Introduction

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The excreta (faeces and urine) of mammals and birds are widespread across planet Earth (Figure 1.1) and frequently contaminate water used for bathing and recreation, for treatment and distribution for human consumption, and for irrigating crops.

The risk that such contamination represents to human health is inadequately understood. It is widely assumed that animal faeces represents a lesser risk to human health than human faeces, because of the “species barrier” and especially the species-specificity of most viruses. This assumption has had important consequences for the selection and prioritization of remedial interventions. For example, studies on the impact of faecally-contaminated coastal “waters on the health of bathers” often report symptoms that are consistent with viral aetiology. Species-specificity among viruses indicates an association with human faeces and a priority focus on reducing sewage pollution where this is occurs.

There is at least some cause for concern about contamination of waters with animal excreta, as animal to human waterborne transmission has been documented for several pathogens. Waterborne transmission of *E. coli* O157 has been repeatedly documented and has been associated with outbreaks, including cases of haemolytic uremic syndrome (HUS), especially through drinking-water and to a lesser extent recreational water use. In one outbreak in Swaziland cattle manure was thought to be the source of more than 40,000 cases of waterborne infection with the organism (Effler *et al.* 2001). One study (Wilson *et al.* 2008) concluded that 96.6% of human clinical infections with *Campylobacter jejuni* in Lancashire, UK could be attributed to farm livestock. Animal reservoir hosts play an important role in the transmission of *Schistosoma japonicum* in both China and the Philippines, with a high level of transmission between species, although evidence suggests that different animal species are important in the two countries (see Chapter 2 and a case study in Chapter 4).

There may be “win-win” opportunities with net economic benefits in better regulation of animal excreta. These arise from the potential to reduce human disease, improve animal health and recover the energy and nutrient value embedded in this resource – which is largely treated as waste at present. These benefits are most readily achievable in more concentrated operations such as large animal feedlots.

Many of the tools that have been used in assessing, managing and regulating risks to human health from contamination of water with human faeces are not applicable, or require adaptation for application, to the control of contamination by animal

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**Figure 1.1** Global human and agricultural sources of faecal pollution FAO (2007).
faeces. As examples: the relationship between the measurements of faecal indicator bacteria that have been used to index the health risk from faecal contamination are derived for sewage-polluted waters and unlikely to be applicable to waters where faecal pollution is significantly non-human in origin. Similarly, while the discipline of microbial risk assessment is advancing rapidly, data to support its application to organisms of zoonotic origin are limited; lack of adequate exposure measures effectively precludes prospective epidemiological studies.

Much of the management and regulatory experience that has been accrued from the control of human excreta is also directly transferable to management of animal waste. Livestock sources are mostly diffuse (e.g. fresh faeces or stored manures applied to land), though some point sources occur (cattle feedlots, manure heaps, etc.) and have variable characteristics, depending on local conditions.

These challenges and opportunities are compounded by differences between correct and incorrect risk perceptions among the general public, professionals and regulators alike, that are likely to be substantive.

During the consultations that led to the preparation of this publication examples were encountered of both over-confidence in the protection afforded by the “species barrier” and of concern driven by alarmist description of risk. For example, the suggestion that gastroenteritis among swimmers and animal non-point source contaminated water were “not associated” (Calderon et al. 1991) has been disputed (McBride 1993) and indeed in a subsequent review USEPA concluded

“Thus, water bodies with substantial animal inputs can result in potential human health risks on par with those that result from human faecal inputs.”

(EPA, 2011 lines 1605–1607).

One anecdote described a country in which responsibility for control of campylobacteriosis was transferred from the Health to the Food Safety authority, whose policy makers then asserted that Campylobacter could not be waterborne, because it is foodborne. Of course it is both, and to exclude the waterborne component would inadequately protect public health (see for example McBride et al. (2011)).

1.1 PROBLEM DESCRIPTION

There is a mismatch between present regulatory approaches and the needs of effective health protection against the potential risks from water-related zoonotic hazards. There is no specific guidance available on the assessment of risks arising from contamination of waters by animal faeces; nor on the development of health criteria for waters contaminated by animal faeces. This initiative is therefore driven by two pressures: regulatory and risk (including perceived risk).
This will be the second book in the series on “Emerging issues in water and infectious disease” to deal with issues related to zoonoses; in part in recognition of the fact that the majority, around 75%, of emerging and re-emerging pathogens are zoonotic. The first book, “Water-borne Zoonoses” (Cotruvo et al. 2004), which complements this volume, focused on three questions:

- The nature of waterborne zoonotic disease threats;
- Identification of new disease candidates; and,
- Adequacy of existing control measures.

In contrast this volume focuses on:

- The adequacy of the evidence base for policy;
- The appropriateness and effectiveness of present regulatory responses; and,
- Opportunities for effective low-cost regulation and management of actual and potential health risks.

For the purposes of assessment, management and regulation, the issue consists of three principal components: the source (animal excreta), its transport (i.e. transfer to, survival in and movement through watercourses); and resulting human exposure. All three can be the object of interventions.

This report, therefore, reflects on understanding what are the assessment, managerial and regulatory challenges, the adequacy of present regulatory approaches, and the characteristics of a better system.

For bathing waters the established approach was, for many years, retrospective compliance testing on an annual basis. However the 1999 “Annapolis Protocol” (WHO, 1999), associated World Health Organization’s Guidelines (WHO 2003; 2006) and their implementation in associated developments (EU, New Zealand 2003) show a strong shift towards prevention and real-time support for informed decision-making by members of the public. These documents also recognize, however, that health risks from zoonotic sources in absolute terms or as compared with faecal indicators are inadequately understood and they are cautious in interpreting the associated risks, except in assuming that the risk presented by animal excreta is less than that from human excreta.

For drinking-water the shift to preventive management is more advanced, with detectable changes in regulation and/or practice since the publication of the third edition of WHO’s Guidelines for Drinking-water Quality which recommended a “Framework for Drinking-water Safety” and associated “Water Safety Plans” (WHO 2004, reconfirmed in the fourth edition, WHO 2011). However, problems remain of inadequate understanding of zoonotic risks and the inadequacy of faecal bacteria as indicators of risk.
In the case of wastewater use in agriculture, preventive management approaches have been long-advocated to control the risks associated with introducing human excreta, and also effluents and sludge derived from sewage processing, into food production systems (WHO 1973; WHO 1989 and, more recently, with a multi-barrier approach, WHO, 2006b). In deriving these guidelines no account has been taken, however, of potential hazards in mixed wastes where human and animal excreta are both present; and there have been no substantive efforts targeted specifically on animal waste.

All of these routes of human exposure (recreational water use, drinking-water consumption and food produce grown with animal excreta inputs) have the potential to transmit a range of hazards including pathogens (micro-organisms capable of causing disease in humans) and toxic chemicals, including heavy metals and pharmaceuticals, including drugs, antibiotics and their residues. Antibiotics and chemicals used in animal care are of concern but are not separately addressed here. Available evidence suggests that the risks to human health are overwhelmingly dominated by microbial pathogens, and interrupting their transmission is therefore the focus of this book.

1.2 CHALLENGES

Available evidence suggests that risk associated with animal excreta is likely to be episodic in nature. This may arise because of sporadic load (e.g. migrating bird flocks) or sporadic transmission (e.g. mobilization of material on the ground surface or from water sediments following rainfall). Further complexity is added by the extreme spatial and temporal variability arising from factors such as seasonal weather patterns, livestock operations management (e.g. washing out of cattle sheds, seasonal grazing) as well as cycles of calving and associated microbial colonization and shedding including the phenomenon of “super-shedders” among herds and flocks. In New Zealand for example, at times of low river flow, Campylobacter isolates are primarily of ovine origin while strains of bovine origin dominate at times of high river flow.

Several studies have quantified the relative impacts of sewage and animal derived fluxes of microbial pollution to bathing waters (Stapleton et al. 2008, 2010; Kay et al. 2009; 2010; 2012). In an early study of rural catchments, Crowther et al. (2002) report on two such studies in the United Kingdom. Both catchments were livestock farming areas and the streams draining these areas were considered “pristine” in ecological terms. In both areas, bathing water quality non-compliance occurred after rainfall events. Studies revealed that this non-compliance was caused by microbial pollution from “normal” farming activities. Sewerage was not a significant cause of non-compliance during dry weather
conditions when anthropogenic load dominated. A similar pattern was reported by Stapleton et al. (2010). Again, livestock-derived, microbial flux dominated during periods of rainfall and improvements to water quality during this period from investments in sewerage systems were imperceptible. In this case, water quality was key to microbial compliance of adjacent shellfish-harvesting waters.

Many of the species of pathogens of concern are circulating naturally within one animal species or the other or among humans, and there may be significant strain or species specificity. Thus, simple and conventional classification and categorization of microbes may be misleading; and criteria based on aggregate microbial groupings may significantly under- or over-estimate risk. Similarly a single water body may be contaminated by faeces from different animal species and this contamination may contain strains of the same micro-organism from different host species. These factors all add complexity to the assessment of risk and to the management and regulation of water contamination with animal excreta.

These complexities highlight some of the demands on risk assessment practice. Neither available tools nor data can adequately respond to the associated challenges. Most available data, for example on the effectiveness of interventions, relate to faecal indicator bacteria (such as E coli, thermotolerant coliforms or intestinal enterococci) and not to pathogens. These faecal indicator bacteria are imperfect measures or indicators of pathogen die-off. Nevertheless, systematic monitoring of zoonotic pathogens in the environment is rare. Much risk assessment practice focuses primarily on steady state conditions but, in fact, zoonotic risk is likely to be very episodic and variable. Similarly, most risk assessment is based on impacts on numbers of individuals, not dynamically on populations (disease dynamics) and there is increasing recognition of the inadequacy of such approaches for the above reasons.

These complexities also point to challenges for effective regulation. For example, present regulatory approaches may permit sporadic failure, especially when associated with extreme events. However, targeting regulation on health risk would mean recognizing that such episodes may represent the periods of greatest risk that should, in fact, be targeted by regulation. A further challenge in assembling an effective portfolio of regulatory measures is that its elements may be many and diverse. Distinct components may be direct (for example, targeted on agricultural practices or land use planning) or indirect (for example, food standards requiring irrigation water quality standards or best practice in manure use in agriculture). Securing a consistent approach that is effective and not onerous or costly across the multiple potential legal instruments that may apply in any given jurisdiction will not be easy. Similarly, while there is extensive experience with regulating point sources of pollution in many
jurisdictions, regulation targeting microbial movement is relatively new and lessons are still being learned; and there is little substantive experience with regulation targeting human exposure.

At the interface of narrowly-defined regulation and wider policy, and including arrangements for inter-sectoral coordination, are the differing perspectives of the individual facility or farm and the collective impact of many such facilities or farms on a single catchment, including its multiple and diverse uses and the value and utility of such uses – extending into the associated coastal zone. This also implies an understanding of overall microbial load and of associated health risks (Kay et al. 2004).

Benefit-cost analysis (BCA) is one means to pursue regulatory efficiency, by demanding that both costs and benefits be described and to the extent possible quantified; and using the evidence derived to compare alternative responses and to reflect on means to minimize cost and maximize benefits of adopted approaches (Hahn & Tetlock 2008). Application of BCA to livestock excreta management for health protection has not been attempted in large part because benefits are poorly understood. For example, many interventions will operate on a number of pathogens and not a single agent. The outbreak of waterborne disease in Walkerton, Ontario, Canada that resulted in seven deaths and over 2300 cases of gastrointestinal illness was associated with infections by both E. coli O157:H7 and Campylobacter jejuni. Intense rainfall is thought to have washed cattle manure into a well which served as the water source for the town (Auld, Klaassen & Geast 2001). The nature of benefits is also evolving as greater attention is given to energy and nutrient recovery; and as the appreciation of the value of the recovered resources increases, so the benefit component of BCA expands accordingly.

1.3 OPPORTUNITIES

There may be opportunities to look for alternative solutions applicable to animal excreta as compared to those associated with the monitoring, management and regulation of human faecal contamination.

Direct targeting of specific pathogens has received little support in monitoring of human faecal contamination, in part because of the large number of potential pathogens, both known and unknown. However, since the number of credible zoonotic pathogens from any given animal species may be more limited, the role of direct pathogen monitoring may merit re-appraisal.

High-intensity production systems presently account for three quarters of chickens, two thirds of milk, half of eggs, and a third of pigs (FAO 2009). More intensive operations (such as the zero-grazing option: cattle managed exclusively
in sheds) may provide opportunities to increase management controls. Overall, livestock production is intensifying with larger facilities accounting for an increasing proportion of total production. In developed nations such as the USA, consolidation of the livestock industry is likely to maintain this trend while in less-developed nations intensive and traditional systems co-exist. High-intensity operations provide more achievable opportunities for recovery of energy and nutrient resources.

Developments in scientific understanding (including the emerging ability to predict health benefits), the increasing global attention to preventive management and accruing experience with its regulation in many countries combine to provide an opportunity to advance significantly the control of pathogens derived from animal excreta and of the associated human health risks.

There are diverse management options (interventions) available that provide approaches that may be directed at sources of contamination (such as stock management, vaccination, test-and-slaughter, quarantining, control of feed and water quality and on-site waste storage and/or treatment); transmission (such as barrier strips, retention ponds, constructed wetlands, timing of land applications and restriction of direct access to water courses by animals); and human exposure (such as drinking-water treatment and provision of public awareness-raising and information on recreational water quality).

Approaches to preventive management have been analysed and advocated for diverse exposure routes (Fewtrell & Bartram, 2001). Examples of their application include the multiple-barrier principle, Hazard Assessment Critical Control Point (HACCP) analysis, applied in food safety, the Annapolis Protocol (applicable to recreational waters); Water Safety Plans (WSPs), applied to drinking-water supply and long-established approaches to regulation of use of wastewater and excreta in agriculture (now evolving into sanitation safety planning). These approaches, especially if combined with recent developments in microbial source attribution and alternative indicators of faecal contamination, may provide opportunities to optimize health protection, contain costs and understand the relative contributions of different compartments to health protection.

By providing multiple opportunities to intervene, including different interventions at the levels of source, transmission and exposure, it is possible to evaluate preventive approaches that are amenable to comparative analysis and to benefit:cost analysis in particular. Experience has shown that “smarter” regulation can increase public health protection without significant increase in cost (see Chapter 11). Tools such as BCA enable the aggregation of multiple benefits and in doing so may point to the greater value of “upstream” interventions, the benefits of which accrue to multiple “downstream” uses.
Health impact assessment (HIA, Quigley et al. 2006) has proven effective in supporting this integrated perspective capturing diverse types and locations of impact and pointing to a range of possible interventions by actors from different sectors as part of a public health management plan.¹

One positive development has been the development and validation of catchment models, although these have focused on describing the movement of faecal indicator bacteria, rather than specific pathogens or classes of pathogens, in river and coastal systems. Early papers in this area have centred on generation of microbial export coefficients for different land use types and sewage treatment (Kay et al. 2008a,b), but more process-based modelling is required to provide management information on the efficacy of field-scale intervention strategies.

### 1.4 DRIVING FORCES AND FUTURE PERSPECTIVES

Available information suggests that the underlying issue confronted by this volume is, and is likely to remain, of ongoing or increasing concern.

*Water-related disease* remains an issue of major global public health concern, with the water-sanitation-hygiene risk complex globally accounting for around 10% of the global burden of disease (Pruess et al. 2008). This disease burden is heavily skewed towards the developing world, and least-developed countries in particular. The largest single disease outcome contributing to this burden of disease is infectious diarrhoea (accounting for 65% of the total), including its direct impact on nutritional status and indirect impact on diseases associated with malnutrition. Humphrey (2009) suggests that tropical enteropathy may be an under-appreciated adverse health outcome with pervasive impacts on child development arising from excessive exposure to faecal bacteria. The contribution of organisms of immediate or recent zoonotic origin to infectious diarrhoea and to tropical enteropathy is unknown. However, given the overall importance of faecal contamination to this large fraction of the global burden of disease, even a small fraction of this total would be of potential public health significance.

The phenomenon of true emergence of “new” pathogens from zoonotic sources (e.g. SARS, H1N1) is itself beyond the scope of this book but will place increasing pressure on entities responsible for public health and will continue to draw attention to the importance of zoonoses to public health in general.

¹ see: http://www.iaia.org/publicdocuments/special-publications/SP5.pdf
Intensification of livestock production places larger numbers of animals in closer proximity to one another, bringing with it an increased likelihood of true pathogen emergence and also of development and transmission of antibiotic resistance.

Increasing numbers and proportions of more vulnerable human population groups (notably the elderly and immuno-compromised) will provide opportunities for different pathogens to attain prominence and points to continuing public health relevance.

Population growth and increasing affluence are associated with increased demand for meat protein. Domestic animals already outnumber humans by a factor of four (FAO 2009). Satisfaction of demand will be through increased livestock production and intensification, aggravating the challenges of their excreta management that are already significant in high-, middle- and low income settings.

Extension and proliferation of human settlements will bring human populations into greater immediate proximity to livestock concentrations with greater opportunities for pathogen transmission from livestock to humans, with water a medium of prominent importance.

Predicted shortfalls in fertilizer availability will encourage use of animal manures on agricultural land. The economic value of nutrients contained in manure may contribute to encouraging source management (containment and close-to-source treatment).

In parallel, increasing concern for the “carbon footprint” of economic activities and the energy value of animal excreta will increase the incentive for their containment and productive management and this will replace their previous consideration as waste products.

Policy attention to climate change mitigation is likely to be sustained and will bring with it attention to greenhouse gas emissions from livestock – it has been estimated that livestock produce between 8 and 18 percent of anthropogenic carbon dioxide (Steinfeld et al. 2006). It is unclear whether this will impact excreta management but it is likely to place pressure on good practices in the industry and the potential clearly exists for animal manure to replace fertilizers with a greater carbon footprint in production and distribution or with finite natural reserves.

Even short-term predicted variability in climate will lead to increased frequency of dry and wet events in many regions (Howard et al. 2010). While impacts may increase or reduce pathogen transport to water courses, including groundwater, specific concern relates to failures in containment of animal wastes and in their mobilization and dispersal in response to increased or more intense rainfall.
1.5 SCOPE OF THIS BOOK

The subject of zoonoses of potential concern for waterborne transmission has a large scope. During the development of this book it was decided to focus on those zoonoses for which there is a credible prospect of regulatory action. This led to a focus on infectious agents from animals that are under human management (both commercial and subsistence livestock), safe management of wastes produced by which might reasonably be required or encouraged. Thus, the focus is on livestock, rather than feral or wild animals. Such a distinction is to some extent artificial and some pathogens may derive from both livestock and wild animals. For example both *Giardia duodenalis* and *Cryptosporidium parvum* infect the intestinal tract of a range of host animals including humans, dogs, cats, cattle, sheep, horses and rodents among others; while the infectivity to humans of strains from different animal sources appears to vary (e.g. *S. japonicum*).

Furthermore, a pragmatic decision was made to exclude domestic pets such as dogs and cats from consideration as the interventions that would contribute to the control of their excreta are distinct. While fish farming may be included under a definition of intensified livestock production, fish excreta were also excluded from consideration.

Finally, this book looks at the assessment, regulation and management of existing hazards. It does not address the issue of true “emergence” that is natural propagation of an entirely new pathogen of human public health significance. Such emergence occurs across viruses, bacteria, protozoa and other pathogens; it is, however, especially frequent among viruses. Examples include Severe Acute Respiratory Syndrome (SARS), that arose from a 27 base pair deletion in an animal corona virus (likely to have previously sporadically infected humans with less severe consequences); this mutation rendered it highly pathogenic for humans. The periodic emergence of novel strains of influenza viruses from recombination provides a further example. True emergence has, presumably, also happened at some point in the past with Hepatitis E virus (HEV). It is noteworthy that around 75% of emerging pathogens are of zoonotic origin.

Notwithstanding the exclusion of true emergence, history suggests that resilience can be embedded into public health systems through recognizing the value of planning for the unexpected.

Thus prevention of faecal contamination of recreational waters and drinking-water sources will impact beneficially on the control of a wide range of known and potentially unknown and yet-to-emerge pathogens; and multiple-barrier treatments that employ multiple and different processes are more likely to be effective against an unrecognized or emergent agent than those which rely on a single process of removal or inactivation.
1.6 STRUCTURE OF THIS BOOK

This book is structured according to the major issues discussed and as summarized in Figure 1.2:

- This introduction summarizes the rationale, context, objectives, scope and structure of the book.
- Chapter 2 summarises the state of knowledge with regard to specific, credible waterborne pathogens. In terms of the further development of the book it importantly introduces the idea of a limited number of priority pathogens that are used to assess and calibrate interventions in the remainder of the book.
- Chapters 3–8 then explore the major components of source (load), transport and (human) exposure:
  - Chapter 3 looks at sources and load as a composite issue, including state of knowledge and the adequacy of available data and tools in assessment and monitoring. Chapter 4 explores current knowledge of interventions to reduce load including specifically those that may be the targets of regulation and issues associated with such regulation.
  - Chapter 5 looks at transport as an issue, including state of knowledge and the adequacy of available data and tools in assessment and monitoring. Chapter 6 explores current knowledge of interventions to manage transport including specifically those that may be the targets of regulation and issues associated with such regulation.
  - Chapter 7 looks at human exposure, including the state of knowledge and the adequacy of available data and tools in assessment and monitoring. Chapter 8 explores current knowledge of interventions close to the point of exposure, including specifically those that may be the targets of regulation and issues associated with such regulation.
- Following introduction of the critical issues of load transport and exposure, three chapters are dedicated to exploring the data and tools used, associated state of knowledge and the adequacy of information generated by them to inform both regulation and management.
  - Chapter 9: Indicators, Sanitary Surveys and Source Attribution Techniques.
  - Chapter 10: Comparative Risk Analysis.
  - Chapter 11 contains a review of epidemiological studies on swimmer health effects associated with potential exposure to zoonotic pathogens in bathing beach water.
  - Chapter 12 looks at economic evaluation – the assessment of risks, costs and effectiveness of interventions and costs and impact of regulatory
alternatives, using a specific example from bathing water in the Netherlands which is relevant to a wide range of similar hazards and their control.

- A summary statement serves as an “executive summary” for the work as a whole and highlights critical implications and recommended actions for different target groups. In convention with other books in this series it summarizes the conclusion of those experts that participated in the process of development of the book as a whole.

**Figure 1.2** Structure and chapters of this book.
REFERENCES


Animal Waste, Water Quality and Human Health

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