Integrated assessment of climate change and sea level rise on the water quality of a coastal lake

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ABSTRACT

An integrated and distributed hydrological model was constructed for a coastal catchment on the island of Zealand, Denmark. Water supply in the area depends on abstraction from a relatively large lake located close to the sea. The model is forced by results from a regional climate model using the SRES A2 scenario and mean sea level rise in the range from 0.5 – 1.0 m. It is shown that the quantity of fresh water in a future climate is predicted to be sufficient to sustain water abstraction even though precipitation decreases during the summer period. However, the rising sea water level results in inflow of saltwater to the lake especially during late summer and autumn where the lake water level is relatively low and storm events results in high sea levels. The study shows that adaptation measures are needed already at a sea level rise of approximately 0.5 m if salt water inflow should not destroy the lake as a fresh water resource.

INTRODUCTION

Global climate is expected to change as a result of increasing emissions of green house gases (IPCC, 2000). Climate change projections for Scandinavia generally show that the temperature increase, and that precipitation increases during winter while stable or decreasing precipitation are expected for the summer period. Evapotranspiration is, as a function of temperature, also expected to increase. Additionally, sea level is predicted to increase. The combined effects of these changes are difficult to access and require integrated impact models. The objective of the present study is to quantify the effects of sea level rise and climate changes on the water quantity and quality of a Danish lake located close to the sea. The lake is presently used for water supply and is threatened by saltwater inflow through the stream connecting the lake to the sea.

METHODS

The study area is located on the western part of the island Zealand, Denmark, Fig. 1, and has a total area of approximately 775 km². The area is bounded by the Great Belt to the west and by water divides on the inland sides. The water supply for the municipality of Kalundborg is based on conjunctive use of surface water from Lake Tissø and groundwater from the quaternary aquifers. The extraction of water from Lake Tissø has increased steadily from 1.6 mill. m³/yr in 1990 to 4.1 mill. m³/yr in 2008. Lake Tissø is located approximately 6 km from the coast line. The lake has a maximum depth of 13.5 m and a volume of 100 mill. m³ (at a water level of 1 masl). The catchment area to the lake is 344 km² at the inlet and 403 km² at the outlet. The lake is recharged by Halleby stream and two minor streams. The average water level in Lake Tissø is 1.25 m but varies with up to 2 meters, from approximately 0.6 m during dry periods in summer
and up to 2.6 m during winter with heavy rain events. Hence, the lake has a significant reservoir capacity, with a change in volume of approximately 12.3 mil. m$^3$ per meter change in water level. A mean sea level in the Great Belt of 0.09 m is found for the period 1990-2008. Analysis of daily averages measurements shows absolute maximum and minimum water levels of 0.81 and -0.50 masl, respectively.

![Figure 1. Map of study area at the western coast of Zealand, Denmark. Discharge stations and stations numbers are indicated by green symbols.](image)

In the present study the delta change approach has been applied on results from the regional climate model HIRHAM to obtain reliable projections of temperature, precipitation, and reference evapotranspiration under the A2 scenario, and sea level rise, both for the period 2071-2100. With respect to temperature and sea level rise the absolute changes projected by the climate model from the present to the future period are added to daily observations of the two variables. Prior to bias-correction the projected sea level rise is adjusted to account for isostatic changes to obtain result for the relative sea level change which is the relevant variable when vulnerability is examined. The distributed and integrated modeling system MIKE SHE (Refsgaard and Storm 1995) is used for hydrological modeling. In the present application the model description includes: 2D diffusive wave approximation of the Saint Vernant equations for overland flow; Muskingum-Cunge routing for flow in the upstream part of the river system and the full Saint Vernant equations for the downstream part of the river system, and 3D Boussinesq equation for flow in the saturated zone.

**RESULTS**

In Figure 2 the mean monthly discharge at station 55.01 and station 55.08, upstream and downstream of Lake Tissø, respectively (see Figure 1), is illustrated for present and A2 climate. At station 55.01 a significant increase in discharge is found during the winter season, whereas discharge is reduced during late summer and autumn. Just downstream of Lake Tissø the
discharge is increased in all months also during summer where the precipitation decreases in the future climate.

![Figure 2](image1.png)

**Figure 2.** Mean monthly discharge upstream (station 55.01) and downstream (station 55.08) of Lake Tissø for present and future climate.

In Figure 3 stream hydrographs for station 55.08 downstream of Lake Tissø is shown for three different scenarios for changes in mean sea level; 0.5m, 0.73m and 1.0m. The maximum discharge typically observed during winter is unaffected by the sea level.

![Figure 3](image2.png)

**Figure 3.** Discharge to Lake Tissø for 19 simulation years representing the period 2071-2100. Results for mean sea level rise of 0.5, 0.73 and 1.0 m are shown. Negative discharge indicates inflow of sea water to the lake.

However, negative discharge corresponding to inflow of water from the Great Belt to the lake is found typically during late summer and fall. Inflow starts at a sea level rise of approximately 0.5 m and the magnitude of inflow to the lake increases with sea water level.
DISCUSSION AND CONCLUSIONS

It was expected that abstraction of water from Lake Tissø would be problematic in a future climate because of decreasing precipitation during the summer period. Results from other studies in Denmark (Roosmalen et al., 2007; Roosmalen et al., 2009) have shown that the summer stream discharge is vulnerable to this change in rainfall pattern. Hence, it was expected that both the water level in the lake and the discharge from the lake into Halleby stream would be reduced in the future resulting in restrictions on the abstraction of water from the lake. However, Lake Tissø acts as a reservoir that is able to store relatively large quantities of winter precipitation that falls in the A2 climate. The water stored during winter is slowly released during the summer period resulting in both increasing minimum water levels and outflow from the lake. Hence, the results presented here indicate that with respect to water resource considerations the production of water from the lake is sustainable also in a future climate.

A critical quality issues was however found to threaten the production of water from the lake. Saltwater from the Great Belt was found to enter to lake during summer and fall where the water level in the lake is relatively low. At a mean sea level rise of 0.73 m, events with saltwater intrusion happen approximately once a year on average. It is likely that the intrusion of saltwater will be critical to both the ecological status of the lake and the possibility to abstract water from the lake. The inflow of saltwater could be prevented if a sluice gate was installed at the down-stream end of the stream between Lake Tissø and the sea. The gate will close in cases where the sea water level is higher than the fresh water level and ensure that the saltwater only affects the outlet of the stream. This solution is presently used at several locations in Denmark and would be a relatively low cost adaptation measure.

REFERENCES


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