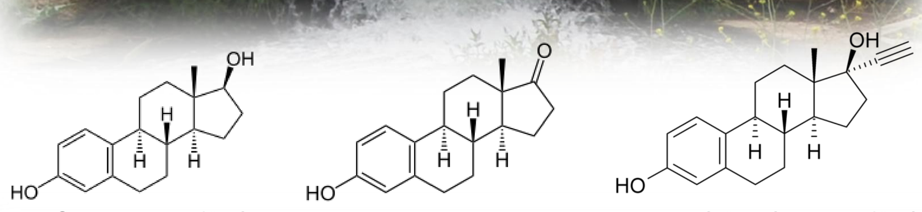
Predictive modelling of steroid oestrogens in sewage effluent and rivers demonstrates the potential for endocrine disruptive effects in wild fish populations in South Australia

Christopher Green[1], Richard Williams[2], Ying He[3], Shaun Thomas[3], Nirmala Dinesh[4], Rakesh Kanda[5], John Churchley[6], Anu Kumar[7] and Susan Jobling[1]

[1]Institute for the Environment, Brunel University, Uxbridge, Middlesex, UB8 2ND, UK; [2]Centre for Ecology and Hydrology, Wallingford, Oxfordshire, OX10 8BB, UK;
[3]Environment Protection Authority, 250 Victoria Square, Adelaide SA 5000, Australia; [4] SA Water House, 250 Victoria Square, Adelaide SA 5000, Australia;
[5]Severn Trent Laboratories Ltd., Britten Road, Reading, RG2 OAU, UK; [6]WatStech Ltd, Technology Centre, Wolverhampton Science Park, Wolverhampton, WV10 9RU, UK;
[7]CSIRO Land and Water, Adelaide Laboratory, PMB 2, Glen Osmond, South Australia 5064, Australia



17β-Oestradiol Oestrone 17α Ethinylestradiol

Endocrine disruption in wild fish has been well characterised in the UK where it has been linked to sewage treatment works (STW) effluent containing the steroid oestrogens: 17β-oestradiol (E2), oestrone (E1) and 17α-ethinylestradiol (EE2). In Australia, they have been detected in effluents at concentrations similar to those found in the UK and there is some evidence of endocrine disruptive effects in fish downstream of STW's (Batty and Lim, 1999). This study is the first to use predictive modelling to assess the concentrations of steroid oestrogens in South Australian STW effluents and the Onkaparinga River as a preliminary risk assessment for wild fish populations. The predicted concentrations in STW effluents and the receiving rivers in South Australia were comparable to those in the UK and when the models were modified to project scenarios under climate change and population growth for 2050, there was generally an increase in the average concentrations in both countries. Under both present day and future scenarios, effluent discharge on the Onkaparinga River in South Australia is projected to cause concentrations of steroid oestrogens in receiving waters exceeding the 1ng/L combined EEQ PNEC, suggesting that without sufficient mitigation there is a risk of endocrine disruptive effects occurring in wild fish populations.

METHODS

Predicting Effluent Concentrations
4 STW's in the UK and 12 in South Australia.

E1 and E2: per capita consumption was calculated using a model modified from Johnson and Williams, 2004 which splits a population into cohorts based on their oestrogen excretion.

$$SE2 = 0.5 \sum_{i=1}^{n} fi\,(UE2)$$

$$SE1 = \sum_{i=1}^{n} fi\,(UE1) + 0.5\,SE2$$

S = per capita consumption of oestrogen arriving at an STW (ug/d)

U= total oestrogen excreted in urine and faeces for a cohort fraction (***fi***) of the population.

Cohort fractions (***fi***) are menstrual females, menopausal females, menopausal females on HRT, pregnant females, males.

Population data from the UK Office for National Statistics (ONS) and the Australian Bureau of Statistics (ABS)

A KT value for E2 of 0.5 assumes that 50% will be degraded to E1 in the sewer system.

EE2: based on the number of prescriptions from health services in each country (Runnalls et al., 2010).

$$\textbf{Effluent Concentration (ug/L)} = \frac{\textbf{per capita consumption (ug/day)}}{\textbf{per capita flow (L/day)}} \times (1 - \textbf{removal})$$

Corroborating the Effluent Model
Modelled data was compared with 6 months of LC/MS-MS data for a UK STW (Baynes et al. 2012).

Predicting River Concentrations
Based on per capita consumption and predicted effluent concentrations.

UK: **LowFlows2000-WQX** was used to predict concentrations on the River Erewash.

South Australia: A modified **Source Catchments** model was used to predict concentrations on the Onkaparinga River.

Predicting Overall Oestrogenic Activity and Risk Assessment

EEQ (ng/L) = [EE2]/0.1 + [E2]/1 + [E1]/3

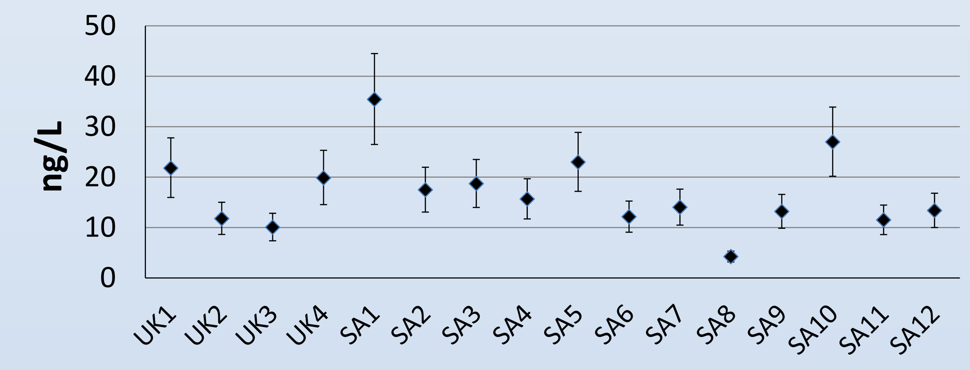
PNEC = 1ng/L EEQ (Young et al., 2004)

Projecting Oestrogen Concentrations in 2050: The Effects of and Population and Climate Change
Three population projections were produced from the Office for National Statistics, UK and the Australian Bureau of Statistics based on demographic assumptions of future fertility, mortality and migration (High (A), Principle/Medium (B) and Low (C).

These data were used to produce per capita consumption rates for E1 and E2 to model effluent concentrations for 2050. Per capita consumption of EE2 was assumed to remain at day present levels.

River models were modified to represent medium sensitivity climate change scenarios with reduced river flow.

RESULTS



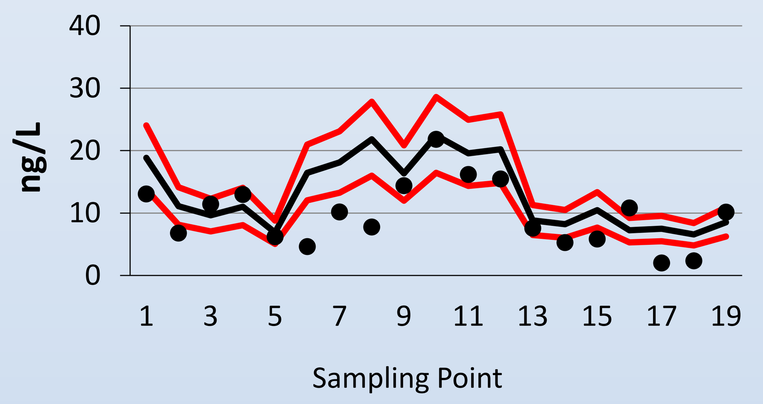


Figure 1: Average predicted effluent EEQ (ng/L) for 4 UK STW's and 12 Australian STW's (left) and a comparison between the EEQ from measured (dots) and modelled (lines) steroid oestrogens (right) . Upper, average and lower values were modelled to provide a range based on excretion.

Oestrogen concentrations in effluent in South Australia are predicted to be **similar** to the UK.

The model provides **representative values** for steroid oestrogens at a STW in line with the precautionary principle. Its slightly overestimates the concentrations.

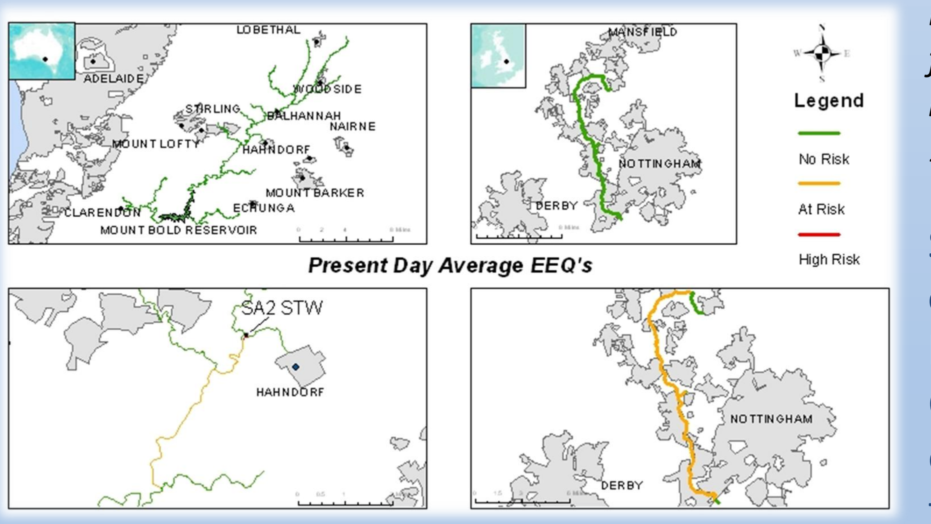


Figure 2: Risk of endocrine disruptive effects in wild fish on the Erewash (left) and Onkaparinga (right) based on the average EEQ (no risk <1ng/L, at risk 1-10ng/L, high risk >10ng/L)

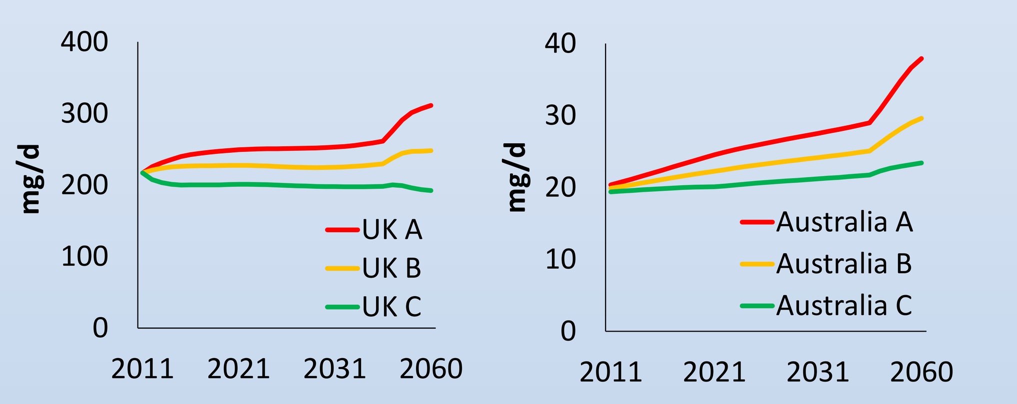
Stretches of both rivers downstream of STW's **exceed** the 1ng/L EEQ **PNEC**. The Erewash has eight STW's compared to only one on the Onkaparinga. As a result the whole river is considered at risk. Predicted concentrations for the two rivers are **comparable**.

What does the future hold?

Figure 3: Predicted volume of 17β-Oestradiol (E2) (mg/day) arriving at Hallam Fields, UK and SA2, Australia under the three population scenarios (2011-2060)

Per capita consumption of E1 and E2 **reduced** under all population scenarios (aging population effect).
(EE2 was assumed to remain constant).

Load arriving at STW's and **effluent** concentrations of steroid oestrogens are projected to **increase** under all scenarios (except UKC).



High Population (A), Principle/Medium Population(B), Low Population (C)

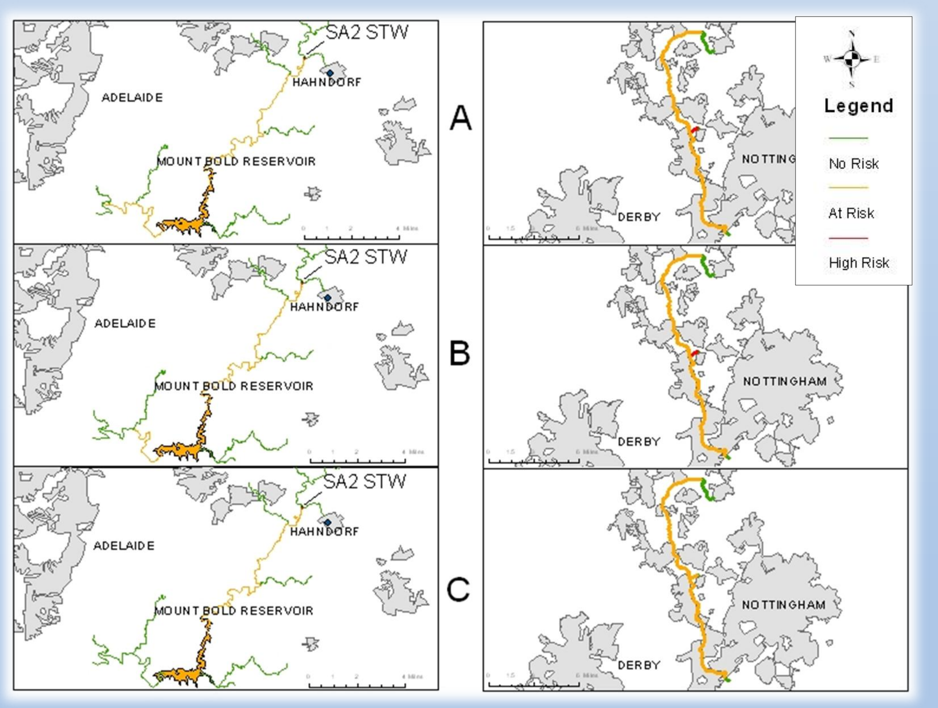


Figure 4: Projected average EEQ's for 2050 on the Onkaparinga (left) and the Erewash (right) (no risk <1ng/L, at risk 1-10ng/L, high risk >10ng/L)

Projected **increase** in average downstream EEQ and number of at risk stretches on the Onkaparinga by 2050 in line with the projections. Potential risk to the Mount Bold Reservoir.

Projected **increase** in average downstream EEQ on the Erewash under projections A and B only. Projected **decrease** under Projection C (low).

CONCLUSIONS

Predictive modelling is a good **first tier assessment tool** for producing a representative value for an STW. Not necessarily for day to day analysis.
Oestrogens are predicted to be present in UK and South Australian effluents and rivers at concentrations **exceeding** the UK **PNEC** for endocrine disruption in fish.
Without mitigation concentrations will potentially **increase** on average in the future.

References: Batty, J. and Lim, R. (1999) Morphological and reproductive characteristics of male mosquitofish (*Gambusia affinis holbrooki*) inhabiting sewage-contaminated waters in New South Wales, Australia. *Archives of Environmental Contamination and Toxicology* 36(3): 301-307; Baynes, A. et al. (2012) Additional treatment of waste water reduces endocrine disruption in wild fish – a comparative study of tertiary and advanced treatments. DOI 10.1021/es204590d. Johnson, A.C. and Williams, R.W (2004) A model to estimate influent and effluent concentrations of estradiol, estrone and ethinylestradiol at sewage treatment works. *Environmental Science and Technology* 38: 3649-3658; Runnalls, T.J. et al. (2010) Pharmaceuticals in the Aquatic Environment: Steroids and Anti-Steroids as High Priorities for Research. *Human and Ecological Risk Assessment* 16(6): 1318-1338. Young, W. F. et al. (2004) Proposed Predicted-No-Effect-Concentrations (PNECs) for natural and synthetic steroid oestrogens in surface waters. EA R&D Technical Report P2-T04/1. 2004, *EA5098*.

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