Climate Change Impacts on Hydropower Potential in Scotland

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Overview

- Very brief look at hydropower and potential in Scotland
- Overview of hydrological and hydropower modelling suite
- Rapid review of UKC09 climate scenarios
- Application to sample catchments within Scotland to explore hydrological implications of climate change
- Examination of how changing river flows impact desirability of hydro and ultimately its potential

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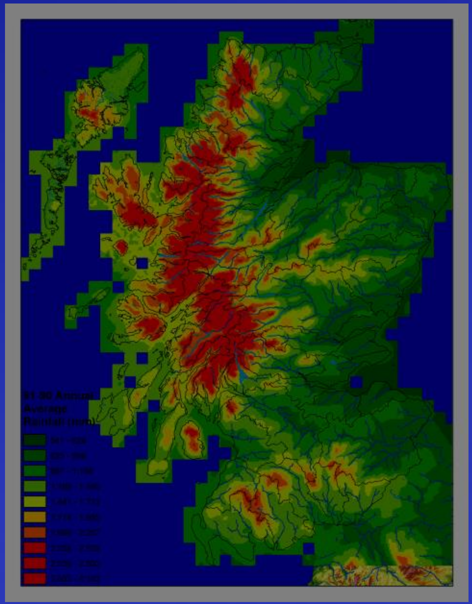
Hydropower in Scotland

- Hydropower-well established in Scotland
  - ~1300 MW conventional (10% of total) and ~700 MW pumped storage
- Scottish Government targets: 100% of electricity from renewable sources by 2020
  - Continued development including plans for extended and new pumped storage plants
- Range of estimates for remaining RoR potential
  - Salford (1980) 322 MW, SHE et al (1993) 1 GW
  - Garrad Hassan (2001) 270 MW, Scottish Government (2008) 657 MW
  - University of Edinburgh (2014): 440-900 MW
- None consider impact of changing climate



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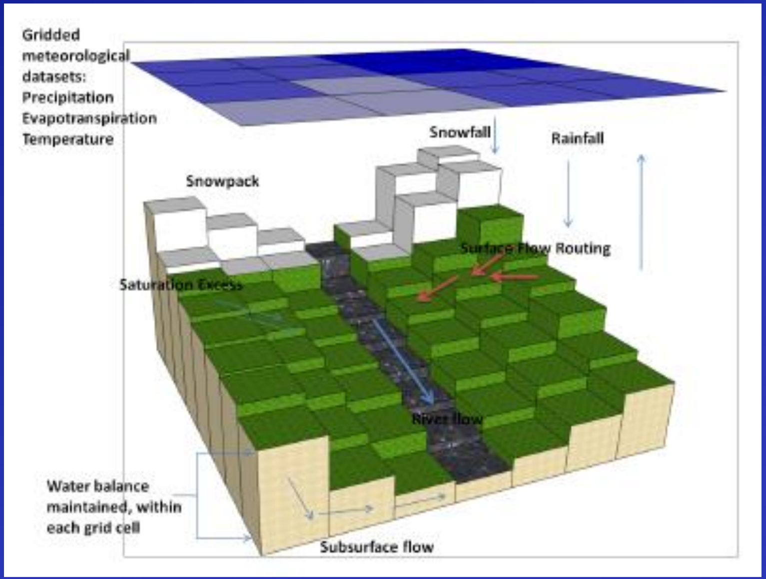
Modelling River Flows

- Bespoke version of G2G distributed conceptual hydrological model (Bell et al, CEH Wallingford)
- Flow routing and snowmelt modelled
- Advantages: good in upland areas where terrain controls flow
- Disadvantages: relatively simple hydrological processes (no explicit account of land use or soil type)
- Inputs: high resolution gridded time series for atmospheric variables
- Outputs: time series of flows at ~200m intervals along river reach across Scotland



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Future Climate Scenario

- UK Climate Projections 09 (UKCP09)
  - Dissemination of probabilistic projections from Regional Climate Model (RCM) output
- Range of emissions scenarios and time periods
  - Medium emissions scenario for 2040-2069 used in this case
- Weather Generator (WG) can produce time series representative of future climate for an area
  - Precipitation
  - Evapotranspiration
- Need to use minimum 100 sets of Weather Generator time series to represent uncertainty

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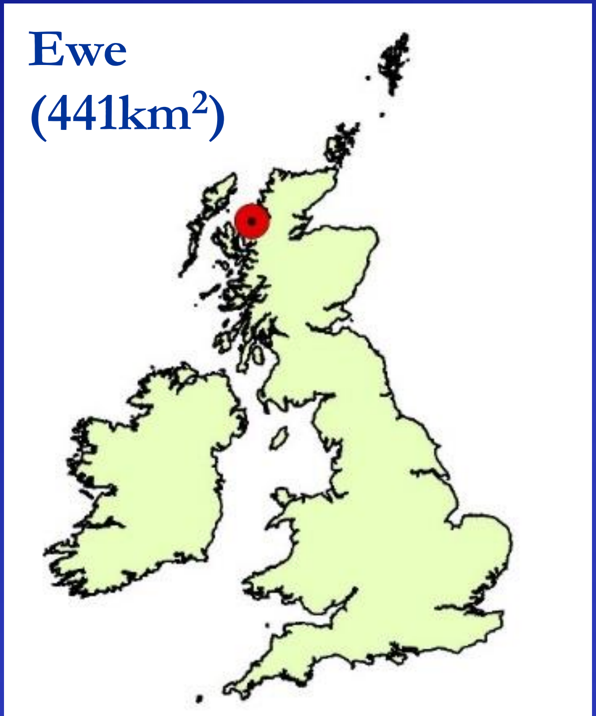
Modelling Approach

- Hydrological model forced with historic time series data and calibrated/validated against stream gauges in 40+ catchments
- 7 catchments chosen which were forced with baseline (1961-1990) climate model data – the results for the Ewe
- Ensure baseline WG data reproduces historic flow duration curve (FDC)
- Produce future FDCs and compare to baseline to understand change



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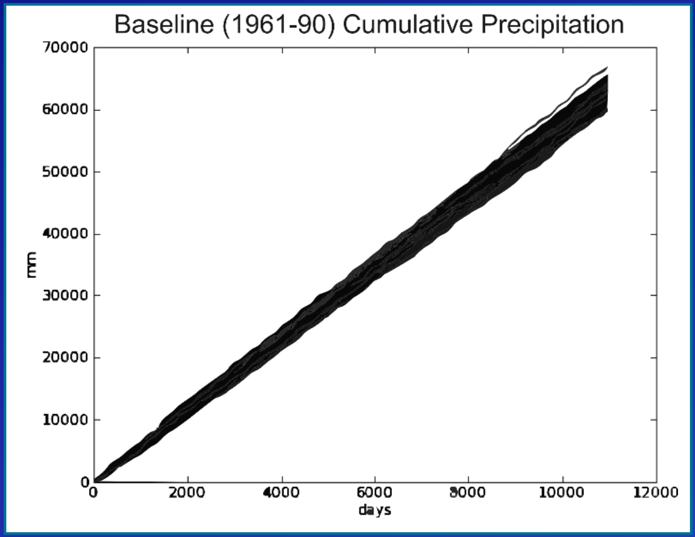
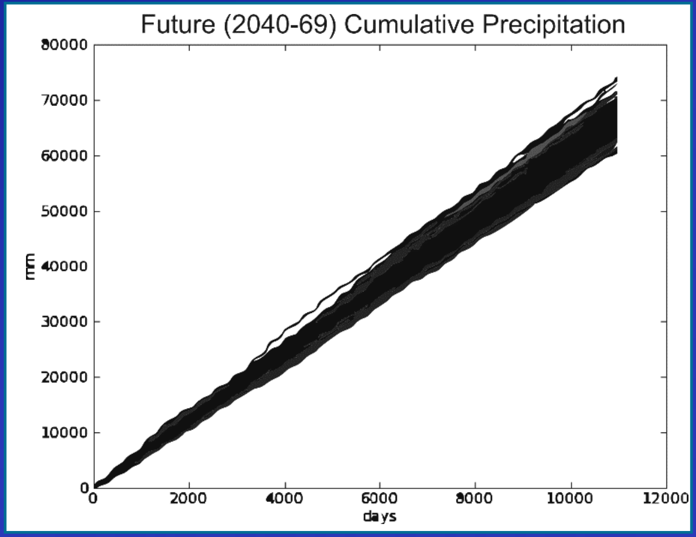
Weather Generator Output

- Plots of 100 sets of Weather Generator Output for ‘baseline’ 1961-1990 and 2040-2069 periods
- Spread shows climate model uncertainty
- Clear that future climate data has greater uncertainty than baseline
- Increase in precipitation and evapotranspiration across most runs





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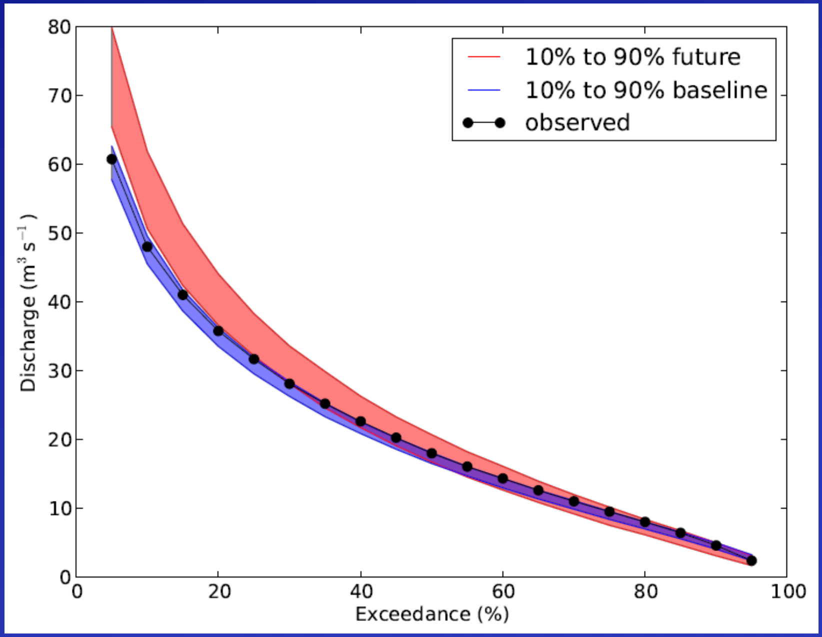
Flow Duration Curves: Quality

- FDC simulated using historic data and 100 sets of weather generator baseline data
- Compared to FDC produced from gauge data for period
  - In most cases such as the Ewe (right) WG baseline compares favourably
  - In some cases (e.g. Teviot) there is clear bias at higher flows
  - The spread between the 10% and 90% percentiles is clear
- Across the catchments there is likely under-representation of peak rainfall and snowmelt



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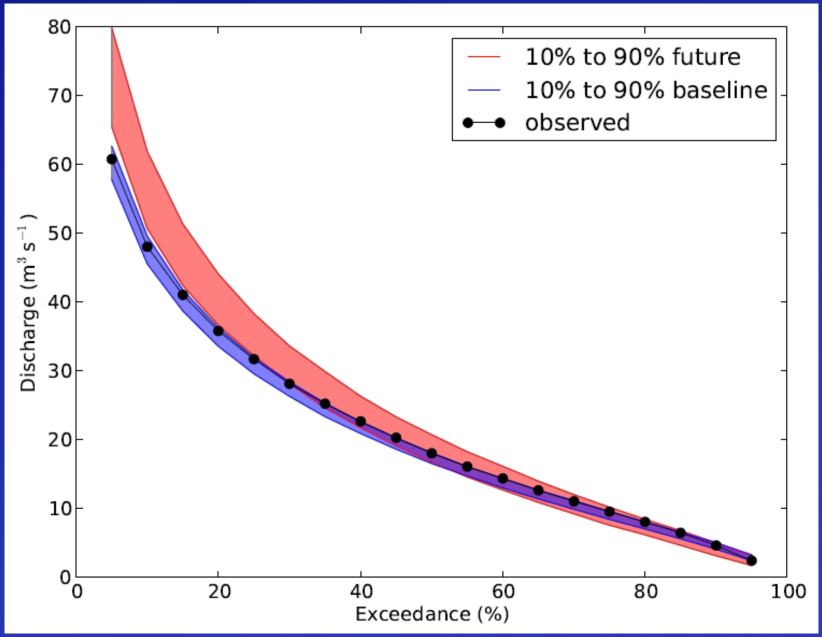
Flow Duration Curves: Change

- It is clear that likely higher winter flows and lower summer flows
  - greatest change at higher flows
  - magnitude will likely vary under different emissions scenarios
  - Agrees with the literature
- Raises a number of issues:
  - What are the operational impacts on existing schemes?
  - How might existing and new hydro adapt to changed flow conditions?
  - What are the implications for return periods of extreme flow events and the design of spillways and weirs?



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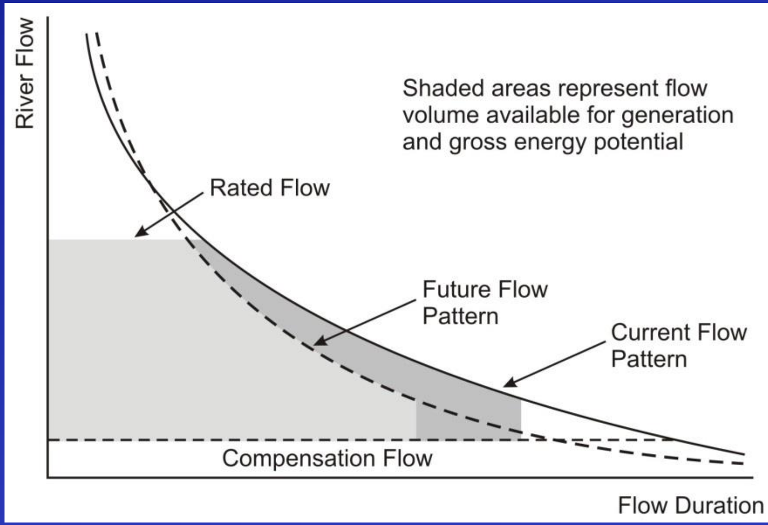
Hydropower Impact

- Hydro schemes are designed to exploit expected flow conditions
- As flows change these may become non-optimal (efficiency, low flow losses, opportunity costs)
- For example with future flows (50%) a hypothetical run-of-river scheme located on the Ewe sees:
  - ~1% increase in annual generation
  - ~6% increase in winter generation
  - ~15% decrease in summer generation
- To examine this a ‘hydro search’ algorithm was applied to the Ewe catchment to examine how hydro scheme characteristics might adapt



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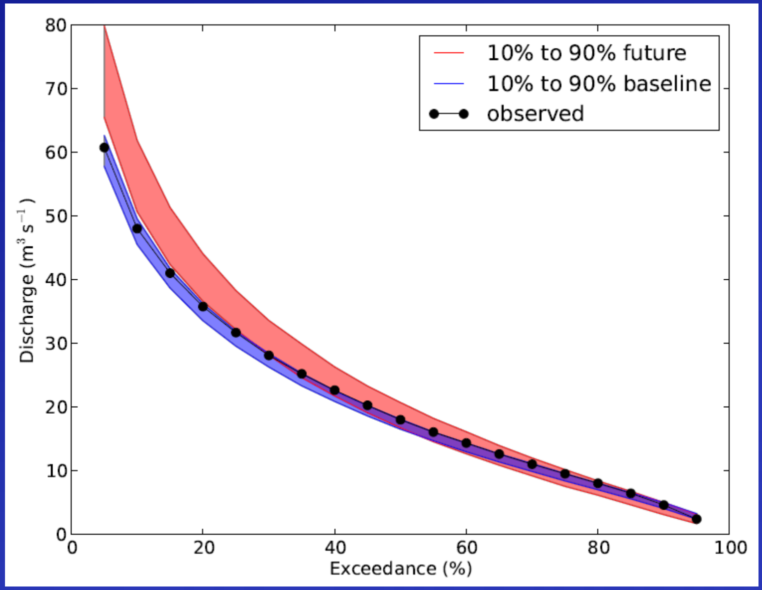

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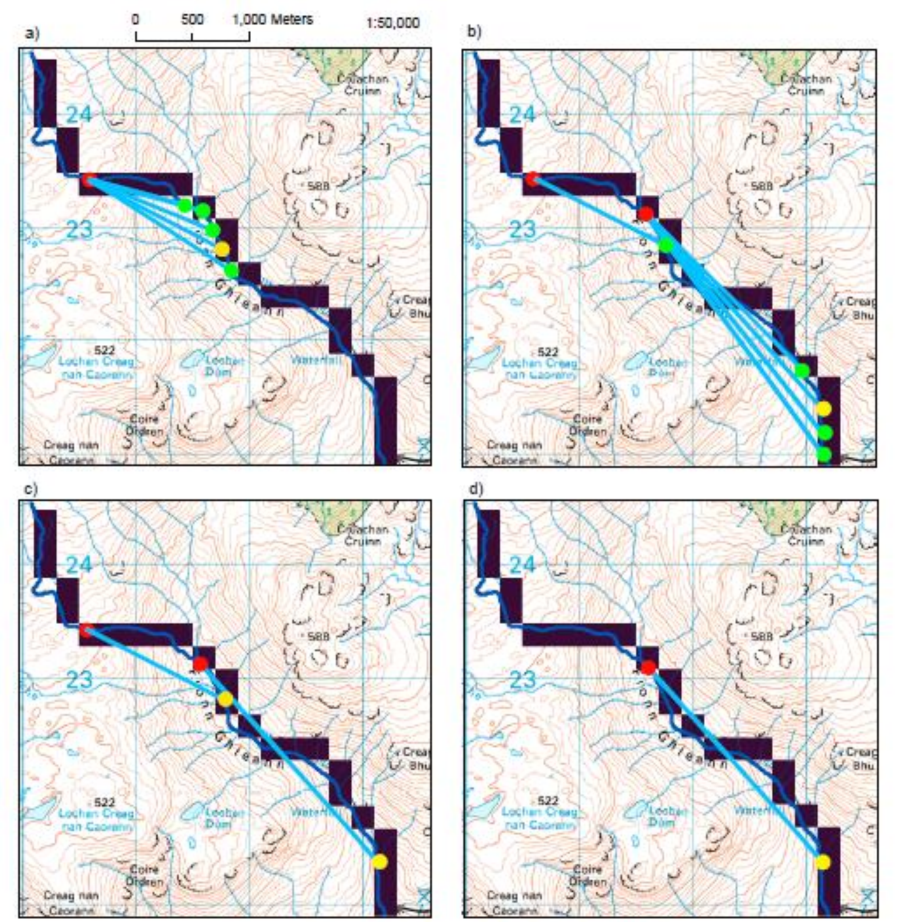
Hydropower Impact

- The search algorithm follows each river top to bottom 'trying out' locations of intakes and power houses (right)
- It uses FDC at the intake and topography to create 'trial' design including penstock length and diameter, turbine type/capacity and distance to road and grid
- Costs and revenues are estimated for each and they are compared according to project value (NPV)
  - overlapping schemes: 'best' selected
- Pretty good at locating pre-existing hydro schemes



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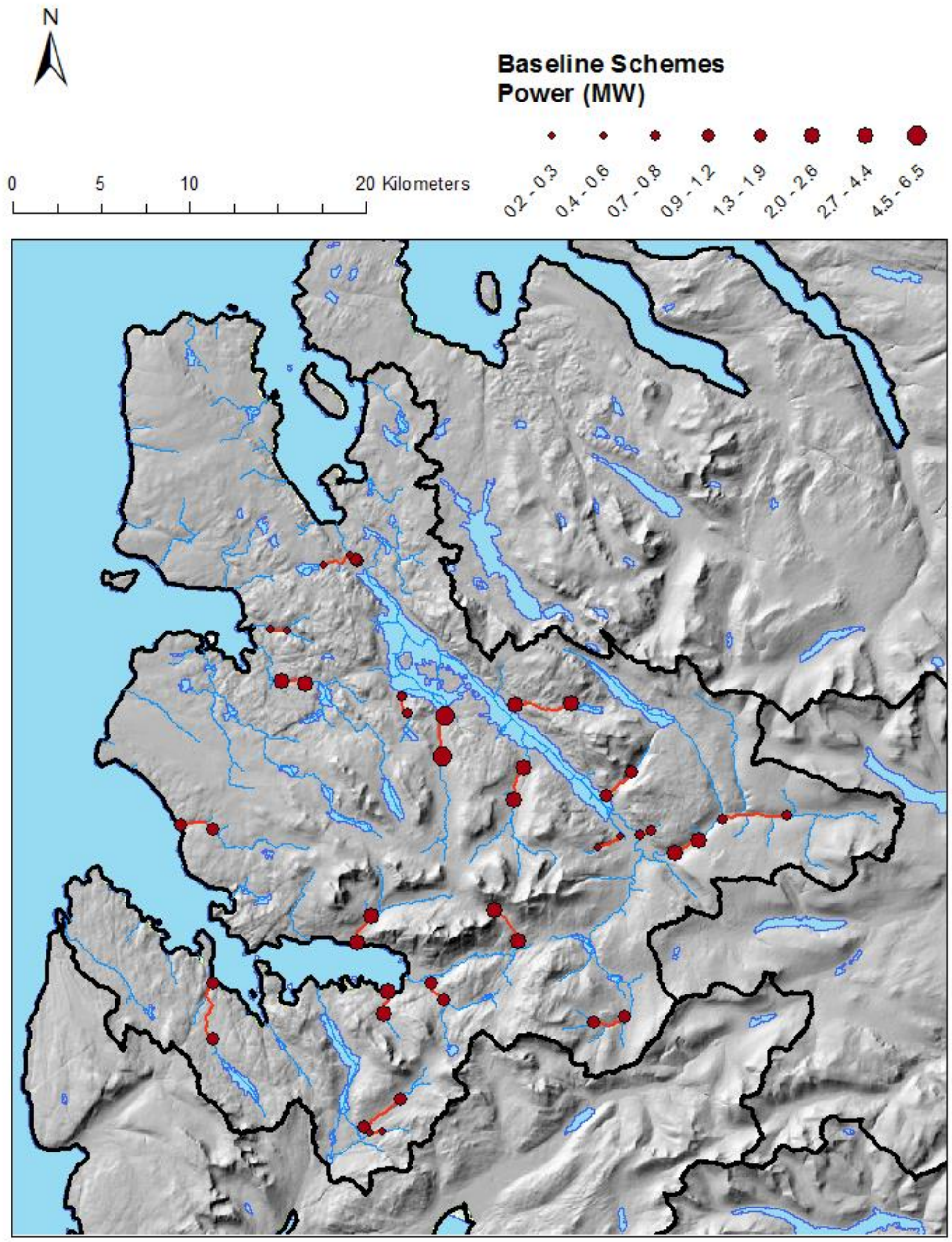
Design Impact

Baseline 50% flows

- 22 schemes (right) are found to be credible
- Ave design flow 1.15 m^3/s
- Capacity 0.2 to 6.5 MW – ave 1.8 MW
- Total capacity 39.9 MW
- Ave capacity factor 42%
- Ave scheme cost £3.5m



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Design Impact

Future 50% Flows

- Average design flow increases to 1.3 m^3/s
- Schemes become larger
- Turbines ave 2.2 MW (+19%)
- Total 49.9 MW
- Larger diameter and longer penstocks
- One additional scheme
- Ave capacity factor 40%
- Ave scheme cost £4.2m

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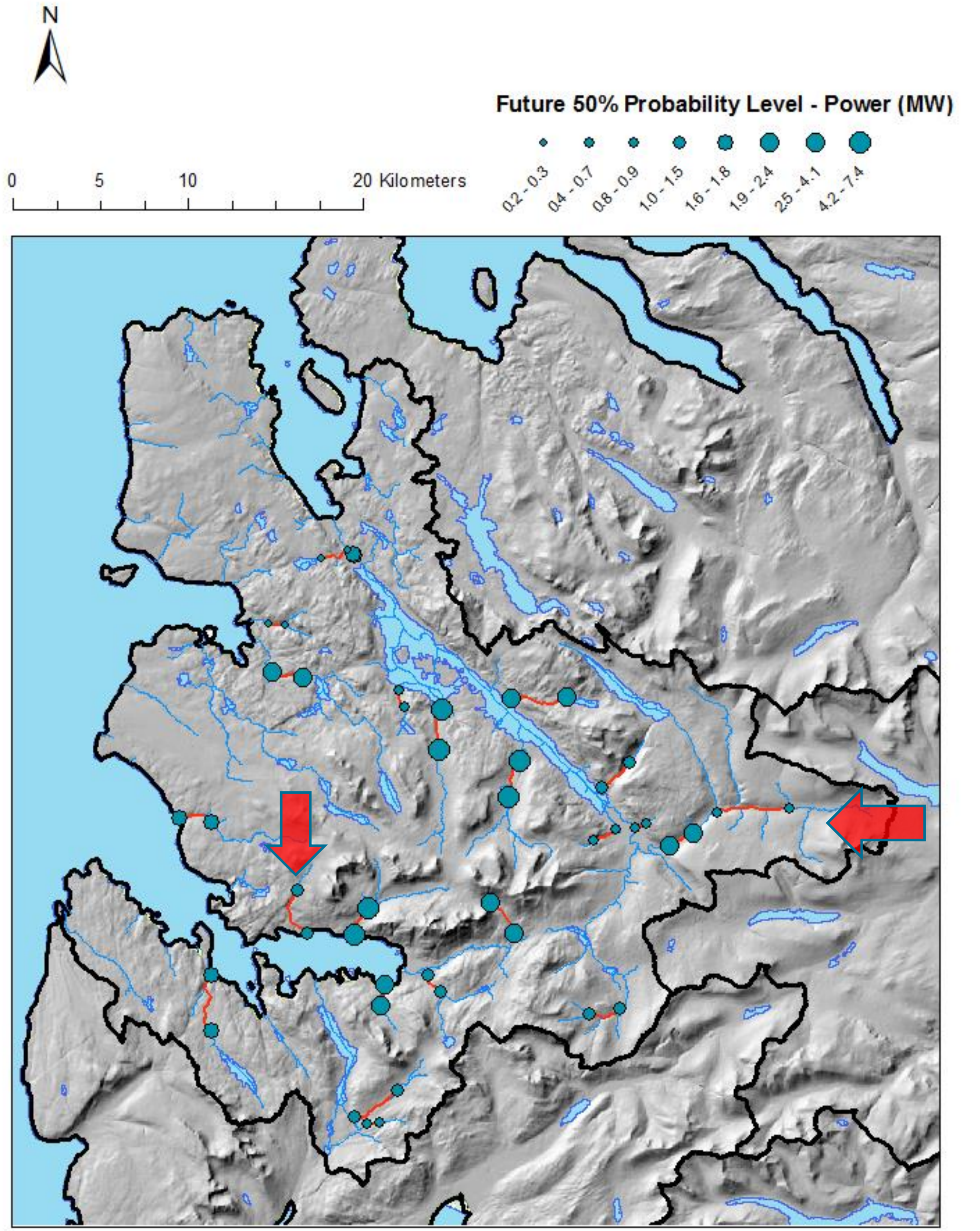

Design Impact

	Baseline Scenario	Future Scenarios – Probability Levels		
		10%	50%	90%
Number of Schemes	22	22	23	24
Average Capacity Factor (%)	42	40	40	40
Average Scheme Size (MW)	1.8	2.0	2.2	2.4
Min Scheme Size (MW)	0.2	0.2	0.2	0.3
Max Scheme Size (MW)	6.5	6.9	7.4	8.2
Average Design Flow (m^3/s)	1.15	1.27	1.31	1.44
Total Installed Capacity (MW)	39.9	43.0	49.6	56.7
Annual Production (GWh)	135	137	155	174
Average Scheme Cost (£m)	3.5	3.6	3.9	4.2
Average Unit Cost (£m/MW)	1.92	1.85	1.80	1.77
Average NPV (£m)	3.1	3.1	3.4	3.6
Average payback (years)	11.2	11.6	11.6	12.0

Summary

- Described a toolkit able to model hydrology of Scotland
- Applied UKCP09 scenarios and weather generator to explore range of future river flows in a representative sample of catchments
- Applied a hydropower search toolkit to examine changes in scheme make up and desirability under future flows
- In the Ewe catchment the hydropower potential increases 25%

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