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

<u>Criticality of decision-making processes</u>: 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.

<u>Usability of S2D climate forecast information</u>: 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.