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.