Multi-objective optimization of the management of a waterworks using an integrated well field model

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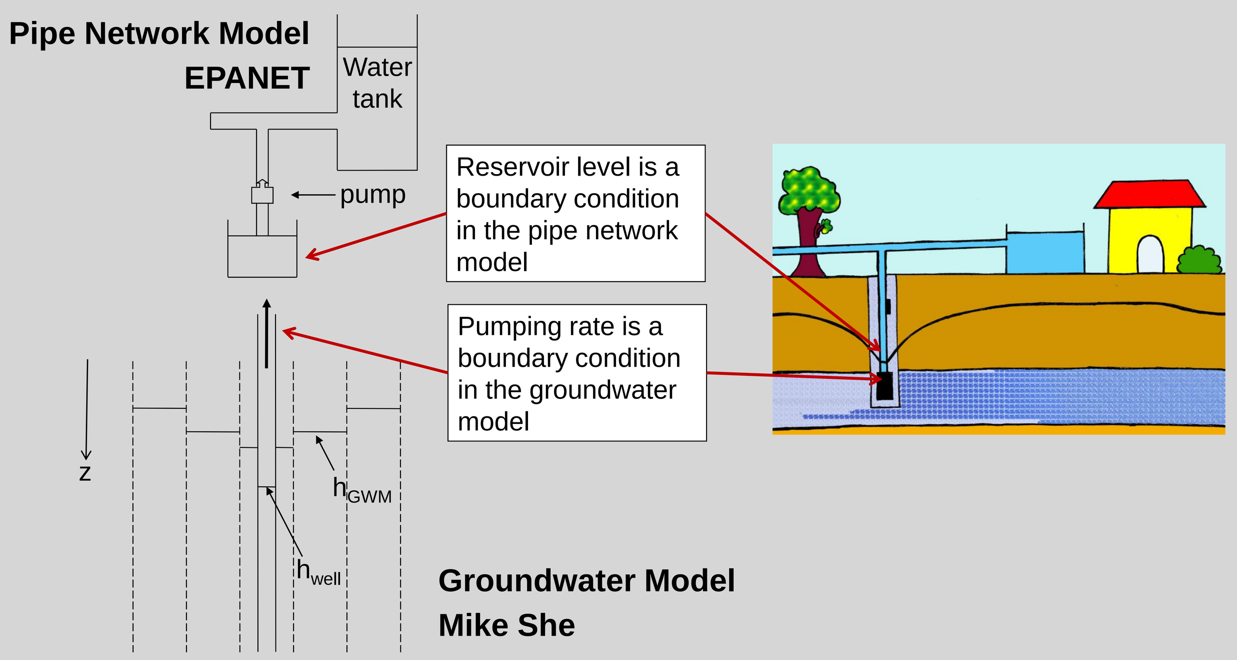
Introduction

In Denmark 98% of the drinking water comes from the groundwater. This has made the management of groundwater an important issue.

The main reasons for this is:

- Groundwater is a limited resource and it is used more extensively.
- The energy consumption of the water works are considerable. Even a small percentage saving can lead to large overall savings.
- Contamination of a well will in most case lead to closing of the well. During the last 15 years on average 100 wells have been closed due to contamination.

1. WELLNES



WELLNES (WELL field Numerical Engine Shell) is a fully integrated hydrological model, which simulates the hydraulic parameters in the aquifer and in the pipe network of a waterworks.

It is capable of capturing the rapid response of the aquifer when pumps are turned on and off.

It can predict the head elevation and power consumption in the wells accurately. The total abstraction is within 3.8% of observed value, and the total energy consumption is within 0.7% of observed value.

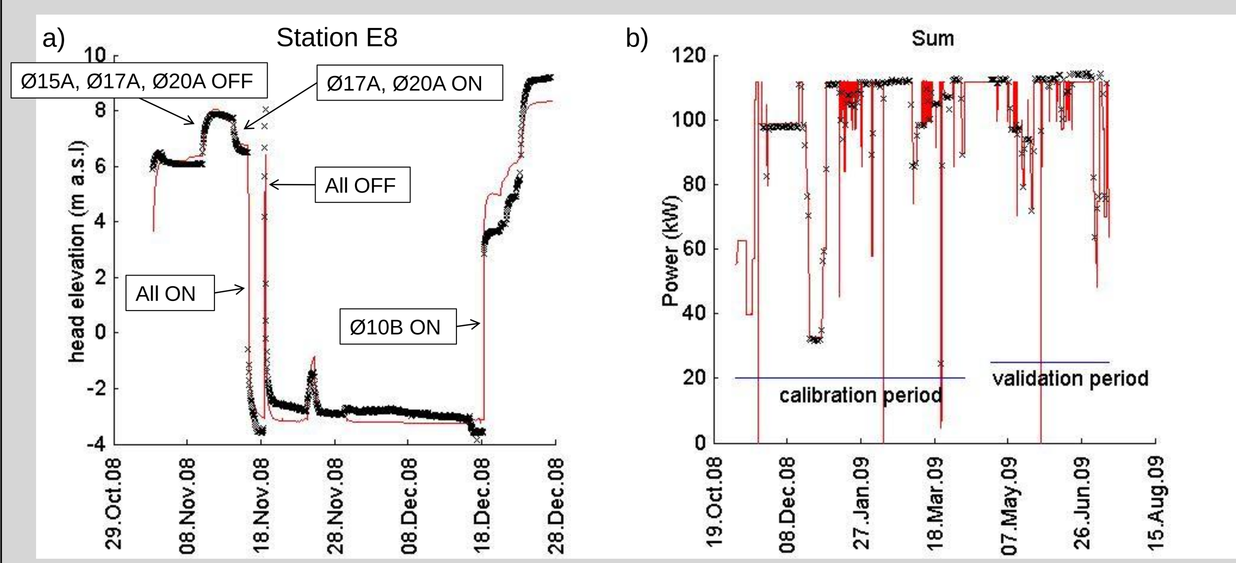


Fig. 1:

a) Observed (black crosses) and simulated (red solid) head elevation in production well E8 (Fig. 4) for a period of two month.

b) Observed (black crosses) and simulated (red solid) total power consumption of Søndersø waterworks for the period of calibration and validation (8 month).

Objectives

1. To construct a **WELLNES** model that predicts the hydraulic parameters in and around a well field.
2. To use **multi-objective optimization** to find the best ways of operating a waterworks with respect to the two objectives of:
   - Minimizing the specific energy consumption, E_{spe}.
   - Minimizing risk of pollution from nearby contaminated site.

2. Multi-objective optimization

Objective functions:

$$\min \quad E_{spe} = \frac{1}{T}\sum_{t=1}^{T}\frac{\sum_{i=1}^{n} P_i(t)}{\sum_{i=1}^{n} Q_i(t)}$$

Specific energy consumption

$$\max \quad H = \frac{1}{T}\sum_{t=1}^{T}\sum_{i=1}^{n}\Delta h_i(t)$$

Average head difference of monitoring wells (Fig. 4)

$$\text{s.t.} \quad Q_{tot} \geq Q_{dem}$$

Demand criteria

P_i is the power

Q_i is the pumping rate

Δh_i is the head difference in monitoring wells,

Q_{tot} is the total pumping

Q_{dem} is the demand of water.

Control variables are pump status:

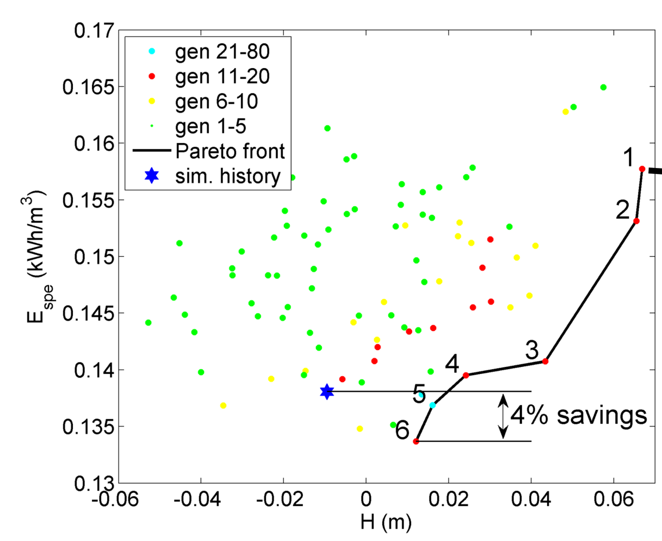
a) On/off
   11 wells, this gives 2^{11} = 2048 pump configurations.

b) Frequency-regulated
   Can vary between 30 and 50 Hz.

The optimization problem is solved by evolutionary algorithms.

Results

a) Existing on/off pumps



Pumping configurations 1 = on, 0 = off

	E1	E2	E3	E4	E5	E6	E7	E8	W3	W2	W1
1	0	1	1	1	1	1	1	1	0	0	0
2	1	0	1	1	1	1	1	1	0	0	0
3	1	0	1	1	0	1	1	1	0	1	0
4	0	0	1	1	0	1	1	1	0	1	1
5	1	0	1	1	0	1	1	0	0	1	1
6	1	0	1	0	0	1	1	1	0	1	1

The pumping configurations for the 6 numbered solutions on the Pareto front are shown.

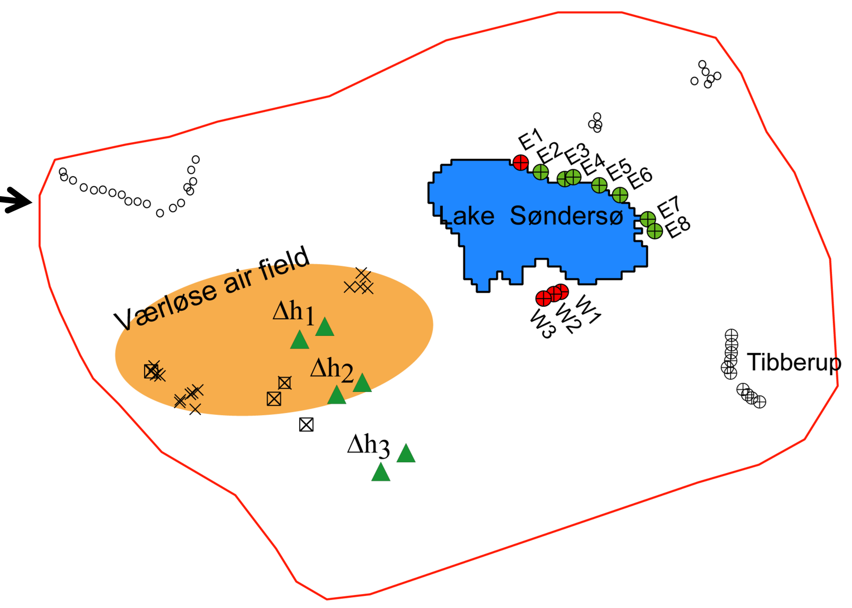


Fig. 2. Optimization results using on/off pumps. E_{spe} is plotted as a function of H. The Pareto front is shown with black line and the evolution of the optimization algorithm is illustrated with the colored dots. The model is evaluated 193 times. The simulated history is shown with the blue star. It can be seen that 4% in E_{spe} can be saved if solution 6 is used instead of the simulated historical configuration.

b) New frequency regulated pumps

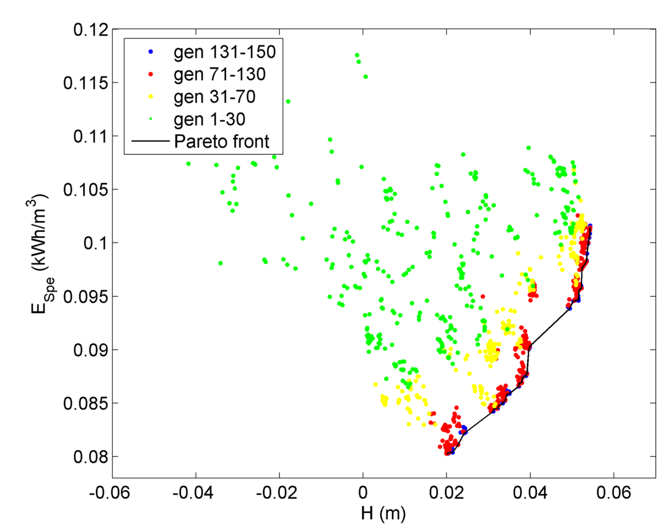


Fig. 3. Optimization results using frequency-regulated pumps. E_{spe} is plotted as a function of H. The Pareto front is shown with black line and the evolution of the optimization algorithm is illustrated with the colored dots. The model is evaluated 4000 times. Note the different scale for E_{spe} on Fig. 2 and 3.

Location: Søndersø waterworks

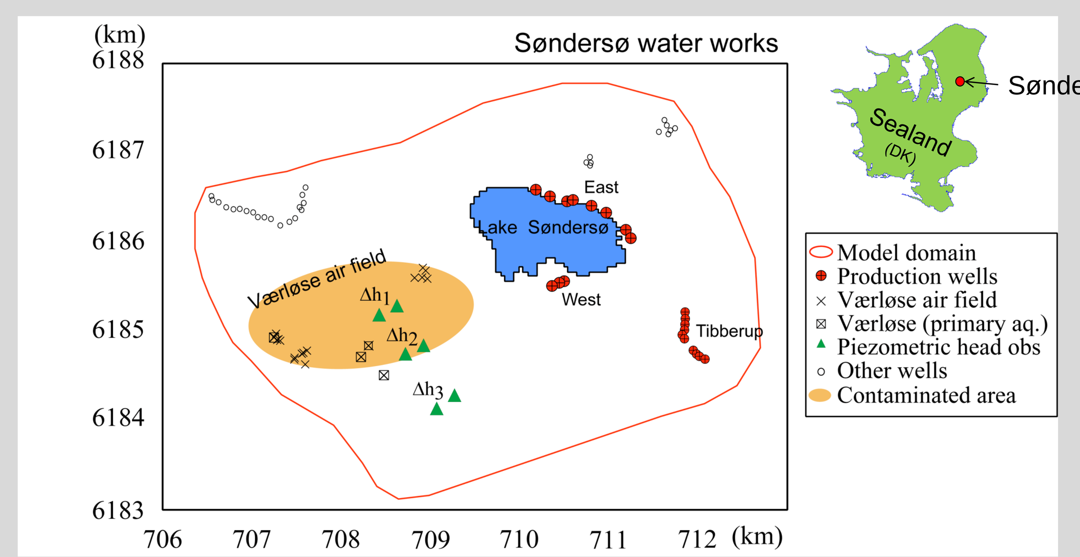


Fig. 4. Map of Søndersø waterworks, located NW of Copenhagen, Denmark. The wells are located around the shore of the lake. Værløse air field is contaminated and it is of concern not to get this water into the drinking water. In the model six monitoring wells (green triangles) are used to control the direction of the flow.

Conclusion

1. Performance of WELLNES:

- Total abstraction is within 3.8% of observed value.
- Total energy consumption is within 0.7% of observed value.

2. Multi-objective optimization

- Finds the set of non-dominated solutions (Pareto front).
- The decision-makers can choose a solution on the Pareto front taking into account the advantages and disadvantage of the chosen solution.
- With on/off pumps 4% can be saved in specific energy (Fig. 2).
- With frequency regulated pumps 42% can be saved in specific energy (Fig. 3).

➤ WELLNES gives accurate prediction of the energy consumption.

➤ The multi-objective optimization algorithm provides a set of optimal pumping configurations with respect to different operation objectives.

Powerful management tool

Reduced risk of contaminated drinking water | Energy saving