Chapter 6 – Water and health

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Recommendations

- National and international funding bodies should fund research programmes to develop portable field-testing kits for arsenic that are quick, accurate, cheap and reliable and support remediation efforts.
- National and international funding bodies should fund research programmes to develop arsenic mitigation technologies that are effective and appropriate for use by the local populations.
- Funding bodies, such as NERC, Economic and Social Research Council and Medical Research Council, should jointly fund research into multiple chemical sensitivity to assess whether this phenomenon is genuine.

Executive Summary

Water transports contaminants, including inorganic, organic and biological materials, from various sources both natural and man-made. Such contaminants can enter the human body via water by ingestion, inhalation of water droplets and contact, particularly with broken skin.

Water borne diseases have historically had the greatest impact upon human health and continue to contribute to millions of deaths globally per year. Water use and sanitation in the form of hygiene practices act as an important barrier to disease transmission. Disease incidences in countries without basic water and sanitation services are estimated to be eleven times higher for than those in areas with clean water, hygiene practices, and the safe disposal of human wastes.

Naturally occurring arsenic compounds (in particular toxic organic species) contaminate substantial groundwater sources. The most seriously affected areas in

the world are in India and Bangladesh. Here, 60–100 million people are currently at risk of poisoning as a result of drinking contaminated groundwater where the arsenic arises from the natural bedrock geology. There is a need for portable field-testing kits that are quick, accurate, cheap and reliable that can support remediation efforts. Additionally there is a need for arsenic mitigation technologies that are effective and appropriate for use by local populations. There is also a growing problem with uranium contamination of groundwater, particularly in Eastern Europe.

Society is reliant upon man-made chemicals, particularly for food and health, and inevitably such chemicals end up in water systems. Typically these chemical contaminants are either neurotoxins, pharmaceutically active or endocrine disruptors. Additionally there is growing concern over multiple chemical sensitivity[1], although scientific evidence is insufficient to prove or disprove this theory at this time. There are two specific problems with man-made chemicals in wastewater: firstly, treatment plants are not designed to remove these chemical products; secondly, chemicals entrained in sediments can be mobilised by chemical and biological processes.

Traditionally, pollution by man-made chemicals is reduced by either dilution or through end of pipe remediation technologies. This can be minimised by adopting good practice and integrated pollution prevention and control. This would include measures such as minimising the quantity of materials used and recovering unused materials. Additionally, industrial waste streams should be concentrated as far as possible and mixtures of materials should be avoided, as this will require additional treatment steps and effort.

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[1] Multiple chemical sensitivity (MCS) is described as a chronic condition characterised by several adverse and variable affects from exposure to otherwise low levels of substances in modern human environments.

Introduction

In water management, we are dealing with closely coupled dynamic systems and the effect of adopting sustainable water management approaches is to make several of those couplings even tighter. The central critical linkage is between land and water: in particular, we essentially manage water in order to make the best use of land. In turn, the way in which we manage land directly impacts upon the water environment. As a system, a catchment is dynamic in both space and time (**Figure 1**), with three main interchanges between land and water: water quantity; entrained pollutants; where all or some of these pollutants are associated with the erosion and deposition of soil.

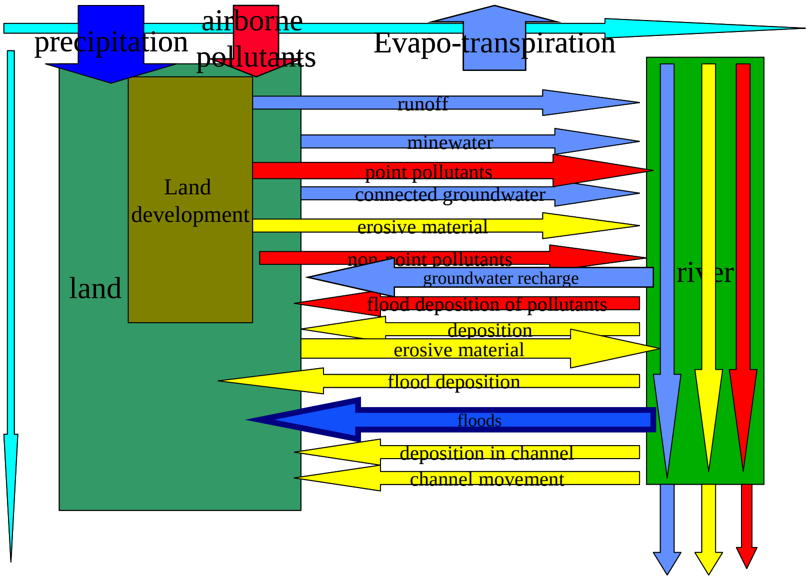

Figure 1: Catchment as a system

Catchments, in short, have to be managed as a system, and a system whose behaviour is dynamic both in time and in space. As a system, it involves interactions between land and water not only in terms of water but also of soil through erosion and deposition, as well as of pollutants. Whilst all water is recycled over the long term, a significant proportion of surface water in a catchment is reused within the catchment, accumulating salts and minerals as it does. Because it is a system, interventions in one time and place, and to one purpose, generally have repercussions downstream, at other times, and upon other functions of the catchment. In a system, there are, by definition, externalities. The dynamic nature of catchments increases the extent of some risks to health; floods move sediment in which is entrained heavy metals and other pollutants (Stachel et al 2004) and inorganic mercury can be converted to the more toxic methyl and dimethyl mercury under either aerobic or anaerobic conditions (Mason 1996). Similarly, floods flush pesticides, helminths and nutrients from farmland into the water courses.

At the same time, the rate of most treatment processes cannot be rapidly changed to adjust to loads so that storage is necessary to provide a buffer between the changing load and the relatively constant processing capacity. Similarly, the capacity of rivers to self-purify some pollutants is dependent on the flow, temperature and DO, all of which vary over the seasons. In turn, parameters such as runoff coefficients are not constants but variables. Thus, it is important to consider any intervention in terms of the functioning of the catchment as a whole, over the full cycle of variation, rather than looking to fix a local problem at one point in time.

Hence, a key problem in water management is to cope with variability; those countries where the temporal variation in rainfall either over the year or between years is high, and so both floods and droughts are frequent, have had to invest heavily in storage. Typically, the predicted effect of climate change is to increase variability; in the UK, for example, there is expected to be higher rainfall intensities and also less rain in the summer and more in winter (Arnell 1996).

Of those land uses, the most important is arable agriculture which produces 77% of all food. Arable land is scarce, much of the available land, in addition to already being in some environmental or other use, is limited by chemical factors (FAO 1995). Food production is by far the greatest demand for water: depending upon their diet, one person's daily food needs have taken 3-6 tonnes of water to grow (Falkenmark and Rockstrom 2004); satisfying all that person's other water needs requires perhaps 300 kgs of water. But the Millennium Ecological Assessment (Alcamo et al 2003) projects a need to increase global food production by 80% over the next 50 years and, whilst there is not a linear relationship between output and water inputs (Molder 2007), this will require a substantial increase in the use of water for agriculture. Thus, the greatest threat to human health associated with water is the potential inability to provide sufficient water to grow crops, a problem manifested in the regional droughts which are particularly prevalent in the countries with arid climates: those with very large variations in rainfall both over the year and between years (Harrison 1987).

To this system we then add water management for human purposes (**Figure 2**): a further complex system, many of whose components are intentionally interconnected but others, whilst notionally independent in practice are closely coupled. In practice, solid waste management cannot be wholly separated from water management: rivers, sewers and drains have always proved to be attractive means of disposing of different forms of rubbish. That practice of disposal has created many of the current problems of environmental pollution of water bodies. Unless adequate, alternative means of disposing of such waste are provided then water will continue to be used for such waste disposal. Whilst there has been increasing adoption of the principle of separate foul and surface water sewers, in practice the two systems are commonly much less distinct in practice because of the high frequency of misconnections of drains. Whether it is practical to drive down the rate of misconnection is an open question. Equally, there is frequently exchange between both types of sewer and groundwater as the result of infiltration (of groundwater into the sewer) and exfiltration (from the sewer to the groundwater).

This system is expensive and capital intensive: each home in England and Wales is served by some £7,000 of sewers where sewers constitute some 65% of the entire asset value of the water and wastewater industry. In turn, water management is generally capital intensive so that it is commonly a Ramsey good (Ramsey 1927), one where the average cost exceeds the marginal cost, and so the conventional economic recommendations are often inappropriate (Green 2003).

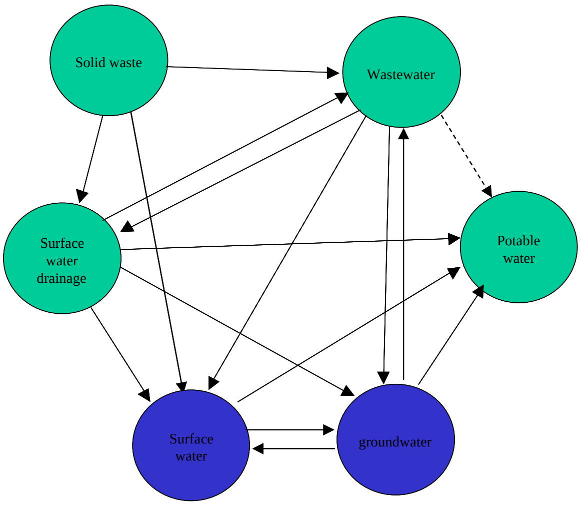

Figure 2: The interconnections between the components of an urban water management system

All wastewater is necessarily reused through the hydrological cycle but to make the most effective use of the available resource, we have increasingly been tightening this recycling loop; sustainable water use involves a further tightening of this loop.

Doing so increases our exposure to human produced hazards since, unfortunately, water is an effective means of transmitting agents which can harm the health of people and damage ecosystems (**Figure 3**). Indeed, water related disease contributes a significant proportion of the total health burden. In many cases, water provides a means of human to human transmission, faeces containing the infective material. Conversely, washing with water frequently provides a critical barrier to such transmission either from human to human or from the environment to human. Where this is an inadequate barrier, other forms of treatment have to be introduced before the water can reach humans or to reduce the wastes we discharge with wastewaters.

The direct routes by which agents can impact upon people's health are:

- Ingestion e.g. food and drink, notably the risk of cholera.
- Inhalation of water droplets, most obviously Legionnaire (Newsome 2001)
- Contact, particularly with broken skin, where Leptospirosis (WHO/International Leptospirosis Society 2003) and Schistosoma (WHO/UNICEF 2006) are the obvious examples. Traditionally, such contact with water was commonplace in irrigated agriculture and fishing, as well as washing, but increasingly is also associated with recreational activities such as swimming and boating (Pond 2005).

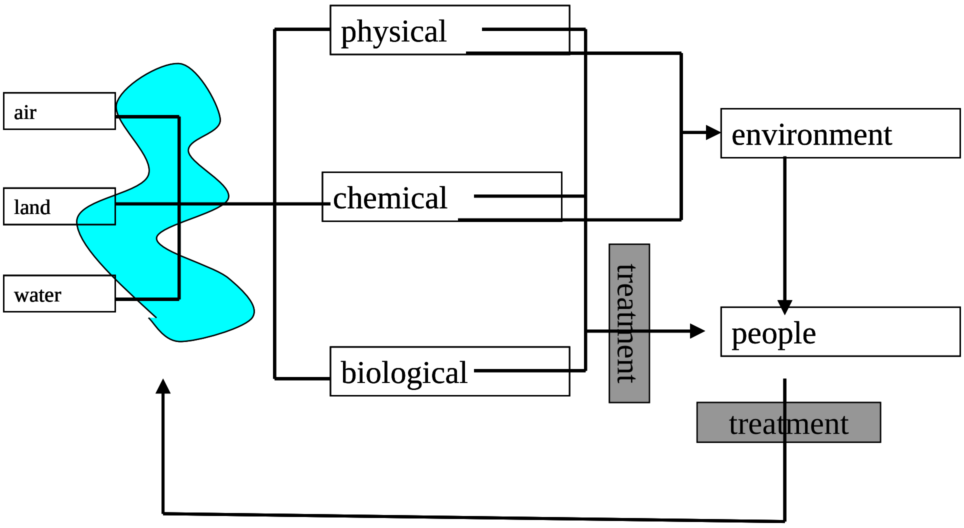

Figure 3: Urban water management

Potentially harmful agents to human health arise in a number of ways. Many are natural: animals and birds are sources of protozoa and helminths, such as leptospirosis and giardia (FWR 2002), and cryptospiridium (FWR 2006). Naturally occurring minerals particularly arsenic and fluoride (Smedley and Kinniburgh 2002) in groundwater present a major risk in some parts of the world, and a problem whose magnitude is still being assessed. Radon has been discovered to be a problem with some fossil groundwaters, most notably in Jordan (Al-Kazwini et al 2003). Similarly, uranium can be found in groundwater which has been in contact with granite and phosphate bearing rock (Smedley et al 2006). Problems with groundwater are particularly important because it is such a critical resource: the water stored in groundwaters is estimated to be equivalent to 70 times annual global precipitation (Falkenmark and Rockstrom 2004). Deep mining usually requires pumping of groundwater and when mines are abandoned, groundwater rebound can liberate a range of minerals including salts, iron and manganese (Younger et al 2002). When those minerals are captured by sediments, a problem is created which continues long after the mine ceases to operate.

Bracken is potentially a source of carcinogens (Rasmussen et al 2005) and the processing of cassava for food and other purposes yields a significant quantity of cyanodes (Balagopalan and Rajalakshmy 1998). Soaking is indeed necessary in order to remove the cyanodes and make the cassava safe to eat; the same being true of other food stuffs, notably some forms of beans which contain lectins. It is a mistake to think that natural is necessarily nice.

A significant fraction of water pollution is from depositions of airborne particulates created as a result of combustion; nitrates (Alexander et al 2000) are one problem but mercury is another airborne combustion product that can then be deposited in water (USEPA 1997). The problem of lead is well known but the risk posed by its replacement in petrol by MTBE is uncertain, and nanoparticles from diesel are also a potential hazard.

Transmission via air is only one of the three routes through which chemicals are released from industry to the water environment. Direct discharge to either to surface water or particularly to groundwater is still a widespread problem. Leaching from soil of chemicals as a result either of abandoned industrial sites or from waste disposal sites is equally a problem (USEPA 2002).

Traditionally, the greatest health burden has been through disease vectors but in those countries where the acute problem of biological vectors has been resolved, the current concern is with the potential problems associated with increased chemical usage (**Figure 4**). The extent of these risks is uncertain and similarly it is an open question is whether the adoption of Sustainable Water Management will result in increased risks to health and the environment. This is a possibility because:

- The number of treatment works will increase by a factor of two or more orders of magnitude. The gross annual probability that at least one treatment works will fail is increased; this risk would be further increased by their operation by relatively unskilled personnel. Some techniques, such as the use of chlorine, a highly toxic gas, for disinfection should probably be avoided in such conditions.
- There is a risk of misconnection between rainwater/greywater recycling systems and potable water supply, particularly in DIY installations.
- All treatment systems produce waste which may not be disposed of properly.

These risks may be non-trivial: in 2003, some 29% of private water supplies in England were found to be positive for E Coli (Health Protection Agency 2004); and a study targeted at a small number of high risk private water supply systems found 60% were contaminated with Cryptosporidium and 53% with Giardia (Clapham and Franklin 1998). The same pattern is found elsewhere; 60% of the waterborne disease outbreaks in the USA in 1985 were associated with private water supplies (Louis 1985).

The instinctive response in these circumstances is to introduce regulations, but this is to beg the questions of: can they be enforced, will they be enforced, and how much will it cost to enforce them? In an apparently compliant society such as the UK, there is very little known as to rate of compliance with Building Regulations, Water Regulations and Planning Consents. In other parts of the world, the rate of compliance approaches zero. Similar issues arise with other mechanisms such as economic instruments with the added disadvantage that prices have proved to be highly ineffective in changing behaviour in relation to water use (Molle and Berkoff 2007).

	biological	**chemical**	**physical**
traditional	♦		
current		?	
SWM	?	?	

Figure 4: Health problems associated with traditional, current and future water management technologies

Historically, the biological route, in the form of disease vectors, presented the greatest burden. Globally, amongst school children, there are estimated to be 320 million cases of roundworm (Ascaris); 233 million cases of whipworm (Trichuris); and 239 million cases of hookworm (Necator/Ancyclostoma). These chronic illnesses reduce their capacity to attend school and to work in later life (White et al 1972). Helminths are endemic around the world; 20-80% of children in North America and Europe are believed to be infected with pinworm. Malaria, carried by mosquitoes which depend upon water for a critical part of their life cycle, is estimated to reduce the economic growth rate in some countries in Africa by more 0.25% per year (McCarthy et al 2000) and disappeared from Europe for reasons which are not well-understood (Reiter 2000). Other illnesses transmitted by insects which are water dependent include Dengue Fever and western equine encephalitis (Spielman and D'Antonio 2001).

Diarrhoeal diseases, 88% of which cases are either water transmitted or preventable through hygiene practices using water, still constitute a large proportion of illnesses, resulting in 1.8 million deaths worldwide each year, (WHO/UNICEF 2006). The 1854 cholera outbreak in Chicago killed 5.5% of the population whilst the 1991-94 outbreak in South America affected slightly over one million people. Of the diseases identified in the last thirty years, it is estimated that at least 20% of school children in the developing countries are affected by Giardia (FWR 2002) and outbreaks of Cryptosporidum occur around the world, with the first recognised outbreak, that of 1993 in Milwaukee, resulting in the deaths of 54 people (FWR 2006). In the countries with advanced treatment systems, the seriousness of the diseases associated with water supply is drastically reduced but the number of cases remain high (Craun et al 2006). As the above examples illustrate, those diarrhoeal diseases are transmitted through a variety of vectors: viral, bacterial and parasitic (Feachem et al 1983).

But, water use and sanitation in the form of hygiene practices (Cairncross 1999) can act as an important barrier to disease transmission; disease incidence in countries without basic water and sanitation services being estimated to be 11 times higher than those areas with clean water, hygiene practices, and the safe disposal of human wastes (Pruss et al 2002). Of the biological vectors, the viruses (e.g. poliomyelitis, hepatis A, rotaviruses) and bacteria (typhoid, paratyphoid, cholera) are currently the potentially most lethal whilst the protozoa (e.g. Giardia) and helminths (e.g. hookworm, whipworm, roundworm) are the most widespread: thus, in the USA, some 4.3 million to 33 million cases of acute gastrointestinal illness (AGI) are estimated to occur as a result of waterborne vectors (CDC nd).

Domestic water use has long been known to result in potentially major problems. The traditional use of human wastes directly as a crop nutrient provided an excellent pathway for the reinfection of people with protozoa and helminths. Here, traditionally, the problem lay with human faeces, urine being generally sterile, as well as a valuable source of plant nutrients in the form of nitrogen and phosphorus (Feachem et al 1993).

Water related issues also contribute significantly indirectly to health issues in the widest sense where the WHO (1946) definition of health is: "*a state of complete, physical, mental and social well-being and not merely the absence of disease or infirmity*." The physical burden of collecting water is disproportionately borne by women, exposing them to injury and increasing their food needs, whilst the time taken to collect water cannot be used by them to earn income or in the case of girls, to go to school (WHO/UNICEF 2006). Since health care is traditional a female role in most cultures, women's time is also diverted to caring from those made sick as a result of water related diseases.

Floods are also a leading cause of death from natural disasters (Guha-Sapir 2004): flood plains are typically differentially desirable for settlement because they contain alluvial soils deposited as a result of previous flooding. An increasingly recognised long term health consequence of flooding, in addition to the disease burden (Gueri et al 1986), are the psychological and psychiatric impacts of flooding both on the individual household (Tunstall et al 2006) but also on the wider community (Erickson 1978). As extreme flows, floods also play a crucial role in the remobilisation and deposition of sediment contaminated with heavy metals and other pollutants (Wilson et al 2005); perhaps most notably in the Elbe flood of 1982 and the Spolana works (Stachel et al 2004), and the similar distribution of dioxin by the Tittabawassee flood in the USA (Michigan State University 2005).

Chemical burden

That water is the universal solvent is both its virtue and the problem: it has the ability to carry a whole variety of undesirable chemicals into contact with humans; the relatively recent discovery of the major problem with arsenic in groundwater (Smedley and Kinniburgh 2002) being simply one example. Apart from such natural occurring contamination of water with toxic materials, both intentional discharges of chemicals and accidental releases also create major health problems. The industrial use of mercury and its release into the environment, first recognised with the Minamata case in Japan in the early 1950s where 730 people died (Mason 1996), continues to cause problems. The problem here is that to be effective, chemicals have to be active but once used, ideally they should become inert.

The greatest current threat to human health arising from chemical contamination of drinking water is exposure to arsenic. Arsenic compounds may be classified into one of three broad categories of differing toxicities: organic arsenic compounds, inorganic compounds and their solutions, and arsine gas. Inorganic species are generally thought to be less toxic than organic ones. Health effects of arsenic uptake include skin lesions, damage to the peripheral nervous system, leucopoenia and anaemia, liver damage, circulatory disease and cancer.

The most seriously affected areas in the world are in India and Bangladesh (see **Figure 5** for distribution in Asia). Here, 60–100 million people are currently at risk of disease as a result of drinking contaminated groundwater where the arsenic arises from the natural bedrock geology.

Figure 5: Arsenic contamination in Asia [question marks indicate uncertain concentrations in Shanxi Province, China] BGS (Smedley, 2003).

In Bangladesh, the problems arose following the search for microbiologically safe supplies of drinking water where10 million tubewells were drilled into aquifers. While this improved microbiological water quality, around 40 million people became exposed to toxic levels of arsenic.

Two current important issues regarding the arsenic problem should be made. First, spatial and temporal variations of arsenic are high and to accurately portray the status of contamination and to effectively monitor remediation efforts there is a need for techniques that provide cheap, quick, on-site measurements. Field testing kits for arsenic currently have unacceptably high frequencies of inaccurate results particularly when the WHO guideline of 10 μg/L is used as a decision making criterion. There is a clear need for an improvement in these technologies.

Second, the chemistry of arsenic is complex and the range of potential mitigation options that exist reflects this. Whichever mitigation options are selected, with developing countries predominantly affected, the technologies should ideally be simple, low-cost, transferable, versatile, use local resources and must engage with and be acceptable to the local community. It is of primary importance that this engagement includes women who in many affected countries collect, carry and use water for their families and as such should be at the forefront of awareness and use of arsenic treatment technologies.

The critical problem is that for the millions of chemicals in use, for the majority there is an absence of data on the risk posed by each and frequently also an absence of affordable means of routinely monitoring their presence in water and the environment (RCEP 2003). Their effects can also be subtle, mutagenic or teratogenic effects rather than acutely toxic. At the same time, we are exposed to a very large array of naturally occurring chemicals; Ames and Gold (1989) estimating that a normal diet may contain up to 10,000 plant produced pesticides. But, some of the chemicals manufactured are different isomers and particularly stereoisomers of naturally occurring materials and may have quite different toxicological properties (RCEP 2003).

Modern society is heavily dependent upon the widespread use of chemicals not only in industrial production and in the home but most importantly in food production. Malthus (1826) was right: in the following hundred years after he wrote, population grew faster than the increase in crop yields, only bringing North America and other land into production bridging the gap between population growth and crop yield. Now we can only feed the world by further increasing yields which have risen dramatically in the last 50 years. Part of this yield increase has been the result of improving the supply of nutrients to plants, the use of fertilisers, but one result has been water pollution as a result of the excess nitrogen and phosphorus being carried off in runoff or infiltrating the groundwater. Pesticides have cut the rate of global loss of rice from pests from 83% to 52%, and for wheat from 52% to 33% (Wood et al 2000). But, again, runoff and infiltration have transported the excess pesticides into surface water and groundwater so that in England and Wales alone some £1 billion capital investment has had to be made by the water supply industry on activated carbon treatment to remove the pesticide residues, with a further annual operating cost of £120 million. Irrigated land is potentially more productive than dry land farming, not least because in the tropical climates its use permits more than one crop to be harvested each year. However, the drainage water from irrigated sites both leaches salts from the soil and concentrates those salts present in the raw irrigation water. Selenium can, for example, become a major problem (National Research Council 1989). Livestock are equally a source of nitrates, zoonoses (Cotruvo et al 2004), and veterinary pharmaceuticals. Greywater irrigation of gardens presents potential problems with both salts and clogging soil pores.

Cities themselves are generally exporters of water (Green 2003) but rainfall both washes them, carrying away surface pollutants (D'Arcy et al 2000), particularly those produced by vehicles (Ellis et al 1986), and the natural corrosion products from buildings, such as copper and zinc (Bertling et al 2006). Traditionally too, pesticides have been used on streets, pavements and railway lines in order to keep down weeds, plants and bushes, the residues from which either being carried away by runoff or infiltrating into the soil.

The water distribution system is a potential sources of contamination (National Research Council 2006), the problem of lead pipes being the best known. But water storage is a further potential source of contamination (Cairncross 1999).

The potential extent of the risk from chemicals is a subject of concern. There is a lack of toxicological data on most chemicals, a problem now being addressed by the EU REACH programme. Methods of detecting and thus monitoring the presence of chemicals in the different environmental pathways are not always available (RCEP 2003). Four areas of possible effect, with varying degrees of possible concern, are:

- Neurotoxins which may cause damage to foetuses (Grandjean and Landrigan 2006); there are some 30,000 chemicals in use in Europe (RCEP 2003), many of them in the home.
- Pharmaceutical residuals and metabolites in wastewater (Kujawa et al 2006): the residuals and metabolites from a broad range of prescription and over the counter medications may be expressed in either urine or faeces (Moll et al 2001). Pharmaceuticals are only one of the many chemicals used in the home, often characterised as Pharmaceutical and Personal Care Products, most of which we have inadequate knowledge of both toxicology and means of removing from waste streams (Ellis 2006).
- Endocrine disruptors both from pharmaceutical and industrial products (Damstra et al 2002); and
- Multiple Chemical Sensitivity (The Interagency Workgroup on Multiple Chemical Sensitivity 1998).

The extent of the risk from each of these four groups has not yet been established and in the case of Multiple Chemical Sensitivity this risk is the subject of considerable scientific doubt.

Two specific problems with chemicals in wastewater are, firstly, that wastewater treatment works are conventionally designed to deal with suspended solids and oxygen demand rather than to remove chemical products, and some of those chemicals can themselves harm the bacteria which are used for wastewater treatment. Secondly, many of these chemicals become entrained with sediment which is remobilised and redeposited by variations in river flows. Chemical and biological processes may then make those chemicals biologically available again (Wilson et al 2005). Increasingly, therefore, sediment management is becoming a critical issue in surface water management.

The environment

The focus here is upon human health but a major reason to manage wastewater is protect, conserve and enhance the environment. There are three rationales for protecting the environment:

1. It is necessary: the economy ultimately depends upon the environment (Green 2003), and the precise interactions between elements of the environment are still being understood (Alcamo et al 2003).
2. It is nice; we like it for recreational and leisure purposes and for other reasons.
3. There is a moral or religious duty to protect the global environment. Islam in particular makes very strong assertions about the duty to protect the environment since it is another aspect of the creation of the deity (Bagader et al 1994). Water in particular is associated with purity in many religions and has strong cultural associations.

In addition, the way in which we treat the environment is also reflective of social relationships in the same way that inter-generational equity is reflective of intra-generational equity. The way that someone treats the environment or acts towards the interests of future generations is also taken as indicative of how that person will behave to others of this generation. Someone, for example, who is prepared to sacrifice the interests of their children or grandchildren for their own present pleasure can be expected to be even more willing to sacrifice the interests of others for the same purpose.

In terms of water management, there is a partial overlap in terms of those materials which are potentially damaging to us and those which will negatively impact upon other species (**Figure 6**). In general, disease vectors are less important for other species than for us, but many substances have the potential to harm both us and other species. Critically, the way in which we physically manipulate the environment has potentially very damaging affects upon ecosystems since they have developed around the prevailing hydrological regime and associated geomorphological form. Traditional wastewater treatment focused upon reducing some of the physical demands of the discharged wastewater in the form of temperature, oxygen demand and suspended solids.

	biological	**chemical**	**physical**
traditional		♦	♦
current		♦	♦
SWM		**?**	

Figure 6: Damage mechanisms for the environment under different water management technological systems

Reducing pollution

The traditional approach of flushing away wastes either into the nearest water course or into the nearest sewer had the effect of both diluting and mixing the materials. Where the environment had a capacity, when the waste was sufficiently diluted, to treat that waste, then the solution was effective over the larger scale. The notable disadvantages are that dilution results in larger quantities of wastes to be treated and that, since different mechanisms are required to treat different forms of waste, mixing greatly adds to the complexity and difficulty of treating the waste. Hence, there is now a strong preference for avoiding such 'end of pipe' approaches and instead focusing upon minimising water use coupled to localised processing through which water is reused or recycled locally. In the industrial and commercial sectors, the evidence is that such approaches can cut water usage by 15-50% whilst simultaneously improving the profitability of the firms involved (Envirowise 2005). Such measures can frequently cut costs simultaneously in four different ways: reducing the quantity of water consumed cuts water bills; cutting the quantity of water discharged cuts trade effluent charges; since water is frequently either cooled or heated for use, energy costs may also be cut by reusing water; and the polluting materials are often residual material from the production process which may be recovered for use (Green 2003). Thus, Severn-Trent Water report that it helped the car manufacturer Jaguar cut its water use from 325 million litres in 1996 to 109 million litres in 2001 partly through a new water test facility that recycles water 110 times before it is discharged (STWA 2002) and China (National Development and Reform Commission 2005) has now set standards for water consumption per unit output in different industries.

Again, whilst the principle of separated wastewater and surface water sewers was an excellent one, the practice has been of a high level of misconnection of surface water drains to foul sewers and vice versa (USEPA 2000) so the expected benefits have not been realised in practice. One potential benefit of SUDS (Sustainable Urban Drainage Systems) has consequently been argued to be that it will make it impossible for surface water drains to be connected to a foul sewer (Jefferies 2007). Similarly, a reversion to composting toilets (Esrey et al 1998) would remove human wastes from the sewer system.

From any form of wastewater treatment, there is always at least one waste stream which must be disposed of: solid, liquid, or gaseous. This is as a true of 'green' solutions as of conventional 'hard engineering' solutions. For example, different forms of wetlands are increasingly attractive means of treating waste streams of different forms (Molle et al 2005; Shutes et al 2005). But, they are likely to collect sediment containing heavy metals which sediment must be collected and disposed of safely. Sludge from conventional wastewater treatment works has itself proved to be increasingly difficult to dispose of as it has become more contaminated with heavy metals and other pollutants. Moreover, it is urine rather than faeces which contain the greater proportion of the useful crop nutrients in the form of nitrogen and phosphorus.

Again, some natural wetlands are major sources of methane gas (Mitsch and Gosselink 2000), a greenhouse gas, some 25 times more aggressive than carbon dioxide. In conventional treatment works, this gas can be captured and burnt to provide electricity.

There are then a number of principles to be applied in regard to the use materials:

1. Minimise the initial quantity of materials utilised, and use those materials efficiently to minimise the material left over at the end of the process.
2. Where possible, select between alternative options in terms of ease of neutralisation after use.
3. Recover excess materials for reuse.
4. Concentrate materials.
5. Avoid mixing materials with different chemical properties which will require different treatments in order to recover them or neutralise them.
6. In considering the final disposal of the waste stream(s), adopt an Integrated Pollution Control approach is selecting between soil, water and air.

The social production of risk

Our problem is always to decide what to do; in particular, where to start, how to set priorities. In the case of risks, of deciding which ones is it most important to reduce first and by how much. 'Risk' is a useful word because it is a nexus of meaning, joining a complex of meanings. But, 'risk', considered in terms of probabilities and outcomes, is both an abstraction from reality and defines no more than a symptom. As an abstraction, the concept of risk forms the bridge between the physical realities of the actual deaths and harmed, and an action to reduce the numbers of such deaths and injuries. Its entire importance in the latter sense lies in the extent to which we could do something to reduce the risk and for that reason wish to compare the risk resulting from alternative courses of action or in different contexts. But it is no more than abstraction connecting the two physical realities of deaths and action.

Risk is also a social construction; it is a social construction of the world. Here, the common term of 'risk perception' is a misnomer: perception refers to the function of the sensory system; what is commonly termed risk perception is technically actually a cognition. Nor is it solely an individual's cognition but a social interpretation of the world and of a particular possible hazard. Risk is an expression of a society's view of the world, including the nature of knowledge, and the social relationships that should make up that world (Berger and Luckman 1967). In particular, whereas 200 years ago, life was a way of death, death being routine from inexplicable and untreatable causes, the rapid development of scientific knowledge has led us to expect that hazards can be both understood and managed. This view has been almost triumphalist, the almost indiscriminate use of antibiotics resulting from a belief that there will always be a new and better treatment invented. This particular social construction of risk also means that we look for cause-effect chains, and in particular we seek for the reasons why a risk exists.

In turn, this means that risks are understood to be socially produced; that they exist as the results either of someone's actions or of their inactions: they could have done something but did not so. In particular, those who bear the risks often do not share the benefits from the activity that produces the risks in proportion to the benefits of that activity. Hence, there is a question of justice (Dworkin 1986); whether it is fair that those who bear the risks should do so. Thus, the real importance of a risk lies in the social relationships which may produce it and through which it is managed. Risk is not therefore a number but the number is an expression of the importance of the relationship and the existence of risk is a signal as to the nature of that relationship. What is important to the understanding of risk is thus the implicit social relationship which has produced it and the forms of social relationship which would reduce the risk.

To illustrate, in the early nineteenth century, the principle of 'caveat emptor' applied in English Law to consumer decisions: the consumer was assumed to have full knowledge and to accept any risks associated with the purchase and use of a product (Lunney and Oliphant 2000). This view no longer holds, those in the supply chain are held instead to have a responsibility for managing any hazards responsibly (Stanton 1994). What has changed, as it has in other areas of life, is the responsibility for managing the hazard; the allocation of responsibility for determining what is the appropriate way of managing the particular risk. Justice here defines both who has responsibility and how they should act. In deciding both questions in respect of a particular hazard, the key issue is that of procedural justice (Lawrence et al 1997): how these decisions should be taken. Any event is then a test of whether those deemed to be responsible have acted appropriately.

In a different context, buildings, it was once argued, fail because of ignorance, carelessness or greed. This assumes that those who build or own structures have the responsibility for the safety of those in and around those buildings. Any failure of a building is then interpreted in terms of those three alternative causal attributions where ignorance may be subdivided into two forms: those hazards which were not previously known, and those of which those responsible should have been aware. Failure due to carelessness or greed implies that someone has failed to behave according accepted social norms, as potentially does failure as a result of a known mechanism of failure. The only exceptions to the known cause of failure rule are the remoteness of that cause of failure, the ‘reasonably foreseeable’ rule in Tort Law (Stanton 1994), or that alternatives were worse with regard to those exposed to the risk.

Thus, the test of whether a risk is tolerated is not the magnitude of the risk but the nature of the alternatives, coupled to the distribution of risks and benefits, the management of the risk, and whether the principles of procedural equity were followed in deciding who should manage the risk and how it should be managed.

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