MARINE CLIMATE CHANGE IMPACTS PARTNERSHIP: SCIENCE REVIEW
MCCIP Science Review 2013: 252-256

Submitted June 2013
Published online 28 November 2013
doi:10.14465/2013.arc26.252-256

Impacts of climate change on pollution (bathing and shellfish)

Andrew Wither [a], Carl Stapleton [b], Mark Wyer [b], Adrian McDonald [c] and David Kay [c]

[a] *National Oceanography Centre, Liverpool, L3 5DA, UK*
[b] *Centre for Research Into Envrionment and Health, Aberystwyth University, Ceredigioin, SY23 3DB, UK*
[c] *Faculty of the Environment, University of Leeds, Leeds, LS3 9JT, UK*

EXECUTIVE SUMMARY

Microbial pollution of coastal waters impacts on health, economic resource utilisation and compliance with EU Directives.

This pollution is episodic and driven by rainfall, making routine monitoring data very misleading.

The evidence-base for policy interventions to minimise these effects is under-developed compared to the chemical parameters.

Predicting the effects of interventions to attenuate this pollution loading is difficult and work to date suggests that farm-level measures have a wide range of effects which are often site-specific.

Climate change may reduce the frequency of summer rainstorms affecting west coast UK bathing and shellfish harvesting waters which should reduce rates of non-compliance against EU bathing water standards.

This reinforces the imperative to understand the relative contributions of sewage and diffuse pollution contributions in the UK through quantitative microbial source apportionment and sanitary profiling of bathing and shellfish harvesting waters.

This is required to take full advantage of new regulatory approaches such as real-time prediction of microbial water quality with related discounting of samples impacted by non-sewage fluxes derived principally from livestock.

This new approach provides the potential for health protection, Directive compliance and cost minimisation and is compatible with climate change scenarios.

1. WHAT IS ALREADY HAPPENING?

New 'health-evidence-based' water quality standards for coastal waters have been proposed by WHO and incorporated in a revised EU Bathing Water Directive which comes into force in 2015 (WHO, 2003; Kay *et al*., 2004; Anon., 2006). The standards proposed are more stringent than the existing criteria (Anon., 1976) and are likely to reduce rates of annual compliance in UK bathing waters in the absence of any climatic drivers of environmental change (Wither *et al*., 2010). (A compliant water is here taken to means a bathing water that complies with the EU 'imperative' standard ('sufficient' or better after 2015). The compliance of bathing and shellfish harvesting waters is assessed using faecal indicator organisms (FIOs) (principally coliforms and enterococci bacteria) which indicate the presence of faecal matter derived from humans, livestock and wildlife. This may have associated human pathogens, if the contributing population is shedding pathogens at the time. The faecal indicator organisms which are used for compliance assessment provide a useful and accepted measure of the potential risk of pathogen presence. In effect, they prove a connectivity from a potential pathogen source to a potentially susceptible population who may ingest the pathogens though recreational exposure, eating shellfish and/or ingesting the water without adequate treatment.

There are five main routes by which FIOs gain access to bathing and shellfish harvesting waters, namely:

i. treated sewage discharges, which form 'point' sources from outfall pipes generally discharging to the marine environment below low water (Kay *et al*., 2008a);

ii. intermittent sewage overflows such as 'combined sewage overflows' (CSOs); 'pumping station overflows' (PSOs) and 'storm tank overflows' (STOs); these often discharge to a foreshore or to rivers which thence flow into the sea (Kay *et al*., 2008a);

iii. surface water drainage from urban areas that commonly have street and roof drainage systems which should not be contaminated by 'foul' drainage from domestic toilets but which are, in reality, often contaminated by urban cross-connection of foul domestic drainage into these surface water systems;

iv. rivers and streams which deliver diffuse catchment sources of pollution from rural and urban areas (Kay *et al*., 2008b); and,

v. livestock contributions directly onto the foreshore by grazing ruminants and dogs and/or avian inputs from sea birds and urban species, (such as starlings) which commonly use foreshore structures, such as piers, as roosting sites (Wither, 2003; Kleinheinz *et al*., 2006; Graczyk *et al*., 2007).

In the UK and most developed nations, treated sewage discharges, potentially impacting on bathing and shellfish harvesting waters, are closely regulated to ensure that the continuous microbial flux from such sites does not impair compliance against existing standards. Disinfection by ultra violet irradiance is often used to kill FIOs in such continuous discharges. Intermittent sewage overflows are also regulated but, in this case, the regulatory and system design approach is to define the number of allowed discharges in the compliance period (e.g. the summer bathing season), thence to design storage and/or diversion to ensure compliance with the allowed spill frequency.

Formal regulation of surface water drainage, riverine flux and direct animal defecation is much more difficult to achieve, although 'responsibility' in these areas is implied by the EU Water Framework Directive (Article 11) which requires member states to design a programme of measures to ensure compliance with microbial standards at 'protected areas' defined in Annex 4 which specifically includes bathing waters and areas used for the cultivation of economically important species; i.e. shellfish (Anon., 2000).

A key characteristic of microbial flux into 'protected areas' is that it is highly episodic and driven by rainfall events. This is particularly true of routes (ii) to (v) above and this characteristic has underpinned prediction of bathing water quality and provision of public information as recommended in the WHO 'predict and protect approach to bathing waters management (Wither *et al*., 2010).

2. WHAT COULD HAPPEN?

There has been significant speculation on the likely change in disease burden attributable to recreational water exposures but this has focused mainly on temperature increases. However, whether temperature is influencing rates of recreational exposure risk through: (i) behavioural change (Semenza *et al*., 2008) resulting in enhanced usage rates; or (ii) alterations to indigenous pathogen ecology and infectivity, is difficult to disentangle, but the association is certainly convincing in the historical data presented in an excellent review paper authored by a team based at RIVM in Bilthoven (de Roda Husman and Schets, 2010) Figure 1.

There is also the possibility that harmful algal blooms and more 'exotic' pathogens, which prefer warmer conditions, such as *Acanthamoeba*, *Naeglaria fowleri* and *V. vulnificus*

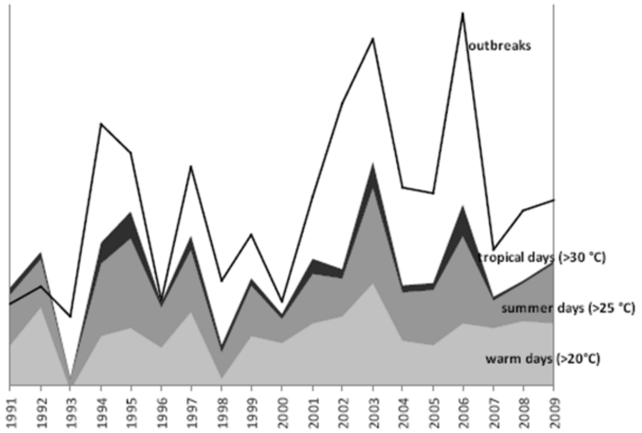


Figure 1: Waterborne disease outbreaks associated with recreational water in the Netherlands 1991-2009 related to daily mean temperature (Source: de Roda Husman and Schets, 2010)

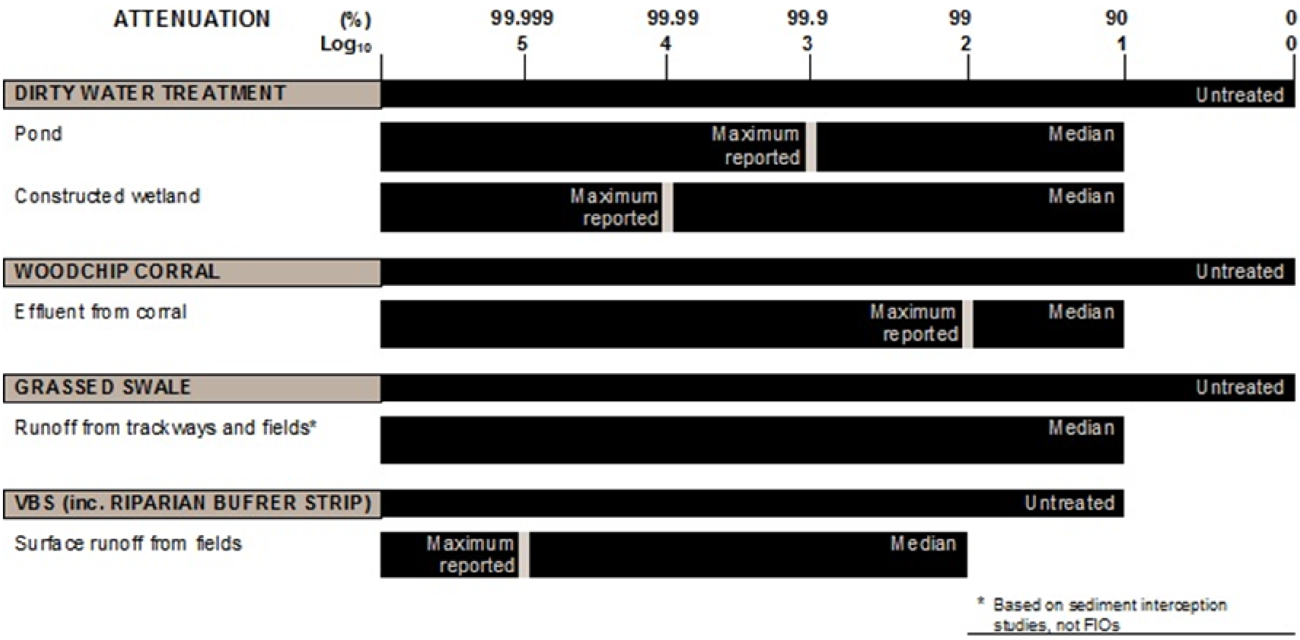
may thrive in a future climate scenario producing warmer seas and freshwaters (de Roda Husman and Schets, 2010).

Whether climate change drivers will alter the risks from exogenous enteric pathogens is more difficult to predict but a series of potential processes that could alter the 'delivery' of enteric pathogens to recreational waters is suggested, including increased storm runoff from agricultural areas and via storm sewer overflows during rainfall events (Schijven and de Roda Husman, 2005). It is suggested that this process could elevate a range of faecal-oral pathogens including *Escherichia coli* O157, *Shigella* spp., *Cryptosporidium* spp., *Giardia* spp., norovirus, rotavirus, hepatitis A virus and enterovirus. The authors also note that a decreased risk from this pathogen group might be expected in parts of Europe where rainfall is predicted to decrease rather than increase during future climate change, however, a decrease in total rainfall does not necessarily indicate a lessening of the intensity of high rainfall events.

In UK western and northern bathing water sites, the frequency of summer rainfall events is predicted to decrease under current climate change scenarios (Kay *et al*., 2011). It is conceivable, therefore, that a 'health gain' attributable to sea bathing exposures will be observed as the current century unfolds. However, the precision of all such assessments is constrained by the paucity of data on usage rates and activity patterns at EU bathing sites. No parallel assessment of risk from shellfish harvesting waters has, to date, been undertaken which would need to consider the full annual pattern of rainfall-induced water quality impairment and, thus, consider the projected winter increase in storm events for most UK regions.

There is increasing scientific and regulatory appreciation of the importance of the intermittent discharges described in (ii) to (v) above which all present significant regulatory challenges in most developed nations. It is here that climate change effects will add to the challenge of regulatory compliance and prediction.

Table 1: Typical rates of FIO attenuation (expressed to nearest log_{10}) in runoff from yards and agricultural land as result of specific measures.



Established and emerging disinfection technologies are being trialled on intermittent discharges in the UK to determine whether target effluent and required receiving water quality can be achieved with the characteristically variable turbidities experienced in CSO discharges. Here, UV disinfection has been investigated as a viable treatment system which is responsive to intermittent application (Wojtenko *et al.*, 2001; Scannell and Ellwood, 2009, Scanlan *et al.*, 2012; White *et al.*, 2012). Alternative electro-chlorination systems are also under investigation (Carragher, 2012) and this suite of end-of-pipe interventions is projected to reduce the heavy costs of installing additional storage in the sewerage network which has been the traditional approach to reducing the spill frequency of intermittent discharges. However, key questions remain on the operational utility of intermittent disinfection systems and wide scale application of these technologies awaits further empirical confirmation of their long term efficacy and carbon footprint with a range of challenging effluent types.

There is a paucity of information on the quality of non-foul surface water flows from urban areas in the UK and internationally (Minervini, 2011). In a study based in Broadstairs, UK, Dunhill (Dunhill, 2003) reported geometric mean FIO concentrations in surface water road drains (i.e. non-foul drainage waters) of 104,713 faecal coliforms/100ml and 30,875 intestinal enterococci per 100ml which are approximately one log_{10} order less than concentrations of the same FIOs observed in typical UK CSO discharges from foul sewerage systems (Kay *et al.*, 2008a, Table 2). More recently, opportunistic sampling of a single rainfall-induced discharge event from an urban surface-water street drainage system in a northern UK conurbation during October 2012 produced geometric means of 48,417 *Escherichia coli*/100ml and 9,462 intestinal enterococci per 100ml (in both cases 'n'=10). These data suggest that urban surface water fluxes, although often not contaminated by foul drainage from the sewage system, may commonly have significant faecal indicator loadings which may represent an unexpected and poorly regulated input to coastal bathing and shellfish harvesting waters.

Control of FIO flux in streams and rivers, derived from upstream point source and diffuse inputs, requires an integrated catchment-scale approach involving management of all point source discharges from inland sewerage systems and attenuation of diffuse inputs from the farming system. The latter was described as '*the challenge of the 21st Century*' in a report for the UK Government in 2005 (Haygarth *et al.*, 2005). Crowther and Kay (2012) recently reviewed the literature on the efficacy of available diffuse source management interventions applied to FIO attenuation within the UK livestock farming industry for the Scottish Environment Protection Agency (SEPA). Table 1 presents the log_{10} attenuation reported in literature sources for five interventions reported world-wide.

In a rare attempt to reduce avian wildlife FIO loadings which were thought to impact on bathing water quality at a Lake Michigan site, Converse *et al.* (2012) deployed trained dogs to scare gulls (*Larus* spp.) which reduced from a population of 665 before the scaring to only 17 during control operations. This produced statistically significant reductions in FIOs and human pathogens on days when this intervention was practiced. This is unsurprising given the reported daily FIO loading of gulls (i.e. 4.18×10^9 *E. coli* and 2.1×10^8 enterococci: both per gull day). This is interesting and it is important to note that this study employed trained dogs and handlers with the removal of any canine faeces produced. However, the current practice to control faecal voiding at many EU bathing waters seeking 'Blue Flag' and other seaside awards is to ban dogs during the bathing season. At the same time, populations of many bird species, increasingly associated with urban food sources, such as gulls and starlings have increased and the North American findings certainly suggest that further examination of EU policy and practice in this area would be worth reconsideration.

3. KNOWLEDGE GAPS

a. Accurate and integrated, process-based prediction models for microbial pollutants in coastal catchments and near-shore receiving waters to allow the UK fully to implement the WHO (2003) 'predict and protect' principles.

b. Empirical data to create the policy evidence-base to predict the impacts of the available policy interventions to reduce pollution fluxes to near-shore waters from both catchment farming, urban diffuse and intermittent sewerage infra-structure sources.

c. Accurate downscaling of regional climate models to facilitate catchment scale prediction of rainfall sequence information under a range of climate change scenarios.

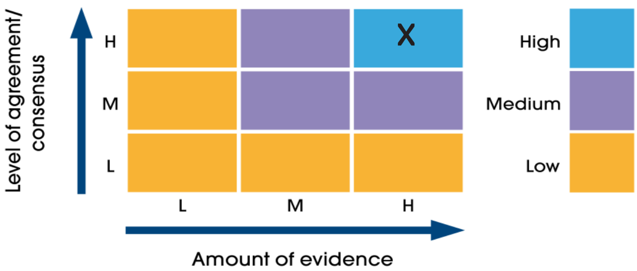
d. Development of microbial tools to: (i) produce reliable quantification of the 'intestinal' component of current faecal indicators; and (ii) provide quantitative assessment of the precision and reproducibility of new molecular methods of source identification and rapid quantification of faecal loadings.

4. SOCIO-ECONOMIC IMPACTS

The principal economic impact is seen in (i) resort town businesses; (ii) shellfish cultivation enterprises; (iii) and health impacts on bathers and shellfish consumers.

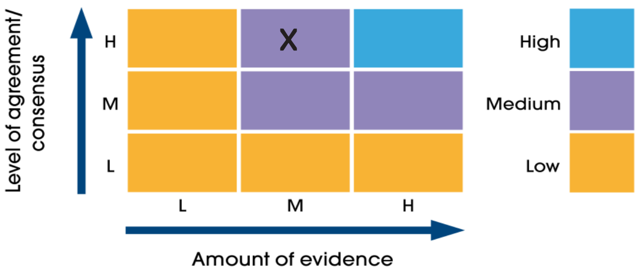
5. CONFIDENCE ASSESSMENT

What is already happening?



There is now a consensus that in the UK where the baseline sources of microbiological pollution have largely been dealt with (better sewage treatment , disinfection etc.etc.) the main fluxes of micro-organisms are found after episodic events of high rainfall.

What could happen?



In the understanding that predictions of the climate change scientists indicates a changed rainfall pattern with significantly more intense events, then high confidence is given in that there will be an increase in microbiological contamination in future. If those predictions are of only medium or low confidence then the confidence rating changes accordingly.

CITATION

Please cite this document as:
Wither A., Stapleton, C., Wyer, M., McDonald, A. and Kay, D. (2013) Impacts of climate change on pollution (bathing and shellfish). *MCCIP Science Review 2013*, 252-256, doi:10.14465/2013.arc26.252-256

REFERENCES

Anon (1976) Council of the European Communities. Council Directive 76/160/EEC of 8 December 1975 concerning the quality of bathing water. *Official J. Eur. Comm.*, **L31**, 1-7.

Anon 2000: Council of the European Communities. Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for Community action in the field of water policy. *Official J. EU*, **L327**, 1-72.

Anon 2006: Directive 2006/7/EC of The European Parliament and of The Council of 15th February 2006 concerning the management of bathing water quality and repealing Directive 76/160/EEC. *Official J. EU.*, **L64**(4.3.2006), 37-51.

Carragher, P. (2012) *The Elimbac process as an alternative to UV.* Presented at the Aqua Enviro Ltd Conference Leeds, Sept.

Crowther, J. and Kay, D. (2012) *Review of sources and measures to control diffuse pollution from agriculture 2012 update*. CREH. 150pp.

de Roda Husman, A.M. and Schets, F.M (2010) *Climate change and recreational water-related infectious disease.* RIVM Report 330400002/2010. 47pp.

Dunhill, I. (2003) *A study of the microbiological quality of the highway drains in Broadstairs, Kent and the implications of gully pot cleaning.* Third Joint Agency Symposium on Improving Bathing Waters, Llandudno, Wales. Environment Agency, Environment and Heritage Service Northern Ireland, Scottish Environment Protection Agency.

Graczyk, T.K., Majewska, A.C. and Schwab, K.J. (2007) The role of birds in dissemination of human enteropathogens. *Trends in Parasitology*, **24**(2), 55-59.

Haygarth, P., Granger, S., Chadwick, D., Sheperd, M., and Fogg, P. (2005) *A Provisional Inventory of Diffuse Pollution Losses*. ADAS Report for DEFRA, London.

Kay, D., Bartram, J., Pruss, A., Ashbolt, N., Wyer, M. D., Fleisher, J. M., Fewtrell, L., Rogers, A., and Rees, G. (2004) Derivation of numerical values for the World Health Organization guidelines for recreational waters. *Water Research*, **38**, 1296-1304.

Kay, D., Stapleton, C.M., Crowther, J., Wyer, M.D., Fewtrell, L., Edwards, A., McDonald, A.T., Watkins, J., Francis, F. and Wilkinson, J. (2008a) Faecal indicator organism compliance parameter conce ntrations in sewage and treated effluents. *Water Res.*, **42**, 442-454, doi:10.1016/j.watres.2007.07.036.

Kay, D., Crowther, J., Stapleton, C.M., Wyer, M.D., Anthony, S., Bradford, M., Edwards, A., Fewtrell, L., Francis, C., Hopkins, M., Kay, C. *et al.* (2008b) Faecal indicator organism concentrations and catchment export coefficients in the UK. *Water Res.*, **42**, 2649-2661, doi:10.1016/j.watres.2008.01.017

Kay, D., Lowe, C., McDonald, A.T., Figueras, M. and Lopez-Pila, J. (2011) I*mpact of Climate Change on Recreational Water Use: Climate Change Risk of Bathing in Coastal Waters Framework Service Contract*. Project Reference: OJ/2009/09/25-PROC/2009/045, European Centre for Disease Control, Stockholm, Final Report, 30th June 2011. 72p.

Kleinheinze, G.T, McDermott, C.M. and Chomeau, V. (2006) Evaluation of avian wastes and bird counts as predicators of *Escherichia coli* contamination at Door County, Wisconsin beaches. *J. Great Lakes Res*., **32**, 117-123.

Minervini W.P. (2011) Characteristics of Suspended Solids, Microorganisms, and Chemical Water Quality in Event-Based Stormwater Runoff from an Urban Residential Area. *Water Env. Res*., **83**, 2211-2212.

Scanlan, P., Stapleton, C., and Kay, D. (2012) *The efficacy of UV in disinfacting storm water*. Presented at the Aqua Enviro Conference Leeds, Sept.

Scannell, C. and Ellwood, S. (2009) *No more tanks – use of UV to meet bacteriological reduction requirements on storm tank effluent*. Aqua Enviro Conferences Ltd. Sept.

Schijven, J.F. and De Roda Husman, A.M. (2005) Effect of climate changes on waterborne disease in the Netherlands. *Water Sci. Tech.*, **51**, 79-87.

Semenza, J.C., Wilson, D.J., Parra, J., Bontempo, B.D., Hart, M., Sailor, D.J., and George, L.A. (2008) Public perception and behavior change in relationship to hot weather and air pollution. *Env. Res.*, **107**, 401-411.

White, C., McTaggart, R. and Loughran, P. (2012) *Low carbon disinfection of wastewater discharges*. Presented at the Aqua Enviro Conference Leeds, Sept.

WHO (2003) *Guidelines for safe recreational water environments Volume 1: Coastal and freshwaters*. World Health Organisation, Geneva.

Wither, A. (2003) *An Update on the Impact of Roosting Birds on Compliance with Bathing Water Standards*. Second Joint Agency Symposium on Improving Bathing Waters, Northern Ireland. Environment Agency, Environment and Heritage Service Northern Ireland, Scottish Environment Protection Agency.

Wither, A., Stapleton, C., Wyer, M., McDonald, A. and Kay, D. (2010) Microbial Pollution of Bathing and Shellfish Waters in *MCCIP Annual Report Card 2010-11,* MCCIP Science Review, 13pp http://www.mccip.org.uk/media/7015/mccip201011_microbialpollutionbathingandshellfish.pdf

Wojtenko, I., Stinson, M.K. and Field, R. (2001)Challenges of combined sewer overflow disinfection by ultraviolet light irradiation. *Critical Rev. Env. Sci. Tech*., **31**, 223-239.