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Delay and loss of production water along the Orkla river

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Abstract

It has been found that a simple fixed delay of the water along a river does not provide accurate enough river flow rates for scheduling of the river power plants. One problem is that production water seems to disappear along the river stretch. Another problem is that the delay time depends on the state of the river and is longer in dry than wet conditions.

The first problem has been that only 50-80% of the production water released into the river actually arrives at the downstream power plant (after some delay). The mechanism responsible is identified as loss of river water to the sandy valley-bottom aquifer. While most of the production water is delayed with a few hours river delay, the lost fraction is delayed by days and weeks in the aquifer. A coupled tank model is proposed to describe this mechanism. This model has been able to explain the water flow variation due to upstream production variation.

The problem with river state dependence of delay has been approached with the method of characteristics, which provides a fast calculation of water wave movement along the river. The river flow rate is specified as a non-linear function of river water content. A two parameter power law is assumed to be valid for the entire river stretch. With this method, it is possible to reproduce the state dependence observed in the river. The studied stretch has a typical delay of 12 hours, but normal variation in the river state can change the delay by several hours. The improved delay calculation probably contributes to reduced production imbalances in the downstream power plant.

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1. Introduction

For a watercourse with several power plants in series, production water from an upstream plant will propagate along the river as a wave, which arrives distorted at a downstream plant after a delay. This delayed production water must be subtracted from the measured river flow when local inflow is calculated (water household), and must be added to the predicted local inflow when the production of the downstream plant is predicted. Since the production is normally increased instantly from zero to a finite value, the production water starts out as a sharp wave at the upstream outlet point. The wave arrives after a certain time, but this time may vary with the river conditions, and the wave may be both broadened and attenuated. The focus of this paper is how to calculate the flow variation when the wave arrives at the downstream power plant.

The simplest description of the propagation process is with a fixed delay time, assuming no broadening or attenuation. The data presented here shows examples that this is not always sufficient. Two problems have been encountered in our data. The first problem is that some production water sometimes appears to be lost during propagation. The other problem is that the delay time varies with river conditions, with larger delay at low river flows. The purpose of this work is to improve the scheduling of the downstream power plants, by improving the calculation of production water propagation along the river.

Several methods for river propagation are available in the literature (references in [1] and [2]). The Muskingum algorithm relies on material balance, but is based on a specific assumption of water distribution along the river stretch. The method does describe the delay and the broadening of fronts (dispersion), but it does not capture the variation of delay with the initial state of the river. This is also the case with numerical waveform tables used for instance by [2] to describe delay and broadening. The river state not being a model parameter, different tables need to be used for different seasons or operating conditions. The full solution is formulated in St. Venant equations [1], and is used with detailed river geometric data in hydraulic software such as Hec-Ras. The full approach is too involved for real-time scheduling applications. For such applications, the fast methods presented here may be useful.

The two problems addressed in this paper require two separate solutions. The loss of water to the valley-bottom aquifer is modelled with a coupled tank model that is specific to this loss mechanism. The model is similar to the hydrological model common in the Nordic countries, the HBV-model ([3]). This type of loss is normally not included in routing models. The state dependence of delays is handled by a method of characteristics solution of simplified St Venant solution. The physics is therefore standard, but this quick method with simple input (a simple two-parameter power law flow-vs-storage function describes all river properties) provides a complex and history-dependent spatial description of the water wave and the outlet water flow.

2. Field description

The models developed here are applied to the hydropower system of the Orkla river in Norway, which contains two river power plants Brattset and Svorkmo separated by a 40 km river stretch. Midway between the two river plants the production water from the Grana power plant enters the river. The upstream Brattset plant receives production water from the Ulset power plant via an 8 km river stretch. The phenomenon of water loss to aquifer is most pronounced in the Ulset-Brattset river stretch, while the modeling of variable delay time is more relevant in the longer stretch between Brattset and Svorkmo.

3. Models

3.1. Aquifer loss model

The problem with apparent loss of production water has been most pronounced in the Ulset-Brattset stretch. When production is started at Ulset, typically only 50-80% arrives at Brattset after four hours delay. This river