Institution: University of Leeds

Unit of Assessment: 14 Civil and Construction Engineering

Title of case study: Case Study 5: Cost-effective safe wastewater re-use for improved food security

1. Summary of the impact

Re-use of wastewater for irrigation is essential to secure global food security, but it poses serious health risks. Research at the University of Leeds into the effectiveness of wastewater treatment in pathogen removal and the subsequent development of quantitative microbial risk analysis (QMRA) methods now enable governments, regulators and NGOs to assess risks and identify cost-effective re-use strategies. World Bank policy documents and country-level analysis strongly recommend the QMRA approach developed at Leeds. These policy guidelines and analyses have subsequently impacted on many countries' ability to reduce the costs of wastewater treatment and grow more food safely. This impacts food grown for local consumption and export.

2. Underpinning research

Effectiveness of wastewater treatment

Between 1993 and 2003 researchers at Leeds carried out field trials (funded by grants from the Overseas Development Administration, ODA [now Department for International Development, DFID]) to establish the effect of different irrigation techniques on pathogen retention on different crops. The work was led by Duncan Mara with Andrew Sleigh at Leeds and included Rafael Bastos (Visiting Professor from Universidad Federal de Vicosa) and Howard Pearson (University of Liverpool), working in collaboration with Ursula Blumenthal (London School of Hygiene and Tropical Medicine) and others [1, 2]. The Leeds team also investigated the effectiveness of wastewater treatment processes typically used in developing countries in the removal of pathogens [3].

Combining findings from these studies, the researchers calculated exposure rates to pathogens for farmers and consumers of crops that are irrigated using treated wastewater of various qualities. **Mara** and Blumenthal thus developed an approach which linked selection of treatment processes and irrigation techniques to resultant health risks faced by exposed downstream users.

Quantifying the risks from re-used water

The Leeds research triggered progressive evaluations of the then current 1989 World Health Organization (WHO) guidelines on wastewater re-use. These guidelines had been based on the assumption that water for irrigation should meet the same absolute water quality limits associated with drinking water. In 2000 Mara and other collaborators used their research findings to call for a risk-based approach to wastewater quality standards for irrigation [4] which would significantly increase the scope for using wastewater in irrigation.

Further studies carried out at Leeds by Mara and Sleigh from 2000 onwards contributed to a growing body of data from many sources which provided the basis for quantitative methods to characterise the human health risks associated with exposure to water-based pathogens. This data-driven risk analysis was formalised into an approach known as Quantifiable Microbial Risk Assessment (QMRA) [6].

QMRA is extremely complex and difficult to apply in practice, not least because it requires epidemiological field data. However, modelling and numerical analyses studies by Mara and Sleigh developed a robust Monte Carlo approach to QMRA, culminating in the production of a simple-to-use suite of programs which produces results close to those obtained from field studies.

Mara and Sleigh, again collaborating with others, used their Monte-Carlo-based QMRA tools to demonstrate that the health risks from consuming crops irrigated with treated wastewater were similar to those posed by drinking fully-treated drinking water. This work was the first to challenge previous thinking and showed the quality of effluent from wastewater treatment plants which can

safely be used for irrigation is significantly lower than was previously thought [5].

Risk-based standards

From 2004 Mara worked closely with Blumenthal and Richard Carr (World Health Organisation) to develop a generalisable approach to risk-based standard-setting which could be used in a new edition of the WHO guidelines [5]. This was the basis for Chapter 3 "Assessment of Health Risk" of the 2006 Guidelines (World Health Organization (2006). Guidelines for the Safe Use of Wastewater, Excreta and Greywater, Volume 2: Wastewater Use in Agriculture. Geneva: World Health Organization) co-authored by Mara. Subsequently Mara, Sleigh, Blumenthal and Carr collaborated again to assess the relative results achieved by using different techniques including QMRA to assess health risks [6].

Key researchers in this work were:
1. Duncan Mara: Professor 01/10/1979 - 30/09/2013
2. P. Andrew Sleigh: Research Fellow 01/12/1990 - 30/04/1996, Lecturer 01/05/1996 - 31/07/2005, Senior Lecturer 01/08/2005 - present

3. References to the research

[1] **Bastos RKX**, **Mara DD** (1995) The bacteriological quality of salad crops drip and furrow irrigated with waste stabilisation pond effluent; an evaluation of the WHO guidelines *Water science and technology.* 31 (12):425-430. http://dx.doi.org/10.1016/0273-1223(95)00529-V

[2] U. J. Blumenthal, **D. D. Mara**, **R. M. Ayres**, E. Cifuentes, A. Peasey, R. Stott, D. Lee and G. Ruiz-Palacios (1996). Evaluation of the WHO nematode egg guideline for restricted and unrestricted irrigation. *Water Science and Technology* 33 (10/11), 277−283. http://dx.doi.org/10.1016/0273-1223(96)00430-1

[3] **D. D. Mara** and H. W. Pearson (1999). A hybrid waste stabilization pond and wastewater storage and treatment reservoir system for wastewater reuse for both restricted and unrestricted crop irrigation. *Water Research* 33 (2), 591−594. http://dx.doi.org/10.1016/S0043-1354(98)00238-3

[4] U. J. Blumenthal, **D. D. Mara**, A. Peasey, G. Ruiz-Palacios and R Stott (2000). Guidelines for the microbial quality of treated wastewater used in agriculture. Recommendations for revising WHO guidelines. *Bulletin of the World Health Organization*, 78(9), 1104 - 1116. http://apps.who.int/iris/handle/10665/57600

[5] R. M. Carr, U. J. Blumenthal and **D. D. Mara** (2004). Guidelines for the safe use of wastewater in agriculture: Revisiting WHO guidelines. *Water Science and Technology*, 50(2), 31-38. http://www.iwaponline.com/wst/05002/wst050020031.htm

[6] **D. D. Mara**, **P. A. Sleigh**, U. J. Blumenthal and R. M. Carr (2007). Health risks in wastewater irrigation: comparing estimates from quantitative microbial risk analyses and epidemiological studies. *Journal of Water and Health* 5 (1), 39−50. http://dx.doi.org/10.2166/wh.2006.055

*Note: Authors from the University of Leeds in **bold**. The three papers selected to demonstrate the quality of the underlying research are [3], [4] and [6]. They are published in internationally-recognised leading international journals and have attracted significant interest through citation and take-up by other researchers.*

4. Details of the impact

The impact of the above research is seen through several aspects in the REF period:
- Changes in international policy and guidelines
- Changes in operations of international organisations
- Changes in national strategies

Cost-effective wastewater reuse for agriculture is becoming an increasingly urgent issue for many countries facing severe water stress. WHO estimates that globally 20 million ha, or 7% of total irrigated land, is at least partly reliant on wastewater or other polluted water. Studies show that several countries are heavily reliant on wastewater for irrigation e.g. the percentage of urban consumption of fresh vegetables irrigated by wastewater is 60% in Shanghai, 80% in Hanoi and

90% in Accra [**Journal of Water and Health**, vol. 8, pp.572-576. 2010]. Such figures are repeated elsewhere, but local authorities and producers are reluctant to publish figures due to the possible public disquiet on the issue.

Food grown with irrigation from wastewater is not only consumed locally and much of it is exported. For example, UK and European supermarkets sell food irrigated in this way and clearly need to ensure that this is done to acceptable standards. GLOBALG.A.P. (http://www.globalgap.org) represents the major UK and European supermarkets; it sets standards for the certification of production processes of agricultural products around the globe, and serves as a practical manual for Good Agricultural Practice (G.A.P.) anywhere in the world. Recognising the scale of wastewater re-use in agriculture, GLOBALG.A.P has followed WHO policies on wastewater use and food from countries not complying with WHO standards is likely to be rejected. Figures on the exact amount of food covered by this are difficult to obtain as retailers and producers are reluctant to divulge figures due to public attitudes. However, given that the UK alone imports nearly half its food the trade is significant.

The Leeds researchers were key to the research behind the WHO policy as confirmed by [A] "…the team at Leeds played a significant and central role in the development of the risk-based approach to setting wastewater reuse standards…", [B] "Basic scientific research carried out by the team at Leeds was used in the establishment of the approach and in setting acceptable levels of health risk" and [C] "…the University of Leeds has played an important role in developing new approaches to assess and manage the risk associated with wastewater reuse, and in helping to operationalize the 2006 Guidelines…".

Changing international policy and guidelines

The scientific justification for risk-based standards for wastewater reuse developed on the basis of this research at Leeds and others, has enabled the widespread adoption of safe and affordable wastewater irrigation in the REF period as confirmed by WHO and the World Bank [A, B, C]. In 2010 the World Bank issued a Policy Research Working Paper [C, D] on wastewater re-use of which **Mara** was a co-author and adopted a quantitative risk-based approach to wastewater re-use which extends the scope of water re-use to crop irrigation [C, D]. Prior to 2010 less than 1% of the World Bank's portfolio of wastewater investments included provision for reuse so this was a significant change in approach.

The adoption of the QMRA approach and risk-based regulation by organisations such as WHO and the World Bank has led to its adoption around the globe, especially in countries with strongly-governed water markets (see below) [C, D].

Changes in operations of international organisations

The impact on policy has in turn been operationalized through the World Bank commissioning country-level analyses (2010 [C]) to assess the potential and benefits of wastewater re-use. For example, work by Barbara Evans (Leeds) for the World Bank [E] on the Nile Basin (where close to 10 billion m^3 of drainage water is used in agriculture annually) developed a QMRA-based methodology to identify the most cost-effective wastewater treatment options in specific drainage basins of the Nile delta [C, E]. Use of the methodology in the study identified lower-cost waste management options that are as much as six times more cost-effective (expressed as dollars spent per Disability-adjusted Life-Year saved in health terms) than the conventional high-energy wastewater treatment processes currently favoured [E]. This is described by the World Bank as "one of the first practical examples of how to operationalize the 2006 WHO Guidelines and the 2010 World Bank Policy Research Paper" [C]

Changing national strategies for agricultural development and practice

The main example of impact in the REF period is through the World Bank policy and operations cited above. However, the reach of this impact can be seen from the following examples of countries which have adopted elements of the approach developed with inputs from the team at Leeds include:

- Australia: senate now requires states to include elements of water recycling in infrastructure redevelopment programmes;

- Jordan: upgraded treatment through a private-sector build-operate-transfer scheme [F];
- Tunisia: now treats most of its urban wastewater, uses 30% of the treated effluent to irrigate 7,000 ha of fruit trees and fodder crops following strict sanitary standards, and plans to expand wastewater irrigation to 20,000–30,000 ha by 2020 [G: Page 167];
- 50% of Israel's irrigation water is provided from sewage [H] and this is being expanded [I].

The impact of the above on food production has been on-going during the REF impact period.

Continuing developments

Mara has continued to work with WHO, to review the approach. Further use of the QMRA tools developed at Leeds has led to a call for a further relaxation of some of the health-risk thresholds used in the 2006 Guidelines, which would make wastewater reuse more cost-effective in poor countries [for example J].

5. **Sources to corroborate the impact**

[A] Individual written corroboration (September 11th, 2013) from Don and Jennifer Holzworth Distinguished Professor of Environmental Sciences and Engineering at the Gillings School of Global Public Health (Formerly Head of the Water, Sanitation and Health Department, World Health Organization), University of North Carolina, Chapel Hill, USA.

[B] Individual written corroboration (February 21st, 2013) from Co-ordinator, Sanitation and Health Department, World Health Organization, Geneva, Switzerland,

[C] Individual written corroboration (October 10th, 2013) from Senior Irrigation Water Economist, Water Anchor, Energy Transport and Water Department, The World Bank, Washington DC, USA.

[D] S.M. Scheierling, C. Bartone, D.D.Mara, P. Drechsel (2010). Improving Wastewater Use in Agriculture: An Emerging Priority World Bank Policy Research Working Paper 5412, Washington DC, http://www-wds.worldbank.org/external/default/WDSContentServer/WDSP/IB/2010/09/07/000158349_20100907090249/Rendered/PDF/WPS5412.pdf.

[E] B. Evans and P. Iyer, (2011). Estimating the Relative Benefits of Differing Strategies for Management of Wastewater in Lower Egypt Using QMRA. Washington, DC: World Bank Water Partnership Program, http://www-wds.worldbank.org/external/default/WDSContentServer/WDSP/IB/2012/04/16/000356161_20120416061058/Rendered/PDF/680550WP0water0rt0Feb019020120FINAL.pdf.

[F] Greater Amman Wastewater Treatment Plant Construction (As-Samra), http://gda.usaid.gov/alliances/detail.asp?s=SVHTWWJYBVBXBPDSHGDMHRBQYLYTQYNT&id=22&t=.

[G] V.J. Jaganathan, A.S.Mohamed, and A. Kremer, eds. (2009). Water in the Arab World: management perspectives and innovations. Washington, DC: World Bank, Middle East and North Africa Region, pp. 447–477 and 157-180, http://siteresources.worldbank.org/INTMENA/Resources/Water_Arab_World_full.pdf.

[H] Impact of Treated Wastewater Irrigation on Antibiotic Resistance in Agricultural Soils, (2012), Y. Negreanu, Z. Pasternak, E. Jurkevitch and E. Cytryn, Environmental Science & Technology 46(9), pp. 4800-4808

[I] "Wastewater that now goes to waste will soon irrigate Negev farms", (2012), http://www.haaretz.com/business/wastewater-that-now-goes-to-waste-will-soon-irrigate-negev-farms-1.422935.

[J] Duncan Mara, Andrew Hamilton, Andrew Sleigh and Natalie Karavarsamis (2010). Options for Updating the 2006 WHO Guidelines − More Appropriate Tolerable Additional Burden of Disease, Improved Determination of Annual Risks, Norovirus and Ascaris Infection Risks, Extended Health-Protection Control Measures, Treatment and Non-treatment Options. Geneva: World Health Organization, http://www.who.int/water_sanitation_health/wastewater/guidance_note_20100917.pdf.