



**Prof. David J Bradley**  
Department of Zoology,  
University of Oxford and  
London School of Hygiene  
and Tropical Medicine,  
University of London  
david.bradley@lshtm.ac.uk



**Dr. Robert Bos**  
World Health Organization  
bosr@who.int

## Water storage: health risks at different scales

Water is stored to facilitate access, and at all scales from huge reservoirs to small pots within the household. But there are health hazards as well as benefits from water storage; these are explored here within the frameworks of geometry, process and functional classification of risk. Hazards depend upon ease of access of people and other biota and pathogens to the water. Insect vectors of disease may breed in the water. Risk tends to decrease in larger water bodies. Methods to reduce the health hazards of large dams are well studied, even if often ignored, but those for small dams are less clear, requiring a choice appropriate to the locally relevant pathogens, and further research attention. Measures against specific diseases will depend on the pre-existing levels of endemicity, and on how far alternative methods of treatment and prevention are available.

**Keywords:** water storage, health, malaria, schistosomiasis, reservoirs, vectors

### Introduction

A key way to improve access to water for the common good is to store it, both to even out variation in availability and to have it closer to the point of use. Such deliberate storage, involving purposive human action, can take place at many scales, from the huge reservoir to the household jar and may be for one of various purposes, from human drinking to agriculture, or increasingly for multiple purposes. A reservoir may be used for both hydropower and irrigation water, a village pool for domestic use and livestock. Multipurpose use for both domestic and productive purposes is increasingly planned (Senzanje

et al., 2008), and in practice unplanned types of use are added to those intended (Ensink et al., 2002).

There are more types of water storage than appear in engineering texts, and different types grade into each other rather than being simple categories. Several scales and types of water storage have been the subject of detailed research but others have been neglected.

Water storage not only has benefits, it may also bring disease to the users or to others nearby, and since human action is involved anyway, it may be possible for interventions to prevent or reduce these health hazards (White et al., 1972). For this group of reasons it may be useful to look at the whole range of water storage activities, the more so as multiple uses are increasingly favoured. All are subject to health hazards, many of which are focused on particular storage modalities although there is a continuum of sizes. Health research has been concentrated on specific types of water storage, such as very large dams, small dams in a few countries, and household water storage containers. The other scales both need attention and can benefit from cautious extrapolation from the existing data.

Water storage implies human action: that either some storage facility has been created by people, or else a natural system has been modified, for example by damming a stream, to make it more fit for storage purposes.

These issues make it desirable to review the health hazards of water storage as a whole, particularly seeking general lessons of use in assessing the likely health consequences of any intervention to store water, when at the planning phase. Two contemporary debates, one on the desirability of multiple use water development (Moriarty et al., 2004) and the other on the application of household-level water

treatment (Mintz et al., 1995; Clasen 2008), make this review timely. The aim will be to move from a rather general analysis of water storage in terms of scale and geometry, process, types of health impact and problem management, towards specific comment on health hazards at certain scales. This will all be preceded by a discussion of types of water storage with special reference to areas often missed, and anomalous situations. The aim in this short paper is to convey the general approach and broad concepts. The topic is to be dealt with in detail in subsequent papers.

The boundary between man-made water storage and natural water sources, conduits, etc., is, of course, arbitrary although the category is self-evident in most cases. Problem examples are where water storage pools and irrigated rice fields are contiguous and have an unclear boundary; where a horse-drawn set of drums of water for sale act as both storage and distribution; and where a village “tank” or pond created for storage of water in Vietnam is also used for washing vegetables grown in fields irrigated with sewage, on their way to market. Moreover, it is common for a constructed village storage pond, created by a small earth dam, to become vegetated and in time to resemble a natural pool in biodiversity and most other respects. The key distinction remains that storage is constructed by human agency and could therefore have been done differently, in particular to decrease health hazards (Bradley, 1977a, 1977b).

Where water is stored for multiple purposes, ideally requiring water of different qualities, then subsequent treatment of the water for domestic use has to be considered. It is desirable to investigate use in some detail, even within the domestic category, to understand what is needed. For example, the Hima pastoralists of south west Uganda frequently use water from the same rural ponds (Figure 1) for both watering livestock and family domestic use. This is clearly of concern, but the Hima traditionally do not drink water, only milk (Jelliffe and Blackman, 1962), so the situation may not be as dire as may at first appear.

## Historical background

Diseases have been associated with proximity to water bodies and their use since the time of Hippocrates. Concern for water quality is of similarly early origin, and demonstration of the water-borne transmission of cholera even precedes the microbiological era of the later 19th century (Snow, 1855). The major infectious disease hazards of water storage for drinking are the faecal-orally transmitted diseases, predominantly the diarrhoeal diseases and dysentery, but sometimes causing grave systemic illness in the case of typhoid and leptospirosis. Attempts were made a century ago in rich countries to exclude people and sometimes livestock from the catchment of drinking water reservoirs, but subsequently water treatment by filtration and chlorination has been increasingly relied on. Most problems were solved for temperate climates with relatively prosperous communities. However, users of surface storage in the rural tropics in particular continue to have major difficulties with supplies polluted by faeces, urine and wastewater. This has repeatedly led to the development and advocacy of methods for the household level treatment of water (Mintz et al., 2001), an important approach whose sustainability needs further data.

Historically, concern for the adverse health consequences of water resource developments increased in the mid 20th century. The damage done to health by thoughtless creation of very large dams became apparent (Stanley and Alpers, 1975), involved the increase of vector-borne diseases, displacement of local residents and disruption of livelihoods, and international development agencies became concerned.

The need to control malaria in the water developments of the Tennessee Valley Authority in the USA (USPHS and TVA, 1947), and schistosomiasis outbreaks in reservoirs funded by the World Bank, were particular driving forces. Key publications in the 1970s (e.g.



Photo: Michael Moore

Stanley and Alpers, 1975) set out principles that are still valid today:

- man-made impoundments have hazards as well as benefits,
- ecological changes need to be monitored,
- planning and implementation of impoundments require a scientific basis, co-ordinated inputs from many disciplines and substantial local data,
- impoundments should preferably be integrated into a regional development programme.

Human health needs to be specifically addressed in planning, construction, operation and use. Much experience has been gathered since then, chiefly around large impoundments, but only recently have issues of small impoundments for multiple use been addressed.

## Boundaries and categories

To consider the variety of forms of water storage is to embark on both description and classification, and in several dimensions. Clearly, there is a huge range of sizes from high dams and their reservoirs (Jobin, 1999) through to small household jars and bottles (Table 1). Roughly parallel to size is the range of ownership, from large public corporations or the central government in the case of great reservoirs, down through medium-sized reservoirs belonging to a town or county, small reservoirs under the control of a group of villages (Figure 1C), community pools created for and sometimes by individual villages (Figure 1B), smaller pools owned by a syndicate of households or by a rich person, community level tanks in an urban block of flats, and then a great diversity of modes of household level storage (White et al., 1972; Thompson et al., 2001). These extend from farm household ponds (Figure 1A) which store water for both people and livestock in pastoral areas, through large concrete jar-shaped tanks in Thailand that have substantial storage for domestic use through the dry season,

much smaller pots and jars, replenished daily throughout the year, underground and within-wall cisterns for older houses in urban Gujarat, India, metal household tanks within richer homes worldwide, and innumerable variations upon all these.

This table below illustrates the range of water storage “containers” in the broadest sense of the word. It does not attempt to be comprehensive. The statements of public access are the common ones for each item, but there are very many exceptions. Containers are open or closed by intention (there is clearly no “lid” on a large reservoir), but many of the “closed” items are leaky in one way or another in many instances. The form of governance will affect the ability to control access and so affect pollution and exposure.

Small multipurpose reservoirs and dams are probably collectively more important for health than are large dams, making up in numbers what they lose in capacity. In part of northern Nigeria, there were over 700 in a limited area. Worldwide, in 2001 it was estimated that there were 40,000 large dams and over 800,000 small reservoirs (Keiser et al., 2005a), although the last figure is probably a substantial underestimate. Multiple small reservoirs pose different problems from big dams. Formal control over them is weak, and is exerted at local level by local government and community pressure. The users need to be convinced if health measures are to be implemented and maintained. The various health risk issues have to be balanced against the different uses to which the water will be put. General rules are less applicable and flexible local inputs are needed. Resources are, however, much more limited and many small dams pose major health hazards. There are then other modes of storage where the usual concept of a container does not apply. Deliberate recharge of groundwater by pumping is one. Another is the form of some irrigation schemes where the canals are massively overdesigned to act as storage as well as being a conduit of water to the fields, as in the Gezira, Sudan.

1A. Farm pond made and owned by one household; 1B. Community-owned small dam used, as are the others, for watering livestock

| Size range     | Category    | Description of size            | Governance                      | Public access                | Open or closed |
|----------------|-------------|--------------------------------|---------------------------------|------------------------------|----------------|
| <i>Biggest</i> |             |                                |                                 |                              |                |
| Very large     | Public      | Large dam                      | Government or special authority | Restricted in some societies | Open           |
| Large          |             | Medium reservoir               | Government                      | Yes                          | Open           |
| Large          |             | Small/medium reservoir         | Local government                | Yes                          | Open           |
| Medium         | Community   | Small dam                      | Community                       | Yes                          | Open           |
| Medium         |             | Small pools                    | Society                         | Restricted                   | Open           |
| Medium         |             | Small pools                    | Individual                      | Conditional                  | Open           |
| Small          |             | Storage tanks on roof of flats | Society                         | Restricted                   | Closed         |
| Small          | Household   | Small ponds                    | Household                       | No                           | Open           |
| Small          |             | Storage tanks, roof catchments | Household                       | No                           | Closed         |
| Small          |             | Household tanks                | Household                       | No                           | Closed         |
| Very small     | Inside home | Containers, planned            | Household                       | No                           | Closed         |
| Very small     |             | Containers, informal           | Household                       | No                           | Vary           |
| Smallest       |             |                                |                                 |                              |                |

Table 1. Varied scales of water storage, indicating the great range of size, governance, access and consequent attributes of the storage containers\*

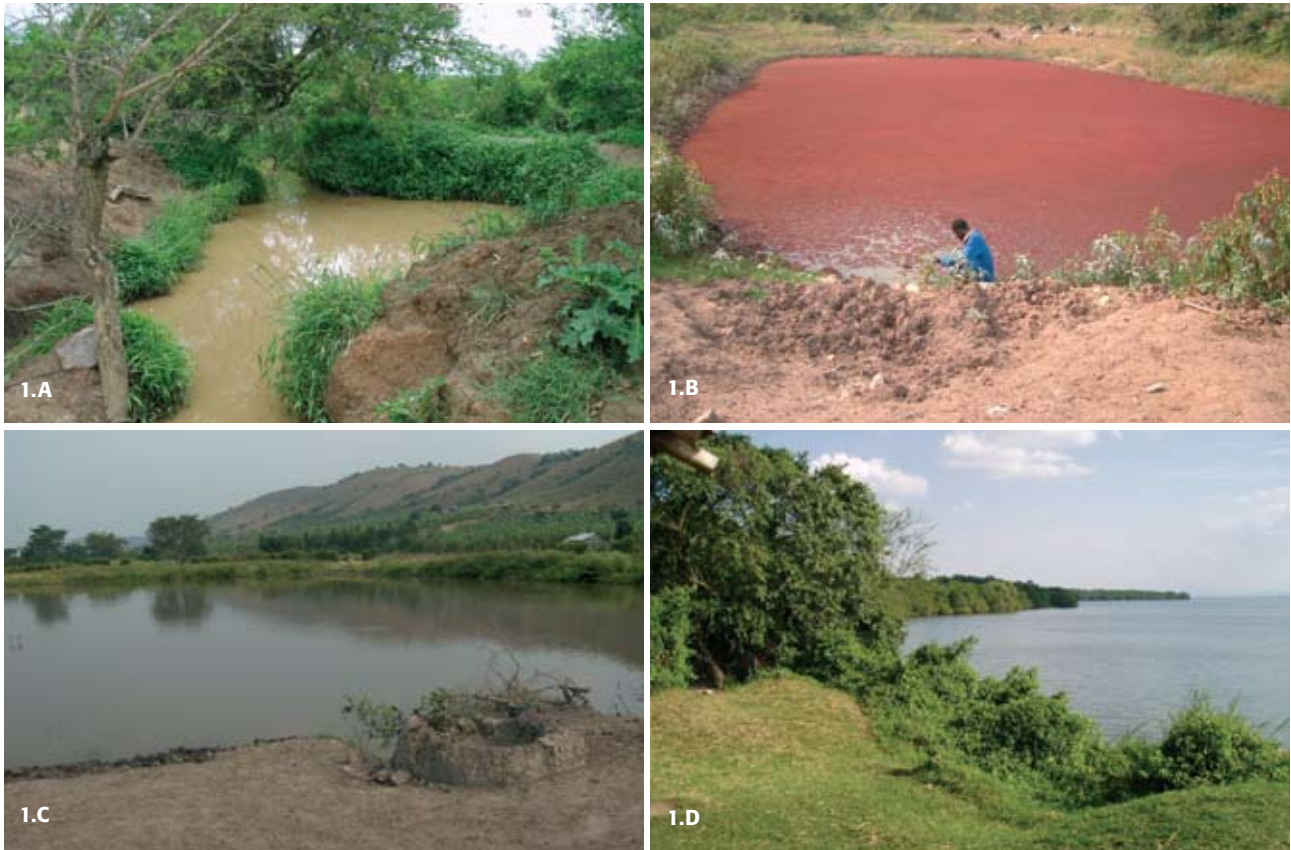


Figure 1. Array of water storage in a water-scarce pastoral area of SW Uganda.

as well as people; surface covered by the floating fern *Azolla* which at high coverage prevents mosquito breeding; 1C. Parish-level impoundment, created and managed by the local government; 1D. Natural lake and the water source of last resort in drought, lying within a national park under central government control.

A critical dichotomy is between open and closed storage. Clearly, the larger types of surface water storage are of necessity open. Many smaller

storage containers, especially at household level, are closed in intention but not always in practice. They either have a complete top in the case of a metal or plastic tank, or a very narrow neck for some water storage jars. Both human unwashed hands and dippers, and also female mosquitoes seeking to lay eggs, need to be kept out. Ensuring that closed containers in fact live up to their name is one of the key health protective interventions.

Generalized relation of Hazard and Storage Capacity of Increasing Storage

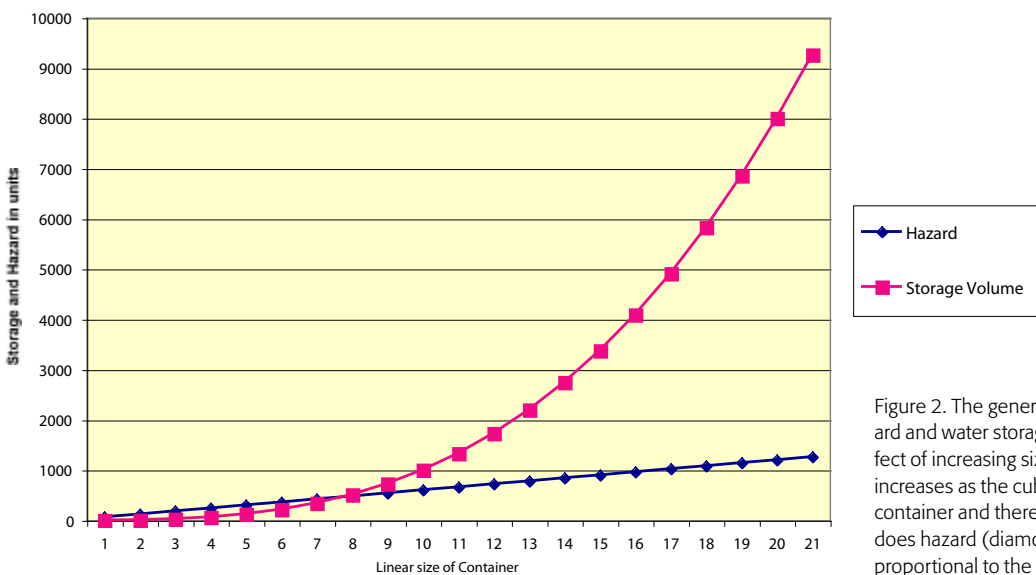


Figure 2. The generalised relation between hazard and water storage capacity, to show the effect of increasing size: storage (square symbols) increases as the cube of the linear breadth of the container and therefore much more rapidly than does hazard (diamond symbols), which is roughly proportional to the linear breadth.

## Theoretical approaches

### Geometry and scale

When considering storage “containers” varying from large reservoirs to household level containers, some general aspects of scale become apparent. The storage capacity of a hemispherical storage container will vary as the cube of its radius since its volume is  $\frac{2}{3}\pi r^3$ . However, its surface area will be  $\pi r^2$ , and, more important for many determinants of disease transmission, the rather small peripheral area close to the shore, where most human water contact occurs, will tend to increase as a function of  $r$  (Figure 2). This last piece of shallow water we may conveniently call “the water’s edge”, and it is where the majority of aquatic insect vectors of disease breed, and where simple polluting activities by people and livestock will be concentrated. People will be in contact with water there and may collect water supplies from the edge. So if storage capacity is a function of  $r^3$ , and health hazards are closer to a function of  $r^1$ , then it follows that as storage volume increases, the health hazard per unit of storage will rapidly decrease.

To give an extreme example of this effect, consider two ways to store a cubic kilometre of water: the first as part of the Volta Lake, a reservoir in Ghana, and the second as a series of ponds of the type found in Nigeria and most other places. Each pond may have a surface area of two hectares and mean depth of 2 m, and a volume of 40,000 m<sup>3</sup>, this will require 25,000 ponds for the cubic kilometre of water, whereas the whole of Lake Volta contains 148 km<sup>3</sup> of water. The perimeter involved, which is key to disease transmission, as explained above, would be 12,500 km for the ponds and 35.1 km for Lake Volta, a ratio between them of 356 times. In this very simple model, the benefits of large capacity storage for diminishing health hazards of storage are clearly seen. Of course, the real world is much more complex and, at the lower scales of storage, the whole water body may be viewed as “periphery” or “water’s edge”. Nevertheless, there are real advantages to large-scale storage, but not at the expense of increasing the journey to water. Large-scale storage requires a distribution network.

### Process

The infectious disease hazards of water storage may be viewed as a problem in pathogen population dynamics. Water enters the storage facility, and leaves it with a certain load of pathogens. It may also act as a breeding site for disease vectors in warm climates. The difference between the entry and exit hazard will depend on the transit time of the water and the specific pathogens involved, but most particularly on whether pathogens or vectors can gain access to the stored water: that is, whether it is open or closed storage (in fact, rather than just in intention). Attempts to keep storage closed often fail; examples include the commonly reported increase in bacterial pollution of water stored in the household, as compared with when it was collected from a source (Wright et al., 2004). Some of this increase may have been in drawing the water at source and in transit, but much may be from people removing water from the storage vessel, while children and animals may access and contaminate open household storage.

Another example of the open/closed category underlies the epidemiology of malaria in the city of Mumbai, India. Here there live

strains of the vector mosquito *Anopheles stephensi* which have become adapted to breeding in the roof water storage tanks of urban blocks of flats. The air vents of these tanks, in theory covered in metal gauze, are often not tightly covered and the female mosquitoes gain access, lay their eggs, and mosquito larvae develop in the tanks, escaping, when the new adults emerge, by the same route through which their mother entered.

The dynamics of pathogens will depend on temperature, substances in the water and on the surfaces of the container, whether the pathogens simply die off exponentially or in some other survival profile, whether they are able to multiply in the right circumstances, as is the case with some pathogenic bacteria and some usually free-living amoebae, and whether those circumstances are present. In the case of pathogens able to cross the human skin, such as schistosomes and leptospires, contact of people with infective water is sufficient to cause infection. Death rates of most faecal-oral pathogens in water tend to lead to a log-linear decrease with time, so that after a time the number of organisms consumed by drinking a usual amount of water has fallen below the usually infective dose. The parameters of die-off are highly species-specific.

## Functional classification of hazards in epidemiology and control

What then are the communicable disease hazards of water storage? As with all water-related diseases (White et al., 1972; Bradley, 2009), they fall into five broad categories (Table 2). Water-borne infections are transmitted by ingestion of organisms in the water and are therefore a problem of domestic water use. Their relation to storage depends on the quality of water being put into storage and on the access of further contamination to the water being stored. Unless the water contains small quantities of nutrients and the pathogenic micro-organisms are able to multiply in the stored water, which is not usually the case, the hazards will decay over time as the bacteria die and viruses become less infectious. The well-studied theme of improving the microbiological quality of water to be used for drinking, food preparation and other domestic uses which will lead to pathogens being ingested, will be familiar to readers.



Photo: BrandXpictures

| Main category                | Sub-category       | Key diseases  | Relation to water storage   |
|------------------------------|--------------------|---|---|
| WATER-BORNE                  | Classical          | Cholera, dysentery  | These may persist through storage; the latter may provide an opportunity to reduce their transmission. Water treatment or filtration will reduce risk.        |
|                              | Other              | Some diarrhoeal diseases  |   |
| WATER-WASHED                 | Intestinal tract   | Diarrhoeal diseases   | These diseases will tend to be reduced by the better access to water; need concomitant hygiene education and available soap.                                  |
|                              | Skin & eyes        | Trachoma, skin infections                                       |   |
| WATER-BASED                  | Percutaneous       | Schistosomiasis, developing in aquatic snail intermediate hosts | Proliferate in snails in open storage pools that are subject to both contamination and water contact. Reducing that water contact is effective in prevention. |
|                              | Oral               | Dracunculiasis  | Poor sources rather than storage but may persist in stored water. Control possible by altering well design.   |
| WATER-RELATED INSECT VECTORS | Breeding in water  | Mosquitoes, midges, spread malaria, filariasis, arboviruses     | The edges of open pools and puddles around them provide breeding habitats, habitats highly species-specific. Alterations to habitat may stop breeding.        |
|                              | Biting near water  | Tsetse flies (some)   | Not relevant to storage of water.   |
| WATER-AEROSOL                | Aerosol from water | Legionella  | Multiply in biofilms of storage and distribution systems, especially of warm water.   |

Table 2. Disease transmission and water storage. This elaborates the system from Bradley (2009) in relation to the communicable disease hazards of water storage.

A key aspect of safe storage for domestic use is for smaller artificial containers not to allow people's hands to contact the stored water. So household tanks need taps to control outflow and, if simple vessels are used, the necks of the jar should be too narrow for hands to pass through. The use of simple dipping cups to take water from storage in the household, which almost inevitably leads to immersion of hands in the water, is to be avoided. Treatment of contaminated (especially surface) water as near to the point of use as possible, whether by filtration, chlorination, or other chemical treatment (Clasen et al., 2007a, 2007b; Lantagne et al., 2007; Lule et al., 2005), is logically preferable if reliable chlorination of the whole supply is not possible, although some doubts about sustainability remain.

The second group of diseases, those washed away by an adequate supply of water for personal cleanliness, benefit from the easy access which is the primary object of water storage, and the actual microbiological quality of this water is less critical than for drinking water. If the water-washed disease hazards are to be reduced substantially, it is essential that effective health education should ensure that washing, especially of hands, takes place at the critical times and that soap is available and made use of (Curtis and Cairncross, 2003; Parker et al., 2006; O'Reilly et al., 2006). Water-washed transmission affects many faecal-orally transmitted diarrhoeal diseases, from cholera to dysentery, also many skin and eye infections, including the potentially blinding trachoma.

The third, "water-based", and fourth, "water-related insect vectors", categories of water-related transmission are most closely associated with open surface water storage. The chief water-based disease group, the schistosomiasis, require double contact with the stored water body for transmission, first to contaminate it with eggs of schistosomes in the human excreta (and animal excreta in the case of *Schistosoma japonicum*) and then, after the parasites have developed in water-snails and emerged into the water as infective cercarial larvae, direct skin contact with the infected water. Hence its importance in reservoirs with gently sloping edges and much emergent vegetation that are used for laundry, bathing and as sources of domestic water to be carried home.

Of the water-related insect vectors of disease, the mosquitoes are by far the most important, widely distributed, and intractable. Whilst mosquito larvae develop in many sorts of fresh and brackish water, they tend to be in smaller and shallow water bodies or the edges of large reservoirs. Although there are very many species (over 3,000) of mosquitoes, the majority have relatively specific habitat requirements and also have a restricted geographical range, so that the number of potentially hazardous species occurring near a given water-storage body will be quite limited. To make a rather gross simplification of a complex topic, there are three groups of mosquitoes of particular importance in relation to water storage. The genus *Anopheles* includes all the species able to transmit malaria. They tend to breed in unpolluted water from larger pools, the edges of reservoirs, down to puddles. They also to some degree transmit filariasis (elephantiasis) and a few virus fevers. At the other habitat extreme is the genus *Aedes*, which are container-breeding mosquitoes. In the wild they may breed in tree-holes, but close to man in flower vases and vessels used to store water at the household level. They transmit insect-borne viruses, of which there are very many, the most important being yellow fever and dengue. Dengue is now the most important arbovirus infection of people and its main vector, *Aedes aegypti*, is primarily urban and a hazard of household-level water storage there. The highly invasive *Aedes albopictus* is rather less associated with deliberate water storage. A third group of mosquitoes of the genus *Culex* lies rather between in habitat preference. Some *Culex* species prefer heavily polluted waters and hence are very prevalent in urban areas but not particularly in stored water; others are floodwater zone mosquitoes with hardy eggs that may persist between floods and produce large numbers of mosquitoes when one comes. Constructed water storage and treatment ponds and wetlands may provide a sequence of habitats which will provide breeding sites for a series of different potential vectors of disease.

The implications for prevention of disease are that prior to any changes in water storage an assessment of the likely hazards and their vectors should be made, that should give a short list on the basis of

which a limited number of modifications can be made to minimise health risks. The most widespread of these risks is malaria.

The benefits that reducing mosquito numbers will have upon malaria in people are highly dependent upon the baseline of malaria endemicity in the area. Under conditions of very intense pre-existing malaria, the increase of vectors that may result from water storage developments may have a trivial effect on the frequency of human disease, as in these circumstances malaria is regulated by human acquired immunity much more than by changes in the level of malaria transmission. By contrast, where malaria endemicity is relatively low, and the area is subject to occasional malaria epidemics, construction of storage reservoirs in the tropics may greatly increase malaria risk. In well-controlled studies of micro-dams for livestock in northern Ethiopia, malaria incidence within three kilometres of the storage reservoirs was raised between five-fold and 8.7-fold at different altitudes, by dam construction (Ghebreyesus et al., 1999).

## Estimating burden and risk of disease

The infectious and communicable disease burden due to water resource development has been assessed for several key vector-borne diseases, primarily in relation to the larger dams and reservoirs (and to irrigation schemes, which are not considered here). Malaria and schistosomiasis are greatly affected by surface water storage; other diseases are more affected by the uses to which the stored water is eventually put, so that, for example, irrigated agriculture has a large effect on disease burden and water with faecal contamination will have a much larger effect if actually consumed as water than when used for other purposes.

The effect will also vary very much with the baseline endemicity and local vector species, so that, for example, four times larger a percentage of schistosomiasis incidence can be ascribed to dams in Southeast Asia than in Africa, though the actual number of people involved is far greater in Africa south of the Sahara. Meticulous calculations have been made by Kaiser, Utzinger and colleagues in a series of systematic reviews of the key vector-borne diseases, and the results are summarised in Table 3, for big dams in the case of malaria and schistosomiasis. Globally it appears that some 42 million people are at risk of schistosomiasis from big water storage dams, of whom 10 million are infected (Steinmann et al., 2006), while 18 million are at

risk of malaria as a consequence of water storage in large dams (Keiser et al., 2005a). Of the two other major vector-borne diseases affected by agricultural water resource developments, Japanese encephalitis (Keiser et al., 2005b) is mainly transmitted by mosquitoes breeding in flooded rice fields and less affected by water storage, and there is very little relevant data on filariasis (elephantiasis). Because several mosquitoes that can act as vectors are differentially affected by water storage, the effect is not clear-cut (Erlanger et al., 2005).

## Interventions

Among specific interventions that are of value in reducing health hazards of water storage, two have received most attention, at opposite ends of the scale of size. In the pre-1939 golden period of environmental management for vector control, particular attention was paid to varying the water level of reservoirs in a controlled way, especially in the USA, deriving from the experience of the Tennessee Valley Authority in malaria prevention on impounded waters (USPHS and TVA, 1947). The water level in medium-scale reservoirs can be rapidly lowered either by manual control of the sluice gates or by an automatic siphon device. By careful manipulation of series of dams on a watercourse, it was possible raise the water level transiently to flood height, so stranding flotsam and floating vegetation that tended to harbour vector mosquito larvae. Subsequently, rapid dropping of the water level was able to strand the larvae of *Anopheles quadrimaculatus*, the local malaria vector, and marshy areas dried out. This was highly successful in malaria control there, and the approach has also been used against *An. culicifacies* in South Asia. However, as with most environmental control methods, this is species-specific. Any attempt to use it against puddle-breeding mosquitoes in the tropics, around large dams with very shallow sloping edges, would be worse than useless: the rate of water level fall would be slow and generate extensive breeding sites for *An. gambiae*, the world's most effective malaria vector, and do more harm than good.

At the other end of the scale, household storage, as discussed above, in the poorest communities often involves not only initially polluted water but means of transport that further increase contamination. The source may have been shared with livestock. Point-of-use treatment has been thoroughly explored recently (Clasen et al., 2007a, 2007b).

|                                   | SCHISTOSOMIASES       |                               |                                  | MALARIA            |                              |
|-----------------------------------|-----------------------|-------------------------------|----------------------------------|--------------------|------------------------------|
|                                   | At risk from big dams | % of total risk from big dams | Estimated infected from big dams | Number of big dams | People at risk from big dams |
| <i>WHO</i>                        | <i>millions</i>       | <i>%</i>                      | <i>millions</i>                  | <i>number</i>      | <i>millions</i>              |
| <i>Region</i>                     |                       |                               |                                  |                    |                              |
| <b>Africa S. of Sahara</b>        | 28.71                 | 5.1                           | 9.62                             | 525                | 3.07                         |
| <b>Latin America</b>              | 1.22                  | 3.4                           | 0.06                             | 1449               | 0.48                         |
| <b>Middle E. &amp; N. Africa</b>  | 2.35                  | 1.7                           | 0.29                             | 812                | 2.46                         |
| <b>S.E. Asia &amp; W. Pacific</b> | 10.09                 | 21.7                          | 0.23                             | 6405               | 12.33                        |
| <b>World</b>                      | <b>42.36</b>          | <b>5.4</b>                    | <b>10.20</b>                     | <b>9191</b>        | <b>18.34</b>                 |

Table 3. Schistosomiasis and malaria risk from water storage in large dam reservoirs. The data are derived from Keiser et al. (2005a) and Steinmann et al. (2006).



Photo: Mats Lammers

Much is known about pathogen survival in water (Feachem et al., 1983) and particular storage regimes can be developed to destroy schistosome cercariae, etc. Indeed, there is sufficient knowledge to propose interventions against many pathogens and vectors but, as with most control by environmental means, interventions need to be appropriate for the local organisms and human activities and also maintained scrupulously, which is operationally not easy.

Measures to control the health hazards of small dams are site-specific, but may include avoiding the need to enter the water, by provision of pumps, cattle troughs (but with adequately drained surrounds), sites for laundry and canoe landing stages. These will reduce schistosomiasis risk. Fencing may be used to prevent access of livestock and consequent pollution, and steep edges to the pool deter emergent vegetation and reduce mosquito breeding (although they may create a drowning risk to children unless fenced), while stocking with appropriate small fish may reduce mosquitoes further. The floating fern *Azolla* will also deter mosquito breeding (especially of anophelines) once surface coverage exceeds 90%, which may or may not be acceptable to users. It is difficult to prevent all pollution of surface waters and some form of post-storage treatment is, if possible, needed for drinking water. In the tropics, sanitation is best directed towards pathogen reduction, rather than relying on water treatment to achieve this.

## Interventions over time: chronotones

There is now much published work on the health hazards of major water storage reservoirs (Stanley and Alpers, 1975; Jobin, 1999). Planning (stage 1) to construct a dam, and even the rumour that this might happen, will lead to a set of social and environmental changes with health consequences of an unplanned as well as intended nature. The construction phase (stage 2) will greatly intensify these, as there will be immigration of workers, of those hoping to provide services for the workers, and often the beginnings of a health infrastructure. The health problems of transient labour predominate: trauma, sexually transmitted and respiratory infections, and outbreaks of locally endemic diseases if the workers are from a non-endemic area. Funds for

infrastructure may enable good facilities for the longer term. The local people displaced from the inundated area almost invariably suffer from inadequate support and lack of planned movement to a suitable site. These indirect health consequences of creating water storage matter, and also provide health opportunities.

The early period after filling the reservoir (stage 3) may see complex biological changes such as rotting forests, explosions of insects, fish, fishermen, and shoreline vegetation with vector habitats being created, leading to outbreaks of schistosomiasis and malaria (in areas of previously low transmission), with gradual progression to a steady state (stage 4) which may or may not include a higher level of health hazards than before. Stages 1–3 comprise a key period or “chronotone” lying between the original state of the landscape and the final relatively steady state of the mature dam and reservoir (Bradley, 2004). The terminology is by analogy with the term ecotone, which is the area in space that lies between two types of ecosystem, whereas the chronotone is an equivalent interval in time rather than space. It includes the structures, water and adjacent land, the ecology, settlement, use and social conditions. Many of the changes that occur during the chronotone are predictable, others not, so there is a need both to plan the management of expected health hazards and to monitor the situation. It is a key time to invest effort in order to reap long-term reductions in health hazards. While this is also true of small impoundments, the strategy needed is different from that appropriate for large reservoirs. For a big dam, such as that for the Volta Lake, Ghana, the chronotone may last for around two decades.

## Conclusion

Thus, while there are many particular and detailed measures to be taken to reduce the health hazards associated with any specific modality of water storage, there are some general principles that are widely applicable across the scales and types of storage container.

It is helpful to consider the continuum of storage containers, varying from the almost natural, with a little human intervention, through to the wholly artificial. There is a particular need to consider



those containers of surface water that do not fit tidily into the engineers' categories, but which may be used by the poor and by those with unusual livelihoods. With the increased perception of multiple use sources and storage, there needs to come a more comprehensive view of the implications for nature and a diversity of health hazards and a means for their prevention. There needs to be a focus on an operational effectiveness of means to reduce hazards for specific multiple uses, and not just on idealised solutions.

While the methodology for reducing transmission of truly water-borne infections is now well understood, the location and extent of water treatment that can be maintained sustainably and at minimal cost still needs more work. The general view that multiple-use storage necessitates, under limited resources, an increase in household water treatment, has not yet been fully matched by operational programmes.

Similarly, we have a good understanding of the ecology and epidemiology of many water-based diseases and of those with water-related insect vectors. However, insufficient attention is given to the local variations in vector ecology so that findings are transferred across regions or across vector species but without sufficient care. Local research and understanding are needed if the disease risks are to be minimised at reasonable cost. Adequate attention must be paid to the endemic levels of specific disease transmission in predicting consequences of new water storage, and hence the allocation of resources for prevention. Whilst the insect-transmitted viral diseases (arboviruses) are a particular concern because of the lack of vaccines against many of them and the limited potential of chemotherapy, molecular methodology for their study and diagnosis in people and the environment is much more powerful than in the past.

Research has been concentrated on health hazards of large dams, but in spite of some excellent local studies, work on smaller water storage dams is relatively neglected. More work is needed on these problems, not only in relation to health but also into linked aspects of agriculture, livestock watering and conservation.

Whatever the scale of water storage, planning for health hazard reduction needs to be undertaken well before the development and construction of new storage. The chronotone, or period of rapid change around the development that is crucial for effective long-term action, is a period of great opportunity to improve health.

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