The Frederick S. Pardee Center
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ISSUES IN BRIEF

# Water Resources Development: Engineering the Future of Global Health

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The World Declaration on Dams and Hydropower for African Sustainable Development, issued at the International Commission on Large Dams (ICOLD) meeting in Paris in 2008, called on the international community to support the achievement of sustainable development on the African continent through construction of dams and small reservoirs. This goal was reiterated in a statement issued by ICOLD and the International Water Resources Association (IWRA) in June 2012 emphasizing the importance of developing a water storage infrastructure for flood management, drought control, drinking water, and hydroelectric production to meet rising electricity demands. These declarations, among others, paved the way for sustainable development on the African continent by means of water resources development.

To this end, Aqua~Media International, along with ICOLD and the Ethiopian Electric Power Corporation (EEPCo), will host a conference in April 2013 in Addis Ababa titled *Africa 2013: Water Storage and Hydropower Development for Africa.* Experts from the international water resources community will gather to discuss water resources development issues pertinent to Ethiopia and the African continent. Surprisingly, the key topics on the agenda omit the public health challenge of water-borne diseases, mentioning only in passing the issue of "mitigation and monitoring measures" without specifically referring to water-borne diseases.

This is a stark omission. Water-borne diseases are oftentimes worsened by water development projects and have enormous consequences on human health. And yet water resources development is crucial for developing countries, particularly for the arid African continent, and will play a key role in meeting rapidly rising energy needs over the next several decades. Thus it is critical to explore the relationship between water-borne diseases and water resources development, and to understand the ways in which water resources engineers can help mitigate the deleterious consequences of dams and reservoirs on human health.

## Water Development Projects

Water development projects — specifically irrigation systems, and large and small dams and reservoirs — profoundly alter water landscapes and surrounding ecosystems. Although irrigation schemes date back to ancient times, widespread construction of dams is a more recent phenomenon. Following World War II, and particularly after the end of colonialism, dams were built across the African continent in an effort to create stronger infrastructures and meet rising electricity needs. The experience of Ghana epitomized this trend. In 1959, construction of the Akosombo Dam began, as well as a number of irrigation projects. The irrigation projects specifically targeted the Upper East Region, leading to the construction of more than 150 small reservoirs for irrigation and water supply. Water became available for agricultural production and as a year-round supply for communities in surrounding areas. Over the next 40 years, many larger dams and reservoirs were built, including Lake Volta, the largest artificial lake in the world. In countries with particularly rapid economic growth, the number of new hydroelectric projects and irrigation schemes continues to grow larger each year. The Renaissance, or Millennium dam, scheduled for completion in Ethiopia in 2014, will be the largest dam in Africa, and the seventh largest in the world.

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Although these water projects can expand agricultural and economic production, decrease flooding, and create a steady water supply source, they also dramatically change the water landscape. Ecosystem balances change fundamentally: plants and wildlife in the area undergo a dramatic transition. Checks and balances that previously mitigated the spread of water-borne diseases in their native areas, such as perennial flooding and the presence of certain aquatic plants, no longer exist. Large, still bodies of water create safe havens, or *refugia,* for disease vectors (such as mosquitoes, snails and black flies) to reproduce and infect human hosts. Moreover, installation of modern irrigation systems has only worsened these changes. In developing countries, less expensive surface irrigation systems are favored over the more efficient, but costlier, drip or sprinkler irrigation. Constructing surface irrigation systems also causes standing bodies of water, which provide ample and reliable breeding grounds for the vectors of water-borne diseases. Local residents use these bodies of water for bathing and recreation, resulting in infection with water-borne diseases such as schistosomiasis, or stronger likelihood of infection with malaria because of contact with mosquitoes that cluster near bodies of water. Vectors proliferate and feed at considerably higher rates during the hours of the day in which local residents use water bodies. Such behavior likely evolved as an adaptive mechanism. These changes in the water landscape due to water development projects lead to changes in habitats for vectors that spread water-borne diseases.

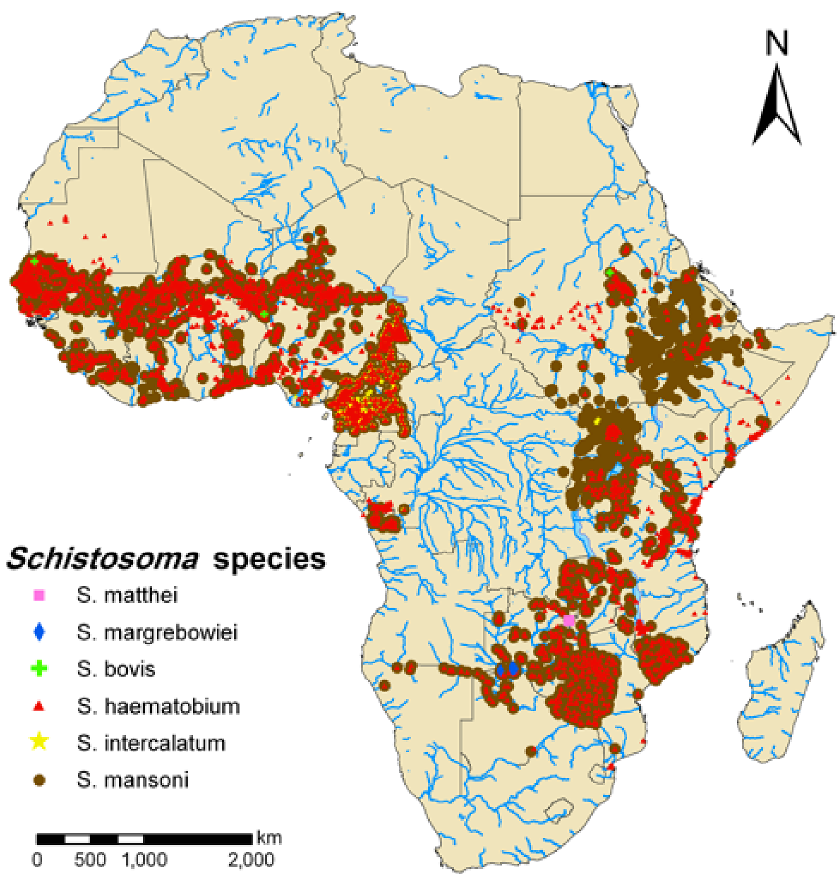
### CONNECTIONS BETWEEN WATER DEVELOPMENT AND DISEASE

Studies have shown strong correlations between construction of dams and small reservoirs and the prevalence of water-borne diseases. Water-borne diseases include malaria, schistosomiasis, lymphatic filariasis and onchocerciasis (also known as river blindness), among others. Although malaria is not directly water-borne, the World Health Organization (WHO) defines it as such because its transmission vectors, mosquitoes, are attracted to areas of still water that typically serve as a haven for vectors of other water-borne diseases. However, the correlations between water development projects and water-borne diseases are more nuanced than they might appear. The majority of studies demonstrate a strong correlation between irrigation dams and small reservoirs and increased risk and prevalence of water-borne diseases, whereas the correlation between hydroelectric dams and water-borne diseases is considerably weaker. There is also a discrepancy between correlations for small dams and "large dams" as classified by the International Commission on Large Dams.

## Water-borne Diseases

Schistosomiasis, also known as bilharzia, is a "sensitive indicator disease" for monitoring ecosystem changes because it is widespread throughout Africa and its prevalence can change immediately following alterations to the surrounding water landscape. Consequently, schistosomiasis can be used as a monitoring tool for the presence of other water-borne diseases – high prevalence of schistosomiasis after the construction of a water impoundment (compared to prevalence prior to its presence) indicates the extent to which dams and reservoirs have influenced the prevalence of malaria and onchocerciasis, regardless of the seemingly disparate epidemiology of the three diseases. Moreover, the method of transmission of schistosomiasis is far less complex than malaria; the parasite does not interact with its environs to the same extent as the malaria parasite. Schistosomiasis is a chronic, debilitating disease endemic to all of sub-Saharan Africa. It is caused by parasitic trematode worms and several types of snails that serve as intermediate hosts for the disease. There are two types of the disease: uro-genital, or urinary, and intestinal. As a public health challenge on the African continent, it is second only to malaria.

**Figure 1: Schistosomiasis Prevalence on the African Continent**




Source: Hurlimann, E., N. Schur, K. Boutsika, A-S Stensgaard, M. Laserna de Himpsl, et al. 2011

**Table 1: Vectors and Species of Water-Borne Diseases on the African Continent**

| | Vectors | Cause | Species | Symptoms and Effects |
|---|---|---|---|---|
| Malaria | Mosquitoes | Protists | *Plasmodium falciparum, P. vivax* | Fever, enlarged liver; *P. falciparum* may cause death |
| Schistosomiasis | Snails | Trematodes | *Schistosoma haematobium, S. mansoni* | Fever; may lead to anemia and cognitive impairment in children, renal and liver failure in adults |
| Onchocerciasis | Black flies | Nematodes | *Onchocerca volvulus* | Itching and swelling; may lead to blindness |
| Filariasis | Mosquitoes | Nematodes | *Filarioidea* | Thickening of the skin and underlying tissues; extreme inflammation and swelling |

## MALARIA AND THE NTDs: EFFECTS OF WATER-BORNE DISEASES

In recent years, malaria has garnered extensive international attention. Efforts such as the President's Malaria Initiative have involved significant distribution of anti-malarial bed nets and other anti-malarial devices. International agencies have provided significant funding for the development of a malaria vaccine. However, in contrast to these global efforts to combat malaria, schistosomiasis, onchocerciasis and filariasis have received far less attention, primarily because the WHO classifies them as "neglected tropical diseases" (NTDs), meaning that the diseases are not targeted for eradication or elimination. Schistosomiasis, onchocerciasis and filariasis (lymphatic, subcutaneous and serous cavity) are transmitted by intermediate hosts (snails, mosquitoes and black flies, depending on the disease) and use humans as hosts, embedding worms in various parts of the human body, which sometimes remain for over a decade. Although they rarely result in death, these diseases lead to varying degrees of long-term health impairment, depending on severity. For NTDs, the WHO calculates burden of disease figures in terms of disability adjusted life years (DALYs), meaning the number of years lost due to death, ill health and/or inability to work. The WHO estimates that schistosomiasis causes 1.8 million DALYs per year, higher than the burden of onchocerciasis, Hepatitis A, B and C, and Chagas disease. In addition to the impact of NTDs on life span and economic productivity, recent research points to a strong epidemiological connection between malaria and other water-borne diseases; individuals infected with schistosomiasis, onchocerciasis and filariasis are more likely to become infected with *Plasmodium falciparum,* the most deadly form of malaria. They are also less likely to respond positively to malaria-control interventions, already exhibited with vaccine prototypes in clinical trials. These same studies have linked NTDs to an increased risk of HIV infection for women and maternal-child HIV transmission, and they have shown that infants can become sensitized to schistosomiasis *in utero.* Thus prevalence of schistosomiasis not only serves as an ecological indicator of other water-borne diseases, it also heightens the susceptibility of affected populations to potentially deadly illnesses such as malaria and HIV. Other NTDs also enhance this susceptibility.

## QUANTIFYING THE RELATIONSHIP BETWEEN SCHISTOSOMIASIS AND WATER DEVELOPMENT

Because schistosomiasis is an ecological indicator disease, understanding its connections to water resources development is paramount. The connections between public health and engineering, particularly in the developing world, must be understood to promote a sustainable future of water resources development. To explore the relationship between schistosomiasis and water resources development projects, a combination of geo-referenced data on schistosomiasis prevalence and dam locations was used. Schistosomiasis prevalence was analyzed using data from the Global Neglected Tropical Diseases database and the measured distance to the nearest dam or reservoir. For Ghana, a strong correlation was found between prevalence of intestinal schistosomiasis and distance to the nearest dam or reservoir. This result showed strong evidence for prevalence of schistosomiasis increasing in the vicinity of a dam or reservoir, implying a similar increase in other water-borne diseases in that area. Results showed almost no correlation, however, for urinary schistosomiasis, a result supported by other studies. In a meta-analysis of schistosomiasis prevalence, Jennifer Kaiser also found that the relationship between proximity to a dam or reservoir and prevalence of schistosomiasis was strongly species-specific. Previous studies noted a similar phenomenon and termed it "Nile shift." This can largely be explained ecologically: irrigation dams and reservoirs typically have stable water levels that are extremely slow moving, if in motion at all. The snail hosts for intestinal schistosomiasis require this type of habitat, whereas the snail hosts for urinary schistosomiasis are far more flexible. Indeed, the dams and reservoirs included in this analysis were for water storage and irrigation purposes. Analysis that included dams and reservoirs used for hydroelectric purposes — in which water levels fluctuate — showed a considerably weaker correlation. These results point to a need for more nuanced engineering design techniques for dams and reservoirs that would significantly reduce the water-borne disease transmission. Although a number of such techniques have been successful in pilot studies, they have yet to be incorporated into water resource development projects on the African continent.

## Engineering Design and Water Management Techniques

### MANIPULATING AQUATIC LIFE

Despite these alarming statistics, engineering solutions and water management options can be integrated into water development projects to mitigate the transmission of water-borne diseases. Engineers have devised ways to make water flowing through canals inhospitable to water-borne disease vectors. In the Ibadan area of Nigeria, studies show that survival of snails that serve as intermediate hosts for schistosomiasis depend on the presence of certain aquatic plants. Another study in Ibadan involved the introduction of certain weeds known to produce allomones, which repel snails by inhibiting feeding activity, growth and reproduction. However, these options depend on the geography of vector habitats, and generally could only be used to target water-borne diseases individually. Moreover, disease transmission rates must be concentrated in smaller areas, called focal transmission, rather than spread equally throughout a large area. Studies on schistosomiasis show this transmission pattern in the northern arid region of Cameroon, whereas the disease is endemic to the entire Lake Volta region. Thus Cameroon might be an area where this strategy potentially could be useful.

### ALTERING WATER FLOW

In endemic areas without focal transmission patterns, lining irrigation canals with certain materials known to alter fluid flow — including asphalt, concrete, plastic and gravel — is a viable option. This is a prospective method of water management that should be integrated into irrigation schemes. Studies have shown that lining irrigation canals with concrete prevents snail hosts for schistosomiasis from proliferating because the lining precludes snails from clinging to the sides of the canal. For example, in a study on the Lajas Valley in Puerto Rico, snail hosts that had previously been extremely prevalent disappeared after canals were lined with concrete. Although the high cost of lining irrigation canals ostensibly outweighs the potential benefits of disease mitigation, in fact it has other economic benefits as well. Lining of canals also significantly reduces seepage from the canal into the groundwater table, which in unlined canals causes water losses of up to 50 percent.

Lining irrigation canals may also raise the flow rate to a certain threshold level, beyond which the canal cannot sustain snails. A study conducted on the Patillas Irrigation Canal in Puerto Rico found that raising the mean flow rate (water velocity) in the canal to greater than two feet per second precluded snail hosts from surviving. Another study found snails absent from sections of streams where the average local velocity exceeded 0.3-0.4 meters per second. A velocity exceeding 0.33 meters per second produced a hydrodynamic drag force that was significant enough to dislodge snails. If a rise in the flow rate of a canal is coupled with removal of aquatic weeds, this combination might decrease the necessary threshold velocity. Previous studies that discussed threshold velocity and its effects on snails did not add nuance to the discussion based on density of aquatic vegetation, nor did they include a meaningful metric for density of aquatic vegetation. However, this technique might not extend beyond snails to other water-borne disease vectors. In contrast to snails, black flies and mosquitoes have proven highly adaptable to changing water speeds. Thus further research is needed to determine if this option could be viable for other water-borne diseases.

For reservoirs, the water level may be varied such that it cannot support disease vectors that require constant, still bodies of water. This method has been used extensively to control malaria as well as other water-borne diseases. In Nigeria, a study was conducted on the effects of varying water levels on schistosomiasis transmission. The study site was the Oyan reservoir near Abeokuta, where previous studies had shown a dramatic increase in the prevalence of urinary schistosomiasis following construction of the reservoir. Due to a drought, the water level had been varied over a five-month period by opening the gates to the reservoir each day, thereby resulting in a high discharge pattern throughout the dry season when water was typically conserved. Varying the water level led to significant declines in the number of snail hosts and thus the prevalence of schistosomiasis. Since that discovery, Oyan reservoir management officials have varied the water level in order to maintain lower prevalence. This option is viable for reservoirs and has been shown to reduce prevalence of malaria, schistosomiasis and other water-borne diseases.

The seasonal draining of bodies of water known to attract disease vectors is a related management tool. This method has been used extensively for combating malaria in Zambia and Nigeria. Since some types of disease transmission are highly seasonal, bodies of water in areas known to be hyper-endemic to certain diseases can be drained during the non-irrigation season. This disrupts the life cycles and reproductive cycles of the disease vectors and hosts, eventually killing them off. Seasonal draining also simulates flood cycles that existed prior to the construction of water impoundments. This method might be suitable for small reservoirs and micro-dams. However, it is important to note that some disease vectors — including some mosquitoes that transmit malaria — have adapted well to seasonal differences.

### CHANGING THE DYNAMICS OF SIPHONS

Water resource engineers have also installed siphons or targeted siphon areas as sites of focal transmission. In the former, a siphon installed near the gate or water control device changes the water flow, enabling a higher flow rate. Studies have suggested this method is useful for the elimination of breeding sites for black flies, the vectors for onchocerciasis. However, it is also applicable to malaria and schistosomiasis. As discussed earlier, if drag force is high enough for snails to be dislodged, they will eventually die. The second method can only be used if there is already a siphon installed as a water control device. In Central Morocco, the Tessaout Amont irrigation system has inverted siphons at road crossings and canal outlets to channel water below a road or track. Siphons have two concrete boxes that are connected with an underground pipe. These siphon boxes are the main transmission sites of urinary schistosomiasis, as the boxes are used frequently by schoolchildren for recreation and urination. Studies found that brushing the inner sides of the siphon boxes and covering the top of the siphon boxes with concrete lids to prevent light from entering the boxes significantly reduced the number of snails. However, this method requires that siphon boxes are already present as a water control device in a given irrigation system, and the boxes must function as focal sites of transmission. Further analysis is needed to discern the effects of this method on other water-borne diseases, and more research is needed to explore the relationship between other types of water control devices and water-borne diseases.

**Summary of Engineering Design Techniques for Mitigation of Water-Borne Diseases**

1. Removal of aquatic plants that vectors feed on; introduction of aquatic plants that repel vectors in their usual habitats
2. Lining irrigation canals with concrete, asphalt, gravel or plastic to prevent snails from clustering on the sides and/or removal of vegetation along the sides of the canal
3. Raising the flow rate (through lining irrigation canals) to a certain threshold known to produce a drag force high enough to dislodge snails from the sides (schistosomiasis) or to render habitats for black flies (onchocerciasis) inhospitable
4. Varying water level in a reservoir or micro-dam, thereby disrupting the reproductive cycle of disease vectors, eventually resulting in mortality
5. Seasonal draining of water bodies known to serve as habitats for disease vectors
6. Installing siphon for changing the flow of water
7. Targeting siphons as areas of focal transmission; brushing the inner sides and covering up siphon boxes with lids to block light from entering (to prevent boxes from functioning as transmission sites for urinary schistosomiasis)

## The Future of Water Resources Development

Water resources projects are fundamental to achieving sustainable development on the African continent. Thus water resources development must be planned and executed to ensure that water-borne diseases are gradually eradicated rather than propagated and worsened. International conferences on water management, such as the one in Addis Ababa in April 2013, must address this issue in meaningful ways. Eradication of water-borne diseases must include NTDs that have received far less international attention than malaria. A variety of engineering design and water management options may be used, and although particular techniques are known to ameliorate the prevalence of certain water-borne diseases, further research must be done. We need to better understand the connections between the epidemiology of water-borne diseases (such as schistosomiasis heightening risk of contracting malaria) as well as connections between disease vectors. The next step is to discern which techniques should be used in particular geographic, topographic, ecological and epidemiological settings, using a combination of modeling tools. Other important factors must also be taken into account, such as climate, altitude and vegetation, which play an important role in the disease ecology of habitats. This research can be used to devise a "toolbox" of techniques that may be used in water resource development projects to mitigate the spread of water-borne diseases. Water resources development will be a significant boon to African economies in the coming decade, providing much-needed hydroelectric power and year-round water supply for agricultural production. But if water-borne diseases are not mitigated in a serious way, the economic and quality-of-life costs of populations facing long-term chronic illness may outweigh the benefits of water resources development.

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