Prediction of health hazards in tropical reservoirs and evaluation of low-cost methods for disease prevention

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Abstract: A new report by the World Commission on Dams underlines the importance of early recognition of risks from water-associated diseases in planning of tropical water projects [1]. Careful site selection and simple changes in design of dams can reduce the risks of lethal tropical diseases such as malaria and schistosomiasis.

1 INTRODUCTION

If dam and canal engineers proposing large water projects in tropical regions learn their lessons from the history of health impacts in that region, they can prevent their projects from causing outbreaks of tropical diseases. This is important because there have been major historical examples during the past century where water projects were completely thwarted by such outbreaks [2].

The first attempt at building a canal across the Isthmus of Panama by de Lesseps and his French company in the late 1800's was stopped by lethal epidemics of malaria, Yellow Fever and cholera among his engineers and workmen. There was also a fatal flaw in his concept of a sea-level canal across the isthmus, but the demoralizing effect of disease and death among his compatriots eventually resulted in collapse of his efforts [3].

2 IMPACT INDICES

For the purpose of illustrating the continuum of quality in large dams, two impact indices were developed for a somewhat arbitrary list of ten well-documented dams. The first index was the Human Impact Index; the number of people forced to resettle because of the dam, divided by the installed power capacity in megawatts [4].

The second index was a crude measure of Environmental impact; the ratio of area flooded by the reservoir at spillway level in hectares, divided by the installed capacity of the turbines in megawatts (MW). In using this environmental impact index, it is assumed that the size of the reservoir is proportional to its environmental impact. Other more precise indices might be developed.

These indices are obviously over-simplifications for complex issues, but they provide a first step in comparative analyses. The dams were light-heartedly grouped into three categories, Good, Bad and Ugly. These should not be taken too seriously, but are used for easy discussion.

3 EXAMPLES OF GOOD, BAD AND UGLY DAMS

It is hoped that the ranking given below, of ten well-documented dams, will be a helpful guide to people evaluating a new dam proposal, as they decide whether to commit increasingly large amounts of time and energy to investigating or opposing the dam. Only hydroelectric aspects of these projects were analyzed because of the large database, but some of the dams were multi-purpose.

In a comparison of the Human Impact Indices for the ten dams, Owen Falls Dam on the upper Nile River in Uganda ranks first, with the least human impact per MW (Table 1). Grand Coulee Dam in the United States ranks second, with Itaipu Dam between Brazil and Paraguay ranking third.

Table 1
Human Impact Indices for Ten Large Dams

Dam	Country or River	Installed Power Capacity in Megawatts	People Displaced in thousands	Human Impact Index Displaced People Per Megawatt	Rank
Owen Falls	Uganda	150	0.01	0.1	1
Grand Coulee	USA	6800	6	0.9	2
Itaipu	Brazil	12600	42	3.3	3
Ertan	China	3300	30	9.1	4
Kariba	Zambezi	1500	57	38	5
Manantali	Senegal	200	11	55	6
Aswan	Egypt	2100	120	57	7
Akosombo	Ghana	833	80	96	8
Three Gorges	China	13000	1600	123	9
Brokopondo	Surinam	30	5	167	10

Owen Falls Dam exemplifies the advantages of a Run-of-River installation in which the dam and turbines are placed in a narrow canyon, and the river flow is almost constant throughout the year. The narrow channel coming out of the northeast corner of Lake Victoria was the optimum site for supplying electricity to the nearby city of Jinja and to the capitol city of Kampala. The dam has the advantage of the huge storage capacity of the lake, without needing new reservoir capacity in the short channel between the lake and the dam. The lake level varies only slightly, over decades.

Itaipu Dam displaced 42,000 people, but the person/MW ratio is relatively low because it is the largest hydropower dam in full operation, with an installed capacity of 12.6 Gigawatts (Table 1).

In terms of the other important Index of Environmental Impact, the amount of land flooded per MW of installed capacity, Owen Falls Dam also has the smallest ratio of flooded land, compared to the other eleven dams. Only about 0.1 hectares were flooded for each MW of installed power at Owen Falls (Table 2).

When Owen Falls Dam was proposed, the issue of obstructing migratory fish was not raised. Probably the absence of salt water or other unusual conditions downstream did not indicate that seasonal migration of local fish would be important in their life-cycles. An important health impact was predicted however.

The river downstream of Owen Falls had been a breeding area for the blackflies which transmit river blindness. The flies lay their eggs in whitewater rapids which are common on the Upper Nile River from Lake Victoria downstream to Lake Kyogo. Blindness was common among people living near Owen Falls, due to infestation of their eyes with a thread-like worm transmitted by the bite of these blackflies.

Entomologists proposed treatment of the river with DDT during the construction of the dam, to at least protect the construction workforce. Unexpectedly, after several years of repeat treatments, the blackfly disappeared permanently. DDT treatment stopped about 1970, but apparently the change in river regime due to the dam had made the rapids unsuitable for the species of blackfly, Simulium damnosum, which transmits the blinding parasite.

Table 2
Environmental Impact Indices for Ten Large Dams

Dam	Country or River	Installed Power Capacity in Megawatts	Reservoir Area in Thousand Hectares	Ecological Impact Index Hectares flooded per Megawatt	Rank
Owen Falls	Uganda	150	0.01	0.1	1
Ertan	China	3300	10	3.0	2
Grand Coulee	USA	6809	26	3.8	3
Three Gorges	China	13000	110	8.5	4
Itaipu	Brazil	12600	135	11	5
Aswan	Egypt	2100	400	190	6
Manantali	Senegal	200	48	240	7
Kariba	Zambezi	1500	556	370	8
Akosombo	Ghana	833	848	1000	9
Brokopondo	Surinam	30	150	5000	10

Other species of blackfly with lower velocity requirements did reinfest the river however, but they tend to bite animals, not people. There may be other explanations for the disappearance of River Blindness, but certainly this seems to be a rare example of a positive health impact from a hydropower project.

The second-ranking dam in terms of low environmental impact is Ertan Dam recently constructed in Southwest Sichuan Province of China. This concrete arch dam on the Jalong River, a tributary of the Yangtze River, is 240 m high, one of the highest. It is in a narrow canyon, but because of its height will create a 10,000 hectare reservoir in order to generate up to 3,300 MW (Table 2). The reservoir is in an area already developed for agriculture, with no areas of special attraction or biodiversity.

Thus Owen Falls Dam and perhaps Grand Coulee Dam could be proposed as examples of Good Dams, based on their relatively low environmental impacts and their low resettlement requirements. Again, it must be remembered that for all dams, the details of resettlement success for human and wildlife populations have consistently been unsatisfactory. Thus this ranking does not suggest that resettlement was a success, only that small numbers had to be resettled in terms of the installed power capacity.

3.1 BAD DAMS

The dams in rankings 4 to 9 were designated for the Bad category. Obviously this is not a precise category, and the dams have no inherent moral defects. The dams, which were ranked 4-5 for human impact were Ertan and Kariba with human impact indices from 9.1 persons displaced/MW to 38 persons/MW (Table 1). Although Kariba Dam on the Zambezi River displaced only 57,000 persons for 1.5 GW of capacity, the callous nature, lack of adequate planning, and the use of lethal weapons in the forced re-settlement scheme indicated that this dam should really be placed in the Ugly category below, despite its theoretical Human Index ranking of 5 (Table 1). For the human impact, the Bad Dams also included Kariba Dam as a special case, Manantali Dam, Aswan Dam, Akosombo Dam and Three Gorges Dam, with indices from 38 to 123 persons/MW (Table 1). In considering the impacts of Manantali Dam in the Senegal River Basin, one should include its combined impacts with the low Diama Dam which functions downstream as a stabilizing reservoir.

Under the Environmental Impact Index, the dams which ranked 4-5 were Three Gorges in China and Itaipu in Brazil, with indices from 8.5 to 11 hectares/MW (Table 2). Itaipu Dam is the largest hydroelectric project in the world until it is displaced by Three Gorges Dam, slated for completion in the next few years. In the lower half of the ranking, the dams which ranked sixth through ninth out of the ten analyzed were also designated as Bad Dams.

Summarizing the ranking by the Environmental Impact Index, the lower tier of Bad Dams included Aswan Dam in Egypt, Manantali Dam on the Senegal River, Kariba Dam, and Akosombo Dam in Ghana. Their ratios of hectares/MW were 190 to 1000 (Table 2).

The combination of the paired Manantali and Diama Dams in the Senegal River Basin is an exceptional instance of two Bad Dams combined, which merits them the rating of Ugly. The two dams together are thus placed in the Ugly category.

3.2 UGLY DAMS

The label of Ugly Dam is meant in a humorous sense, knowing that the dams are probably beautiful engineering structures. This category was reserved for those dams which clearly ranked at the bottom for the two Indices and had very significant negative impacts. Brokopondo Dam in Surinam merited this ranking both for its relatively high environmental impact, and for its high human impact. Other dams – Kariba Dam and the combination of Manantali and Diama Dams - also belong in this Ugly category.

Extremely unfavorable conditions were created by a low dam at Afobaka on the Suriname River, creating a shallow reservoir upstream of Brokopondo, now also called Lake Prof. van Blommenstein. The dam at Afobaka produces only 30 MW of power capacity, but created a reservoir flooding 150,000 hectares of tropical rain forest, and displacing over 5,000 persons. Note that this was nearly the number of people displaced by Grand Coulee Dam for the production of 7 Gigawatts of electricity, over 200 times the amount of power produced at Brokopondo.

Manantali and Diama Dams in the Senegal River Basin were constructed under the aegis of the OMVS. Although the environmental and human ratios calculated for Manantali Dam by itself only place it in the Bad category, the combined effect of the two dams has been a widespread tragedy, meriting the rating of Ugly. While finally supplying electricity to the cities of Bamako, Dakar and Nouakchott, they have caused major outbreaks of water-associated diseases in the area of Diama Dam, one of which continues to worsen.

Finally, based on these simple indices of relative environmental and human impact, Owen Falls Dam in Uganda and Grand Coulee Dam in the US of America could be proposed as models for Good Dams, while Brokopondo Dam in Surinam, Kariba Dam on the Zambezi River, and the pair of Manantali and Diama Dams on the Senegal River exemplify the qualities of Ugly Dams.

4 DAM ASSOCIATED DISEASES

The diseases of concern to dam builders in the tropics are mostly related to aquatic insects and snails and to human contamination of water. There are additional risks of sexually transmitted diseases, especially AIDS, among large construction workforces and prostitutes. These diseases are found in other tropical areas of the world as well, especially in Africa and in tropical Asia[4]. The water-associated diseases include malaria, Yellow Fever, schistosomiasis, cholera, typhoid fever and River Blindness.

Dams, and the reservoirs they create, play three roles related to health. Firstly the reservoirs can serve as breeding habitats for the aquatic insects and snails which transmit the tropical diseases. Secondly the reservoirs attract large numbers of people because of the potential for fishing or other economic activity related to water. And thirdly the dams often displace people from the flooded zone of the reservoir, requiring construction of large resettlement communities, most of which are poorly constructed. All three of these roles can affect transmission of tropical diseases.

4.1 Malaria

Engineers should be encouraged to know that careful selection of a dam site and determination of the best Full Supply Level for a proposed reservoir can be done in ways which will minimize habitat areas for malaria mosquitoes around the shoreline of the reservoir, and thus minimize transmission of the disease. Malaria is the most wide-spread of the water-associated diseases in the Tropics, transmitted by anopheline mosquitoes which must have access to stagnant waterbodies for egg-laying. If the water stands for more than a week, the eggs of these blood-sucking insects have time to develop and hatch.

One of the methods still in use for mosquito control by Tennessee Valley Authority engineers in the U.S. of America is repeated fluctuation of the reservoir water level during the breeding season of the mosquitoes [5]. This operational technique causes the mosquito eggs to be stranded on the shoreline or flushed out into open water where fish can eat them. The fluctuation cycle used by the TVA dam operators is 1 foot vertically with a period of one week, and requires steady inflow and certain corresponding design features in the outlet structures. This fluctuation schedule is adequate for controlling malaria mosquitoes in most of the Americas, but must be adapted to the seasonal pattern of mosquito breeding and malaria transmission for other tropical regions.

Mosquitoes downstream of reservoirs can also be flushed out of stream-side habitats by periodic releases of water into the stream, as opposed to a continuous steady discharge from a dam outlet. Flushing siphon spillways have been used successfully on small reservoirs for this purpose, especially in Asia (2,6).

An important concept to be used in evaluating the risk of malaria for communities around a reservoir or water project is the daily flight range of the mosquito. The adult female must return to a breeding site after she digests her bloodmeal, in order to lay another batch of eggs. If the distance between human habitation and breeding sites is too great, the biting rate falls drastically, and transmission of the malaria parasite is reduced. Thus people in a village 100 m from the edge of a stable reservoir will suffer large numbers of bites every night, and many of them could become infected with the malaria pathogen. Conversely a village 10 km from the nearest breeding site might have very few bites from malaria mosquitoes, and transmission would thus be low.

A typical species of malaria mosquito common to the southern USA and to the Caribbean Region has a maximum flight range of about 7 km, although its normal daily range is much less, about 2 km 4. For a specific damsite the relevant species should be identified, and flight ranges obtained from the malaria literature. The flight range can then be used in both evaluating proposed resettlement locations, and in selecting the location of construction camps.

One of the most effective measures against malaria mosquitoes is carefully screened sleeping quarters, or bednets treated with insecticides. The malaria mosquitoes bite primarily at night, thus bednets can be very effective.

4.2 Yellow Fever and other hemorrhagic fevers

For engineers planning the resettlement of people from the area to be flooded by a reservoir, proper design of housing and domestic water supply is an important method of reducing the risk of Yellow Fever in the resettled population. This highly lethal fever is spread by certain species of mosquitoes which lay their eggs in small artificial containers, often found in and around human habitations. The disease is preventable by immunization but is still a potential hazard in most of tropical America.

Unlike the malaria mosquito, the species of mosquito which transmits Yellow Fever is often found in open cisterns or water-supply tanks near houses. Thus drinking water supplies for construction camps and resettlement communities should have covered containers for water storage. This mosquito lives around houses and bites at all times of the day. Thus bednets are not an effective preventive measure against them, although complete screening of houses is helpful.

When forests are cut in preparation for dam construction or reservoir filling, there may also be risks to the loggers of hemorrhagic fevers similar to Yellow Fever but contacted through other means. This is a very rare and complex risk, requiring expert advice; advice that is only needed when extensive work is proposed in tropical rain forests 7.

4.3 Schistosomiasis.

Similar to the technique for mosquito control, fluctuations of the water-level in reservoirs in the Americas help control the aquatic snails which transmit a parasitic disease called schistosomiasis [2].

These tropical snails find stable reservoirs, ponds, irrigation canals, drainage ditches and swamps to be ideal habitats.

Another form of the disease is found in Asia, especially in the Yangtze River Valley of China. Although it has been considerably reduced by national control efforts, there is some risk that these improvements might be endangered by the Three Gorges Dam. Current estimates are that there might be both negative and positive impacts on the geographic extent of the disease, once the reservoir is full[7].

People wading in the snail habitats become infected by a microscopic larvae issuing from certain snails which are infected with a schistosome worm parasite. The larvae penetrate human skin in quick order, then migrate to the large veins around the human intestines, to develop into adult worms. The worms lay eggs which pass through the intestinal wall and out with feces. If the feces contaminate a snail habitat, the snails become infected from this schistosome parasite and the cycle continues. Continuous exposure of people to heavy doses of these parasites can cause severe liver disease and death.

There are places where engineers have played major roles in controlling schistosomiasis. In the irrigated sugar-cane fields of Puerto Rico, schistosomiasis killed many canefield workers in the decades after dams and canals were constructed on the South Coast of the island, prior to World War Two [2]. After the war, US Public Health Service engineers and scientists who had learned public health engineering in the Tennessee Valley, first used their experience to control malaria in Puerto Rico. Then they developed an integrated control program against schistosomiasis, using drainage engineering, safe water supplies and other methods. However the disease persists in many other places in the Americas; specifically in some islands of the Caribbean, in lowlands of Venezuela and much of coastal Brazil. It is also potentially a problem along the southern borders of Brazil.

In Asia the disease has largely been controlled by economic development and the filling and drainage of snail habitats, especially in Japan. The disease still exists in the Yangtze River basin, and small foci of the disease exist in the Mekong River Valley.

Usually, engineers already have much of the information needed for controlling these diseases. When a dam is being planned, the information collected by engineers - such as topography, annual flows in the river, and climatic conditions - can also be used to estimate the potential for disease transmission, especially for schistosomiasis and malaria. Particular attention should be given to those factors which can be used to predict expected seasonal changes in shoreline configuration of proposed reservoirs and expected changes in water level which affect snail and mosquito breeding areas.

A topographical map showing the expected reservoir outline and maximum water level can be used to divide the reservoir into uniform shoreline segments with similar depth, width, shore slope and orientation toward prevailing winds[2]. The snails, or malaria mosquitoes, can flourish in coves protected from wind and waves. However they cannot colonize stretches of exposed, eroding shore. Data on wind speed can then be used to outline areas of shoreline erosion which will not be suitable habitats, and to identify areas of protected shoreline which might be suitable.

Further information on water temperatures, water clarity, and water and soil nutrients can also help in estimating the amount of protective vegetation, which also affects the suitability of a shore zone for the various species of snails and mosquitoes. Snail and mosquito species have to be identified for the particular geographical location, and their breeding requirements determined from the biological literature.

4.4 Cholera and Typhoid Fever

The proper location and sanitary design of construction camps and resettlement communities for the people who are expected to be displaced by a proposed dam, can be major tools for engineers and planners to avoid diseases caused by poor sanitation. Makeshift construction camps or poorly designed resettlement communities can be the source of severe outbreaks of cholera, typhoid fever and other diarrheal diseases in the tropics. These rapidly spreading diseases are caused by fecal contamination of drinking water and food, thus the availability of a convenient and adequate supply of safe water is a primary design requirement for preventing these diseases.

4.5 River Blindness

Engineers who design spillways for dams and other water projects can do a great deal to prevent outbreaks of a disease called River Blindness, common in hilly areas of Central America, Ecuador, Venezuela and northern Brazil[2]. It is also found in Africa, and along the Red Sea in Arabia. This parasitic infection is spread by small blackflies which breed in white-water rapids of mountain streams, and also on dam spillways. The parasite is transmitted to people through the painful bite of the blackfly. As the parasite develops in its human host, it lodges in the eye of the victim, eventually causing blindness. The disease is also known as onchocerciasis.

Adjustment of the water velocities or periodic drying of the spillway can be used by engineers to prevent breeding of the blackflies. The local blackfly has to be identified in order to determine the water velocities which it requires for breeding, but in general, the blackflies will lay their eggs in white-water rapids with water velocities between 0.9 m and 1.2 m. If spillways are dried out once a week, they become poor sites for egg-laying by these blackflies[2].

The flight range of blackflies in the Americas can best be estimated from extensive data on African blackflies. These data indicate that the normal daily range is about 30 km, thus blackflies travel much further than do malaria mosquitoes. Because these blackflies bite outdoors during the day, screens and bednets are not effective against River Blindness.

4.6 AIDS

Outbreaks of AIDS, caused by sexual transmission of the Human Immunodeficiency Virus (HIV), is to be scrupulously avoided when large construction projects are planned for isolated zones where the virus is not currently found. The introduction of this lethal virus into such isolated communities can cause devastating and long-term harm. Also in areas where the disease is currently found, extensive preventive measures should be included as part of the normal impact remediation plans.

During the construction phase of large dams, materials and equipment have to be transported over long distances. A relay system for this trucking might be used to reduce transmission of the HIV by allowing the truck drivers to sleep at home every night. Long-distance truck drivers have been implicated in the spread of HIV in Africa [2].

The preventive methods used against AIDS will require expert assistance for engineering planners, because the methods are generally sociological and medical in nature. However engineers can play a part by trying to avoid the housing of single men in large construction camps around the damsite. Instead, family housing for workers, and daily transport of workmen from residences in stable communities could help to reduce the spread of all sexually-transmitted diseases. Single men in large camps lose many of the social controls on their sexual behavior which normally minimize sexually transmitted diseases. In normal, stable communities, these social controls can be strengthened by health education and other preventive programs.

5 IMPROVING DESIGN AND OPERATION OF DAMS.

When dams are being planned, there are many aspects of the process which might benefit from early consideration of health and environmental impacts. These considerations can be introduced during the site selection, during design of the dam or irrigation system at the selected site, and during operation of the system. Operation is often contingent on proper design, so the desirable operational features have to be specified early in the design process.

5.1 Siting

Selection of the optimum site for a dam is usually a stepwise process in which many possible sites are gradually narrowed to a few preferred sites, then arriving at a final choice. This process of elimination is usually irreversible, partly because the amount of site-specific information developed for each step increases as the choices narrow. Unfortunately health and environmental considerations are usually omitted until the last step, giving little flexibility if serious negative impacts are found. Thus it is important for health and environmental advocates to be involved in the earliest steps, indicating preferences before favorable sites are eliminated for other reasons.

5.2 Design

Spillway and outlet designs should be tailored to meet the need for periodic fluctuations in the reservoir level, and to prevent blackfly breeding when necessary. One of the other negative impacts of dams is the physical blockage of migratory fish runs. Thus such a dam should be designed with spillways, outlet structures and other features which facilitate fish passage

5.3 Operation

For environmental benefits downstream of storage reservoirs it is often desirable to mimic natural river flow patterns as much as possible. In many storage reservoirs there is a large annual fluctuation in the water, with predictable and usually seasonal rates of rising and falling water levels. With a detailed knowledge of these fluctuation patterns and the reservoir topography, fringe fisheries and water-fowl habitats around a reservoir might be protected by maintaining adequate cover for breeding areas during the proper season.

Depending on the shore slopes and drawdown rates, the annual drawdown may strand debris, floating vegetation, larvae of mosquitoes, and aquatic snails. This effect can be manipulated to reduce malaria and schistosomiasis transmission, to reduce outbreaks of floating vegetation, and to minimize damage from debris passing over spillways or through turbines [2].

Saline barrier dams at the mouths of estuaries often drastically interrupt migratory patterns of fish in African rivers (Diop et al 1994). Such an annual pattern might also be used to reduce populations of the schistosomiasis snails. Salt intrusion would also have to accommodate the freshwater needs of the irrigation systems which these barrier dams are usually designed to supply [2].

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