both reserve modes run permanently and adjustments occur automatically since power imbalances in this temporal scale are normally not predicted or scheduled (Gül and Stenzel 2005, Dubus 2015). In contrast, wind power variabilities within a temporal range of a sub-hour to a day pose the most significant challenge for system balancing, since this has to be done manually. Magnitudes of variability in this temporal range are quite high and forecast systems are of limited certainty (van Hulle and Gardner 2009, van Hulle, Fichaux et al. 2010).

Decision-making processes: Decision-making in this situation relates to the organization and coordination of balancing options. This implies the activation of capacity reserves (tertiary reserves) which are flexible power plants and energy storage systems like hydropower (which is specifically important for the NSCOGI) and the import of energy from interconnected neighbouring grids. The specific reserve capacity required to balance supply-demand discrepancies in the very near future has to be declared until an agreed point in time (gate-closure time) at which a price for the energy will be determined. Common gate-closure-times in Europe are between 2 and 36 hours. Reserve capacities are declared on the back of wind power forecasts and the amount of required reserve power is a result of forecast error especially extreme forecast errors. Forecasts errors decrease with the reduction in time forecasting ahead (Gül and Stenzel 2005). Therefore there is great interest to have short-term gate-closure-times to reduce the time span between the final declaration of capacity and the actual use of it. This is to reduce the costs of power reserves due to uncertainty (van Hulle, Fichaux et al. 2010, Dubus 2014). However, the operation of appropriate power reserves often demands specific lead times. Smaller changes in wind generation are potentially challenging, since replacements with shorter lead time are required which is often more difficult. Consequently there is a trade-off between reduced gate-closure-times and thus short-term forecasts with lower errors and the increased demand for flexible operational reserves which come along with potentially higher costs (van Hulle, Fichaux et al. 2010, Dubus 2014).

Critical situation: Wind power is generated at very low marginal operating cost. Therefore, it is typically used to meet users demand when it is available. Considering that, it is not the total amount of wind power (i.e. wind speed) which is critical but rather the knowledge of expected wind power produced in the very near future. Thus, the rate of wind power change over different relatively short time periods is critical since it may significantly influence the certainty of wind power forecasts (Wiser, Yang et al. 2011). Consequently, for grid operators the critical factor is not even wind speed but rather the ability or certainty to forecast it assuming that compensation of power supply and demand is generally possible if the demand is known.

The critical situation arises by unexpected wind speed resulting in wind power variabilities deviating from the alternator's guiding value frequency of 50 Hz over a time period of up to 36 hours.

Long-term variability of wind power

Hazard: Active balancing operations of wind power variability occur on time scales between minutes and several hours. However, longer periods of electricity deficits especially where periods of peak demand coincide with periods of low wind power production may cause problems in managing appropriate balancing measures. Especially in power systems where the share of wind power is high (e.g. NSCOGI) energy deficits due to still weather or stormy conditions for a longer period may be significant.

The threshold for black-out is defined for the smallest scale (significant deviation from a frequency of 50 Hz). For larger time scales a maximum amount of black outs per year is determined by the 'security of supply' which is at 99% to 91% security level for Europe. The ability of system to meet expected cover peak load demands in the future considering uncertainties in the generation availability and load level and providing adequate transmission capacities for in- or export flows is expressed by the system's adequacy (van Hulle and Gardner 2009, van Hulle, Fichaux et al. 2010).

Decision-making processes: Decision-making processes refer to adjusting balancing units and measures for a long-term compensation of expected energy deficits. Since the interconnection of grids provides a kind of 'unlimited' availability of power, the challenge is rather the timely organization of appropriate and economic power reserves. Critical factors are capacity limits of transmission lines which only allow a certain amount of energy imported at a time as well as the limited availability of power sources of neighbouring grids which might be limited due to maintenance activities or limited storage or production capacity (e.g. water level for hydropower production) (van Hulle and Gardner 2009, Dubus 2014, Najac 2014, Dubus 2015). Climate information on this scale does not contribute directly to technical operations. Other important factors, like commodity prices and political issues are much more uncertain to make a decision at this point of time (Dubus 2014, Najac 2014). Thus, climate information on this scale rather provides orientation for decision-making on respective planning issues (Dubus 2014). Critical time frames of operational relevance are therefore very problem specific. However, estimated temporal scales for long-term management operation are between a few days up to a couple of months. But in general it can be stated that the more time available for planning (i.e. climate information is available) the greater the benefit (Dubus 2014, pers. com. Dubus).

The critical situation arises due to a long-term low-level of wind power production for periods of a couple of days to a couple of months causing discrepancies between supply and demand of energy which challenges the reserve capacities available on a day-to-day basis.

Buffer system characteristics

Wind power production is directly dependent on wind speed or more precisely on the cube of wind speed. Wind turbines commonly operate at wind speeds between 2.5 and 25m/s. Above and below this range wind power may become unavailable due to the lack of wind or shut-down measures to avoid damage of equipment (Gül and Stenzel 2005). Thus, to produce wind power no temporal buffer effect is required and threshold values are climatic.

However, the attribute of concern which is the total power output from the power system should be considered as the basic element of critical situations. Sources of electrical energy are diverse and wind power is only one of many which feed power into the system. Thus the power grid can be considered as buffer system which consolidates electricity from different power sources producing a net power output (and also net power variability). In contrast to other buffer systems, this buffer system does not buffer the climate input signal (wind speed) but the power input to the power system (no matter what source). Variabilities in power generation can be reduced by smoothing output variability of specific power generators. Wind power output can be smoothed by the use of wind farms and their geographically diverse locations which do not correlate with respect to power output. Total power output can be balanced by the interconnection of different power generation technologies and the interconnection with neighbouring grid systems. The broader the interconnectivity and diversity of the grid system the greater the robustness or resilience to variable wind power (Gül and Stenzel 2005, Wiser, Yang et al. 2011). The outstanding characteristics of this buffer system are its technical nature and the ability to control or at least accurately measure the individual components which contribute to the total output.

Critical climate conditions and climate information

Critical climate conditions

The production of wind power is directly linked to thresholds in wind speed and thus to climatic parameter. Wind speeds need to be above 2.5 and below 25 m/s to be used as power generator. (However, these values are due to the current standard of wind turbine and may be changing in the future with new technology.) *Critical weather conditions are high changes of wind speed rates especially on the scale of 2-36 hours at which decision on power balancing have to be made.* Thus, critical climate conditions for the production of wind are on the scale of weather events (very short-term) similar as the related decision-making processes which imply respective balancing measures.

However, the challenge to balance supply and demand increases with an increase of the lengths of wind still periods. The thresholds which define critical situations and especially its temporal delineation are primarily dependent on the prevalent grid system and its characteristics (generation mix, i.e. share of wind power, degree of interconnection), the efficiency of the operator to handle variability (use of forecasts, balancing strategy) (van Hulle, Fichaux et al. 2010). The critical climate or weather conditions for longer-term discrepancies of wind-power supply and power demand are periods with low wind speeds which go beyond seasonal intermittency. The longer such periods last, the greater the probability to create a critical situation. For example, periods of low wind with a durations of around 1-2 weeks had significant economic impact in Denmark and Germany in 2007 (Bach 2010) and can serve as a landmark to assess critical time periods. However, the point in time at which periods of low wind may have significant impact can clearly be determined since they are strongly related to periods of peak demand which are commonly in winter and summer when extra energy for heating or cooling is required (Sinden 2007).

Critical climate conditions are low-wind (below average) speed conditions over periods of 1-2 weeks or longer.

Climate information

Decision-making on sub-seasonal to seasonal time scales implies planning and organization of power supplies to balance expected gaps of power supply in the near future. Forecasts on periods of below average wind speeds starting from one week and more are desired and of potential use. However, the longer the periods of low wind speeds the greater the effort to compensate expected lack in wind power production. Thus, longer lead-times for decision-making are required. Consequently, wind speed forecasts on multiple scales are potentially useful but also desired. However, winter and summer times are obviously risky periods, since high power demands are expected.

Vulnerability attributes

Criticality of decision-making processes: the assessment of the future power supply is of elementary importance to avoid black-outs and keeping the power system stable. However, the share of wind power is still rather low for most power systems and its particular relevance for systems stability manageable. Of much more relevance is the total contribution of variable energy sources (renewable energies) for power supply and most important is the variability of power demand (Dubus 2014). Thus, climate takes the role of a production factors rather than a resource. With respect to the problem of balancing supply and demand to avoid black-outs the adequacy of the grid, i.e. its ability and flexibility to cope with power imbalances (resilience) is probably the most sensitive factor. For a robust (resilient) grid it doesn't much matter whether wind is blowing or not as long as its share for the power system is not too high and as long it can be sufficiently accurately predicted. A more relevant impact of longer-term low wind periods is probably on the pricing of wind power and thus for energy traders.

Usability of S2D climate forecast information: the informational content of S2D forecasts comprise mean values of wind speed for temporal periods at different time scales (1-12 months) is basically compatible with the information needs of DMP's on these scales. Since decisions on specific power balancing measures are made on the day-to-day basis, information with high resolution on wind power timing and temporal distribution are not yet required on S2D scales. Information on the approximate amount of power to be supplied for a specific period is sufficient planning issues. This has also consequences for the ***level of certainty***: any skill of the forecasts provides some benefit in terms of additional information. Due to the smoothing effect of wind farms the relative coarse ***spatial scale*** of the North Sea region is favourable for the usability of S2D forecasts since no substantial down-scaling is required. Finally, the planned S2D forecasts for RESILIENCE do meet the demands for decision making with respect to ***timing*** (winter and summer months) and ***temporal scales*** (1 month to 1 year) and constitute no barrier from the technical point of view.

3.2.2 RIFF

Introduction

Scope of prototype

Water resource management in the Seine river catchment and Adour-Garonne river catchment implies decision-making processes of great importance. Essential public infrastructures and economic sectors are potentially affected: e.g. for the Seine river, fresh water supply for more than 6 million people, cooling for 1 Nuclear and 2 Thermal power stations, economical loss estimation of severe flooding in Paris reaching up to 6.5 billion Euros and for the Adour-Garone river low flow support potentially leading to buy water from external providers. The prototype intends to help the EPTB Seine Grands-Lacs (Seine) and DREAL Midi-Pyrénées (Adour-Garonne) in their current decisions making to:

- anticipate drought and maintain minimum rivers flows in summer;
- ensure the refilling of reservoirs at the end of the winter;
- especially for EPTB Seine Grands-Lacs, adapt the management in Winter to damp possible flooding events at Spring while ensuring efficient low flows support in summer and autumn.

Behind these decisions, the major stakes concern fresh water supply (contribution of the river flow from 50% to 80% in summer) and flood control over the Paris metropolitan area for the EPTB Grands Lacs and irrigation for agriculture over the Adour Garonne river catchment for DREAL Midi-Pyrénées (this region ranking first in France for farming). The stakeholders are already using models to monitor their reservoir dams. They use a range of possible situations issued from their historical records (over more than one hundred years) to make their water volume prediction. The benefits of using seasonal forecasts are real if they allow reducing the range of possible scenarios. The overall value to our stakeholders of the prototype is promising since, as demonstrated, using seasonal forecasting brings more skill than using climatology as they used to do.

Scope of vulnerability analysis

Water management problems comprise many different tasks and aspects covering diverse sectors. The number of critical situations caused or influenced by climate is therefore manifold and probably difficult to identify and analyse completely. Thus, the scope of this vulnerability analysis will be focusing on the problem of water supply management which is within the scope of local authorities and related organizations. This implies decisions on reservoir management controlling rates of water inflow and release considering diverse interests, safety issues and user needs. The focus will also be on the Seine catchment with the EPTB Grands-Lacs as decision-maker.

System of concern

The river basins are the logical physical boundaries of the system. Nevertheless, some hazards may affect larger area. As an example, drought could persist over months or years; it can affect large areas and may have serious environmental, social and economic impacts (Horion et al. 2012). For the prototype this comprises the catchments of the Seine River. The French water policy is defined and coordinated at the national level by the Ministry of Ecology, Energy, Sustainable Development and the Sea. But water management occurs decentralized on the level of river basins considering geographical boundaries instead of political. In France there are 13 river basin districts in accordance with the European Water Framework Directive (WFD) which is implemented in accordance with the national water policy on basin level (Master Plan for Water Development and Management [SDAGE]) (Noel 2009). For the Seine catchment it is the EPTP Grand-Lacs who is responsible for the regional water management issues.

The *Seine Normandy basin* drains an area of about 97,000km^2 which comprises a river network of 66,000km among which the Seine has a length of 776km and a mean discharge of 460m^3/s draining a catchment of 64,500km^2. The climate is oceanic with an average rainfall of 750mm (varying between 300 and 1600mm depending on the area) and a mean evapotranspiration of 500mm with a maximum in summer (90 mm/month). Average temperatures range from 2.5°C (January) to 24.6°C (August) (AESN 2003, Dorchiesa, Thirelb et al. 2014). 17.500 million people live in the Seine Normandy basin which is 30% of the French population. Respectively, the main purpose of water use is for drinking water. 100% of the population receives their drinking water from the river network. About 40% of surface waters and 60% of ground waters are used which is around 1.5 million m^3 per year or 190l per inhabitant per day. Four dams with a total capacity of 800 million cubic meters and water towers with a total capacity of 880 million cubic meters are available to manage variable water needs. Besides the provision of drinking water, the dam reservoirs provide water for industry and agriculture, to protect urban areas from flooding and offer leisure activities on the local scale (AESN 2003, MEDDE 2006).

Critical situation

The general task of water managers is to provide water supply to cover respective demand of different stakeholders and users within a specific basin. This relative straightforward task is complicated by the plurality and diversity of users like industry, energy production, agriculture, inland waterway transport, tourism and especially municipal use of water (drinking water and wastewater) which all have individual needs especially with respect to volume, purpose of use and timing (Noel 2009). Since 2000 in the context of the Water Framework Directive management does not only imply the managing of available water supplies (quantity) and its related hazards like droughts and floods but also the preservation of flow rates, quality and feedbacks from affected systems (Atwi and Arrojo 2007). To predict future water availability in a reasonable way water managers require a firm understanding of the natural water cycle and the variability of water resources at different scales within a catchment. A common critical method of managing hydrological variability is the use of dam reservoirs. Reservoirs provide a significant although limited opportunity to control water supplies by storing water at times where water availability is greater than the demand for seasons with potential water scarcity. Reservoir design is tightly related and based on historical streamflow, current water needs and projections for future water needs as well as future water availability. Thus, assuming stationarity, prevalent water supply systems do meet the need of current and near future water use. Challenges may occur with respect to the reliability (buffering of variability) and the sustainability (future reliability) of such systems (Brown, Baroang et al. 2010).

Hazard: A major problem is the major water consumption which causes low river flows. In summer drying the rivers upstream from Paris which has serious consequences on water supply, ecological conditions and especially water quality (AESN 2003, Dorchiesa, Thirelb et al. 2014).Flooding is a further major concern for the area especially since large parts of the basin rendered impermeable and thus increased surface runoff. Floods are prevalent in spring season (January-April) and have the potential to inundate urban areas and also mobilize wastewater causing severe health problems. The role of dams to control floods is important but limited because of their distance from the large urban areas and their limited capacity compared to the volumes of major floods (800 million m^3 vs. 4 billion m^3 in 1910) (AESN 2003, Dorchiesa, Thirelb et al. 2014). In the context of this analysis the hazard of flooding will only be considered secondarily since the focus is on water supply management and flooding comprises different decision-making processes.

To determine thresholds for high- and low-flows relevant for decision-making it needs to be considered that the critical aspect is the reservoir management and not the final consequences. Since the water management system is aligned or rather based on historical hydrological respective extreme events are also relevant for water managers.

Decision-making processes: the main purpose of the four dam reservoirs in the Seine catchment is to provide sufficient high water supply during the summer season (for irrigation and drinking water) when natural water availability is low and to prevent flooding in urban areas downstream of the reservoirs. Thus, the focus of reservoir management is to reach maximum volume shortly before the beginning of the dry season (July-October) considering the provision of sufficient buffer capacity to damp flood events during the filling period. Each of the four dams is operated independently following a filling curve (FC) which determines the reservoir volume for each day within a year. The curves are designed using the information from the analysis of historical hydrological regimes (Ficchi, Raso et al. 2014).The main filling periods in France are thus during the rainy periods between autumn and early summer (November - June). The emptying period lasts from July to October and can be extended until December in case of low-flows. Thresholds are determined for a minimum flow during the filling period to preserve aquatic life downstream of the dam and a maximum flow during the emptying period to avoid unexpected high flows. A desired storage volume at the end of the filling period is determined considering a respective buffer to damp flood events and a “reserve tranche” is defined determining a minimum storage volume for the release period (Dorchiesa, Thirelb et al. 2014, pers. com. Viel).

Decisions related to reservoir management in the Seine basin occur within the technical committee or user meeting (COTECO) which takes place around three times per year according to the three main periods of decision-making: (i) in June the low-flow for the coming dry season is projected to adapt the safety reserve threshold; (ii) in September at the end of the low-flow period projections until December are made to extend the release period if necessary and decisions about under-filling measures are made to prevent future flooding; (iii) in February at the end of the filling period projections of the coming summer conditions are made to review and adjust the refilling of the reservoir (pers.com. Viel).

Critical situation: the critical situations related to decision-making processes for reservoir management in the context of balancing supply and demand are twofold:

A critical situation arises by a high variable discharge regime during the rainy season (October-June) challenging the balance of maximizing the reservoir capacity until June and buffering unexpected flood events prevalent between January-April.

Buffer system characteristics

For water management issues in context of reservoir management the availability of water in form of discharge is the attribute of concern. Water managers and users get a problem when there is a "prolonged period with below-normal water availability in rivers and streams, and lakes or groundwater bodies due to natural causes" (VanLanen, Wanders et al. 2013 p.1716) thus, a hydrological drought. Hydrological droughts evolve slowly and are due to periods of low precipitation combined with high evaporation losses which causes soil moisture deficits and subsequently reduces groundwater recharge and head and eventually lowers stream flows (Maybank, Bonsal et al. 1995). The area affected by droughts is primarily climate driven whereas local variability is influenced by characteristics of the terrestrial system. Hydrological storage or a combination of catchment characteristics which relate to catchment storage and release (e.g. land use and geology) is the most important factor controlling drought propagation and causing lag times between a meteorological drought and hydrological drought and its spatial characteristics (Tallaksen, Hisdal et al. 2009, VanLoon and Laaha 2014). The monitoring of hydrological reservoirs within a catchment is also a central element of the Spanish Drought Management Plan (Monreal and Amelin 2008).

In contrast, the occurrence of flood events is much more sensitive to changes in hydrological reservoirs. For flash floods the soil do not even need to be saturated. High magnitude rainfall events may exceed the infiltration rate of the soil, causing surface runoff and thus provoke local flooding despite rather dry soil conditions. Also snowmelt floods and rain-on-snow floods are often dominated by temperature which controls the activation and the draining of the respective hydrological storage (Merz and Blöschl 2003).

Dams and reservoirs can also be considered as hydrological storages and thus as an additional buffers. However, these storages should be considered as different buffer systems, since this storage type is controllable and stored water is available at discretion. The infilling of these storage types is dependent on the discharge of the catchment draining the area uphill of the reservoir but the release rate can be controlled by decision-makers.

Critical climate conditions and climate information

Critical climate conditions

The relation between discharge and rainfall is strongly dependent on catchment characteristics especially the state of hydrological reservoirs. The development of hydrological droughts is a slow process and not only dependent on periods of low rainfall but also on temperatures and evapotranspiration potentials. Required time-scales over which precipitation events need to be below average or even lacking to provoke hydrological droughts are in general seasonal for fast responding catchments and may be inter-annual in catchments with large hydrological storages (vanLanen and Tallaksen 2007).

For the Seine basin little information could be found on typical climate conditions responsible for drought events. However, the Seine basin possesses large geological aquifers and thus a large natural storage capacity conferring a long hydrological memory. Compared to other regions in France drought events in the Seine basin do have a lower frequency but are of longer duration and typically start in autumn or winter (Vidal, Martin et al. 2010). Consequently, longer lead times of below-average precipitation are expected to create a drought. The study of Hannaford et al. (2011) confirms this hypothesis and fond a correlation of RDI/RSPI (Regional Deficit Index / Regional Standardized Precipitation Index) which is best for a time scale of 12 months for the Seine basin.

In contrast, flood events occur due to much shorter reaction times of the catchment: flash floods or short-rain floods which happen on the local scale due to saturated soil conditions or high magnitude rain events which exceed the infiltration rate are at the time scale of less than 1 day. But even long-rain floods which cause floods on a larger spatial scale are in the temporal scale of several days to maximum weeks. Floods due to snow melt are often even independent of rain but rather related to temperature (Merz and Blöschl 2003).In the Seine basin floods typically occur in the winter time and last around 20 days. Simple floods are caused by high magnitude rainfall events of 2-3 days and double floods require rain spells separated by around 4-6 days rainfall. Multiple floods are caused by a succession of rainfall events during a few weeks (Rousset, Habets et al. 2004).

Critical climate conditions are below-average precipitation during the year combined with above-average temperatures. Furthermore, extreme high rainfall events during and especially at the end of the rainy season.

Climate information

To assess the potential inflow in dam reservoirs information on total rainfall and temperature means for the infill-season (October-February) is required. Thus the demand is for a 6 month-forecast available at beginning of October. In June another 4-6 month forecast would be required to recheck the water availability and demand of the dry season to adapt the safety reserve in the reservoirs.

To assess flood events during winter information on total water availability is sufficient however information on the distribution (magnitude-frequency) would be desired to be able to cope with individual events especially at the end of the filling season when reservoirs are rather full.

Vulnerability attributes

Criticality of the problem: water availability in a drought-prone region is basically a very critical factor and thus related decision-making processes are of general criticality. But, no information is available about risk preferences of the EPTB Grands Lacs. However, decision-makers in Spain appear to be risk-averse an attitude that could also be prevalent within RIFF: uncertainties on water availability are countered by worst-case hypotheses to avoid risky (irreversible) decisions of users (e.g. farmers) (CHE 2014). Thus, the decision to exhaust the storage capacity of reservoirs within a catchment is a robust (low risk) decision with respect to water availability. In this context floods do constitute greater risk since they don't allow exhausting the total storage capacity due to dam safety reasons (CHE 2014).

Usability of S2D climate forecast information: decision-making of water managers refers to the fill-level of the reservoir which is aimed to be exhausted at the end of the rainfall season but requires considerations for in-seasonal release rates due to a number of issues including flood-protection and the protection of ecosystem. Thus, decision-makers are interested in total water available at the end of the rainy season. Discharge rates during the season and thus the timing of high- and low-flow events are of minor importance with respect to this goal. This interest is systemically and technically supported by the buffer effect of the catchment and dam reservoirs. Consequently, information on mean temperature and effective rainfall over a certain period is general desired and usable due to the systemic buffering of rainfall and evapotranspiration rates by the catchment and reservoir system. Furthermore, since temporal scales of the critical climate conditions is much longer than the temporal scale of decision-making seasonal climate forecasts must not cover the entire time-scale. At the time of decision-making a great deal can be covered by using climatology.

Timing is however an issue for the coping of flood events. Especially when approaching the end of the rainy season when the reservoir tend to be close to maximum capacity and the timing of high-magnitude flood events becomes a critical information. Thus, climate information with higher temporal resolution would be desired to reduce uncertainty of such events.

River catchments do not only aggregate rainfall events on a temporal dimension but also on a spatial dimension. Compared to problems of other sectors the need for high ***spatial resolution*** is limited and thus the tolerance to lower spatial resolution is expected to be higher. Furthermore, since water resource planning is traditionally made by the use of historical climate (discharge) data, the overall catchment water management system is aligned to climatology and thresholds of low- and high flows relevant for decision-making are also related to the local hydrology. The ***timing*** of decision-making processes is also aligned to the hydrological year. Thus, forecasts periods do match periods of climate information needs no complicating demands are set for the seasonal climate forecasts. Referring to the relative risk-averse decision-making forecasts are supposed to have very little uncertainty to cause any change in decision-making.

3.2.3 LMTool

Introduction

Scope of prototype

The problem considered by the 'Landmanagement Tool' (LMTool) is for now the management of winter cover crops. However, the tool is supposed to provide general useful weather information for decision making for farmers (users have also indicated lots of potential additional uses e.g. planning cattle feed etc.) in the future. The major purpose of planting cover crops is to prevent the loss of soil and nutrients due to erosional processes. But also help to manage issues related to carbon storage, weeds, pests, diseases, biodiversity and wildlife. Thus, the application of cover or winter crops approaches a plurality of problems which are more or less climate sensitive.

Scope of vulnerability analysis

The focus of the vulnerability assessment with respect to the provision of appropriate climate information will be linked to the primary purpose of the LMTool: this is the management of winter cover crops and especially in the context of soil erosion and the erosion of newly planted crops. Thus, the discussion of this specific management problem is only one part of the scope of the prototype.

System of concern

Clinton Devon Estate (CDE) is a major regional land owner in the South West UK, with responsibility for 25,000 acres of land. Its areas of business cover farming, sustainable forestry, conservation management, deer management, commercial and residential property and businesses including the region's premier equestrian venue. CDE's decision making depends critically on land and weather conditions, covering timescales from hours to decades.

Practical cover crop management occurs on the *field scale* by the farmer as decision maker. The farmer is also in the focus of the LMTool which targets to enhance farmers decision making. The farm-system can therefore be considered as system of concern, at which the farm grounds delineate the spatial and operative boarders of this system. Success criteria for the decision-making are finally financial benefits due to a more effective workflow and economic use of resources. The workflow of winter cover crops management involves several decisions which tangent and thus affect other management decisions introducing a great deal of complexity into this system. Three basic decisions for crop management can be identified:

1. Whether to plant a winter cover crop
2. Which cover crop to choose & when to plant the crop
3. How to manage the cover crop (e.g. timing of grazing, harvesting)

Critical situations

The identification of the critical situations in this chapter is aligned to DMP's of land management which are accompanied by climate induced hazards. This is in contrast to other case-studies where DMP's are aligned to specific hazards in terms of coping.

Decision on planting cover crops

The basic decision of field planning regarding cover crops is, whether they should be planted or not. Cover crops are desired when there is a risk of soil erosion and nutrient leaching due to very wet conditions during the winter months (Perrott and Baughen 2015). This decision may become redundant when political regulations control crop rotation patterns and mixtures (Stevens 2015).

Hazard: The scope of this decision from a physical perspective is to mitigate long-term consequences of soil and nutrient loss. On the long-term the loss of soil will detract the basis to grow crops. Time scales over which impacts on crop yields will become apparent tend to be in the order of hundreds of years (Boardman 2013). However, tolerable upper limits of soil erosion rates for Europe, i.e. any actual soil erosion rate at which a deterioration or loss of one or more soil functions does not occur, are estimated to 1.4 t ha^{-1} yr^{-1} which is 3 to 40 times lower than actual soil erosion rates from tilled arable land in Europe (Verheijen, Jones et al. 2009). Growing winter crops reduces soil erosion rates by up to 10 times compared to bare soils in Europe (Cerdan, Govers et al. 2010). On the short term the occurrence of gullies may provide inconveniencies for field operations especially harvesting. However, erosion rates of about $50m^3$ ha^{-1} yr^{-1} on a particular field and the occurrence of gullies are necessary to inhibit operations on a field and to constitute serious conditions for the farmer. And even then, financial losses are relative small compared to off-site losses (Boardman 2013).

Decision-making processes: Planting winter cover crops is a robust coping measure to reduce the general vulnerability of the ground to erosive effects of surface runoff. The purpose is to aim for the long-term effect and consequences rather than any short-term single event consequences within a seasonal or annual time scale. The decision on planting cover crops has to be made early enough so that cover crops have enough time to capture nutrients and get established to withstand wet winter conditions and contribute to prevent surface runoff and thus soil erosion and nutrient leaching. The timing of planting cover crops is strongly dependent on the type of cover crop and especially the type of the preceding summer crop and its timing for harvest. To keep flexibility in the crop-shift period with respect of the timing of harvest and the choice of winter cover crop the decision on planting winter cover crops should be in July/August (Perrott and Baughen 2015). The criteria for an upper limit of acceptable amount of soil erosion within one year can only be determined theoretically (as a statistical mean value) and has no operational impact on decision-making. Decisions on soil erosion are made in context of the risk of precipitation events and individual valuation.

The critical situation arises when the erosion rate for the coming season (especially October-February) is expected to be above an acceptable limit (*1.4 t ha^{-1} yr^{-1} or $50m^3$ ha^{-1} yr^{-1}*).

Decision on type of cover crop and timing for plantation

The decision on the type of cover crop and the timing of plantation are closely interlinked and condition each other to a great extent.

Hazard: The timing of plantation is very dependent on the climate conditions in the period of crop-shift operations. In general autumn- and spring-sown crops are especially problematic providing vulnerable periods at which soils remain bare without protecting vegetation cover

(Burt and Allison 2010, Boardman 2013). E.g. winter cereals require in average a period of two months to gain a crop cover value of about 30% which is enough to provide adequate protection for the soil (Boardman 2013). Within this vulnerable period which lasts around 2 months one single erosional event triggered by a short-term convective rainstorm is already enough to destroy a newly planted field by eroding seeds and young crops (Perrott and Baughen 2015).

Decision-making process: The knowledge of a possible very wet transition period gives the farmer the opportunity to avoid this period and postpone or bring forward the crop-shift (Perrott and Baughen 2015). The timing of the crop-shift-period also determines the type of winter crop which shall be planted. The later the planting date the higher the required growth rate of the winter crops to be resistant to low temperatures and wet winter conditions (Knasckeil 2015, Stevens 2015, Wastenage 2015). If the crop-shift-period is earlier than usual due to expected wet weather conditions in October, harvesting activities of the summer crops have to be adapted which possibly requires the organization of additional machines and staff to bring in the harvest more efficiently (Stevens 2015). The timing of this decision should be in summer when plantation of winter cover crops should be happening in case of a wet autumn. July/August is suggested by local farmers from Devon (south England) as date where information on autumn/winter conditions regarding rainfall and soil temperature is desired (Perrott and Baughen 2015).

The critical situation arises when convective rainfalls hit bare fields after sowing impend to erode newly planted crops especially around October.

Buffer system characteristics

The link between rainfall and surface runoff which provokes soil erosion and nutrient leaching is buffered by the soil system. Surface runoff is generated mostly by saturation excess, where continuous rainfall raises the water table to the soil surface or sometimes by infiltration excess where rainfall rate is greater than the infiltration rate. For erosion to occur the shear stress of the moving water must exceed the shear resistance of the soil surface. Geology, topography and especially soil characteristics and its physical and chemical properties as well as vegetation do control surface runoff and erodibility of the ground (Burt and Allison 2010). Despite the buffer function of the soil systems the turnover of soil water seems to be rather high, since runoff generation and especially soil erosion events are strongly related to rainfall events. Especially individual high magnitude short-term rainfall/runoff events are responsible for a great deal of soil erosion. However, to account for most erosion moderate to large rainfall events need to be monitored over a longer period of time (Boardman 2006, González-Hidalgo, Luis et al. 2009). Thus, the buffer capacity of soils is in general very limited and readily exceeded by prolonged or especially high magnitude events. On the other hand, the storage characteristics of the soil system are very dynamic and mediates the local interaction of fluctuating water supply (rainfall) and demand (potential evapotranspiration) (Milly 1994, Porporato, Laio et al. 2001).

Referring to the final consequences (ability to grow crops) of soil erosion the soil system provides another kind of buffer function with respect to climate impact since it takes several decades of erosion (i.e. aggregation of erosive events) to cause significantly reductions in crop production. Thus, soil erosion is a long-term problem at which, however, climate may not even be the dominant factor. Slaymaker (2001) states that certain changes land-use practices are likely to have greater impact on erosion rates than any climate change scenario (Boardman 2006).

Critical climate conditions and climate information

Critical climate conditions

Necessary rates of rainfall to produce soil erosion are very dependent on the specific site but they are in the range of tenth of mm in a couple of days. For the South of England it is determined for at least 30mm within a two-day period (Boardman 2013) or short duration convective rainstorms with rainfall rates with at least 10mm h^{-1} (Fullen and Reed 1986). For that reason information like mean rainfall of the wettest month or mean values on maximum rainfall, or subsequent indices derived from such data are no useful indicators to assess erosion potential (dePloy, Kirkby et al. 1991). Critical climate conditions for general soil erosion are not to be defined since mean erosion rates for Europe are already critical under normal climate conditions (Verheijen, Jones et al. 2009).

Critical climate conditions for erosive events are high magnitude rainfalls over short periods of time (30mm in 2 days or 10mm h^{-1}) during a period of 2 months in autumn.

Climate information

Decision on planting cover crops: Short-term high magnitude rainfall events within a period of about 3-4 months (October-February) are critical for soil erosion. Information on mean max values on precipitation for this period would be desired climate information since mean values on precipitation have little information on individual high magnitude events which are identified as critical for soil erosion (Stevens 2015, Wastenage 2015). Also the relation of forecasts to the past 1-5 years may be of greater value for the decision maker. Since recently past years can be remembered, the significance of the forecast can be assessed on the basis of personal experience instead of a statistical mean value (Knasckeil 2015, Perrott and Baughen 2015). Decision-making processes require a lead time of 2-3 months to keep alternative decision options available.

Decision on type of cover crop and timing for plantation: To cause the flushing of newly planted crops one single erosive event exceeding the threshold of 10mm h^{-1} or 30mm in a two-day period can already be critical for the vulnerable 2-month period around October. Thus, required climate information should ideally resolve such events to be useful. The period of concern for such events is a two month period around October. Decision-making processes require a lead time of 2-3 months to keep alternative decision options available.

Vulnerability attributes

Criticality of decision-making processes: soil erosion in the context of land management has a destructive impact. Thus, the role of climate is that of a hazard which do affect agricultural activities but are not fundamental for the sector. The decision on whether to plant cover crops is rather specific problem for the CDE region. In the context of political regulations even on European level, the use of cover plants to mitigate soil erosion and nutrient leaching may become mandatory (Knasckeil 2015). However, considering the overall criticality of the problem this is very significant since the availability of fertile soil is the basic requirement for growing crops. In this long-term context, climate may lose relevance since land-use practices are likely to have greater impact on erosion rates than any climate change scenario (Slaymaker 2001).

The criticality of the decision on ’type of cover crop and timing for plantation’ is much more significant compared to the decision on planting cover crops since no robust decision option with respect to land-use practices is available. Climate is dominating this problem and adding a great deal of uncertainty. However, the overall criticality of this decision is relatively low, since the worst case scenario would be a lost harvest (in case the cover crops are cash crops) and thus some economical losses.

Usability of S2D climate forecast information: the individual high magnitude rainfall event is not of major concern but the total amount of eroded soil within one year. Therefore mean values are of general use, however information on the distribution is desired since mean values on precipitation have little information on individual high magnitude events which are identified as critical for soil erosion. The required knowledge on precipitation distribution increases the uncertainty of the climate forecast and thus the informational output. The available S2D climate forecast for LMTool aims for precipitation with a temporal resolution of 3 month from October to February. This information seems therefore of general use whereat the integration of all autumn months would be desired.

The temporal scale of the forecast and the scale of the critical climate conditions deviate significantly. Information from a climate forecast with a 3 month temporal resolution as it is currently available is linked to significant uncertainty and decision-making is thus rather risky. Furthermore, climate information for the autumn month would be desired which contradicts the available S2D climate forecasts which aims for the period from October to February.

3.2.4 SPRINT

Introduction

Scope of prototype

As recent years have demonstrated, wintry conditions have a significant impact on most forms of transport in the UK. Airport closures, road accidents and delays/cancellations of train services are just few examples of the possible consequences of widespread snowfall over the British Isles. The exceptional winter of 2013/14, in which a series of storms crossed the UK, also resulted in widespread impacts with severe flooding affecting the rail and road networks. Long-range forecast information is, therefore, of significant value to the transport sector, alongside its current use of weather forecast products to inform operational planning, and its increasing knowledge of impacts at the climate change timescale.

Scope of vulnerability analysis

The transport sector is diverse and in multiple ways sensitive to different weather conditions. The focus of this analysis will be put on the road network and problem of snow and ice and their effect on road safety conditions. Respective management issues comprise the procurement of de-icing material and snow-clearing equipment as well as the management of trained staff.

System of concern

The prioritized stakeholder for the 'Winter Transport' Prototype is the UK Government Department for Transport (DfT) and the related highway agency 'Highways England'. Highways England has the responsibility for investments, operation and maintenance of around 4.300 miles of the motorway and trunk road network in England. The maintenance of this strategic road network is done by contractors. Local Highway authorities are responsible for 180.000 miles of England's roads which carry around 69% of total traffic. Both highway authorities have to ensure that the safe passage along the highway is not endangered by snow and ice and have the duty to remove obstructions caused by accumulated snow. This implies the preparation of winter service plans including procurement and application of de-icing material (typical rock salt). Maintenance practices at both scales of the road network (both types of authorities) are determined by standards (management manuals and best practice codes) and are thus central organized (Quarmby, Smith et al. 2010).

Thus, the spatial delineation of the system of concern is the motorway and trunk road network (Highways England) and the local roads (Local Highway authorities) in England and at which winter service operations can be considered as the operational boundaries. The attribute of concern is the road condition as well as stock levels of de-icing material. The goals (success criteria) of the DfT and local authorities are mainly the functionality of the road network maintaining high standards of safety and security for passengers and freight (GOV.UK , Kerwick-Chrisp 2014).

Critical situation

Hazard: the occurrence of frost, ice or snow on roads causes hazardous conditions for any type of traffic due to its slippery effect. Important for ice formation are freezing temperatures below the freezing point and moisture at the surface. The type of ice and frost formation is of lower relevance, i.e. if the water freezes on the surface (e.g. glaze), ice develops at the surface (frost) or the ice is sedimented onto the surface (as hail or snow). The temporal scale for the ice formation process is very short and happens instantaneously (MetOffice 2014). Specific types of road-ice may enhance the threat (e.g. black ice) and local ground conditions may be more sensitive to ice formation (due to topo-climate conditions) and have thus different effect on slipperiness (CROW 2000, CROW 2006). But in general, the hazardous effect of ice (slipperiness) occurs as soon as it is formed. This is also because the actual slipperiness of ice is only one factor of many which causes accidents. Consequently, the effect of ice is virtually instantaneous on the safety of the road traffic. Thus, there is no relevant threshold with respect to ice parameter required (or rather to determine) to constitute a potential hazard for road traffic. At which the hazard of ice on roads is increasing with its distribution and persistence.

Decision-making process: Immediate decision-making processes of highway authorities related to the hazard of icy roads are (i) whether to undertake the precautionary treatment of the network, (ii) the spatial extent of gritting or snowploughing activities and (iii) the respective allocation of equipment as well as operational plans such as rotas and staff-cover. Additional short-term decisions are the informing of the public and stakeholders about action being taken and the expected road conditions for the next couple of days. The required lead time for such decisions is rather short-term and a couple of hours are enough to prepare and coordinate respective operations. In the case of England, road management of local highway authorities does work quiet well even under severe winter conditions like the winters in 2008/09 and 2009/10. However, when local salt supplies impend to exhaust, local authorities have little options to cope with salt shortage besides the reduction of salt for gritting or the mutual aid of neighbouring communities. But at the end the limiting factor for short-term de-icing activities is the volume of salt supply at the local scale (Quarmby, Smith et al. 2010).

A key decision for every local highway authority is thus the volume of salt to be stored. This implies a decision on the pre-season storage volume and the management of in-season re-stocking of salt supplies (i.e. just-in-time deliveries). Minimum storage volumes for road salt of local Highway authorities are suggested by the UK Roads Liaison Group (UKRLG) and cover severe winter conditions for at least 6 days per season. For each day 6 runs (for the strategic road network) and 4 runs (local highways) with 20g/m^2 are calculated. This volume corresponds to the need of an average winter. Consequently, the minimum storage capacity is seriously challenged and suggested to expand to 12 days after the winters in 2008/09 and 2009/10 (Quarmby, Smith et al. 2010). However, these mid-term decisions are mainly complicated by two factors: (i) the cost factors and (ii) salt-supply-chain throughput rates. Thus, the decision how much salt should be procured either on a pre-seasonal basis or in-season as just-in-time delivery is not only a matter of costs but also of salt availability (see buffer system). Thus, the characteristics and structure of the salt-supply-chain throughput is limiting and determining the decision-making processes and especially the lead times: whilst national delivery lead times are between two days and one week, lead times for salt imports are up to three weeks (LCP 2010). However, since just-in-time deliveries are risky with respect to severe salt supply shortages, winter service planning need to be started already directly after the end of the previous de-icing season which ends in April (Quarmby, Smith et al. 2010).

Critical situation: the occurrence of icy road conditions is no extreme but rather a regular event. A well-functioning winter service system is developed and established. Furthermore, the formation of ice and its respective coping measures is a short-term vulnerability (scale of weather events). On a seasonal scale the formation of ice on road networks is therefore not considered as the critical situation but rather the planning issues coping with icy roads for a longer period:

The critical situation arises when icy road conditions last for too long or rather occur too often within a season so that winter service cannot be provided as planned (e.g. road salt for 6 days with 20g per m^2 and 4-6 runs per day).

Buffer system characteristics

The impact of freezing temperatures and moisture (either air moisture or precipitation) on the formation of frost, ice or icy precipitation (i.e. snow, hail, etc.) on surfaces is immediate. Local ground conditions may have a small buffer effect and influence the specific threshold value of temperature and moisture, but the threshold is predominantly climatic and thus no relevant buffer effect is required to cause the formation of frost or ice on surfaces.

However, the duration of severe conditions has an indirect but significant impact on the availability of de-icing material (rock salt) which is the attribute of concern and thus a primary component of the critical situation. The characteristics of the salt-supply-chain which control the annual availability of salt have significant consequences on the temporal scale of seasonal decision-making processes and can be thus considered as a buffer system.

Since there are only three salt producers in England, salt production is limited. Salt production capacity in England is sufficient to meet the British demand for an average winter. For a moderately sever winter (2008/09) or a nationally severe winter (2009/10) production capacity falls considerably short. In the severe winters named above this was around 0.9 million tonnes which is more than 25% of the demand for a severe winter. This gap needs to be covered by imports which cost 50-100% more per tonne than UK production. The need for imports depends on the cycle of average and severe winters and the respective precedent salt demand and stock management. Stockholdings at highway authorities and mines may have been significantly stressed by high salt demands in preceding winters. But pre-season stockholding (i.e. 1st of November) is the most important requirement since the ability to procure salt in-season is constrained by UK production capacity and the limited available and higher priced imports (Quarmby, Smith et al. 2010). The British salt market is currently unable to cope with sudden increases in salt demand since there is no capacity to increase production rates. Thus, just-in-time deliveries only work under stable supply-demand conditions. Consequently, the characteristics and structure of the salt-supply-chain throughput is limiting and determining the decision-making processes and especially the lead times (see above).

Critical climate conditions and climate information

Critical climate conditions

The formation of frost or ice on the ground and other surfaces is directly linked to thresholds of climate parameters. Depending on the type of frost or ice, ground temperatures have to be at or well below freezing temperatures (< 0°C) with sufficient available (super-cooled) water at the same time. The latter may originate from air moisture, precipitation or prewetted surfaces. Related air temperatures are respectively at or well below freezing temperatures. Thus, critical climate conditions are on the scale of weather events (very short-term) since the effect on ice formation and thus the safety risk is virtually instantaneous. However, the risk of an incident increases with the duration of icy roads and consequently severe winter conditions. Additionally the capacity to cope with icy road conditions (gritting, snow ploughing, etc.) rapidly decrease when a specific number of snow days are exceeded or especially a respective period of snow days has elapsed (i.e. around 6-12 days).

Critical climate conditions are thus periods at temperatures below the freezing point. Criticality increases with the duration of such periods or their amount and frequency within a season exceeding 6-12 days.

Climate information

For seasonal decision-making, information on the total seasonal amount of rock salt is required which corresponds to the amount of days per season well below 0°C. In contrast information on the timing of rock salt application is determined by weather forecasts. The information on the total need of rock salt would be required with a lead-time of up to 6 months. Furthermore, information on the onset and duration of cold spells are of special interest, since continuous periods (here: 6 days) give no or limited opportunity for in-season restocking or mutual help by neighbouring communes. According the delivery times of in-seasonal restocking of rock salt this information would require a lead time of 1-3 weeks.

Vulnerability attributes

Criticality of decision-making processes: the problem of frost and ice on the transport infrastructure is a seasonal event which is expected every year. The role of these climate induced conditions are however destructive and therefore hazardous. The challenge of the decision maker is the assessment of the required pre-seasonal stock-level to ensure the availability of sufficient de-icing material for the coming winter and concurrently avoid unnecessary cost due to storage of redundant de-icing material. Climate forecasts on winter conditions for the coming season (e.g. temperature) may support this decision-making process. However, success criteria of highway authorities are primarily related to functionality of the system: the provide people access to the logistic services and ensure the reliability, functionality and safety of these services (Kerwick-Chrisp 2014, Woolston 2014). Economic criteria are important but not a priority since no shareholders are involved and 'making money' is therefore not a goal of highway authorities (Kerwick-Chrisp 2014). Thus, decision-makers consider themselves as generally *risk-averse* (Woolston 2014) and consider the pre-seasonal situation of decision-making as too risky to make any changes regarding the management of equipment and staff. Decision makers do not see any potential change in procedures and standards of pre-seasonal winter service planning as consequence of seasonal forecasts, disregarding the skill of the forecasts (Kerwick-Chrisp 2014). Highway authorities rather tend to robust decisions which are also reflected in the recommendations of the review of the resilience of England's transport system in winter (Quarmby, Smith et al. 2010).

Usability of S2D climate forecast information: decision-making beyond the scale of weather events implies planning and organization of sufficient de-icing material, equipment and staff to be prepared for local icy road conditions during winter. Thus, information on the total seasonal amount of rock salt is required which corresponds to the amount of days per season well below 0°C. Mean values on temperature for the coming winter-season are of potential good use for highway authorities since information on the timing of rock salt application is sufficient to be provided by weather forecasts. Demands on the spatial scale are high since each local highway authority is in charge of managing winter services for its own district. Some flexibility on spatial resolution is given by the intra-seasonal mutual aid of neighbouring districts and in-season restocking opportunities which refer to stockholdings at mines or imports. Regarding the rather risk averse decision-making tendency very high certainty of the forecast would be required to have any potential impact on decision-making (90% according to Woolston (2014)).

Referring to decisions on intra-seasonal restocking the onset and duration of cold spells is critical information. Thus, distribution of temperature is important and requires high temporal resolution. This information may be provided by weather forecast products, but related decision making processes require lead times of 1-3 weeks depending on the available source of salt supply (national or import).

3.2.5 HSFS

Introduction

Scope of prototype

A multi-model seasonal forecast system for forecasting runoff will be implemented for the Ångerman River. The basin is Sweden's third largest by area (31864 km^2) and second largest by hydropower production with an average annual production of 6900 GWh. Seasonal discharge forecasts are primarily used by the Swedish hydropower industry for dam regulation and production planning. Improvements in the forecasts allow for better operation strategies and this can translate to improve efficiency: this implies on the one hand a sufficiently large water volume for optimal power production and on the other hand a sufficient remaining capacity to handle sudden inflows in a safe way.

Scope of vulnerability analysis

Water management problems comprise many different tasks and aspects covering diverse sectors. The number of critical situation caused or influenced by climate is therefore manifold and probably difficult to identify and analyse completely. Thus, the scope of this vulnerability analysis will be focusing on the problem of spring-flood assessment which is a major concern for the reservoir management with respect of hydropower production in Sweden.

System of concern

The physical system of concern is the 31864 km^2 catchment of the Ångerman River aggregating the water which is stored to produce hydropower with an average annual production of 6900 GWh. The Ångerman River has a length of about 460 km and a mean discharge of about 500m^3/s. It is regulated by 59 reservoirs which a total operating regulation volume of 6126.3 Mm^3 (36,2% of mean annual flow) and individual reservoir volumes range from 6 Mm^3 to 554 Mm^3 (median = 62 Mm^3, mean = 160 Mm^3). Since the most reservoirs in the Ångerman catchment are for hydropower production the reservoir operation is done by the regulating authority which has the goal to maximize the energy production of the respective power companies (SMHI 2012 pers. com. Foster).

Critical situations

The main purpose of hydropower reservoirs is to provide hydraulic head for energy production to meet the required energy demand. Storage reservoirs help to adjust the flow availability to the energy demand by storing water when discharge is naturally available and release water and thus produce energy to meet energy demands which varies on a daily to annual scale. Typical objectives of reservoir operators are to minimize water deficits or to maximize hydropower production, revenue or profit but are influenced by political regulations due to the ecological impact of hydropower production (Jager and Smith 2008, Renöfält, Jansson et al. 2010). Power demand and especially hydrological conditions are the two main sources of uncertainty which do have significant consequences on reservoir operations. A better knowledge on reservoir inflows provides operators the opportunity to allocate less space for flood storage and increases the flexibility for flow release options. Hydrological uncertainty is met by optimization techniques to determine operation rules which define optimal release rates and timings based on the available information (Olivares 2008, Renöfält, Jansson et al. 2010).

Hazard: natural discharge in northern Swedish rivers is highest during the spring flood which is the result of the melting snowpack releasing the stored winter precipitation from a period of 4-6 months and is thus a seasonal and periodical event typically between May and July. The discharge becomes respectively low in summer and winter with small peak in autumn due to increased rainfalls and reduced evapotranspiration (Renöfält, Jansson et al. 2010). The duration of the spring flood is about 1-4 months depending on the location and catchment size. The total quantity of the water during the flood is dependent on the quantity of snow at the beginning of the flood and the amount of rainfall during the flood. For the Ångerman River the spring-flood volume is about 7900 Mm^3, which is around the half of the annual discharge volume and exceeds the total storage volume of the reservoirs in the catchment (SMHI 2012, Olsson, Uvo et al. 2015). The temperature has significant influence on the rate of melting and thus determines the onset of the spring flood as well as the timing of the maximum flow. Thus, the inter-annual variation of onset and duration is variable which is critical since the total length of the spring-flood is very limited (Melin 1937 pers. com. Foster). For reservoir managers the information on the start of the spring flood, the intensity (total duration) and the total volume of water is important (pers. Com. Foster).

Decision-making processes: The purpose of regulation is to save water, and thus energy, from the spring flood period for use during the next winter season. This maximises the production of energy during the winter when the demand is highest and the profit is the best. To be able to accommodate the spring flood the lowering of the reservoirs during the winter has to be adapted to the forecasted volume of the spring flood. Reservoir operators intend to keep the 90% level of the reservoirs over the summer to guarantee maximum possible energy production. Thus an overestimation of the spring flood would result in an reservoir level below the capacity level at the end of the filling period (decreasing efficiency and causes economic losses) and an underestimation of the spring flood would result in an overload of the reservoir which causes serious safety issues within the dam (e.g. dam break) and downstream flooding (due to uncontrolled water releases). But also the timing of the reservoir lowering is important, since reservoir managers want to avoid a too early release of water which could be used for power production especially after the low flow period and intend an optimal refilling schedule of the reservoir.

There are two levels of management thresholds. Mandated regulation thresholds, maximum and minimum reservoir levels, are governed by a legal framework (or ‘vattendom’) for each of the different reservoirs (see also for RIFF and S-ClimWaRe). Within these limits there are individual agreements, between operators, regarding regulation according to their operating strategies. The production capacity for the year is divided up amongst the different operators according to their market share in the system and it is the task of the regulating authority, a company owned by the different, to regulate the system such that each operator maximises their production potential.

The determination of a time plan and preparation of reservoir lowering measures to integrate spring flood inflows requires lead times which are in the range of weeks to months (pers. Com. Foster).

Critical situation: Around half of the annual discharge volume accumulates during a couple of weeks to months and impends to exhaust the storage capacity of the reservoirs. On the other hand, the discharge of the spring-flood provides a major share of the water supply which has to be captured and stored for the winter season.

A critical situation arises when discharge from spring-flood are unexpected in volume, timing and rate so that reservoir storages cannot be used in an optimum way.

Buffer system characteristics

Spring floods are predominantly snowmelt floods and are thus related to the amount of water stored in the snowpack available at the catchment. Rainfall may occur during flood events but is only of secondary importance (Melin 1937, Merz and Blöschl 2003). The snowpack can therefore be considered as buffer system since it stores much of the winter precipitation. Volume and conditions of the snowpack are strongly dependent on the catchment characteristics and especially the topography which determines micro-climatic conditions (Hock 2003). Whilst the accumulation of the snowpack (restock of storage) is related to winter precipitation (snowfall), the draining is dependent on the available melt energy (e.g. global radiation or turbulent heat exchange) which is often indicated by temperature (Merz and Blöschl 2003). As noted above, spring floods occur in spring when temperature rises and can last for a couple of weeks to months depending on the melting rates, i.e. the respective climate conditions.

Critical climate conditions and climate information

Critical climate conditions

Since spring-floods are predominantly fed by melting snowpack available in the catchment, these events are strongly seasonal and can be roughly allocated to specific months within a year. For Sweden and the region of concern the melting season is around May, June and July (Olsson, Uvo et al. 2015). The activation of the snowpack, the dominating source for spring-floods, is caused by melting processes which are dominated by longwave radiation and sensible heat flux which both are highly affected by air temperature. Thus, a common measure to model melting rates is the 'degree-day factor' (DDF) which relates the amount of melted snow or ice to the sum of positive air temperatures for a specific period of time (DDF expressed in mm d^{-1} $°C^{-1}$), whereas the temporal unit is variable. The DDF varies seasonally due to variations of direct solar radiation and due to the metamorphic evolution of the snow cover causing a change of the albedo. But also diurnal variations can be significant (Hock 2003). However, since there is an upper limit of available melting energy no sudden outburst-flood is expected. Snowmelt usually occurs over a period of weeks in sequence until the soil is saturated and channel flow increase to cause a flood (Merz and Blöschl 2003).

Critical climate conditions are high magnitude winter precipitation (above average) followed by fast increases and persistence of temperatures (above average) in spring which activate melting process. High rainfall adds to the flood volume and may support melting.

Climate information

For the volume assessment of a spring flood information of total winter precipitation is required at the beginning of the year. This maybe combined information on snowpack volume until January and total precipitation until March/April. To assess the onset and intensity of the spring-flood temperature information is required in high temporal resolution at the beginning of spring which should be available also at the beginning of the year with a lead-time of a couple of weeks to months.

Vulnerability attributes

Criticality of decision-making processes: the spring-flood is the major source to fill the reservoir for the coming high-demand season for electricity (autumn-winter). Water is the resource on which hydropower is based and climate has therefore a central position for related decision-making processes. Furthermore, decision-making considering the resource refer to the basis of this sector and is therefore of fundamental relevance. Consequently, decision-makers have a great interest to use this source as efficient as possible to keep flexibility in energy production and to get reasonable revenue. Thus, uncertainties in assessing the volume and timing are primarily reflected in the profit. Safety issues with respect to overspill or dam break are of lower importance since this can be prevented by robust decisions on emptying of the reservoir before the spring-flood with an adequate temporal buffer.

Usability of S2D climate forecast information: regarding the spring-flood volume reservoir managers are predominantly interested in the total volume existent in the reservoirs at the end of the season. Thus, the total volume of the spring-flood is of interest which primarily refers to the total winter precipitation which is mostly stored in the snowpack. Thus, mean values of winter precipitation given by S2D climate forecasts are of good use for decision-makers.

Regarding the spring-flood timing and rate information on temperature change at the end of the winter beginning of spring is crucial since temperature is the critical value for the onset of the spring-flood. The onset of the spring-flood is a matter of 2 weeks which need to be resolved in the forecast to be anticipated in an appropriate way. Considering a decision lead-time of several weeks or months adds a lot of uncertainty to a temperature forecast aiming for the onset and rate of the spring flood.

Some flexibility is given to the spatial resolution since the entire head-water of a catchment contributes to the spring-flood. Thus, no very high spatial resolution is required which diminishes one source of uncertainty.

3.2.6 LEAP

Introduction

Scope of prototype

LEAP is an integrated food security early warning system, owned by the Government of Ethiopia's Disaster Risk Management and Food Security Sector (DRMFSS) and supported by the United Nations World Food Programme (WFP). LEAP uses precipitation monitoring data to estimate the number of people in need of food assistance due to drought. By providing early and objective estimates of the expected magnitude of needs, LEAP helps increase both the speed and transparency with which a humanitarian response can be triggered. Currently, LEAP uses monitoring data to calculate needs at the end of the season. The aim of the prototype is to integrate seasonal precipitation forecasts into the calculations, which will enable the model to provide earlier and more accurate projections of beneficiary numbers.

Scope of vulnerability analysis

The vulnerability assessment will be focusing on the physical dimension of food security which is the climate impact on crop yield. Other factors (e.g. political, social, and economic) are as much relevant as seasonal crop yield and may be influenced by climate as well but won't be considered in this analysis.

System of concern

The Ethiopian Government's Productive Safety Net Program (PSNP) was launched in 2005 and represented a pivotal departure from the cycle of annual emergency food aid appeals in Ethiopia. Following the drought of 2002/2003, the Government of Ethiopia formed the New Coalition for Food Security to identify key actions to break the cycle of emergency appeals—which saved lives but did little to protect household assets—and comprehensively address food insecurity in Ethiopia. This process resulted in the creation of the Food Security Program (FSP). Launched in 2003, the FSP was funded by the Government of Ethiopia (GoE) and Development Partners and implemented, mostly through government structures, in Amhara, Oromiya, Tigray and Southern Nations, Nationalities and Peoples Region (SNNP), with Harari and Dire Dawa added in 2005.

The PSNP is one component of the FSP and provides food and/or cash transfers to food insecure households in chronically food insecure woredas (districts) in exchange for labor-intensive public works, while households which are not able to contribute in labour (due to old age/health reasons) receive unconditional "direct support" transfers. The public works component, which covers approximately 80% of program participants, focuses on the implementation of soil and water conservation measures and the development of community assets such as roads, water infrastructure, schools, and clinics. The PSNP has gone through 3 different phases and in 2015 the PSNP 4 has been launched. This phase will cover all regions in the country except Gambella and Benishangul Gumuz.

Critical situation

Within the last 10 years Ethiopia has achieved a substantial decrease in poverty and food insecurity levels. Nonetheless, poverty and food insecurity remain a big concern. Almost a third of the population is considered to be below the poverty line and unable to afford the minimum caloric intake to sustain healthy living conditions. Chronic malnutrition affects children disproportionally: 44% of all those under 5 years of age are stunted and 10% are affected by acute malnutrition (ECSA WFP).

Food security is highly sensitive to climate conditions in Ethiopia, since the agricultural system is predominantly rain-fed –only 1% of agricultural land is irrigated (Zekaria, Yigezu et al. 2014). Climate events in the years 2008/2009 and 2011 highlighted the impact of extreme weather events, especially droughts, on food security, affecting food production, access to markets and livelihoods. Reduced food production due to dry years has impact on food access: less food available forces households to consume more of their own food instead of selling it to the market; and prices going up force households to spend more of their income on food. Besides, climate-related hazards such as floods, limit physical access to markets. This has further impact on the livelihoods especially for the poorest that have to reduce quantity and quality of meals and have to rely on selling livestock or labour migration (WFP 2014).

Food insecurity in Ethiopia is highly seasonal and is directly linked to rainfall patterns. All rural livelihood systems like crop cultivation (89% of population), pastoralism (6%) and agro-pastoralism (5%) are vulnerable to climate variability and associated hazards. All types of livelihoods are closely linked to seasonal cycles of rainfall: the dominant rain seasons are Belg (February-May) and Meher (June-October). In general low rainfall events in 2000-2002, 2008, 2009 and 2011 can be associated with less land being cultivated. The rainy seasons have different relevance for different regions and cultivation type. Crop-cycles are regionally adapted and span across one or both rainy seasons. The most critical period in terms of hunger is represented by the pre-harvest months, at the end of the rainy season, and immediately after that, in case of a bad harvest (WFP 2014).

Hazard: The link between rainfall trends and crop production during different seasons is significant in Ehtiopia for both Belg-rains and Meher-rains. The correlation is strongly crop dependent: teff and wheat are very sensitive and maize and sorghum are more drought-tolerant (WFP 2014). However, the link between crop production and changes in food security is less obvious. A threshold of crop production (crop yield) to cause a shock event regarding food security (i.e. equivalent number of households requiring food assistance) is difficult to determine. This is probably also because the ‘normal situation’ in Ethiopia is already ‘shocking’: 28% of the Ethiopian households live permanently below the food poverty line and 40% of the households have food energy deficiency resulting in a number of around 8.3 million people require chronic food assistance. This comes along with the per capita production of grain which is just above the minimum consumption threshold level of 0.218 mt/person/annum required to cover the basic food requirements of 2100 kilocalories/day (Zekaria, Yigezu et al. 2014).

Consequently, the threshold between ‘normal’ and ‘exceptional’ with respect to food security cannot be determined due to ‘healthy conditions’ and ‘unhealthy conditions’ but due to the degree of capacity utilization of the food assistance system. This constitutes a very vulnerable situation with a high sensitivity to even low variabilities in crop production and thus precipitation variability amplified by subsequent impacts like food prices and market access.

Decision-making process: The implementation of the PSNP occurs almost entirely by national government systems, operating at the regional and local level of administration. The responsibility for the program management lies on the Ministry of Agriculture, with the DRMFSS being tasked with the overall program coordination. Within the DRMFSS, the Food Security Coordination Directorate (FSCD) organizes the day-to-day management and coordination of the PSNP using early warning information from the Early Warning Response Directorate (EWRD). These federal arrangements are replicated within the eight regions covered by PSNP, which comprise 319 woredas (World_Bank 2013). There are several processes and a number of actors involved to the current process of food assistance:

Need estimation: The multi-agency assessment team determines the needs every six months following the two main rain seasons *Belg/Gu/Sugume* and *Meher*. The findings of the team are then endorsed by the regional and federal government, and finally the annual Humanitarian Requirement Document (HRD) is developed.

After the need assessment it takes around six weeks in average to organize and execute the food distribution. The main steps, actors and time scales are noted:

Food allocation: Based on the HRD document, the *federal DRMFSS* prepare *monthly* food allocation for each woreda. Initially prioritization committee meeting conducted within the *first week of the month*. Food allocation conducted in the *second week* of the month based on the decision of the prioritization committee.

Food Dispatch: Dispatch of food to final distribution points/woredas is conducted in three ways. In all areas of the country except for Somali, the government and *NGOs/JEOP*[1] deliver the food to final distribution points found in government managed woredas and JEOP supported woredas respectively. In Somali region, food is transported to woredas/final distribution points by *WFP*. It takes on average *two weeks* to transport the food to final distribution point.

Food Distribution: Distribution of food from the final distribution point to clients is conducted by the *government institutions* at woreda level together with community representatives. It takes around a *week* to complete food distribution to clients.

The estimated maximum annual program caseload of the PSNP is 10 million clients, consisting of 8.3 million chronic food insecure clients and the capacity to support an additional 1.7 million transitory clients if need exists. The determination of absolute and especially transitory food assistance needs are currently supported by LEAP through meteorological real-time data (met-stations and satellite data) and agricultural data (observation of crop development; calculation of the Crop Water Requirement Satisfaction Index) to estimate the outcome of the current rainy season and the potential yield. Currently, real forecasts are only used on a temporal scale of 10 days with a focus on the agricultural sector and for the highlands. Furthermore, seasonal climate forecast are not routinely used yet and decision-making processes are therefore not yet aligned to the information potential of seasonal forecasts. Informational outputs of a seasonal forecast within the prevailing decision-making system of LEAP could help to identify bad rainy seasons with additional time to prepare food assistance activities. However, robust seasonal forecasts could also enable to initiate mitigating and preventive coping strategies (e.g. distribution/application of

[1] JEOP/Joint Emergency Operation Programme

drought resistance crops, destocking programs in pastoralist areas etc.) instead of or in addition to reactive and compensating measures. Thus, no lead-times for specific decision-making options can be determined at present. Minimum lead times are set to one month but in general the more time available the better (WFP 2014 pers. com. L. Bosi).

Critical situation:

Critical situations arise when there is a significantly reduced crop production which implies a need of food assistance for more than 8.3 million households. The situation becomes seriously critical when the number of indigent households impends to exceed 10 million.

Buffer system characteristics

Considering the physical system the climate signal is buffered by the terrestrial system. The topographical conditions and the interlinked soil system store water and determine water availability and its sensitivity to evapotranspiration and percolation. The better water holding capacity of clay soils for example helps to cope insufficient rainfall during flowering stage of maize compared to maize growing on sandy soils. The water storage characteristics of the ground can thus reduce sensitivity to dry spells (Barron, Rockström et al. 2003). The crop system accumulates water during the entire growth cycle. However, the storage function of the crop system is restricted by the need of a continuous input of water to assure photosynthesis and nutrient uptake (Porporato, Laio et al. 2001). Crops are especially sensitive to water availability at the stage of flowering and grain filling (Barron, Rockström et al. 2003, Arayaa, Keesstrab et al. 2010). In general, the movement of water within the plant-soil-atmosphere system is controlled by gradients of water potential. The water storage within the soil-plant system is very dynamic and mediates the local interaction of fluctuating water supply (rainfall) and demand (potential evapotranspiration) (Milly 1994, Porporato, Laio et al. 2001). The temporal scale for the storage factor of the soil, or the approximate period over which soil water storage can supply plants without experiencing significant stress, can be classified in the range of 20 to 60 days in dependence on the soil type and thus water holding capacity (Laio, Porporato et al. 2001, Porporato, Laio et al. 2001).

Considering the decision-making system the scale of decision-making also provides some buffering effect: since seasonal climate forecasts are supposed to help assessing the total number of people who are expected to require food assistance due to an ongoing bad rainy season, information on the individual needs and specific locations (woreda-level) is not yet required. This information is required as soon as distribution activities are going to be started and more detailed information on food assistance needs are being available. Thus, uncertainties with respect to local impacts can be tolerated at this stage.

Critical climate conditions and climate information

Critical climate conditions

With respect to the critical situations described above, the climate or weather conditions become critical when they are a significant factor for a decrease in crop yield or even crop failure so that food assistance is required. Rainfall totals of less than 400-500 mm during the rainy seasons (or 900 mm for long-cycle crops) in Ethiopia are assumed to be critical for viable farming and pastoral operations (Makurira, Savenije et al. 2010, Funk, Rowland et al. 2012). However, in many times the information from rainfall totals is limited since crop production in semi-arid areas of Africa is determined rather by rainfall distribution because dry spells strongly depress the yield (Barron, Rockström et al. 2003, Meze-Hausken 2004, Segele and Lamb 2005). The three major causes for crop failure in north-eastern Ethiopia are 'dry spells', 'short growing period' due to replanting or late onset ('false start') and/or early cessation of rain as well as 'total lack of rain' (Segele and Lamb 2005, Arayaa, Keesstrab et al. 2010). The most severe consequences on crop yield do have 'short growing periods' and 'total lack of rain' (Arayaa and Stroosnijderb 2011). Thus, the crop performance depends not only on the distribution but especially on the onset and cessation which often coincides with the critical stage of the crop growth (Barron, Rockström et al. 2003, Arayaa, Stroosnijderb et al. 2011). Depending on the local soil conditions, dry spells of 10-15 days have already significant impact on maize yields in semi-arid regions in east Africa (Barron, Rockström et al. 2003) and maize as well as sorghum are rather drought-tolerant compared to teff and wheat (WFP 2014). However, dry spells which occur at the late-season are more pronounced regarding their impact since they coincide with the flowering and yield formation stages (Barron, Rockström et al. 2003, Arayaa, Keesstrab et al. 2010).

Critical climate conditions are dry spells of around 10-14 days. The criticality increases with the spatial extend of such events and with the timing during stages of flowering and yield formation.

Climate information

Lower limit critical climate conditions for crop failure are dry spells of around two weeks which occur around April and especially September. Climate information with a temporal resolution of such events over a period which corresponds to the length of rainy season would be desired. Lead-times for information on potential crop failure are desired to be available as soon as possible. However, accuracy is required to integrate this information in decision-making.

Vulnerability attributes

Decision-making processes: the problem of food security is very sensitive, ethical, and political issues. Economic factors are important but will not take the dominant role. Success criteria are rather the reduction of hunger, associated fatalities and loss of livelihood capacities. Consequently, the risk to adjust food security provision to a forecasted "good rainy season" (i.e. reducing food security capacity) is much higher than the risk to adjust to a forecasted "bad rainy season" (i.e. increasing food security capacity). The first scenario would result in fatalities and probably in an increased demand for food security (and thus costs) in the coming seasons due potentially reduced livelihood assets. In contrast the second scenario would imply some financial losses which might be minimized by consecutive coping options. Furthermore, climate is only one of many factors influencing the decision to provide food assistance. Thus, decision-makers are rather risk-averse with respect to climate information even in the context of robust decision-making (low uncertainty required) (WFP 2014).

Usability of S2D climate forecast information: decision-making on the seasonal scale requires information on the expected total number households requiring food assistance with respect to the outcome of the prevalent rainy season. Thus, the exact location of the affected household and the exact timing of crop failure within this season are not (yet) required. This basically matches the informational content of seasonal forecasts which provide mean values of climate parameters (here precipitation) for the rainy season for a large region.

However, since critical climate conditions are dry spells of 1-2 weeks the distribution of rainfall is important information which is supposed to be desired by the climate service product. Also the timing of such dry spells is crucial especially when they occur during the flowering period. This could be a critical aspect of a climate information product for this purpose. Required lead times are rather flexible since no technical restrictions do determine these at which as long as possible lead times are desired. On the other hand is the tolerated uncertainty rather low since decision-makers are risk-averse and definitely would prefer a robust decision and consider rather more households than actually affected.

3.2.7 SOSRHINE

Introduction

Scope of prototype

Reliable seasonal streamflow forecasts have great potential to become a valuable tool for medium-term to long-term waterway-management and the planning and optimization of the water bound logistic transportation chain. Extended lead-times offer the possibility to optimize the fleet structure of shippers as well as the stock management of enterprises. By taking into account periods with above- or below-average water-levels for the coming months the timing of transport could be rescheduled to an earlier or later date or multiple smaller ships could be ordered in times of lower water-levels to execute the transport efficiently. The results of the prototype would be important information for the stakeholder Federal Institute of Hydrology to advice the ministries of transport and environment as well as the Water and Shipping Administration and to provide seasonal forecast products for the users of the waterways operationally.

Scope of vulnerability analysis

The focus of this vulnerability analysis is the low flows in the Rhine catchment and the impact this may have on inland navigation. Respectively shipping companies will be the considered stakeholder since they are directly affected by restrictions due to low flow events.

System of concern

The Rhine River drains an area of about 185000km^2 with a total length of 1320km from which 800km are shippable between Basel and Rotterdam. The discharge regime is dependent on the geographical section. For the shippable part the section between Basel and Bingen (Oberrhein) is predominantly nival (influenced by the Alpine section) with a discharge peak in early summer and low flows in winter. For the Mittelrhein (Bingen-Bonn) the influence of major tributaries (e.g. Main and Mosel) which show consistently a pluvial runoff regime with maximum flows in winter and low flows in summer, leads to a complex mixed runoff regime with a relative balanced seasonality. For the lowest part of the Rhine (Niedderrhein) downstream from Bonn pluvial elements prevail with high flows in winter and low flows in late summer/ autumn. At the gauge Lobith near the German – Netherland border before the Rhine forms together with the rivers Meuse and Scheldt the Rhine-Meuse-Scheldt delta the River Rhine has an average runoff of 2220m^3/s. Around 30 reservoirs do store water in the catchment of the River Rhine with a total capacity of 1,9 bn m^3 which are mainly used for electricity production. Consequently they store the water in early summer when water is available and release in winter for electricity production (KHR 2007).

The stakeholder of concern are the shipping companies, i.e. these people who decide if shipping is possible and if yes under which conditions (size of vessels, max. loading, etc.). The success criteria of the shipping companies are primarily the satisfaction of customer needs. These are the provision of the desired loading space and also the timely delivery of the transported goods. Thus the ultimate success criterion is profit maximization (Jonkeren, Rietveld et al. 2007, Bruinsma, Koster et al. 2012, Nilson, Lingemann et al. 2012).

Critical situations

Low-flow events are seasonal phenomena, which occur every year due to the hydro-meteorological conditions. The use of the river channel for inland navigation is more or less aligned to the average annual discharge behaviour and its seasonal variations. However, hydrological extreme low-flow conditions may have significant impact on the operation of inland navigation. Especially, because low-flow conditions are relatively long living compared to other hazardous hydrological events like high-flows. The reduced depth and width of the channel increases the danger of ship grounding and ship-ship collision which limits the maximum vessel size and transport load and thus the economic efficiency of each trip (Nilson, Lingemann et al. 2012).

Hazard: Low-flows have different definitions depending on the purpose. For waterway management issues different thresholds for critical low flows are defined. On the Rhine River the ‘Gleichwertige Wasserstand’ (*equivalent water-level*) is applied. This threshold is related to a discharge which is undercut at 10-20 days per year in the long term mean which is statistically comparable to the 97.5th to 95th percentile of the long-term flow-duration curve (Nilson, Lingemann et al. 2012). I.e. the goal of the federal administration of water and shipping is to provide a minimum channel depth to enable inland navigation at minimum 345 days per year. This corresponds to a channel depth of 190cm (i.e. water level of 80cm or discharge of 719m3/s) for the gauge at Kaub (start of Mittelrhein). However, unlike at high-flow conditions there are no official guidelines for ship operators on how to behave in such situations (Nilson, Lingemann et al. 2012). Consequently, thresholds of channel depth are not absolute and universally valid. For shipping companies operating on the Rhine a critical situation already results at channel depths of 2,50-2,20m. Economic disadvantages start to be evident at this threshold range, whereas the Upper Rhine Region is more susceptible than the Lower Rhine Region. This condition starts to become critical for companies for a period longer than one week (Scholten and Rothstein 2012).

Decision-making processes: ship-owners do have several options to cope with low-flow conditions. Long-term coping options (time scales much greater than one year) are related to technical adjustments on the vessels which would imply the purchase of new vessels or the establishment of strategic alliances with other transport companies to avoid traffic bottlenecks. Also river engineering would be a solution which is however not in the scope of decision-making of ship-owners. On a seasonal time scales as a reaction on an early warning system ship-owner have 3-4 options (Lingemann, Body et al. 2012, Scholten and Rothstein 2012, Ubbels, Quispel et al. 2012):

- Adaptation of the load to low-flow load capacity of existing vessels. This measure requires a lead time of 1-2 weeks to organize and is of limited risk since the decision can be easily rectified unless the trip already started. Furthermore this option is valid only for the specific trip.
- Ordering of additional smaller vessels. This measure requires a lead time of around 3 months to get enough vessels for a reasonable price. This decision is more risky, since it is binding and not easily rectifiable. Furthermore, the vessels are supposed to be used for several trips to be profitable.
- Temporary storekeeping and delay of the transport. Possibly renting of additional storage space. This will also require a lead time of several months.

- 24h operations and coupled convoys. This is an additional option to reduce economic losses when going with reduced load or smaller vessels and is thus linked to the upper two measures.

Critical situation: In general all options are possible and are directly linked to an increase of the price of the transported product. Thus, a technical threshold at which no inland navigation is possible anymore is far below the economic threshold which is probably reached much earlier (see above). Ship-owners are dependent on the demand of the producing sector and their willingness to pay the respective price.

The critical situation arises when water levels (or discharge) fall below a threshold which is comparable to the 97.5th percentile of the long-term flow-duration curve. The critical situation is enhanced when the number, frequency and duration of such periods increases.

Buffer system characteristics

For inland navigation the availability of water in form of discharge (water level) is the attribute of concern. Inland navigation companies and ship-owners get a problem when there is a "prolonged period with below-normal water availability in rivers and streams […] due to natural causes" (VanLanen, Wanders et al. 2013 p.1716) thus, a hydrological drought or stream flow drought. Hydrological droughts evolve slowly and are due to periods of low precipitation combined with high evaporation losses which causes soil moisture deficits and subsequently reduces groundwater recharge and head and eventually lowers stream flows (Maybank, Bonsal et al. 1995). The area affected by droughts is primarily climate driven whereas local variability is influenced by characteristics of the terrestrial system. Hydrological storage or a combination of catchment characteristics which relate to catchment storage and release (e.g. land use and geology) is the most important factor controlling drought propagation and causing lag times between a meteorological drought and hydrological drought and its spatial characteristics (Tallaksen, Hisdal et al. 2009, VanLoon and Laaha 2014).

Critical climate conditions and climate information

Critical climate conditions

The relation between discharge and rainfall is strongly dependent on catchment characteristics especially the state of hydrological reservoirs. The development of hydrological droughts is a slow process and not only dependent on periods of low rainfall but also on temperatures and evapotranspiration potentials. Required time-scales over which precipitation events need to be below average or even lacking to provoke hydrological droughts are in general seasonal for fast responding catchments and may be inter-annual in catchments with large hydrological storages (vanLanen and Tallaksen 2007). Since the Rhine catchment is very large and characterized by different discharge regimes, no general statements can be made on response times and temporal resolutions of low flow conditions to climate events. However, past hydrological extreme events give a clue on the approximate scales of necessary deviations from normal conditions to produce relevant low-flow conditions. The European summer of 2003 was characterized by extreme temperatures for the months June-August which were 5°C warmer than the 1961-90 average. Precipitation anomalies developed already in March 2003 and lasted until September only interrupted by a relative normal July. Minimal low flows in Cologne were observed in August/September of the same year which implies a lead time of below average rainfall of around 6 months (Fink, Brücher et al. 2004). Similar conditions were responsible for the low-flow in November 2011: in the winter 2010-2011 there was little snow in the Rhine head waters in the Swiss and Austrian Alps accompanied by a rainy and warm January. The period from February to May 2011 was very dry in the entire catchment and October was extremely dry up until the mid of November. The consequence were record low-level conditions at Lobith at the end of November (50% below normal) prepared by a series of unexceptional dry periods spread over almost 12 months (IKSR 2012). Demirel et al (2013) did a systematic study of the temporal lag and resolution[2] of low flow indicators for the River Rhine and could identify lag times of 3-7 months (discharge reacting on precipitation and/or potential evapotranspiration index) for the Middle Rhine and Lower Rhine with temporal resolutions of 8-10 months.

Critical climate conditions are below-average precipitation during the year combined with above-average temperatures.

Climate information

Decision-makers require information on low-flow conditions at least 2-12 weeks before the event to be able to initiate appropriate coping measures. Since the buffer effect of the catchment aggregates precipitation volumes and smooths short-term variability the informational content of seasonal forecasts is useful. Forecasts would be required throughout spring and summer when low-flows finally develop (dependent on the part of the Rhine River). If possible as 6 month forecasts but always in consideration of preceding temperature, precipitation and flow conditions (BfG 2014).

Vulnerability attributes

Criticality of the problem: no direct information from decision-makers is available about the criticality of this problem. Shipping companies are directly dependent on discharge volumes to be able to run their business and critically decreased discharge has direct impact on the profit. On the other hand, there are no sharp thresholds and thus multiple coping options available to minimize or prevent a significant impact. This also due to the purely economic risk and no human life are at risk.

Usability of S2D climate forecast information: to create a hydrological drought in the middle and lower part of the Rhine requires meteorological droughts or sequences of those being prevalent over several months. Mean information on temperature and effective rainfall over several months is therefore generally desired and usable due to the systemic buffering of rainfall and evapotranspiration rates by the catchment system. Furthermore, since temporal scales of the critical climate conditions is much longer than the temporal scale of decision-making seasonal climate forecasts doesn't need to cover the entire time-scale. At the time of decision-making a great deal can be covered by using climatology. River catchments do not only aggregate rainfall events on a temporal dimension but also on a spatial dimension. Compared to problems of other sectors the need for high ***spatial resolution*** is limited and thus the tolerance to lower spatial resolution is expected to be higher. Furthermore, the overall inland navigation system is aligned to climatology and thresholds of low- and high flows relevant for decision-making are also related to the local hydrology which enables the use available climatological and hydrological statistics. Also,

[2] Lag: response time of the basin; Resolution: temporal scale of the water volume entering or leaving the system

timings of decision-making processes are also aligned to the hydrological year. Thus, forecasts periods do match periods of climate information needs no complicating demands are set for the seasonal climate forecasts.

3.2.8 S-ClimWaRe

Introduction

Scope of prototype

The Mediterranean area is dependent on the state of the water resources for assuming several activities such as agriculture, domestic supply and leisure activities. In the last decades, important investments have been made to manage interannual climate variability (construction of dams, intense exploitation of aquifers, etc.) and to adapt activities to drought periods (restrictions rules, control of water demand, etc.). New solutions, such as the use of seasonal predictions, are now useful to cope with future challenges in water management in this area: increasing population, climate change, environmental objectives, economic efficiency…

In the water sector-specific case-study and prototype, the use of the seasonal predictions would be tested for some key applications in water resource management:

- domestic water demand forecast
- water resources availability forecast
- dam management (operative rules)
- rules concerning the distribution of the resources in the river basin (restriction, ecological flow allowance…).

Scope of vulnerability analysis

Water management problems comprise many different tasks and aspects covering diverse sectors. The number of critical situations caused or influenced by climate is therefore manifold and probably difficult to identify and analyse completely. Thus, this vulnerability analysis focuses on the problem of water supply management i.e. specifically reservoir management which implies controlling of rates of water inflow and release considering diverse interests, safety issues and user needs.

System of concern

The river basins are the logical physical boundaries of the system. Nevertheless, some hazards may affect larger area. As an example, drought could persist over months or years; it can affect large areas and may have serious environmental, social and economic impacts (Horion, Carrao et al. 2012).

The river basin agencies are the key organization involved in the management of the resources according to the water framework directive. Their work is done in collaboration with the state (MAGRAMA in Spain) and European agencies, and with the local stakeholder in the river basin.

The river basins are also the main operational boundaries of the system, including sub-systems at a lower administrative level. At this lower level, Spanish regulation ("Reglamento de la Planificación Hidrológica") define the water operating system ("sistema de explotación de recursos") as a surface water bodies and groundwater, water infrastructures and water use rules to comply with the environmental objectives. In these systems, the rules of management are defined and applied in collaboration with the local stakeholders and users (e.g. representative of agriculture, hydropower, water supply…).

At the upper level (national administration), some links also exist between the river basins such as water transfer, or supervision of the state agency (MAGRAMA) for the river basins shared between various autonomous communities in Spain. Currently, Spain has 25 river basin districts, out of which 6 are international sharing water courses with France to the northeast and Portugal to the west (EC 2015).

Critical situations

The general task of water managers is to provide water supply to cover respective demand of different stakeholders and users within a specific basin. This relative straightforward task is complicated by the plurality and diversity of users like industry, energy production, agriculture, inland waterway transport, tourism and especially municipal use of water (drinking water and wastewater) which all have individual needs especially with respect to volume, purpose of use and timing (Noel 2009). Since 2000 in the context of the Water Framework Directive this rather *resource based approach* is shifting towards a new *ecosystem approach* on a basin level (Integrated Water Resource Management). Besides the issue of water supply managers also have to consider regulations of natural protection to preserve water resources and aquatic environments and integrate different stakeholders (institutions, economic services, natural hazard management).Thus water management does not only imply the managing of available water supplies (quantity) and its related hazards like droughts and floods but also the preservation of flow rates, quality and feedbacks from affected systems (Atwi and Arrojo 2007).

To predict future water availability in a reasonable way water managers require a firm understanding of the natural water cycle and the variability of water resources at different scales within a catchment. A common critical method of managing hydrological variability is the use of storage reservoirs. Reservoirs provide a significant although limited opportunity to control water supplies by storing water at times where water availability is greater than the demand for seasons with potential water scarcity. Reservoir design is tightly related and based on historical streamflow, current water needs and projections for future water needs as well as future water availability. Thus, assuming stationarity, prevalent water supply systems do meet the need of current and near future water use. Challenges may occur with respect to the reliability (buffering of variability) and the sustainability (future reliability) of such systems (Brown, Baroang et al. 2010).

Hazard: With respect to water supply the hazard is related to the water availability relative to the demand in terms of volume and especially timing. The Ebro Basin in Spain was the first river basins in Spain considered into the EUPORIAS project (Ebro Basin agency entered as a stakeholder from the beginning of the project); later other basins were also considered in the study (Tagus, Douro, etc.). Accordingly, the situation of the Ebro Basin is analysed more in details in the following sections and most of the analysis would be representative of the other basins in Spain (with some limitations). The basin drains an area of about 85,000km^2 which comprises 347 main rivers. The annual water flow varies significantly between summer and winter and can fluctuate from 3,811 hm^3 to 26,134 hm^3 per year causing a rise of water levels of 7-9m above average during the heavy rain season in fall and spring (Water2Adapt 2010). Water availability is also unevenly distributed in space and time: at which the head of the tributaries in the Pyrenees receives much more rainfall (~3,800 mm/year) than the central river valley (100 mm/year) where the main economic activities are located. Inter-annual variability is also significant and ranges between 800 mm and 450 mm in wet and dry years (Omedas, Galvan et al. 2011). Ebro River and its tributaries are managed by about 187 dams which have a total capacity of about 60% of the total mean annual runoff (Batallaa, Gómezb et al. 2004) which is about 7,500 hm^3 in total and thus more than the half of the mean annual available water (Iglesias, Cancelliere et al. 2007, Omedas, Galvan et al. 2011). Mean available water resources are estimated at around 14,600hm^3 per year from which around 8,400m^3 are extracted. Agriculture claims the greatest demand with around 7,700hm^3 (92%) and the rest is used for industry, energy, urban use and for transfers to other basins in Spain. Future demands are expected to increase by 30% until 2027 while water availability is expected to decrease by 10% (2040) to 30% (2100) (Kahil and Albiac 2014).

The major problem is to provide sufficient water to cover the demand during summer (peak water demand, mainly for irrigation purpose) and during one year or several consecutive years of below normal inflows (dry years). Thresholds for high- and low-flows used in decision-making are generally static, but some little adjustments could be done during the year for exceptional situations (very high inflow, drought, etc.). These rules have been elaborated based on historical hydrological records and the analysis of the consequences that extreme events may have on the system.

Decision-making processes: Water and reservoir management on the basin scale is strongly influenced by national (e.g. National Hydrological Plan), European (e.g. Water Framework Directive) and international laws and directives which regulating water distribution and quality issues, dam safety and emergency management, ecosystem preservation and flood and drought management (prioritization of water allocation) (Santaengracia and Argüello 2012, Castillo-Rodríguez, Morales-Torres et al. 2015). This has fundamental consequences for decision-making processes on management of multi-purpose reservoirs: water storage for drought management and hydropower rather demands the exhaustion of the storage capacity. In contrast, flood management requires a certain storage buffer and regulations on water quality require a minimum reserve within the reservoir. Ecological and health issues require a minimum flow of water to avoid eutrophication and sedimentation of the reservoir and alteration of downstream aquatic ecosystems. Flow regulation is also desired for flood protection and the prevention of erosion (Horne, Dracup et al. 2003, Palau 2006, López-Moreno, Vicente-Serrano et al. 2009).

Since the main purpose of the reservoir in Ebro basin is irrigation (~90% of total water demand) the focus of reservoir management is to reach maximum volume shortly before the beginning of the hot season when irrigation is required. The main filling periods in Spain are thus during the rainy periods in autumn and spring (October until April/May). The velocity of infilling largely depends on the rainfall regime and especially on the seasonality and intensity of flood events. Especially in Mediterranean regions a large proportion of the annual discharge concentrates on a few events which highlight the importance of flood events. Floods in October and November are often used to quickly increase the stored volume. Infilling is then partly paused for safety reasons and the definite infilling occurs in spring (López-Moreno, Beguería et al. 2004). The sensitivity of the reservoirs is dependent on their storage capacity: small dams with limited capacity are filled and emptied in a yearly cycle and are thus sensitive to intra-annual variability of discharge. In contrast, larger dams with a high storage capacity can regulate climate intra-annual variability but are sensitive to successive years of drought.These characteristics of reservoir management explains the uncertainty of inflow control and flood-risk assessments to meet dam safety regulations which requires high flexibility in decision-making.

For the Ebro-basin decision-making on the water needs for the coming season happen in general meetings with River Basin Agencies and users in October and March ('junta de explotación'). At the beginning of the hydrological year (October) the current situation (reserve in dam) will be analyzed, and the expected state for the next 6 months will be assessed. This prediction over the next months is commonly based on historical information only (e.g. historical inflows) and physically based climate forecast are not considered. As a result, the decision making process is directly connected to the current state of the system. In March there will be a look at the current state of water levels in reservoirs and the situation of snow reserves in the mountains. Decisions are made on water allowance for the coming irrigation period (April-October) which is mostly based on average resources from the past 10 years (pers. com. L. Pouget).

Under normal conditions, the Reservoir Releases Commission (Comisión de Desembalse, which is one member of the "*junta de explotación"* commented before) will meet in ordinary session and will define some actions relative to reserve management, onset of right exchanging centres, revision of ecological flows and ground water abstraction and definition of precautionary water allocation schemes. All these measures affect farmers, hydropower units, environment, urban users and others. The commission meets in October to decide upon the proper filling level of the reservoirs during the wet season and at the beginning of spring to decide upon the allocation of reservoir releases during the dry season. The commission's recommendations must take into account the water supplies expected to be available and the licenses held by water users (Bhat and Blomquist 2004).

Drought indices are calculated on a monthly basis during the dry season (as defined in the Sub-basin Management plan) which is used to take measures for drought management (restrictions, emergency infrastructure operation, increasing monitoring and surveillance, minimum ecological flow discharges, etc.). In contrast, intense precipitation events are anticipated especially between October and March on a 48 hour time scale (minimum) to assess flood volumes and improve flood management and respective dam operations on the basin scale (CHE 2014; pers. com. L. Pouget).

Critical situation: the critical situations related to decision-making processes for reservoir management in the context of balancing supply and demand can be defined as follows:

A critical situation arises when a high variable discharge regime occurs during the rainy season (October-May) as this challenges the ability to balance the need for maximizing the reservoir capacity until June and buffering unexpected flood events between January-April.

Buffer system characteristics

For water management issues in context of reservoir management the availability of water in form of discharge is the attribute of concern. Water managers and users get a problem when there is a "prolonged period with below-normal water availability in rivers and streams, and lakes or groundwater bodies due to natural causes" (VanLanen, Wanders et al. 2013 p.1716) thus, a hydrological drought. Hydrological droughts evolve slowly and are due to periods of low precipitation combined with high evaporation losses which causes soil moisture deficits and subsequently reduces groundwater recharge and head and eventually lowers stream flows (Maybank, Bonsal et al. 1995). The area affected by droughts is primarily climate driven whereas local variability is influenced by characteristics of the terrestrial system. Hydrological storage or a combination of catchment characteristics which relate to catchment storage and release (e.g. land use and geology) is the most important factor controlling drought propagation and causing lag times between a meteorological drought and hydrological drought and its spatial characteristics (Tallaksen, Hisdal et al. 2009, VanLoon and Laaha 2014). The monitoring of hydrological reservoirs within a catchment is also a central element of the Spanish Drought Management Plan (Monreal and Amelin 2008).

In contrast, the occurrence of flood events is much more sensitive to changes in hydrological reservoirs. For flash floods the soil do not even need to be saturated. High magnitude rainfall events may exceed the infiltration rate of the soil, causing surface runoff and thus provoke local flooding despite rather dry soil conditions. Also snowmelt floods and rain-on-snow floods are often dominated by temperature which controls the activation and the draining of the respective hydrological storage (Merz and Blöschl 2003).

Dams and reservoirs can also be considered as hydrological storages and thus as an additional buffers. However, these storages should be considered as different buffer systems, since this storage type is controllable and stored water is available at discretion. The infilling of these storage types is dependent on the discharge of the catchment draining the area uphill of the reservoir but the release rate can be controlled by decision-makers.

Critical climate conditions and climate information

Critical climate conditions

The relation between discharge and rainfall is strongly dependent on catchment characteristics especially the state of hydrological reservoirs. The development of hydrological droughts is a slow process and not only dependent on periods of low rainfall but also on temperatures and evapotranspiration potentials. Required time-scales over which precipitation events need to be below average or even lacking to provoke hydrological droughts are in general seasonal for fast responding catchments and may be inter-annual in catchments with large hydrological storages (vanLanen and Tallaksen 2007). For the Ebro Basin the response of monthly runoff to precedent climate conditions (represented by the standardized precipitation evapotranspiration index (SPEI)) was analysed for different catchments of varying size. Three main sub-basin groups could be identified with respect to their streamflow response to SPEI at different time scales: the unregulated head-water areas are sensitive to time-scales of 2-4 months. In contrast, sub-basins which are groundwater controlled do have response times from 10-20 months and sub-basins at the lower sectors of the Ebro Basin which receive flows from the other sub-basins and where dam regulation play a significant role have response times from 6-10 months (López-Moreno, Vicente-Serrano et al. 2013).

Critical climate conditions for floods are short-term (see above). However, since flood management with respect to dam safety is a short-term event with short-term decision-making this problem is not further considered in this analysis.

Critical climate conditions are below-average precipitation during the year combined with above-average temperatures. Furthermore, extreme high rainfall events during and especially at the end of the rainy season (October-May).

Climate information

To assess the potential inflow within the filling season information on total rainfall and temperature from October to March is desired. Thus the demand is for a 6 month-forecast available at October. In March another 6-month forecast is required to assess the demand for the hot season and assess the final requirements on infill during spring. Consequently, year-round climate information is desired portioned to infill-season and release-season which also define the timing of decision-making.

To assess flood events during winter information on total water availability is sufficient however information on the distribution (magnitude-frequency) would be desired to be able to cope with individual events especially at the end of the filling season when reservoirs are rather full.

Vulnerability attributes

Criticality of the problem: water availability in a drought-prone region is basically a very critical factor and thus related decision-making processes are of general criticality. However, decision-makers which have to decide on water resources and their allocation do rather have a risk-averse attitude: uncertainties on water availability are countered by worst-case hypotheses to avoid risky (irreversible) decisions of users (e.g. farmers) (CHE 2014). Thus, the decision to exhaust the storage capacity of reservoirs within a catchment is a robust (low risk) decision with respect to water availability. In this context floods do constitute greater risk since they don't allow exhausting the total storage capacity due to dam safety reasons (CHE 2014).

Usability of S2D climate forecast information: decision-making of water managers refers to the fill-level of the reservoir which is aimed to be exhausted at the end of the rainfall season but requires considerations of in-seasonal release rates due to flood-protection, ecological system maintenance and other reasons. Thus, decision-makers are interested in total water available at the end of the rainy season. Discharge rates during the season and thus the timing of high- and low-flow events are of minor importance with respect to this goal. This interest is systemically and technically supported by the buffer effect of the catchment and dam reservoirs. Consequently, information on mean temperature and effective rainfall over a certain period is general desired and usable due to the systemic buffering of rainfall and evapotranspiration rates by the catchment and reservoir system. Furthermore, since temporal scales of the critical climate conditions is much longer than the temporal scale of decision-making seasonal climate forecasts doesn't need to cover the entire time-scale. At the time of decision-making a great deal can be covered by using climatology.

The matter of timing is however an issue for the coping of flood events. Especially when approaching the end of the rainy season and the reservoir is rather full and the timing of high-magnitude flood events is critical information. Thus, climate information with higher temporal resolution would be desired to reduce uncertainty of such events. This information would be particularly useful for improving the decision taking in the Reservoir Releases Commission in October (e.g. maximum and minimum release during winter, maximum reservoir filing to buffer potential flood) and March (e.g. minimum reserve in dams at the end of the irrigation period, end of irrigation period). Compared to problems of other sectors the need for high ***spatial resolution*** is limited (e.g. most of the dams have upstream basins of more than 500km^2) and thus the tolerance to lower spatial resolution is expected to be higher. Furthermore, since water resource operation management and planning are generally based on historical climate (discharge) data, worst-case scenarios are commonly used in planning (e.g. drought management plan, dam capacity) and recent records used in operation (e.g. average of last 10 years inflow records used in the user´s assemblies). The use of climate forecast could be easier for the stakeholders if some references are made with recent historical events (e.g. prediction of more or less rainfall than the last 10 years).

3.2.9 PROSNOW

Introduction

Scope of prototype

The level of activity, employment, turnover and profit of hundreds of ski resorts around the Alps depend on snow falls and associated snow levels, highly variable in space and time. By nature seasonal, winter tourism is also affected by a high inter-annual variability, which makes all the more important the improvement of seasonal forecasts. For mountain tourism operators, seasonal snow forecasts could be useful in decision-making, managing ski areas, promoting mountain destinations and communicating with clients. The objective of this prototype will be to deliver an operational system of seasonal forecasting of snowfall probabilities, and an evolving model of snow cover (depth…), constantly updating the forecasted snow cover from the recorded depth at a "t zero". The prototype itself will cover the Savoy (French northern Alps), with potential extension to other Alpine domains. Due to potential misuse of such forecasts by individual customers, this system will be reserved for tourism professionals.

Scope of vulnerability analysis

The focus of this vulnerability assessment is on the operation of ski-areas and the dependency on snowfall. Thus, ski-area operators and their decision-making processes will be considered. The critical situation of sub-optimal snow conditions for other decision-makers cannot be considered in this analysis.

System of concern

In France, mountain tourism takes place in six mountain ranges, which cover 25% of the country's surface area. Mountain regions generate 15% of tourism GDP, 120,000 jobs and 55.3 million skier days each year. France has 357 resorts, over 200 of which are located in the Alps. They range in size from village facilities to large international stations. Experts generally distinguish between the Northern and Southern Alps, which together account for around 80% of the country's ski areas. Key decision-makers are ski area operators, which manage ski trails and ski lifts. They are key players in resorts and central to economic activity. Some 44% of operators are publicly owned, 43% are private companies and 13% are semi-public companies (sociétés d'économie mixte or SEMs, where the government holds a majority interest). Almost all resorts are members of Domaines Skiables de France (DSF), an association of French ski areas.

Critical situations

The key climate change impacts of interest to the winter sports industry relate to 'natural snow reliability' and also 'technical snow reliability' (i.e., cold temperatures to make snow). The latter is important in areas where snowmaking is almost universal among ski areas and covers a high proportion of skiable terrain. Studies on climate change impact on winter tourism in the European Alps determine that the number of ski areas that were considered 'naturally snow reliable' will drop from 609 (91%) to 404 (61%) under a +2^0 warming scenario and further decline to 202 (30%) under a +4^0 warming scenario (Abegg, Jetté-Nantel et al. 2007). Thus snowmaking will become more important in the future. Snowmaking is already a widespread climate adaptation in the region, with the proportion of skiable terrain currently equipped with snowmaking estimated only at 15% in the French Alps (50% in Austria, 40%

in Italy). Major uncertainties on the impacts for businesses also relate to the acceptance of customers to ski on partially snow covered ski runs, or the potential for large reductions in opportunities for Nordic skiing at low mountain elevations. Inter-annual variability is very likely to be more pronounced under climate change, creating increasingly challenging business conditions. Two or three consecutive extremely warm winters, could cause substantive economic losses and if frequent enough perhaps adversely affecting skier perceptions and demand in the longer term (Abegg, Jetté-Nantel et al. 2007, WMO and UNEP 2008).

Hazard: Economic conditions, employment and earnings at hundreds of Alpine winter sports resorts depend almost entirely on one thing: snow. Winter tourism is, by nature, seasonal. Climate conditions of ski areas affect, in the first place, the possibility for the ski resort to exist (no snow, no ski). It also impacts the reputation of the resort and the willing of tourists to book a stay in this resort (guaranteed quality of skiing) and thus the turnover of the resort and of all socio-economic stakeholders. It is therefore affected by inter-annual variations in snowfall frequency and duration, as well as snow cover quality. The snow cover evolution and conditions is thus the attribute of concern and its variability in time space a potential hazard.

Natural snow conditions suitable for skiing are generally defined by an ideal snow-depth of 30-50 cm (Elsasser and Messerli 2001, Fratianni 2001, Bürki, Elsasser et al. 2003) and quality which is generally assumed to decline at surface temperatures above -2°C. However, good skiing conditions are not predominantly determined by depth, since 30 cm dense snow provides better conditions than 1 m of powdery snow (pers com Lootvoet). The volumetric and spatial degradation of snow covers can occur by liquid precipitation >5mm but is dominantly controlled by air temperature > 6°C (Fazzini, Fratianni et al. 2004). Thus, lower lying ski-areas where beginner ski runs are typically found are especially affected by lack of snow. Especially because most people learn to ski on these lower-lying beginner slopes and the implications of fewer such slopes for discouraging beginning skiers or possibly diminishing the industry's client base over time remains uncertain (Abegg, Jetté-Nantel et al. 2007, WMO and UNEP 2008). Regarding the temporal scope of a good skiing season, 120-130 days are assumed for the Alps from December to March. At least 100 days per season are supposed to be covered by natural snow conditions to define an area as 'naturally snow reliable' (Bürki, Elsasser et al. 2003, Abegg, Jetté-Nantel et al. 2007; pers. com. Lootvoet). However, the total length of the season is not the critical factor but the periods of high demand. It may not matter to ski area operators if every ski season by mid-century is a couple of weeks shorter, as much of the season loss will occur at the beginning and end of the season when skier visits are relatively low. High demand periods are accompanied by school holidays which are in France two weeks at Christmas and four weeks in February/March. In one of these weeks, a resort earns 9% of its annual turnover. Visitor numbers during these weeks are therefore a major concern for most socio-economic operators (pers. com. Lootvoet).

Threshold for quality of skiing depends also on the capacity of the resort to produce snow from water. If the resort can guarantee a reasonable proportion of the ski area with artificial snow, then only temperature will be really important factor. Water droplets generally freeze between -6 and -10 °C which is the ideal temperature for snowmaking. However, the minimum temperature is at -2° C. Snowmaking is more difficult at these high temperatures, hence additives are sometimes used to induce freezing (Forget 1997, Schneider and

Schönbein 2006, Hofstätter and Formayer 2007). For the system of concern ski-area operators use this artificial snow in order to guarantee 30% of the ski area to have enough snow to allow skiing (pers com. Lootvoet).

Decision-making processes: the main challenge for decision-makers is basically to meet the demand for skiing and provide favourable snow conditions when this is desired. From a climatological point of view snow conditions are most critical at the beginning and end of season. However, the demand for skiing is closely linked to school holidays which are at Christmas and French winter holidays in February/March, this period is central to resorts' economic performance. Some ski trails may open around 10th of November but the period before Christmas is critical as this is the time when many tourists make decision to book ski holidays. Major difficulties may therefore arise during warm winters without snow or when no snow has fallen by Christmas. Thus, decision-makers have to be prepared for (i) late onset of snowfall and early finishing of snow-season and (ii) variability of snow conditions.

The ***start of the skiing-season*** has to be carefully prepared. Especially the promotion of the coming skiing-season is very sensitive. From September onwards, tourism promotion agencies and resorts face questions from the media about the upcoming winter season. Snow quality and conditions for snow-related activities are the most frequently raised issues that can affect customer decision-making and therefore turnover. *Promotion and communication strategies* like the pricing and promotion policy have to be adapted to an unfavourable start of the skiing-season. But also the *Human Resource (HR) policy* e.g. the offer of goods and services (e.g. activities that are not snow-related) have to be adapted and HR management (less seasonal jobs, different skills…) and orders. The latter requires a lead-time of a few days and can be optimized during the season. But the more anticipated it is, the lower the operational costs will be.

Decision-making on ***variable snow conditions*** implies the preparation of snowmaking and trail maintenance activities. Preparations begin mid to late October, when *snowmaking* resources are first mobilised. When preparing the season, decisions must be made regarding snow production: whether to put machines on standby, start snowmaking, etc. At the beginning of the season (around 10th of November) decisions must be made regarding *grooming machines and schedules* to ensure good trail quality and optimised operating costs as well as hiring and training seasonal employees for trail maintenance and security. Towards the middle of the season (late January), resort managers analyse the quality of snow cover, predictions for the next two or three months and temperature forecasts for April to anticipate end-of-season conditions for trail maintenance and snowmaking. Most of these decisions can be made and adjusted on a day-to-day basis but the more anticipated it can be (about one month before the start of the season), the lower the operational costs will be.

Critical situation: the demand on snow conditions are clearly defined by tourists and thus ski-area operators:

A critical situation arises when the coming winter season is unexpectedly bad which is especially characterized by low snow cover (<30cm), late start of the season (after mid-December) and warm temperatures (> -2°C) which prevents snowmaking.

Buffer system characteristics

The impact of climate conditions on the attribute of concern (snowpack) is very direct. For the accumulation of a snowpack, very few heavy snowfall events may already be sufficient to accumulate a snow pack suitable for skiing (Spreitzhofer 1999). Also the degradation of the snowpack may occur over very short time scales (days) (Hock 2003). The persistence of a snowpack is dependent on snowfall but mainly on temperature which significantly influenced by local topographic and geomorphic conditions. Thus, as soon as a snowpack has accumulated, it continuously persists as long as temperatures do not cross a critical threshold (>0°C) and precipitation becomes liquid and thus significantly degrades snow pack quality and decreases its volume. Such temperature conditions are generally a function of elevation which in turn makes snow pack conditions sensitive to climate conditions (Beniston, Keller et al. 2003, Fazzini, Fratianni et al. 2004, Scherrer and Appenzeller 2004, Gajić-Čapka 2011). Consequently, snow packs are sensitive to the start of the snowing season and the initial accumulation of a snow pack and to the end of the snow season when temperatures frequently become positive, enhance melting processes and degrade the snow pack. The sensitivity of snow packs to climate variability and change is thus measured by its duration in snow days in relation to elevation (Egli 2011, Gajić-Čapka 2011, Serquet, Marty et al. 2013).

Critical climate conditions and climate information

Critical climate conditions

Snow pack accumulation is primarily dependent on the availability of snow and thus snowfall events. However, the persistence of the snow pack is dominated by temperature which controls melting processes but also the aggregate state of precipitation (snow or rain). Also the option of snowmaking is primarily temperature dependent. Thus, consistent low temperatures can compensate the lack of snowfall at least to a certain extend by the provision of an already existing snow cover (with probably lower quality) or the opportunity to make artificial snow. Furthermore, decision-making processes put a focus on the timing of snowfall and low temperatures. Thus, critical climate conditions are lack of snowfall or rather low-magnitude events especially at the beginning of the season (November/December) and at the end of the season when mean temperatures start to increase again. But high variability of snowfall during the season may also be critical since it creates need for more snowmaking (low snowfalls) and need for more trail grooming and maintenance (very intense and frequent snowfalls). Additionally, warm mean temperatures for all the winter season are critical with a special temporal focus again on the beginning of the season.

Critical climate conditions are (in order of priority)

- ***a late onset of seasonal snowfall (after mid-December),***
- ***warm temperatures (>2°C) and***
- ***highly variable in-seasonal snowfall.***

Climate information

Of major importance is the information on the start of the winter season, i.e. the onset of the first snowfall events which provide skiing conditions. Or rather the snow conditions for the beginning of December with a lead time of one month. Climate information on snowfall and temperature with a respective high temporal resolution for November/December is desired.

A general knowledge on the snow conditions of the coming winter season is desired in October to adjust the availability of staff and machines. To assess the need for grooming and snowmaking activities, information on the snowfall and temperature variability during the season and especially at the end is desired.

Vulnerability attributes

Criticality of decision-making processes: Economic conditions in mountain resorts are almost entirely dependent on tourism. In Northern Alpine resorts especially, winter is often the main season. A resort earns 9% of its annual turnover within one week of the high-season. Thus, snow is the basic resource on which business is built on which implies a very high dependency on climate. The opportunity of snowmaking moderates this climate dependency or rather shifts or spreads the dependency from snowfall to temperature. Consequently, decisions on promotion for the coming winter season are crucial for business development and climate takes a major role in this decision.

Usability of S2D climate information: the basic climate information required by ski area operators is whether the winter season becomes good or bad with respect to the amount of snow available and the need for snow making. Since decision on concrete measures can be made short-term the timing of high- or low snowfall events is not critical for strategic decisions on the coming winter season. Thus, information about snow conditions referring to mean values is potentially of good use. However, the temporal focus on the start of the season as well as the school holidays complicates the usability of climate information: the timing of snow conditions gains importance which adds a lot of uncertainty to information from S2D climate forecasts or requires sub-seasonal forecasts covering short time periods.

This misfit of S2D climate information and critical climate conditions is increased by the related decision-making processes which requires lead-times of up to 3 months for climate information comprising a couple of weeks. Furthermore, the very demand for spatial high resolution of climate information (micro climate of valleys and slopes) additionally increases the challenge of the use of climate information for this problem.

3.2.10 CMTool

Introduction

Scope of prototype

Temperature-related illness and death is putting strain on public health systems; strengthening health systems and building capacity is crucial to providing climate-resilient healthcare and to protecting the health of millions of European Union citizens. Health service delivery needs to be assured at all times, particularly when challenged during times of crisis, such as during summer heat wave emergencies. Climate forecasts would allow for better short-to-medium-term resource management within health systems and would help authorities prepare and respond ahead of heat waves and cold spells. Heat–Health Action Plans (HHAP) and cold weather plans (CWP) depend on reliable early-warning systems to allow for long-term planning (e.g. energy use, urban design, health workforce management), as well as timely activation. This helps local authorities prepare and respond to emergency situations and thus reduce excess morbidity and mortality due to temperature extremes.

In this study, a climate-driven mortality model is developed to provide probabilistic predictions of exceeding emergency mortality thresholds for heat wave and cold spell scenarios. To evaluate the model, daily mortality data corresponding to 187 regions across 16 countries in Europe were obtained from 1998–2003. Data were aggregated to 54 larger regions in Europe, defined according to similarities in population structure and climate.

Scope of vulnerability analysis

This vulnerability analysis focuses on the impact of heat waves on the general public and the ability of the local health system to cope with such situations. For the purposes of this analysis, major decision-makers are defined as those responsible for implementation of the HHAP, i.e. ministries of health and senior public health professionals and administration.

System of concern

The majority of the heat–health action plans in Europe are organized at the national level and are usually developed by the national ministry of health in cooperation with national meteorological services and other state and non-state actors. Implementation is mostly at a regional or local level involving the local health infrastructure, such hospitals, pharmacies, other health centres and social services (Matthies and Menne 2009). Thus, the operational boundaries and physical boundaries are related to the respective administrative unit for which health service institutions are responsible. Success criteria are primarily safety of the general public and resilience of the health system, which has the goal to prevent morbidity and mortality, and to ensure continued functionality (business continuity) health system. Limiting factors may economic in nature (UniversityHospital_Barcelona 2014), or lack of technical capacity for implementation.

Critical situation

Heat can have negative health effects for individual persons when the thermoregulation system fails. Typical heat-related health problems include heat rash, heat œdema, heat syncope, heat cramps, heat exhaustion, and ultimately heat stroke and death (WHO 2008). Cardiovascular and respiratory diseases are commonly considered as underlying cause for death during heat waves; however, the link between deaths and heat exposure on hot days is difficult to establish as heat exposure can exacerbate many existing medical conditions other than heat-stroke and hyperthermia and have compounding effects with medication. Consequently, mortality attributed to heat-related causes are commonly underestimated. Heat mortality is usually studied by measuring the short-term associations between numbers of daily mortality and temperature at the community level. The vulnerability of a population to heat is indicated by a heat threshold (temperature above which heat effects can be observed) and the heat slope (measure of effect size). Both parameters may vary significantly across populations depending on differing geography and climate, as well as demographic and socioeconomic characteristics (Hajat and Kosatky 2010). Vulnerable population members are often elderly, socially isolated, chronically or mentally ill, homeless, individuals with cognitive disorders or those taking medication that affects thermoregulation, cognition or have photosensitive side effects. The build environment can significantly increase the heat exposure of population groups, especially in urban centres (e.g. through the urban heat-island effect) (Lowe, Ebi et al. 2011).

Hazard: Studies referring to heat-mortality in Europe clearly indicate that mortality due to heat exposure is not related to annual mean temperatures. In regions with warmer summers, minimum mortality occurs at higher temperatures than in regions with colder summers. Thus, heat-mortality is a function of days with maximum temperatures above the regional minimum-mortality band. Interestingly, the number of days above the minimum-mortality band is not greater in the hotter countries, nor is the annual heat-related mortality significantly greater. Furthermore, the rise in daily mortality in relation to temperature increase shows no significant difference between regions. Upper limits of the minimum-mortality band range from 17.3°C (in northern Finland) and 22.3°C (in London) to 25.7°C (in Athens) (Keatinge, Donaldson et al. 2000). However, other studies state a higher mortality in cities in Mediterranean regions as they are exposed to higher heat-wave frequencies. But in general, the daily mortality increases significantly with an increase of the intensity and duration of heat waves all over Europe (WHO 2008).

Decision-making processes: Measures to prevent or mitigate the impact of heat waves are usually determined by heat-health action plans which are developed by national authorities and implemented on the regional or local scale. Heat–health action plans can be evaluated based on inclusion of nine core elements (Matthies, Bickler et al. 2008, Bittner, Matthies et al. 2013):

- Agreement on a lead body and clear definition of actors’ responsibilities
- Accurate and timely alert systems, heat–health watch-warning systems
- Health information plan
- Reduction in indoor heat exposure
- Particular care for vulnerable groups
- Preparedness of the health/social care system
- Long-term urban planning
- Real-time surveillance
- Monitoring and evaluation

The elements 2, 6 and 7 of an ideal HHAP would benefit from early-warning systems providing information on upcoming and ongoing heat waves on different scales (weather [2], seasonal climate [6] and climate change [7]) on the local level. On the scale of weather forecasts, heat–health warning systems (HHWS) are used to initiate acute public health interventions. HHWSs vary widely in structure, implementing partner agencies, and the specific interventions deployed. Temperature 'thresholds' for action (e.g. magnitude, duration, temperature-humidity index) are strongly related to the local population's adaptation to the local climate. An effective HHWS requires (Kovats and Ebi 2006):

- Reliable meteorological forecasts.
- Robust understanding of cause–effect relationships and evidence-based identification of high-risk meteorological conditions.
- Effective response measures implemented within the window of the warning lead-time.
- Involvement of appropriate institutions with sufficient capacity, resources and knowledge.

HHWSs in Europe basically address emergency services helping to outline plans to recruit, increase or recall staff to respond to emergency situations. Additionally, they can target particularly vulnerable population groups to initiate individual protection measures. Such warnings may be tailored due to the individual needs of specific population groups and are disseminated using multiple, and user specific, methods. Almost all HHWSs in Europe are active at least between May and September and provide heat wave warnings with lead-times between 1 and 5 days, often graded in different levels of warning (Lowe, Ebi et al. 2011).

Heat wave alerts mainly address the initial trigger conditions (highest alert level), which comprises the initial days of a heat wave. Thus, prolonged heat waves or high frequencies of heat waves which cause the greatest increase in mortality, as well as accumulated effects due to continuous heat exposure are little considered in HHWS's (Kovats and Ebi 2006, Lowe, Ebi et al. 2011).

Decision-making processes which might benefit from longer-term climate forecasts to prepare for prolonged or higher frequency heat waves may address the necessary resource allocation and capacities of health services for longer-term emergency situations, and are loosely considered in HHAPs (Matthies, Bickler et al. 2008, Lowe, Ebi et al. 2011). Thus, the development of longer-term climate forecast tools are justified by such decision-making processes (Koppe and Jendritzky 2005, WHO 2008). However, despite the fact that mortality significantly increases with intensity and duration of heat waves, a similar relationship of heat wave characteristics and hospital admissions is not consistent within Europe. Many studies from Europe indicate a rather low or inconsistent correlation of temperature on hospital admissions compared to incidence of mortality (Kovats, Hajat et al. 2004, WHO 2008). The impact of heat waves on hospitals is widely discussed and analysed especially after summer 2003. Most aspects are related to the basic hospital infrastructure and design which appeared to be limited by technical failure of machines or insufficient cooling configurations (WHO 2008, Carmichael, Bickler et al. 2013). These issues would be addressed by long-term planning activities which might go beyond the seasonal time scale of decision-making. The importance of mid-term forecasts (weeks ahead) is also indicated by health service decision-makers who are generally interested in such climate information to be prepared for exceptional high hospital admissions. However, climate (e.g. heat waves) is only one of many factors influencing hospital capacity utilization, thus no specific decision-making structures exist at which such climate information would find direct impact. Statements on general lead times to prepare for exceptional utilization are around 4 weeks (UniversityHospital_Barcelona 2014).

The critical situation arises when local temperatures rise to extreme values referring to local climate conditions and persist for too long so that local medical coping capacities will be exhausted.

Buffer system characteristics

The impact of temperature on health conditions is very immediate; the critical threshold is related to the physical condition of the individual and their adaptation to local climate conditions. Thus, no buffer effect can be attributed to the direct climate cause–effect relationship. However, with respect to the second critical situation, a potential exhaustion of health system capacity, the attribute of concern changes: here, health service provision is the attribute of concern. This might be stressed by the total number of people requiring health care. With respect to heat waves, it is the total number of people within a specific affected system of concern (e.g. in a municipality) affected by heat to such an extent that they require primary health care, a service provision that is critical to a functioning health system. Thus, the constitution of the local population (i.e. proportion of a population that is vulnerable) defines the criticality of a heat wave (i.e. its intensity) and can therefore be considered as buffer system (Hajat and Kosatky 2010). However, the correlation of heat waves and hospital admissions is inconsistent (see Kovats, Hajat et al. 2004), and the temporal scale of this buffer effect is still dependent on the weather conditions since emergency health care provision is immediately implemented, irrespective of the number of people are affected.

From the perspective of the health system, an increase in demand for primary health care induced by a heat wave is only one of many factors stressing the system. The extent of the heat wave impact on the health system is strongly related to its basic capacity (resilience) to handle variabilities in demand (e.g. hospital admissions) and can additionally be stressed or challenged due to limitations of the basic infrastructure or the occurrence of multiple stressors at once. The health system can therefore be considered as buffer system: the critical duration and intensity of a heat wave and its subsequent consequences for health service demand is dependent on the resilience of the health system. The temporal scope of this buffer system may go beyond the scale of weather events.

Critical climate conditions and climate information

Critical climate conditions

High temperatures become critical for health and life when they become extreme in relation to average local climate conditions; the extremity is the dominant factor. This is very location-specific and may be compounded by local conditions, such as like surface and air circulation conditions, humidity and pollution. The effect of heat waves on health, and especially mortality, increases significantly with duration and intensity. The frequency of heat waves is also important, whereas the first heat spell within a season appears most dangerous. Subsequent heat waves occurring after a short time interval do have less effect than those which occur after three or more days (WHO 2008).

Critical climate conditions are continuous extremely high temperatures (compared to local climate).

Climate information

For the prediction of heat waves the information on the number of consecutive days with extreme temperatures are of special interest. The frequency of heat waves is of lower importance. Short-term medical service requires lead-times of 1-3 days. Mid-term preparation of the health system to distinct heat waves requires lead-times of around one month (UniversityHospital_Barcelona 2014).

Vulnerability attributes

Criticality of decision-making processes: Extreme temperatures and their impact on health are seasonal events, which are largely expected to happen every year. The negative impact role of these climate-induced conditions play would therefore define them as a hazard. The challenge of the decision-makers is to prepare health systems for periods of exceptional demand with respect to resources (e.g. medication), staff (e.g. doctors, nurses and other health professionals) and capacities (e.g. beds available, operations time, and equipment). To provide appropriate supply capacity during the acute phase of the emergency is the major goal of health services, and the preparing to prevent ultimate exhaustion of resources and potential failure of the health system.

However, studies and reports on the impact of heat waves on the health service system as well as HHAP primarily aim for the optimization of short-term warning, prevention and medical provision (at the weather timescale) as well as for the long-term adaptation of health service facilities to a warmer climate and the associated risk of the increasing frequency of heat waves (up to decadal timescales and longer). Decisions related to seasonal time scales of heat/cold events which imply mid-term resource and staff management are considered as important but appear as being less critical than short-term and long-term issues.

The impending exhaustion of health system capacities is of general criticality and not exclusively related to weather phenomena. Heat waves may cause a temporal high demand in medical services stressing health system capacities likewise other non-climate related factors which may be concurrently relevant. However, climate is considered as important, but not a crucial factor to assess and plan health service management issues (UniversityHospital_Barcelona 2014).

Usability of S2D climate information: Climate information with respect to prolonged heat waves has a great potential for respective decision-making processes regarding capacity management of health-services. However, no specific demands regarding critical period length can yet be articulated and also lead times are oriented at established (non-climate related) decision-making processes. Irrespective of very vague boundary conditions for climate services required for decision-makers, the characteristics of critical climate conditions is quiet clear. Consecutive days of exceptional heat are increasingly critical the longer the duration of such periods. Thus, distribution of extreme temperature is obviously a dominant factor. An estimated temporal scale according to the little information available would be that of 1 to maximum 5 months (length of the hot season) with high temporal resolution which provides the opportunity to identify heat spells of a couple of days.

3.3 Evaluation of results

In the following chapter the vulnerability components of the EUPORIAS prototypes and case-studies are evaluated and discussed with respect to commonalities and differences. The goal is to identify indicators which sufficiently represent the characteristics of each vulnerability component.

3.3.1 Critical situation

The critical situation is characterized by climate influenced physical conditions which may cause potential problems to the system of concern as well as by system-specific DMP's which will be activated to cope with potential impacts. Both attributes do have influence on thresholds which are relevant for the determination of a critical situation.

The relevance of climate for the thresholds is of particular interest with respect to the vulnerability assessment to climate variability. Therefore, the critical situations of the EUPORIAS prototypes and case studies were analysed according the influence of climate and DMP on the composition of thresholds.

Objects of analysis are: (i) the role of climate for the system of concern and (ii) the dominant factor which defines the threshold of the critical situation. An overview of the results is given in Table 2.

According the analysis, the 'role of climate' may provide the most suitable and harmonic classification to describe the climatic influence on the critical situation. The following categories for 'the role of climate' were identified to:

- **Production factor:** climate impact is in basically **beneficial** for the system of concern but climate is **one of many factors** relevant for the CS.
- **Resource**: climate impact is in basically **beneficial** for the system of concern and climate is the **only or dominant** factor relevant for the CS.
- **Hazard**: climate impact is basically destructive for the system of concern and takes a **dominant** or at least significant role for the CS.

Using this classification system a relative sound pattern for critical situations can be delineated:

Climate as 'production factor': climate is an important factor which influences the critical situation besides many other factors. A climate impact affects the attribute of concern and may diminish the output and cause economic losses. The climate impact may be compensated by strengthening the other factors or replacing the climate factor by respective coping measures. Thresholds are therefore predominantly defined by DMP's and physical thresholds are rather of secondary importance.

LEAP and RESILIENCE fall in this category. Rainfall is an essential production factor to grow crops in LEAP. However, the attribute of concern is food security. Both, crop growing and provision of food security can be managed at limited rainfall if necessary (emergency mode). The attribute of concern of RESILIENCE is power production. Wind power is only one (small) part and can be compensated by other power generators if necessary. However, if the boundaries of the system of concern would be limited to wind production this example should be classified in the resource category.

Climate as 'resource': climate is directly or indirectly used as resource by the system of concern and represents the economic basis of this system. This resource is the only or predominant factor for the system of concern. A climate impact diminishes the availability of this resource causing supply shortages and thus economic losses. In a worst case the production of the system's product is stopped. Thresholds are determined physically, i.e. they are aligned to extreme values of the climatic parameter. Coping implies preventive measures which aim to reduce the reduction of the resource by the climate impact.

The prototypes and case-studies which are related to ***water***-management issues and hydropower production fall in this category (***RIFF, S-ClimWaRe, HSFS***). Water (discharge) represents the resource which is aimed to be stored as efficiently as possible to meet water demand. Hydrological droughts and floods are critical events complicate the water management and require decision-making to optimize the availability and thus flexibility in water use. This category is not distinct for ***SOSRHINE***, since the discharge is not a resource in a classical meaning but rather a 'production factor'. However, decision options allow a compensation of economic shortages due to low-flow conditions, at least to a certain extent. But low-flows dominate the operational scope: critical low-flow conditions may even cause a total stop of the transport operation when last too long and may be therefore classified as 'resource'. A similar situation is valid for ***PROSNOW***. Snow as economic basis should be clearly classified as resource. However, the option of snowmaking and thus the possibility to produce the required resource weakens the climate dependency and provides more flexibility in decision-making options for limited compensation. Furthermore, relevant thresholds are determined by the system of concern and not by climate which is typical for problems classified as 'climate as production factor'. In contrast, snowmaking is again climate-related and the snow is the dominant factor which cannot be compensated as such which makes it rather fit into the category 'resource'.

Climate as 'hazard': climate has no constructive role for the system of concern but is an external disturbing factor. Climate impact is destructive and causes harm and thus fatalities and economic losses. The threshold is predominantly defined by the system of concern (related to its individual vulnerability) but often aligned to physical thresholds assuming a relative good adaptation of the system of concern to local climate conditions. Coping implies mitigating measures which aim to reduce the destructive effect of such unavoidable climate impacts.

The prototype '***SPRINT'*** and the case-study '***CMTool***' fall in this category. The formation of ice as well as exceptional heat are disturbing and destructive climate impacts and DMP's aim to reduce the harmful impacts or at least the consequences. The ***LMTool*** also falls into this category but is defined less distinctly: soil erosion events are clearly destructive but it primarily affects a production factor and not directly the attribute of concern. Thus, compensation measures for coping become an option and thresholds are defined by the physical system (magnitude of rainfall in relation to land cover conditions) what shifts this prototype closer to the category 'climate as production factor'.

Findings: the critical situation directly combines the physical hazard and the related decision-making process to define a relevant threshold for coping. Evaluating the critical situations it is noteworthy, that DMP's do have a great influence on thresholds and thus the determination of a critical situation. Climate dominates the threshold only when it plays the role as resource and thus a central role within the system of concern. Consequently, the organization of the system of concern predominantly aligned to the natural system (e.g. water sector).

3.3.2 Buffer factors

The climatic relevance of a critical situation is caused by the buffer factor. The buffer factor is the reason why climate conditions (or climate information) beyond the scale of weather events need to be considered to appropriately cope with critical situations. Table 2 indicates the buffer factor relevant for the climate dimension of the critical situation for each prototype and case-study. The buffer factor can be classified intuitively in three types: (i) natural buffer systems, (ii) capacity of coping system, (iii) scope decision-making and (iii) lead-times of DMP.

Natural buffer systems are interconnected often terrestrial systems which modify and delay the climate signal. Typical systems are catchments, soil-vegetation systems or other terrestrial sub-system which can store climate input signals. Prototypes of the water-sector (***RIFF, HSFS, S-ClimWaRe, SOSRHINE***) fall in this category since they are dependent on streamflow conditions. The sensitivity of streamflow conditions to precipitation is dependent on the catchment and its hydrological characteristics. For ***PROSNOW*** the snow cover (and topography) constitutes a buffer system and for the ***LMTool*** the soil-vegetation (topography) sub-system controls the cause-effect relation of rainfall events and soil erosion rates. Also for ***LEAP*** a natural buffer is involved since the soil-vegetation sub-system controls the relevance of heat spell durations and intensity.

Coping systems provide the opportunity to cope with short-term critical weather conditions. This coping option is however limited by its capacity which might be exceeded due to the duration or persistence of critical weather conditions which can have climatic dimensions. ***SPRINT***, ***RESILIENCE*** and ***CMTool*** fall in this category since the salt stock (***SPRINT***), alternatives for power generation (***RESILIENCE***) and the capacity of the medical system (***CMTool***) are the limiting factors which determine the length of the period which can be managed under exceptional climate conditions.

The **scope of decision-making** defines a specific temporal scale for which climate information is desired. The temporal scale of interest is often related to seasonal climate characteristics and DMP implies strategic and planning issues. Thus, this buffer factor may be relevant for most examples on a secondary level of DMP on a specific problem. The most prominent example in this study is ***PROSNOW*** and the vulnerability to a general bad winter season. Decisions on promotion and communication strategies are very sensitive to this information. In contrast specific snow management decisions rely on short-term weather information. The scope of decision-making is also significant for systems from the water-sector (***RIFF, HSFS*** and ***S-ClimWaRe***). In this context, natural buffer systems often dominate the climate relevance of the critical situation. For the problem of floods, however, it is the scope of DM which defines the temporal scale of interest. Also for ***SPRINT*** this may be a relevant buffer factor with respect to pre-seasonal rock salt restocking planning. However, since the priorities of decision-makers are rather on in-seasonal solutions (for reasons of costs) this information would rather be of interest for the salt production industry.

The **lead-time of DMP's** can add a climate dimension as soon as the lead-time required to initiate coping measures required for a specific critical situation significantly exceeds the temporal scale of the critical climate or weather conditions. This is the case for ***LMTool*** and the problem of the erosion of newly planted crops in autumn which is sensitive to short-term heavy rainfall events but which requires a decision already a couple of weeks before.

Discussion on the buffer factor types: The attempt to allocate buffer system to the case-studies shows that there is mostly more than one buffer system involved for each problem which is basically related to the scale of decision-making. This observation may be less significant when one buffer system dominates the other which is exemplified by the problem of 'general soil erosion' (***LMTool***) at which the natural buffer of soil-vegetation sub-system is negligible compared to the required lead-time of the DMP. Or the other extreme is the problem of low-flow conditions (prototypes of water-sector) at which the natural buffer system (catchments) dominate the lead-times of DMP's or scope of decision-making. In other cases the effect of natural buffer systems and DMP's need to be considered in combination to get into S2D relevant climate scales (e.g. ***LEAP, RESILIENCE*** and ***CMTool***).

3.3.3 Critical climate conditions and climate information

The characteristics of the critical climate conditions are the result of the type of buffer system. As discussed above the only 'real' buffer system which justifies climatic impact in a systemic way (i.e. integrating climate parameters over time and space) are terrestrial systems (natural buffer). And even then, aggregated time scales may not yet in the range of S2D climate variability (see Table 2). Thus, for most of the systems the climate (or rather weather) impact is on a sub-seasonal to weather scale. In large parts DMP's and structures of coping systems are responsible for the climatic relevance critical situations. This has significant consequences for the usability of climate information.

For the evaluation and discussion of the critical climate conditions climate-impact types are identified which try to describe and classify the systemic character of an impact relevant critical climate conditions.

Climate impact types

With respect to the available climate related problems identified and tackled by the EUPORIAS' prototypes and case studies, four climate-impact types could be identified. These types can be attributed to (i) systemic reasons which refer to the buffer effect of interconnected systems, (ii) the resilience of the system of concern, (iii) the capacity of interlinked coping systems, and (iv) the temporal scope of decision-making processes. Referring to these mechanisms four categories of 'climate impact types' are used to classify and discuss critical climate conditions:

<u>Systemic climate impact</u>: the climate signal is buffered by an interconnected natural and/or technical system which constitutes a reservoir for specific climate parameters. The reservoirs' capacity has to be exceeded so that the climate signal contributes to the output of the buffer-system and thus can be felt by the system of concern. Typical buffer-systems are catchments which buffer precipitation and produce discharge or ecosystems which buffer precipitation and temperature signals and produce crops. Consequently, climate impact is always indirect and the actual impact felt by the system of concern is the integrated climate forcing over time (and space).

The prototypes and case-studies which fall in this category are especially those from the water sector (***RIFF, HSFS, S-ClimWaRe, SOSRHINE***). The catchments as well as the dam systems provide natural and anthropogenic reservoirs which store water from precipitation and provide discharge as output. These reservoirs aggregate climate input (precipitation; temperature) over space and time and control the effective output (discharge) in dependence of their storage volume and sensitivity. Especially the propagation of a meteorological drought to hydrological drought can take long time in dependence of catchment characteristics and thus introduces a climatic dimension on the problem of water availability for whatever purpose (irrigation, drinking water, inland navigation, hydropower production). Other prototypes and case-studies are also exposed to systemic climate impact effects. For example the impact of lacking precipitation on crops (***LEAP***) is buffered by the soil-vegetation system and the impact of snowfall on the skiing conditions (***PROSNOW***) is buffered by the snowpack. Also the cause-effect relationship of precipitation and soil erosion is buffered by the hydrological characteristics of the soil system. However, these systemic impacts are of limited temporal relevance since they hardly go beyond the scale of weather events and stay at a monthly or even sub-monthly scale. Consequently, the climatic relevance of these prototypes and case-studies is caused or dominated by other reasons (see below).

Statistical climate impact: the climate or weather impact on the system (direct or indirect) is harmful but non-critical in terms of a critical situation (i.e. a decision is required), because the system of concern can absorb the impact's consequences or cope with it on a short time-scale (i.e. short-term impacts are not critical for DMP on this scale). However, the reoccurrence of such non-critical events may become critical when it happens too often within a certain period of time (critical magnitude-frequency relation) and thus exceeding the resilience of the system of concern. The resilience can be physically defined or by the ability to cope with individual impacts.

The case-studies and prototypes which fall in this category is most of the remaining especially ***LEAP***, ***CMTool, RESILIENCE***, ***SPRINT*** and ***PROSNOW***. For ***LEAP*** this is mostly true because decision-making does not happen on the local scale (farmer) but on a national scale (government) so that the individual local impact is not critical with respect to the success criterion of the decision-makers (number of households who require food assistance). But the accumulation of local impacts can become critical (total number of households) and exceeding the systems resilience (or coping capacity, i.e. number of households which can be supported). The limitation of the coping system is the critical aspect for ***RESILIENCE*** and ***SPRINT***: lacking wind power and icy road conditions can easily be compensated or coped with short-term as long as the capacity for compensation is available. The capacity of the coping system (power gird or rock-salt stocks) defines the length of the period short-term coping is possible. Within this period the timing of coping measures is not of relevance since this happens short term. ***CMTool*** is a similar case-study at which a critical number of people suffering from heat and require medical assistance is required to create a critical situation and exceeding the systems resilience (here determined by the capacity of the medical service system). However, in the example of CMTool but also SPRINT the temporal scope the critical situation is rather short compared to the required lead-time of the related DMP. Consequently, this example may fall in the category of 'decision-conditioned (pseudo) climate impact' under these circumstances. Also the example from ***PROSNOW*** belongs to the statistical climate impact type. Strategic and communication

DMP aim for the trend of the coming season. Thus, single 'snow-free' days do harm but are not critical because they can be compensated be artificial snow. But a bad winter season (too many snow-free days) is a big problem for the ski area operators. The most prominent example is ***LMTool*** at which soil erosion becomes a problem over a time scale of decades when many erosive events have diminished the arable and fruitful soil layer.

Decision-conditioned (pseudo) impact: is no real climate impact referring to the relevant scale of the critical climate conditions since this is rather short-term (weather events). However, interlinked DMP's require a lead-time which goes beyond the scale of weather events to apply respective coping measures. Consequently, the scale of required climate information is on a climatic scale in contrast to the critical climate (weather) conditions.

The prototype which clearly falls in this category is the ***LMTool*** referring to the 'vulnerability to specific erosion events'. In contrast to the 'vulnerability to general soil erosion' one erosive events is already critical since this can destroy the newly planted crops and thus a great deal of the expected harvest. The erosive precipitation event is on a weather scale but the interlinked decision-making process requires a lead-time of 2-3 months and thus enters a climatic dimension of climate information needs. But also the prototypes of ***SPRINT*** and ***CMTool*** do have the potential for this category when the lower limits of the critical climate conditions do occur which are still or close to the scale of weather events (weather forecasts) and decision lead-times exceed the scale of weather events. Also the problem of onset of the melting period in the example of ***HSFS*** falls in this category. The onset is rather short term (up to 2 weeks) but requires lead-times of several weeks to months.

Discussion of the climate-impact type categories

Comparing the categories of the climate impact types it can be stated that there is a general relation to the buffer type: natural buffer factors are generally linked to the systemic climate impact type, coping buffer factors and scope of DM are linked to the statistical climate impact type and buffer effects due to DMP's are linked to the decision-conditioned or pseudo climate impact type. This relation seems to be obvious or even trivial on the first sight but it is very revealing with respect to the implications:

Considering the delineation of the categories it can be stated that they are generally a matter of temporal scale or rather the relation of the temporal scale of the critical climate conditions to the temporal scale of DMP's: in the category of 'systemic climate impact' the natural buffer systems alone (here: catchment) cause critical climate conditions on seasonal scales. In contrast, for ***PROSNOW*** the natural buffer system (i.e. skiable snow cover) causes critical climate conditions on a scale of several days. Here, the scope of interlinked DMP's is required to attain a seasonal scale and the case-study falls thus in the category of the statistical climate impact type. However, if the relevant scope of DMP for e.g. the water sector would be extended to decades (e.g. climate change adaptation) the category for the climate impact type would be 'statistical' as well. The same is true for the decision-conditioned (pseudo) climate impact type: this would also fall into the 'statistical' category as soon as temporal scope of decision-making would be extended in time (e.g. for the ***LMTool***: asking, if winter crops will be generally necessary in the future instead for a specific year). The only difference between the systemic and the pseudo impact type is the relation of the temporal scale of the natural buffer and the decision-conditioned buffer (lead-time).

A similar effect has the scale of decision-making on the climate impact type. This can be clearly observed on the example of the ***LEAP***: considering the natural buffer system (soil-vegetation system) which causes critical climate conditions on a sub-monthly scale and assuming a farmer as decision-maker this problem would be similar to that of the ***LMTool:*** critical climate conditions are short-term (here: dry spells of ~10 days) relative to decision lead-times (here: couple of weeks to months) and thus be classified as decision-conditioned or pseudo climate impact. However, since decision-making in ***LEAP*** happens on a national scale individual local impacts are not critical but a certain amount of local impacts all over Ethiopia may become critical. Thus, the scale of decision-making and thus the decision-maker makes a big difference on the climate-impact type and thus on the usability of climate information (see discussion below).

Findings: Summarizing the findings of the discussion the three categories of climate impact types basically differ in the share of DMP's on the buffer systems which are required to make the scale of S2D climate events relevant for a specific critical situation. The systemic climate impact type has no share of DMP on the time scale of critical climate conditions in contrast to the decision-conditioned (pseudo) climate impact type at which DMP's dominate the share on the critical time scale. Consequently it can be stated that the potential usability of S2D climate information decreases with the share of DMP on the time scale of critical climate conditions.

Table 2: overview of key-attributes from vulnerability identification process for the EUPORIAS prototypes and case-studies.

Prototype	Role of climate	Threshold		Hazard	Climate relevance (Buffer system)	Climate-impact type	Param.	Critical Climate Conditions (CCC)	Scope of DMP (scale)	Decision lead-time
		Phys	DMP							
RESILIENCE	Production Factor (Resource)	(X)	X	Wind speed variability	Power grid (Coping system)	--	Wind	variability of wind speeds (min-hrs)	Min-hours	Hours-days
				Periods of low wind speed		statistical	Wind	below normal (> 1-2 weeks)	4-5 months	> 1 week
RIFF	Resource	X	X	Low-flow	Catchment & dams (natural)	systemic	Precip.	below normal (up to 12 months)	Ca. 9 months	February (4 months)
				High-flow		Systemic/ statistical	Precip.	above normal (9 months)	9 months	September (3 months)
LMTOOL	Hazard	X	(X)	Soil erosion	Soil-vegetation, topography (natural); scale of DMP	statistical	Precip.	rainfall events (hrs-days)	??	6 months (none)
				Erosive event	Lead-time of DMP	pseudo	Precip.	high magnitude rainfall events (hours to days)	2 months	2 months
SPRINT	Hazard	(X)	X	Icy roads	--	--	Temp.	below 0°C (Min-hours)	Min-hours	Hours-days
				Persistent icy roads	salt storage capacity; Scale of DMP (Coping system)	Pseudo	Temp.	below 0°C (> 6 days)	6 months	1-3 weeks (in-season)
						Statistical				6 months (pre-season)
HSFS	Resource	X	X	Spring-flood	Snowpack & catchment (natural)	Systemic	Precip.	above normal (6 months)	6 months	Weeks-months
					Lead-time	pseudo	Temp.	sudden increase (>0°C) (2 weeks)	3 months	Weeks-months
LEAP	Production Factor (Hazard)		X	Diminished crop yield	Scale of DMP; Soil-vegetation	Statistical systemic		dry spells (10 days)	2 X 4-5 months/year	> 1 month

Table 2 continued

Case-study	Role of climate	Threshold		Hazard	Buffer system	Climate-impact type	Param.	Critical Climate Conditions (CCC)	Scope of DMP (scale)	Decision lead-time
		Phys	Phys							
SOSRHINE	Resource (Production Factor)	X	X	Low-flow	Catchment & dams (natural)	systemic	Precip.	below normal (up to 12 months)	Ca. 3 months	2-12 weeks
S-ClimWaRe	Resource	X	X	Low-flow	Catchment & dams (natural)	systemic	Precip.	below normal (2-20 months)	Ca. 8 months	October (6-7 months)
				High flow		Systemic/ statistical	Precip.	above normal (ca.7 months)	Max. 8 months	October (6-7 months) for threshold definition
PROSNOW	Resource (Production Factor)	(X)	X	Snow variability	Snow cover	systemic	Precip. (snow)	lack of (days) Temp.: above -2°C	days	days
				Snow season	Scale of DMP	Statistical	Precip. (snow)	lack of snow (20 days/season) Temp.: above -2°C (mean)	Season (3-6 months);	September (3 months) Oct./Nov. (3 months)
CMTool	Hazard	(X)	X	Extreme temperatures	--	--	Temp.	extreme high	Hours to days	1-3 days
				Persistent extreme temperatures	Health service system (Coping system)	Statistical/ pseudo	Temp.	heat spells (> 5 days)	Season (6 months)	Ca. 1month

3.3.4 Vulnerability attributes of the prototypes and case-studies

Based on the prototypes and case-studies two fundamental attributes of vulnerability were discussed from which indicators may be derived which might help to get an idea on the degree of vulnerability. These attributes refer to (i) the criticality of the problem-specific decision-making process, and (ii) usability of S2D climate forecasts for the specific problem.

Criticality of decision-making processes

Decision-making processes are a dominant factor for the determination of sector-specific vulnerabilities. As shown before, relevant thresholds of the critical situations are primarily influenced by DMP's and thus determine the role of climate for this specific critical situation. However, the criticality of DMP's was not explicitly assessed by interviews and surveys but the available data gives some information on that issue. Consequently, this information is not consistent for all prototypes and case-studies. But some general statements can be made:

Limited priority of DMP's on seasonal scales: for some prototypes and case-studies a problem implies DMP's on different scales at which DMP's on the seasonal scale prepare and thus support or even enable short-term decision-making for extreme situations. Sub-optimal preparation work can often be compensated by improvised short-term measures or by robust coping options on a very long scale. This could be observed for ***CMTool***, ***SPRINT, LEAP, RESILIENCE*** and ***LMTool***. A basically well-equipped and organized health-service system (***CMTool***), sufficient local storage capacity for rock-salt (***SPRINT***), permanent sufficient capacity for food assistance (***LEAP***), a sufficient large and diverse grid-net (***RESILIENCE***) as well as a regulation for standardized winter crop plantation (***LMTool***) would render respective decision-making on a mid-term scale. Robust coping, however, is often considered as costly option for which reason decision-making on intermediate scales are desired. The commonality of these examples is a 'statistical climate impact' which is also due to the multi-scale nature of the problems.

Success criteria as indicator for risk balance: some decision-makers are rather risk averse and thus prefer a robust decision option if available. This could be observed for ***S-ClimWaRe***, ***SPRINT***, ***RIFF, CMTool*** and ***LEAP***. Success criteria for DMP of these systems are often the functionality of the system rather than economic criteria since the sectors are part of a critical infrastructure (e.g. water [***S-ClimWaRe***, ***RIFF]*** and transport ***[SPRINT]***) and thus of fundamental importance for the function of society or the attribute of concern is very sensitive due to its ethical and humanitarian nature at which the consequences are injuries and fatalities (***LEAP*** and ***CMTool***). Those examples do have no balanced risk, which means that less robust options are much more risky than robust options with respect to potential losses (fatalities vs. economic losses.

Sensitivity to the 'role of climate' for the system of concern: for systems which are part of the critical infrastructure climate plays often the role as resource or as hazard which threatens a resource. Consequently, these systems are very sensitive to the respective critical climate conditions since their economic or physical existence is threatened or significantly affected. This would be valid for ***S-ClimWaRe***, ***RIFF***, ***PROSNOW***, ***HSFS*** and ***LMTool***. Systems for which climate is only a production factor or some hazard which might cause some physical damage, this threat would be less significant. Consequently, the 'role of climate' for the system of concern gives some basic indication on the sensitivity to S2D climate variability even when this is not evident but only indicative by these examples.

Usability of S2D climate forecasts for the specific problem

The basic purpose of this vulnerability analysis is the provision of S2D climate forecasts to enhance decision-making. Climate forecasts may provide the opportunity to anticipate specific climatic hazards and is therefore part of the coping capacity or rather the basic prerequisite to appropriately apply the systems coping capacity. The usability of such forecasts can be limited or even not existent for two reasons: (i) the technical characteristics of a forecast do not fit to the problem (e.g. parameter, time of year, temporal and spatial resolution, skill, etc.), and (ii) the information content of the forecast does not has any or much value for the decision-maker. The latter may be a function of technical parameters like a misfit of temporal and spatial resolution as well as skill.

The ***information content*** of a S2D climate forecast can basically be characterized as mean values of single climatic parameters over the specific time period of the forecast. This mean value is not absolute but relative to climatology. And its validity is expressed in probability of occurrence. The usability of such information is dependent on the problem-specific critical climate conditions and the way climate parameters are buffered over time (and space) as well as the related decision-making processes. Thus, best usability is given when mean values of climate parameters are of interest and worst usability is given when small scale events within a relative large period of time and especially the timing is needed. The relation of critical climate conditions and buffer systems was already analysed and classified in the context of climate-impact types (see above) which characterize the 'climatic relevance' of a critical situation. It is stated here, that this classification can be useful to assess the structural usability S2D climate forecast information for decision-makers. The potential usability for each climate-impact type is shortly discussed:

Systemic climate impact: The potential usability of climate mean values is assumed to be favourable since climate input signal is aggregated over space and time until the physical threshold of the interconnected system is exceeded. Thus, temporal peaks of the climate parameter and their timing within the time frame of the critical climate conditions are not critical. Mean values of the climate parameter over the critical time period are therefore of general use. Prototypes and case-studies which fall in this category are those at which natural buffers dominate like ***RIFF***, ***HSFS***, ***S-ClimWaRe***, and ***SOSRHINE***.

Statistical climate impact: The potential usability of climate mean values is assumed to be reasonable but not as good as for a systemic climate impact. Individual climate impacts are on a smaller time scale than critical climate conditions but since they are sub-critical their exact timing is not of dominant concern. However, the magnitude of such individual events is desired to be known to assess the timeframe of the critical climate conditions. Prototypes and case-studies which fall in this category are those at which 'coping systems' or scale of decision-making serve as buffers dominate like ***CMTool, RESILIENCE, LEAP, SPRINT*** and ***PROSNOW***.

Decision-conditioned (pseudo) climate impact: The potential usability of climate mean values is assumed to be insufficient since critical climate conditions are short-term in relation to the timeframe which is basically determined by the lead-time of DMP's. Thus small scale events have to be predicted in a relative large temporal scale which adds loads of uncertainty and is virtually impossible. Prototypes and case-studies which fall in this category are those at which decision lead-times determine the climate relevance of a critical situations like the problem of the beginning of the winter season (***PROSNOW***) and the onset of the spring-flood (***HSFS***), the lower limits of ***CMTool*** and ***SPRINT*** as well as the problem of specific erosion events of the ***LMTool***.

In Figure 2 the composition of the climate relevance of each critical situation is displayed in a graphical way. In shows the temporal scope of the critical situation of each prototype and case-study and the share of each buffer factor type on this temporal scope. The examples are sorted by climate-impact type. The ‘decision-conditioned (pseudo) climate impact type’ is assumed to have the lowest information value of S2D climate forecasts since short-term events are supposed to be predicted within a relative large period of time which is technical impossible or adds a lot uncertainty. It concurrently shows a share of DMP on the temporal scope greater than 50%. In contrast, for the ‘systemic climate impact type’ DMP have no additional share on the temporal scope. The consequence is that examples classified as ‘systemic’ do not even require a climate forecast for the entire period of the critical climate conditions but only for the period which is defined by decision lead-times. Climate (forecast) information for this climate impact type is assumed to be beneficial since the natural buffer effect allows the use of mean values. For the rest of the time scale of critical climate conditions historical records can be used which has significant advantages with respect to the certainty and thus usability of climate information. Consequently, as discussed already earlier, it can be stated that the potential usability of S2D climate information decreases with the share of DMP on the time scale of critical climate conditions.

The ***technical characteristics*** of the prototypes and case-studies cannot be analysed in detail, since they are under construction and technical characteristics change during the prototype development. Thus, no consistent analysis has been possible. However, the fit of the temporal scale of the critical climate conditions and S2D forecasts can be evaluated. The climate-impact types are related to the time-frame of each specific problem. That means, that the value of S2D climate forecast information is related to the specific time-frame of each specific problem. The subsequent assumption is that a climate forecast on this specific scale is available. Assuming that S2D climate forecast products have a lower temporal limit of 3 months this has significant consequences for the usability of these climate service products. The relation of the temporal scales of a minimum S2D climate forecast as well as that of the critical situations is also displayed in Figure 2.

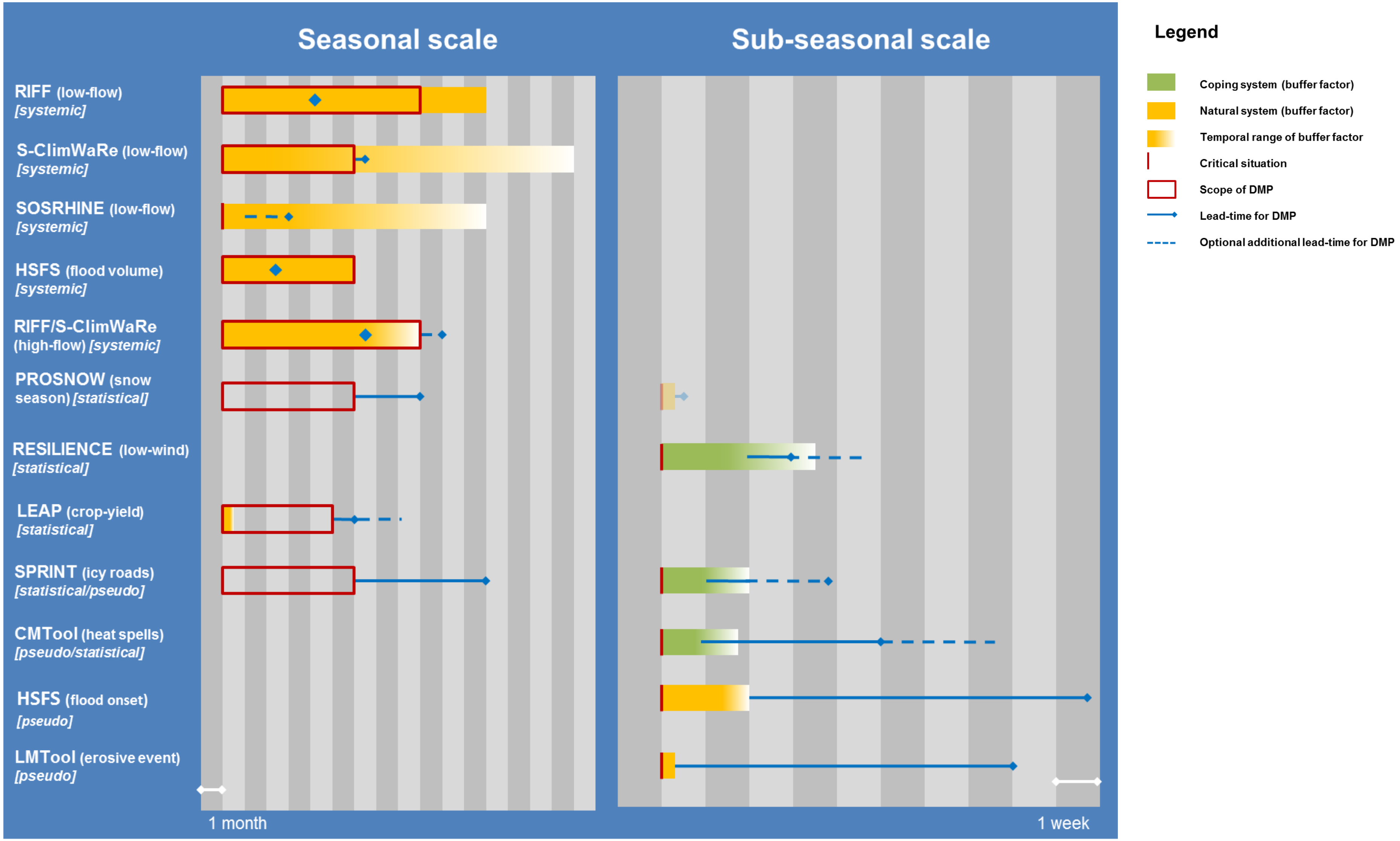

Figure 2: composition of buffer functions and temporal scope of the critical situation from the EUPORIAS prototypes and case-studies.

3.4 Towards a vulnerability assessment

3.4.1 Delineation of vulnerability indicators

The data basis provided by the examples from the EUPORIAS prototypes and case-studies is far too small to develop robust vulnerability indicators. However, an approximate delineation of vulnerability commonalities can be identified which might provide a basis for an indicator development. As discussed in part 3.1 three attributes are considered as relevant to describe vulnerability in the context of S2D climate information for economic sectors:

- Relevance of climate for decision-making.
- Criticality of decision-making processes for a specific critical situation.
- Usability of S2D climate forecast information for the specific critical situation.

Referring to the evaluation of examples from the EUPORIAS prototypes and case-studies classification systems were identified which can be allocated to the three vulnerability attributes and thus serve as potential indicators of these attributes.

The '**relevance of climate for decision-making**' can be indicated by the '**role of climate**' for the threshold composition which define a critical situation. Concluding the discussion above the categories for the '**role of climate**' can be roughly ranked with respect to vulnerability:

- *Climate as resource*: the influence of climate has probably the highest impact on decision-making since climate parameters provide the economic basis of a company or institution. This is the only category in which climate dominates the thresholds relevant for a critical situation.
- *Climate as hazard*: the influence of climate is very dependent on its characteristics (magnitude, frequency, duration, etc.) and may damage or even paralyze a system. However, it is always destructive and no win-win situation is possible.
- *Climate as production factor*: the influence of climate is less significant since its impact can be (partly) compensated in the best scenario without negative impact.

The '**criticality of decision-making processes**' can be indicated by the '**success criteria**' of a system of concern as well as by '**priority of scale**'. Concluding the discussion above '**success criteria**' can be coarsely discriminated between economic companies whose success criteria are basically defined by *revenue* and companies, organizations and institutions which are related to critical infrastructures and social systems whose success criteria are defined by *system functionality* and the *preservation of health and life*. The decision-making of the latter group is often very risk-averse and robust decision-options are often preferred. Climate information has consequently less impact on DMP of this group. The '**priority of scale**' refers to relevance of the decision-making on this particular scale. This might be limited when short- or long-term decision-options do exist and are preferred for different reasons (see discussion above). The categories for this indicator are roughly delineated assessing the *first* (high vulnerability), *second* (moderate vulnerability) or *third* priority (low vulnerability) of mid-term DMP (DMP on S2D scale) for the specific problem.

The '**usability of S2D climate forecast information**' can be indicated by the '**climate impact types**' since they reflect the composition of buffer-system responsible for the climate relevance of a critical situation. Referring to the discussion above climate information has the potentially greatest usability for '*systemic climate impact types*' followed by '*statistical climate impact types*' and is probably insufficient for '*decision-conditioned (pseudo) climate impact types*'.

Many other factors may be important to assess the influence of climate for decision-making, the criticality of decision-making and the usability of S2D climate forecast information. However, these three vulnerability attributes provide an approximate classification for vulnerability indicators which might help to develop detailed indicators. For example the concept of 'critical infrastructures' could help to identify key-elements of systems which are central for functionality of a system and are thus more sensitive to external (climatic) disturbance than others (e.g. Lenz 2009, Fekete 2011).

3.4.2 Vulnerability profiles of the EUPORIAS prototypes and case-studies

The preliminary vulnerability indicators are used to assess the vulnerability of the EUPORIAS prototypes and case-studies. Since no normalized and weighted indicators do exist this assessment occurs qualitatively with an approximate ranking of vulnerability according the assumptions made above. For that reason no final statement on total vulnerability is made but only an assessment of the individual parameters. The ranking follows a traffic light scheme with three categories: 'high vulnerability' (+++ in red), 'moderate vulnerability' (++ in yellow) and 'low vulnerability' (+ in green).

A vulnerability profile was assembled for each prototype and case study. The vulnerability profile gives information about the vulnerability characteristics (hazard, critical situation, critical climate conditions and temporal scope) as well as an assessment regarding the identified indicators and an preliminary ranking. The vulnerability profiles can be found in appendix.

3.4.3 Definition of vulnerability in the context of S2D climate information

Concluding from this study, the definition of vulnerability and its components can be rethought and adjusted to the context of S2D climate forecasts. As shortly discussed at the beginning vulnerability in the context of climate services is basically related to the ability to activate the available coping capacity and the relevance of the climate event (or information) for the respective decision-making process required to initiate coping measures.

Referring to this assumption the IPCC definition of **vulnerability** can be adopted or rather considered as valid for the context of climate service provision: "*The degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change, including climate variability and extremes"* (Carter, Jones et al. 2007). Vulnerability in this context denotes to the ability to forecast critical climate conditions, the usability of the respective climate information and the impact on decision-making. Consequently, the definitions of vulnerability components have to be adjusted to some extend:

For **Exposure** the definition of McCarthy et al (2001) can be used within this context, which is '*the nature and degree to which a system is exposed to significant climatic variations'*. However, the 'significant climate variations' are sector- or even problem specific and need to be identified from case to case. Thus, the exposure is not variable since its information is reflected by the critical climate conditions.

For **Sensitivity** the definition of Parry et al. (2007) can basically be used with some marginal adjustments, which is '*the degree to which a system is affected, either adversely or beneficially, by climate variability […]*'. However, indicators of sensitivity are related to decision-making processes, i.e. the role of climate for decision-making as well as the criticality of DMP's.

For **coping capacity** the definition of Parry et al. (2007) can basically be used with some marginal adjustments, which is "*the ability of a system to adjust to […] climate variability and extremes to moderate potential damages, to take advantage of opportunities, or to cope with the consequences*". However, the key-aspect and distinction within this context to the original meaning is the term 'ability'. 'Ability' in the context of climate services should be understood as the 'ability to use the existing coping capacity by having access to valuable climate information'.

3.4.4 Towards sector-specific vulnerabilities

In the context of climate service provision the issue of sector-specific vulnerabilities is a very central one, since it can help to efficiently produce and successfully disseminate S2D climate service products. Referring to the definition of vulnerability in the context of S2D climate services the scope of sector-specificity of vulnerabilities implies that S2D-specific problems can be summarized as one 'sector' if they have similar critical climate conditions which can be forecasted by similar S2D forecast tools and which have a similar (potential) usability for decision-makers.

The attributes relevant for 'sector-specificity' of vulnerability are certainly the climate parameters to be forecasted but also the composition of buffer-systems which are responsible for the climate relevance of a critical situation. This discussion on sector-specific vulnerabilities needs to remain theoretical since almost no prototype or case-study share a specific problem to be analysed with the exception from ***RIFF*** and ***S-ClimWaRe.*** But this study can initiate a discussion on this issue which is supposed very relevant for the provision of S2D climate service products. Some examples from the analysed prototypes and case-studies:

- With respect to the buffer systems, ***HSFS*** should be grouped with other examples which depend on catchments as buffer-systems (i.e. water sector) than with examples from the 'energy sector' (e.g. ***RESILIENECE***) with which it has almost nothing in common with respect to climate information (except the forecast of energy demand).
- The four examples from the water sector (***RIFF, HSFS, S-ClimWaRe; SOSRHINE***) can be grouped to one sector with respect to the problem of low-flow conditions and also with respect to floods. However, these grouping needs to be challenged as soon as on example has not the ability to actively store water by dam reservoirs.

Especially for floods this would turn a ‘systemic’ climate impact type in an ‘statistical’ or even ‘pseudo’ climate impact type.

- As initially discussed above, the commonality of ***LEAP*** and ***LMTool*** with respect to climate service provision is not existent although they both belong to the agricultural sector. This would not even change if the farmer in ***LMTool*** would consider drought as a problem instead of soil erosion. The major difference is the scale of decision-making and thus the need for climate information.
- In contrast, ***CMTool*** and ***SPRINT*** have very much in common although they are different sectors. But both require temperature as climate parameter and share the same scale of DMP and have thus a similar composition of buffer-systems.

4. Conclusion and lessons learnt

The focus of a vulnerability assessment in the context of climate service provision is primarily the identification of the climate hazard (critical climate conditions) relevant for a system of concern which is supposed to be forecasted or at least assessed to support and give value to decision-making processes. The identification process of the climate hazard is critical since climate impact is often indirect and climate events are no discrete events but a statistical description of weather conditions for a considered period of concern. Referring to S2D climate forecasts the problem-specific period of concern is critical to provide appropriate and valuable climate service products. Thus, the starting point to assess vulnerability components needs to be the critical situation and the related decision-making processes from which critical climate conditions and finally appropriate climate information needs can be derived. This is the strategy of the presented vulnerability assessment framework. Concluding the identification process some fundamental findings can be summarized:

- *‘Decision-making processes’* is a very sensitive factor which significantly influences
  - the determination of threshold which define critical situations;
  - the characteristics of buffer functions and thus the temporal scale of critical climate conditions;
  - the specification of *climate information* needs and thus their potential usability (value) for decision-making.
- The climatic relevance of a critical situation refers to *buffer-systems* or factors which have buffer functions. Buffer systems are required to assess the *critical climate conditions* and especially their time-scales of a specific critical situation. Most critical situations refer to more than one buffer-system.
- The critical climate conditions of some critical situations are on the transition of daily scale to monthly scale (sub-seasonal scale). The climate relevance of these critical situations is often caused by required lead-times of DMP’s.
- Consequently, the *composition of buffer factors*, especially the *share of DMP’s* is critical for the development and potential usability of climate service products.
- Critical situations often dependent on different climate parameters which however are relevant on different temporal scales. *Different climate information products* are required (e.g. ***HSFS***).

A second goal of the vulnerability assessment is the assessment of the degree of vulnerability of a specific problem. This can be done by the identification of indicators which help to assess the degree of vulnerability and enable the comparison of different case-studies and allow the identification or grouping of sector-specific vulnerabilities. The latter may be important for S2D climate forecast providers to develop sector-specific climate service products. The process of indicator-finding and identification of sector-specific vulnerabilities is only preliminary in this study. The findings from this process can be concluded in some statements:

- The classification system of the '*climate-impact types*' is a promising concept because
  - it reflects and thus differentiates the cause for the climate relevance of a specific problem (compositions of buffer factors);
  - it integrates DMP's which proved to be a significant factor;
  - it indicates a potential usability of S2D climate service products and thus integrates coping options;
  - it is systemic approach which goes beyond the established 'snap-shot' of vulnerability assessments.
- The relevance of climate on DMP's as well as the relevance of DMP's on S2D scales are important aspects for the vulnerability to climate variability and thus the value of S2D climate information products. Thus, decision-making processes and organizational structures of the system of concern should be analysed more extensively to identify indicators for vulnerability assessments.
- Indictors like the '*role of climate*' and '*success criteria*' are preliminary but promising indicator groups which might be worth for further development.
- A technical evaluation of existing S2D climate service products (e.g. parameter, timing, scale) and the identification of indicators may help to assess the potential usability of such products for specific problems.

The presented vulnerability assessment framework was primarily developed for the context of the EUPORIAS project scope to collect vulnerability information for the specific examples form the prototypes and case-studies. However, the conceptual approach allows the use beyond the project for a similar purpose but requires further development. In the prevalent stage the framework may be useful as preliminary assessment or 'quick scan' of the vulnerability of specific systems to climate variability in the context of S2D climate service provision.

5. Links Built

The work provided by WP12 on the user needs was very valuable for the production of this deliverable. A close communication relation was maintained with the lead partner from WP12.

The output from this deliverable (vulnerability profiles) serves as direct input for the Online European Climate User Platform [CUIP] (D11.3) as well as for the development of a sector-specific climate watch prototype (also WP 11).

Discussions on climate information needs within the specific prototype chapters often link to issues discussed and tackled by WP22. However, no direct exchange of results was happening.

RESILIENCE

Vulnerability identification and characteristics: Referring to the analysis of the critical situation, decision-making processes and critical climate conditions, two different vulnerabilities can be identified.

The primary vulnerability is related to climate conditions with the focus on wind is the '***vulnerability to the variability in wind speed***' causing power supply demand deviations which become critical at frequencies of 50Hz on time scales of 30 minutes to 36 hours. The interlinked DMP implies the identification and allocation of suitable power reserves to balance expected gaps in power supply and demand and happens within the time-scale of the critical climate conditions. The temporal category of this vulnerability is on the **scale of weather events**.

The secondary vulnerability is the ***'vulnerability to below average wind speeds'*** on time scales of 1-2 weeks and beyond with no physically defined threshold. The interlinked DMP implies the organization and management of appropriate power supply for compensation of lacking wind power which requires variable lead-times with a minimum of around 2 weeks. The temporal category of this vulnerability is on the **scale of one month**.

Role of climate (+): the role of climate is that of a ***production factor*** since it is only one of many sources of energy with a relative low share.

Priority of scale (+): decision-making processes on seasonal scale are of secondary importance. Short-term balancing is of greater relevance and a robust grid (long-term decision) can also mitigate seasonal problems.

Success criteria (+): the success criteria are in large part of economic nature. Especially as long as the share of wind power on power production is small.

Climate-impact type (++): the 'climate impact type' can be classified as '***statistical climate impact***': wind speed variabilities do affect the system of concern already on the small temporal scale (minutes to hours). On a climate scale such small-scale variabilities are sub-critical since they can be balanced on individually. However, longer periods of time with a critical share or number of such individual short-term impacts may become critical since the capacity of balancing lack in wind power may be exceeded.

RIFF

Vulnerability identification and characteristics: Referring to the analysis of the critical situation, decision-making processes and critical climate conditions, two different vulnerabilities can be identified.

The primary vulnerability is the '***vulnerability to decreased discharge***' which causes a deficient filling of the catchment's dam reservoirs. Critical climate conditions are precipitation and temperature anomalies of around 12 months for the Seine catchment. Water reserve planning-decisions occur at the beginning of the rainy season (October) and the dry season (June) which consequently implies no lead time for respective forecasts. The temporal category of this vulnerability is on the **scale of up to one year**.

The second vulnerability is the '***vulnerability to flood events***' which can cause dam break or threaten downstream regions due to late and thus high reservoir release rates. Critical climate conditions are precipitation anomalies between2 days and around 2 weeks for the Seine catchment. Decisions on the fill curve of reservoirs are made in September for the period until December. The temporal category of this vulnerability is on the **scale of 4 months**.

Role of climate (+++): the role of climate is that of a ***resource*** since water availability of a region is dependent on rainfall conditions.

Priority of scale (+++):decision-making processes on seasonal scale are of primary importance. No short-term DMP is available and no long-term robust decision-options are available.

Success criteria (++): the success criteria are societal relevance going beyond that of economic interests.

Climate –impact type (+): the 'climate impact type' can be classified as primarily '***systemic climate impact***': this is due to the buffer effect of the catchment which controls the propagation of a meteorological drought to a hydrological or stream flow drought. Thus, a specific period of 'below average rainfall' is required to affect the streamflow which is the attribute of concern. The man-made reservoirs are an additional buffers system which stores water flows occurring during a specific period of time. Both buffer systems (but especially the reservoirs) do have the effect to smooth rainfall variability and aggregate rainfall totals over a period of time. However, with respect to high flows, floods may constitute individual problems especially at the end of the rainy season when the reservoir's capacity is about to be exhausted. In this context the timing of individual floods becomes relevant and the character of this climate impact is rather 'statistical'.

LMTool

Vulnerability characteristics: Referring to the analysis of the critical situation, decision-making processes and critical climate conditions, two different vulnerabilities can be identified.

The first vulnerability is the '**vulnerability to general soil erosion'** which implies the loss of soil and thus the ability to grow crops. Soil erosion becomes critical at estimated erosion rates of 1.4 t ha^{-1} yr^{-1} and is primarily caused by high magnitude rainfall events on bare fields especially during spring and autumn. The interlinked DMP implies the plantation of cover crops to avoid or minimize soil erosion which requires lead-times of 2-3 months. The temporal category of this vulnerability is on the **scale of 6 months**.

The second vulnerability is the '**vulnerability to specific erosive events**' which implies the erosion of newly planted crops. Such erosive events are triggered by high magnitude rainfall events (30mm in 2 days or 10mm h^{-1}) during a sensitive period of 2 moths in autumn. The interlinked DMP implies the shift of the sowing date which requires lead-times of ca. 2 months. The temporal category of this vulnerability is on the **scale of 3-4 months**.

Role of climate (++): the role of climate is that of a ***hazard*** since the impact is destructive. Soil erosion indeed affects and destroys a resource (soil) in the long-term.

Priority of scale (+++): decision-making processes are necessarily seasonal due to the growing conditions of plants. Even the decadal problem of soil erosion requires seasonal DMP.

Success criteria (++): the success criteria are of economic nature on the short-term but may become of societal relevance in the long-term (destruction resource – critical infrastucture)

Climate-impact type (+++): the climate-impact type for the 'vulnerability to specific erosion events' is a **'decision conditioned (pseudo) climate impact'.** For the scale of consideration (field-scale) individual short-term events (high magnitude rainfalls on the scale of hours to days) are already critical and require coping measures. To initiate appropriate coping measures information on such weather events are required several weeks before they impend to happen.

SPRINT

Vulnerability identification and characteristics: Referring to the analysis of the critical situation, decision-making processes and critical climate conditions, two different vulnerabilities can be identified.

The primary vulnerability is the '***vulnerability to icy road conditions***' which provokes the risk of traffic obstructions and accidents. The interlinked decision-making process implies the operation of winter services like gritting which requires a lead-time of a couple of hours. Critical climate conditions are temperatures below 0°C. The temporal category of this vulnerability is on the **scale of weather events**.

The second vulnerability is the '***vulnerability continuous icy road conditions***' and implies the procurement planning of de-icing material which requires lead-times of 1-3 weeks (in-seasonal restocking) or even 3-6 months (pre-seasonal restocking). This temporal scope of this vulnerability is primarily determined by the availability of de-icing material which is 6 days for England. Critical climate conditions are continuous weather conditions of freezing temperatures (here: > 6 days). The temporal category of this vulnerability is on the **scale of 3 weeks (in-seasonal re-stocking and 1-6 months (pre-seasonal re-stocking).**

Role of climate (++): the role of climate is that of a ***hazard*** since the impact is destructive by affecting health and life and is thus general negative.

Priority of scale (++): decision-making processes on a sub-seasonal scale are of secondary importance. Short-term winter service provision has priority and long-term facilitation of the rock-salt availability (seasonal) can mitigate seasonal shortages but is not always desired.

Success criteria (+++): the success criteria to preserve health and life and has an ethical character which is of interest for society.

Climate-impact type (++): The 'climate impact type' for pre-season rock-salt restocking can be classified as '***statistical climate impact***': for-pre-season planning of resources the exact timing of application is not necessary, yet. Information on the total amount of days at which winter service is required is sufficient (here: 6-12 days/year). For in-season rock-salt restocking rock-salt storages may be exhausted already after cold spells of around 6 days. For longer cold periods or subsequent cold periods an in-season restocking is required which requires lead-times of 1-3 weeks. Thus, if no robust coping is desired this problem may get the character of an 'decision-conditioned (pseudo) climate impact type'.

HSFS

Vulnerability identification and characteristics: Referring to the analysis of the critical situation, decision-making processes and critical climate conditions, a primary vulnerability can be identified.

The primary vulnerability is the '***vulnerability to spring-flood discharge***' which can result in an inefficient reservoir management and thus economic losses. Critical climate conditions are high winter precipitation over a ***couple of months*** and sudden and significant increases in air temperature in spring over a period of ***2-4 weeks*** possibly accompanied by high rainfall events earlier than expected (i.e. climatology). Related reservoir management measures imply the timely management of the reservoir levels and require lead times of several weeks to months. The temporal category of this vulnerability is on the ***range of 4-6 months***.

Role of climate (+++): the role of climate is that of a ***resource*** since climate parameters define and control the snowpack which provides the water for hydropower production.

Priority of scale (+++): decision-making processes on seasonal scale are of primary importance. No short-term DMP is available and no long-term robust decision-options are available or desired.

Success criteria (+): the success criteria are primarily of economic nature and aligned to profit optimization.

Climate-impact type (+) (+++): The 'climate impact type' can be classified as '***systemic climate impact***': the climatic impact is basically systemic since the snowpack buffers winter precipitation but also moderates discharge process and thus the spring flood development.

However, the critical part is rather the onset of the spring-flood and its intensity which occur on a rather sub-seasonal time-scale (weeks). The related decision-making processes, however, require lead times of a couple of weeks to months. With respect to temperature the climate-impact type is rather '***decision-conditioned or pseudo***'.

LEAP

Vulnerability characteristics: Referring to the analysis of the critical situation, decision-making processes and critical climate conditions, a primary vulnerability can be identified.

The primary vulnerability is the ***'vulnerability to reduced crop production'*** which is specified by the amount of people exceeding 8.3 million per year and implies the provision of food assistance services. Critical climate conditions are dry spells of around 10 days within the rainy season which correspond to a mean 400-500mm during the rainy season. Interlinked decision-making refers to the provision of food assistance which requires lead-times of at least one month but the earlier the better. The temporal category of this vulnerability is on the **scale of 4-6 months**.

Role of climate (++): the role of climate is that of a ***production factor*** even with a ***hazardous character***. Rainfall is only one factor for food production which is only one reason for food insecurity. However, the impact in the context of LEAP is rather destructive.

Priority of scale (++): decision-making processes on a seasonal scale are of primary importance. Concrete decision-making occurs short-term but its success is very dependent on mid-term DMP to avoid long-term consequences of hunger and decrease of livelihood capacities.

Success criteria (+++): the success criteria to preserve health and life and has an ethical character which is of interest for society.

Climate-impact type (++): the 'climate impact type' can be primarily classified as '***statistical climate impact***': decisions based on seasonal forecast intend to assess the total number of people requiring food assistance. Thus, individual local impacts on the household scale are uncritical but the situation becomes critical as soon as the total number of households exceeds 8.3 million and seriously critical exceeding the number of 10 million. Exceeding these thresholds implies the exhaustion of the PSNP and thus the resilience of this help system.

SOSRHINE

Vulnerability identification and characteristics: Referring to the analysis of the critical situation, decision-making processes and critical climate conditions, a primary vulnerability can be identified.

The primary vulnerability is the '***vulnerability to decreased discharge***' specified by a critical water level (range) of 2,50 to 2,20m. The critical climate conditions are below-normal precipitation events continuous or in sequences over periods of 3-12 months depending on the location within the Rhine catchment. The interlinked DMP implies the adjustment of vessel size, loading and scheduling to the respective water depths which requires lead-times of 2-12 weeks. The temporal category of this vulnerability is on the **scale of 3-12 months**.

Role of climate (++): the role of climate is that of a ***production factor*** with the character of a ***resource*** since critical water levels can be compensated but are of dominant importance.

Priority of scale (++):decision-making processes on seasonal scale are of primary importance. No short-term DMP is available. Long-term robust decision-options are available but not necessarily preferred.

Success criteria (+): the success criteria are or purely economic nature.

Climate-impact type (+): The 'climate impact type' can be classified as primarily '***systemic climate impact***': this is due to the buffer effect of the catchment which controls the propagation of a meteorological drought to a hydrological or stream flow drought. Thus, a specific period of 'below average rainfall' is required to affect the streamflow which is the attribute of concern.

S-ClimWaRe

Vulnerability identification and characteristics: Referring to the analysis of the critical situation, decision-making processes and critical climate conditions, one primary vulnerability can be identified.

The primary vulnerability is the '***vulnerability to decreased discharge***' which causes a deficient filling of the catchment's dam reservoirs. Critical climate conditions are precipitation and temperature anomalies of 2-20 months dependence of the location, size and characteristics of the considered catchment. Water reserve planning-decisions occur at the beginning of the rainy season (October) which consequently implies no lead time for respective forecasts. The temporal category of this vulnerability is on the **scale of several months to over one year**.

Role of climate (+++): the role of climate is that of a ***resource*** since water availability of a region is dependent on rainfall conditions.

Priority of scale (+++):decision-making processes on seasonal scale are of primary importance. No short-term DMP is available and no long-term robust decision-options are available.

Success criteria (++): the success criteria are societal relevance going beyond that of economic interests.

Climate-impact type (+): The 'climate impact type' can be classified as primarily '***systemic climate impact***': this is due to the buffer effect of the catchment which controls the propagation of a meteorological drought to a hydrological or stream flow drought. Thus, a specific period of 'below average rainfall' is required to affect the streamflow which is the attribute of concern. The man-made reservoirs are an additional buffers system which stores water flows occurring during a specific period of time. Both buffer systems (but especially the reservoirs) do have the effect to smooth rainfall variability and aggregate rainfall magnitudes over a period of time (at least for drought conditions). This is concurrent to the desired information for decision-makers who are not interested on the timing of discharge/inflow as a priority but the total discharge/inflow over the rainy season. However, with respect to high flows, floods may constitute individual problems especially at the end of the rainy season when the reservoir's capacity is about to be exhausted. In this context the timing of individual floods becomes relevant and the character of this climate impact is rather 'statistical'.

PROSNOW

Vulnerability identification and characteristics: Referring to the analysis of the critical situation, decision-making processes and critical climate conditions, two different vulnerabilities can be identified.

The basic vulnerability is the ***'vulnerability to highly variable snow conditions'*** specified by snow depths of less than 30cm or more than 1m and at the worst accompanied by temperatures above -2°C. This implies the decision on trial and slope maintenance and HR management requiring lead times of at least a few days at which longer lead times are welcome. The critical climate conditions are high magnitude snowfall events and periods of no snowfall at temperatures above -2°C. The temporal scale is basically on the scale of ***weather events*** (1 week); however optimal decision-making processes expand that to up to ***one month***.

The climate-relevant vulnerability is the '***vulnerability to bad winter season'*** specified by a snow depth of below 30cm and temperatures above -2°C and especially a late start of the snowing season. This implies the decision on promotion and planning of communication policy which requires lead times of around 3 months before the start of the season. The critical climate conditions are warm seasonal temperatures (> -2°C) and low snowfall means and a late start of snowfall. The temporal category of this vulnerability is on the **scale of 6 months**.

Role of climate (+++): the role of climate is that of a ***resource*** since the snow cover provides the basis for skiing business.

Priority of scale (++): decision-making processes on snowmaking and grooming can be done short-term, however promotion and communication strategies are of primary importance which implies decision-making on seasonal scales.

Success criteria (+): the success criteria clearly of economic nature.

Climate-impact type (++)(+++): The 'climate impact type' can be classified as basically '***statistical climate impact'***: DMP's on promotion strategies and equipment and staff management for the coming winter season consider snow conditions of the entire season. Individual high- or low-snow events are manageable on the scale of weather events and are not critical as long as they do not dominate (< 20-30 days per season). However, the problem of the beginning of the snow-season may have the character of a '***decision-conditioned climate impact***'.

CMTool

Vulnerability identification and characteristics: Referring to the analysis of the critical situation, decision-making processes and critical climate conditions, two different vulnerabilities can be identified.

The primary vulnerability is the '***vulnerability to extreme temperatures'*** compared to local climate conditions and implies warning of the general public and short-term preparation of health services. Critical climate conditions and decision-making processes are short-term (hours to days) and on the **scale of weather events**.

A secondary vulnerability is the '***vulnerability to heat waves'*** and implies the planning and organization of the health system with respect to longer-term exceptional situations and extreme events. A critical length of such heat waves cannot be determined based on experiences. The temporal category of this vulnerability has yet to be defined but is probably on the **scale of a couple of weeks (ca. 1-2 months)**.

Role of climate (++): the role of climate is that of a ***hazard*** since the impact is destructive by affecting health and life and is thus general negative.

Priority of scale (+): decision-making processes on a mid-term scale (sub-seasonal) are of secondary importance. Short-term medical assistance and long-term facilitation of the medical system has greater relevance.

Success criteria (+++): the success criteria to preserve health and life and has an ethical character which is of interest for society.

Climate-impact type (++)(+++): The 'climate impact type' can be classified as '***statistical climate impact***': decision-making on heat waves and cold spells generally occur on a short-term timescale. The critical length of heat waves is defined by the health system and its capacity to cope with exceptional situations caused by heat waves. However, the length of a heat wave critical for the heat health capacity is relative short compared to the required lead-time to initiate appropriate coping measures. Thus, if no robust coping is desired this problem may get the character of a '***decision-conditioned (pseudo) climate impact type'***.

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