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DAMS AND RESERVOIRS - CLIMATE CHANGE ADAPTATION STRATEGY

Hubert LOHR

Managing Director, SYDRO CONSULT GMBH

Felix FROEHLICH

Marius HERBER

Sandra RICHTER

Project engineers, SYDRO CONSULT GMBH

GERMANY

1. INTRODUCTION

The aim of the project is to develop adaptation strategies for dams and reservoirs that take into account shifting precipitation regimes and their resulting discharge and water quality conditions.

For several years, changes in the precipitation regime have been observed in Germany. Rainfall in February to April shifted more into the summer. Although total annual rainfall remained nearly the same, the resulting discharge was less due to higher losses in the summer months. As a consequence, reservoir operators experience difficulties in reaching full supply level in spring in order to fulfill existing and competing uses and requirements over the course of each year. This also impacts on local communities and water suppliers.

The emphasis of this study lies on the early recognition of droughts and corresponding reservoir management. The identification of possible counter measures if a drought situation becomes more likely is part of the project. The approach will be transferred into a concept for the adaptation of operation rules taking into account competing uses and target conflicts.

The approach uses hydro-meteorological indices to identify the need for counter actions at an early stage. Based on this, necessary individual and site-specific solutions can be worked out for each reservoir. It is envisaged to integrate the course of action identified during the research project into a guideline for Germany. German water authorities and a wide range of reservoir operators from Germany are involved in the research project.

The project ends in spring 2019.

2. DATABASE

Observation data on precipitation, run-off and climate data such as temperature, evaporation or sunshine duration was provided for the project from the participating reservoir operators. The data was collected from monitoring stations located in the study area for the period from 1970 to 2016 with a temporal resolution of one day.

Forecast data on precipitation was obtained from the National Oceanic and Atmospheric Administration (NOAA) [1]. Since May 2011, NOAA issues long-term forecasts of monthly values. This is a relatively short period, so that the data still lack extreme values or extreme events respectively.

NOAA data is given in a grid format with a resolution of approximately 0.94 degrees. In the context of bias correction, it had to be determined with which ground stations (see Fig. 1) and observed values the NOAA data can best be correlated in order to be able to recognize and correct any bias.

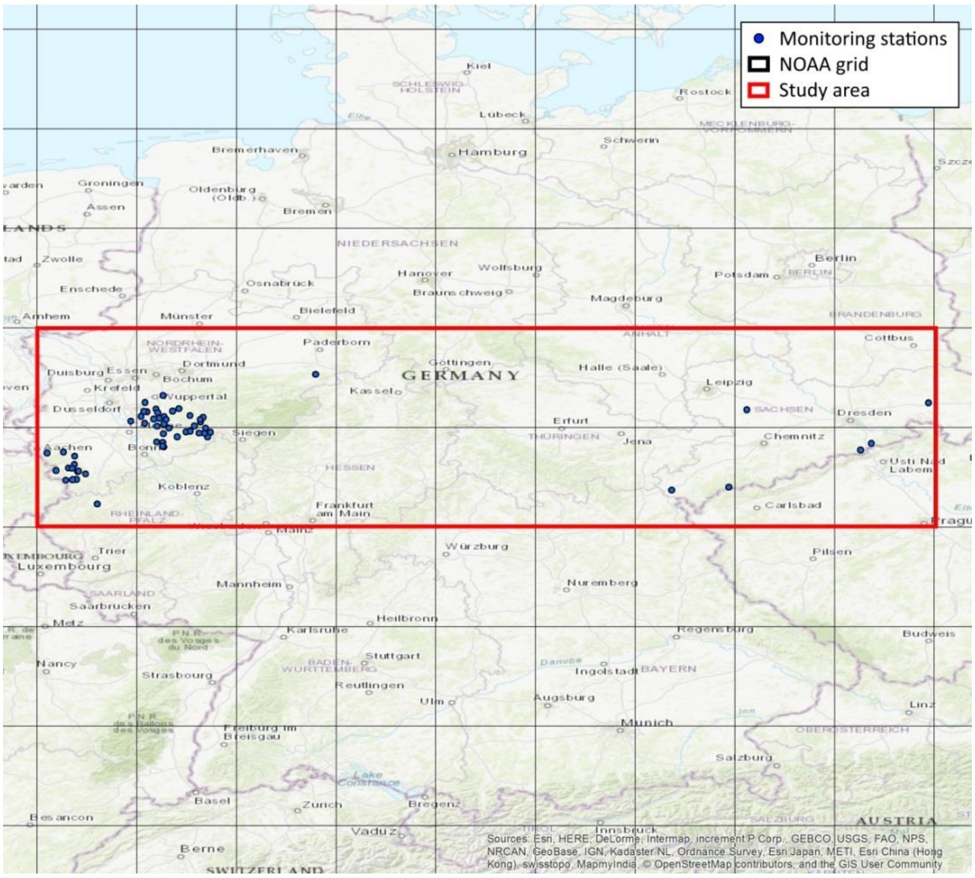


Fig. 1
Relation between study area, monitoring stations and NOAA raster data

3. METHODS

3.1. NOAA FORECAST DATA / BIAS CORRECTION

Bias correction was performed using two different methods: quantile mapping and formation of monthly factors.

The monthly factors were calculated for each calendar month. First, average values for each month were calculated for each observation station and forecast grid over the entire time period for which observed and forecasted datasets are available. This was the time period from 2011 to 2016. Then, the correction factor was calculated for each month by computing the ratio between the observed and the forecasted values. The correction factors are specific to each combination of observation station and forecast grid. Bias corrected forecasts could then be obtained by multiplying each value of the forecasted time series with the appropriate monthly correction factor.

Bias correction using quantile mapping (qmap) was performed according to the method developed by Gudmundsson et. al. [3]. This method entails an empirical adjustment of the distribution of the forecasted values to fit the distribution of the observed values.

The results of using both bias correction methods individually and of using quantile mapping followed by a correction using monthly factor were evaluated using goodness of fit indicators such as the Pearson coefficient, Nash-Sutcliffe efficiency coefficient, bias error, mean absolute error and mean square deviation.

3.2. INDICES

Hydro-meteorological indices play a crucial role in the project. Indices have to be interpreted from the viewpoint of reservoir operation. As indices have differing inertia and apply to different periods, they can be used for predictive operation.

The appropriateness of these indices, the way they should be interpreted and their usefulness regarding early detection of hydrological stress, is tested by conducting hindcast experiments. Indices providing the best skill in hindcast experiments are selected for conducting forecasts. As long as the forecast quality is adequate, this will lead to an enhancement of the current early detection methods.

For a start, the Standardized Precipitation Index (SPI) was used. The SPI is recommended by the World Meteorological Organization for meteorological drought monitoring [2]. The SPI can be calculated for different aggregation periods, e.g. only one month or even up to 60 months.

In order to address uncertainty contained in the forecasts, the SPI is calculated for time periods that extend both into the past as well as into the future, thus consisting of different amounts of observed and forecasted values. The performance of indices calculated with different observed and forecasted aggregation periods was compared with results that used only observed values for computing SPIs. In doing so, it is possible to determine how reliable the SPI computed using forecast data is for different forecast lengths.

In a next step, the Standardized Precipitation Evaporation Index (SPEI) and the Water Supply Index will be tested in terms of their suitability.

4. RESULTS

4.3. BIAS CORRECTION OF FORECAST DATA

Examples for a monitoring station in eastern Germany are shown. The accuracy of the bias-corrected forecast time series was evaluated by means of the above-mentioned goodness of fit measures (see Table 1). Mean absolute error as well as mean square deviation were significantly improved, the Pearson coefficient only slightly. Looking at the bias error, the perfect value of one is nearly achieved.

Table 1
Error values before / after correction, example eastern Germany

Goodness of fit measure	before correction	factor corrected	qmap corrected	qmap + factor corrected
Pearson coefficient	0.51	0.62	0.54	0.55
Bias error	0.77	1.00	1.01	1.02
Nash Sutcliffe eff. coefficient	0.05	0.39	0.001	0.19
Mean absolute error	29.04	21.87	26.57	24.69
Mean square deviation	37.34	28.78	33.46	31.70

In addition, a qualitative statement can be made using a line graph (see Fig. 2), which maps the graphs for the forecast values before and after bias correction and the observed values. A direct comparison of the original NOAA monthly mean values with the values of the stations showed that amplitudes were not sufficiently reflected. After the bias correction, however, the range of observed values was enhanced and an improved representation of inner-annual patterns was achieved.

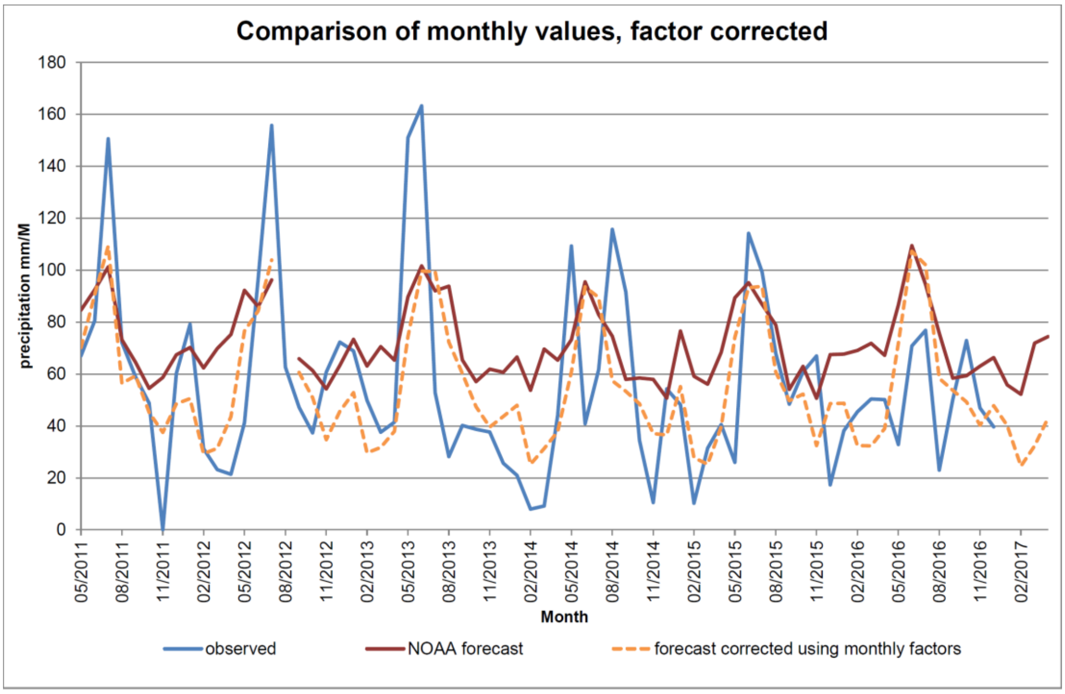


Fig. 2
Comparison of NOAA forecast data before / after factor correction, example eastern Germany

It was found that the quantile mapping method does not produce results that are usable for this study. The reason is that quantile mapping does not take the temporal sequence of values into account, but only adjusts the distribution of values. If, as is the case here, the input time series already contain large differences regarding the temporal sequence of values, quantile mapping can even amplify these differences and produce time series whose goodness of fit parameters are in some cases worse than those of the original time series (see Table 1 and Fig. 3).

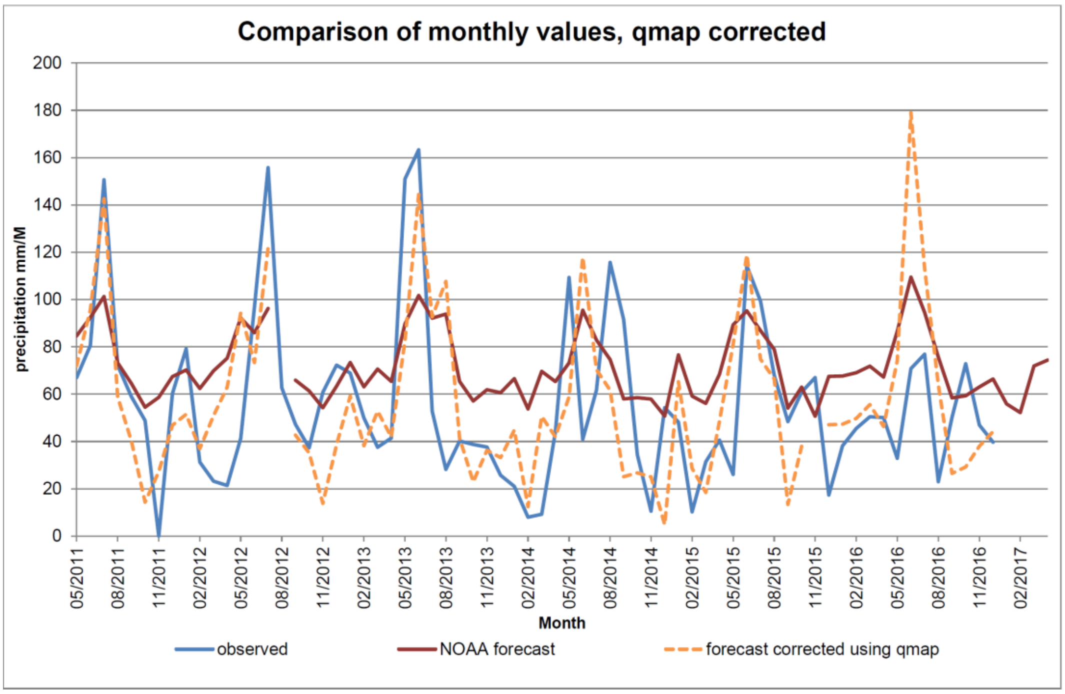


Fig. 3
Comparison of NOAA forecast data before / after qmap correction, example eastern Germany

Performing the bias correction using monthly factors consistently produced better goodness of fit parameters (see Table 1).

Tests using quantile mapping and monthly factors in sequence also produced worse results than using monthly factors alone (see Fig. 4).

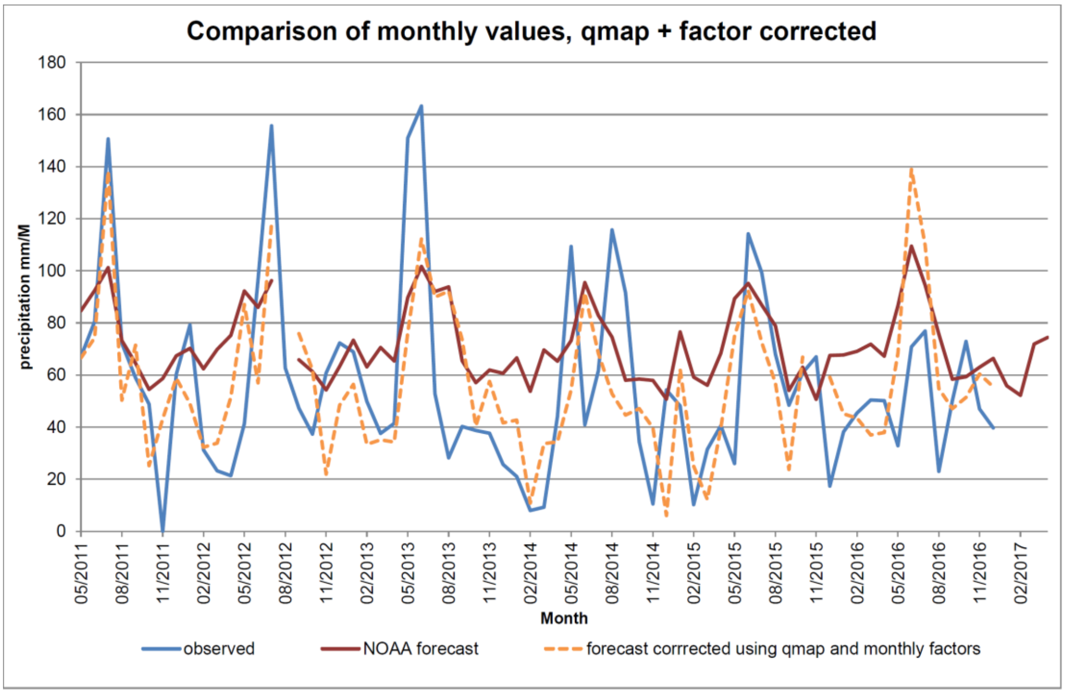
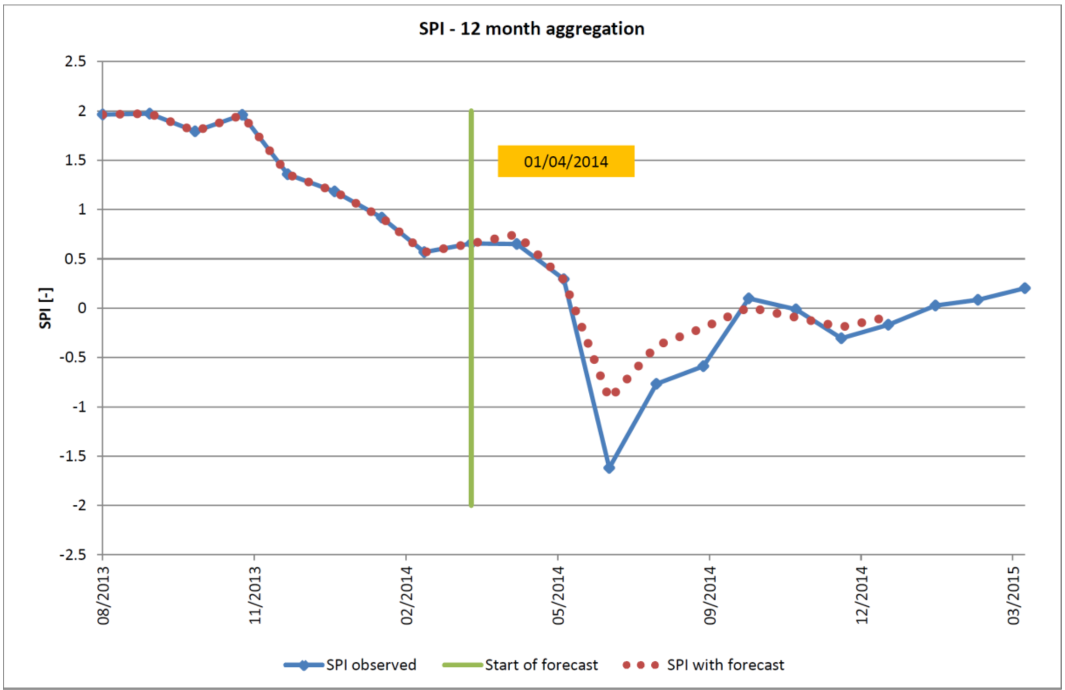


Fig. 4
Comparison of NOAA forecast data before / after qmap and factor correction, example eastern Germany

4.4. INDICES: SPI

Based on observed and bias-corrected forecast data, the SPI was calculated for different aggregation periods. The SPI calculated using only observed data ("certain knowledge") was compared with the SPI obtained by considering different fractions of observed records and NOAA forecasts.

Fig. 5 shows results for a 12-month aggregation period for two ground stations in eastern Germany. The SPI calculated using NOAA forecasts reveals a good fit in comparison to the SPI based on measured data and more significantly exhibits the same tendency for upcoming dry periods.



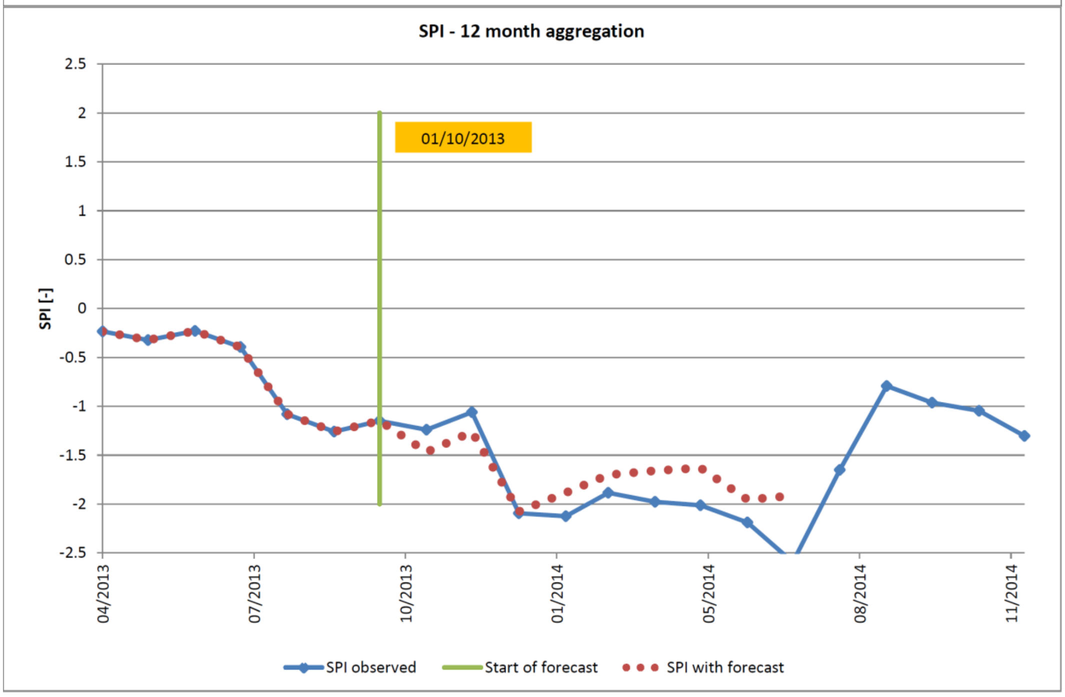


Fig. 5
SPI calculated with observed / NOAA forecast data, examples from different sites in Germany

5. ADJUSTMENT OF OPERATION

Once the SPI (or indices in general) is calculated based on past and forecasted values, it can be used to adjust operation of reservoirs. Adjustment cannot be established in a general way but requires site-specific rules. However, what can be generalized is the way in which the results of indices are introduced. First, site-specific operation rules best suited for intervention must be identified. Second, threshold values for indices must be identified for when intervention should be triggered. Third, the aggregation period is highly dependent on the local situation and needs to be determined for each individual case.

Reservoirs in West-Germany with catchment areas ranging from 250 to 600 km², operated with pool-based rules, could be improved by using a 9 to 12 month aggregation period and a threshold value of -1.5 (SPI + Evaporation based indices). When the index dropped below -1.5, release rules associated with the next lower pool were applied to counter an expected decrease of inflow. This meant a reduction of downstream releases or a different release pattern related to inflow and depending on the time of year and current storage volume. Not surprisingly, not all critical periods could be identified by applying this approach. However, two thirds of critical low flow conditions with corresponding low water levels in the reservoirs could be tackled in a timely way. The approach was used without forecasts prior to 2011 and as of 2011 with forecasts to make full use of the observation period with more than 100 years.

In central Germany, a reservoir with a catchment area of less than 50 km² revealed a different pattern. Only aggregation periods longer than 18 months with a threshold value of -1.0 showed good results. Shorter aggregation periods or lower threshold values were either not consistent enough or started too late to result in counter measures that took effect. In this case, the target operation rules for intervention was water supply provision. Similar to a hedging rule, water provision was subjected to a quota of a rather small percentage as soon as the index dropped below -1.0 to prevent larger reductions later on. In doing so, the reservoir could be mostly kept above a water level that becomes critical from the viewpoint of water quality.

The initial assumption that the size of a catchment area is a reasonable parameter for estimating aggregation periods could not be confirmed. The interplay between climate, the catchment area’s geology as an indicator for inertia and the reservoir itself seems more complex. As a result, each reservoir or reservoir system must be individually scrutinized to find the best set of aggregation periods and threshold values.

ACKNOWLEDGEMENTS

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SUMMARY

The aim of the project is to develop adaptation strategies for dams and reservoirs that take into account shifting precipitation regimes and their resulting discharge and water quality conditions.

The emphasis of this study lies on the early recognition of droughts and corresponding reservoir management. The approach will be transferred into a concept for the adaptation of operation rules taking into account competing uses and target conflicts.

The approach uses hydro-meteorological indices to identify the need for counter actions at an early stage. Long-term precipitation forecasts from NOAA are bias-corrected for individual ground stations in Germany, for which observed precipitation data is available. The forecasted precipitation values are then used to calculate indices (e.g. Standardized Precipitation Index (SPI)).

Conclusions are that the SPI calculated using forecasted data adequately represents the SPI calculated from observed data. In particular, upcoming dry periods can be detected using the forecasts.

Using the forecasted SPI to adjust reservoir operation rules based on a certain trigger threshold for the SPI in one case lead to reduced critical low flow conditions. In another case, using operation rules adjusted to respond to a certain SPI threshold resulted in fewer occurrences of reservoir water levels below a critical level. These case studies also showed that the SPI aggregation period and the SPI threshold value for triggering adjustments to the operating rules have to be determined individually for each site.

Further steps in the study will involve testing different indices and establishing generalized approaches for integrating index forecasts into reservoir operation.