REGIONAL FORECASTING OF GENERATION FROM SMALL HYDROPOWER PLANTS

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NTNU / CEDREN

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CEDREN
Centre for Environmental Design of Renewable Energy

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CENTRE FOR ENVIRONMENT-FRIENDLY ENERGY RESEARCH

Background

TSO (Transmission System Operator) - in Norway this is Statnett

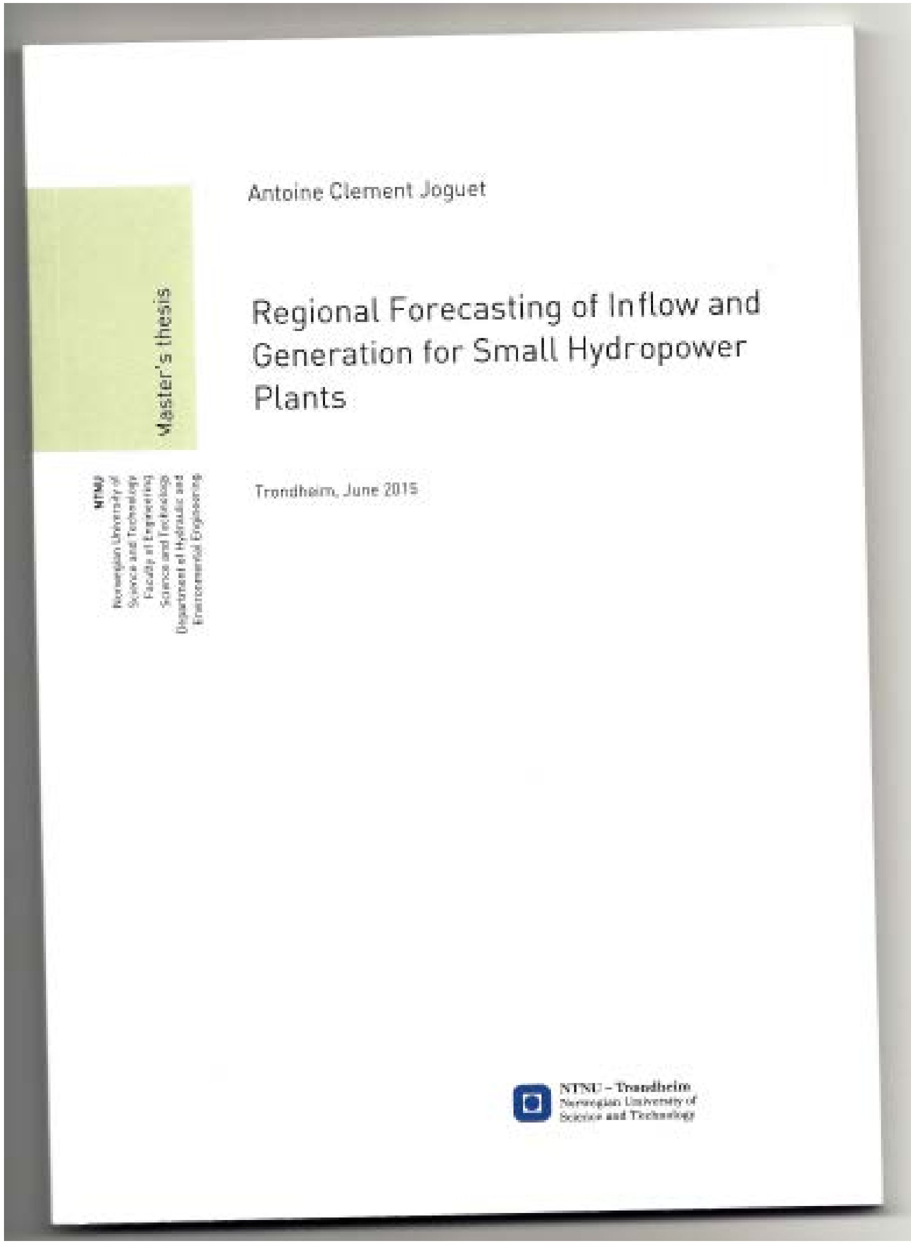
TSO is responsible for security of supply and stability in the power grid
➔ Therefore need to know balance between supply and demand at all time scales

To maintain balance TSO needs to make reliable forecasts for supply & demand
➔ Power generators have to submit detailed plans for generation next day

Intermittent and unpredictable power generation requires more backup for balancing
Increasing number of small hydro have been built in Norway in recent years
Small hydropower operators have limited possibility to forecast generation
➔ A high share of small hydro increases uncertainty in power balance

Separate planning for each small hydro plant is not practical (or necessary)
Regional generation forecasts for groups of small HPP's will be enough – and cheaper

Objective of this project: Develop a forecast method for sum generation in all small hydropower plants in a region, and verify its practical capability


Antoine Clement Joguet

Master's thesis

Regional Forecasting of Inflow and Generation for Small Hydropower Plants

Trondheim, June 2015

NTNU
Norwegian University of Science and Technology
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Department of Hydraulic and Environmental Engineering

NTNU – Trondheim
Norwegian University of Science and Technology

Analysis mainly by MSc student Antoine Clement Joquet at the International MSc program Hydropower Development, 2015

Data supplied by Statnett and NVE

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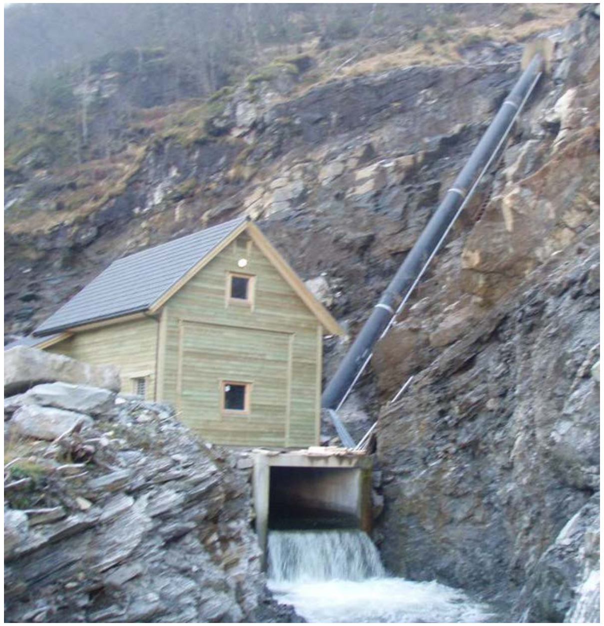
Co-supervisor
Gerard Doorman Statnett/NTNU

Size distribution for hydropower plants in Norway

In Sep 2015 there were

213 with capacity < 100kW
304 with capacity from 100 kW to 1 MW
446 with capacity from 1 to 5 MW
113 with capacity from 5 to 10 MW
254 with capacity from 10 to 100 MW
79 with capacity > 100 MW

26 pumps or reversible pump turbines



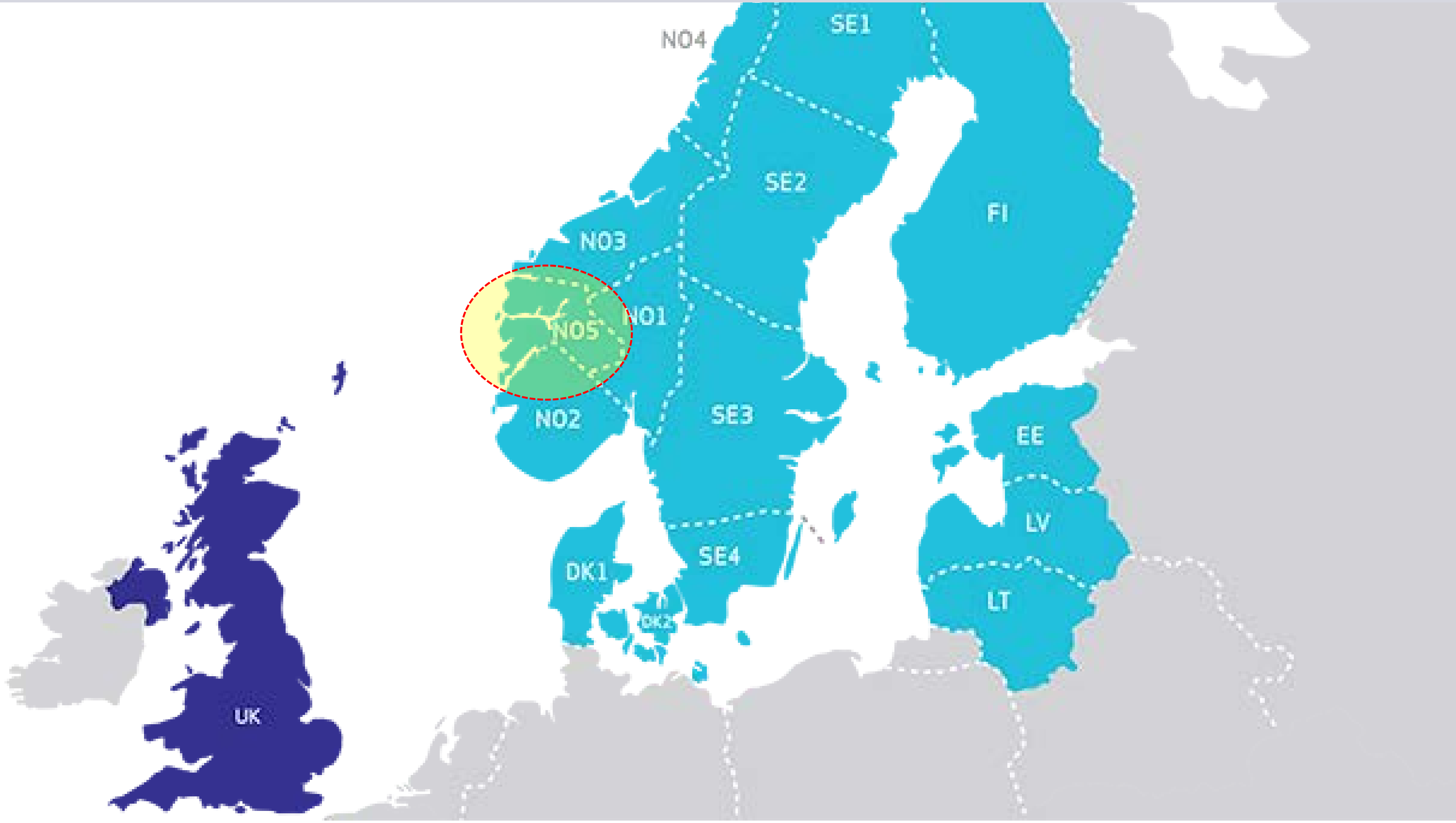
In total there are

1076 hydropower plants < 10 MW	**Sum capacity 2124 MW**
254 with capacity from 10 to 100 MW	Sum capacity 9762 MW
79 with capacity > 100 MW	Sum capacity 18876 MW

Small hydro (<10 MW) contributes to 7% of total capacity in Norway
In some regions and during some seasons the share is much higher

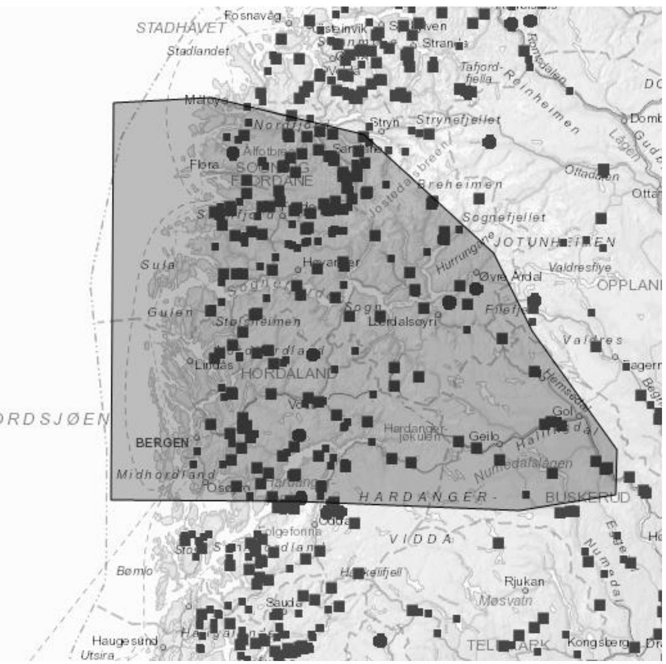
Source NVE-Atlas downloaded 10.09.2015

Bidding areas for the Elspot market
Region NO5 was selected for this study



(source: http://www.nordpoolspot.com/)

Some data for Elspot Region NO5



<u>Small hydropower plants (<10MW) in NO5 in 2014</u>

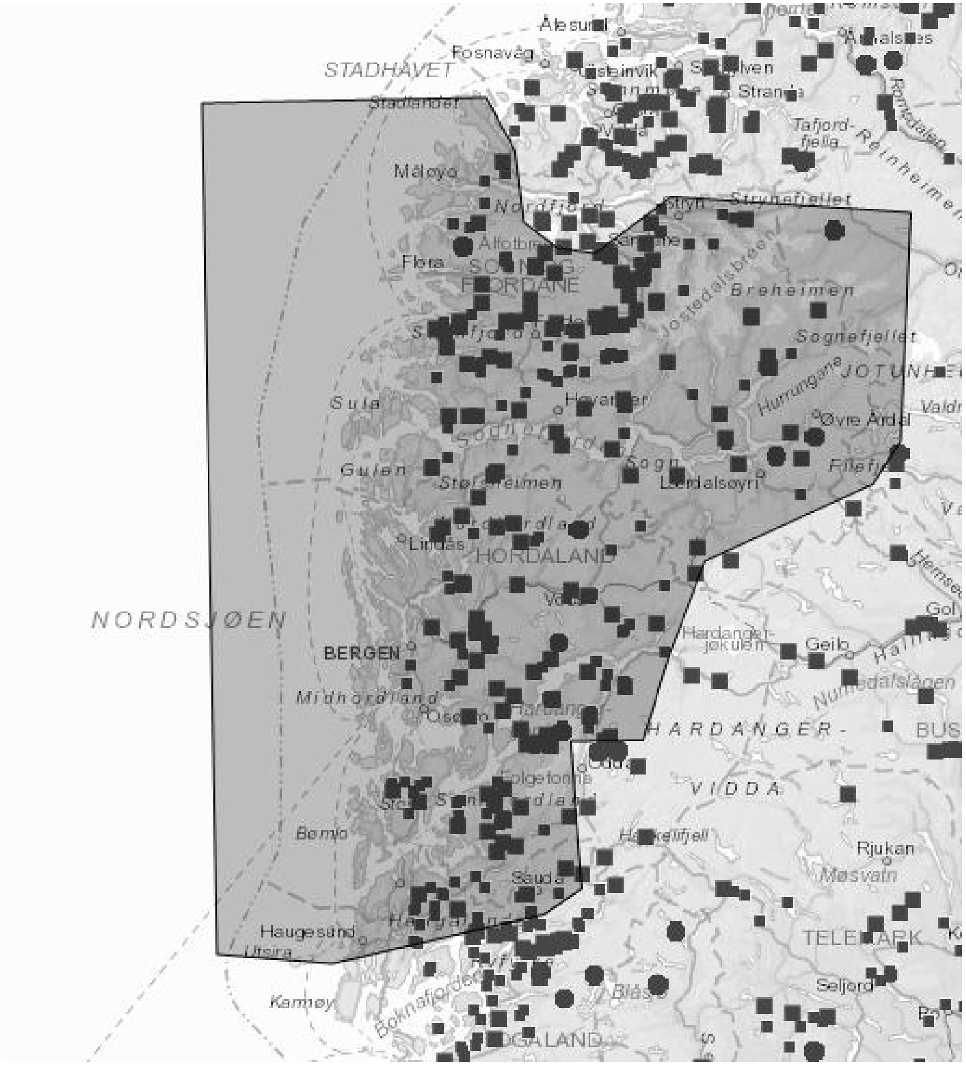
252 reported by NVE	Tot capacity 522 MW
239 found in NVE Atlas	Tot capacity 499 MW
143 with good data	Tot capacity 420 MW
193 reported by Statnett	Tor capacity 194 MW
165 of these also by NVE	Tot capacity 179 MW
81 with good data both from NVE and Statnett	Tot capacity 139 MW or 27% of total

NVE data: Head, Capacity, Catchment, River flow (daily)

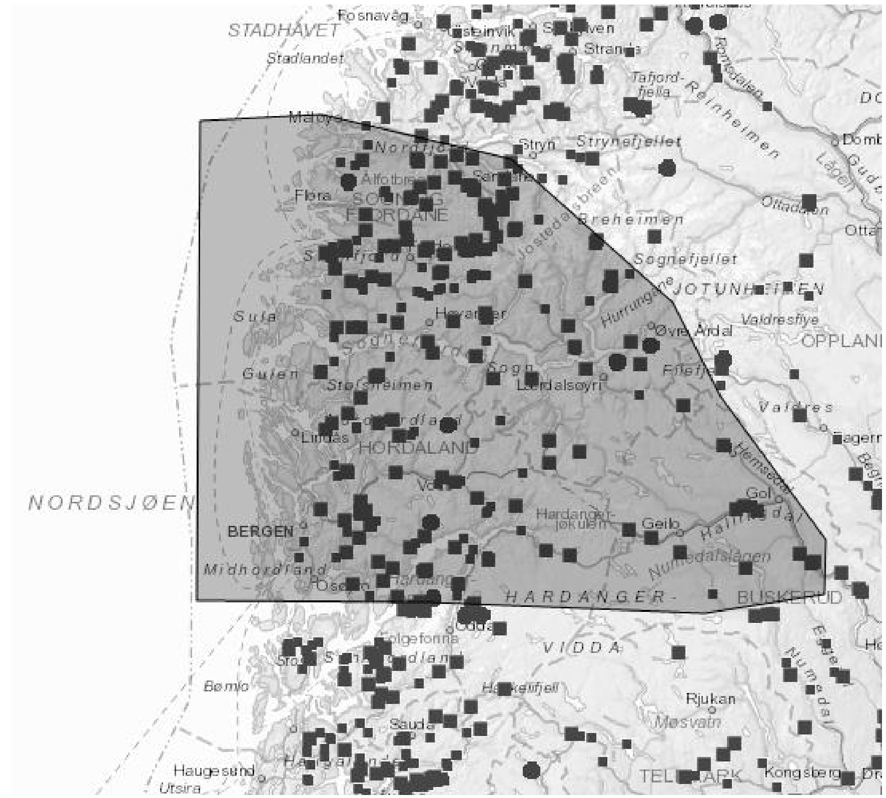
Statnett data: Generation (MW) per hour

Very difficult to find consistent data NVE/Statnett

Borders for Elspot Region NO5



2010



2014

(source: NVE-Atlas)

Regional computing and forecasting of generation

Two methods were tested:

1. Regional analysis by multiple linear regression
   - regional generation as a function of river flow at gauging stations
   - model parameters computed by multiple regression analysis
   - model quality will be given as a direct result of the analysis

2. Detailed distributed modelling
   - each HPP is modelled individually
   - inflow to station computed from nearby gauging stations
   - generation at station N computed as $P_N = f(\text{flow, capacity, head, } \eta)_N$
   - regional data computed by aggregating individual values
   - model quality, by comparing observed and computed regional generation

Best modelling approach decided by:

- Goodness of fit
- Complexity of model
- Data requirements
- Cost of operation
- …

FINALLY, THE BEST MODEL WILL BE USED FOR FORECASTING FUTURE GENERATION

Data for actual generation (Statnett)

Hourly data for actual generation exists for years 2010-2014

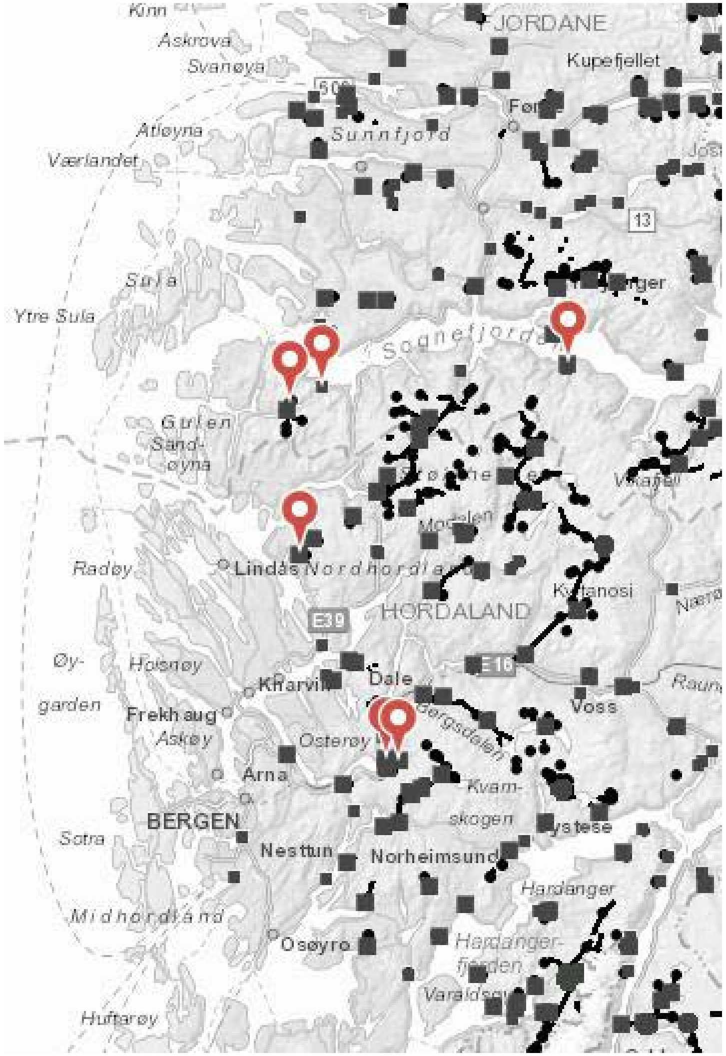
Generation data are aggregated for grid nodes (not single power plants)

Node configuration varies from year to year with 12-17 different nodes in NO5

Nodes may contain from 2 up to >20 different power plants

Comparison between observed and computed generation was possible for 10 nodes for all years

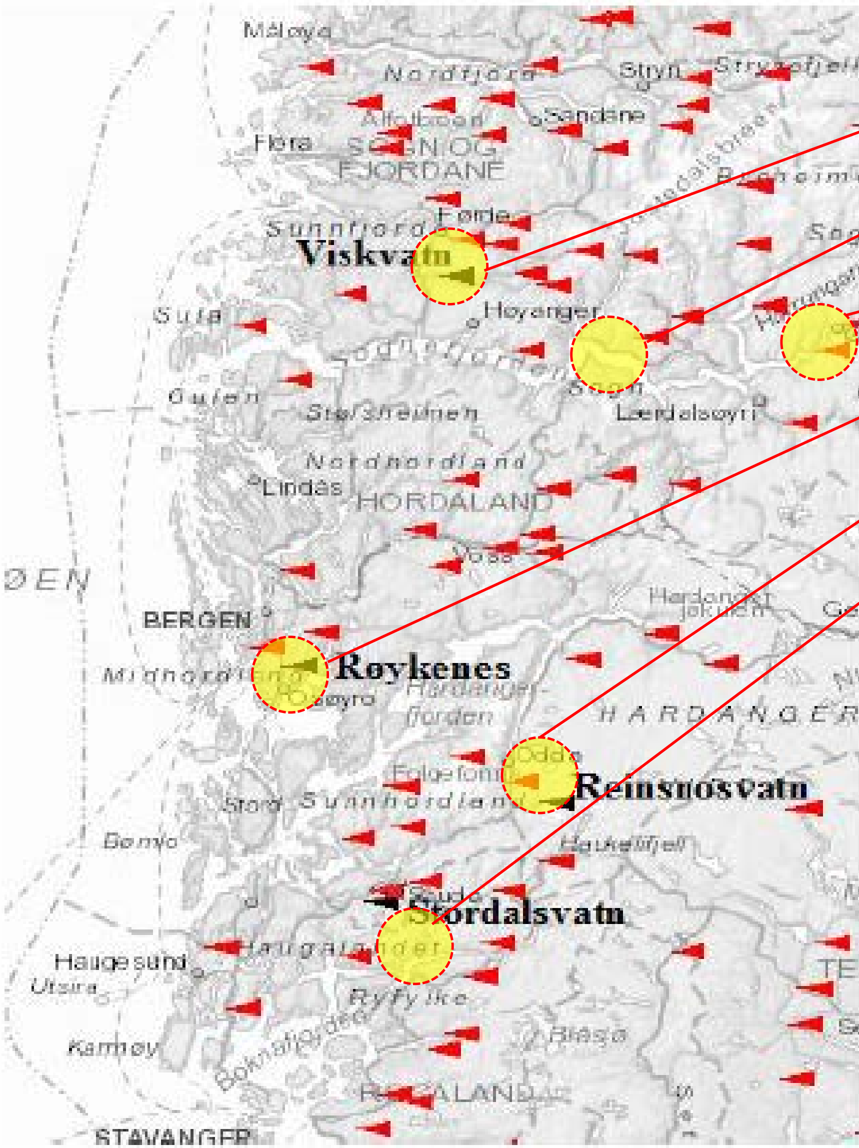
Power plants in one node could be located in different hydrological regions

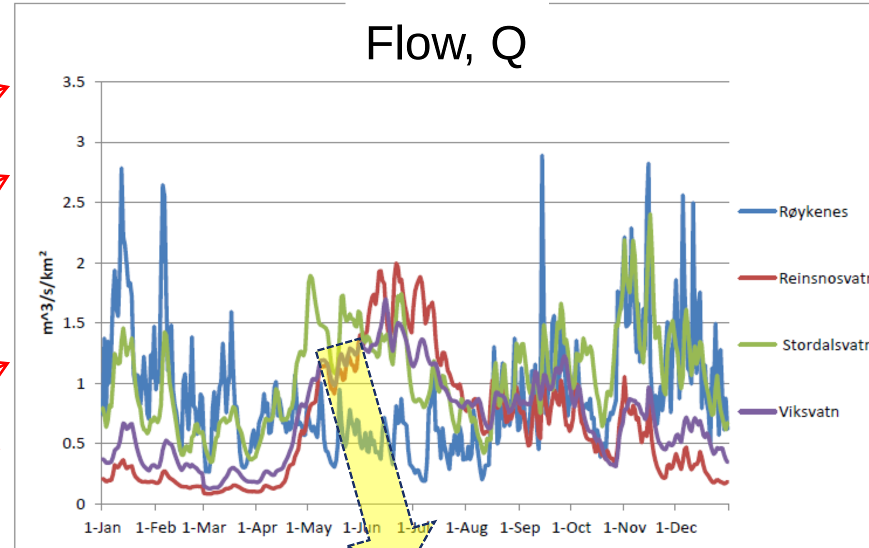


Example: Power stations linked to node Arna

Methodology 1 – Regional regression model

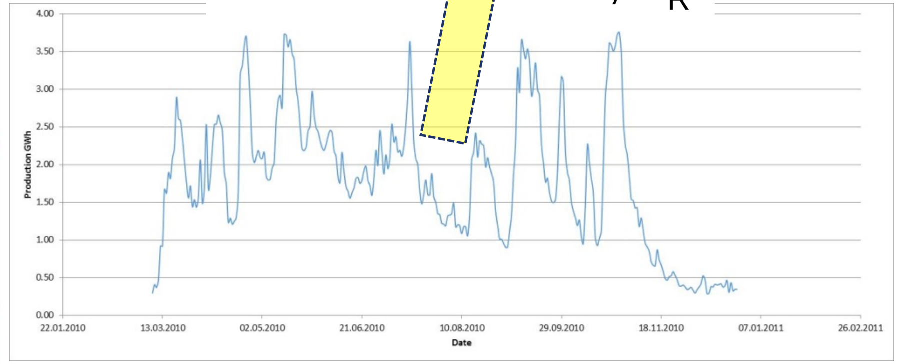
Multiple regression model for regional generation



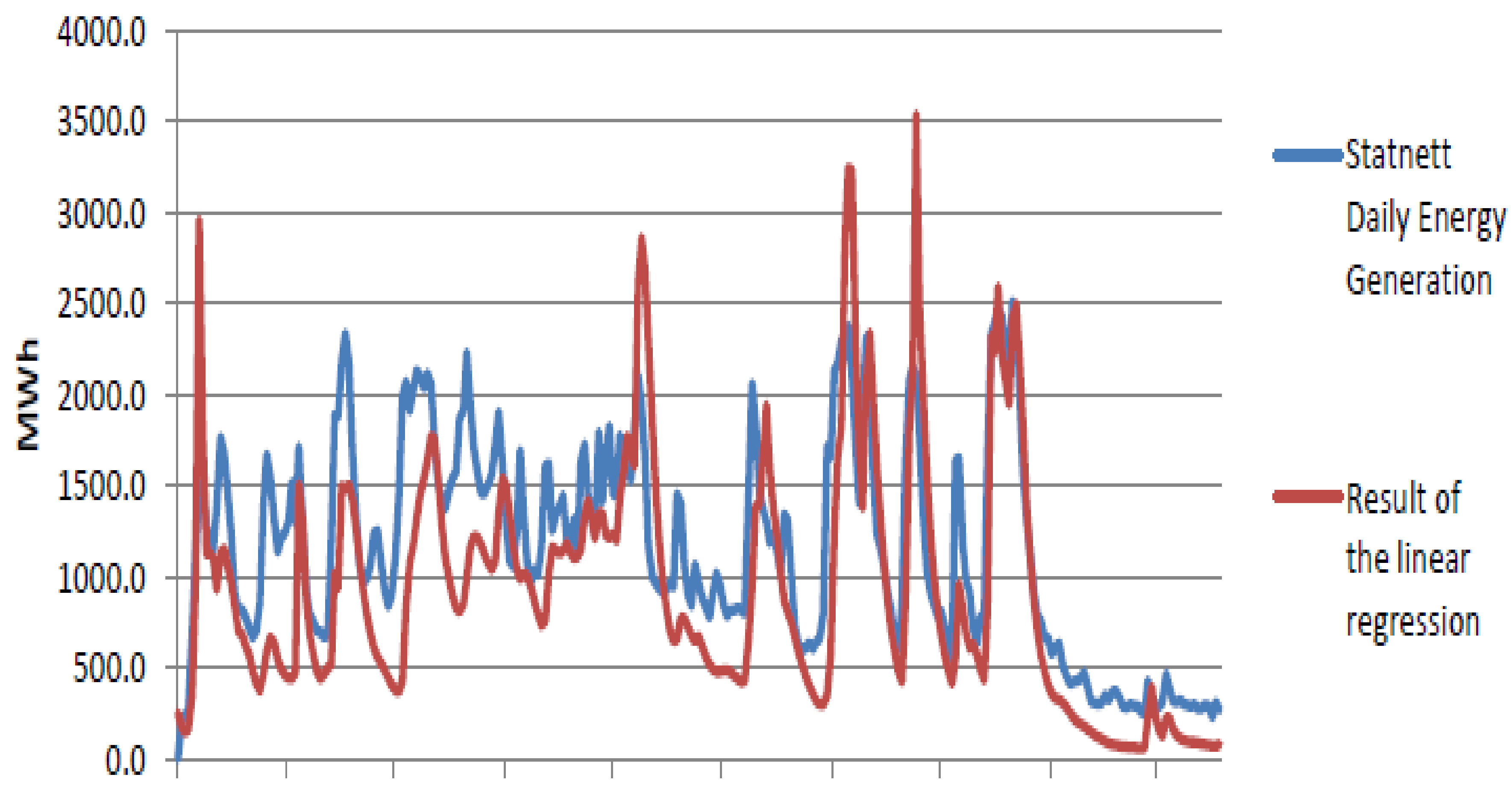


$$P_R = k_1*Q_1+k_2*Q_2+k_3*Q_3+\ldots+k_n*Q_n$$

Actual Generation, P_R



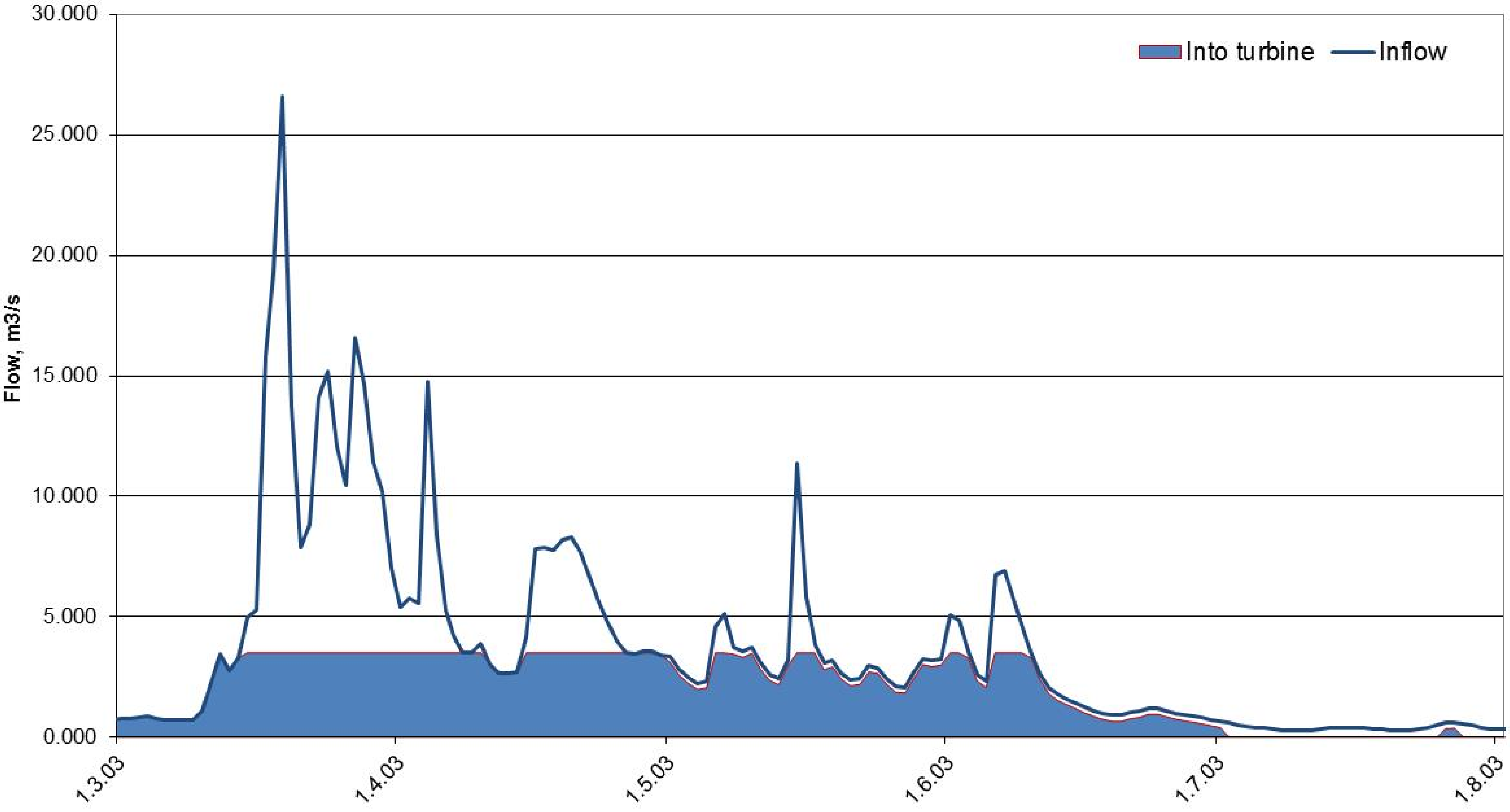
Best results for multiple regression model (2010)



A regression model was established where:
regional generation $\mathbf{P_R = k_1{*}Q_1{+}k_2{*}Q_2{+}k_3{*}Q_3{+} \ldots {+}k_n{*}Q_n}$
using runoff Q_i from n different runoff stations in the regression

«Cutoff» problem typical for small no-storage hydro

Highly variable «cut-off» makes linear model less suitable for unregulated hydro



Methodology 2 – Conceptual model

Method 2 – Detailed Conceptual model

Historical data
Model development

Forecast data
Model use

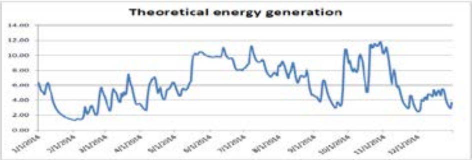
Observed flow at gauging stations

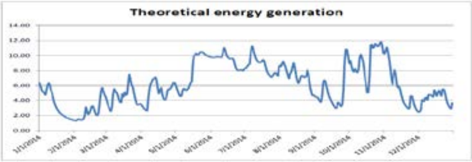
Forecasted flow at gauging stations

Scaling to hydropower site

Flow at hydropower intake

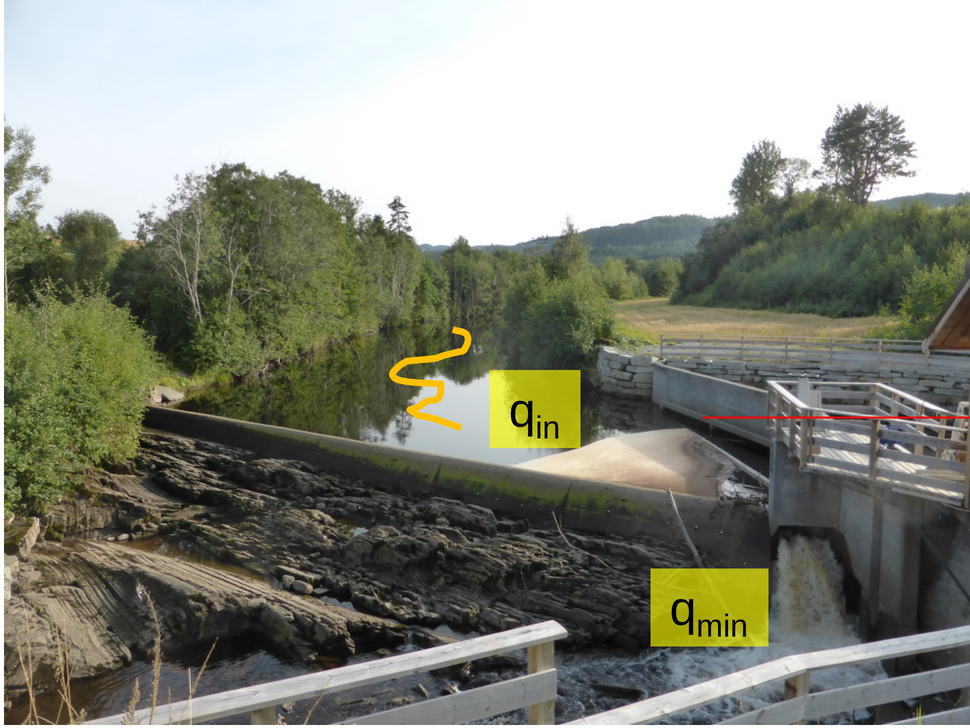
Plant characteristics
(head, capacity, efficiency)

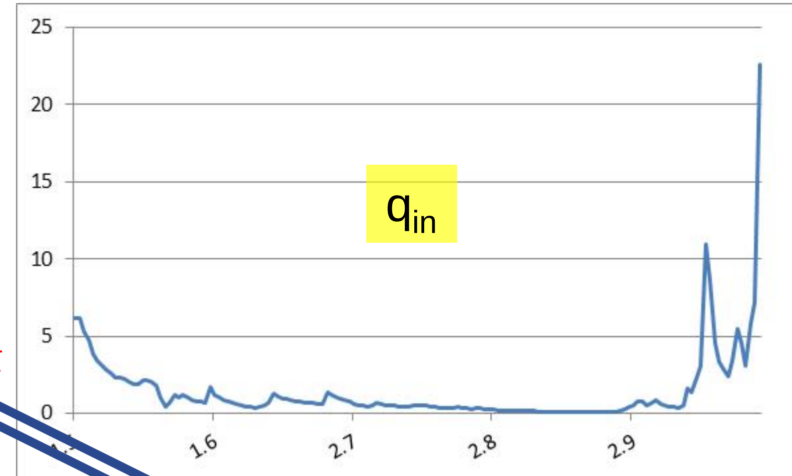


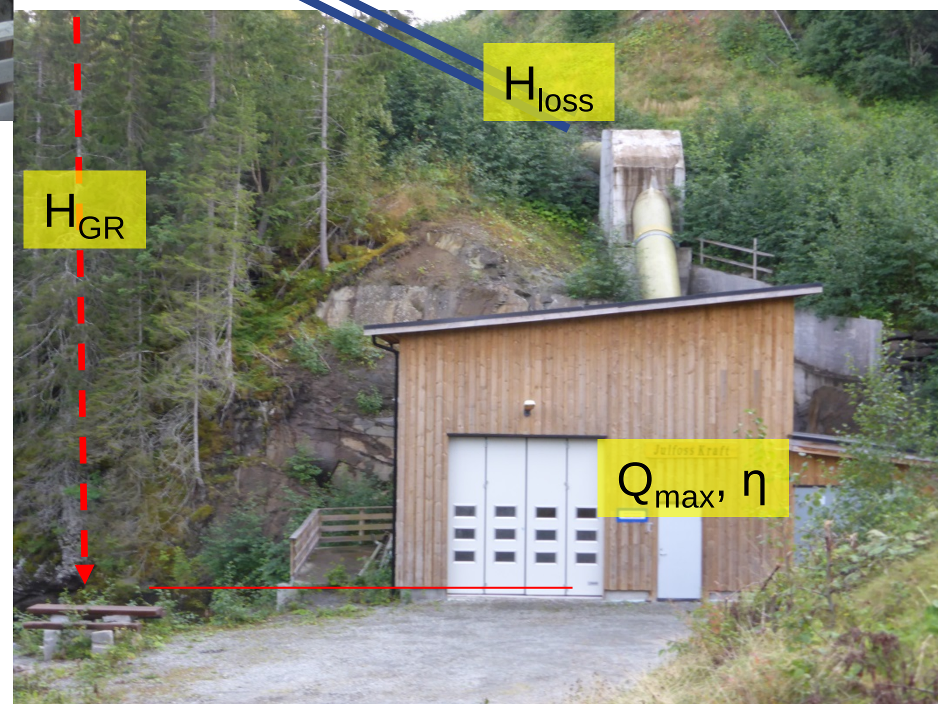


Computed historical generation

Forecast of future generation



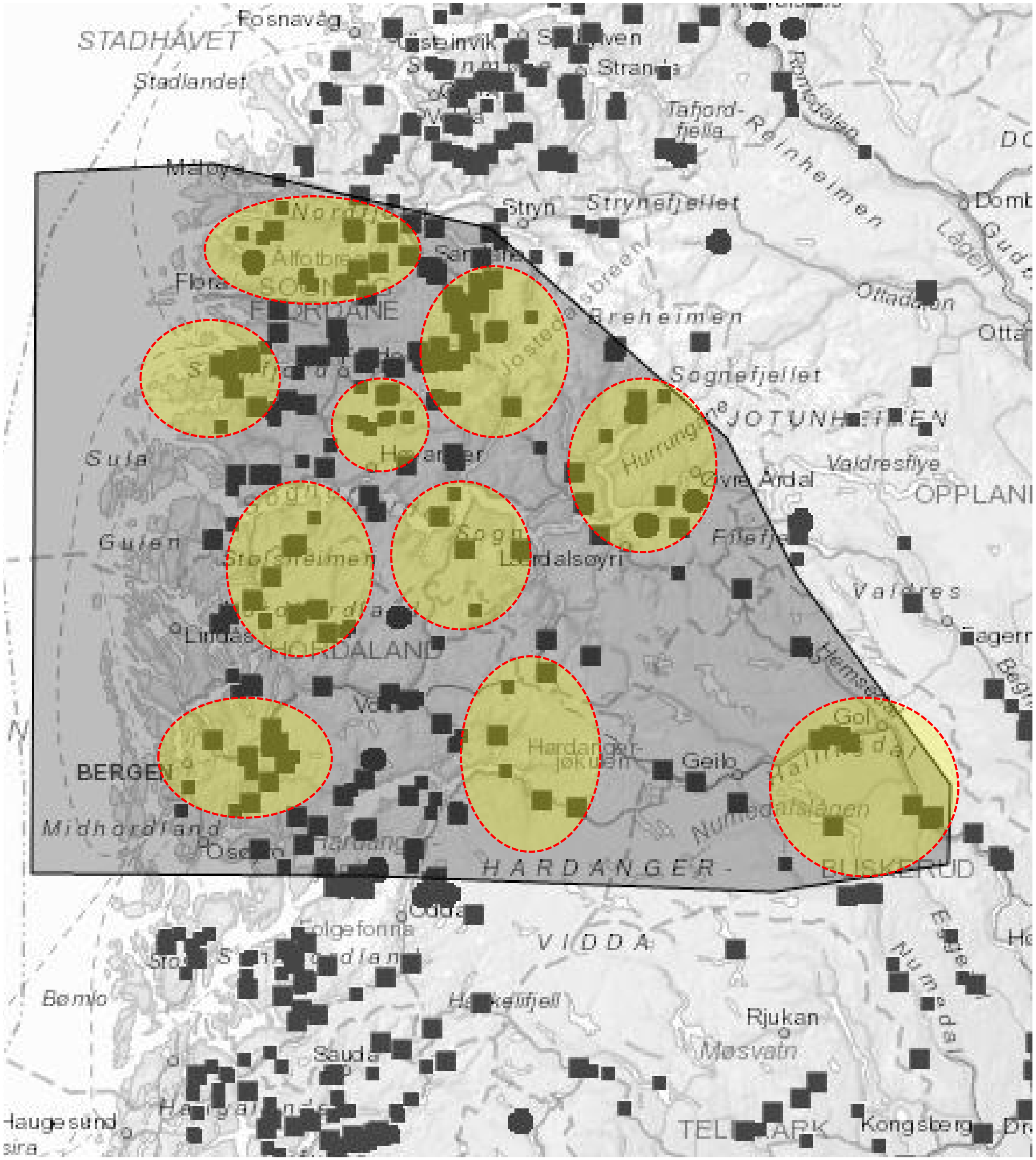




<u>Hydropower generation P_t depends on:</u>

Inflow at the Intake (q_i)
Environmental flow (q_{min})
Turbine flow $q_t = q_i - q_{min}$
Gross Head (H_{GR})
Net Head $H_n = H_{GR} - H_{loss}$
Capacity (Q_{max})
Efficiency (η)

$$P_t = 9.81 * q_t * H_n * \eta \text{ (kW)}$$



Hydropower generation model was established for 252 small hydro plant in region NO5

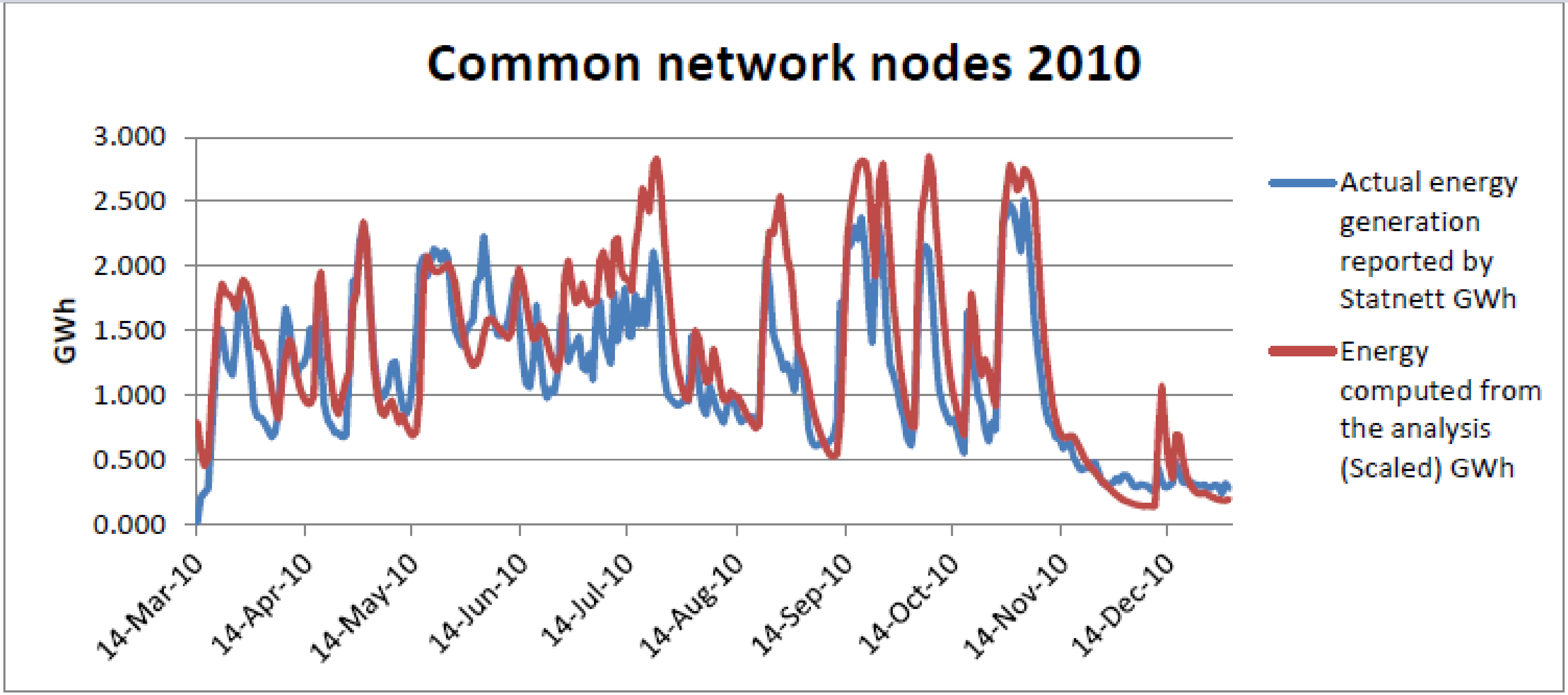
Flow at each station was computed from nearby NVE runoff stations

Computed generation was aggregated and compared to Statnett data in nodes and in the whole region

Smalles unit possible are called nodes. Up to 20+ stations in one node

Some 10 nodes were found with data for all years 2010-2014

Observed (actual) and computed generation for 2010
Sum for all nodes with data reported by Statnett

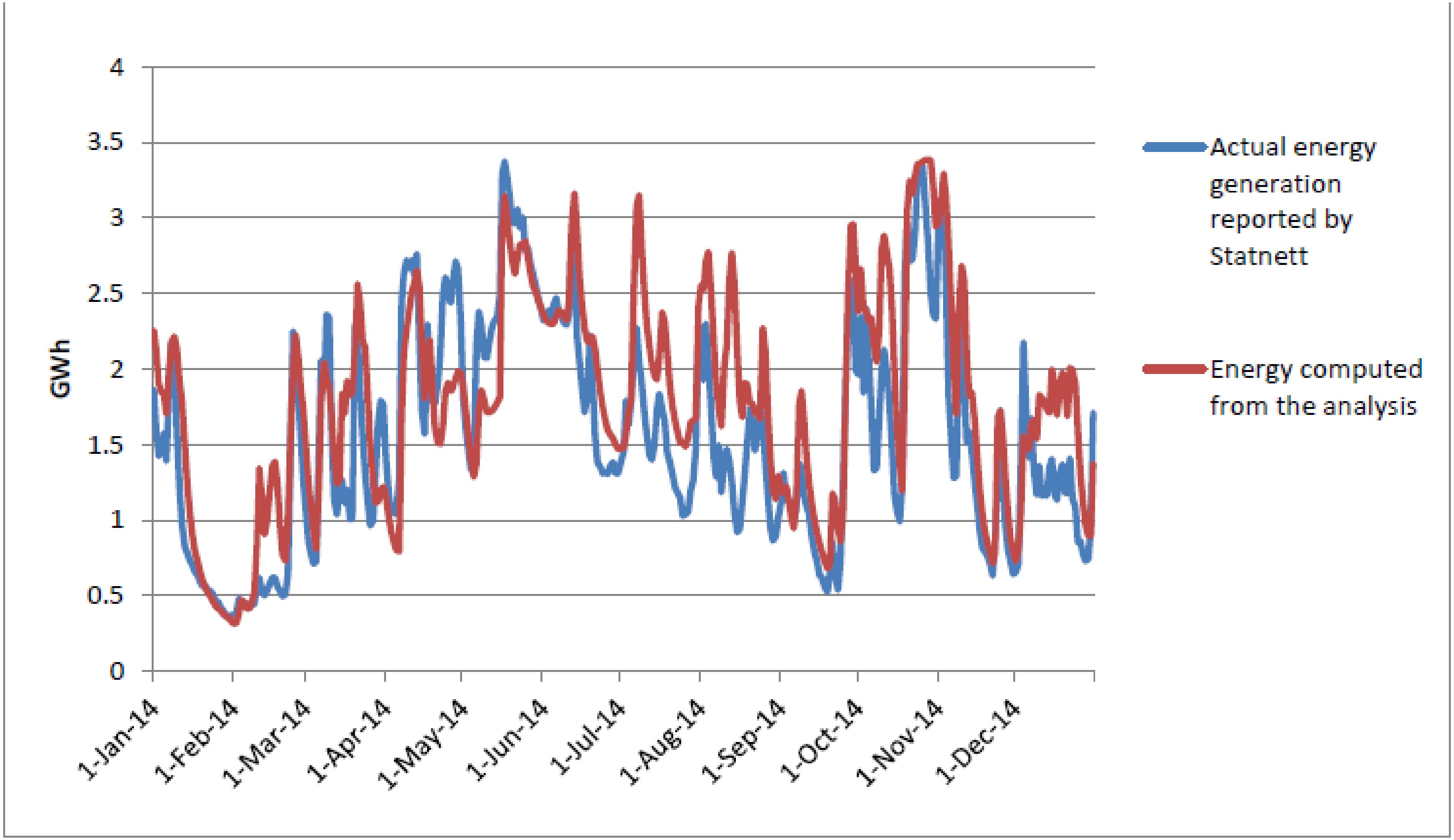


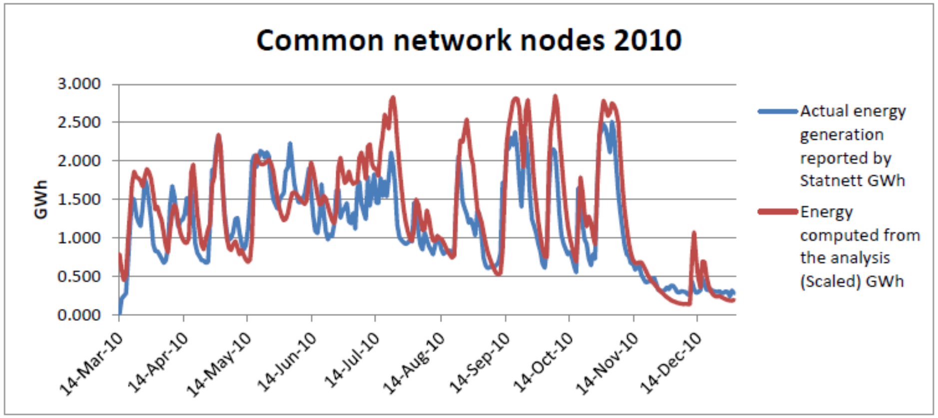
Generation computed for each station by equation
Then aggregated to each node and to region NO5

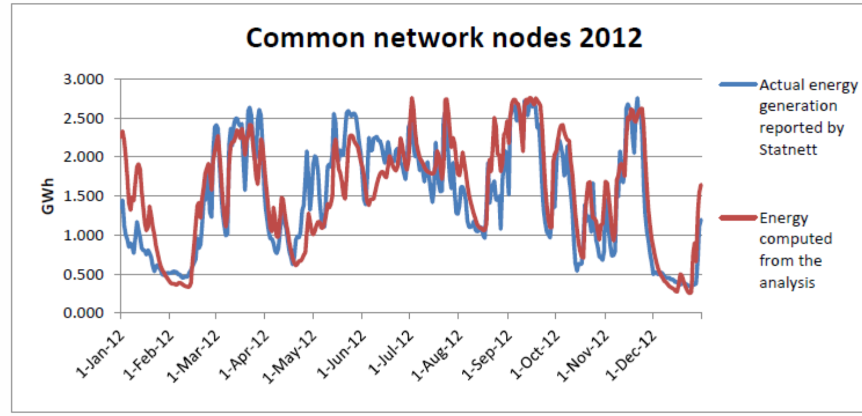
$$P_t = 9.81 * q_t * H_n * \eta \text{ (kW)}$$

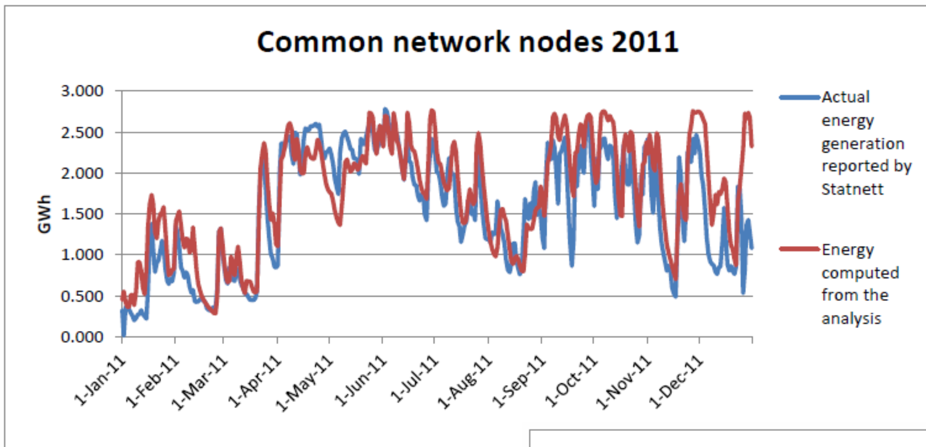
Flow at stations computed by scaling from one of the 5 runoff stations by hydrological analysis

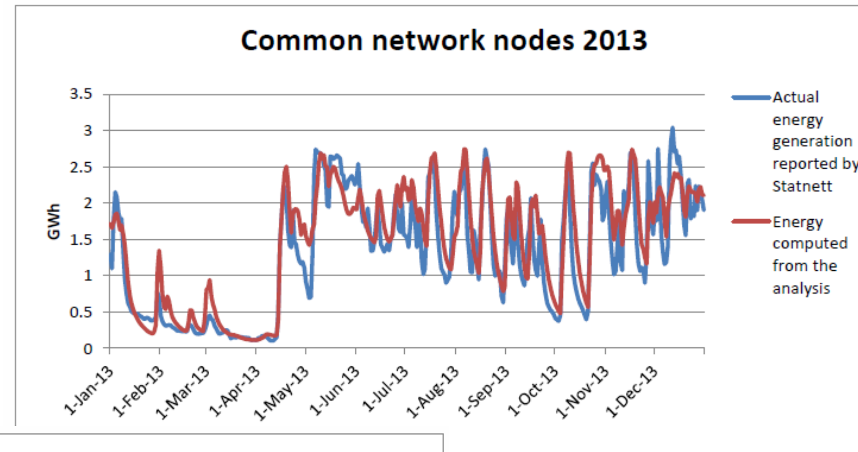
Observed (actual) and computed generation 2014
Sum for all nodes with data reported by Statnett

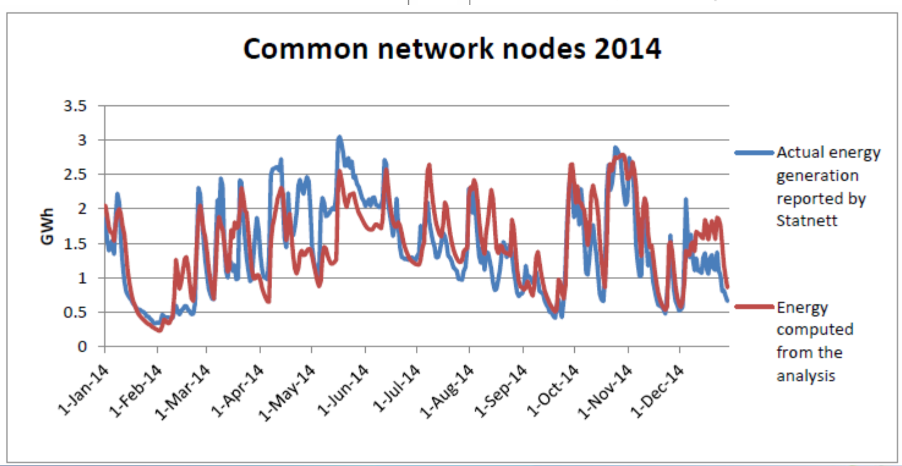



Common network nodes 2010
3.000
2.500
2.000
1.500
1.000
0.500
0.000
GWh
14-Mar-10
14-Apr-10
14-May-10
14-Jun-10
14-Jul-10
14-Aug-10
14-Sep-10
14-Oct-10
14-Nov-10
14-Dec-10
Actual energy generation reported by Statnett GWh
Energy computed from the analysis (Scaled) GWh

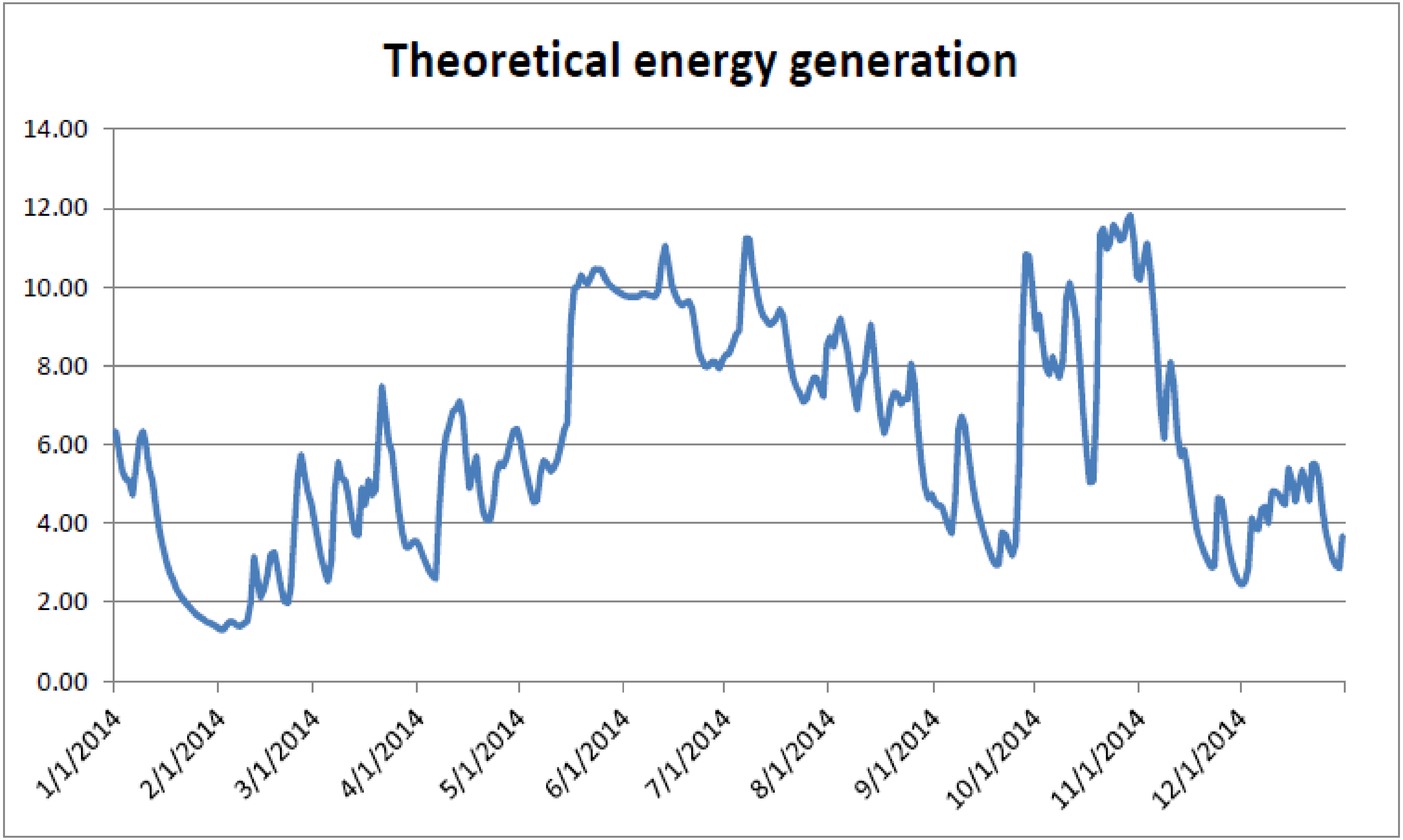

Common network nodes 2012
3.000
2.500
2.000
1.500
1.000
0.500
0.000
GWh
1-Jan-12
1-Feb-12
1-Mar-12
1-Apr-12
1-May-12
1-Jun-12
1-Jul-12
1-Aug-12
1-Sep-12
1-Oct-12
1-Nov-12
1-Dec-12
Actual energy generation reported by Statnett
Energy computed from the analysis


Common network nodes 2011
3.000
2.500
2.000
1.500
1.000
0.500
0.000
GWh
1-Jan-11
1-Feb-11
1-Mar-11
1-Apr-11
1-May-11
1-Jun-11
1-Jul-11
1-Aug-11
1-Sep-11
1-Oct-11
1-Nov-11
1-Dec-11
Actual energy generation reported by Statnett
Energy computed from the analysis


Common network nodes 2013
3.5
3
2.5
2
1.5
1
0.5
0
GWh
1-Jan-13
1-Feb-13
1-Mar-13
1-Apr-13
1-May-13
1-Jun-13
1-Jul-13
1-Aug-13
1-Sep-13
1-Oct-13
1-Nov-13
1-Dec-13
Actual energy generation reported by Statnett
Energy computed from the analysis

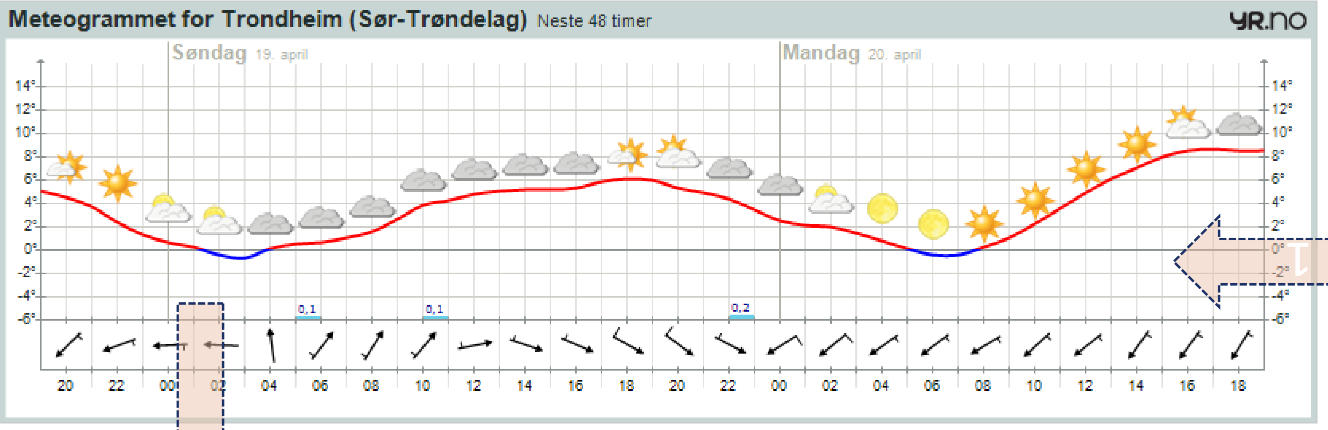

Common network nodes 2014
3.5
3
2.5
2
1.5
1
0.5
0
GWh
1-Jan-14
1-Feb-14
1-Mar-14
1-Apr-14
1-May-14
1-Jun-14
1-Jul-14
1-Aug-14
1-Sep-14
1-Oct-14
1-Nov-14
1-Dec-14
Actual energy generation reported by Statnett
Energy computed from the analysis

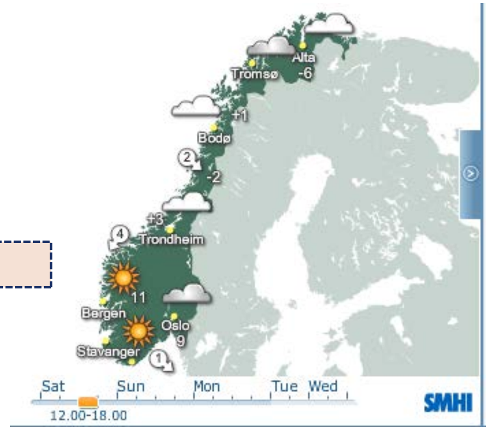
Computed generation for all 252 power plants in NO5 in 2014

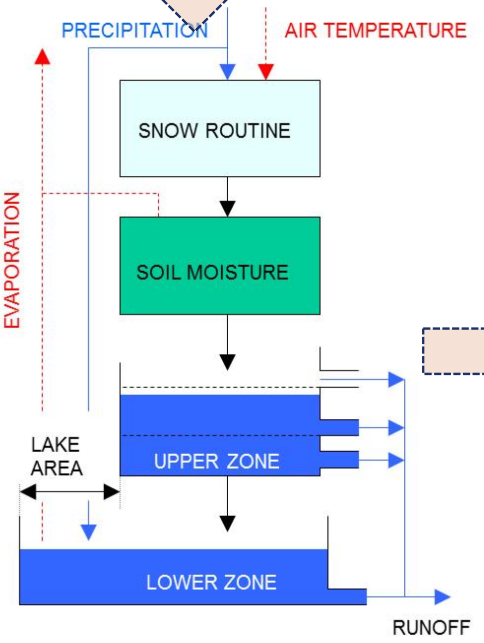


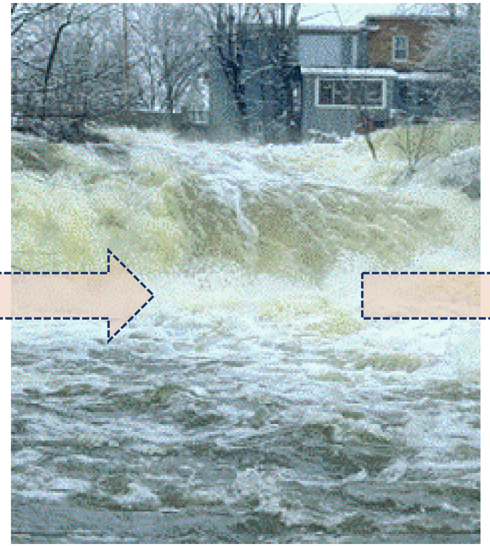
Forecasting future hydropower inflow/generation

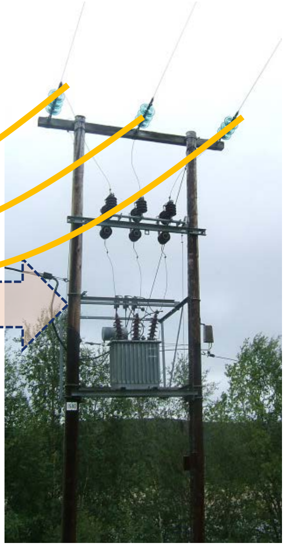
Forecasting hydropower inflow/generation



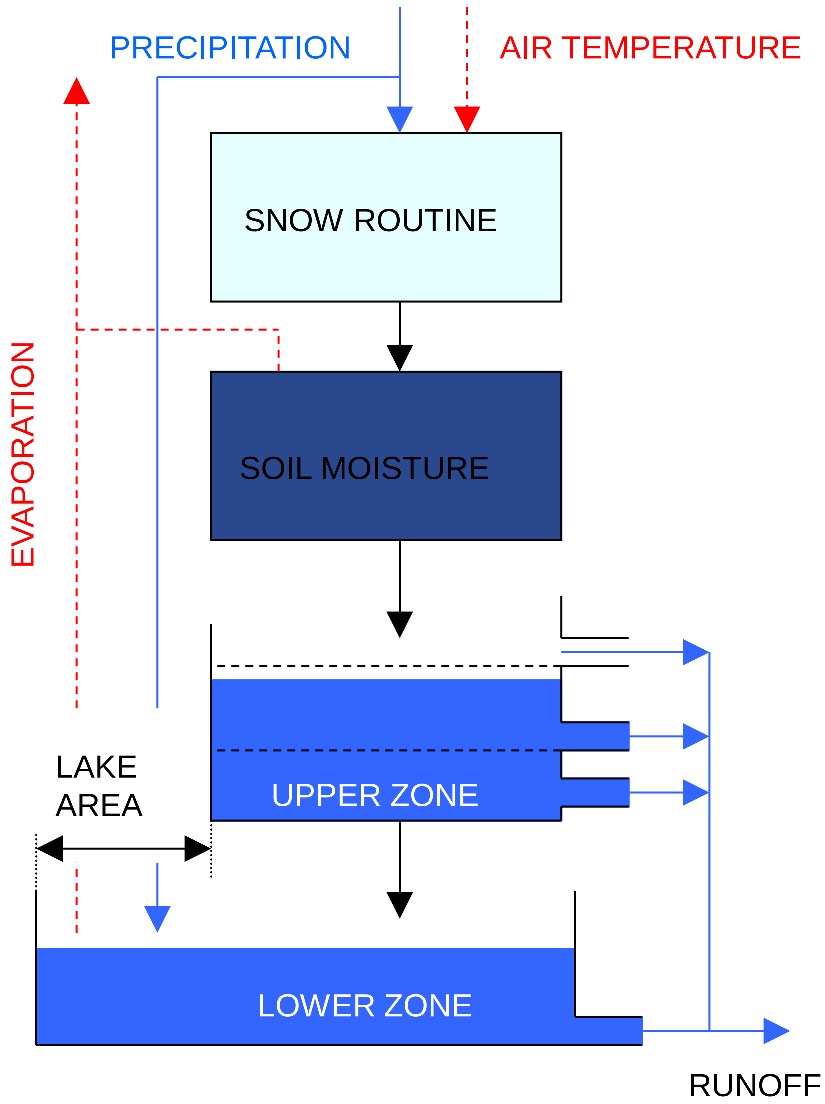






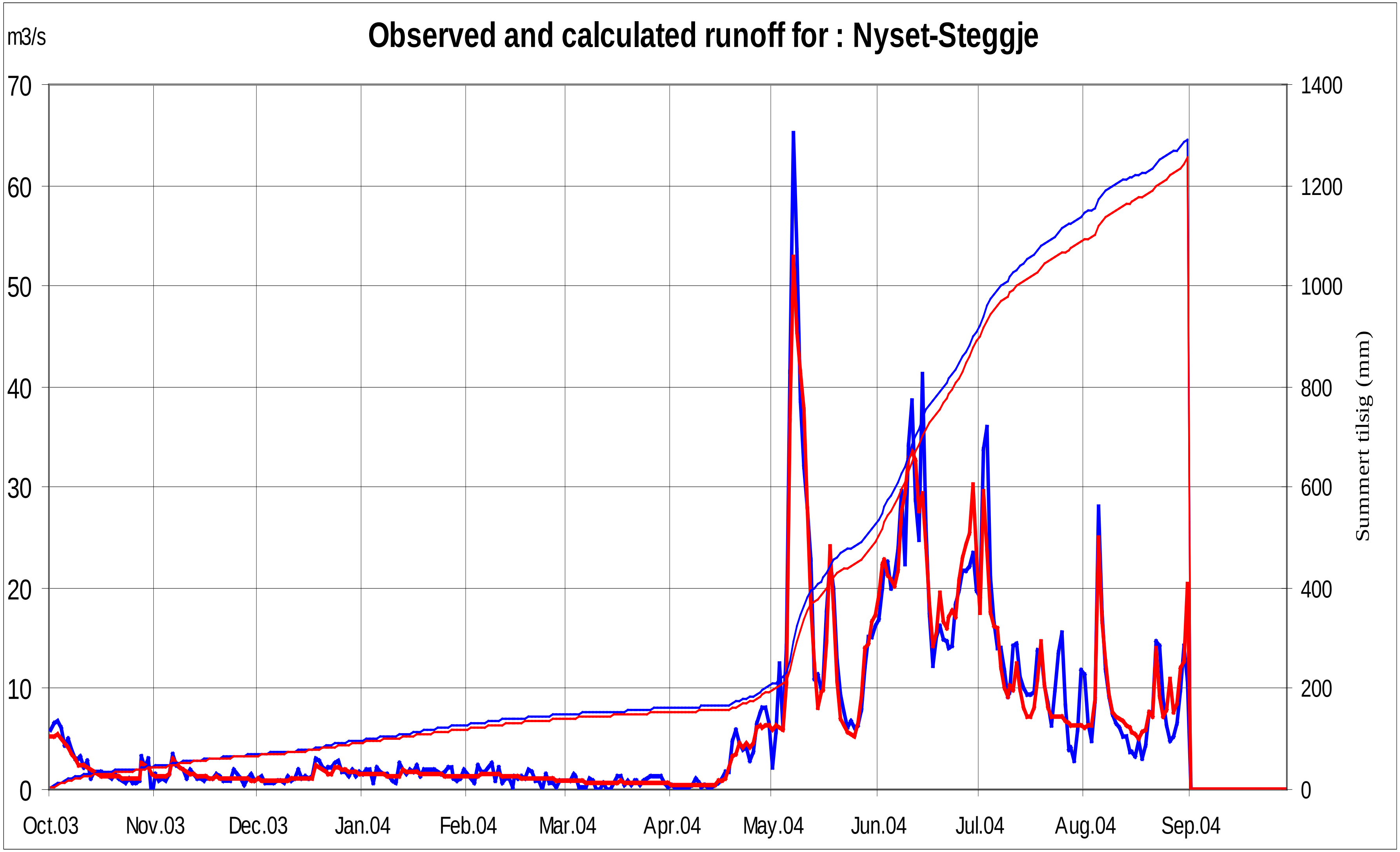


HBV-model – a Precipitation-Runoff model

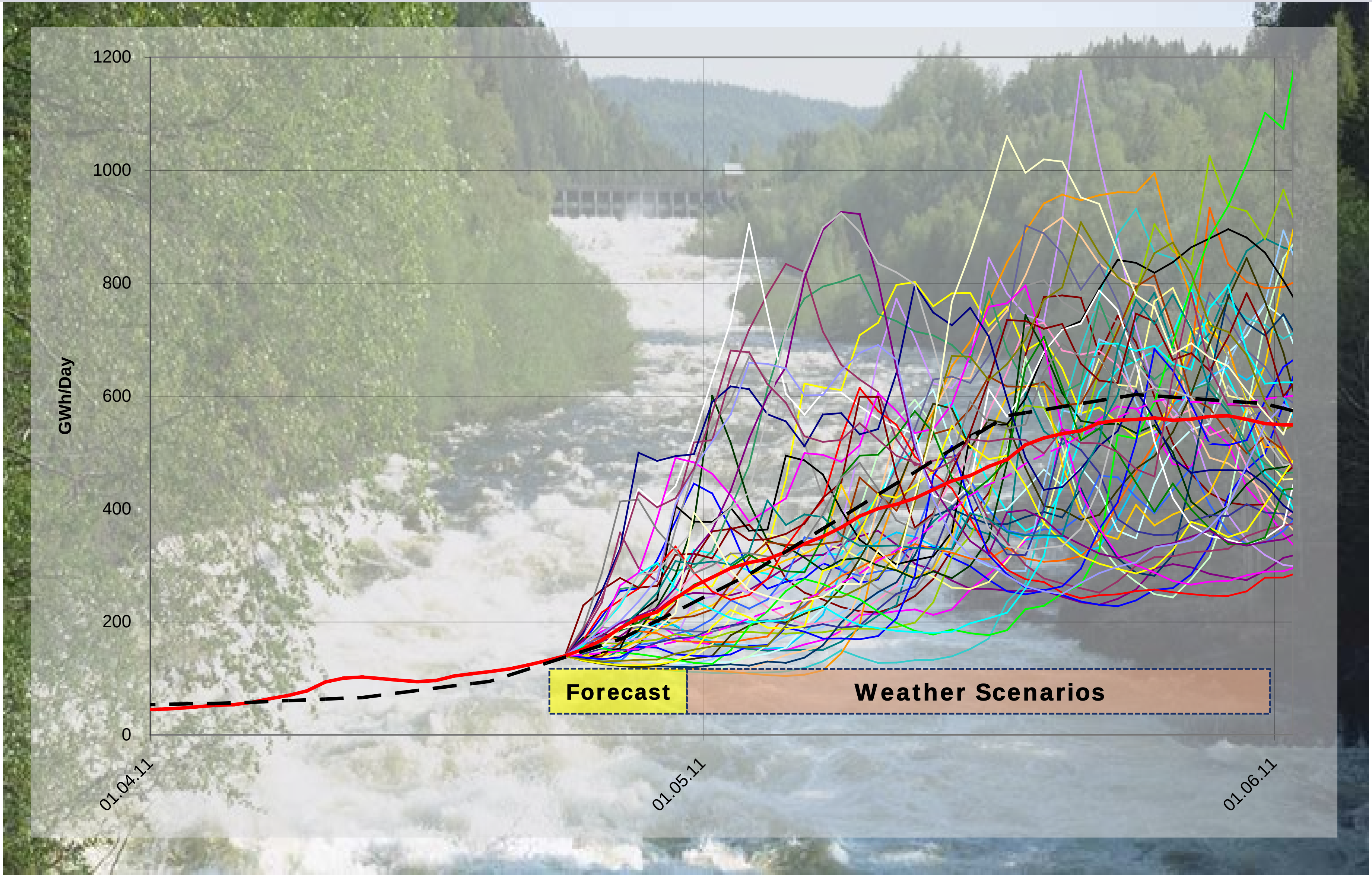


Example of HBV-model calibration – Inflow to Nyset-Steggje power system

Blue – Observed **Red-Simulated by HBV**



Using the HBV-model: Runoff forecast and runoff scenarios



Summary - Conclusions

Models for sum hydropower generation for hundreds of small hydropower plants have been demonstrated for Elspot Region NO5, based on runoff from NVE-stations

Only a few (<10) runoff stations is needed to get reasonable good results for a region

Generation forecasts can be based on runoff forecasts for the same (few) runoff stations, using calibrated HBV-models and quantitative weather forecasts

In this case, only 5 runoff stations were used for modelling > 250 power stations

Using more runoff stations will improve results, but the model calibration and operation cost will also increase. Optimum number should be studied.

Collection and combination of data from NVE and Statnett was very challanging, but will be easier now when main problems and bottlenecks have been identified

In Region NO5 252 stations were modelled – going to all 1076 stations in Norway < 10MW will be possible with an estimated 8-10 months of work

Next year we hope to model Region NO3 with 260 small HPP in another MSc Thesis

http://www.cedren.no/