Interactions between land use, climate and hydropower in Scotland

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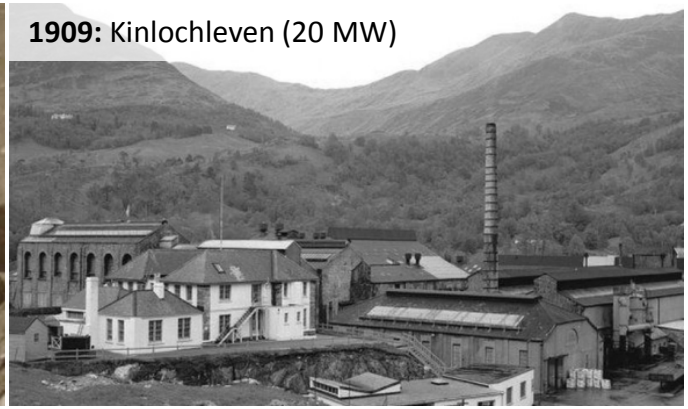
The James Hutton Institute

Scottish hydropower: development

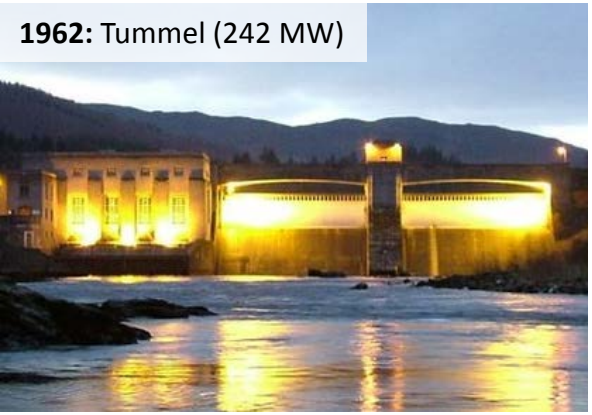
1890: St. Benedict's Abbey (18 kW)

1909: Kinlochleven (20 MW)

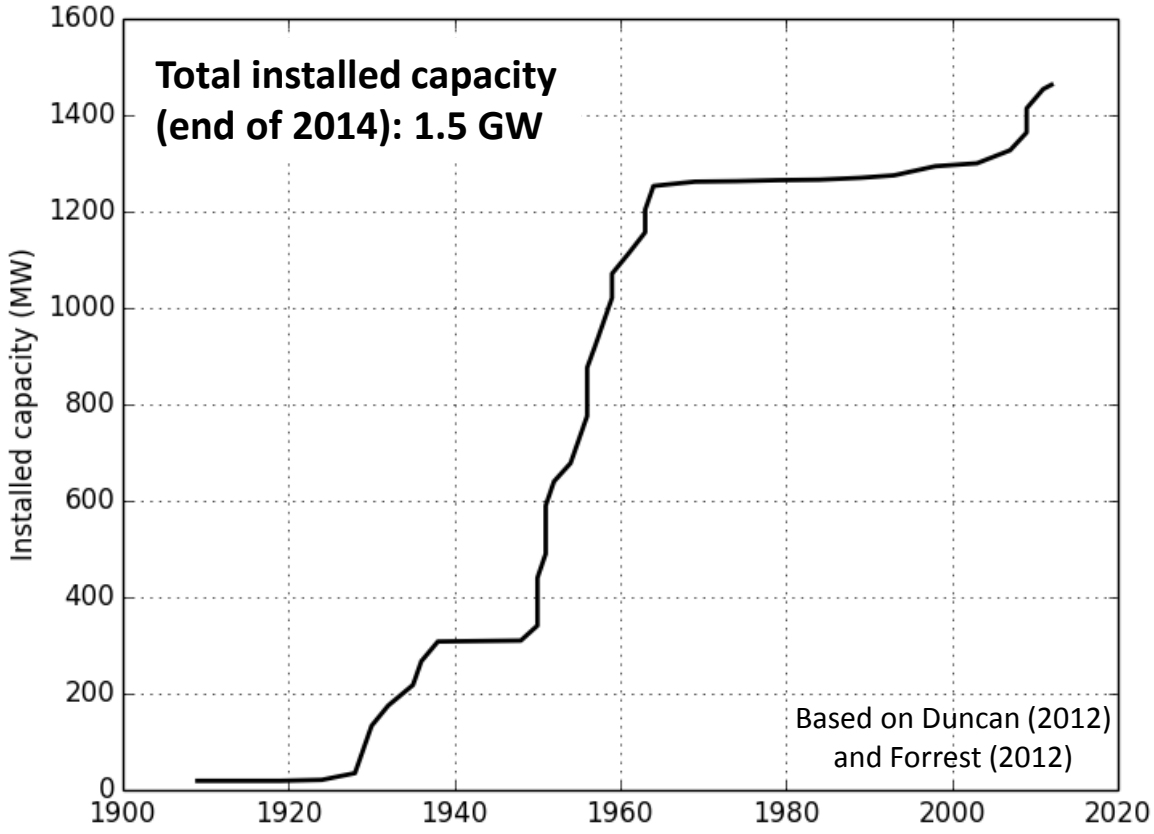


1950: Loch Sloy/Awe (262 MW)

1962: Tummel (242 MW)



2008: Glendoe (100 MW)



Scottish hydropower: the present

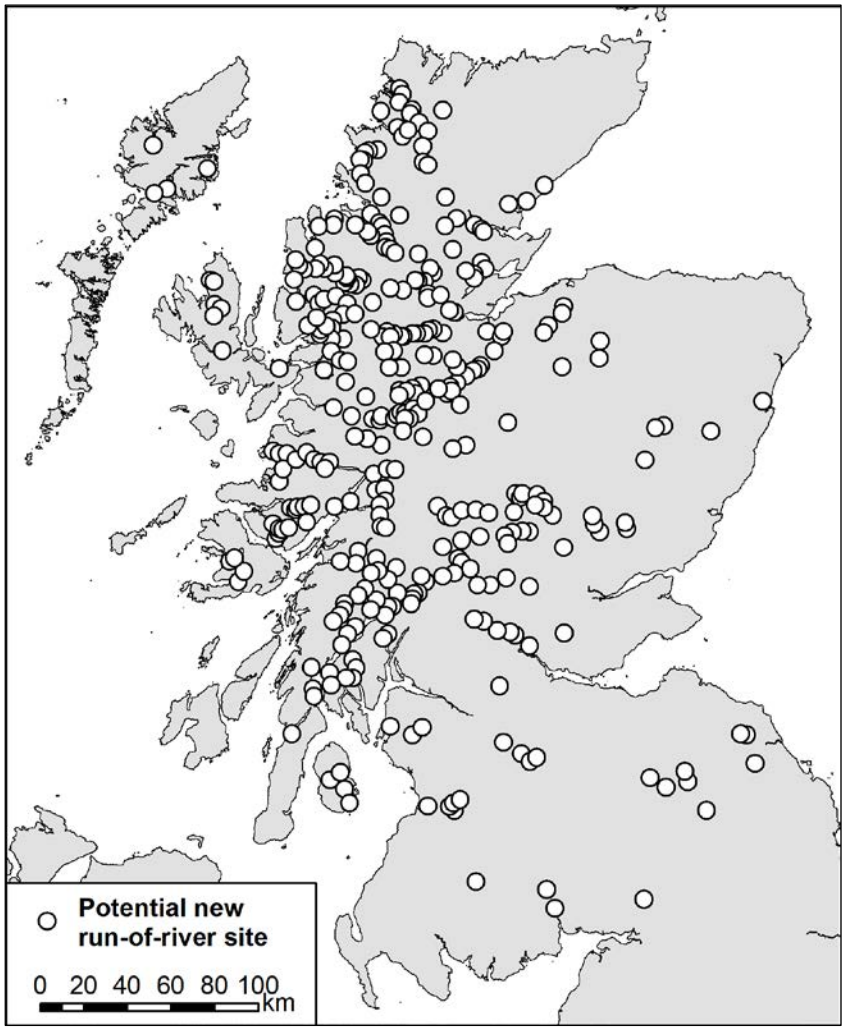
- Scottish Government (2005):
  - *"the work done in the 1940s, 1950s and 1960s […] was almost totally successful in fulfilling the potential for hydroelectricity in Scotland"*
- In recent years, small scale "run-of-river" hydropower has been incentivised (e.g. by the Feed-in Tariff)
- Recent studies estimate **<500 MW** of commercially viable new run-of-river hydropower in Scotland

Study	New hydro potential (MW)
Salford Civil Engineering Ltd. (1989)	286
Garrad Hassan (2001)	270[2]
Nick Forrest (2008)	217[2]
Nick Forrest (2009)	397[2]
Nick Forrest (2012a)	233[2]
Nick Forrest (2012b)	384[2]
Duncan (2012)	440[1] or 898[3]

[1]10% discount rate; [2]8% discount rate; [3]5% discount rate

Scottish hydropower: the future

- Scottish Government hopes to generate equivalent of all gross annual electricity consumption from renewables by 2020
- Requires significant development over next 5 years

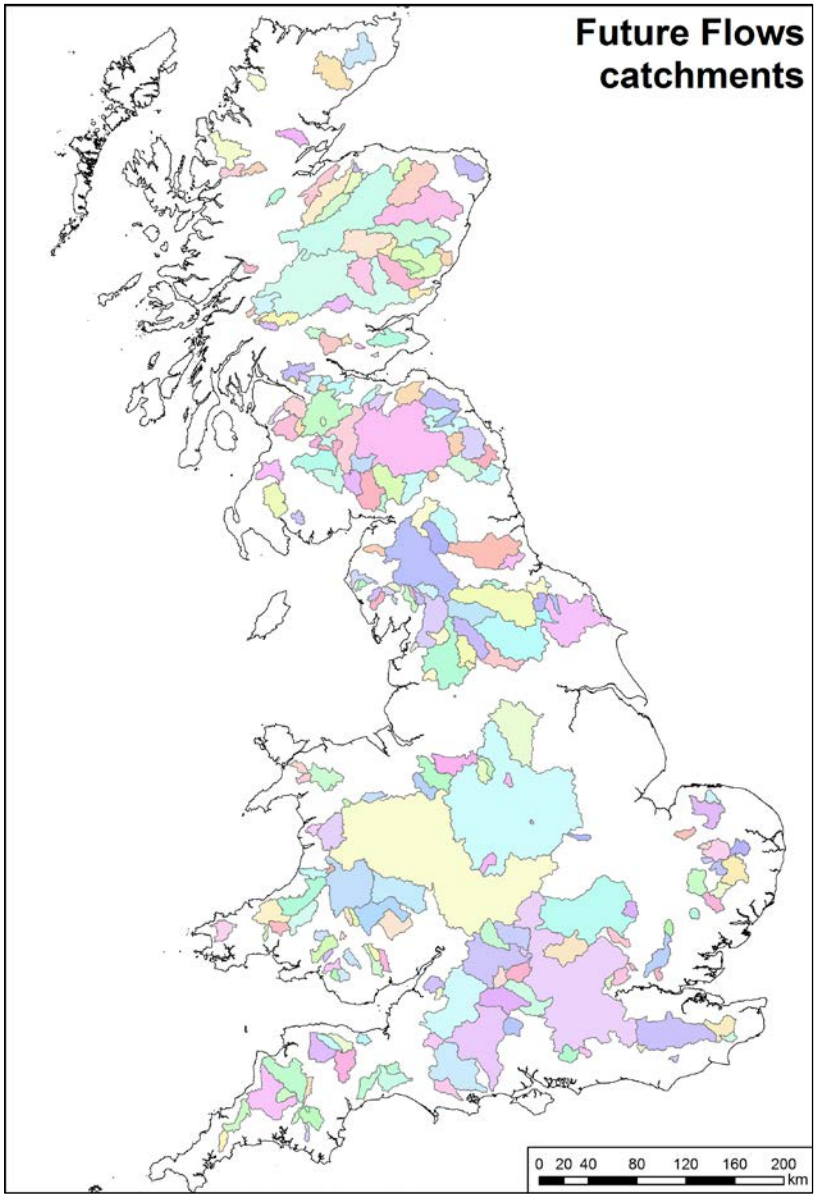


- Run-of-river hydropower is sensitive to changes in flow
- What are the potential effects of land use and climate change on Scotland's future hydropower potential?
- Initial idea:
  - Take the sites identified by **Duncan** (2012)
  - 440 MW in total (assuming 10% discount rate)

Duncan, N. 2012. *Mapping Scotland's hydropower resource*. PhD thesis, University of Edinburgh.

Future Flows data

- CEH project led by **Christel Prudhomme**
- 276 catchments across the UK (~100 in Scotland)
- 11 climate simulations from the medium (A1B) emissions scenario
- Up to 3 hydrological models
- Gives up to 33 realisations of future flow per catchment
- Daily time step, from 1961 to 2098



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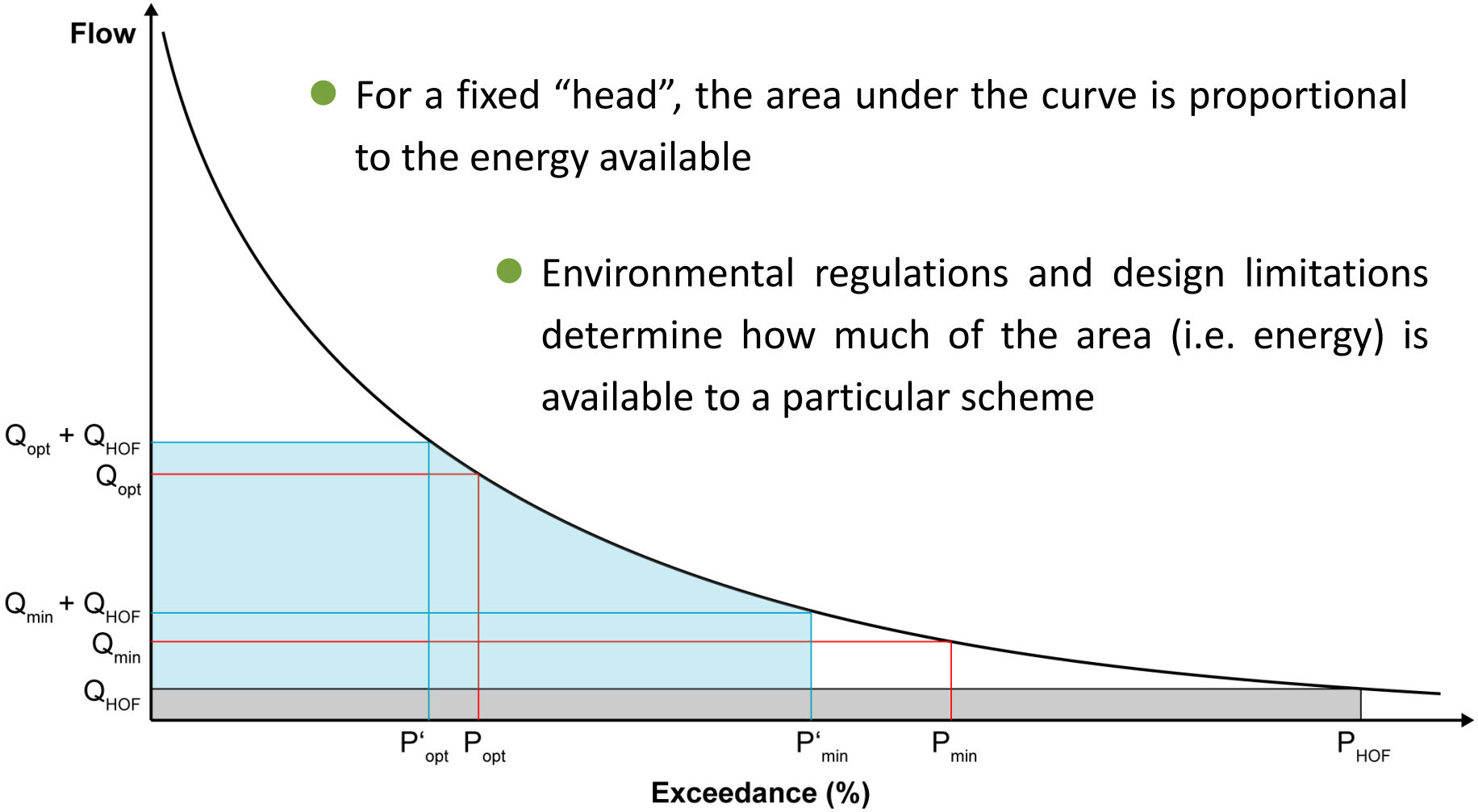
http://www.ceh.ac.uk/sci_programmes/water/futureflowsandgroundwaterlevels.html

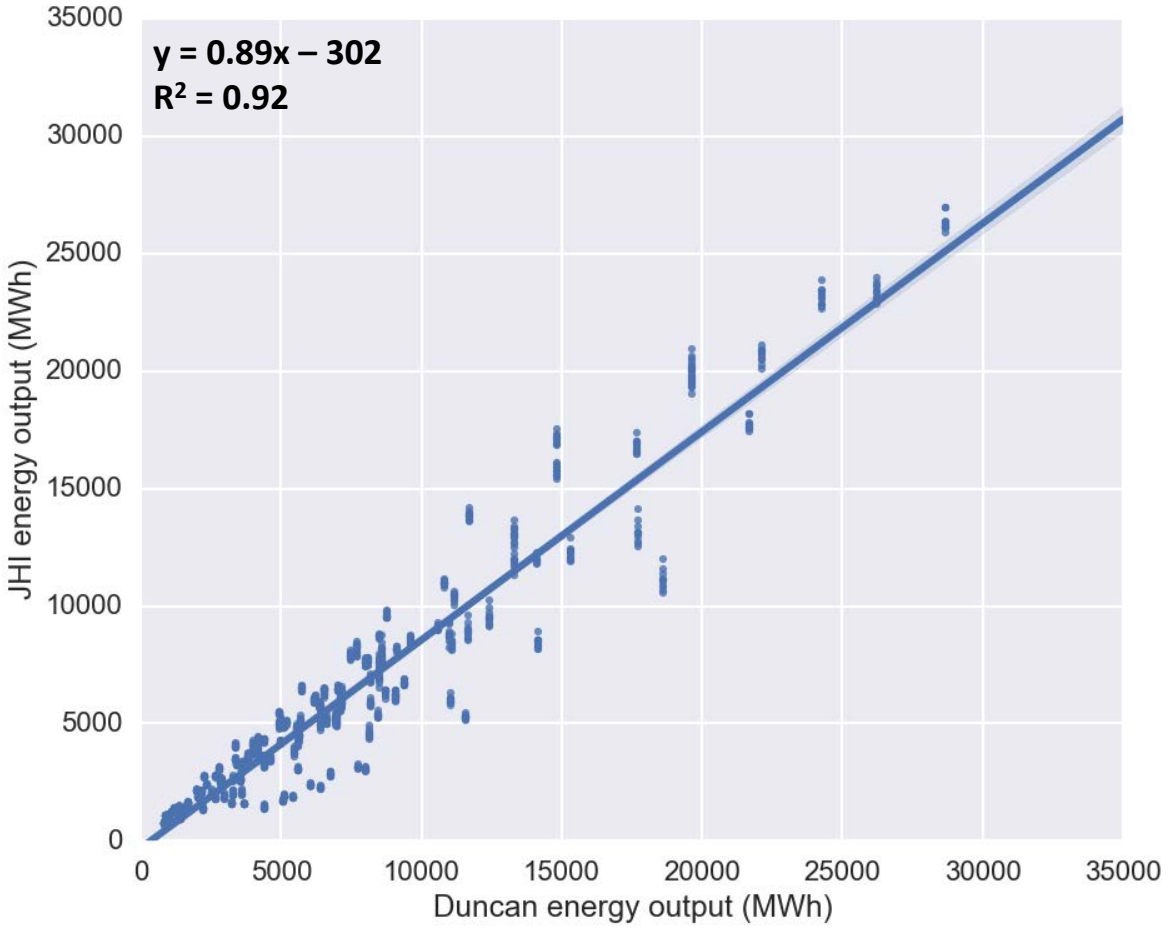
Simple hydropower model

- Based on **Flow Duration Curves** (FDCs)
  - FDCs are a standard tool for preliminary hydropower assessment
    - For a fixed “head”, the area under the curve is proportional to the energy available
      - Environmental regulations and design limitations determine how much of the area (i.e. energy) is available to a particular scheme

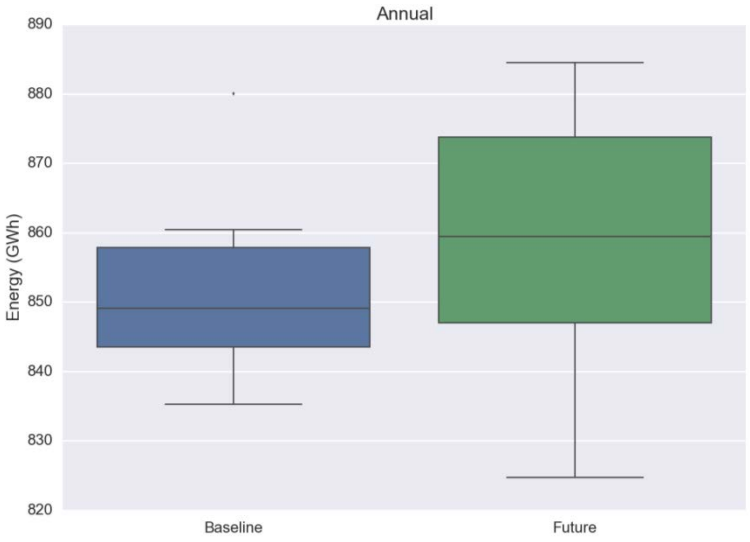


Hydropower assessment: attempt 1

- 136 out of 339 of Duncan's identified sites lie within Future Flows catchments
- Take site specifications (net head, rated capacity etc.) from Duncan (2012)
- Estimate future flow regime by area-scaling Future Flows data
- Test the model output against Duncan's more sophisticated methodology for the baseline period
- Area-scaling slightly **underestimates** headwater flows (and therefore energy output)

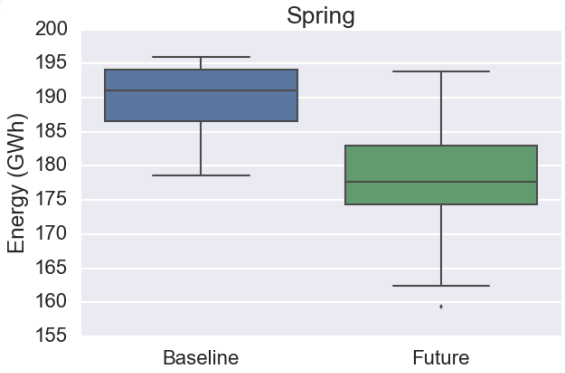


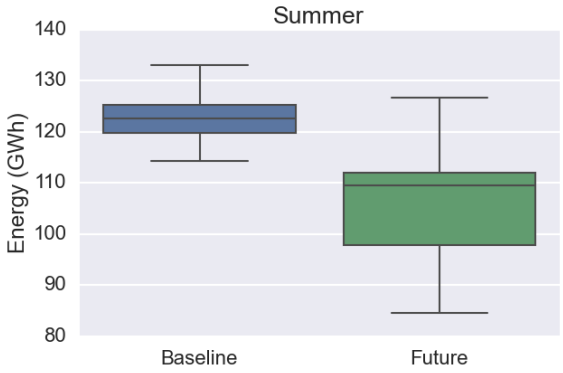
Hydropower assessment: attempt 1

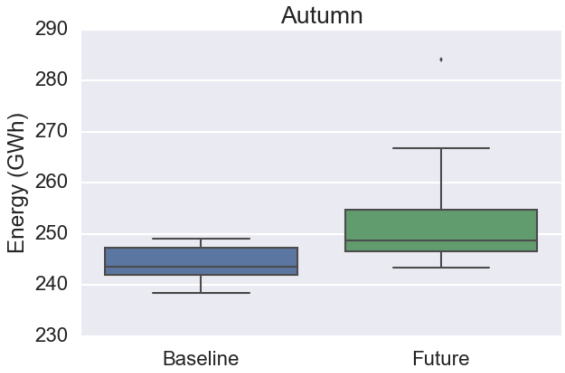


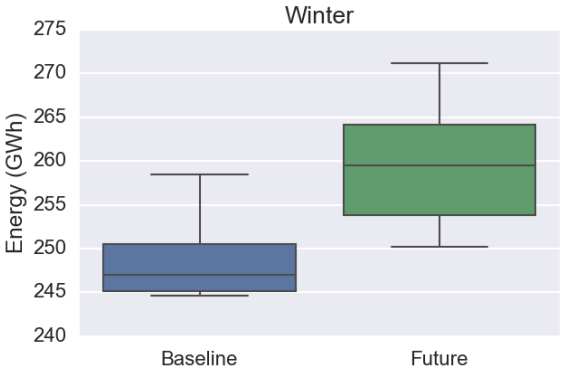
- Plots show the total run-of-river generation potential across 136 sites
- Baseline (1961 to 1990) compared to future (2041 to 2070)
- Overall, the model predicts **little change in annual generation potential**

- But the output becomes significantly **more seasonal**:
  - Increases in autumn and winter
  - Decreases in spring and summer



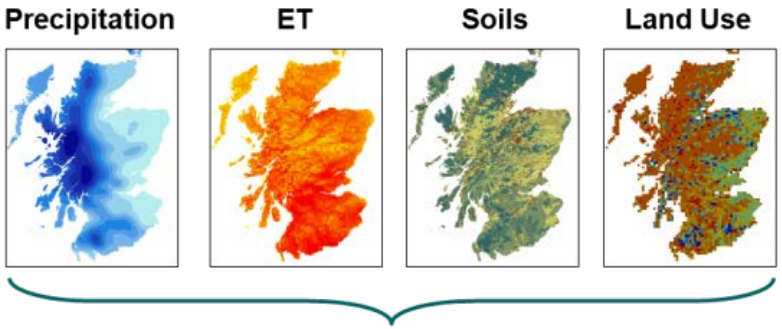


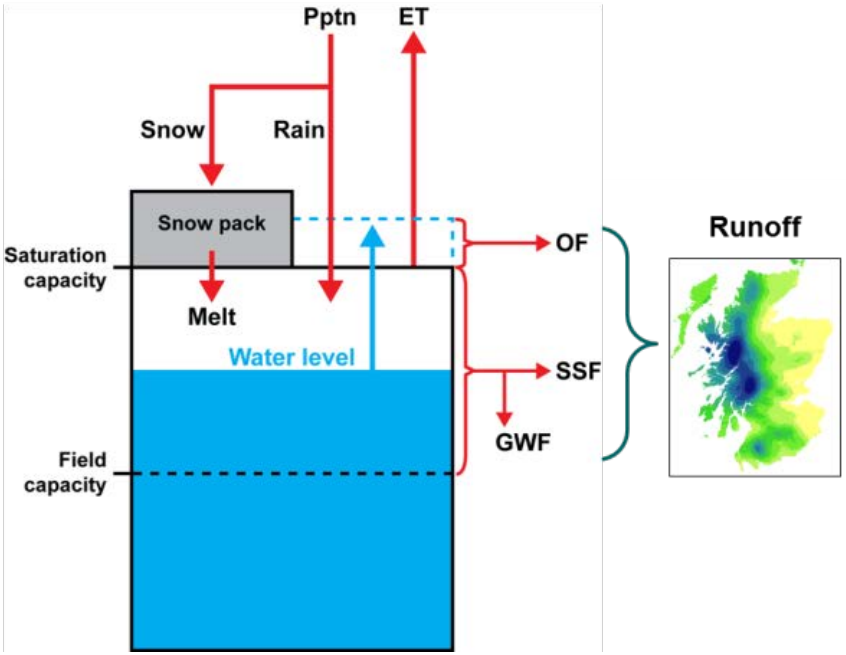




Attempt 1: limitations

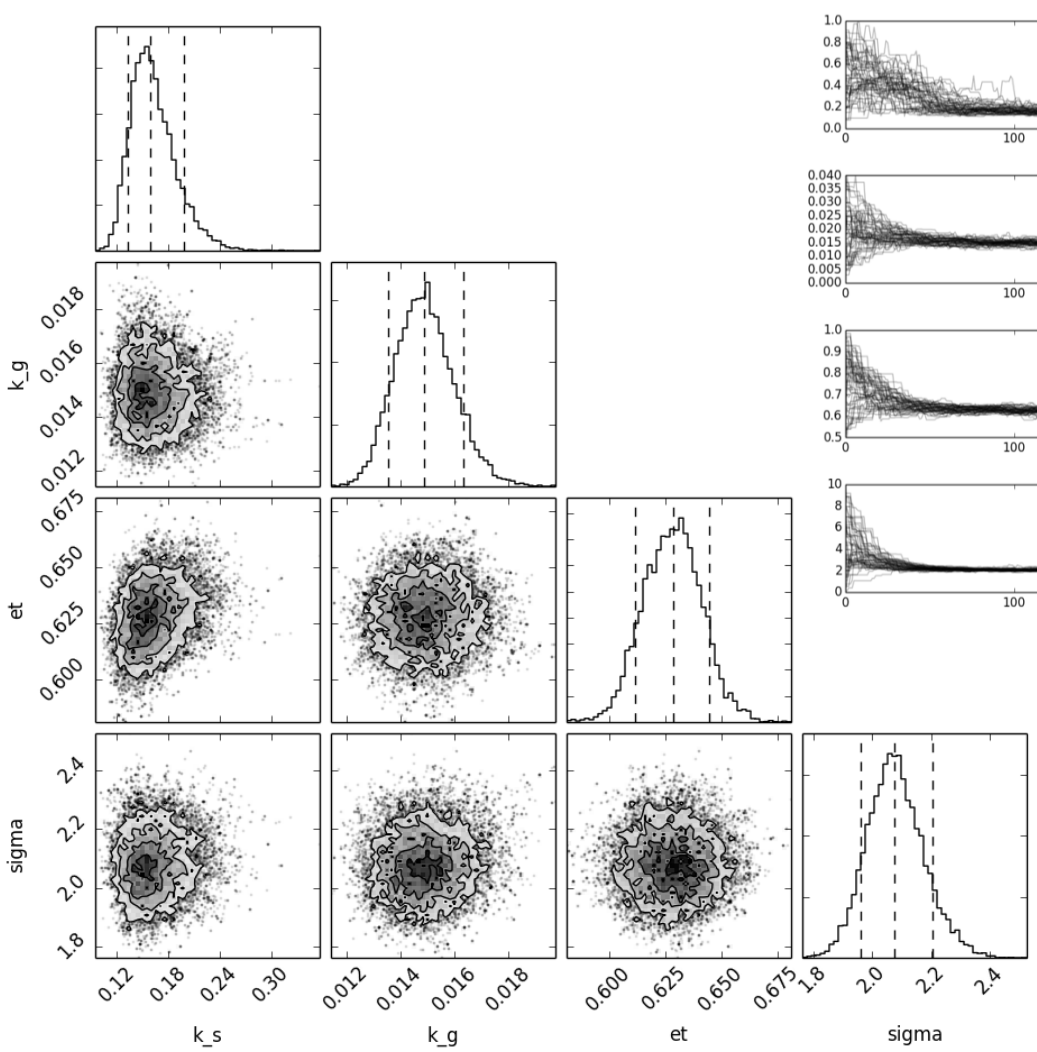
- Not considering all potential sites
- Area-scaling flows is prone to error
- Can't account for influence of land use change
- **Attempt 2:**
  - Develop spatially distributed **water balance model** to estimates flow duration curves for any point on the river network
  - Can incorporate scenarios of land use and climate change

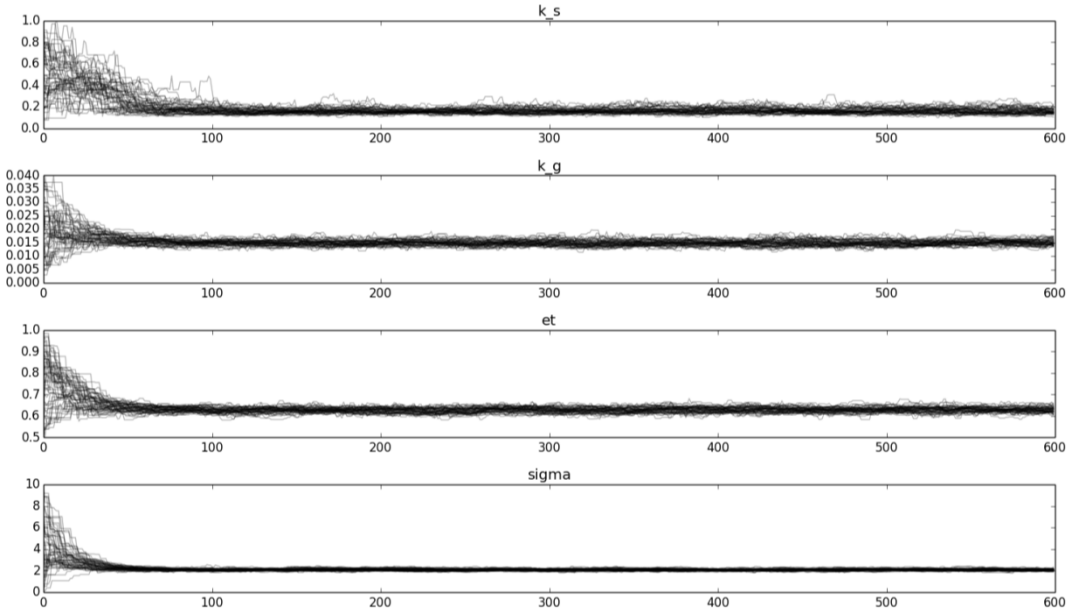




Attempt 2: water balance modelling

- Model calibration at national scale within a Bayesian MCMC framework
- Allows assessment of parameter-related model uncertainty



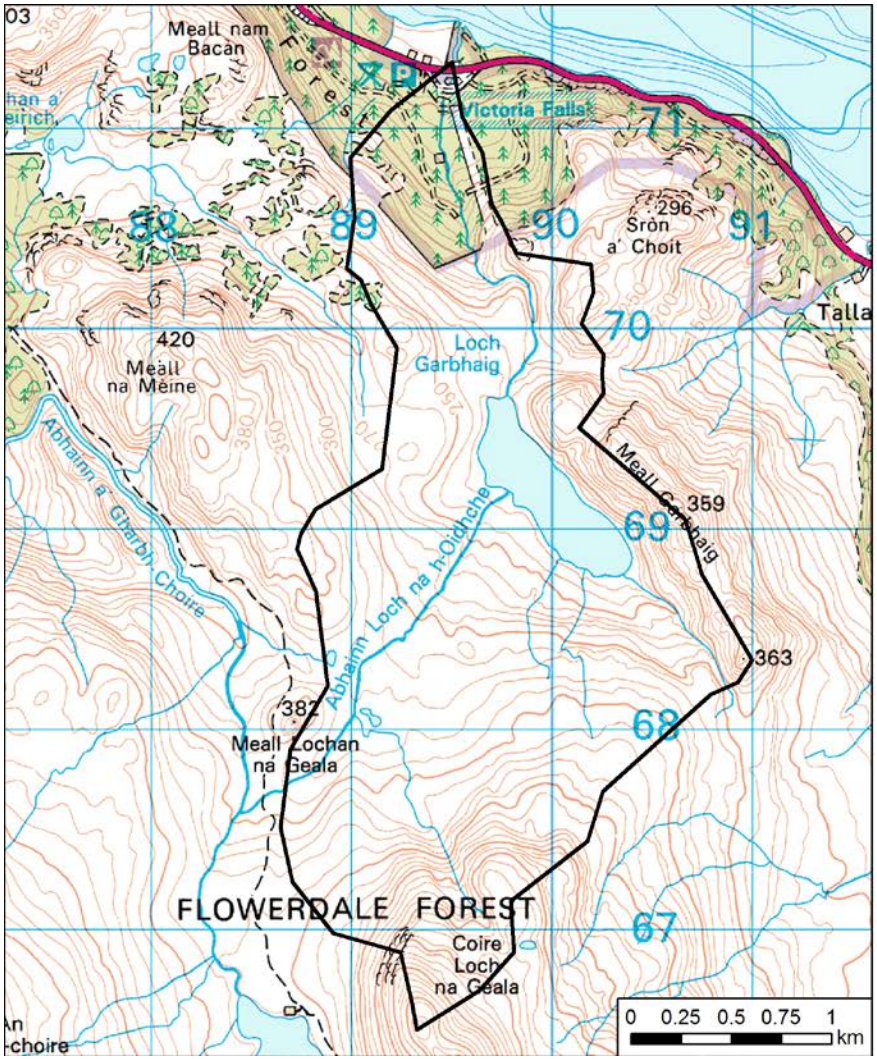


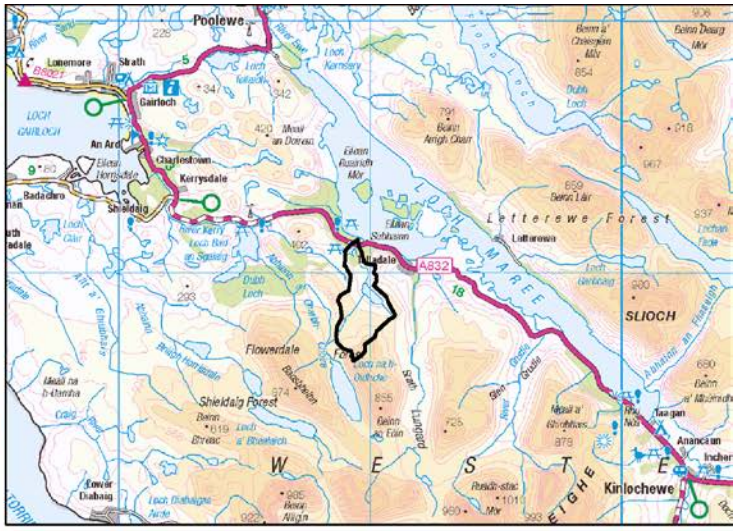
- Example shows 50 “chains” used to calibrate 3 model parameters (plus error term)
- Prior distributions were all uniform

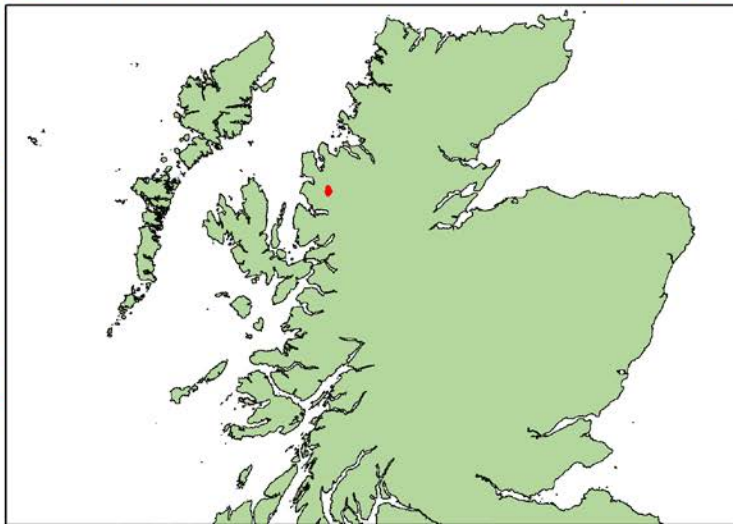
MCMC details: http://dan.iel.fm/emcee/current/

Attempt 2: water balance modelling

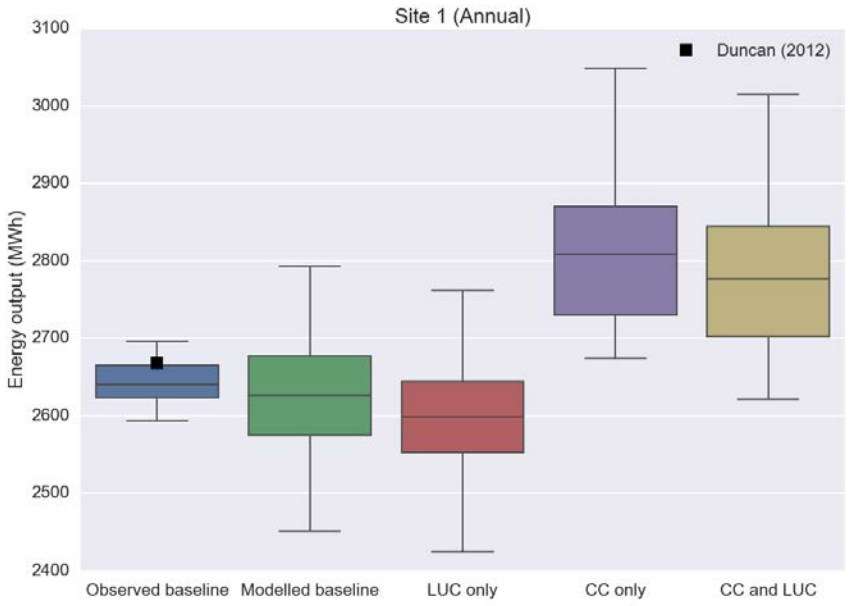
- Example for a single site at Loch Garbhaig, near Kinlochewe



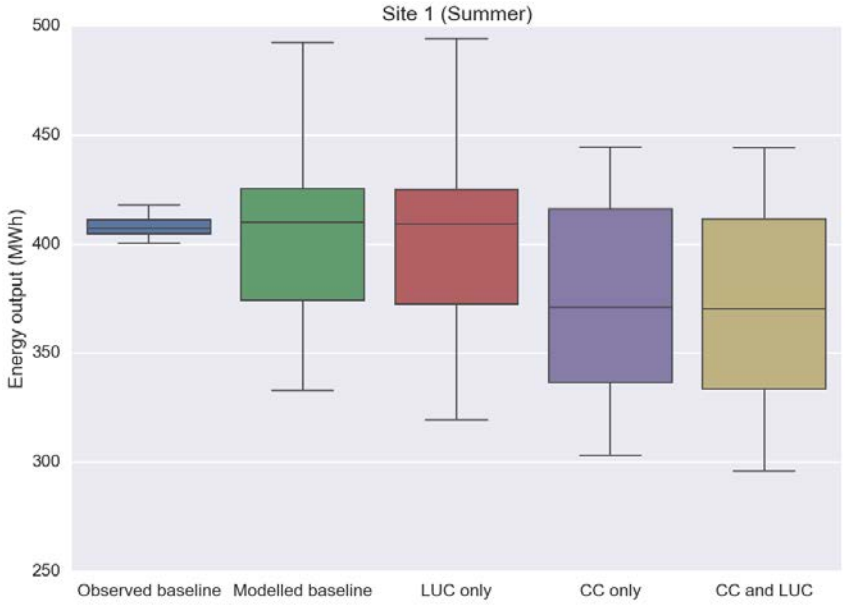


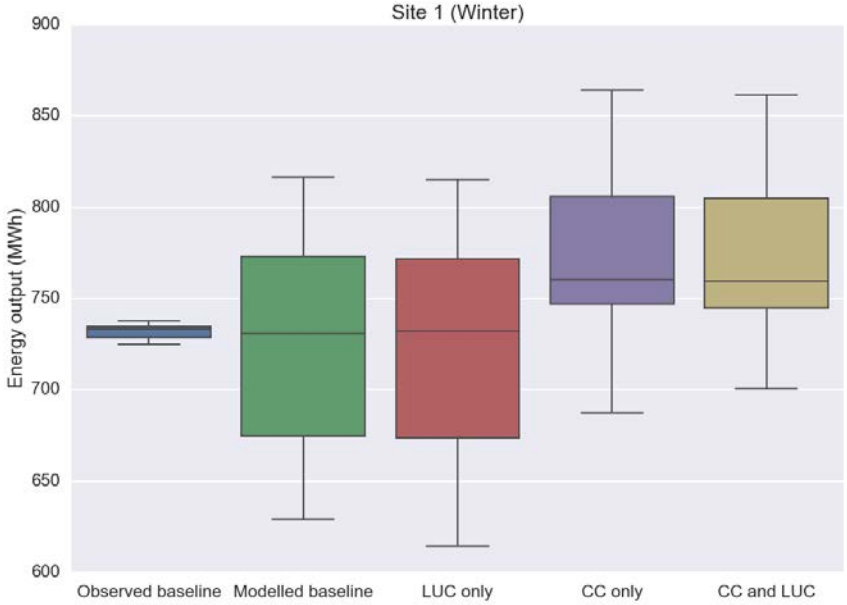


Attempt 2: water balance modelling



- Land use change effect negligible in this example
- Climate change produces a significant increase in annual potential, but with exaggerated seasonality





Summary

- Preliminary work suggests that:
  - Annually, run-of-river hydropower potential may increase slightly by the 2050s
  - But with significant increases in variability
    - Lower output in summer; higher in winter
  - Design changes may increase resilience
    - Several small turbines instead of one large one?
    - Consider oversizing turbines to make the most of high autumn and winter flows?
- Uncertainties are large, but key messages seem fairly robust
- More detailed modelling work is being undertaken to better characterise the resource

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Thank you!

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